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PRESENT-DAY ANTENNAS

by

A.A.Pistol'kors

1. Introduction

One of the basic elements of the system, invented by A.S.Popov, of radio receiver (storm indicator) and transmitter, is an antenna, previously made of a long wire. In fact, the use of antennas permitted Popov to sharply increase the sensitivity of the first radio receiver, while the development of new forms of antennas resulted in a subsequent increase in the communication range, in his experiments on ships. The success of radio communication across the ocean achieved by Marconi in 1901 is due to a large extent to the use of a special antenna, highly complex for that period. One can readily understand the exceptional important part played by antennas in establishing radio communication, if taking into consideration that the transmitting antenna is that component of a radio station which transforms the energy of high-frequency currents into energy of radio waves which propagate over the surrounding space and establish connection with the receiving radio station. The antenna of the latter produces a reverse transformation of the energy of the electromagnetic wave which actuates it, into energy of high-frequency currents.

The development of the technique of transmitting and receiving antennas as well as of transmission lines connecting them with transmitters and receivers, proceeded simultaneously with the development of radio technique in general and determined to a large extent its success and sphere of application. The basic stages of this development, during the first 50 years of the existence of radio are covered in the compilation "50 Years of Radio". The purpose of this article is to give a short survey of the achievements of Soviet antenna technique during the last 10 - 15 years as well as to describe the achievements in this field in other countries over the same period of time, thus presenting the main features of the present status of antenna technique.

It is obvious that such a survey cannot be complete; only the most important trends determining the character of the development in antenna technique will be discussed, and only a few of the more typical examples of achievement in the field under review will be given.

From the point of view of presentation, it is convenient to subdivide the various antennas into the following groups:

a) Antennas for radio broadcasting stations

b) Television antennas

c) Antennas for radio networks

d) Antennas used in radar

e) Antennas for radio astronomy

In addition to the types of antennas listed above, we also discuss the achievements in the field of feeder lines and in conclusion also the progress made in the theory of antenna installations.

2. Antennas for Transmission and Reception of Radio Broadcasts

Antennas for radio broadcasting stations can be subdivided into radio broadcasting antennas of long, medium, short and ultrashort waves.

The main task to be solved in constructing radio broadcasting antennas for the long-wave range (1100-2000 m) is to obtain a sufficiently high radiation resistance making it possible for the antenna to pass the necessary frequency bands without distortion and to radiate high power without voltage overload. In order to increase the field strength in the areas services by the radio stations, the antenna is often required to produce directive radiation. Occasionally, it is required to operate in the broad band of waves.

The necessity of meeting a whole series of specifications requires the development of new methods of building an antenna able to operate on long radio waves. One such method is to use complex aerial systems made of free-standing supports (towers) insulated from the ground. According to this principle, an antenna array of the type shown in Fig.1 was built during the period of the Great Patriotic War, consisting of four towers for a radio broadcasting station of 1200 kw power. The design for this antenna was suggested by L.A.Kopytin. Its creators are M.S.Neyman and B.B. Braude. When all four towers are fed cophasally, the antenna is nondirective. For directive radiation, two of the towers are fed, while the other two act as passive reflectors. Both the active and the passive towers have their own tuning elements. Energy from the transmitter is fed to the antennas across a coaxial cable, whose inner conductor has a diameter of 150 mm (consisting of several 10-mm copper tubes located along the circumference of a circle with a diameter of 150 mm), while the outer conductor (seen from the inside) has a diameter of 570 mm. To test the operation of the line when tuning to a traveling wave, a reflectometer, recommended by the author of this article and by M.S.Neyman is used. This is a device which permits comparing the amplitudes of the reflected and incident wave and which directly indicates the coefficient of the traveling wave. Antennas designed for operation in the 750-1500 m wave band have been successfully used for radio broadcasting for over ten years.

As far as medium radio waves (180-550 m) are concerned, no difficulties are experienced in obtaining sufficiently high values of radiation resistance, due to the fact that, with a shortening of the wave the required height of the mast decreases (usually by 100 m).

The efforts of Soviet specialists were directed toward a possible simplification of the antenna system for a given range or band, with the purpose of a further lowering of the antenna height. An example of the results in this direction is a low cylindrical antenna, developed during the last several years under the guidance of G.Z.Ayzenberg. It represents a circular cylindrical surface, made of wires, with a diameter of 60 and a height of 20 m, on top of which is placed a plate, also made of wires, with a diameter of 120 m. Underneath the antenna there is a grounding system consisting of 120 radial cables of 150 m length. Although the resistance of this antenna is lower than that of a mast of 100 m, its efficiency is substantially higher because of the increase in cross section of the surface along which the current flows in the antenna itself as well as in the part of the grounding system adjoining

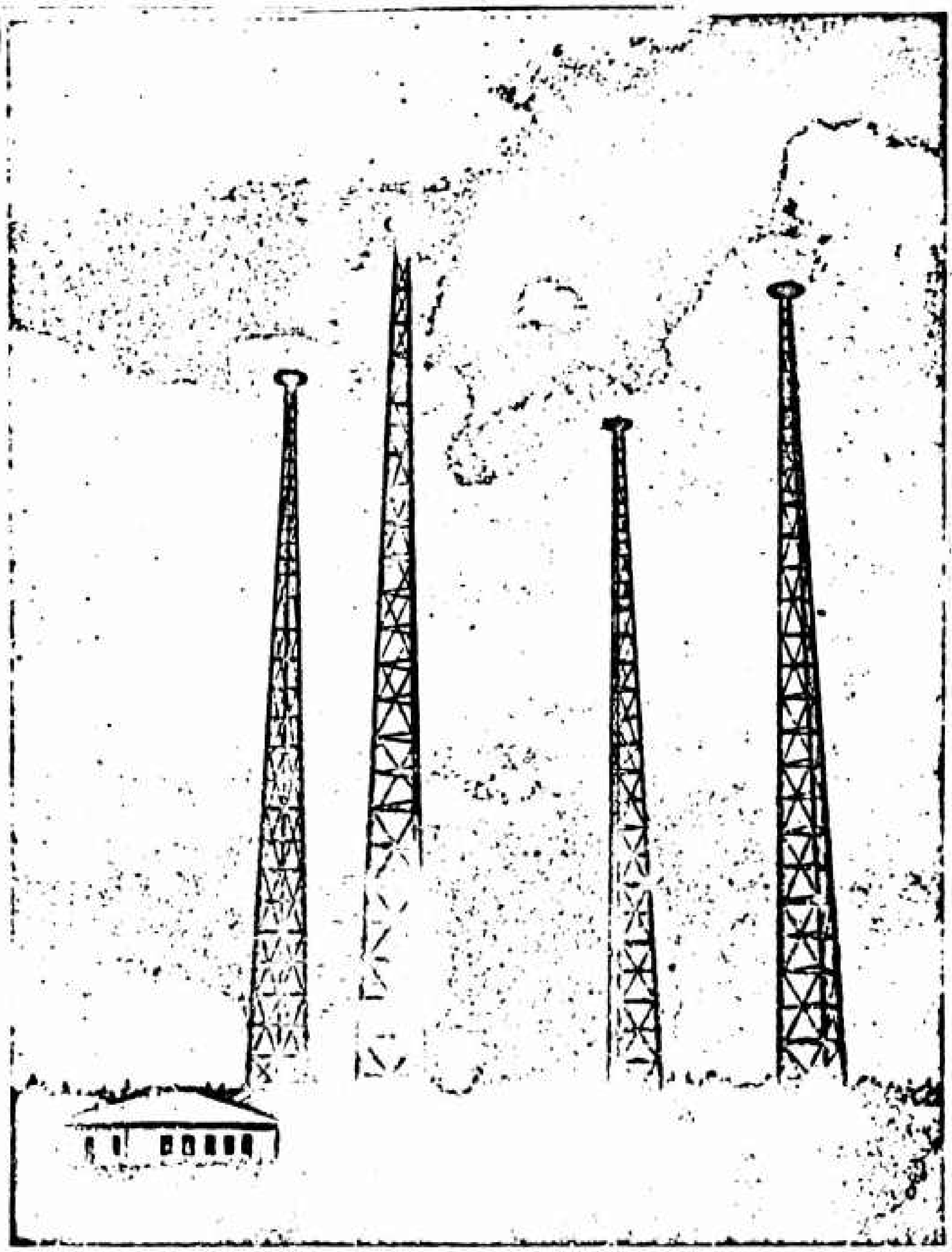

Fig.1 - Antenna of a Radio Broadcasting Station, 1200 kw Power

it. The lower current density in the given sections results in a reduction energy loss in the antenna and particularly in the ground. The antenna cables are connected to the concentric feeder which runs around the antenna. Both ends of this feeder are led out underneath the cylindrical part of the antenna and are provided with short-circuiting bridges for tuning. The feeder leading to the transmitter is connected in parallel with the tuned concentric line, in order to obtain a traveling wave there.

The antenna of the described type, in whose development A.M.Model, L.P.Pozdnyakov, and M.A.Slutsker participated, guarantees (by means of retuning) operation in the wave band from 200 to 600 m; the antenna efficiency in the 500-m wave band is of the order of 90%.

In many cases, one antenna has to service a wave range from 180 to 2000 m. The main difficulty there lies in the fact that the height required for long waves may be excessive relative to short waves, and will cause a current distribution of the current in the antenna of a magnitude to direct the basic radiation at an angle to the ground rather than along it. G.Z.Ayzenberg and Ye.A.Anfilov designed a broad-band antenna which eliminates this difficulty. This antenna is a mast of 250 m height, insulated from the ground, with its lower third surrounded by a screen of cables (Fig.2). The current produced on the outer surface of the screen, together with the current of the upper part of the mast and guy wires, ensures a concentration of radiation along the earth when operating on shorter waves, thus imparting antifading qualities to the antenna.

Directive radio broadcasting antennas in the 180 - 550 m band came recently into increasing use. Antenna tuning is carried out in a pavilion connected with the transmitter by means of the feeder. The necessity for such antennas is especially acute in the USA, where many radio broadcasting stations are providing service in the territory of a single State and must, therefore, operate in such a way as to create a minimum of interference with the reception in other States, where radio stations operate on short waves. The number of emitters in the form of tower antennas, used for this purpose, comes to five in one antenna system.

A special group are the antennas used for radio broadcasting on short waves.

This function is usually taken over by rhombic and horizontal cophasal antennas. It is well to note the improvement of the latter effected by V.D.Kuznetsov, which permitted an increase in the operating frequency range by 1 - 1.5. The basis for this

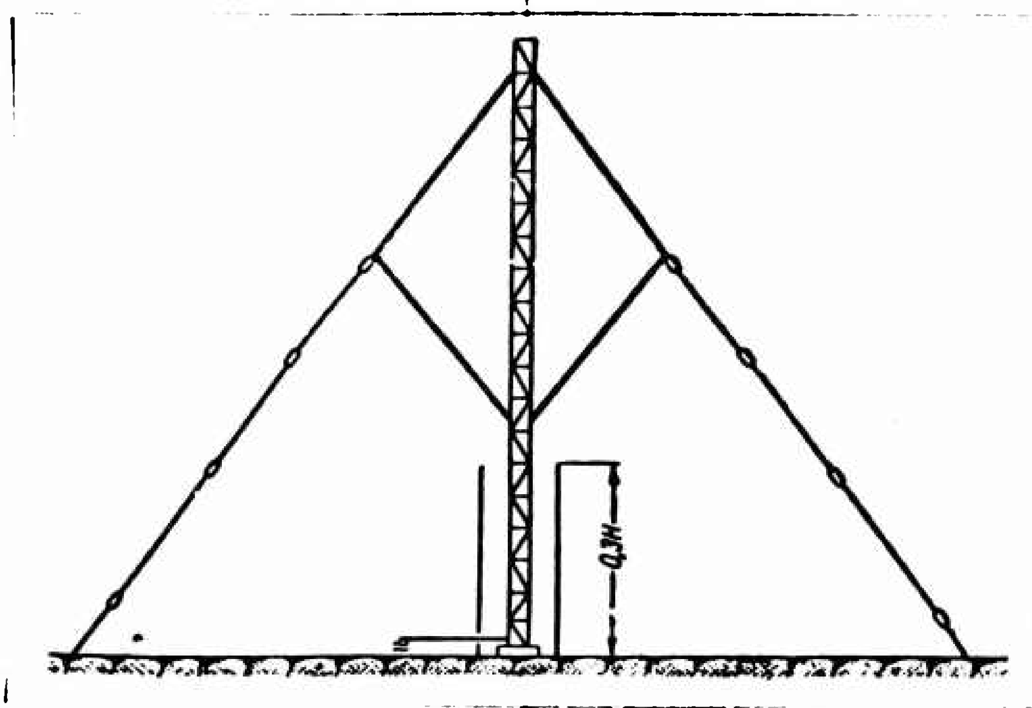

Fig.2 - Broad-Band Antenna, 200 - 2000 m

improvement is a substitution of the half-wave oscillators by Nadenenko dipoles and a change in the feeder system of the antenna.

In a number of countries in Western Europe and America, radio broadcasting on ultrashort waves (4.10 - 4.55 m band) came into increasing use. In this connection, special types of ultrashort-wave antennas are used, which must radiate uniformly in the horizontal plane and focus the emitted energy in a horizontal direction.

Antennas of this type are used for nondirective emitters of, usually, horizontal polarization, arranged in several stages at the top of a high support. A rather high support is necessary to obtain coverage of a larger area in view of the fact that guaranteed ultrashort-wave reception is only possible within the direct visibility range. As nondirective elements, horizontal loops or vertical slot antennas, arranged on the surface of the cylindrical support, are usually used.

Finally, we have to mention one new type of receiving antenna used in portable medium-wave radio broadcasting receivers, shaped like a small suitcase. In this particular case, it is inconvenient to use grounding and conventional antennas, even in the form of a cable sector; therefore, builders of the receivers in question have used loop antennas mounted inside the suitcase. However, the fact that the receiver operates in the field of the loop causes additional energy losses and lowers the efficiency of the loop. Instead of the conventional receiving loops, loop antennas (coils) with a ferromagnetic core are used. As ferromagnetic material, various kinds of ferrite can be used, which have small losses at high frequency and a **high relative permeability** (order of magnitude of tens and even hundreds). Ferrite is a ferromagnetic semiconductor with a very high resistivity, as a result of which practically **eddy** currents are produced, which are the main cause of energy loss in other ferromagnetic materials. Ferrite used for the receiving loop usually has the form of a rod (diameter 1 - 2 cm and length 20 - 30 cm) with a single- or two-layer winding.

The success achieved in the field of radio broadcasting antennas is based on extensive scientific research and exploratory work. An important role is played here by preliminary research and development - done on decimeter and centimeter waves - using models of the projected antennas. The wavelength, in these cases, decreases in proportion to the size of the model. Research is being continued on antenna models for radio broadcasting bands, both here and abroad.

3. Television Antennas

Antennas for television transmitters are produced differently in different countries. However, all of them have two basic functions: to permit passage, without distortion, of the wide frequency bands necessary for good quality of the transmitted television program, and to transmit, simultaneously with the spectrum of the television waves, the spectrum of the sound track. The latter requirement necessitates rather complicated filters, which permit transmission to the antenna of two different frequency spectra without interference.

Figure 3 shows a television transmitting antenna array of the type used in the USSR. The main element of the antenna is a flat vibrator of the lattice type (1), made of tubular steel. On the first tier there are four such vibrators, staggered at an angle of 90°. For the first and second television frequency channels, two tiers are used and for the third to fifth channel, three tiers. All vibrators are mounted to the vertical steel tube (diameter 58 mm) which accomodates the main and individual coaxial feeders, connected to the center of the vertical inner rim of each vibrator (point 2). The vibrators of all tiers of one semiplane (on one side of the main tube) are fed with the same phase. The phase of the feeding voltage in one semiplane is shifted relative to the phase of the next semiplane by 90°, which ensure nondirectional radiation in the horizontal plane. The shifting of the phases takes place at the expense of the length of the feeders (one quarter-wave) which connect the vibrators of the various semiplanes with the principal feeder.

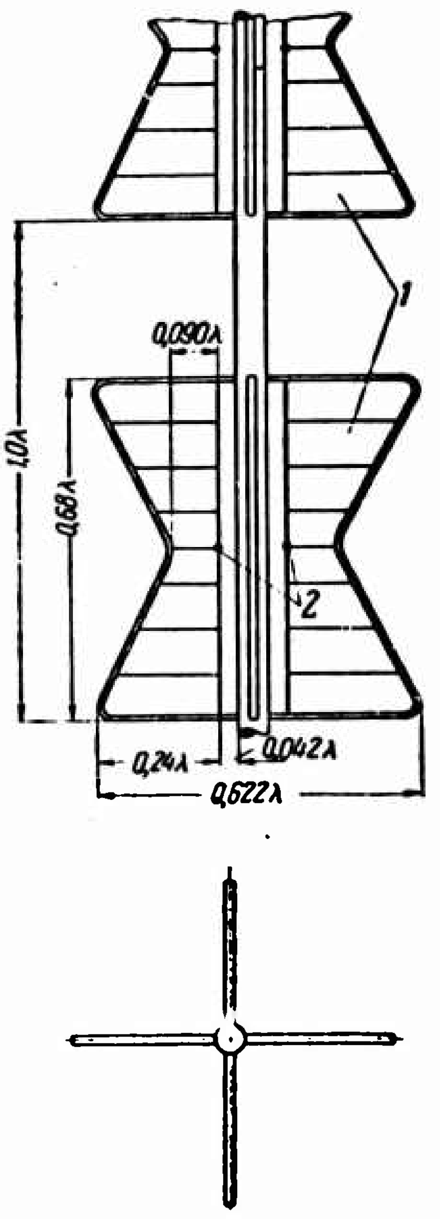

Fig.3 - A Typical Television Transmitting Antenna

The range characteristics of the described television antenna are specific in that the coefficient of the traveling wave never drops below 0.85 in the frequency band, which amounts to 15 - 20% of the carrier wave.

In connection with the development of television, receiving television antennas came into increasing use. As a rule, a symmetrical or bent vibrator is used as an antenna, the vibrator being connected, across a symmetrical arrangement ("U-elbow"), with the coaxial cable leading to the receiver.

In proportion to the distance from the transmitter and the weakening of the signal power, it becomes necessary to complicate the antenna, by first adding a reflector behind the antenna and then one or several vibrators known as directors - in front of the antenna.

A "forest" of television antennas on the roofs of large towns is now very common. However, this is not desirable since it spoils the architecture of the building and causes distortion of reception due to mutual reflections between the antennas; in addition, this is responsible for an irrational usage of high-frequency cables.

Therefore, in the new apartment houses in Moscow, arrangements are now being made for television receiving antennas for collective use. From the high-quality receiving antenna, which is supplied with a reflector and director, a distributing network leads to the apartments of the section of the house served by this antenna.

Special intermediate systems are placed at the branching points, for obtaining a distribution schedule in the cable near the traveling wave. A system of resistances is installed in the sockets of the receiver, which smoothes the oscillations of the signal level in the mains when plugging in the receiver or when shutting it off. When the distances from the television transmitter are short or when the number of television sets in service is insignificant, no amplification of the signals received is necessary; otherwise, a special broad-band amplifier for television signals must be inserted between the antenna and the mains. In the Soviet Union, the systems of television receiving antennas for collective use were developed by V.D. Kuznetsov and R.I.Perets (without use of an amplifier) and by S.G.Kalichman (with amplifier).

Besides in the fundamental wave band assigned to television (3.0 - 6.5 m), solid steel carriers have been used in recent years for the decimeter band (34 - 64 cm).

The advantages of the decimeter band consist in that the required frequency band is smaller with respect to the carrier; for this reason, the requirements on the broad-band antenna decrease and its construction is simplified. Apart from that, when the vertical dimensions of the antenna are small (but not of its supporting pole), a considerable concentration of energy can be obtained in the horizontal plane (coefficient of amplification of the order of 25), which results in considerable power savings of the transmitter. The television antennas for this band are of the multi-tier system of emitters which give nondirectional radiation in the horizontal plane.

4. Antennas for Radio Networks

The types of antennas for various forms of radio communication are extremely numerous. It suffices to mention the antennas of the national short-wave lines of radio communication - transmitting and receiving antennas, antennas for short-wave stations of regional radio links, antennas for radio-relay lines, antennas for military radio stations, antennas for radio stations on ships, and airborne radio networks.

Among the various types of antennas for the national short-wave lines of radio communication, a receiving traveling-wave antenna came into use, in which a large number of symmetric oscillators are connected across small capacitors to a two- or four-cable feeder, which terminates by absorbing resistance. This antenna is characterized by good directional qualities and a large range, which makes it possible to use only two types of antennas for covering a short-wave band (12 - 50 m). The disadvantage is its low receiving power, due to the weak coupling of the vibrators with the feeder line. Strengthening this coupling is impossible without impairing the directional qualities of the antenna.

Recently, G.Z.Ayzenberg and A.M.Model developed a traveling-wave antenna with resistances instead of capacitances, previously used for communication (Fig.4). The use of resistances permitted not only to increase the power of reception but also to widen the band of the antenna, embracing by one antenna the entire short-wave band.

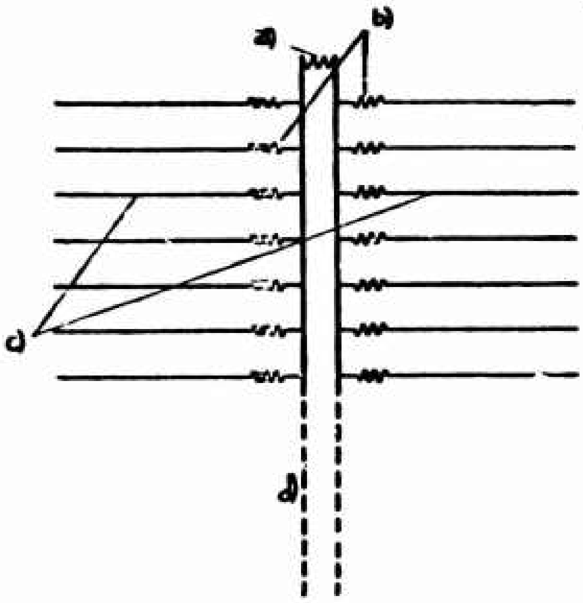

Fig.4 - Traveling-Wave Antenna with Resistances

a) Terminal resistance; b) Coupling impedance; c) Vibrator; d) To the receiver

The increase in the range of the antennas of the type of symmetric oscillators, intended for non-National short-wave lines of radio communication, was achieved by using a broad-band dipole, developed by G.Z.Ayzenberg (Fig.5). The special feature of this doublet is a wire shunt. The inductive susceptance of the shunt compensates in part for the capacitative susceptance of the doublet, which coincides with the lengthening of the wave and which permits to obtain in the feeder line charged by the oscillator the coefficient of the traveling wave, being lower than 0.3 in the 12 - 50 m band.

The original type of antenna for a radio network operating in the band of short meter waves, was developed by G.Z.Ayzenberg, A.M.Model, V.D.Kuznetsov and V.V.Lyamkov. The antenna was to give an amplification factor of the order of 1000, and simultaneous operation on two waves (transmitting and receiving), in the wave band of 1 : 2. The antenna has a mirror made of vertical cables, and represents part of the surface of a vertical parabolic cylinder. In the focal line of this cylinder, a linear system of broad-band vibrators equipped with angular counter-reflector, which concentrates the radiation in horizontal plane surface. Thanks to this arrangement, the energy emitted by the broad-band oscillators in almost its entirety is incident on the mirror and, after being reflected from there, coincides with the direction of the correspondent. The same system of oscillators is also used for reception. The signals received and emitted are separated by means of a filter system.

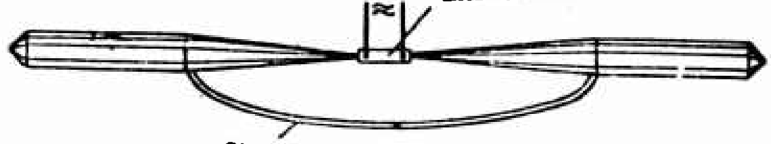

Fig.5 - Broad-Band Dipole

The described antenna system serves as an original example of the example of transferring methods, employed in the technology of image antennas, from the zone of cm and short dm-waves into the zone of much longer waves - meter waves.

During the last decade, a new type of radio communication antennas came into increasing use - antennas of radio-relay stations operating on centimeter or short decimeter waves. These antennas are installed on the tops of high towers or masts and serve for receiving and transmitting the wide spectrum of frequencies, which includes not only hundreds of telephone channels but also the spectrum of the television channel. Rigid requirements are made with respect to antennas of radio-relay stations, primarily, relative to coordinating the antennas with their feeder lines (the coefficient of the traveling wave must be about 0.95 in the frequency band of the order of 10% of the medium frequency of the band in which the antenna is operating). Such a requirement is based on the necessity to ensure a linear phase change of the signal in the antenna channel as a function of the frequency, in order to prevent distortion of relayed signals. Meeting this requirement is complicated by the filter system, which has to be used for parallel connection of several transmitters into the antenna, serving separate parts of the transmission spectrum.

Rigid requirements are made on antennas of radio-relay lines with respect the side lobes, particularly in cases where only two frequencies are used in the intermediate point: one for reception (from both sides), and the other for transmission (also from both sides).

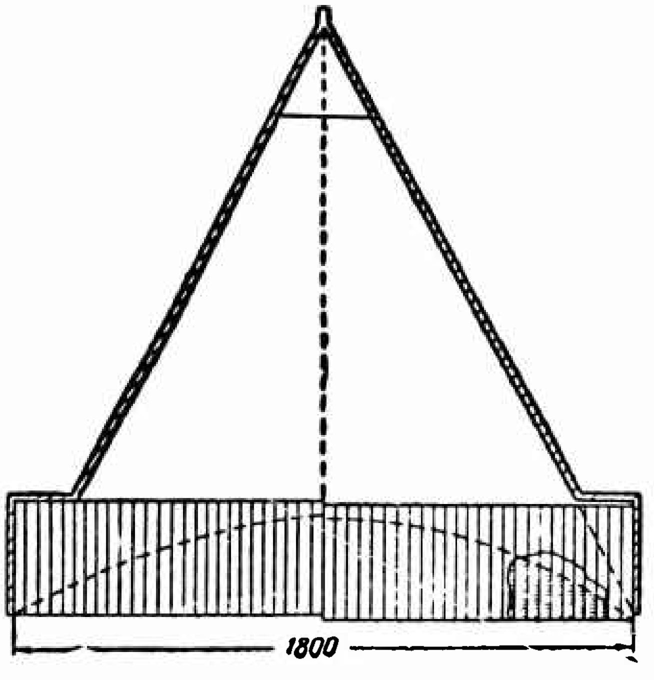

Fig.6 - Horn-Type Lens Antenna

In such a case, the lobe level behind the antenna must be at least 50 db lower than the maximum of the directional diagram.

As far as radio-relay stations are concerned, mostly two types of antennas are used: horn-type lens antennas and image antennas. The antennas of the first type are widely used by the Bell Laboratories in the U.S.A. and represents a pyramidal horn carrying a planoconvex lens of an artificial dielectric at its inlet (Fig.6). The artificial dielectric recommended first by A.N.Kaptsov is actually a system of flat narrow and long metal strips imbedded in polystyrene foam and intersected at short intervals. Due to the considerable amplitude and the shortness of the wave (7 - 8 cm), these antennas produce an amplification of the order of 10,000, while the shielding qualities of the horn ensure a lowering of the side lobes of the directional diagram.

Image antennas for radio-relay stations consist of a uniform or reticulated reflector with a paraboloid surface of revolution in whose focus an emitter in the form of a small horn or oscillator with reflector is placed.

Considerable difficulties are encountered in solving the question of channeling the energy from the transmitter to the antenna, because of the considerable antenna height (usually from 50 to 100 m). The use of long coaxial or wave lines is impracticable because of design difficulties, considerable energy losses, and detrimental effect on the coordination of the heterogeneity in the junctions. The Bell Labora-

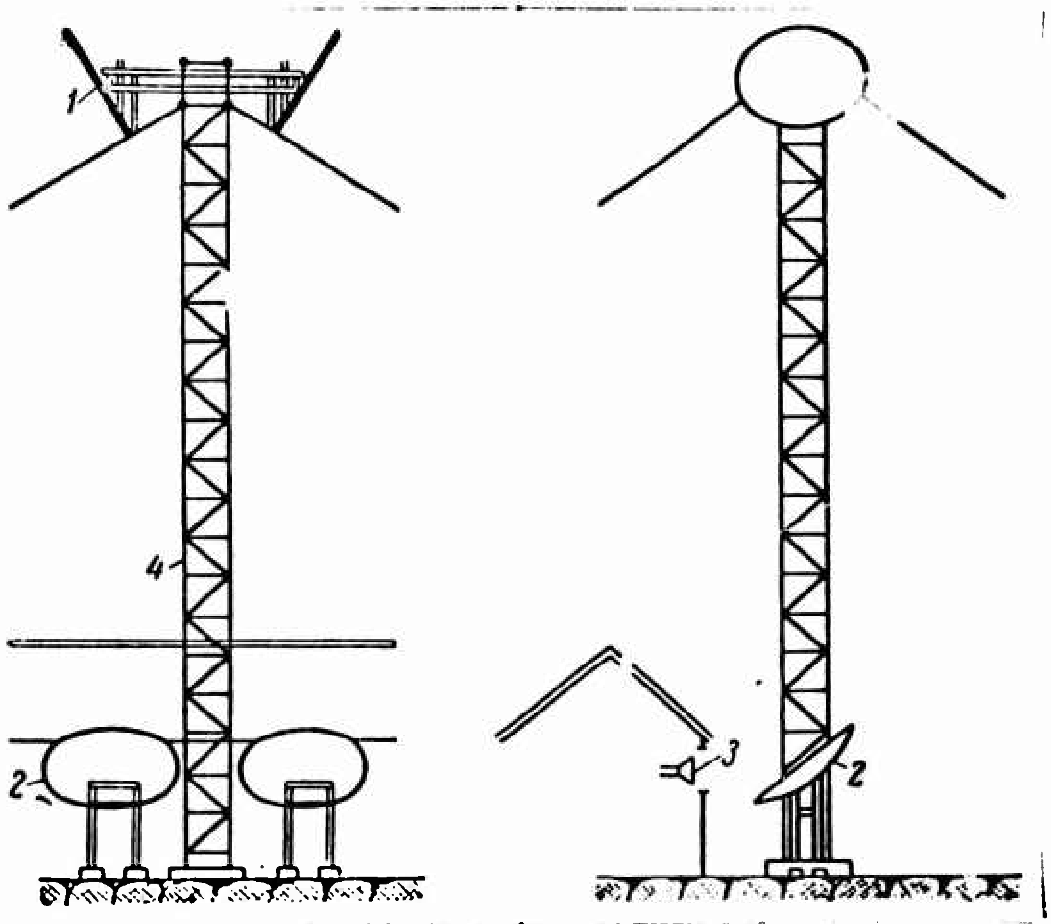

Fig.7 - Feeding the Antenna by Means of Reflectors

tories erect the transmitter on the platform, slightly below the antenna. Another way of solving the problem is to transmit energy from the ground to the antenna (and vice versa) with the aid of a system of reflectors. Figure 7 shows the design of an antenna developed by V.D.Kuznetsov and A.A.Metrikin, built according to this principle and designed to operate in the 15 - 20 cm band.

The horn (3), actuated by the transmitter, exposes a slanted elliptical reflector (2) which directs the radiation upward along the support (4). An inclined flat reflector (1), fixed at the top of the support, reflects and thereby focuses energy in the direction of the correspondent. The efficiency of such a transmission amounts to about 50%.

It is also of interest to mention antennas of so-called passive rebroadcasting or relaying, which were used in radio-relay lines during the last several years whenever obstacles are met in the path of propagation of radio waves between the transmitter and the receiver (for example, high elevations like hills or mountains in the vicinity of a station). In such a case, the passive relay in the form of a system of reflectors or lenses is placed on the hill in question and re-radiates the absorbed energy.

In summation, we will briefly discuss the special features of a radio network used in aircraft. The high speed of modern aircraft makes the application of previously used wire antennas (whether of the trailing type or strung above the fuselage) and those of the horn type impossible. Quite popular at present are antennas for meter waves in the form of vertical rods, fitted into the dielectric plate which is part of the vertical fin of the aircraft. For radiation of short waves one had to find methods of producing oscillations of the entire conducting body of the aircraft.

5. Antennas for Radar Stations

The technique of radar antennas developed during the last decade, represents a broad and multiform branch of antenna technique corresponding to a variety of problems solved by radar stations and the broad wave band used in modern radar.

It is naturally impossible for this survey to give, even briefly, a more or less systematic review of antennas for the various types of radar stations. Therefore, we will deal only with a few types of antennas and with a few questions characteristic of the field of antenna technique under review.

The largest antennas, as far as size is concerned, are those of spotter radar stations which detect aircraft at considerable distances from the ground. In accordance with the function of the station, the antenna must have a high amplification coefficient (of the order of several thousand) and be capable of handling pulses of substantial power (1 megawatt and more). The antenna must permit a panorama search of the air space and be supplied with means for determining not only the azimuth but also the elevation of the spotted aircraft.

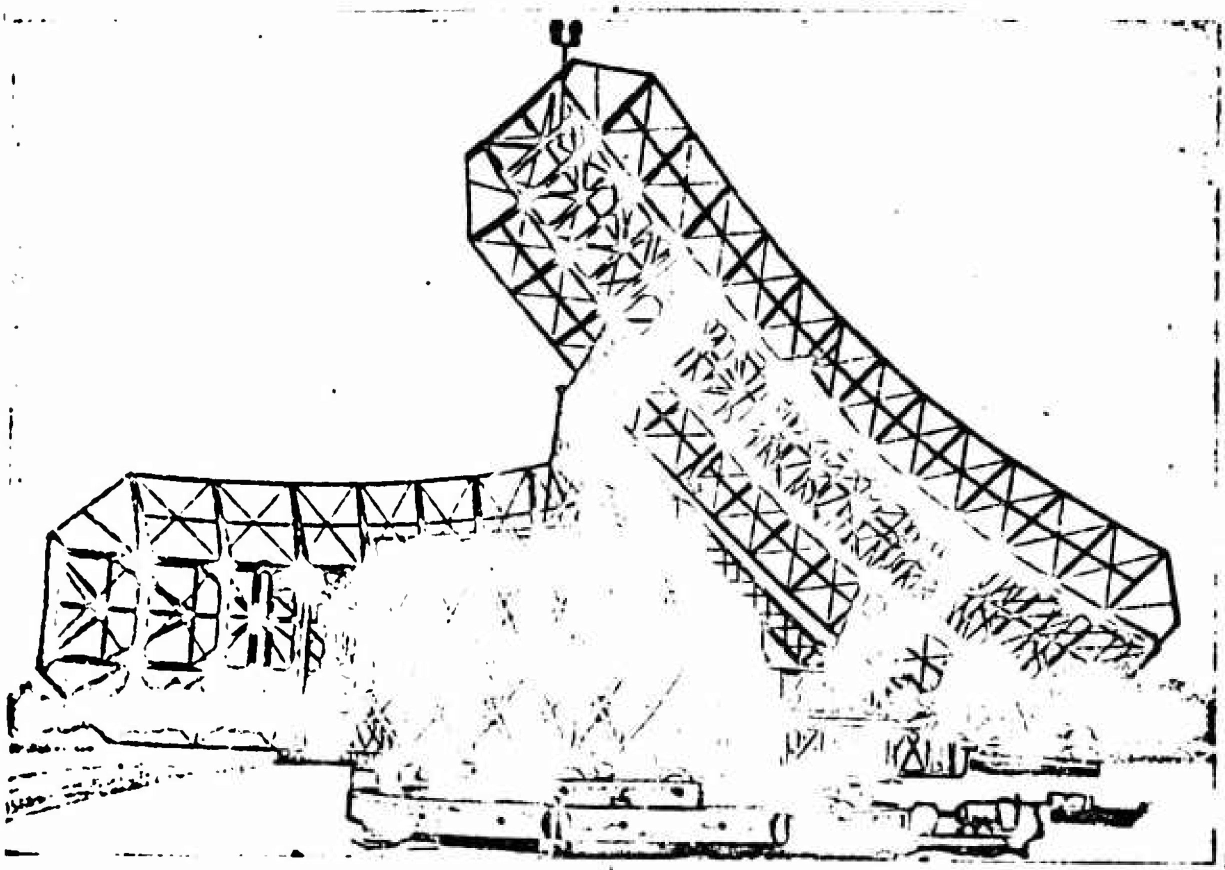

Fig.8 - Antenna of a Radar Spotter Station

Figure 8 shows such an antenna. It consists of two truncated cylindrical parabolic reflectors, made of metal netting: horizontal (with a vertical focal line) and slanted. The dimensions of each reflector are 305 - 762 cm^2 and the focal distance about 2 m. Along the focal line in each of the reflectors, a complex system of exciters which ensures reception of the given pattern in the vertical plane. The width of the radiation pattern in the horizontal plane is of the order of 1^o at half-power. The slanted reflector with its exciter in conjunction with the horizontal antenna permits determining the height of the spotted aircraft. The entire system rotates about the vertical axis at a speed of 6 rpm.

Another characteristic example of a radar antenna is an antenna for scanning the ground from an aircraft. To ensure an even contrast of the image of the object on the PPI of the radar station, the antenna must have a so-called cosecant radiation

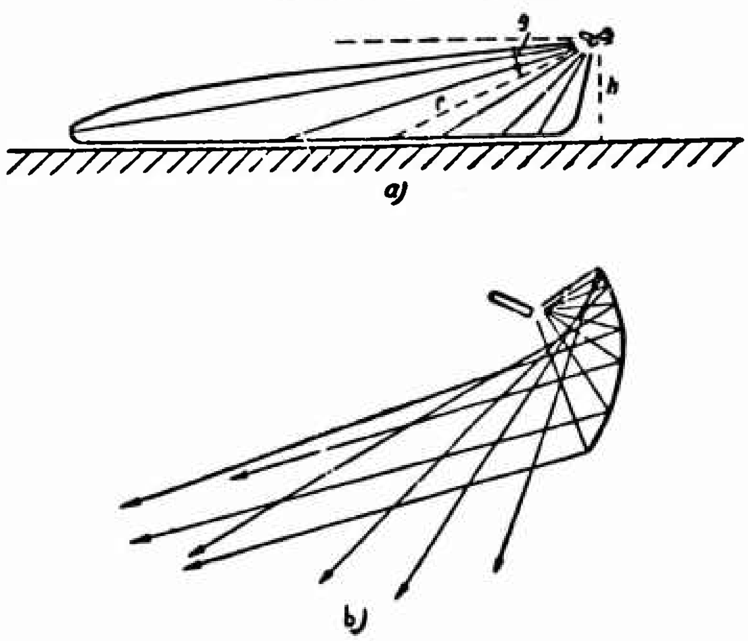

Fig.9 - Cosecant Pattern and Cross Section of Reflector

pattern in the vertical plane (Fig.9a); in this case, the intensity of the signal at the receiver input, created by the reflection from some section of the earth's surface (free of buildings), does not depend on the distance from this section r. In order to obtain a cosecant pattern a cylindrical reflector is normally used, whose cross section has a special form close to parabolic in its lower part, forming the maximum of the cosecant pattern. Figure 9b gives an example of such a cross section, also showing the path of the rays which form the various sections of the cosecant radiation pattern.

For exciting the cylindrical parabolic reflector, a linear exciter (of the type of the luminescent line), fixed along the focal lines must be used. Such systems include the popular segment-parabolic exciter (or, as it is sometimes called "cheese") schematically shown in Fig.10. Between the two conducting parallel planes, a reflector mirror in the form of a parabolic cylinder, swept by a hornlike cheese is inserted, in the zone of the focal line of this reflector. The radiating surface is a long and narrow slot (aperture) of the "cheese" at which the rays reflected from the reflector arrive in phase. The field created by such an aperture corresponds to the field of the linear exciter. The linear exciter can also be made in the form of a slotted waveguide operated cophasally, or in the form of a system of two conducting parallel planes between which the exciter is placed at one end and the focusing lens at the other (in the aperture).

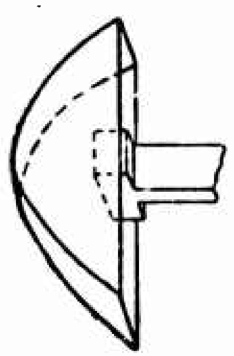

Fig.10 - Plano-Parabolic Radiator

An important item in the technique of radar antennas is the question of "scanning", i.e. rapid shifting or swinging of the radiation pattern. Thus, for gun-laying stations conical scanning is used in which the radiation pattern (Fig.11) is displaced slightly from its direction and rotates about this equisignal direction. When the direction at the sight does not coincide with the equisignal direction, the intensity of the received signals will be modulated by the rotation frequency. At the instant the sight coincides with the equisignal direction, the modulation stops.

To obtain conical scanning, reflectors having the shape of a paraboloid of revolution are used. The exciter is not placed in the focus but at a certain distance from it and rotates about the axis of the reflector with a speed of several thousand rpm. If instead of rotating the exciter it is rapidly swung to the right and left of the focus, the radiation pattern will swing in the horizontal plane. However, if the pattern is varied by more than 5 - 8° (depending on the focal distance of the lobes), its shape will quickly deteriorate due to the broadening of the principal lobe and the appearance of side lobes.

To increase the swing sector of the rays, more complicated reflector antennas are used, by giving the surface of the reflector a special form and by shifting the exciter in the above-mentioned system of two conductive parallel plates.

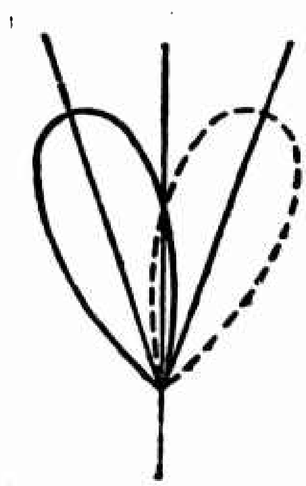

Fig.11 - Radiation Pattern for Conical Scanning

In a number of cases, requirements are made on radar antennas to ensure radiation with circular polarization, where the vector of the electric field does not have a fixed direction but makes one full revolution for each period. For obtaining circular polarization, many methods are used. Quite widespread are spiral antennas which are easy to build and have good range qualities.

The development of radar for aircraft created the problem, in antenna technique, of protection from the airflow. This problem is solved by using special casings of streamlined form, so-called fairings. The design of the latter, while satisfying the requirements of mechanical strength, must simultaneously permit the passage of emitted energy without significant loss, without reflections from the inner walls of the fairing and without distortion of the directive properties of the antenna.

At present, the vast majority of directive antennas used in radar belong to the reflector type. However, it should be mentioned that intensive research is being done on designing new types of directive antennas for the centimeter wave range, such as lenses. Considerable attention is being paid to the development of antennas of the surface type, based on the use of corrugated conductive surfaces, which have the property of concentrating in their vicinity the field of a wave propagating along the surface and to regulate its phasal speed by means of changing the parameters of the corrugation.

6. Use of Antennas in Radio Astronomy. Radio Telescopes

In 1929, K.Yanskiy, with the aid of a beam antenna, discovered a special kind of interference with radio reception in the 10 - 15 m wave band, caused by cosmic radiation from the direction of the Milky Way. Thus was born a new branch of science - radio astronomy, which was intensively developed during the past several years. Radio astronomy uses that section of the spectrum of radio waves (from 8 mm to 10 - 15 m) which has the property of passing through the layers of the earth's atmosphere without significant absorption. To pick up the weak radiation of energy in the wave range arriving on earth from the sun, the moon, and other cosmic sources, a highly sensitive receiver with a good antenna is required. The beam antennas used in radio astronomy are called raio telescopes. The requirements made on radio telescopes are for greater directivity which raises the level of the picked-up power and results in a high resolving power of the system; all this must be accomplished in the widest possible wave range, under the condition that the radio telescope must possess the necessary mobility permitting to aim it to any part of the sky.

The above requirements led to the construction of huge mobile parabolic reflectors, with a diameter of several tens of meters, whose manufacture presents considerable technical difficulties. The rigidity of the system when exposed to high winds and the precision of surface finish must be such as to keep the deviation of the reflector shape from a paraboloid to less than 1/16 of the shortest wave received.

The above difficulties are being successfully overcome by modern technique. Figure 12 shows a radio telescope of 66 m diameter, set up in Manchester (England) and intended for studying radio radiation from the Galaxy. At a wavelength of 1.9 m, the principal lobe (at half-power) has a width of 2°.

In the near future a radio telescope of the above type will be set up at the Observatory of Pulkovsk in the Soviet Union.

However, even huge radio telescopes do not give radio astronomists the resolving power required nowadays. For example, the angular diameter of the sun equals $\frac{1}{8}^{\circ}$. In order to observe radio radiation of different sections on its surface, a ray, whose width is measured in minutes is required. This problem is solved by so-called radio interferometers, which consist of two or more antennas connected in parallel and spaced at a distance of several wavelengths. As is known, in such a case the

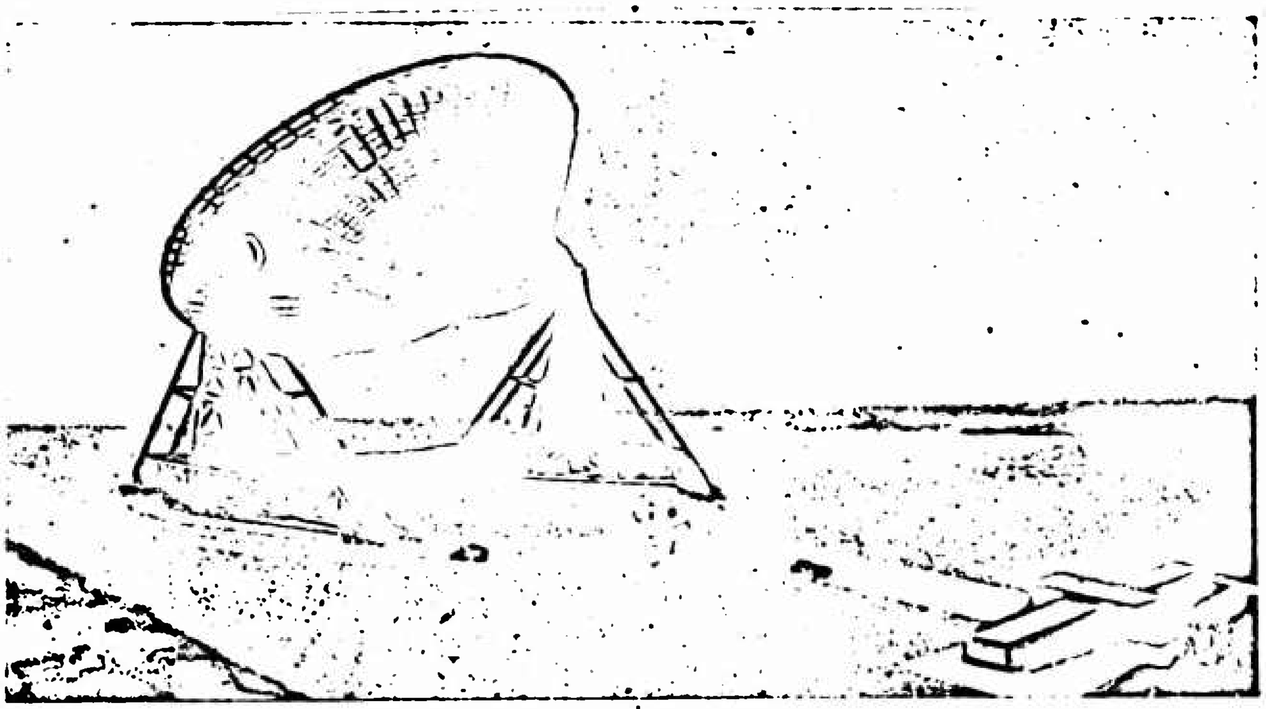

Fig.12 - A large Radio Telescope

radiation pattern for two antennas will have multilobe character, similar to the one shown in Fig.13. What is important is that the width of the lobe of the radiation pattern is smaller than the angular diameter of the sun, while the distance between the lobes is larger than this diameter. Then, for the motion of the earth relative to the sun, the lobes will scan the surface of the sun and record the radio radiation of the individual sections.

Figure 14 shows a multielement radio interferometer, designed for operating on the 21-cm wave. The device consists of 32 image antennas, with a diameter of about

2 m each, placed in a row at equal intervals, making a line of 200 m. The radiation pattern of such an antenna system consists of a few narrow lobes, about 3 minutes wide, spaced at an angle of 1.5 degrees. In radio astronomy, the antenna technique was given an unexpected and independent direction of development. However, this powerful and complicated technique originated in the primitive receiving antenna, which was used by A.S.Popov in observations of storm discharges, occurring in the earth's atmosphere.

From this antenna grew huge radio telescopes which permit exploration of remote sources of radio radiation spread out in the limitless spaciousness of the universe.

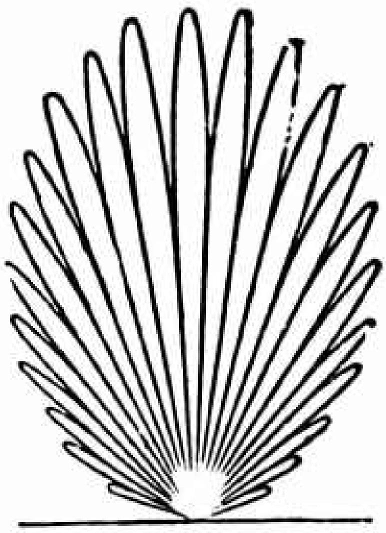

Fig.13 - Radiation Pattern of the Radio Interferometer

7. Achievements in the Field of Transmission Lines

During the last 10 - 15 years significant progress was made in the technique of transmission lines (feeder lines), mainly in the field of ultrashort waves. During that period the problem of finding a plastic dielectric with low energy loss at high frequency was solved (polyethylene), which permitted the construction of a flexible cable, now in widespread use (particularly, for the erection of television receiving antennas). For short decimeter waves, special high-frequency cable systems were designed which permitted expansion of the field of application to waves of the order of 10 cm.

When channeling high-frequency currents, it is generally known that the surface effect must be taken into consideration; this requires conductors consisting of heavy-gage wires (usually silver-plated) or of a large number of very thin braided wires. In 1951, an American, A.M.Klogston, proposed a new design in the form of a multilayer conductor, which presents, in cross section, a series of concentric very thin layers of wire and dielectric. (Fig.15). In the cross section of such a cable, the current density is distributed by a cosine curve, with zero at one of the center layers. On both sides of this layer the current flows in opposite directions. A large quantity of conducting material in the cross section decreases the attenuation

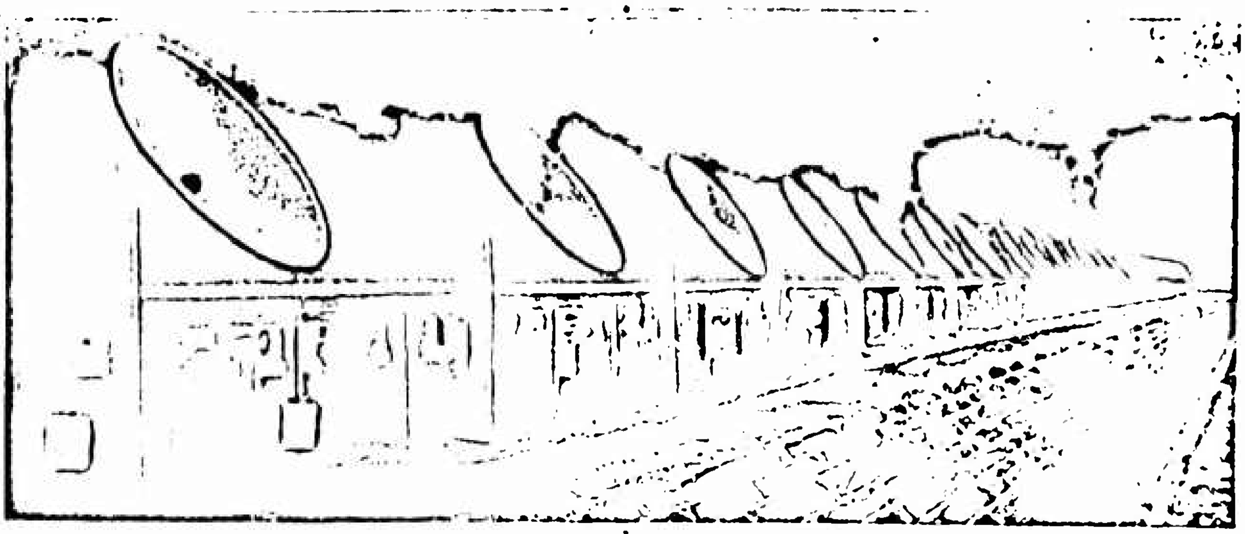

Fig.14 - Interferometer of 32 Antennas

(as compared with the coaxial cable) in some frequency band which is determined by the structural data of the cable. Thus, when the thickness of the layers of the conductor and the dielectric is 0.0025 mm and the outside diameter is 2.5 mm, the band will be in the range of 21 kc to 20 mc and when the diameter is 19 mm this will be 370 cycles to 2.5 megacycles. In the given wave range, the attentuation of the multilayer cable does not depend on the frequency.

During the past 15 years, a new field was created in the technique of channeling high-frequency energy - waveguides - used for long millimeter waves and in the entire region of centimeter waves. The use of waveguides in the practice of radio networks and particularly radar stations required solutions of a series of problems, such as design of butt joints, bends, rotating couplings, waveguide commutators, not to mention the problem of coordination of the entire waveguide channel with its feed generator. It was necessary to solve all these problems - and still is - not only from the point of view of obtaining the maximum band of operating frequencies, but also with the aim of ensuring electric strength (disruptive strength) when transmitting signals of high pulse power, which may reach the value of several megawatts.

Considerable attention is being paid by our radio specialists and those abroad to the problem of using round waveguides with a wave of the type H_{01}. The structure of the electromagnetic field of this wave is such that the propagation of the energy in the waveguide takes place at relatively weak currents on the surface of the wall. Therefore, the energy loss in the waveguide becomes insignificant.

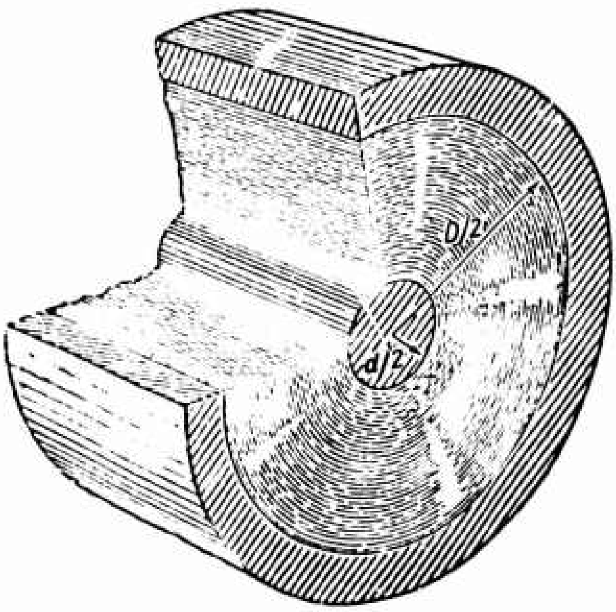

Fig.15 - Klogston's Cable

The application of waveguides with the H_{01} wave is interesting in two directions: for use in the waveguide channels of the millimeter wave band and in long channels of the centimeter range, as well as for independent excessively long communication lines, which have low attenuation and possess an exceptionally wide frequency band (instead of a high-frequency cable). Unfortunately, even the slightest heterogeneity in the cross section of the waveguide (and more so any bends), causes a conversion of the energy of wave type H_{01} into energy of wave type E_{11}, which has high attenuation. With a view to solving this and other problems, encountered in the practical use of the H_{01} wave, intensive research and development work is constantly being done.

During the last four years two new types of feeder lines were developed which are becoming of practical use. The first type is the single-cable line for the decimeter and centimeter range. The propagation of electromagnetic waves along the cylindrical conductor, coated with a layer of dielectric, was theoretically explored as far back as 1907 by the German scientist F.Kharms (Harms). However, only in 1950 did the German engineer, G.Gubo, draw attention to the fact that the presence of the dielectric layer results in a concentration of energy transported by the electromagnetic field in the immediate vicinity of the cable. This necessitates a comparatively small area around the cable free of other cables, so as to permit transfer of energy without loss due to eddy currents created in adjacent cables.

Fig.16 - Single-Cable Line

Figure 16 shows the transfer system of a coaxial feeder to the single-cable line, having the shape of a horn, covered with a dielectric cone for protection from precipitation, and the outgoing cable. While it is still impossible to achieve high efficiency when changing from cable to line, the single-cable line can successfully compete with the coaxial cable, when long lengths are involved. For example, the line shown in the diagram (made of a brass wire with a diameter of 2.56 mm, coated with an 0.35 mm layer of polyethylene) of a length of 32.5 m, has an attenuation 2.1 - 2.4 db in the 1.6 - 2.4 mc range and a coefficient of the traveling wave not lower than 0.77.

The second new type of feeder lines, intended for the centimeter range, is the so-called belt line, which came into existence in 1952. Such a line presents two conducting belts, divided by a layer of dielectric (Fig.17). The lower, electrically grounded belt is wider. When properly laid out, only a small part of the energy conveyed by the field is contained in the area surrounding the line, outside of the dielectric.

The energy loss in belt lines is larger than in waveguides, mainly because of losses in the dielectric itself. Recently, however, progress has been made in reducing these losses substantially. Belt lines are now used only in receiving apparatus, since they do not permit feeding of large amounts of energy without disruption.

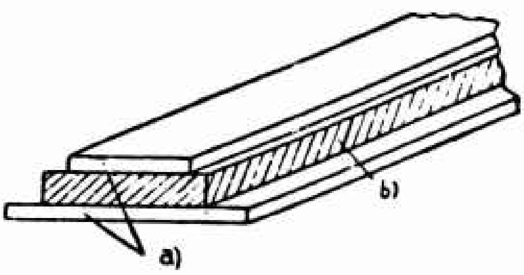

Fig.17 - Belt Line

a) Conducting belts; b) Dielectric

Another question of recent interest whose solution would mean a further step in the development of waveguide technique will be discussed below. This is the use of magnetized ferrites in waveguide channels.

If a section of the waveguide is partly filled with ferrite to which a constant magnetic field is applied, then - as theory teaches and experience confirms - various conditions relative to phasal speed, attenuation, or rotation of the polarization plane for waves traveling in opposite directions could be created. This property of magnetized ferrite permits, for instance, a separation of the reflected wave from the incident wave and its absorption, preventing it from reaching the generator. Thus, the problem of coordination of the waveguide channel with the generator can be solved in a new and much simpler way. Arrangements with ferrites open new prospects also in other directions, such as the creation of current-controlled high-speed waveguide commutators, various kinds of filters, etc.

In summation, it may be stated that the layout technique with regard to channeling high-frequency energy has made great progress during the last 10 - 15 years and that the future offers still bigger opportunities of doing so.

The success achieved in the technique of antenna arrays and feeder systems during the last period would be unthinkable had there not been considerable scientific research and exploratory work, dealing with all kinds of theoretical questions raised in this connection. Important results have been obtained in this direction during the last 10 - 15 years.

In 1938, E.Gallen in Sweden and, independently, M.A.Leontovich and M.L.Levin in the USSR, have worked out a new method of calculating the current distribution in oscillators of different forms, based on the solution of integro-differential equations, which takes into account the electromotive forces induced in the various elements of the oscillator by the current distribution wanted. Despite the complexity of the calculations, this method precipitated the publication of a series of articles on current distribution, not only in different versions of a single oscillator but also in a system consisting of two oscillators.

A great deal of attention was devoted to the theory of slot antennas, which came into increasing use of late. The most significant part of this work was done by Soviet scientists, among them M.S.Neyman and Ya.N.Feld.

A great deal of theoretical work was undertaken to clarify and explain various questions relating to the directive emission of antennas, in particular the question of erecting an antenna with a given radiation pattern. A series of new ways to solve the task was suggested. Besides, it was established that although, in principle, an antenna of such dimensions will give any radiation pattern desired, in practice the maximum directivity conforms to an even current distribution in the cable or the excited field. A further increase in directivity demands such a current distribution as to make a practical application impossible, in view of the frequent change of phase, high peak values, and sharp dependence on frequency. This question was discussed in Russia in papers by the author of the present study, by E.G.Zelkin, L.D. Bakhrakh, and L.B.Tartakovskiy and in other countries by S.A.Shchelkunov, G.Zh.Riblet, P.M.Vudvard (Woodward), Zh.D.Lawson and others.

Considerable attention was also devoted to the question of supressing the side lobes. In 1946, K.L.Dolf suggested a method of calculating radiator systems - based on Chebyshev's polynomials - with a completely uniform level of the side lobes of the radiation pattern (Fig.18). This level, at certain dimensions of the antenna, determines the width of the principal maximum, which increases somewhat with the decrease of the level of the lobes.

The Soviet scientist L.A.Vaynshteyn succeeded in finding a strict solution of the problem of radiation from the open end of the waveguide.

Tremendous work has been done in developing the theory of image antennas and devising methods for their calculation. Basic results were obtained which led to the present level of the technique of image antennas. Important in this field are reports by Yu.K.Murav'yev, L.D.Bakhrakh, B.Ye.Kinber, K.I.Mogilnikov, and abroad those by A.Denbar and K.S.Kellekher.

The introduction of waveguides into radio technique led to studying questions on the excitation of electromagnetic waves and their propagation. Credit in this field is due to I.I.Volman and G.V.Kisun'ko.

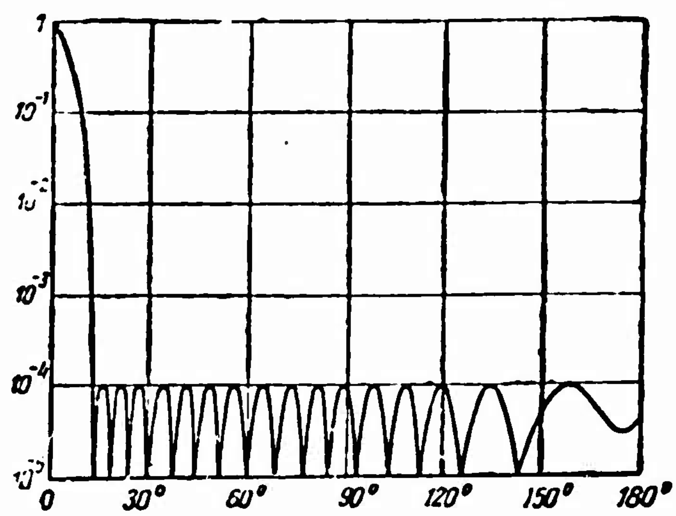

Fig.18 - Radiation Pattern of Dolf - Chebyshev

Recently, research was done on working out methods for broadband coordination of waveguide channels. Considerable success in this direction was achieved by A.L.Drabkin, A.L.Feldshteyn and others.

In connection with the prospects of using ferrites in waveguide channels, it became necessary to work out the question of propagating electromagnetic waves in waveguides filled completely or partly with magnetized ferrite. Successfully working in this field are A.L.Mikaelyan in Russia and M.L.Keylz, G.Sul, L.R.Walker, etc. in other countries.

Here only the basic trends and results of the theoretical work done in the field of antennas during the last several years are mentioned. This, of course, does not cover the multitude of theoretical questions reviewed during this period in reports by Soviet and foreign scientists.

In completing this survey, the fact must be stressed that it does not comprise many fields of radio technique, which contain antenna techniques of their own. Such are, for example, radio navigation and aerial radio surveying of localities where the principle of radio altitude measurement is used in determining the topography of the locality.

However, such a brief survey of the present-day status of antenna technique characterizes, on the whole, its exceptional complexity, the high rate of development, and the outstanding part played in this development by Soviet radio specialists.

THE PROPAGATION OF RADIO WAVES

by

M.P.Dolukhanov

Introduction

The study of the basic rules of the propagation of radio waves was begun by the inventor A.S.Popov during his experiments in the Baltic and Black Seas in the summer months of 1897, 1898, and 1899. On the basis of these and later observations, A.S. Popov came to the conclusion that the previously expressed views on the coordination of the laws of propagation of radio waves in the earth's atmosphere with those of light waves are wrong. A.S.Popov concluded that the waves which propagate above the earth's surface are affected by a factor which forces the radio waves to bend round the convex surface of the globe.

A further study of this question showed that two factors, acting separately or in conjunction, may cause propagation of radio waves around the spherical surface of the globe. These factors are diffractions, i.e., the natural tendency, characteristic of every wave process, to bend round the obstacles met on the path of propagation (such an obstacle in the given case is the convex surface of the globe) and the reflection of radio waves from the ionized layers in the upper atmosphere. Exploring, in 19?1 - 1923, the phenomenon of diffractions and reflection from the ionosphere (as the ionized area of the earth's surface is now commonly called), Academician M.V.Shuleykin, made a further detailed study on the mechanism of reflection of radio waves from the ionosphere and proved that, in complete agreement with the classical views on the phenomenon of diffractions, the latter are strongest on the longest waves of the band and that their effect decreases gradually in proportion to the shortening of the wave. M.V.Shuleykin further studied in detail the mechanism of reflection of radio waves from the ionosphere and proved that the ionosphere will reflect only waves longer than about 10 m. Shorter waves, similar to light waves, are not reflected from the ionosphere but penetrate it.

It is now accepted to call the waves which bend round the convex surface of the globe, as a result of the phenomenon of diffraction, ground waves (or surface waves). The distance of propagation of ground waves does not usually exceed 2000 km. The waves propagating around the globe as a result of single or repeated reflection from the ionosphere are called ionospheric (or spatial).

Thanks to the work by Sommerfeld, van der Pol, and M.V.Shuleykin, convenient formulas were obtained for calculating the field strength of ground waves at small distances from the transmitter, when the earth's surface can be considered plane. Developing and going deeply into the work of the English physicist Watson, B.A.Vvedenskiy established formulas for calculating the diffraction field at large distances from the transmitter. The thin structure of the ground waves was explored in a series of work done under the guidance of L.I.Mandel'shtam and N.D.Papaleksi.

The study of the characteristics of the propagation of ionospheric waves went in two directions. First, a large amount of work done mainly by physicists and geophysicists was devoted to the study of the structure of the upper layers of the atmosphere and to the processes taking place there. Another series of work done mainly by radio engineers related to the special features of the propagation of ionospheric waves of various ranges.

The basic attention of the explorers was centered on the range of short waves. Experiencing the minimum absorption in the ionosphere (in comparison with medium and long waves) the short waves proved to be particularly useful for establishing communication over large distances. At the same time, the short waves were characterized by rigidly expressed inconstancy of the conditions of propagation. Observing over a number of years the specific properties of short waves, M.A.Bonch-Bruyevich established in 1925 the basic rules of the processes of propagation. Fading and certain other phenomena, accompanying the propagation of short waves, were studied by

A.N.Shchukin. The latter is the author of the first method of calculating field strength in the short-wave range.

The development during the last several years of television, frequency modulation, pulse systems of communication, radar, radio navigation, and several other applications of radio technique, is the cause of heightened interest in the range of meter waves and much shorter waves. The study of the propagation processes of meter waves was begun by B.A.Vvedenskiy in 1921. Vvedenskiy was the first to call attention to the part played by the ray reflected from the earth's surface and to establish formulas (which are now called "reflecting") for calculating the field strength at the point of reception. The increasing application of diffraction formulas to the meter range and to the band of shorter waves is also to his credit.

In proportion to the increase in the number of transmitters, regularly operating in the ultrashort-wave range, the existence of a connection between the metereological status of the lower layers of the atmosphere (troposphere) and the conditions of propagation of ultrashort waves was discovered. The necessity was established of taking into account the phenomenon of atmospheric refraction, i.e., the effect of the bending of the rays when they are propagating in a heterogeneous atmosphere. A number of authors suggested to take into account the phenomenon of atmospheric refraction when using reflecting formulas, by means of an apparent increase of the radius of the globe.

In 1945, it became obvious that the effect of the troposphere on the processes of propagation of ultrashort waves is substantially greater than it was originally believed to be. About the same time the strong variability in the meteorological status, inherent in the layers of the air near the earth's surface became apparent. A new branch of science was born, called meteorology, which explores the thin structure of the troposphere and the changes occurring there.

DEVELOPMENT OF THE SCIENCE OF THE PROPAGATION

OF RADIO WAVES

1. Propagation of Ground Waves

a) Derivation of Approximate Boundary Conditions

A thorough examination of the process of propagation of radio waves along the spherical boundary along the interface of air and semiconductor surface of the earth, belongs to the most complicated problems of modern mathematical physics. The exceptional complexity of the mathematical computations is responsible for the fact that only in a very few of the simplest cases of this problem were solutions suitable for engineering practice ever found.

In the light of the above, the derivation in 1948 by M.A.Leontovich of the so-called "approximate border conditions" was of considerable significance. These conditions were called "approximate" for the reason that they are satisfied when observing the following inequality:

$$\sqrt{\varepsilon'^2 + (60\lambda\sigma)} \gg 1,$$

where ε' = relative electric permeation;

σ = specific conductivity of the soil, above which the radio waves are propagating, in $\frac{1}{\text{ohm-m}}$;

λ = wavelength in air, in m.

The above condition is being well satisfied in the majority of practical cases, so that its restrictive action is insignificant.

The principles of M.A.Leontovich establish a definite correlation between the radio waves composing the electric field in the air, directly above the earth's surface, depending on the electric parameters of the soil (i.e. size ε' and σ). The application of the principles of M.A.Leontovich permits a substantial simplification of the solution of a series of known problems of the propagation of ground waves as well as a solution of new problems, which until then were not susceptible of exploration.

Utilizing these approximate boundary conditions, M.A.Leontovich and V.A.Fok succeeded in reducing the problem of the diffraction of radio waves around the globe to an equation of the parabolic type, i.e. to well-known equations of mathematical physics.

2. The Conception of L.I.Mandel'shtam of "Take-Off" and "Landing" Fields

Modern theories of the propagation of ground waves are all based on the conception by L.I.Mandel'shtam of take-off and landing fields, when given radio waves are propagating. The essence of this conception is the following: The authors of earlier theories of the propagation of ground radio waves believed that the mechanism of absorption of radio waves propagating above the earth's surface, is in general outline similar to the mechanism of absorption of the wave of a current, propagating in a long cable. Every section of the cable, independent of its location, contributes to the magnitude of the total absorption.

L.I.Mandel'shtam expressed the assumption, a long time before actually formulating a strict theory, that it was possible to compare, to some extent, the process of the propagation of ground waves to the flight of an aircraft, which takes off near the transmitter, flies at some altitude above the earth's surface in the direction of the point of reception, and lands in the area of propagation of the receiving antenna. It is assumed that the absorption of the radio waves is highest in sections of the route where the aircraft flies at a low altitude above the ground, i.e., in the zones of take-off and landing fields. Thus, in conformity to the views of L.I. Mandel'shtam, the part played by the individual sections of the route in the creation of absorption phenomena is not identical. The greatest absorption is contributed by the sections of the route in the immediate neighborhood of the transmitting and receiving antennas. The strict theory of the propagation of ground waves, developed in the articles by E.L.Feynberg, confirmed in full the justification of the L.I.Mandel'shtam concept.

3. Speed of Propagation of Ground Waves

One of the conclusions of the L.I.Mandel'shtam concept is that the speed of propagation of ground waves is independent of the kind of soil above which they propagate. In fact, as long as the basic flow of energy which reaches the point of reception does not propagate immediately above the earth's surface but at a certain altitude above it, there is no reason to expect any strongly expressed dependence of the speed of propagation on the kind of soil.

The speed of propagation will depend on the kind of soil only in the immediate vicinity of the transmitting antenna, i.e., in the area of the take-off field. Exactly to these conclusions came P.A.Ryazin, who in 1940 theoretically examined the question of the speed of propagation of ground waves. These deductions were experimentally confirmed in a series of works, both in the Soviet Union and abroad.

4. The Phenomenon of Shore Refraction of Radio Waves

Still in the period of the First World War, when radio direction-finding stations first came into use, it became known that when the shore line is intersected by radio waves, a phenomenon occurs which greatly resembles the refraction of light rays at the transition from one medium to another, and which consists of a change in direction of propagation of the wave. It is obvious that the "shore refraction of radio waves" (as this phenomenon is now called) leads to errors in radio direction finding, as a result of which the skill in calculating the error assumes an important practical value.

Still in 1919, the English scientist, T.L.Eckersley tried to calculate the angle of deflection of the propagating wave by means of a direct application of the law of refraction (law of sines). Basing himself on the theory of Tsennek, Eckersley proceeded from the (as is now known) erroneous assumption that the velocity of propagation of ground waves depended on the kind of soil above which they propagate. It is of interest to note that the angles of deflection obtained by Eckersley not only did not coincide with the observed values with respect to the absolute size but differed from them with respect to the direction of the deflection.

In the light of the above, this should not come as a surprise since the velocity of propagation, as indicated, is practically independent of the kind of soil. On the basis of the L.I.Mandel'stam concept, it is possible to foresee that the phenomenon of shore refraction will be particularly strong in cases where the shore line is in the zone of the "take-off" or "landing" fields, in other words, near the transmitting or receiving antenna. If the radio waves intersect the shore line in the center section of a sufficiently extended route, it can be asserted beforehand that the effect of the shore refraction will be insignificant.

Only during the last decade, thanks to the work by V.A.Fok, G.A.Grinberg, and E.L.Feynberg, it became possible to work out a sufficiently rigid theory of shore refraction, which confirms in full the above-formulated premises. E.L.Feynberg, in particular, established a formula for determining the error of direction finding. The resultant equation represents a purely local disturbance of the field of radio waves which causes the error in direction finding only at small distances from the shore line.

5. The Propagation of Radio Waves over Heterogeneous Paths

As heterogeneous one describes paths (i.e., lines of radio communication) over different soils. It is easy to see that, in the overwhelming majority of cases encountered in practice, heterogeneous paths are involved; consequently, knowing how to calculate the field under such conditions is of exceptional practical importance.

Until recently, P.Eckersley's method of calculating the field of ground waves along heterogeneous paths was used. The non-strictness of this method is confirmed by the fact that it did not satisfy the principle of reciprocity, in other words, the calculation result depended on the direction of propagation of the wave, which should not be the case in s strict calculation method.

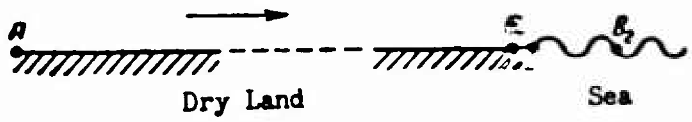

Fig.1 - Shifting of the Point of Reception from B_1 to B_2, accompanied by an Increase in Field Strength

In the light of contemporary opinion, the non-strictness of Eckersley's method is explained by the fact that it attributes to all the sections of the path an equal part in the creation of absorption and does not take into account the special part played by the sections in the area of "take-off" and "landing" fields.

Continuing and further developing the work by M.A.Leontovich, G.A.Grinberg, and V.A.Fok, E.L.Feynberg explored in detail the conditions of propagation of ground waves over heterogeneous paths and established formulas for calculating, under such conditions, the field strength at the point of reception. Similar to other authors, E.L.Feynberg figured that the radio waves are propagating above the plane surface of the earth. The deductions obtained by E.L.Feynberg also fully confirm the theory of L.I.Mandel'shtam. The formula of E.L.Feynberg, in complete agreement with the experimental data, shows that, in some types of paths, cases occur where, at a certain distance intervals proportional to the distance from the transmitter, the field strength does not diminish (as is usually the case).

A similar phenomenon is observed, for instance, in cases where the receiver, formerly located along the coast or dry land (point B_1 in Fig.1) is shifted to the sea into position B_2. If, in the former position of the receiver, the "landing field" was situated above dry land and was causing a noticeable absorption of radio waves, in the second position the "landing field" will be above the sea and would cause only an insignificant absorption because of the fact that the sea possesses a higher conductivity and that, with increasing conductance, the absorption of ground waves decreases.

6. Derivation of a Strict Solution of the Equation of Diffraction

Notwithstanding the fact that the problem of diffraction of radio waves around the globe attracted the attention of the most outstanding scientists of world renown, all the calculation formulas and methods of computation recommended during the last period were suitable for determining the field strength only in the shadow zone, i.e., at distances well above those of direct visibility.

As long as only long, medium, and short waves found application in the technique, this presented no inconvenience. In the given ranges, as a result of strong diffraction, the equations for the field strength, derived under the assumption that radio waves propagate above the plane earth, proved suitable for the calculations also in the initial part of the shadow zone (i.e., in the part immediately adjoining the boundary of direct visibility).

After the meter waves and much shorter wave bands came into increasing use in radio technique, the entire aspect of things changed radically. In this range, the diffraction (as is known) is very weak, whereas the formulas used for calculating the field strength in the zones of illumination (i.e., at distances within the direct visibility range) and based on the principle of interference of direct rays with those reflected from the earth's surface, can be applied up to distances not exceeding 70 - 80% of the direct visibility range. At the same time, the diffraction formulas known until recently could be applied to practical calculations, starting with distances exceeding by about 30 - 40% the direct visibility range. Thus, the interval between the distances from 0.7 r_o to 1.4 r_o (where by r_o denotes the range of direct visibility) - the interval within whose boundaries, under normal conditions, it is highly essential to know the magnitude of the field strength - was left essentially without formulas for computations.

The gap was filled in 1944, when V.A.Fok, applying new and original methods of totaling the rows, to which the problem of the diffraction of radio waves around the globe was reduced, and utilizing the specific qualities of the functions newly introduced by him (called the functions of Eyri) obtained a strict expression for the field strength at the point of reception, at any distance from the transmitter. It is essential to note that the expression obtained by V.A.Fok could be directly converted into the conventional diffraction formula at large distances from the transmitter, and into the reflection formula at small distances from the transmitter.

In 1948, in a joint study with M.A.Leontovich, V.A.Fok proved, by using the approximate boundary conditions, that the solution of the diffraction problem could be reduced to a diffraction equation of the parabolic type. This proved the possibility of substantially simplifying the solution of the problem of diffraction.

7. The Spatial Area Required for the Propagation of Radio Waves

Until recently the question as to the area of space essential for the propagation of radio waves was of academic interest as a means for illustrating the wave nature of radio waves, the Fresnel zone, and other concepts of wave optics.

In connection with the vigorous development, during the past several years, of the technique of ultrahigh frequencies and the necessity of working out engineering methods of calculating radio relay lines of communication, the question as to spatial area required for the propagation of radio waves assumed great practical importance. This will be illustrated by an example. It is known that in the area of exposure to light, the field, at the point of reception, is the result of interference between direct rays and rays reflected from the earth's surface. The size of the resulting field is greatly influenced by the absolute value of the coefficient of reflection of the wave from the earth's surface which, in turn, is determined by the electric parameters of the soil at the point of reflection and by the topography of the soil (such as the character of roughnesses, form and height of vegatation, etc.). From the viewpoint of geometric optics, the reflection from the earth takes place at one point, namely, at the point where the angle of incidence is equal to the angle of reflection. Wave optics has a different answer to this. A participating factor in the formation of the ray reflected from the earth's surface participates the section of the surface, which is limited by the first Fresnel half-zone. As far as we know, it was M.A.Leontovich who first emphasized the usefulness of the construction of Fresnel zones on the reflecting surface. In constructing the given half-zone on the layout of the locality, it is easy to determine accurately which section of the earth's surface participates in the generation of the reflected ray and precisely determine the value of the coefficient of reflection.

No less important is the knowledge of the measurements of the half-zones of Fresnel on the path of propagation of a direct ray, since these measurements determine the necessary clearance between the trajectory of this ray and the obstacles (in the shape of tops of hills, isolated buildings, etc.) encountered on the path of propagation. Recently, a suitable calculating procedure was worked out for determining the dimensions of the Fresnel zones, both along the path of propagation of the direct ray and of the rays reflected from the earth.

TROPOSPHERIC PROPAGATION OF RADIO WAVES

1. Calculation of Atmospheric Refraction from Reflection Formulas

The question as to the effect of meteorological processes on the conditions of propagation of long, medium, and short waves, which attracted the attention of many researchers and was the subject of numerous discussions, is now solved in the sense that these effects can practically be disregarded, whereas the question as to the effect of the troposphere on the propagation of radio waves shorter than 10 m was solved quite differently. It has been established that the troposphere (i.e., the lower part of the atmosphere extending up to 12 - 16 km) plays an extremely important role in the processes of propagation of meter and shorter waves.

The cause of the troposphere effect is the heterogeneity of the atmosphere: The refractive index of the air depends on pressure, temperature, and humidity. Each of these factors changes with the altitude, causing the magnitude of the refractive index of the air to vary. Under so-called "normal conditions" the refractive index near the earth's surface has a value of $n = 1.000338$ and decreases uniformely with the height, by 4×10^{-8} with each meter. As shown by elementary calculation, this heterogeneity of the troposphere, which at first glance seems rather insignificant, causes a considerable bending of the ray paths; under these conditions, they acquire the shape of arches with a peripheral radius of 25,000 km, rotating convexly upward. This phenomenon, which takes place also in the propagation of light waves, is called atmospheric refraction. This makes it plausible that such bending can be disregarded in the propagation of long, medium and short waves.

In the given ranges, the bending of waves around the globe is caused by more strongly acting factors, such as diffraction and reflection from the ionosphere. Therefore, one can disregard the insignificant bending of rays in the troposphere, caused by atmospheric refraction. However, in the range of waves shorter than 10 m, the effect of diffraction of radio waves decreases sharply, so that even insignificant curvatures of the paths must be taken into consideration.

In 1933, it was shown that the effect of atmospheric refraction, when using reflection formulas, can be discounted by substituting, in the mathematical formulas, the real value of the radius of the globe R with a certain effective (usually larger) value R'. The quantity R' is determined by the condition of equality of the relative curvature between the actual trajectory of the wave and the surface of the earth - the relative curvature between the rectilinear ray and the surface of the earth of the effective radius.

The question of the admissibility of such substitution was explored by B.A.

Vvedenskiy and M.I.Ponomarev in their joint work published in 1946. In this report, the authors proved the admissibility of using the theory on the effective radius of the globe for sufficiently slanting rays; the same report also defines the limits of applicability of the given concept.

In 1933, the results of research on the conditions of propagation of ultrashort waves in a heterogeneous atmosphere, obtained by the Czech scientist P.Bekman, were published.

2. Calculation of Atmospheric Refraction from Diffraction Formulas

After the theory of the effective radius of the globe was first applied to the calculation of the phenomenon of atmospheric refraction on the basis of reflection formulas, individual authors started using an analogous procedure in calculations with diffraction formulas.

In the report by B.A.Fok, published in 1948, the question of simultaneous calculations of the effect of diffraction and atmospheric refraction was thoroughly reviewed. It was also shown, that, if the value of the refractive index of the air changes uniformely within the boundaries of the atmosphere area, where the radio waves bending around the globe are propagating, then the effect of atmospheric refraction can actually be disregarded by substituting the effective value of the radius of the globe for the one entering into the diffraction formulas. Generally, when the refractive index changes with the altitude according to a more complicated law, it is necessary to use a special formula for computing the effective radius of the globe.

3. Experimental Data on Long-Range Propagation of Meter and Decimeter Radio Waves

The results of extended observations on long-range propagation of meter waves were described in a series of works by the scientists Lauter and Klinker of the German Democratic Republic.

In proportion to the increase in the number of television stations, more and more references to long-range reception of television programs appear in the literature. In analyzing these cases of long-range reception of transmissions in the meter range, governed by the effect of the troposphere, it was found that all these can be subdivided into two groups. The first group includes cases of regular (daily) reception of signals. The second group comprises cases where the long-range reception of signals is recorded only during fixed intervals of time and where the farthest transmission is not of a regular character. In both these groups of observations, the reception of signals is accompanied by irregular and more or less sharp fluctuations in the power of reception. In analogy to the effects in the short and medium wave bands, these fluctuations are called fading.

Figure 2 gives the results of measurements of the field strength in the range under review, at substantial distances from the transmitters. The distances are plotted on the abscissa and the field strength in decibels is plotted on the ordinate in relation to 1 μ volt/m.

The obtained findings are converted into 1 kw of radiated power for the isotropic transmitting antenna. The height of the transmitting antenna is of the order of 150 m and that of the receiving antenna is 10 m.

Inasfar as the field at the point of reception is subjected to continuous oscillations (fading), three curves "a" are plotted on the diagram for the simultaneous characteristic of mean values and degree of fading. The lowest curve characterizes the so-called mean values of the field strength, i.e., values, which, in fact, are exceeded in 50% of the time of observation. The center curve characterizes the values which are exceeded in 10% of the time of observation. The upper curve represents the level of the field exceeded in 1% of the total time of observations. For comparison, curves "b" are plotted on the same diagram, calculated from diffraction formulas, taking into account normal atmospheric refraction. At the selected scale, these curves degenerate into straight lines. The upper one corresponds to the wave λ = 6 m and the lower one to the wave λ = 50 cm.

A study of the curves permits the following deductions:

1) The fields under actual observation begin to exceed the values computed on the basis of diffraction formulas, at distances above 100 km. The greater the distance from the transmitter, the larger will be the excess. At a distance of 200 km,

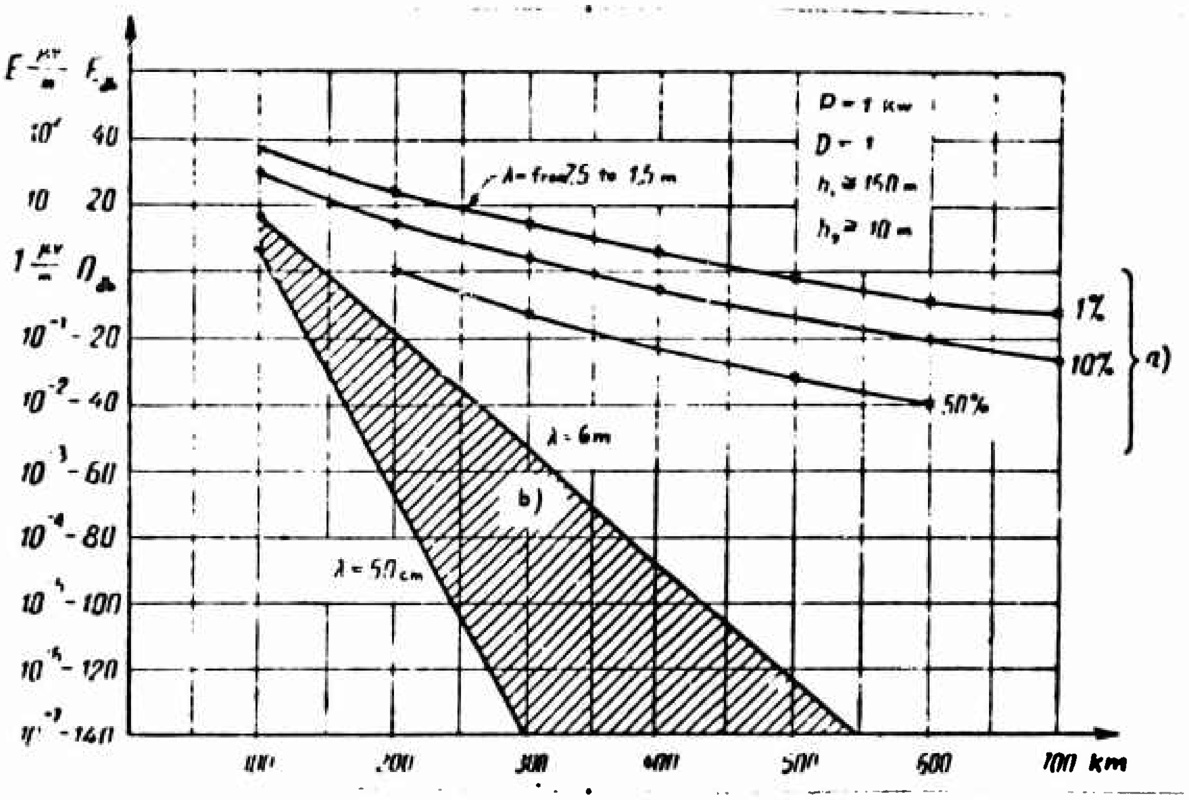

Fig.2 – Field Strength as a Function of Distance

a) According to experimental data; b) According to calculations by diffraction formulas

this excess (for waves of 6 m) amounts to 20 db, at 500 km to 86 db, and at 700 km to 150 db)*.

2) The fields, actually observed at considerable distances from the transmitter, do not depend on the frequency in the broad band. The inscriptions on the curves

* The calculated curves for waves of 6 m cover only the distance of 550 km.

show that, in the interval of $\lambda = 1.5$ m to $\lambda = 7.5$ m any dependence on frequency is completely absent.

3) The depth of fading is practically independent of the distance and reaches 30 db (counting from the median values to the 1% level).

Observations showed that telephone transmission is not accompanied by noticeable distortions (no observations of television transmitters were carried out because of the limited power of existing television transmitters).

All the above relates to regularly (daily) observed levels of the field at considerable distances from the transmitter, i.e., to cases of long-range reception which pertain to the first group.

As far as the characteristic of cases of long-range reception of the second group is concerned, it has been so far impossible to plot any generalized curves for the dependence of the field on distance. This is explained by the fact that the irregular cases of long-range reception strongly depend on local conditions and on the meteorological medium: At some instants of the period the field strength may reach magnitudes equal to those of the level of the field in free space. As a rule, long-range reception is accompanied by strong fading; the depth of the fading is also variable.

4. Classification of Different Cases of Atmospheric Refraction

In meteorology and physics, the concept of the so-called "standard atmospheric conditions" came into increasing use, by which, conventionally, temperature of the air at 15°C at a pressure of 1015 millibars is understood. It is absolutely clear that, at a given point on the surface of the globe, such conditions can occur only when there is a somewhat favorable concurrence of circumstances.

The first approximate measurements of the dependence of temperature on altitude showed that the temperature decreases on the average by 6.5°C with the elevation of each kilometer. Taking into account this circumstance, the International Commission on Aeronavigation introduced the concept of the so-called "standard atmosphere", where the temperature equals 15°C near the surface of the earth and decreases evenly by 6.5° with every kilometer. This temperature distribution conforms to the even decrease of the refractive index of the air of the order of magnitude of 4×10^{-8} with every meter. Such a dependence of the refractive index on the altitude agrees rather well with the theoretical value obtained for a well-mixed atmosphere at an adiabatic temperature change with altitude. The atmospheric refraction taking place when such dependence of the refractive index on the altitude exists, will be denoted as "normal".

Until recently, meteorologists used rather coarse devices for measuring the dependence of pressure, temperature, and humidity of the air on the altitude above the surface of the earth, which gave no information on the microstructure of the troposphere. Probably as a result of this, the opinion became widespread that the actual distribution of the refractive index with altitude differs, in the majority of cases, only insignificantly from the "normal" distribution.

When it was established that even insignificant deviations in the distribution of pressure, temperature, and humidity with altitude have a strong effect on the propagation of ultrashort waves, it became desirable to develop more sensitive measuring devices which would permit an investigation of the microstructure of the troposphere. Some authors began to call this new branch of meteorology, micrometeorology.

At present, the literature contains publications on the results of the measuring the dependence of the refractive index on altitude, for many points of the globe. An analysis of the results shows that, only in a comparatively small number of cases, can it be expected that the actual distribution differs little from the so-called "normal" one. In the majority of cases, substantial deviations take place.

All types of the observed distribution of the refractive index with altitude can be subdivided into the following groups:

1) Absence of Atmospheric Refraction. If pressure, temperature, and air humid-

ity change with the altitude according to a law where the refractive index will not depend on the altitude at certain intervals of distance, "absence of atmospheric refraction" in the given interval of altitudes is involved. In this area of the troposphere, radio waves propagate in rectilinear trajectories.

2) Negative Atmospheric Refraction. If the troposphere is characterized by such a distribution of pressure, temperature, and humidity with altitude that the refractive index increases with the altitude, then the ultrashort waves will propagate in trajectories rotating convexly downward. In this process, the rays diverge from the earth's surface. In cases of negative refraction, the range of direct visibility as well as the range of propagation of the ultrashort waves decrease.

3) Positive Atmospheric Refraction. A positive atmospheric refraction takes place in cases where the refractive index of the troposphere decreases with altitude, causing the ultrashort waves to propagate in trajectories rotating convexly upward. In all, three different possibilities of positive atmospheric refraction can be differentiated.

a) The so-called "normal atmospheric refraction", where the refractive index of the air decreases uniformly with the every meter of height to a magnitude of 4×10^{-8}. This case was discussed above;

b) The so-called "critical atmospheric refraction", where the refractive index of the air decreases uniformly with every meter to a magnitude of 1.57×10^{-7}. At such a fast change in the magnitude of the refractive index, the paths of the ultrashort waves assume the form of arcs of a circle whose radius is equal to the radius of the earth;

c) The so-called "super-refraction", where the refractive index of the air decreases with altitude even faster than in the case of critical refraction. The refractivity of the troposphere increases greatly in the process, so that the sufficiently slanting rays, which undergo full internal reflection, return to the surface of the earth. Under the influence of super-refraction, the distance of propagation of ultrashort waves increases sharply. In Fig.3, the trajectories of radio waves are shown schematically at various atmospheric refractions.

5. The Phenomenon of Super-Refraction of Ultrashort Waves

In 1944, working on the theory of propagation of radio waves in waveguides, P.Ye.Krasnushkin mentioned the possibility of long-range propagation of ultrashort waves in waveguides, taking place in the lower layers of the troposphere. Less than a year later, cases of super-distant propagation of decimeter and centimeter radio waves were actually discovered in various places of the globe, which confirmed the accuracy of the theory developed by P.Ye.Krasnushkin.

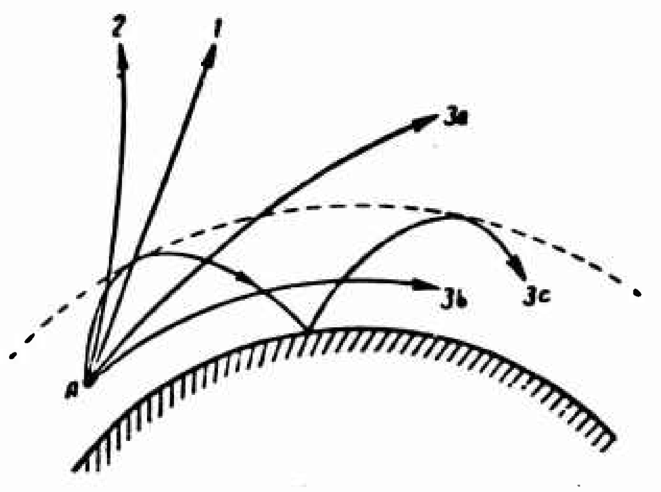

Fig.3 - Trajectories of Meter Radio Waves at Different Forms of Atmospheric Refraction

1 - Absence of atmospheric refraction;

2 - Negative atmospheric refraction;

3a - Positive atmospheric refraction;

3b - Normal atmospheric refraction;

3c - Super-refraction

The problem of super-refraction or propagation of ultrashort waves in atmospheric waveguides attracted the attention of many researchers. It should be mentioned here that detailed theoretical investigations were made by the Soviet scientists L.M.Brekhovskiy and V.A.Fok and by the foreign scientists Buker, Pekeris, MacFarlan, and others. While P.Ye.Krasnushkin proceeded in his investigations from the idea of so-called "normal waves", V.A.Fok, using the analogy between the waveguide propagation of radio waves and the quantum-mechanics passage of particles through the potential barrier as basis, obtained a more general and more rigid solution of the problem of super-refraction.

A comparison of the observations of super-distant propagation of meter waves and shorter waves with the results of meteorological measurements showed that two processes are instrumental in producing the phenomenon of super-refraction; the occurrence of temperature inversion and the sharp decrease in air humidity with altitude. Temperature inversion is the disturbance of the normal dependence of the temperature of the air on altitude, which manifests itself in that, at a certain interval of altitudes, the temperature starts increasing instead of decreasing with altitude, as is usually the case. The existence of the phenomenon of temperature inversion had been known in the last century; however, detailed investigations of this interesting phenomenon were made only during the last several years, in connection with the development of micrometeorology. Both the temperature inversion and the sharp decrease in air humidity with altitude, promote an accelerated decrease in the refractive index of the air in proportion to the increase in altitude, which, as mentioned above, is the cause of the phenomenon of super-refraction.

At present, the conditions leading to temperature inversion have been studied rather thoroughly. Without enumerating all these conditions, we will merely mention that the formation of temperature inversion is promoted by anticyclones, i.e., the formation, on the earth's surface, of areas with high atmospheric pressure, characterized by good, stable weather. In the area encompassed by the anticyclone, settling of air masses takes place, which warm up in the process of compression. It is this heating up that leads to local elevations of temperature.

A thorough study of the process of propagation of ultrashort waves in waveguides shows that the "trapping" by the waveguide of the propagating radio waves can occur only in cases when the altitude of the waveguide fromation exceeds by some tens of times the length of the propagating wave. It follows from this that the atmospheric waveguides which are usually formed, contribute to the long-range propagation of only decimeter and centimeter waves. High waveguide formations in which meter waves could propagate are observed much less frequently.

The formation of waveguide channels explains the long-range propagation of meter waves in odd cases, belonging to the second group. Even a partial encompassing of radio waves (when the waveguide formation is not fully developed) leads, in a number of cases, to a noticeable increase in the distance of propagation of meter waves.

6. The Phenomenon of Diffusion of Meter Waves in the Troposphere

It is impossible to use the phenomenon of super-refraction for explaining the systematic excesses of the field in the ultrashort-wave band at considerable distances from the transmitter, by comparing with the field computed from diffraction formulas, taking into account normal atmospheric refraction. Among other explanations for this interesting occurrence, by far the most plausible is the theory of diffusion of radio waves in the troposphere, first elaborated by V.A.Krasil'nikov and developed by Buker, Gordon, and other authors.

The essence of this theory is as follows: The multitude of phenomena involved shows convincingly that a turbulent, i.e., irregular movement of the air in the troposphere is taking place continuously. In particular, observations on the motion of smoke plumes from factory stacks prove this effect. The smoke usually swirls, i.e., rises along a winding path, at times of bizarre shapes. The phenomenon of twinkling of the stars is also explained by the state of turbulence of the air.

The cause of this turbulence lies in the unequal heating (and, accordingly, cooling) of different parts of the earth's surface. A plowed area is warmed up in a different way than a surface of a lake or mowed meadow. The air currents rising above these areas ascend at different speeds, come into contact, intermix, and form vortices. Any, even the most insignificant, temperature changes during this process leads to equally insignificant changes in the values of the refractive index of the atmosphere. In the end, the atmosphere acquires a sort of granular structure, where the "grains" which correspond to the values of the refractive index, differing slightly from the values of the environment, are propelled back and forth incessantly and irregularly.

The effect on the propagation of ultrashort waves is produced by areas of the troposphere which are situated high enough (from 5 to 10 km) and which, simultaneously, are visible from points on the earth's surface several hundred kilometers apart.

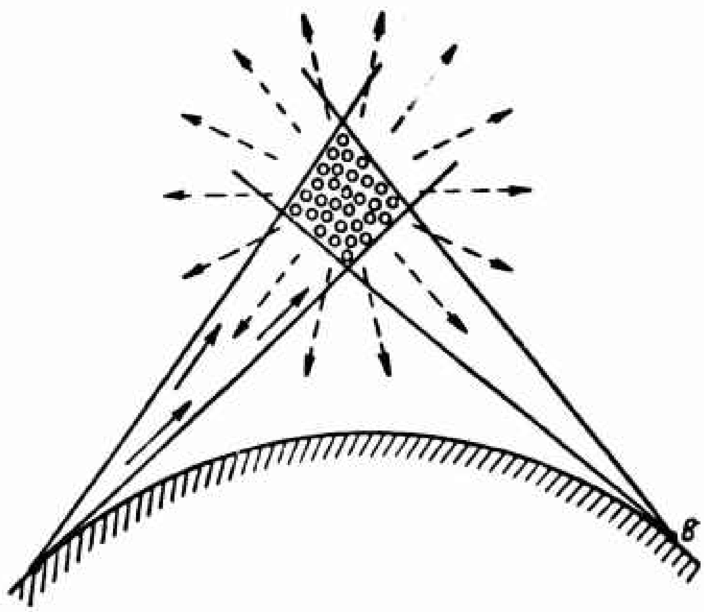

Fig.4 - Diagram of the Diffusion of Meter Radio Waves in the Troposphere

The radio waves, emitted by the transmitter, on reaching the given area, are partially diffused as a result of the granular structure of the troposphere, as is shown in Fig.4. Part of the diffused radiation, entering the zone of the receiving antenna, permits long-range reception of the signals. Inasmuch as turbulence of the troposphere is always present, while various types of weather have an effect only on the magnitude of individual heterogeneities (grains), it is this very quality of the troposphere that is responsible for the regular reception of signals at distances exceeding the normal distance of propagation of the diffractional radio waves.

Some authors, including Feynshteyn, explain the long-range propagation of ultrashort waves by partial reflections from the heterogeneities of the troposphere.

IONOSPHERIC PROPAGATION OF RADIO WAVES

1. Newest Data on the Composition and Structure of the Earth's Atmosphere

It seems plausible that progress in realizing reliable and uninterrupted communications on short waves is based on the knowledge of the formation of the ionized layers of the air and the processes taking place there.

Until recently, our information on the composition of the upper layers of the atmosphere was based on indirect observations (observations of the aurora polaris, the luminescence of the night sky, movement of meteors, etc.), as well as on direct observations, obtained from radio exploration of the ionosphere with the aid of radio pulses, emitted by the ionospheric stations. In recent years, the literature contained publications on preliminary results of direct study of the ionosphere by means of measuring devices installed in rockets. Up to the present time, altitudes of 160 km were reached. A preliminary evaluation of the results of the measurements confirms the previously expressed theory on the existence of a maximum temperature at an altitude of 50 km and a sharp rise in temperature, beginning with altitudes of 80 km. The results of the measurements also show that, up to altitudes of 100 - 120 km, the atmosphere has the same composition as at the surface of the earth.

Explorations of the atmosphere by rockets are only in their beginning, and there is every reason to believe that in the next few years considerably more complete data will be obtained with respect to the composition and structure of the atmosphere of the earth.

2. Ionospheric Winds

Among the explorers of the ionosphere the view was widespread for quite a long time that intensive mixing is peculiar only to the lower layers of the air. Thus, it was assumed that in the area of the ionized layers, the atmosphere is in a comparatively stable state.

Complex studies made during the last several years at different points of the globe, showed the fallacy of this concept. These studies are called "complex" for the reason that the conclusions as to the character of the movement of the ionized air masses were drawn by comparing the data on radio probing of the ionosphere with observations on the character of fading, on meteor trails in the atmosphere, on the twinkling of radio stars, and on the auroras.

It can now be taken for granted that constant and rather rapid shifting of the ionized air masses is taking place in the ionosphere, known under the common name of "ionospheric winds". The main cause of this is the thermal and gravitational effect of the sun (i.e., the phenomenon of tides in the ionosphere), while the tidal effect of the moon plays only a secondary role. The simultaneous vertical shifting of air masses in the lower layers of the atmosphere leads to a horizontal displacement of the air.

The rate of the horizontal shifting is hundreds of meters per second, whereas the vertical rate of displacement is only 5 m/sec. The measurements carried out by V.A.Baranul'ko showed that, in July 1952, the rate of travel of ionized clouds above Moscow, at the altitude of a sporadic E layer was 85 m/sec.

3. Fluctuating processes in the Ionosphere. The Fine Structure of Ionized Layers

The last few years are characterized also by a change of views as to the fine structure of the ionized layers of the atmosphere. The results of the evaluation of the first measurements at atmospheric stations gave reason to believe that during calm ionosphere days the D, E, and F_2 layers have a normal structure and are characterized by a monotonous change in the electron concentration in the interval from the minimum to the maximum; in pace with the perfection of the technique of ionospheric measurements and with the greater permissible capacity of the ionosphere stations, it became apparent that fluctuations, i.e., irregular oscillations in the values of the electron concentration, in the ionosphere are taking place constantly. The fluctuations are due to the heterogeneity of the ionizing radiation and to the turbulent (eddy) movement of the ionized air. Taking into consideration all these factors, we cannot fail to reach the conclusion that the ionosphere possesses a coarse structure and that any reflection from the ionosphere will inevitably have a partially diffusing character. More than that, the propagation of the ray in the heterogeneous atmosphere will be accompanied by a partial diffusion of energy similar to what is happening in a "turbid medium".

Contemporary ideas on the composition and formation of ionized layers and distribution of the ionization on the scale of the globe are based to a considerable extent on the fruitful work of many years by V.N.Kessenikh and his pupils.

The fine structure of the ionosphere was explored in a series of works by Ya.L. Alpert, which give numerical data on the measurement of heterogeneities, the rate of chaotic motion in the ionosphere, and the "degree of turbidity" of the ionosphere.

4. Ionospheric Disturbances

The basic cause of disruption of ultrashort wave communications are ionospheric disturbances. Therefore, it is easy to understand, that rsearch during the last ten years centered on the study of processes taking place in the ionosphere during disturbances and to the development of methods of predicting these perturbations.

Worthy of attention are the new theories of atmospheric disturbances, in which, in contrast to the now classical theory of Chapman and Ferraro, it is presumed that the immediate cause of the perturbations in the ionosphere during disturbances, is not the stream of corpuscles penetrating the ionosphere but the electromagnetic field of these streams which, in their movements, envelop the globe, similar to the flow of a fluid around the obstacles encountered on its course.

A comparison of data on ionospheric measurements with the processes taking place on the surface of the sun, characterizing the manifestations of solar activity, permitted substantial success in the forecasting of atmospheric disturbances. In this light, a paper of considerable interest is the monograph by the Soviet astronomers M.S.Eygenson, M.N.Gnevyshev, A.I. Ol', and B.M.Rubashev, devoted to the activity of the sun and its terrestrial manifestations.

5. Sporadic Phenomena in the Ionosphere

The question of formation in the ionosphere of sporadic layers E_c and F_{2c} is closely connected with the ionospheric disturbances. A large number of papers in the literature was devoted to further experimental and theoretical research and study of sporadic formations in the ionosphere, yielding complementary data on the frequency of their generation, magnitude, and rate of displacement. The question as to the cause of the formation of the sporadic layers still remains open. The majority of authors link the formation of sporadic layers to the corpuscular as well as to the meteoric ionization. Interesting is the effort to explain the effect of reflection from the sporadic E layer by the turbulent motion of ionized air. According to this theory, the reflection of radio waves is caused by the heterogeneities of the sporadic E layer.

6. Nonlinear Processes in the Ionosphere

M.A.Bonch-Bruyevich, in 1932, was the first to point to the possibility of the existence in the ionosphere of nonlinear phenomena, Soon afterwards, the so-called Luxembourg - Gorkiy effect was discovered, i.e., interfering influences of powerful radiobroadcasting stations on the transmission of other stations in the medium-wave range. The elementary theory of this occurrence was worked out in 1934 by Bailey and Martin.

During the last several years, the question of nonlinear processes in the ionosphere was subjected to a more complete and rigid review in a series of works by V.L.Ginzburg. The theory developed by V.L.Ginzburg permits exploring not only the

Luxembourg - Gorkiy effect, but also other manifestations of the nonlinearity of the ionosphere, such as for example the dependence of the absorption of radio waves on their amplitudes (V.P.Tselishchev referred to this in 1940), the generation of distortions in the propagation of modulated oscillations, etc.

7. Development of the Theory of Propagation of Radio Waves in the Ionosphere

During the last several years, considerable success was obtained in the study of the processes of propagation of radio waves in the ionosphere. While the first theories of propagation were based on the conception of the ionosphere as an electron gas, modern theories are characterized by a more general approach to the phenomena under study; in these, the ionosphere is regarded as an electron-ion plasma in the magnetic field of the earth. The existence of the electromagnetic field imparts to the plasma the properties of an anisotropic environment, whose properties depend on the direction of propagation of the waves.

One of the most complete and rigid theories of propagation of radio waves in the ionosphere was developed by V.L.Ginzburg. This theory takes into account the phenomena of ionization, of simple and complex recombination, adherence of the electrons to the neutral molecules, detachment of the electrons from the neutral molecules under the influence of the quanta of extrinsic radiation, elastic and rigid collisions of the electrons with neutral molecules, ions, and other electrons. For an analysis of some of these processes, methods of quantum mechanics are applied.

A more general analysis of the question shows that, in addition to the forced oscillations of the charged particles in the plasma due to the action of the propagating wave in the plasma, specific, longitudinal, so-called plasmatic waves otherwise called magneto-hydrodynamic waves are generated in the plasma itself (these waves were first submitted for an analysis by the Swedish astronomer Kh.Alfven, when he was exploring certain problems of cosmic electrodynamics).

As yet it is difficult to define the part played by the plasmatic waves in the ionosphere, from the point of view of propagation of radio waves there. It is possible that these generate shifts of the ionosphere, which are the cause of the fading of signals. It is well possible that the plasma waves immediately start interacting with the transverse radio waves. However, there can be no doubt of the great usefulness of the new approach to the processes in the ionosphere, based on the conception of the ionosphere as a fluid contained in the constant magnetic field of the earth, and based on the application of the theory of conducting fluids to the studied processes of the mathematical apparatus of hydrodynamics.

A whole series of works by Soviet authors, published in recent years, was devoted to the question - important for modern technique of radio communications - of propagation of pulse signals in the ionosphere. Here, the papers by V.N.Kessenikh and his pupils, the papers by V.L.Ginzburg and others should be mentioned. Their reports give a sufficiently complete idea on the character of the distortions accompanying the propagation of pulse signals.

The contemporary theory of propagation of radio waves in the ionosphere permits satisfactory solutions only for the simplest cases of propagation of radio waves, in particular, for the vertically directed ray. The problem of inclined propagation of radio waves, the most interesting radio communication system for practice, is still far from a strict solution.

8. Modern Methods of Computating Short-Wave Lines of Radio Communication

The production of more complete data on the composition of the ionized layers of the atmosphere and a more profound understanding of the process of absorption and reflection of radio waves in the ionosphere served as a reliable basis for the development of a new method of computating short-wave lines of radio communication. Special mention should be made of computation method suggested by A.N.Kazantsev. Contrary to previously recommended computation methods, this method - simple and convenient to apply - permits a consideration of the absorption suffered by radio waves in all layers of the atmosphere, including the reflecting layer, a fact of particular importance when calculating fields in nocturnal hours.

During the last few years, some papers were published on the graphic calculation of short-wave radio-communication lines.

9. Diffusion of Meter Radio Waves in the Ionosphere

Most recently reports were published on the discovery of a systematic reception of transmissions in the meter-wave range, at distances exceeding 1000 km. Such cases of distant reception cannot be explained either by the phenomenon of diffusion in the troposphere or, even less so, by super-refraction.

The most plausible seems the concept that the cause of super-distant propagation of meter waves is the diffusion in the ionosphere, similar in its mechanism to the diffusion in the troposphere. There is reason to believe that these heterogeneities in the ionosphere originate not only as a result of the fluctuating processes but also under the influence of meteor streams. Apart from large meteors observed in the form of "shooting stars", particles of cosmic dust constantly penetrate the atmosphere, which, in the aggregate, create ionization leading to noticeable heterogeneities in the ionosphere.

It is well possible that the phenomenon of diffusion of meter radio waves in the ionosphere can be utilized for establishing distant telegraph and telephone communications in this range.

RADIOTRANSMITTING SYSTEMS

by

Z.I.Model'

Introduction

The history of the development of radiotransmitting systems has its beginning in the works of the great inventor of radio, Alexander Stepanovich Popov. In his first experiments, a spark detector with a Hertz oscillator served as a radio transmitter, fed by an induction coil with chopper. The connection of a telegraph switch into the primary circuit of the coil permitted A.S.Popov to establish, for the first time, radiotelegraph communication.

Later experiments of A.S.Popov, carried out with a view to increasing the range of the transmitter, led to a substitution of the oscillator by an antenna with a ground system. Transmitters for the Navy during the last several years were manufactured according to this principle.

In 1899, the system of A.S.Popov was further developed by the German physicist K.Braun by housing the spark gap into a closed circuit connected with the antenna. The introduction of spark gaps with high-speed deionization (the multiple spark gap of M.Vin, the rotating one of G.Marconi) which followed later, opened possibilities for a considerable growth of the capacity of spark transmitters and improved the quality of reception of radiotelegraph transmissions.

The development of the technique of spark transmitters was further promoted by the classical exploration of the influence of spark discharges on the processes in the oscillatory circuit, made by the Russian physicist, D.A.Rozhanskiy.

In proportion to the increase in the number of spark transmitters and their capacity, the inadequacy of fading oscillations became more apparent: interference due to the rather wide frequency spectrum; difficulties in insulating the antenna because of the increased voltage during the initial oscillations; impossibility of establishing radiotelegraphic transmission. During the Forties, the spark transmitters were gradually superseded by transmitters of nonfading oscillations - arcs and alternators.

At first, arc transmitters were preferred. Their capacity reached 1500 kw which ensured radiotelegraph communication at distances up to 10,000 km. Then, alternator transmitters became predominant, due to their higher efficiency, more stable frequency, and absence of secondary emissions. Within a short time, several types of high-frequency alternators were developed. In the majority of these, the frequency did not exceed 20 kc so that the frequencies necessary for radio communication had to be obtained by the use of static multipliers. Since the multiplication of frequencies was connected with energy losses, alternator transmitters as well as arc transmitters were built mainly for operation on long waves.

The possibility of generating high-frequency oscillations by electron tubes was discovered by A.Meissner (Germany) in 1913. Later on, it was found that such tubes can generate oscillations with a considerable frequency stability over a rather wide range, starting with the long waves and ending with very short ones; it was also found that radiotelephone modulation is obtained more readily and with smaller distortions in a vacuum-tube generator than in generators of the arc and alternator type.

After the First World War, low-power vacuum-tube transmitters, mainly medium-wave transmitters, were being used for telegraphy, telephony, and radiobroadcasting. Low-power transmitters designed by radio anateurs, to whom the unused short-wave band was allotted, made their appearance.

At that time, the majority of radiotechnical experts believed that the use of electron tubes would be limited to transmitting equipment of low power and that, for long-range communication, realizable only on long waves, alternator transmitters would have to be used.

This prediction was soon refuted by the vigorous growth of radiobroadcasting, the success in vacuum technique, and records of long-range communications, established on short waves by amateur transmitter sets of low power. M.A.Bonch-Bruyevich, being the first to use water-cooling of the tube, proved the possibility of producing high-power tubes. In 1923, he produced an oscillator tube of 25 kw power, and during 1924 - 25 one of 100 kw. In the field of professional radio communication, short waves supplanted long waves, and the construction of alternator transmitters ceased*.

Creating new types of radiotransmitting arrays of the tube category, Soviet radio specialists simultaneously did detailed research and developed original calculations methods.

Primarily, it became necessary to create a method of calculating the vacuum-tube generator, suitable for a theoretical analysis and engineering planning. In other countries, a graphic method was developed, rather bulky and unsuitable for engineering practice. The outstanding Soviet scientist, M.V.Shuleykin, suggested to idealize the tube characteristics in the form of straight lines. On the basis of such an idealization, rather simple and at the same time sufficiently accurate methods for calculating the tube generator were developed during the last several years. The method of linear idealization reached full completion in the work by A.I.Berg who, in 1936, created an orderly procedure for calculating the various conditions of the generator.

Approximately up to the middle Twenties, tube transmitters were designed as single-phase devices with self-excitation. With the increase in number of transmit-

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* It is interesting to note that during the Second World War a long-wave tube transmitter (waves above 20 km) of 1000 kw power was built in Germany despite the existence of alternator generators. In the USA, in 1952, a long-wave radio station (range 8.6 - 20.7 km) was built, consisting of two tube transmitters of 500 kw each.

ters, the requirements grew as to their frequency stability. The single-phase devices were replaced by two- and three-phase devices and soon afterwards by polyphase devices with low-power exciters, characterized by their higher frequency stability. Success in the field of frequency stabilization of radio transmitters was achieved because of the work of many radio specialists, including B.K.Shembelm M.S.Neyman, Yu.B.Kobzarev (USSR).

The switching to separate excitation was readily accomplished only in transmitters operating on waves longer than 500 - 1000 m. Substantial difficulties were created with respect of shorter waves: The interelectrode capacitance and inductance of the tube output generated parasite connections between the input and output circuits of the steps, which were disturbing their normal operation. On short waves, the parasite connections led to self-excitation of the steps.

To eliminate these parasite connections, oscillator tubes were developed toward the end of the Twenties with plate grids, first tetrodes and then pentodes. However, the first experiments showed that, at sufficiently high frequencies and at high power, the screen grid loses its properties because of the inductance of its output. Therefore, the field of application of screen-grid tubes was limited to frequencies lower than 30 megacycles and powers of the order of 1 kw.

To eliminate parasite connections in the stages of the transmitter, based on triodes, neutralization devices known from radio receiving technique were applied. The theoretical investigations by G.A.Zeytlyenk, I.Kh.Nevyazhskiy, and other Soviet specialists, as well as those by V.Kumerer and V.Bushbek (Germany), V.Dogerti (USA) and others, showed that these devices are of little use in the wide band of short waves, since they disconnect the input and output circuits of the HF amplifier only in a certain frequency band and since, beyond these boundaries, the spurious coupling may even intensify. The neutralization devices offered by G.A.Zeytlyenk, V.V.Tatarinov, Z.V.Topuria, V.Bushbek, and others, permitted to make the amplification on short waves more stable. However, in full measure, the problem of stable operation of high-power amplifiers on high frequencies, particularly in the ranges of short and ultrashort waves, remained without a solution.

The development of radiobroadcasting is characterized by a continuous step-up of the quality factors of the transmitters and the increase in their power.

At first, the basic task was to obtain a stable linear radiotelephon modulation. Therefore, plate modulation was generally applied to single-phase transmitters. On changing to separate excitation and increased power, it was easier to keep distortions to a minimum by using plate or grid modulation in the low-power stage and by amplifying the modulated oscillations in the subsequent stages. Thus, in the beginning of the Thirties, the system of amplifying modulated oscillations was universally accepted. A thorough elaboration of the questions of the linearity of the amplification and of the frequency distortions permitted the construction, according to this system, of transmitters with rather high electro-acoustic indexes.

In proportion to the further growth of the power of radiobroadcasting transmitters, the deficiencies of the amplifying system of modulated oscillators became more and more pronounced - the low efficiency of the transmitter (no more than 20%) and a considerable rated power of the tube.

The search for new, more efficient, systems led again to the method of plate modulation in the final stage of the transmitter, but now with a high-power modulator, operating on a class B two-cycle circuit. In the middle Thirties, the system of "class B plate modulation" started to supersede the system of amplification modulated oscillations. Simultaneously, unsuccessful efforts were made to maintain the latter by applying powerful amplification of modulated oscillations according to the complicated device of V.Dogerti, which ensures a higher efficiency of the amplifier. Full utilization of the energy resources of these systems led to higher nonlinear distortions relative to the usual amplification of modulated oscillations. The use of a deep negative feedback eliminated this deficiency, permitting a substantial lowering of the nonlinear distortions.

The perfection of the methods and technique of modulation can be attributed to a large extent to the work by Soviet radio specialists (M.A.Bonch-Bruyevich, A.L. Mints, I.G.Klyatskin, N.K.Titov, S.V.Person, Z.I.Model', N.I.Oganov, and others). They worked out engineering calculations for modulation, recommended original devices, and explored the questions of distortions and their elimination.

The foundation for the erecting of powerful radiobroadcasting stations was laid by M.A.Bonch-Bruyevich. In 1922, a 12 kw radio station was built under his guidance, and in 1927 a 10 kw radio station. At that time, both radio stations were the most powerful in the world. From 1928, work in the field of constructing powerful radio stations was headed by A.L.Mints. In 1929, the most powerful radio station in Europe, the 100-kw radio station VTsSPS, was built under his guidance; in 1932, a 500-kw radio station was built, named Komintern; and during 1937 - 38, a short-wave 120-kw radiobroadcasting station was erected (the last two stations are the most powerful in the world). The erection of each of these stations constituted a new forward step in the development of radiobroadcasting technique, strengthening the lead of Soviet science and industry in the field of powerful radio constructions.

In the Twenties, in connection with the construction of powerful transmitters, the question as to the sources of their B supply was raised. At that time, other countries used kenotron rectifiers, which had a low efficiency due to the steep voltage drop in the kenotrons. V.P.Vologdin - a pioneer in the field of designing high-voltage rectifiers based on ionic tubes - developed high-voltage mercury lamps, created the theory of the ionic rectifier based on the smoothing filter, and recommended an original device of cascade rectification. A.M.Kugushev developed a rectifier (first on kenotrons, then on mercury lamps) according to the three-phase bridge principle suggested by A.N.Larionov in 1923. A few years later, this system, based on gas rectifiers and other types of tubes, became the most common type in rectifiers fed by three-phase current.

In the Twenties, studies began on the specific qualities of the generation of ultrahigh frequencies (UHF), at first with the aid of tubes with control grids, and then by means of magnetrons and klystrons. In the Thirties, the use of the meter-wave range for television, radiobroadcasting with frequency modulations, radar, and other applications was intensified. The rapid development of radar and radio-relay communications that followed, led to a new branch or radio technique, based on the application of decimeter and centimeter waves.

Toward the end of the prewar period, the technique of radiotransmitting devices, operating in the ranges of long, medium, and short waves, reached high perfection. This permitted building, in the USSR during the years of the Great Patriotic War, a medium-wave radio station, which is even now the most powerful in the world.

In subsequent years, intensive and creative work in all branches of radiotransmitting technique was continued, improving the prospects for further perfection and new possibilities for the application of radiotransmitting devices.

FREQUENCY STABILIZATION

The growing "congestion in the ether", the tendency to increase the protection of receivers from interference by narrowing the frequency band received, and the problem of easy connection to the networks - were all factors responsible for the general trend toward increasing the frequency stability of the transmitter.

The exciters of high-frequency oscillations in multiphase transmitters are designed for operation: a) in the continuous or discrete frequency range, b) on one or several fixed frequencies.

A typical example of an exciter of a continuous frequency range is the self-oscillator with an oscillating circuit whose tuning is changed by a variable capacitor or variometer. The frequency stability of the oscillations of the self-oscillator is determined by the constancy of its natural frequency and the quality of the circuit, the stability of the operating conditions of the tube and the accuracy of frequency calibration. In the prewar years, the frequency stability of the exciter of the continuous range was brought up to $(2 - 3) \times 10^{-4}$.

It is much easier to ensure frequency in a single-wave oscillator by using a quartz plate as the oscillating circuit. The generated frequency here is 1 - 2 magnitudes more stable than in a generator with a change-over circuit.

In 1933, G.A.Zeytlyenok suggested stabilizing the frequencies in the continuous range, by mixing the frequency f_o of the quartz oscillator of high stability with a much lower frequency F of the generator of the continuous range. In this method, the frequency stability at the exit of the mixer (equal to $f_o + F$ or $f_o - F$) changeable within the boundaries of the range of the second oscillator, is of the same high magnitude as in the frequency f_o.

This schematic method of stabilizing frequencies in the band ("direct method of frequency interpolation") was applied in practice on only a limited scale, due to the existence, at the exit of the mixer, of a large number of oscillations of secondary frequencies near the rated frequency f ($f_o \pm 2F$, $f_o \pm 3F$, $2 f_o - nF$, etc.), which are not filtered by the circuit of the subsequent stages of the transmitter and are emitted into the ether.

As a result of the work during the postwar years, a ten-fold increase or more of the frequency stability in the band as well as in single-wave quartz exciters was obtained. Both in the band and the quartz single-wave exciters, the self-oscillator is mostly built according to the tritet principle: the oscillating circuit is connected between the control and screw grids of the pentode; in the plate circuit, the oscillations are amplified according to the aperiodic principle - by means of resistance. The tritet arrangement permits attenuation of the disturbing action of the tube itself and of the subsequent stages of the transmitter.

In self-oscillators with change-over circuit, substantial improvements were achieved on the basis of the theoretical work by G.T.Shitikov and the structural innovations of B.V.Voytsekhovich, V.V.Berenev, B.V.Kuznetsov, and other Soviet radio specialists (use of ceramic variometers and capacitors, cermet screens, printing by photo-optical methods of a graduated scale with a large number of divisions, etc.).

The success of quartz stabilization was due primarily to the progress made in the manufacture of quartz plates: at the existing cuts, the dependence of the temperature on the frequency in the plate is so slight that the main destabilizing factor became the aging of the plate. Recently, plates of lenticular shape were used, characterized by single frequency and better quality ($10^5 - 10^6$).

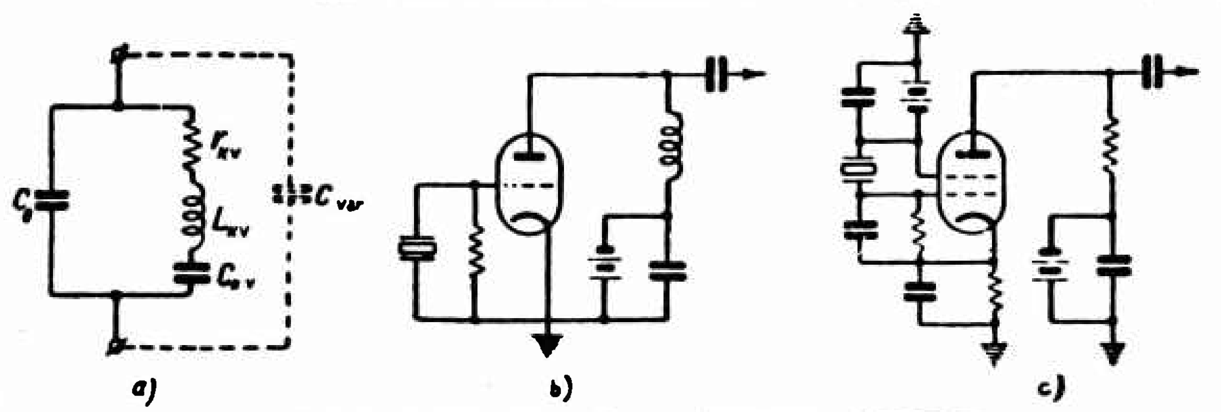

Fig.1 - Schematics of Quartz Self-Oscillators

A more thorough study of the system of quartz exciters explains the disappearance of the frequency in the quartz self-oscillator by the fact that the variable capacitance (C_{var}) of the tube and other circuit elements are connected in parallel to the quartz (Fig.1a).

Formerly, the "circuit" arrangement of a quartz self-oscillator, with the quartz connected between grid and cathode was frequently used (Fig.1b). In the postwar years, the "circuitless" system, with the quartz connected between the control grid and the anode or screen grid, was preferred (Fig.1c). This system, with more stable elements, ensures satisfactory constancy of frequency - of the magnitude of 10^{-6}.

An analysis of the quartz circuit shows that it has two frequencies of "parallel" and "series" resonance, where its equivalent resistance R_{oe} is active. In the process, any change in the variable capacitance has a much greater influence on the frequency of the "parallel" resonance (when R_{oe} is high) than on the resonance (when

R_{oe} is low). In this widely used arrangement, the generation takes place exactly at the frequency near the parallel resonance. Consequently, the use of series resonance will permit a further increase in the frequency stability.

In high-stability oscillators, the bridge circuit of quartz exciters, recommended by Mitcham (USA) in 1938, in which the quartz operates in the range of series resonance is often used at present (the theory of the bridge circuit was developed in the USSR by L.I.Klepatskaya). This device ensures frequency stability of the order of 10^{-7} to 10^{-8}.

In the field of frequency stabilization in the band, considerable success was achieved by schematic methods - the oscillations of secondary frequencies were attenuated and the stability increased by the use of more stable self-oscillators.

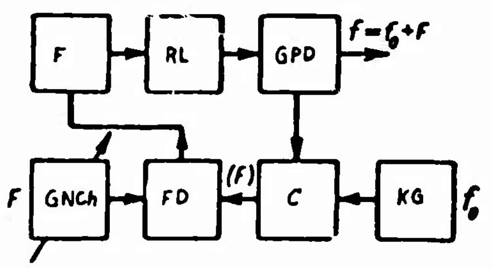

Fig.2 - Block Diagram of Indirect Interpolation of Frequencies

Figure 2 shows one of the circuit arrangements for "indirect interpolation of frequency". Here, the exciter of the high-frequency oscillations of the transmitter is the self-oscillator of the continuous band GPD. Its frequency f, equal to the sum frequency of the quartz self-oscillators KG and F of the LF band generator GNCh ($F \ll f_o$), is maintained stable by means of a ring of the self-trimmer, consisting of the mixer S, the phase detector FD, the filter F, and the reactance tube RL (instead of a reactance tube, a variable capacitor of low capacitance, rotated by a small delayed-action motor can be used). In this arrangement, the oscillations f are sustained equal to the sum frequency of the generators KG and GNCh: $f_o + F$ with precision to phase. Because of the voltage surges at the output of the phase detector, which produces frequency modulation, secondary frequencies may be generated in the self-oscillator GPD. The filter F is used for eliminating the surges.

Figure 3 shows a version of another method of schematic frequency-band stabilization, based on frequency pulsation in the continuous-band self-oscillator GPD. Here, oscillations from the generator GPD are transmitted to the pulse-phase detector IFD and short voltage pulses with a follow-up frequency of f_o from the pulse system I, stabilized by the quartz KG. By means of the reactance tube PL, to which voltage is applied by the detector IFD and smoothed by the filter F, the oscillation frequencies of the self-oscillator GPD are maintained by the n^{th} harmonic of the quartz oscillator. When the pulses are sufficiently short, a synchronization of the discrete frequency band down to the 200^{th} harmonic of the frequency f_o is obtained.

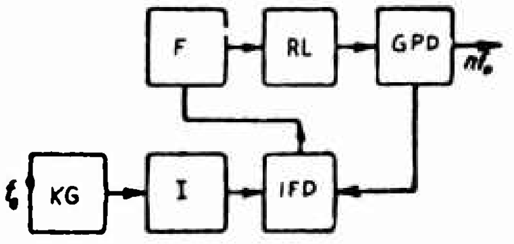

Fig.3 - Block Diagram of the Exciter of a Discrete Frequency Band

METHODS OF HIGH-FREQUENCY AMPLIFICATION

The technique of high-frequency amplification in the transmitters of the post-war period was further perfected by the progress made in the design of oscillator tubes, the development of high-power amplification circuits with a common grid, and structural improvements of the entire set.

In low and medium-power stages, pentodes are primarily used. Their improved design, with a plane mount, reduces the output inductance, while the resultant improvement in the shielding action of the second and third grid permits the use of oscillator pentodes for amplification on meter waves. At higher frequencies, stable amplification is obtained by double-grid tubes suggested by S.A.Zusmanovskiy in 1934.

The power stages in transmitters of medium waves are constructed, as before, on triodes with neutralization. In the USSR and other European countries, the push-pull circuit is usually applied, which damps the even harmonics and is more suitable for neutralization. In the USA the single-cycle circuit is often used with primitive resonance neutralization of the plate-grid capacitance.

In the transmitters for short and ultrashort waves, it is usually possible to obtain stable operation of the neutralized stages after capacitance regulation. Because of the neutrodyne capacitors, the initial capacitance of the circuits increases substantially, causing a narrowing of the wave band and a decrease in the power and efficiency of the transmitter on the shortest waves.

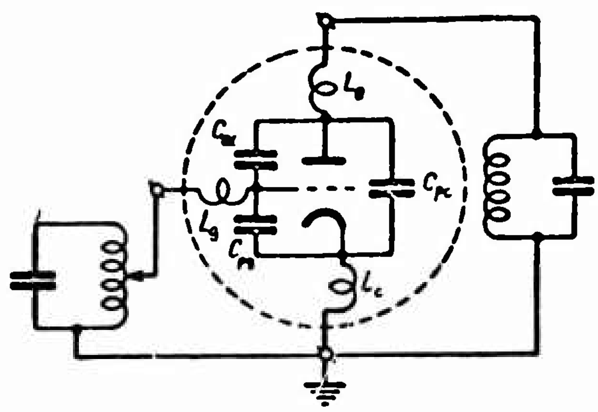

Fig.4 - Amplification Circuit with Grounded Cathode

In 1929, M.A.Bonch-Bruyevich suggested to eliminate the harmful influence of plate capacitance by shortwave amplifiers operating on the principle of "grounded grid" (in modern terminology designated as "common grid"). In contrast to the usual circuit with a common ("grounded") cathode (Fig.4), the grid in the new arrangement is grounded on high frequency across the blocking capacitance C_{co} (Fig.5) and the output circuit is connected between the plate and grid. A comparison of these circuits shows that the spurious coupling between the output and input circuits are much weaker in circuits with a common grid: this coupling is created by the plate-cathode capacitance C_{pc} which is substantially smaller than the transfer plate-grid capacitance $C_{pз}$ in the circuit with a common cathode, and the inductance at the output grid L_g which is smaller than the inductance of the cathode L_c.

In previous years, the circuit with a common grid was not applied on a large scale in practice because of its special features, regarded as basic drawbacks: a) since the solid source of incandescence cannot be isolated on high frequency, it is necessary to combine it with the cathode, which is either at a high-frequency potential, by means of HF chokes; b) the circuit yields a small increase in power, as additional power of excitation is required, transferable into the output circuit; c) the plate and grid modulation become somewhat complicated.

Further, it was established that these drawbacks are not essential in view of the great qualities of the arrangement. Thus, at a determined value of the capacitance C_{co}, grounding the grid (Fig.5), stable amplification in a certain wave range is ensured without application of other means of neutralization. In this process, the initial capacitance of the plate circuit is decreased by about two times, which permits tuning it to shorter waves.

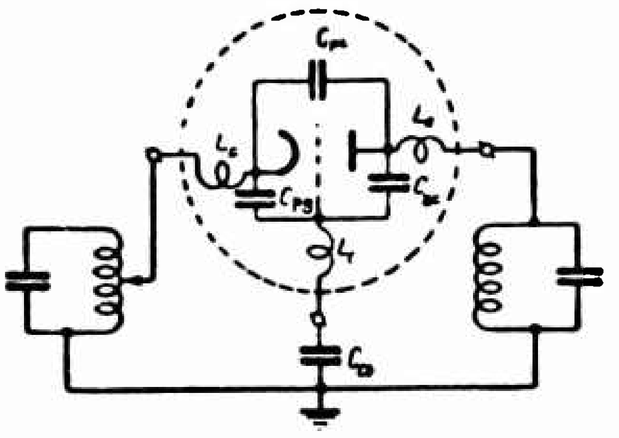

Fig.5 - Circuit Amplification with "Grounded Grid"

With the aim of a more efficient utilization of the advantages o the hookup with a common grid, a series of high-power triodes was developed in postwar years, of special design "with a plane mount". In such a triode, the grid serves as a good shield between anode and cathode (the capacitance C_{ak} being very small); due to the ring-shape lead, the inductance of the grid is also rather small. As shown by experiment, such tubes ensure stable amplification on meter waves, no longer requiring matching of the blocking capacitance C_{co}.

At the present time, the system with a common grid superseded amplification with neutralization in transmitters of short and ultrashort waves. As far as television transmitters are concerned, application of this system promised substantial simplification.

Previously, aperiodic HF amplification was applied in low-power stages of the transmitter. The utilization of cathode repeater circuits and new magnetic materials permits efficiently designs of aperiodic power amplifiers. For example, in modern long-wave transmitters, all stages with the exception of the terminal stage are designed without oscillating circuits. A certain increase in the number of amplification stages is worth the simplicity of retuning in the band.

RADIOTELEPHONE TRANSMITTERS WITH AMPLITUDE MODULATION

At the present time, in practice, preference is given to such modulation methods which permit modulation up to 100% with rather small distortions, possess high power factors and, in the case of band transmitters, are not sensitive to variations in the HF stage operation which latter are unavoidable when operating in the wave band.

The question of undistorted modulation is closely linked to the progress achieved in the field of negative feedback. The modern theory of circuits permits in many cases to so adjust the frequency-amplitude characteristics of the system (amplifier, transmitter) in the broad frequency band that negative depth feedback becomes possible, leading to a substantial decrease of distortion at the output. Therefore, the methods of modulation, distinguished by insufficient linear characteristics may become competitive if use of depth negative feedback is possible.

Postwar radiotelephone transmitters are designed mainly according to the system of Class B plate modulation. The terminal plate-modulated HF stage of the transmitter operates with high efficiency and rather insignificant nonlinear distortions. Its indexes are little affected by variations in HF excitation of the grid and the plate load, when operating in the wave band. The modulating device is a multistage audio-frequency amplifier operating on the push-pull principle. The final stage - modulator - operates in Class B with higher efficiency and yields a power equal to about 75% of the rated power of the transmitter. The depth negative feedback encompassing the modulating system, ensures small distortions in the modulator and stable voltage at its output so that the transmitter is modulated with equal depth on the different waves of the band.

During the last decade, the power factors and the electro-acoustic index transmitters, designed with Class B plate modulation, have increased substantially. For

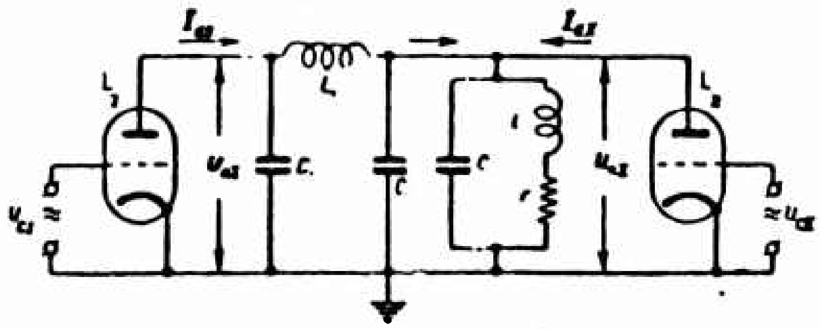

Fig.6 - Principal Wiring Diagram of the Dogerti Amplifier

example, modern high-power radiobroadcasting transmitters commonly reach an efficiency of 45 - 50%, the nonlinear distortions at percentage modulation (95%) are about 2%, the level of stray modulation (background) is less than 0.1%, frequency distortions in the 50 - 10,000 cycle band are rather small, etc.

A series of innovations was instrumental in raising the indexes: a) The submodulator is designed as a cathode repeater instead of the previously used circuit of transformer amplification. Elimination of the submodulating transformer significantly simplified the task of the modulating arrangement for depth negative feedback. b) The ultrasound harmonics are effectively suppressed in the circuit of the modulating transformer by designing it according to the principle of a band-pass filter. c) Apart from plate modulation in the terminal HF stage, additional modulation is applied in the excitation circuit. Thus, for instance, in short-wave transmitters designed on the principle of high-frequency amplification with a common grid, the stage before the last is further modulated, which permits decreasing the power of its tubes, results in a more linear modulation, etc. (with the same aim in mind, the next to the last stage in medium-wave transmitters is sometimes modulated). In pentode transmitters, plate-screen modulation is applied frequently.

Some firms in the USA and Western Europe continue to design medium-wave radiobroadcasting transmitters according to the system of amplification of modulated oscillations with powerful HF amplifiers of the V.Dogerti type. Figure 6 shows the principal wiring diagram of such an amplifier. To the load circuit LC_r two tubes are connected: one (L_{II}) directly, the other (L_I) across the inverting circuit $C_1L_1C_1$, equivalent to a quarter-wave line. During the negative half-period of modulation, the tube L_{II} is switched off, leaving only the tube L_I to operate as a Class B amplifier. When there is no modulation, the tube L_I, emitting carrier frequency power, operates with full utilization of the plate voltage at high efficiency. During the positive half-period of modulation, the tube L_{II} is also operating; at an increase of its plate current I_{aII} the load impedance of the tube L_I decreases due to the circuit $C_1L_1C_1$. As a result, the tube L_I continues to operate at constant oscillating voltage U_{aI} and high efficiency.

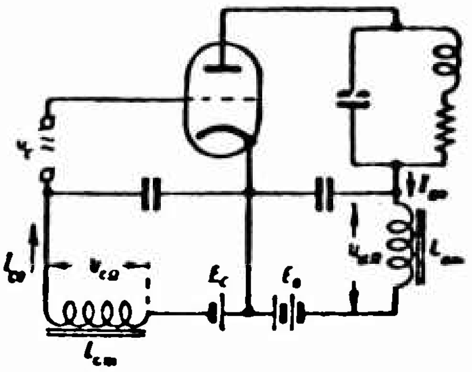

Fig.7 - Schematic of Self-Plate Modulation According to N.G.Kruglov

The oscillating plate voltages of the tubes L_I and L_{II} are dephased by 90° because of the inverting circuit $C_1L_1C_1$. This necessitates connection of an additional inverting circuit into the excitation circuit of one of the tubes. Due to the frequency distortions in these inverting circuits, an accurate sequence of the operation of the tubes is maintained only in a relatively narrow band of side frequencies; on waves longer than 500 - 600 m, the modulation by high audio frequencies may be strongly distorted.

For operation in the wave band, transmitters with Dogerti amplifiers are of little use because of retuning difficulties; the power factors obtained were worse than in the system of Class B plate modulation.

Apparently, designers were finally successful in eliminating this latter drawback. According to data in the literature, the average efficiency of the new 500-kw

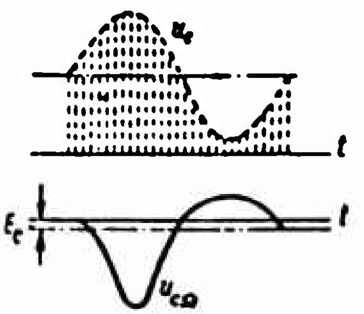

Fig.8 - Voltages in Grid Circuits

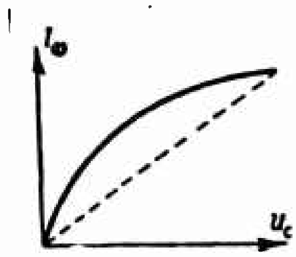

Fig.9 - Modulation Characteristics in the System of Self-Plate Modulation

transmitters, designed in the USA, is 50% when there is no modulation and increases to 54% at 100% modulation. The nonlinear distortions in the 60 - 4000 cycle band do not exceed 2% when operating on waves up to 550 m, while the nonlinear distortions increase on waves longer than 1000 m.

Rather promising is the original idea of self-plate modulation suggested in 1943 by the Soviet radio specialist N.G.Kruglov. Its essence is the following (Fig.7): The grid of the terminal stage of the transmitter is fed with HF oscillations modulated in one of the initial stages. The circuits of its plate power supply and grid bias contain chokes L_{am} and L_{cm} with high inductance, due to which the direct plate (I_{ao}) and grid (I_{co}) currents do not change in the process of modulation (as distinct from other methods of amplitude modulation).

The constancy of the grid current I_{co} can be explained differently: The choke L_{cm} is supplied with the variable voltage of the bias $U_{c\Omega}$ which varies inversely to the modulation of the excitation U_c - when U_c increases the instantaneous bias voltage must decrease, and when U_c decreases, it must increase (Fig.8). Correspondingly, at maximum excitation, the pulses of the plate current in the tube must have the smallest cutoff angle and at minimum excitation, the largest angle.

If the circuit of plate power supply would contain no choke L_{am}, then the direct plate current of the tube I_{ao} would also vary inversely to the excitation modulation U_c. When the choke L_{am} is present, the current I_{ao} must remain constant, which is the result of audio-frequency voltage $U_{a\Omega}$ arising in the choke L_{am} thus increasing the plate voltage $(E_a + U_{a\Omega})$ in the positive half-period and decreasing it in the negative half-period of modulation.

Thus, due to the presence of the choke L_{cm} and the choke L_{am}, the modulation of high-frequency excitation automatically causes antiphasal grid and synphasal plate ("self-anodic") modulation. Figure 9 shows a typical (for self-plate modulation) dependence of the first harmonic of the plate current I_{a1} on excitation U_c. As can be seen from the diagram, the modulation of the current I_{a1} is strongly distorted. To eliminate the distortions, the grid excitation of the tube must be modulated with artificially created reverse distortions, or by the steps with modulated oscillations with depth negative feedback.

The magnitude of the direct plate current I_{ao} rises with an increase of the modulation factor - at 100% modulation, it is 20 to 40% higher than when modulation is absent.

At the present time, the theory and engineering calculations of the self-plate modulation are developed in the works by N.G.Kruglov and other Soviet radio specialists, where it was established that the self-plate modulation can be applied to band transmitters.

Calculations and experience show that, with self-plate modulation, the tubes of the terminal high-frequency stage may furnish almost the same power as with plate modulation (in some cases, the utilization according to power is limited by the admissible magnitudes of power dissipation on the plate and grid). Consequently, in comparison with Class B plate modulation, there is no need for a powerful modulator, which results in a gain in the overall size, cost of equipment, etc. The common consumption of energy is of the same magnitude as with Class B plate modulation - it is larger when modulation is absent and smaller, when modulation is at 100%. Thus far, self-plate modulation is achieved in practice when re-designing some transmitters previously designed on the principle of amplification of modulated oscillations. It can be assumed that, in the next few years, this method of modulation will come into increasing use.

SINGLE-BAND RADIO TRANSMISSION

The most promising kind of national radio link on short waves is definitely the single-band radio communication.

With the usual amplitude modulation applied in broadcasting and also until now in radiotelephone circuits, the power of the transmitter is utilized only to a small degree: the continuously emitted oscillations of the carrier frequency (f) in the receiver are not utilized, and the telephone effect is created solely by oscillations of the side frequencies (f ± F). When single-band transmission is used, oscillations of one sideband are emitted (f + F or f - F) as well as the so-called "pilot signal", necessary for accurate tuning of the heterodyne of the receiver to the carrier frequency f and representing oscillations of a fixed frequency (usually, carrier frequency f) with a small amplitude (of the order 10% of the maximum amplitude).

At conventional modulation with carrier frequency, the total amplitude of the side frequencies (f ± F) reaches 0.5 of the maximum amplitude. In the case of single-band transmission, the amplitude of the side frequency reaches 0.9 of the maximum amplitude, which gives a 3-fold gain in power. At the expense of narrowing the frequency band by 2 times when using single-band transmission, the selectivity of the receiver can be correspondingly increased, which results in an additional gain in the power of the transmitter by 2 times. Consequently, at equal power of reception, the power of the single-band transmitter can be 6 times smaller than the usual power.

With respect to input power, the comparison is even more advantageous for the single-band transmitter: the average power used by it, at equal volume, is approximately 10 times smaller than in a transmitter designed according to the system of plate modulation class C or plate self-modulation.

Efforts to use a transmitter with conventional modulation for multichannel telephone and telegraph transmission met with little success because of the necessity of widening the frequency band occupied by the transmitter and due to its poor utilization with respect of power. The application, for this purpose, of a single-band transmitter yields a substantially higher power effect. Besides, the multichannel transmission permits to condense the ether substantially: in single-channel transmitters, between the bands occupied by them, the nonutilized frequency intervals

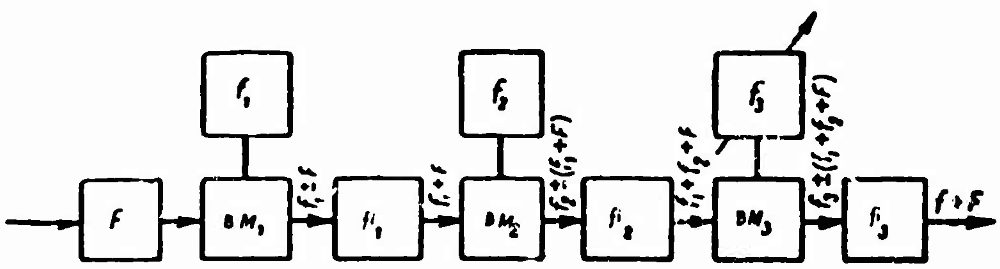

Fig.10 - Block Diagram of a Single-Band Exciter

exceeding the possible frequency departure of their exciters must be left. The interval between adjacent channels can be narrowed in the case of multichannel transmission, since the high-frequency exciter is the same for all channels.

Single-band transmitter consists of a low-capacitance device, which separates the oscillations of the sideband and the pilot signal, and of a multistage high-frequency amplifier.

At the present stage of development of the technique of short-wave transmitters, a more complicated task is the separation of a single frequency sideband from the carrier frequency f and another sideband, differing very little with respect to oscillation frequency. For example, when modulating with a frequency of 100 cycles on the 30-m wave, it is necessary to separate the side frequency 10 000 100 cycles

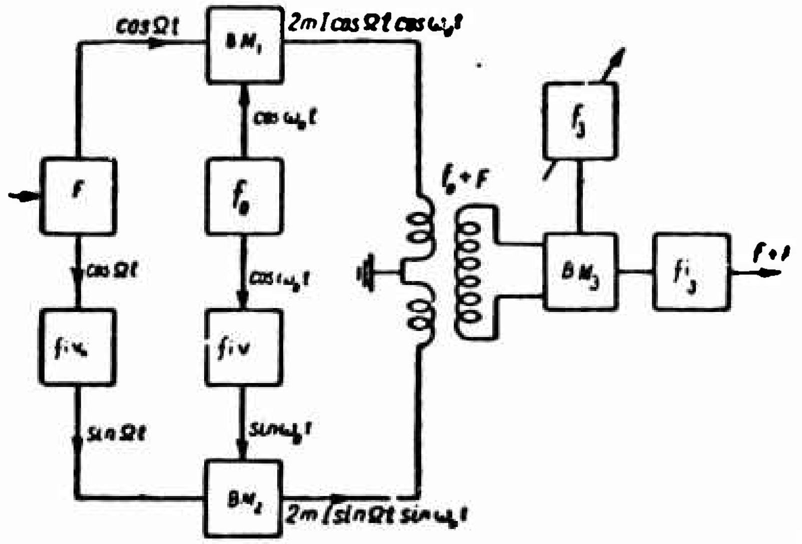

Fig.11 - Block Diagram of Balanced Quadrature Modulation

from the carrier frequency 10 000 000 cycles and from the second side frequency 9 999 900 cycles.

In order to suppress the oscillations of the carrier frequency f, balanced modulation based on subtraction of two oscillations modulated in antiphase is used:

$$i_1 = I(1 + m\cos\Omega t)\cos\omega t \text{ and } i_2 = I(1 - m\cos\Omega t)\cos\omega t.$$

At the output of the balanced modulator, the following oscillations of the side frequencies remain:

$$i_1 - i_2 = 2\,m\,I\cos\Omega t\cos\omega t = mI[\cos(\omega + \Omega)t + \cos(\omega - \Omega)t].$$

Even the most up-to-date band filters are not capable of dividing the sidebands which do not differ much in frequency (in the above case, 2×10^{-5}). This problem is solved by two methods: a) by repeated balanced modulation; b) by balanced quadrature modulation.

With repeated balanced modulation, the sidebands are artificially separated by means of a few balanced modulators. Thus, Fig.10 shows a block diagram designed on the following principle: the first balanced modulator BM_1 is supplied with the oscillations of the intermediate frequency f_1 and the oscillations of the audio band F, as carrier. The selection of the frequency is determined by a compromise between the requirements of undistorted modulation (for this purpose, the frequency f_1 must be much higher than the modulating frequencies F) and the necessity of suppressing one of the sidebands by means of the filter fi_1. In former years, the frequency f_1 amounted to 20 - 40 kc which made it impossible to obtain slightly distorted modulation by high audio frequencies. The quartz filters now in use with a rather steep transconductance of the pass band permit a separation of sidebands, with intervals of 100 - 200 cycles, at a carrier frequency of f_1 = 100 kc. Besides, to decrease the nonlinear distortions, the balanced modulator BM_1 is designed as a ring circuit.

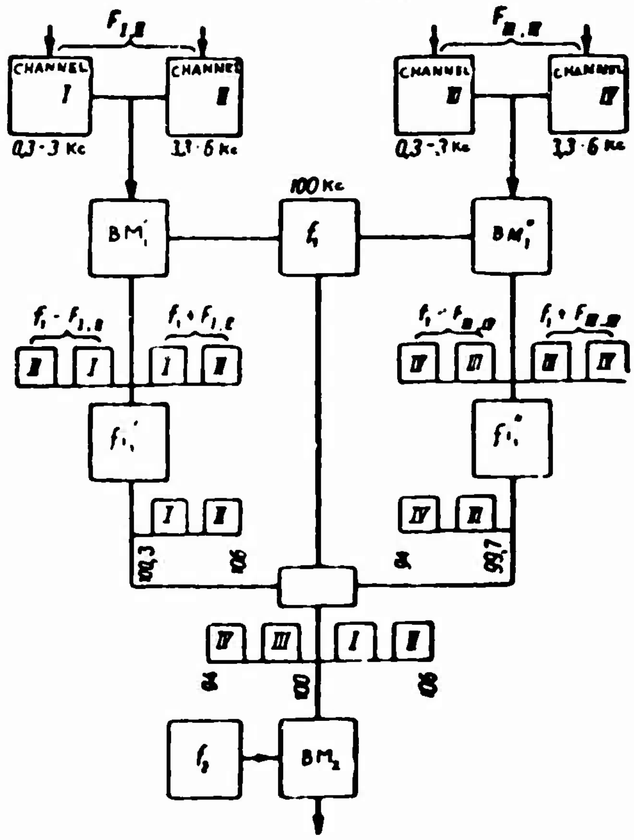

Fig.12 - Block Diagram of a Single-Band Device in 4-Channel Telephone Transmission

The frequency band (for example, f + F), transmitted by the filter fi_1, is fed as modulating frequency to the input of the second balanced modulator BM_2. The same modulator is fed with the intermediate frequency f_2 as carrier, selected in such a way that a relatively simple filter fi_2 can be used for separating one of the side frequencies (for example, $f_1 + f_2 + F$). Usually, the frequency f_2 is selected within the limits of 1.5 - 2.5 mc.

In modern short-wave transmitters, the required side frequency (such as f + F) is obtained after triple balanced modulation. For this purpose, the third balanced modulator BM_3 is supplied with the carrier frequency f_3, which differs from the nominal carrier f of the transmitter as to the magnitude $f_1 + f_2$, for example $f_3 = f - (f_1 + f_2)$. The required sideband (f + F) is separated by the filter fi_3.

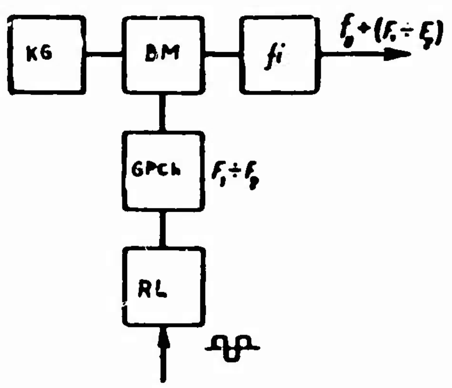

Fig.13 - Block Diagram of Frequency Keying According to the Principle of Frequency Interpolation

On the whole, the device for separating one sideband, designed on the principle of multiple modulation, is complicated and requires careful tuning. To simplify the operation of the device in the wave range, the part connected with the intermediate frequencies f_1 and f_2 is kept constant, and only the exciter f_3 and the balanced modulator BM_3 as well as the connected filter fi_3 are being retuned.

Balanced quadrature modulation permits in principle to separate any amount of adjacent side frequencies and thus dispense with multiple modulation and complicated sideband filters. The block diagram of a balanced quadrature modulation is shown in Fig.11. Here, BM_1 and BM_2 are equal balanced modulators. Their inputs are supplied with the voltages of the carrier frequency f_o and of the audio band F, with equal amplitudes but spaced at 90^o. For this purpose, the input of the modulator BM_2 is provided with two phase inverters FV_v and FV_n. Accordingly, the currents in the output circuits of the modulators will be

$$i_1 = 2mI \cos \Omega t \cos \omega_0 t \text{ and } i_2 = 2mI \sin \Omega t \sin \omega_0 t.$$

In the master circuit, the oscillations of one sideband are obtained:

$$e = i_1 - i_2 = 2mI(\cos\omega_0 t\cos\Omega t - \sin\omega_0 t\sin\Omega t) \equiv \cos(\omega_0 + \Omega)t;$$

Another sideband can be separated by changing the phase of oscillations in one modulator to the opposite - then, $e \equiv \cos(\omega_0 - \Omega t)$.

Evidently, realization of this method would permit a considerable simplification of the device for separating one sideband: It would become possible to separate the side frequency at a carrier f_0 of the magnitude 2 mc without complicated filters and feed the frequency to the balanced modulator BM_3, as shown in Fig.11. However, until now no sufficiently simple phase inverter has been designed, which, in the broad-band of audio frequencies, would shift the oscillation frequency to 90^o, with rather small frequency-amplitude distortions. Therefore, modern devices for separation of one sideband are based primarily on the method of repeated modulation.

Significant success was achieved in recent years in the field of multichannel communication on short waves. Figure 12 shows a block diagram of a single-band device with 4-channel telephone transmission. To each channel is alloted a band of 0.3 - 3 kc, where in the channels II and IV the spectra are shifted to 3 kc (3.3 - 6 kc). Each pair of channels occupying the 0.3 - 6 kc band is fed to the balanced modulator operating on the intermediate frequency $f_1 \approx 100$ kc. The filters fi_1' and fi_1'' pass, respectively, the upper and lower sidebands. As a result, the balanced modulator BM_2 is fed with the frequency spectrum from the pilot signal and two side channels.

Another important question is that of utilizing the power of a single-band transmitter in multichannel operation. At equal power N of the channels, each of these can have an amplitude of not more than $\frac{1}{N}$ of the critical amplitude in single-channel operation. Correspondingly, each channel can have a power of not more than $\frac{1}{N^2}$ of the power in single-channel operation and the total power of the channels is N times smaller than the power of the transmitter.

As the probability of simultaneous operation of all channels with maximum volume is rather small, it is possible to obtain a substantial improvement in the utilization of the transmitter as to power, by using a compressor device, maintaining the total amplitude of the channels at a level near the critical one. Then each channel will operate with a much higher power: if, at a given instant, one channel operates on a high level while the others operate at a low one, then its power will almost equal the power of the transmitter. The resultant decrease of the dynamic range is not essential for voice transmission, of importance is only the accomplishment of compression without nonlinear distortions.

In multichannel transmission, sufficiently linear amplification of oscillations is required in the subsequent stages of the transmitter to prevent inadmissible cross distortion leading to interference between the channels. In the low-power stages, linear amplification can be obtained, just as in LF amplifiers, by operation of the tubes in the linear segment of their characteristics (amplification class A); poor utilization of the tubes and their low efficiency in these stages will have little bearing on the power balance of the transmitter.

Operation in class A of high-power stages of the transmitter would cancel the power advantages of the single-band transmitter. Therefore, in these stages, the tubes must operate in class C, i.e., with half-period HF pulses of the plate current. Under these conditions, however, it is more difficult to ensure linear amplification of weak oscillations, since the tubes operate on the lower bend of their characteristics. This nonlinearity can be eliminated by the use of negative feedback. The existence of compression also leads to a weakening of the cross distortions, due to the nonlinearity of the lower part of the characteristics, as the total amplitude of the channels increases.

RADIOTELEGRAPH KEYING

Formerly, radiotelegraph communication was accomplished by interruption of high-frequency oscillations during intervals. The development of radiotelegraph keying proceeded by improving the form of the telephone signal envelope and increasing the speed of transmission. Introduction of the electronic relay to replace mechanical relays raised the telegraph speeds to 500 - 1000 words per minute. In Soviet transmitters, electronic circuits of telegraph keying came into increasing use, as suggested by I.Kh.Nevyazhskiy, Ye.I.Kamenskiy, Z.I.Model, A.I.Eylenkrig, G.S.Koropov, and others.

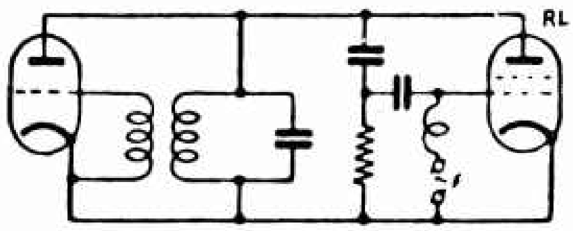

Fig.14 - Frequency Modulation with Application of a Reactance Tube

In the prewar years, research was done on methods of frequency keying in which the high-frequency oscillations in the transmitter are not interrupted, and their frequency changes suddenly to low values, corresponding to telegraph sending. It was established that the change-over from amplitude keying to frequency keying increases the protection from interference in the receiver to such an extent as to permit rapid communication by printing at decreased transmitter power.

At present, frequency keying has replaced amplitude keying in the nation-wide lines of communication. In the letterprinting process, two-way sendings are fed to the transmitter; in the case of positive sending, a frequency $f_1 = f + \Delta f$ is emitted and in the case of negative sending a frequency $f_2 = f - \Delta f$. The magnitude of the frequency difference Δf from the nominal frequency f is known as frequency deviation.

The postwar development of frequency modulation tended toward an increase in the protection from interference in communications and a decrease in spurious emissions of the transmitter, which create interference in adjacent communication channels. The increased noiseproof feature was achieved by increasing the selectivity of the receiver; for this purpose, it was necessary to decrease the frequency deviation Δf and increase the frequency stability in the transmitter.

To start with, the frequency deviation amounted to a few kilocycles, and the frequency keying in the transmitter was achieved by means of switching the two quartz exciters with corresponding frequencies. Such a method of frequency keying was inconvenient since, when operating on some waves, it required a large number of quartz crystals. Besides, there were substantial spurious emissions during sudden frequency changes in keying. The point is that in connecting the independent quartz master oscillators, a frequency change may occur at any rapid change in phase - up to 180°. This considerably intensifies the transient processes in the transmitter circuits, due to frequency changes of the excitation. The oscillation frequency briefly exceeds the boundaries of the interval $f_1 - f_2$, causing a sharp decrease in the oscillation amplitude. For this reason, keying methods were developed in which the frequency change takes place without a rapid change in phase.

The method of frequency keying directly in the quartz self-oscillator found some application in practice by connecting a reactance into the quartz circuit, which alters the oscillation frequency; during keying, the key (relay) blocks this reactance briefly. This method has several drawbacks. In particular the frequency stability is impaired and the conditions of self-excitation of the quartz oscillator are disturbed.

The method of frequency keying, based on frequency interpolation came into wider use. For instance, Fig.13 shows a block diagram where the balanced modulator BM is fed with oscillations of the high-frequency quartz oscillator KG and of the low-frequency generator GPCh controlled by the reactance tube RL. The change in the direct voltage in the circuits of the latter creates frequency keying. This circuit suffers from spurious emissions - in the new frequency-keying circuits, the spurious emissions are greatly attenuated.

Another practical application is the principle of frequency keying based on balanced quadrature modulation (Fig.11): High frequency and audio frequency $F = \Delta f$

are fed to two balanced modulators, with a frequency shift of 90°. During the keying, the phase of frequency F in one modulator is shifted to 180°, which causes a transition from one side frequency f + F to another f - F.

FREQUENCY MODULATION

Improved noiseproof feature in the receiver at broad-band frequency modulation is responsible for its wide application in the ultrashort-wave range for radiotelephony and radiobroadcasting. In the USSR, radiobroadcasting with frequency modulation is utilized at present mainly for sound accompaniment of television programs.

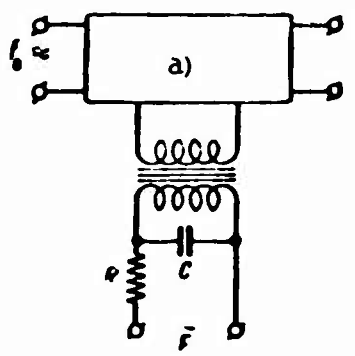

Fig.15 - Circuit Diagram for Transforming Phase Modulation into Frequency Modulation

a) Phase modulator

When broadcasting on meter waves, the frequency deviation amounts to $\Delta f = 50 - 70$ kc. The electroacoustic index of ultrashort-wave transmitters with frequency modulation is, as a rule, higher than for amplitude modulation: the audio-frequency band is wider (the upper boundary is 10 - 15 kc), the nonlinear distortions are smaller (up to 1 - 2%), and the hum level is lower (lower boundary -60 db).

Transmitters with frequency modulation are designed according to the following block diagram: Frequency modulation is achieved in the exciter operating on a lowered carrier frequency f_o, with correspondingly decreased frequency deviation $\Delta f_o = \Delta f \frac{f_o}{f}$. This exciter is followed by the frequency multiplication and amplification stages.

Frequency modulation of high-frequency oscillations can be accomplished by two methods: a) by changing the circuit parameters of the self-oscillator; b) by obtaining phase modulation and transforming it into frequency modulation.

During the 20-year period of use of frequency modulation, numerous variants of both methods were suggested and many of these were put into practice.

The most common method usually operates with a reactance tube RL (Fig.14), subconnected to the circuit of the self-oscillator and acting as a reactance which changes with the frequency modulation F. For this purpose, the voltages in the circuit of one of the grids of the reactance tube are modulated.

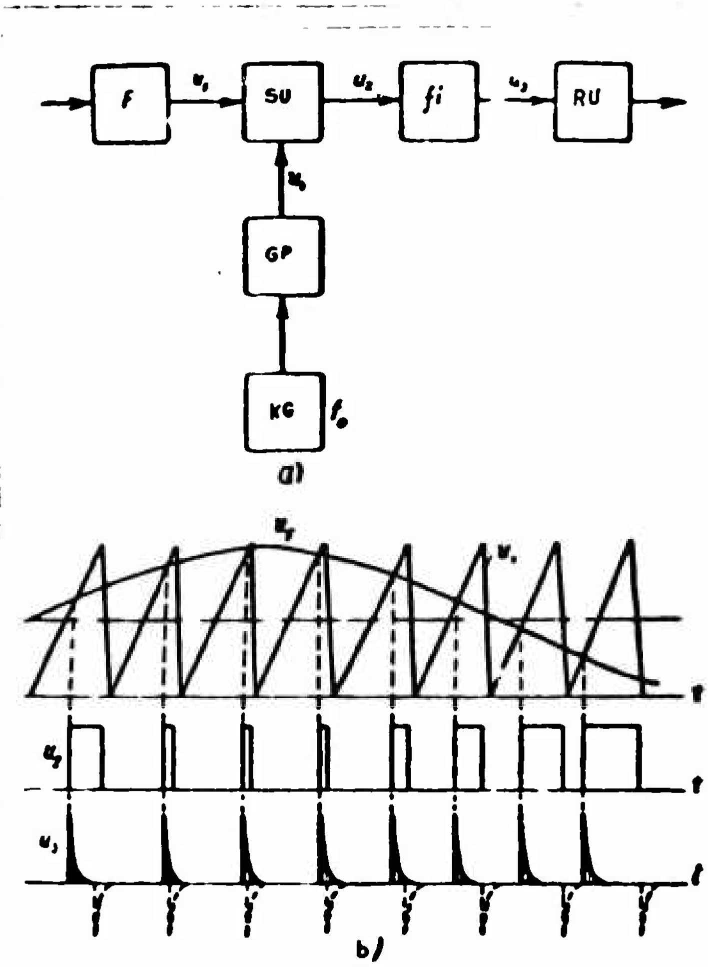

Fig.16 - Pulse-Phase Modulation: a) Block-Circuit; b) The Shape of the Pulses

The usual carrier (medium) frequency f_o in this circuit amounts to 5 - 6 mc, and the frequency modulation with rather insignificant distortions is obtained without difficulties. It is much more difficult to ensure constancy of the medium frequency f_o in the exciter. The point is that, on connecting the reactance tube to the circuit of the self-oscillator, the frequency stability, which was initially rather low, decreases still further. For this reason, the frequency departure f_o may substantially exceed the frequency deviation Δf_o, required for frequency modulation.

In order to ensure the required stability of the medium frequency, various devices of automatic frequency control, based on a comparison of the medium frequency of the self-oscillator with the frequency of the quartz self-oscillator are in use. Originally, frequency comparison was achieved with the aid of a frequency discriminator, whose output voltage controlled the frequency f_o of the self-oscillator by means of the reactance tube. Later, the frequency discriminator, which is an additional factor for the frequency instability, was replaced by a phase detector; more perfected devices of automatic frequency control were developed which have a lot in common with the devices of indirect frequency interpolation (Fig.2).

The nature of phase-modulated oscillations is the same as that of frequency-modulated oscillations. The oscillations, phase-modulated by the frequency F to a value of $\Delta\psi$ are identical with the frequency-modulated oscillations for which

$$\Delta f = \Delta\varphi F.$$

In order to obtain equal frequency deviation Δf at various frequency modulations F, the phase deviation $\Delta\varphi$ must vary inversely proportional to the frequency F. Consequently, the phase modulation device can be transformed into a frequency modulation device, by varying the modulating voltage inversely proportional to the frequency F. This is usually done at the input of the audio frequency by means of an integrating circuit RC (Fig.15), in which

$$R \gg \frac{1}{\Omega C} = \frac{1}{2\pi FC}$$

for a transmission factor

$$\frac{U_2}{U_1} \approx \frac{1}{F}.$$

In phase modulation, high-frequency excitation can be obtained from the high-stability quartz self-oscillator so that the problem of IF stability does not exist here. Basic difficulties formerly occurred in obtaining the required large phase deviation $\Delta\varphi$. For instance, in order to obtain a frequency deviation of $\Delta f = 70$ kc at a modulating frequency of $F = 50$ cycles, the phase deviation must be

$$\Delta\varphi = \frac{\Delta f}{F} = \frac{70\cdot 10^3}{50} = 1400 \text{ radians} = 80\,000^\circ.$$

To facilitate the task, phase modulation of the lowered frequency f_0 of a magnitude of 200 kc is done, after which the required deviation decreases accordingly.

However, to obtain a reduced deviation $\Delta\varphi_0$ = 300 - 400° was a difficult task for a long time.

The original methods of phase modulation were based on transformation of amplitude modulation into phase modulation: In the equipment developed by Zeytlenok and Ye.I.Kamenskiy (1932), two high-frequency oscillations are combined in quadrature, modulated in antiphase; in the Armstrong circuit (1935), the unmodulated oscillation are combined in quadrature with the oscillations of the side frequencies. These methods permit phase modulation with small distortions within the limits of ± 20°. However, their use for frequency modulation leads to a rather bulky multi-tube exciter.

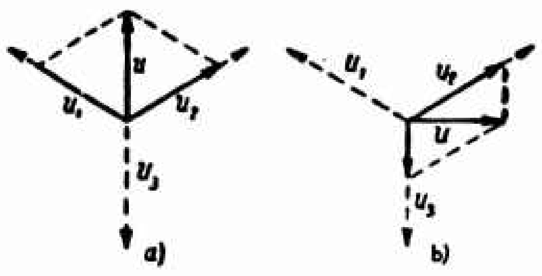

Fig.17 - Principle of Obtaining Phase Modulation

Special vacuum devices were developed (the Shelby tube and, in the postwar period, the phasitron) which permitted modulation with a large phase deviation. However, they were not widely applied in practice, due to their complexity. More were circuit methods of the type of:

a) The pulse-phase method, borrowed from the pulse technique. The block diagram and the shape of the pulses, illustrating this method, are shown in Fig.16 a and b. Here, high-frequency oscillations from the quartz self-oscillator KG are fed to the saw-toothed oscillator GP. The oscillations of the latter u_1 are fed jointly with the audio-frequency voltage u_F to the comparator SU, at whose output rectangular pulses u_2 are obtained, whose leading edges undergo temporary modulation. In the shaping unit Sh, the pulse leading edge u_2 is transformed into short intermittent pulses u_3, where the required harmonic is separated by the resonance amplifier RU;

b) The method of the Soviet radio specialist A.D.Artym, based on the addition of several HF oscillations, nonlinearly amplitude-modulated and shifted in phase.

Let there be, for instance, three vectors of high-frequency voltage, phase-shifted by 120° (Fig.17 a), where at a given instant, one of the voltage equals zero. At a modulating voltage of zero, the vectors u_1 and u_2 are identical, and the vector u_3 is absent. With an increase in the modulating voltage, the vector u_1 decreases, while the vector u_2 increases and the resultant vector u is shifted by 60°.

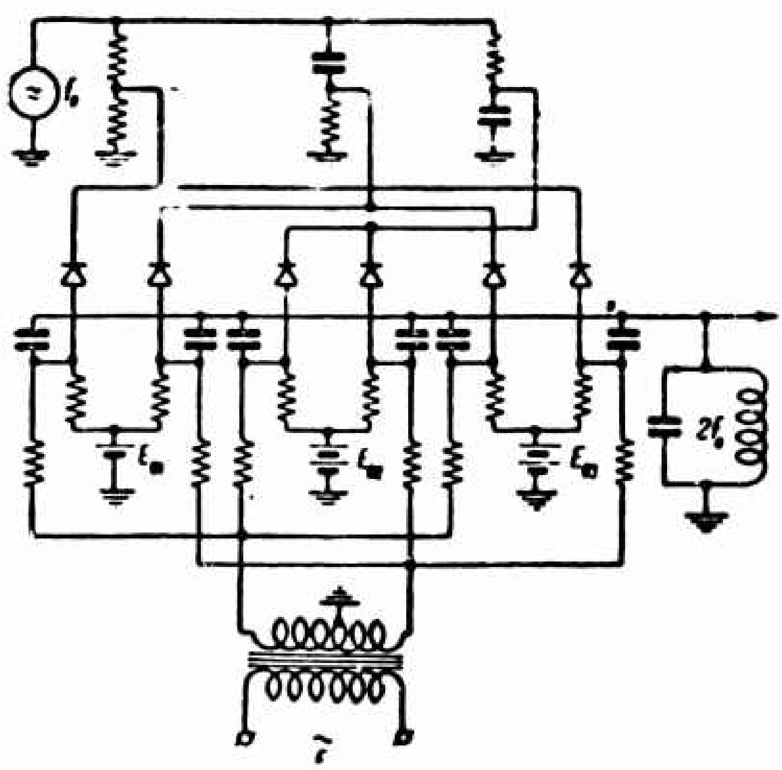

Fig.18 - Circuit Diagram for Phase Modulation

After this, the vector u_2 decreases, while the vector u_3 increases (Fig.17 b), and the resultant vector u is shifted another 120°, etc.

The required law of amplitude modulation of each vector can be obtained by means of a diode, whose plate circuit has three voltages: high-frequency u_{fo}, fixed bias E_o, and audio frequency u_F, with the circuit tuned to the second harmonic. Figure 18 shows a device which, with six diodes, permits a phase deviation of $\Delta\varphi_o = \pm 300°$.

In modern broadcasting FM transmitters, mainly exciters with phase modulation are used. These are simpler than exciters with direct frequency modulation and more reliable in use.

TELEVISION RADIO TRANSMITTERS

The development of television and the constant improvement in its quality factor stimulated progress in the radio-transmission technique in this field.

For television transmitters the following features are characteristic:

a) Operation in the meter and decimeter band in conjunction with a rather broad frequency band of the television signal;

b) Amplitude modulation with transmission of the constant component of the television signal. Accordingly, for modulation only such methods can be used which permit control of the magnitude of the intermediate amplitude. The power of the transmitter is determined by the maximum value of the amplitude of the current during modulation;

c) In the USSR and in most of the other countries, the band of emitted frequencies is narrowed by a partial suppression of a single sideband;

d) The necessity of passing a rather wide frequency band of the television signal in the stages with modulated oscillations, generally leads to a poor utilization of their tubes with respect to power, to low efficiency and to a small amplification factor in the power stages. This is explained by the fact that the plate circuit of such a stage, in order to pass a wide frequency band, must have a rather low quality factor Q. On the other hand, when operating on SHF, the wave impedance of the plate circuit $\rho = \frac{1}{\omega C}$ is small, since the capacitance C is formed by the relatively high output capacitance of the tube (this capacitance increases substantially in the case of application of neutralization). As a result, the equivalent resistance of the circuit $R_e = \rho Q$ is much smaller than the optimum for this type of tube; for better utilization as to power ($P_{\sim} = 0.5 I_{a1}^2 R_e$), it is necessary to increase to the limit the first harmonic of the pulses of the plate current I_{a1}. If the oscillating plate voltage $U_a = I_{a1} R_e = \sqrt{2P_{\approx} R_e}$ is too small, the plate feeding voltage is reduced to prevent further loss of power. For full utilization of the tube with respect to emission, a high amplitude of the oscillating voltage in the grid is required and a corresponding power of excitation - the amplification factor of the stage as to power is rather insignificant.

In prewar years, the definition of the image was 240 - 343 lines, which corresponded to the band of modulating frequencies up to 1.3 mc. Television broadcasting was done on 4 - 6 m waves. Partial suppression of a single sideband was achieved by SHF filters, connected with the antenna feeder, and, therefore, the stages with modulated oscillations had to pass the double band of modulating frequencies uniformly. In connection with the use of neutralization, which increases the capacitance of the circuit, and the double frequency band, tubes of such a stage operated with extremely low efficiency.

Due to the difficulty of passing a wide band of side frequencies, modulation was usually accomplished in the grid circuit of the terminal stage of the transmitter. But then a powerful modulating device was required, which proved to be complicated and rather bulky commensurate, as to overall size and input power, with the high-frequency part of the transmitter. The total efficiency of the transmitter in such a case was rather low - of the order of 5%.

In order to decrease these difficulties, an effort was made in the Thirties to revive modulation in television transmitters by absorption, which was applied in the first years of the existence of radiotelephony. At absorption modulation, the stages of the transmitter operate with unmodulated oscillations with high efficiency and good utilization of its tubes. The power of the terminal phase is distributed between the antenna and the modulator tubes, serving as absorbing resistance, which changes in conformity with the television signal. A close study made in 1940 by A.I.Lebedev-Karmanov showed that, at absorption modulation, the simplification of the high-frequency channel is achieved at the cost of a substantial complication of the modulating device, and the power indexes of the transmitter prove to be still lower. Therefore, absorption modulation was found impractical and abandoned.

In the postwar years, still stricter requirements were made with respect to television standards - in the USSR, 625 lines scanning is accepted, which corresponds to a frequency band of about 6 mc. With respect to the application of an amplification circuit with a common grid, in triode-containing stages the principles of designing television transmitters were subjected to a radical survey.

The amplifier, designed as an amplifier circuit with a common grid, has a small output capacitance of the tubes and thus a high wave impedance of the circuit; consequently, the amplifier can pass a wide frequency band with better power indexes. Besides, the increase in the circuit of the high-frequency power of excitation leads to a similar decrease of the quality factor of the circuit of the initial stage and to a widening of the frequency band passed by it. This circumstance permits a transfer of the modulation into one of the initial low-power stages and thus a substantial simplification of the modulating device.

Subsequent amplification stages of modulated oscillations are tuned to the passage of the required narrowed frequency band, due to which their tubes operate with a higher efficiency and are better utilized as to power. A special filter for partial suppression of a single sideband proves unnecessary.

In home television transmitters other modifications suggested by E.S.Glazman were introduced: Simple filter circuits are connected in the circuit for improving the band characteristics of the circuit system and increase the power indexes of the transmitter.

All these measures led to an increase in the common efficiency of the transmitter at a substantial reduction in the over-all size and improvement of the quality factor.

In connection with the substantial increase in the number of television stations and the introduction of color television with a wider frequency band for telecasting, a series of additional channels in the decimeter range has been set aside. For these, special types of SHF generators were developed, reviewed below.

METHODS OF OBTAINING HIGH POWER

The increase in power of radio stations is achieved both by increasing the power of the generator tubes and by addition of the power of high-frequency generators.

In the middle Thirties, the power of generator tubes of the sealed-off type reached 300 kw. A further increase in power was more easily achieved in tubes of demountable construction, operating in vacuo. In the USSR, such tubes are developed with a power of 500 kw and more.

In the postwar years powerful tubes (up to 500 kw) of the "semidemountable" type were developed, which permitted their disassembly and assembly in the radio station; these were so hermetic that a constant vacuum was no longer required. Apparently, such a design which combines the qualities of the demountable and sealed-off type of tubes, has prospects of wide application.

The creation of powerful tubes does not exclude the problem of addition of the power of tube generators. The construction of a powerful radio station in the form of several generator units, capable of operating jointly, greatly increases the maneuverability of the station and increases the continuity of its operation. In this case: a) the number of operating units can be changed in accordance with the required power; b) the inoperative unit is switched off and after eliminating the trouble is switched on again, with these operations taking place without interrupting the operation of the station; c) a reserve unit to replace the faulty part can be provided so as to maintain the power of the station unchanged.

The realization of this principle by parallel connection of a large number of powerful tubes proved impossible. This problem was solved for the first time in

1931 in developing the 500-kw radio station "Komintern": the final stage of the transmitter consisted of six operating unit groups and of one similar reserve unit; each unit contained 12 tubes of the type GDO-30 and a plate oscillating circuit; the plate circuits of the units were connected to a master intermediate circuit, feeding the antenna. As shown by experiment, such a system of units operates practically without interruption; a breakdown in one of the units does not entail stoppage of operations in the remaining units: During their operation, the reserve unit is cut in and the trouble in the disconnected unit is eliminated.

An analogous system of units was used in 1934 for the 500-kw radio station WLW in the USA, designed on the principle of class C plate modulation. Its terminal stage and a powerful modulator were composed of units, with the units of the modulator forming a separate arrangement, modulating on the plate system of units of the terminal HF stage.

For powerful transmitters designed according to the system of class C plate modulation, A.L.Mints suggested in 1934 an improved system of units. Each unit of the modulator forms a single whole with the unit of the terminal HF stage. This system of "generator-modulator units" was put into practice during World War II in the USSR on the most powerful radio station in the world, as well as in England.

The weak feature of the system of units is the strong intercoupling between them, due to the common load. Therefore, the nonphasal excitation of the units leads to their detuning, where the degree of mismatch depends on the connection of the units with the load. Besides, the tuning operations of the unit, control of its communication with the load, etc. reflect on the operation of the other units.

With the shortening of the wave and the increase of power, these deficiencies become more and more pronounced. Therefore for the short wave range, the system of "compounding of power in the ether", recommended in 1935 by I.Kh.Nevyazhskiy proved more adequate. In this system, the radio station consists of transmitter units, each of them having its own antenna, weakly coupled with the antennas of the other units. Thus, the compounding of power takes place "in the ether" at sufficiently weak interaction between the units. The total polar radiation pattern of the antennas becomes sharper than that of the antenna of a single unit (nondirectional radiation can also be obtained by compounding of power in the "ether" in the form of a rotary electromagnetic field with corresponding antenna bearing and a specific phase shift of the feeder currents).

The drawbacks of the system of power compounding in the ether are: bulkiness of

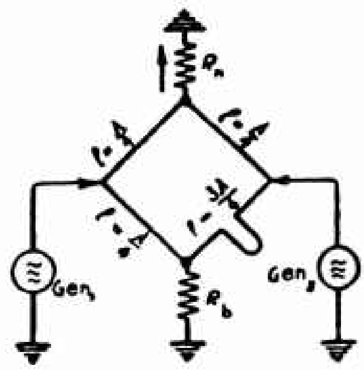

Fig.19 - Bridge Circuit of Power Compounding for SHF Generators

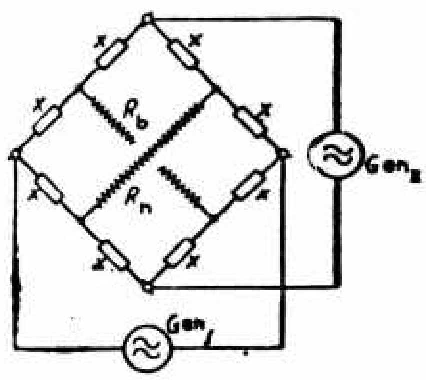

Fig.20 - Circuit of a Balanced Bridge, by B.P.Terentyev

the antenna feeder and dependence of the form of the polar radiation pattern on the number of switched-on units.

In the postwar years, the bridge method of power compounding came into use. The principle is as follows: To eliminate feedback between the generators, the latter are connected to the diagonals of the balanced bridge, consisting of reactances or line sections. Since the active load resistance R_n serves as one of the bridge elements, another active load resistance, known as a ballast resistance (R_b) must be included to balance the bridge. Correspondingly, when connecting one generator to the bridge, the power of the generator will be distributed evenly between the load resistance R_n and the ballast resistance R_b. The bridge elements are so selected that, upon connection of both generators, the resultant currents are added in the load resistance R_n but are subtracted in the ballast resistance R_b. In the case of identical generators, there is no current in the ballast resistance and the total power of the generators 2P is fed to the load.

Originally, variations of the bridge circuits were suggested, which permitted to add the power of the SHF generators. These bridges consist of elements with dis-

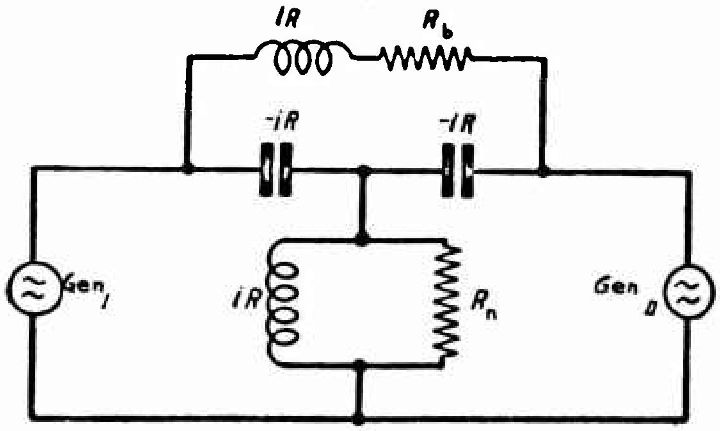

Fig.21 - Version of a T-Network Bridge Circuit

tributed constants: sections of waveguides or lines. Such a device is shown in Fig.19. Quarter-wave line sections serve as three arms of the bridge, while the fourth arm, connected with the ballast resistance, is a three-quarter-wave line section, so that the currents in the ballast resistance, created by the generators, are subtracted. At lower frequencies, the line sections are replaced by lumped reactances. B.P.Terentyev suggested a version of a balanced bridge, consisting of uniform reactances (Fig.20), in which the balance does not depend on the frequency. Since the input resistance of the bridge is complex for the generators, changing with the frequency, the points of input must be supplied with devices which transform the input resistances into active resistances of the required magnitude.

Figure 21 shows a version of a T-network bridge system which ensures, in balance, full decoupling of the generators and represents an active input resistance equal to the load resistance R_n. When one generator is permanently disconnected, the second generator can be switched directly to the load, bypassing the bridge, in order not to l 1e half of its power in the ballast resistance. An analysis of such a device shows that the balance can be restored there in case of various disturbances inevitable in practice.

With the aim of ensuring uninterrupted operation, transmitters are now frequently designed of two equal parts, whose power is compounded in the bridge circuit. In England, a network of small medium-wave broadcasting stations were constructed with remote control.

HIGH-FREQUENCY GENERATORS

The basic difference between high-frequency generators and generators of lower frequencies consists in the following:

a) The electron tube is not an electronic device, inasmuch as the period of oscillation proves commensurate with the transit time of the electrons between the electrodes;

b) The oscillating system of the generator cannot be separated from the tube so that, at very high frequencies, hollow-space oscillators instead of circuit coils and line sections are used.

At first, conventional tubes with control grids (triodes and tetrodes) were used for high-frequency generators. It was established that relatively high interelectrode capacitances and inductances of the lead-outs, limit the reception of high frequencies, lead to a low efficiency of the generator, and impair the conditions of self-excitation. The most practical device of self-excitation proved the system with an oscillating circuit between plate and grid. The method of its technical calculation was developed by A.M.Kugushev, who was the first to show the possibility of controlling feedback by means of cathode chokes. The theory of the device of the triode high-frequency self-oscillator was later developed by G.A.Zeytlyenok, S.A.Drobov, and Ye.P.Korchagina.

Simultaneously with theoretical investigations of electron processes in the triode, made by a number of authors (the most rigid study in the USSR was undertaken in 1936 by G.A.Grinberg), showed that the inertia of the electrons must have a substantial influence on the operation of the tube: during their transit, the voltage on the electrodes has time to change substantially, which reflects on the conditions of the movement of the electrons. As a result, a) part of the electrons, emitted by the cathode, does not manage to reach the grid and returns to the cathode, heating it additionally; b) the pulses of the plate current are condensed and a phase shift takes place between its first harmonic and the grid excitation, resulting in a decrease in the power and efficiency of the generator; c) the input conductance of the tube increases, due to which more power of excitation of the generator is required.

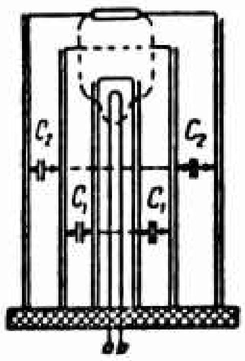

Fig.22 - Circuit Diagram of a Decimeter Wave Generator

To weaken these effects, it is necessary to reduce the distances between the electrodes, which results in a decrease of the oscillating power of the tube, or in an increase of the plate feed voltage, admissible at pulse operation.

Further development in the meter-wave oscillators led to the use of concentric lines as oscillating systems. In the second half of the Thirties, M.S.Neyman developed the theory of closed oscillating systems and suggested their various forms. Later, N.D.Devyatkov and his coworkers created an original design of an oscillator, containing a new type of triode with planar electrodes and circular leads, and also oscillating circuits in the form of concentric lines. This oscillator and its tube were the prototypes of present-day oscillators with lighthouse tubes (cermet and metal-glass), which find wide application at present in the decimeter-wave range.

The idea of the device of such a generator is shown in Fig.22. Here, three coaxial cylinders serve as a continuation of the disk lead-outs of the tube electrodes. The input circuit of the generator is formed by the grid-cathode capacitance of the tube and by the inductance of the concentric line section, composed of the cathode and grid cylinders, between which the capacitance piston C_2 is shifted.

At the lower frequencies of the decimeter range, the operating sections of the lines are shorter than quarter-wave. At higher frequencies, such a tuning of the circuits may be impossible; in that case, tuning at which the electric length of the lines corresponds to three-quarter wave is used.

In the case of a generator with self-excitation, the connection between the two circuits is established either by means of special coupling loops or probes extending through the wall of the grid cylinder, or by means of increasing the plate-cathode capacitance of the tube. The presence of many natural waves in each circuit may lead to self-excitation due to stray frequencies. This is eliminated by so selecting the feedback parameters that self-excitation is possible only on the operating wave. The power of modern triode generators of decimeter waves reaches hundreds of watts in continuous operation and hundreds of kilowatts at pulse operation (when more power is required, several generators are connected in parallel).

In the postwar years, papers published by Soviet scientists and specialists - M.S.Neyman, G.S.Ramm, G.A.Zeytlyenok, N.I.Ivanov, and others - contain the development of the theory of electron processes in SHF triodes, operating with high amplitude oscillations and current cutoff, i.e., under conditions characteristic of a generator.

The conditions for motion of the electrons, obtained in the SHF tetrode are more favorable than those in the triode: In the space between the control grid and the screen grid the electrons accelerate and, therefore, travel back and forth between screen grid and plate to which is connected the output high-speed oscillating circuit. This fact permits improving the pulse shape of the current as well as increasing the distance between the electrodes with the aim of reducing the spurious capacitance between them. In the cathode-control grid space, also negative phenomena occur, as in the triode: a) additional heating of the cathode by returning electrons, b) increase in input conductance and thus in the power of excitation.

For television, lighthouse tetrodes with air cooling of the plate and 1200 watt power, operating on waves up to 30 cm, were developed.

The development of the SHF tetrode generator led to the "resnatron" which is a high-power tetrode with the input (grid-cathode) and output (screen grid-anode) oscillating circuits located inside a balloon. The plate and screen grid are interconnected by direct voltage and are grounded; the cathode, under high negative voltage, is insulated. The design of the electrodes ensures sharp electron focusing, due to which the screen grid receives only part of the electron flow of the cathode. Besides, the possibility of the secondary electrons of the plate striking the screen grid is excluded at values of the instantaneous plate voltage closer to the voltage on the screen grid. In the Forties, resnatrons of the demountable type were designed with power up to 80 kw at continuous operation. On waves of the order 50 cm, their efficiency amounts to about 60% and the power amplification to about 10.

The difficulties in obtaining high power on meter and decimeter waves in tubes with control grids necessitated, as early as the Twenties, to start development and research on magnetrons. Intensive work in this field done in the USSR by A.A.Slutskin, M.T.Grekhova, G.A.Grinberg, V.S.Lukoshkov, S.Ya.Braude and others, led to the construction of magnetrons with split anode and later to the multisegment anode, which permitted obtaining high power and increasing the generating frequencies. In the second half of the Thirties, a multiresonator magnetron was designed under the guidance of M.A.Bonch-Bruyevich, N.F.Alekseyev and D.Ye.Malyarov, which is the prototype of modern magnetrons, finding wide application on centimeter and millimeter waves. Their pulse power reaches hundreds of kilowatts on the shortest waves of the centimeter range and thousands of kilowatts on waves longer than 10 cm.

Possessing the highest efficiency in comparison with other generators of the centimeter range (on waves of the order of 10 cm the efficiency reaches 65%), the magnetron generator has substantial deficiencies: a) change of load and feeding conditions have an effect on the generating frequency; what is more, a skip effect is possible to another frequency of a multiwave system, represented by the magnetron; b) the amplitude and the broad-band frequency modulations of the oscillations in the magnetron generator are made more difficult.

In recent years, means of stabilizing the frequencies of the magnetron generator were developed; thus, for instance, the frequency generated by it is held by a high-stability generator (having the same or twice as low a frequency), whose power amounts to 5 - 10% of the power of the magnetron. In this manner, deep amplitude modulation of the magnetron generator by changing its plate voltage is obtained.

The klystron generator has a much lower efficiency than the magnetron generator. Therefore, it previously seemed that this generator would be useful for low-power transmitters. In connection with the increased demands as to frequency stability and the requirements of television and other fields of radio engineering, utilizing the SHF modulated oscillations, intensive development of powerful klystrons was undertaken, which could fully satisfy the new requirements, as generators with independent excitation. To achieve these aims, three-resonator (cascade) direct-transit klystrons are used today. In comparison with two-cavity klystrons, they possess a much higher efficiency and a substantially higher power amplification factor, reaching 1000. The shape of the pulse of the current in klystrons is rich in the highest harmonics, which permits their effective use as frequency multipliers. As a result, a klystron transmitter with a quartz exciter, frequency multiplier and intermediate amplifiers, is no more complicated than a short-wave transmitter.

In many types of klystrons, the resonators are external which facilitates their retuning in a wide wave band. The application of magnetic focusing for reducing the harmful effect of the repulsion of electrons as well as gridless resonators of a special design (with the aim of reducing losses in these) permitted an increase in the efficiency of the klystron generators on waves in the 30 cm range, up to 30% at a power of 5 - 10 kw.

In view of the high quality factor of the input and intermediate resonators (the output resonator has a lower quality factor because of the load), the klystron, in principle, is a narrow-band SHF amplifier. Despite this fact, by means of some detuning and lowering the quality factor of the first two resonators, undistorted passage of the band of the television signal is made possible. This somewhat reduces the power amplification factor in the klystron amplifier, but leaves a relatively high value. This greatly simplifies the tuning of the television transmitter.

There is also a positive experiment of the development of super-powerful pulse klystrons at 20 - 30 megawatt in the 10-cm wave range at an efficiency of 33%. Accordingly to literature data, the joint operation of 20 such klystrons, furnishing the linear accelerator with a power of 400 megawatt, does not present special difficulties, inasmuch as the phasing of the oscillations in the klystron generator is easily achieved.

In recent years there was intensive work done on other types of powerful SHF amplifiers - tubes of moving and magnetron amplifiers, which open up possibilities of SHF amplification of an extremely broad band. For instance, a new type of traveling-wave tube furnishes a power of 1200 w in the 60-cm wave(500 mc) range on the 100 mc band.

In low-power radiotransmitting devices, utilized for radio relay lines, etc., lighthouse triodes and reflector klystrons are used. By changing the voltage on the reflector in the latter, automatic control and, rather simply, frequency modulation are obtained.

HIGH-FREQUENCY GENERATORS FOR INDUSTRIAL USE

The work by the outstanding Soviet scientist V.P.Vologdin and a number of other radio specialists led to widespread application of high-frequency generators in various fields of the national economy.

At present, the total power of high-frequency vacuum-tube generators, used only in metal-working plants, substantially exceeds the total power of radio stations. Vacuum-tube generators are used for casehardening, smelting, soldering, and tin-plating of metals, for drying lumber, yarn, canning of food items, for heating plastics, for extermination of pests, etc. Vacuum-tube generators also have found wide application in medicine.

The extreme diversity of the purposes of the generators permits the application of all radio frequencies, beginning with the lowest and ending with superhigh frequency. The power of generators in use already reached hundreds of kilowatts.

In connection with the tremendous importance of high-frequency generators for the national economy, the problem of practical design of the circuit and the construction is very acute. Let us take note of a few specific features of high-frequency generators:

a) The load parameters change in the heating process. This leads to poor power utilization of the generator during a substantial part of its operating cycle. If the cycle of heat treatment is sufficiently long, manual power control of the generator is possible. In short cycles, most generators at present operate without automatic power control;

b) So long as frequency stability is of no importance, the generators are usually designed as devices with self-excitation. A more suitable balancing between tube and load can be ensured by a two-circuit connection with the latter. This frequently leads to backlash, a skip effect from one frequency of the connection to the other, accompanied by drastic changes in the load current, in the operating conditions of the generator, its power, efficiency, etc. (in itself, a small frequency surge during the tempering process is of minor importance).

Formerly, attempts to eliminate the backlash were made by applying single-circuit systems, containing high-frequency matching transformers of special design. Such systems are still in use today in cases where the generator operates on a fixed load. In the postwar years, two-circuit systems were used in generators intended for universal loads, designed in such a way that self-excitation was possible only on a single coupling frequency (feedback to the grid of the secondary circuit, the system of frequency-dependent feedback by Yu.B.Vigdorovich);

c) For a number of reasons (distortion of the form of grid excitation, complex character of feedback, etc.), the efficiency of generators is often low. At the same time, the problem of increasing the efficiency is rather acute in view of the tremendous total input power of the generators;

d) In the postwar years, serious attention was devoted to the elimination of radiation in generators, which created substantial interference in the reception of radio stations. This was achieved by shielding and feeding across high-frequency filters;

e) The feeder sources of generators used in standard production must be stabilized.

Directing the attention of a broad circle of radio specialists to the above questions will no doubt increase the level of this tremendously important field of radio technique.

RADIOTRANSMITTING EQUIPMENT

The development of radiotransmitting technique during the last decade is closely linked with the improvement of equipment, more perfected construction, and progress achieved in the technology of manufacture.

To the above statements on new types of generator tubes, one may add that in modern high-power generator tubes the cathodes, as a rule, are made of thoriated tungsten. The resultant decrease in the input power of the filament circuits by 2.5 - 3 times noticeably affects the efficiency of the transmitters. New designs of anodes with forced cooling were developed which permit the construction of transmitters with powers of 100 and more kilowatts, with air cooling as well as with a rather economical system of water cooling.

Designers of radio transmitters now have at their disposal a more perfected set-up of high-frequency circuits. In the long and medium-wave ranges, mica capacitors subjected to aging, particularly at higher temperatures, are replaced by ceramic capacitors and, in powerful stages, by gas-filled capacitors under pressure and oil-filled capacitors. In the short-wave range, huge air capacitors are replaced by ceramic and high-voltage vacuum capacitors. The application of circuit coils with sliding contacts along the loops permits designing short-wave transmitters in the two-dimensional rather wide wave range. The decrease in the overall size of their circuits in conjunction with a more rational space arrangement of the equipment, contributed to the widening of the range in the direction toward shorter waves and to an increase in operating stability. Great improvements were made in the design of transmitters of other ranges due to the use of new materials and parts. The application of magnetodielectrics (ferrites) permits electric tuning, without inertia, of the circuits in a broad wave band.

The development of feed sources of the transmitters tended toward new types of small-size, high-voltage kenotrons, dry rectifiers, and powerful high-voltage thyratrons. The replacement of gas-filled tube rectifiers by thyratrons increased the operating stability of the rectifiers, owing to the introduction of rapid-action grid protection from overcurrents caused by flash-back in the valves and breakdown in the tubes.

Success was achieved in the field of control, automatic tuning, and protection of the equipment.

NEW STRUCTURAL SOLUTIONS

The task of mass delivery of radiobroadcasting receivers for the population involves the necessity of producing receivers by mass-production methods, together with a decrease in weight and size of the receivers, lowering of their cost, and improvement of their quality indexes.

It is known that the reproduction of the lowest frequencies of the sound spectrum is connected with the perimeter of the housing and the diameter of the cone of

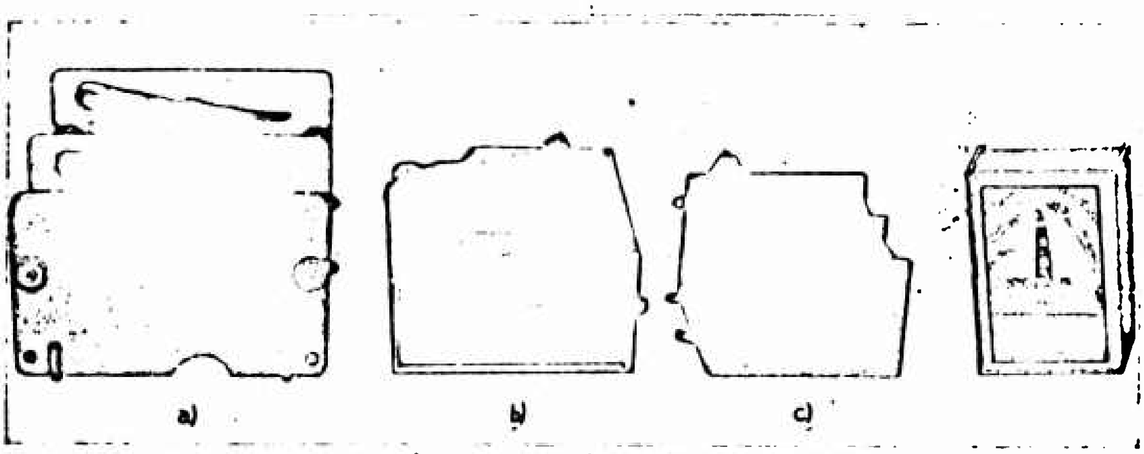

Fig.7 - Two-Section Units of Variable Capacitors:

a) Old design, b) and c) New designs

the loudspeaker. In order to ensure the reproduction of the lowest frequencies (60 - 100 cycles) by the receiver one usually utilizes loudspeakers with low frequency of the resonance of the mobile system and the casing is made with a relatively high perimeter. With a decrease in the size of the casing and the diameter of the cone of the loudspeaker, the low frequencies "vanish", leading to a deterioration in the sound qualities of the receiver.

It is also known that one of the specific characteristics of the human ear is its nonlinearity, manifesting itself strongly on the lowest frequencies. If instead of the lowest frequencies the receiver were to reproduce their harmonics, then, on the strength of the nonlinearity of the ear, the impression would be created of perception of the lowest frequencies.

A sharp accentuation of the harmonics of the lowest frequencies is achieved by means of a circuit solution or by selecting an appropriate mobile loudspeaker system.

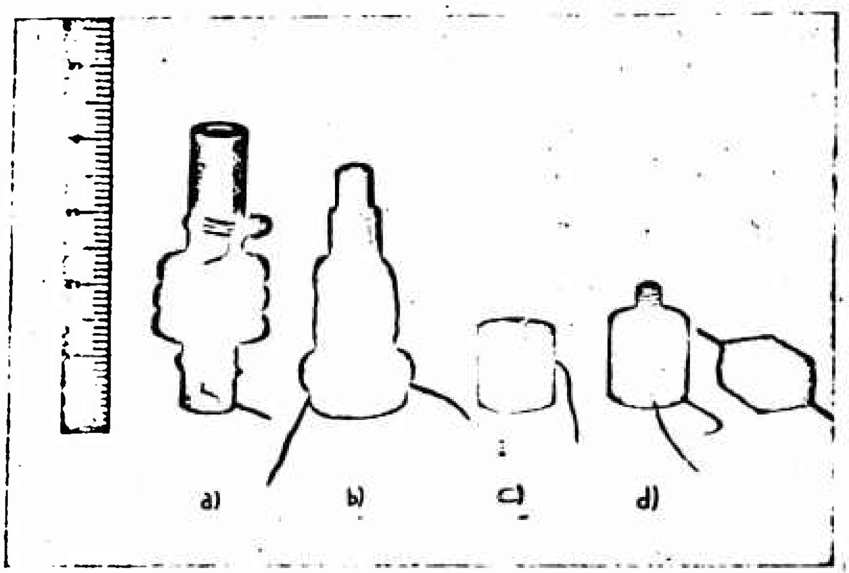

Fig.8 - Inductance Coils of Different Designs

a) Without magneto-dielectric, b) With "alsifer" core, c) With alsifer shell-type core, d) With carbonyl core; extreme right - with ferrite core molded into the plastic

The latter method finds much more application, since it does not require complication of the circuit and is relatively easy to attain by a proper structural design of the mobile loudspeaker system.

The reduction in size and cost was greatly furthered by the decrease in size of the radio tubes, i.e., the change-over to small-button tubes. The decrease in power of the heater of the cathodes of these radio tubes also exerted an influence on the reduction in weight and size, and consequently on the cost of the receivers, in view of the fact that the power of the power transformers is reduced.

The use of selenium rectifiers, germanium detectors, and new magnetic and insulation materials permitted a qualitative change in many elements of receiver design and thus lower the total consumption of materials.

It suffices to say that the total use of materials for Class III receivers was reduced in recent years by more than 50% and in Class II receivers by as much as 30%.

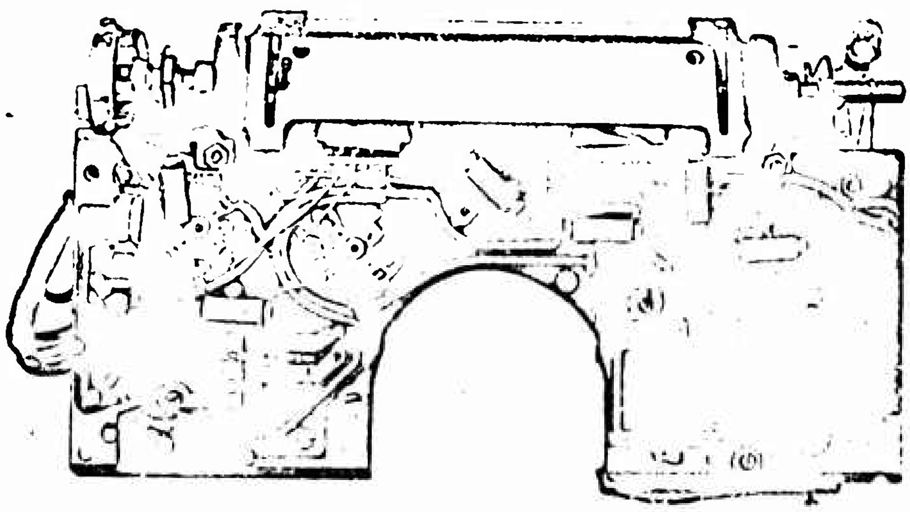

Fig.9 - Printed Mounting Plate of the Receiver "Dorozhny" with Details of Assembly

Significant success was also achieved in the field of the structural perfection of the basic units of radio receivers. For instance, modern variable capacitors of radio receivers are reduced in size and weight by more than 2.5 times. This was achieved by narrowing the air gaps from 0.5 mm to 0.25 mm and by using a more accurate rolling of the aluminum strip of which the capacitor plates are made. In Fig.7 two-section units of the old and new design are shown.

The use of ferrite permitted a reduction in size of the inductance coils, intermediate frequency filters, etc. Figure 8 gives a comparison of the design of inductance coils having ferrite cores with coils having carbonyl or "alsifer" cores.

The increase in the specific capacitances of the electrolytic capacitors permitted a reduction in their size by 2 - 3 times in comparison with older models.

The decrease in the overall size of the loudspeakers, in combination with the improvements in design (of both the mobile and the magnet system), permitted, without impairing the acoustic qualities of the receivers, to reduce the size of the casing and to increase the productivity of labor in its manufacture. For example, the most popular receiver "Moscovite", which is several times smaller in weight and size than the Class II receivers formerly produced, has acoustic indexes close to these latter.

Further perfection of radio receivers with respect to lowering their cost is obtained by the introduction of completely new methods of design and manufacture; one of these is the method of "printed circuits", used in the production of both radio and television receivers. The basic advantage of printed circuits is their adaptability to the highly mechanized and automatic manufacturing processes.

For example, in the five-tube superheterodyne receiver "Dorozhny", a large portion of the circuit is based on the printed method. Figure 9 shows the printed mounting plate of this receiver with mounted printed conductors and resistors.

PROSPECTS OF THE DEVELOPMENT OF RADIOTELEGRAPH SYSTEMS

In the modern theory of communications, two directions are clearly marked: 1) increase in the operating efficiency of the channel by the fact that statistical features of the language or of other material transmitted via the communication channel are utilized and 2) search for methods of transmitting messages which would ensure maximum possible stability of the communication channel. The first direction is most pronounced in the work by K.Shannon (USA), and the second found its most advanced form in the work by V.A.Kotelnikov, "Theory of Potential Noiseproof Feature".

Let us review some special trends of the first direction.

Modern transmission of telegrams by telegraph teleprinters is based on letter transmission, where each letter is given a fixed combination of five elementary sendings. As each elementary sending has the possibility to transmit one of two messages + or -, then five such sendings can form $2^5 = 32$ various combinations or transmit 32 different messages. In the Russian alphabet there are exactly 32 letters, if the letter ё is excluded.

Consequently, by utilizing all the combinations of the five elementary sendings, any worded text can be transmitted. But this text will contain no numerals, punctuation marks, or even spaces between words.

The question is how this problem is solved in telegraph communication. Each telegraph apparatus has two recorders: one for letters, one for numbers. On the letter and the number recorders one can transmit 29 conventional combinations on each, a total of 58 conventional combinations. It would appear that this number ought to equal 64, and not 58. However, one must not forget that of the 32 possible combinations from 5 elementary sendings, one combination must be used for spaces between words, another combination for shifting the recorder, and still another combination as the inoperative sign. The last two combinations are necessary on both recorders. The spacing can be on only one recorder, but this complicates the operation.

Thus, on the letter recorder, 29 letters out of 33 are transmitted. On the number recorder the remaining letters, numbers, and necessary marks are transmitted.

The question arises whether it would not be more practical to produce a code of six elementary sendings rather than of five; then all the letters, numbers, and marks could be arranged on one recorder. From the point of view of simplification of the design of the telegraph apparatus, this way would be practical but would decrease the carrying capacity of the channel. Let us examine this on an example of a simple telegram:

Moscow Gorkovo 17 apt 35

Sokolova

Await aunt coming Ufa arrives June 18

Dunya

In this telegram there are 60 letters and numbers, 13 intervals between the words, and 6 shiftings from recorder to recorder. Altogether for its transmission would be required 5 x 79 = 395 elementary sendings. If a six-digit code were used for transmission of the same telegram, the saving would be at the expense of six shiftings from recorder to recorder, and consequently, would necessitate 6 x 73 = 438 elementary sendings, and the time of transmission of the given telegram would be lengthened by 11%.

Thus, the use of two recorders shortens the time of transmission of telegrams and, consequently, increases the operating efficiency of the channel. It seems logical to attempt to develop this concept further, by applying, e.g., four recorders instead of two and in this way still further increase the operating efficiency of the channel. It appears that this is feasible. As is generally known, the first letters of the alphabet are used more often than the last. If one were to place the most frequently used letters on the first recorder, and those used less often on the second recorder and in an analogous manner distribute numbers and marks, the five-digit code could be replaced by a four-digit code. With four recorders and a four-digit code, one could transmit a total of 44 signs instead of 58, since four combinations of the possible number $2^4 = 16$ on each recorder are used up for shifting of the recorder and for the intervals between letters, while one combination is used for absence of transmission. If one were to familiarize oneself with the transmission of normal telegrams, disregarding the established practice of composing telegrams without punctuating marks, then 44 combinations would suffice. As an example, Table 2 gives the possible distribution of letters, numbers and necessary marks on four recorders.

If we were to transmit the above telegram with the aid of the newly composed alphabet on four recorders, then 336 sendings in all would be required, i.e., we would obtain a saving of almost 12%.

Of course, the discussed measure is only an example illustrating the basic idea that an increase in the operating efficiency of the channel is possible by practical

Table 2

Combination No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Recorder I	a	v	g	m	o	k	s	r	'	ya	l	Shifting to Recorder I Intervals on Recorder I	Shifting to Recorder II Intervals on Recorder II	Shifting to Recorder III Intervals on Recorder III	Shifting to Recorder IV Intervals on Recorder IV	Absence of Transmission
Recorder II	b	d	i	n	t	ye	yu	u	f	zh	y					
Recorder III	sh	shch	z	p	kh	ts	ch	e	"	+	-					
Recorder IV	1	2	3	4	5	6	7	8	9	10	11					

coding of the messages. Let us give another example. In this book, there are 40,000 typographical signs on each author's sheet of text. In order to transmit all these signs by the Baudot telegraph, $40 \times 10^3 \times 5 = 200,000$ elementary sendings are required, not even taking into account the combinations for shifting to the number recorder and vice versa. If we were to count each word as consisting of five letters on the average, which, as far as the Russian language is concerned, constitutes a gross underestimate, then each author's sheet has to contain 8000 words. Assigning to each word a fixed combination from a certain number of elementary sendings, one can prove that 13 sendings are fully sufficient for the description of 8000 words. Actually $2^{13} = 8192$. If, from this number, we were to allot 32 combinations for numbers and signs, a total of 160 combinations could still be utilized for the distribution of all possible words on 160 recorders. In all, with the aid of combinations from 13 elementary two-digit sendings, one can transmit $160 \times 8000 = 1,280,000$ different words plus 32 signs and numbers. These possibilities are evidently sufficient for the transmission of any worded text.

However, with this method of coding, the author's sheet will require for its transmission approximately 13 x 8000 = 104,000 elementary sendings instead of the 200,000 required with the usual method of telegraph transmission. The saving obtained, as can be seen, is 2 times. In other words, the operating efficiency of the channel can be increased to twice its original value. The above two examples suffice to show the tremendous possibilities in a practical coding.

However, it is not difficult to grasp that the utilization of practical codes like those discussed above leads to a lowering of the resistance of the communication channels to interference. As a matter of fact, when transmitting coded words, individual letters in words are distorted. The intelligibility of the text generally remains complete. In the transmission of coded words, an error in one elementary sign means substitution of a whole word so that, in this case, full intelligibility of the text cannot be expected. This creates the necessity of looking for new methods of transmission, which would insure high protection from interference together with the utilization of practical coding.

The basic principle, developed in "The Theory of Potential Noiseproof Feature" by V.A.Kotelnikov, applicable to telegraph systems, boils down to the requirement of transmission of sendings reflecting different messages (letters, words, etc.) with the aid of orthogonal functions. This means that signals carrying various messages must differ to the maximum extent. Therefore, the problem arises to find economical methods of encoding which, together with maximum operating efficiency of the channel and without widening of the band, would ensure maximum possible distinctions of the code combinations in order to increase the protection from interference.

It seems that the development of radiotelegraph systems is bound to go along such a synthetic course.

RADIO RELAY COMMUNICATION ON ULTRA-SHORT WAVES

by

V.A.Smirnov

1. Brief Historic Review

The development of the technique of ultrashort waves (VHF) down to waves of the millimeter range, was considerably furthered by the scientists of our country. A series of papers of fundamental importance in the field of propagation, generation, and reception of ultrashort waves by B.A.Vvedenskiy, A.A.Glagoleva-Arkad'yeva, M.A.Bonch-Bruyevich and others belong still to the Twenties of the present century. The same period includes also the first work on testing the practical feasibility of establishing communication on ultrashort waves, conducted by B.A.Vvedenskiy, A.I.Danilevskiy, A.G.Arenberg, A.V.Astaf'yev, Yu.N.Sheyn, S.Ya.Turlygin. The designing and creation of the first ultrashort wave lines of communication began in the Thirties. Thus, during 1932 - 1934 in the USSR, equipment operating on meter waves was developed and installed on the experimental communication lines Moscow-Kashira and Moscow-Noginsk. Later, during 1934 - 1936, experiments on telephone communication were conducted on the 60-cm wave, with the suburban zone of Moscow (10 - 15 km). In the prewar years, work was being done on the creation of a more powerful ultrashort wave communication channel for multichannel telephone and telegraph communication.

During the same years work was begun in other countries on using ultrashort waves for communication purposes. In Germany, approximately during the period

1932 - 1934, the first satisfactory results in communication on meter waves were achieved. In 1934, the firm Telefunken established for the first time a communication on the 50-cm wave, at a distance of about 10 km.

In 1932, the first communication on the 5-m wave was organized over the British Channel in England. In 1934, England was the first to use an ultrashort wave "insert" into the conducting line, which ensured operation of six telephone channels. In 1937, a 9-channel service was accomplished through the Channel between the points Belfast-Stranrir on a wave band of about 4 m over a distance of about 55 km.

The first link in the USA, which operated on a wave band of about 3 m was established between New York and Philadelphia in 1936. This link had already two intermediate booster stations and can be considered as the first radio-relay communication system.

However, all these single lines erected during the decade 1930 - 1940 in different countries were of an experimental character. Communication on these lines was realized in the majority of cases on meter waves and the number of simultaneously operating telephone channels on these lines did not exceed six.

In the following decade 1940 - 1950, owing to the rapid development of the ultrashort wave technique, the development of the technique of decimeter and centimeter waves in particular, and also as a result of mastering new methods of modulation (frequency, pulse), ultrashort wave systems found wide application in practice. Systems appeared which permitted simultaneous operation of several tens of channels and, toward the end of 1950, even of hundreds of telephone channels in one "radio trunk" (i.e., in a single broad-band radio transmission), accompanied by the development of systems for television transmission. The field of application of ultrashort wave systems also widened: short ultrashort wave "inserts" into the conducting communication lines found rather wide application in places where the laying of a conducting line was hampered (for example, under water or at mountain conditions). Single, relatively short ultrashort wave lines began to replace cables for the connection of studios with broadcasting transmitters or of transmitting and receiving centers with radio centers. Special stationary-mobile ultrashort wave communication systems were created for servicing railway and automobile transportation, for postal service in towns, etc. The transmission of television programs from stadiums, public squares, theaters, etc. is effected in the majority of cases with the aid of such ultrashort wave lines. At present, there exist multichannel telephone and television radio relay systems of many hundreds and thousands kilometers length.

The radio relay communication systems are undergoing final development in the current decade, after 1950. The technique and economics of these systems have already reached such a level that they are fully competitive with aerial wire and cable systems of long-distance communication. Radio relay communication systems began to be put into operation on a large scale. The industry produced for this purpose a series issue of highly perfected equipment.

During the war years and during the first postwar years, the technique and introduction of ultrashort wave communication systems in the USSR was somewhat delayed. However, during a later period, particularly in connection with the directives of the Nineteenth Congress of the Communist Party, on the introduction of ultrashort wave radiobroadcasting and radio relay systems, an expansion of operations in this direction began in every way. Several radio relay systems have already been established, none of them being in any way inferior in quality to foreign systems of the same power. Development of still more perfected systems is being continued. The existing network of radio relay systems in the country has been considerably extended. The technical foundation has been created, on whose basis this network will expand rapidly in the coming years.

2. Radio Relay Communication Systems and Their Status of Development

According to literature data, and mainly judging by the material of the MKKP and MKKF, quite a clear idea can be formed both about existing radio relay systems and those in the stage of development as well as their adoption for operation in a number of countries.

In the majority of systems of multichannel telephone service, the principle of frequency division of channels and the same terminal equipment as in wire communication are used. The use of one and the same terminal multiplexing equipment in radio relay and wire lines substantially simplifies the interconnection of these lines and lowers the cost of the system as a whole.

Both in telephone and television ultrashort wave systems, frequency modulation (FM) of the carrier frequencies of the transmitters are generally used. In some countries, multiple telephone systems have been developed with time division of channels, but with the total number of channels not exceeding 24. In the overwhelming majority of such systems, pulse time series modulation and amplitude modulation on radio frequencies (PTM-AM) are used. Less popular is amplitude modulation of the pulse series with frequency modulation of the radio frequencies (APM-FM) or pulse-duration modulation with amplitude modulation of the radio frequencies (PDM-AM).

In some countries, systems for a number of channels, 600 and more in a single radio trunk, are in the stage of development.

The present status of radio relay lines is characterized by the total length of these lines, which in different countries varies from 600 (Switzerland) to 60,000 (USA) km*.

During the next 3 - 5 years, about 20,000 km of radio relay systems equipped with modern apparatus will be erected in the countries of Europe and Asia. Projected radio relay lines for communication are as follows: USA-Europe (via Greenland), Ankara-Beirut - Kairo, etc. At present, England, France, Belgium, Denmark, Holland,

* In addition to the main lines, this also includes the communication lines of the transportation system and other systems.

Switzerland are in the process of interchanging television programs over radio relay lines.

Of interest is a comparative economic analysis of radio relay and cable lines, published in the English literature (Table 1).

Table 1

Comparative Economic Indexes of Radio Relay and Cable Lines for Transmission of Television Programs (England)

Basic Indexes	Radio Relay Line	Cable Line
Relative Weight of Steel	2	1
Relative Weight of Copper	1	35
Relative Weight of Lead	1	280
Relative Weight of Aluminum	1	-
Size of Buildings, m^3/km	7.8	11.3
Electric Power Consumption, w/km	156	81
Total Number of Radio Tubes per 1 km	13	7

The cost of installation of a modern radio relay line with a small number of channels is comparable to that of a cable line, while with an increase in the number of channels, the cost is reduced. According to presently available approximate data, the cost of erecting a radio relay line with a capacity of 60 - 960 telephone channels amounts to approximately 90% - 60% (depending on the number of channels) of the cost of a cable line of the same length and capacity.

3. Block Diagrams of Radio Relay Systems

Radio relay communication systems, as is generally known, consist of an iterated network of ultrashort wave radio stations, placed between conforming correspondents. Two extreme stations of the line are called terminals, while all others between these are called relay stations. If the surface of the terrain between the terminal points of the communication lines is fairly uniform and if waves

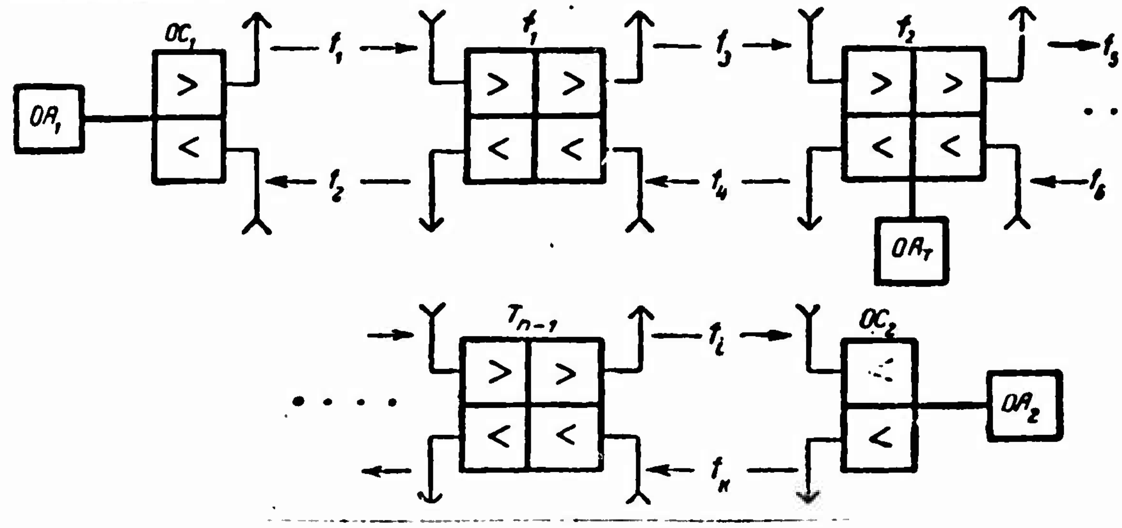

Fig.1 - Simplified Block Diagram of a Radio Relay Line

of the centimeter range up to several tens of centimeters are used, the average distance between the stations is of the order of 50 km. Depending on the length of the operating wave and the topography of the locality, these distances may vary considerably, reaching at times several hundred kilometers. Each station on the line is a complex of difficult radiotechnical devices and installations. The most powerful modern radio relay systems have several (up to 7) radio-frequency trunks, in each of which several hundred telephone conversations or one television program can be transmitted. All trunks are usually identical as to composition of the equipment; therefore, it is practical to first give the composition of the equipment of a single-trunk line, and then show how the

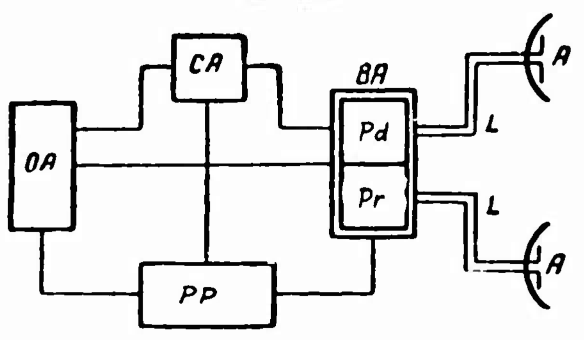

Fig.2 - Simplified Block Diagram of a Terminal Office

trunks are united into the total system.

Figure 1 gives a simplified block diagram of a radio relay line consisting of n bays, where OC_1 and OC_2 are the terminal stations, T_1, T_2 ... T_{n-1} are relay stations, OA_1 and OA_2 are the terminal offices at the ends of the communication line, OA_T is the terminal office which is connected with any one of the relays where a separation or a parallel branching of a part of the channels (for example, of the audio or television channels) occurs, while f_1, f_2, ... f_i, f_k are the operating frequencies used on the individual sections of the line.

Many of these frequencies may be equal, i.e., on different areas of the line

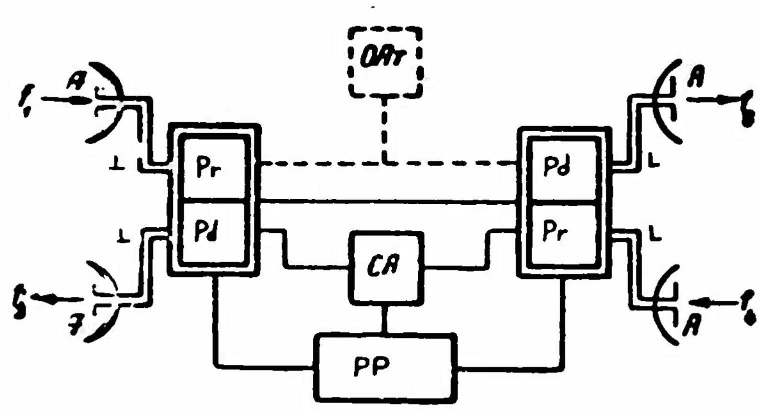

Fig.3 - Simplified Block Diagram of a Radio Relay Station

the frequencies may repeat themselves. In the simplest case, only two frequencies: f_1 and f_2 are utilized on the whole line.

Let us review the basic composition of the equipment of the terminal offices and relay stations.

The block diagram of the terminal station shown in Fig.2 indicates that the entire equipment of the terminal offices is divided into the following basic assemblies:

1. High-frequency equipment - BA, comprising the transmitting device Pd and receiving device Pr;

2. Service equipment CA;

3. Terminal equipment OA;

4. Devices of primary feeding PP;

5. Transmitting and receiving antennas A;

6. High-frequency antenna feeders (waveguides) L.

The function of the Pd and Pr units, entering the complex BA and comprising also a series of modulation and demodulation stages, consists in filtration, generation, and amplification of frequencies corresponding to ultrashort waves. With the

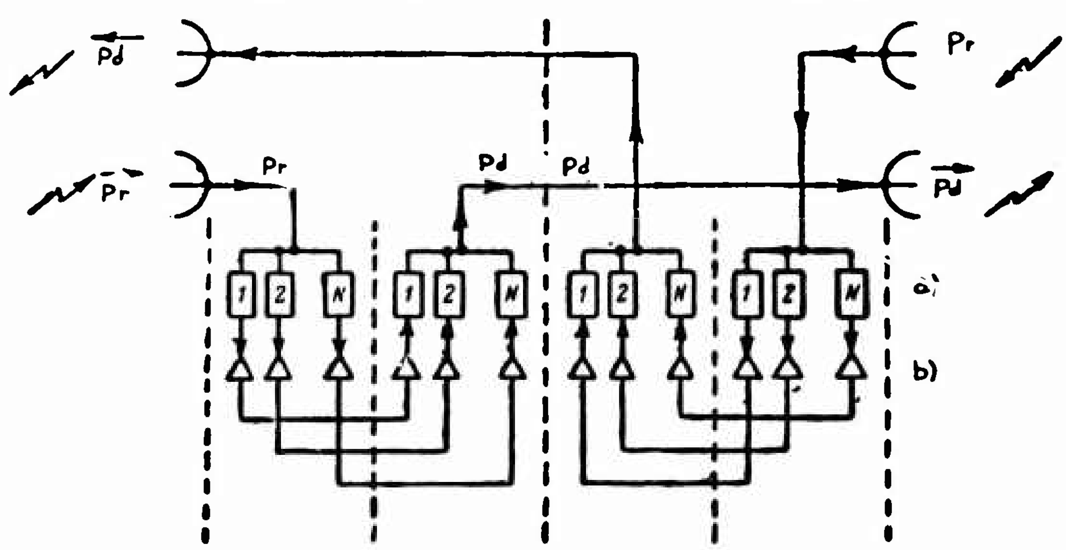

Fig.4 - A Simplified Block Diagram of a Station with Multitrunk System

a) Intertrunk filters; b) Apparatus

aid of the high-frequency lines L, usually in the form of a concentric cable or hollow waveguides, Pd and Pr are connected, respectively, to the transmitting and receiving antennas A which generally have high directivity.

The terminal equipment OA serves the following purpose: either a) to bring up one or several telephone or other channels to a fixed level, to place the channels in the frequency spectrum, or to time them so as to create a common primary modulation spectrum entering the transmitting part BA; or b) to effect a reverse process of separation of individual channels from the master primary modulation spectrum, obtained at the output of the receiving part BA.

The service equipment CA comprises signaling devices, not provided for directly in the OA and BA units, devices for establishing service telephone communication and for automatic control and administration of stations.

The volume and technical solution of each of the basic assemblies depend on the type of communication system, which is determined mainly by the quantity and quality of the channels formed and the type of modulation used.

A block diagram of a radio relay station is shown in Fig.3.

The relaying part consists of a compensating unit for the attenuation of the ultrashort wave field, created during propagation, also when a change in the direction of the propagation is required. For this purpose, a weak signal, received from one of the directions, is amplified and then re-emitted in the same direction or in another one. It is essential to note that, for the time being, relays in which such amplification is effected on operating high frequencies are hardly ever used in practice. Therefore, modern relays have a very complicated equipment containing several demodulation and modulation stages, while amplification of the signal is done on the relatively low intermediate frequencies.

As indicated by the block diagram, a relay station is a combination of two BA units. Sometimes, the BA of the relay stations coincide fully with the circuits and sizes of the BA in the terminal offices. This is the case for the practical relay types where the process of complete modulation takes place prior to receiving of the primary modulating signal, which arrives from the terminal office. In other relay types, the number of modulation and demodulation stages in the BA is decreased, so that there is no demodulation prior to receiving the primary signal. Sometimes, the separation or branching of all or part of the channels is done in the intermediate relays. In this case, a corresponding terminal equipment OA_T , shown in Fig.3 by a dotted line, is subconnected to the BA relay. The necessity of separating in each station the service communication channel and the control and direction channels further complicates the equipment.

At present, the technique of ultrashort wave communications is very near to a practical realization of amplification on high frequencies and thus to the realization of simpler relay stations without frequency transformation.

The joining of several trunks in a single radio relay line is done in the block diagram shown in Fig.4. In this case, individual trunks operate on different carrier frequencies, but with common antennas, and the connection of the equipment of the individual trunks to the common antennas must be accomplished by separating band filters. In some multitrunk systems, only two antennas are used instead of four, so that transmission and reception in one and same direction are achieved on one antenna. This further complicates the filter system.

4. Fundamental Equations of the Radio Relay System

The calculation of any radio relay line can be done with the aid of two basic equations. These equations establish the connection between the most important parameters of the radio relay system: of the actual power of the transmitter P_{pd} of each station; of the signal-to-noise ratio at the output of an individual communication channel (for example, of the telephone channel) at the end of the line $\frac{S_a}{N_a}$; of the effective band of the system Δf; and of other parameters.

The first equation has the form

$$\frac{P_{pd}}{P_{np}} = \mu = LWF \qquad (1)$$

where μ is the total attenuation of the section, equal to the relation of the actual power of the transmitter P_{pd} to the power at the input of receiver P_{np};

L is the attenuation in the elements of the equipment between the output circuit of the transmitter and the grid circuit of the first tube of the receiver. Here the attenuations of the waveguides, output and input filters in the antennas are connected. Practically, the largest attenuation component L is due to losses in the waveguides;

W is the attenuation, fixed by the ratio of the magnitude of the power $P\Sigma$, emitted by the transmitting antenna, to the magnitude of the power arriving at the receiving antenna $P_{\leftarrow}$, under the assumption that the propagation of electromagnetic energy takes place in a vacuum;

F is the attenuation, fixed by the fact that propagation actually takes place not in free space but in the atmosphere near the rough surface of the earth. The factor F is a magnitude, varying in time as a result of constants changes in the atmosphere.

The study of the propagation conditions of ultrashort waves permits computing the average value of the output WF as well as evaluating the magnitude of the oscillations of the factor F, when the structure of the atmosphere is changed. Fundamental work in the field of propagation of ultrashort waves was carried out in the USSR. This mainly includes the papers by B.A.Vvedenskiy who, still in the Twenties, elaborated the methods of calculating the field of ultrashort waves within the limits of direct visibility and later in the field of diffraction beyond the limits of optical visibility. At a much later stage, V.A.Fok specified more accurately the calculation of the field of ultrashort waves within and without the limits of visibility by taking into consideration the refraction in the atmosphere. The new methods of calculation developed by him are today the most common and the most rigid. In recent years, B.N.Troitskiy and A.I.Kalinin contributed valuable information to the question of propagation of ultrashort waves, as applied to actual conditions encountered in radio relay systems.

The second basic equation, necessary for the calculation of radio relay lines is as follows:

$$\frac{1}{B} \cdot \frac{P_a}{N_a} = \frac{P_{pd}}{N_{pd} \Sigma \mu_i} \qquad (2)$$

Here P_{pd} is the actual power at the transmitter output;

N_{pr} is the power of the fluctuation noise, relative to the first tube of the receiver (usually at the input of the mixer);

This power equals

$$N_{pr} = N_o \, KT \, \Delta f \qquad (3)$$

where N_o is the noise factor of the receiver, which for quality receivers is within the approximate limits of 5 - 30;

K is the Boltzman constant;

T is the absolute temperature. At a temperature of 20°C, KT = 0.4×10^{-20} w;

Δf is the effective width of the band of the receiver, in cycles;

$\frac{P_a}{N_a}$ is the signal-to-noise ratio at the receiver output in the band of an individual channel. This magnitude is usually rated and, for telephone trunk lines, is equal to 6 nepers;

B is the noise gain, depending on the form of modulation and on the correlation of the bands at the receiver and individual channel input.

Finally,

$$\Sigma \mu_i = \mu_1 + \mu_2 + \dots + \mu_n \qquad (4)$$

represents the total attenuation of all sections of the radio relay system.

It can be assumed that

$$\Sigma \mu_i = n \, \mu_e \qquad (5)$$

where μ_e is the fading of the equivalent section equal, consequently, to

$$\mu_e = \frac{\Sigma \mu_i}{n} \qquad (5a)$$

Then eqs.(1) and (2) can be written in the following form:

$$\frac{P_{pd}}{P_{np}} = \mu_e \qquad (1a)$$

$$\frac{P_{np}}{n\,N_{pr}} = \frac{1}{B} \cdot \frac{P_a}{N_a} \qquad (2a)$$

In order to assign the parameters of the communication system accurately and to fix the possible stability of the communication line as to time, it is necessary to know the behavior of each μ_i as to time or, what amounts to the same, of each F_i. In this connection, an increasing number of publications in recent years gave the distribution curve F_i for various kinds of tracks, representing the result of long experimental research. However, due to the considerable variety of the tracks as to length and profile as well as due to the utilization of different frequencies in the systems, there is no sufficiently large amount of such experimental data available at present so that a suitable classification is still missing. Therefore, the calculation according to eqs.(1) and (2) or (1a) and (2a) is only approximate. Besides, it must be noted that establishing the law of distribution of the quantity μ_e, even at assigned laws of distribution for μ_i [eq.(5a)], presents in the majority of cases a rather difficult task.

5. Distortions in Radio Relay Systems

The transmission of signals of a given kind through the actual communication systems is always accompanied by distortions. The distortions encountered in practice can be divided into two basic categories: distortions of independent origin and distortions of dependent origin. The distortions of independent origin include all kinds of noises (interference), such as external interference of atmospheric or industrial origin and fluctuation or smooth noises, generated in the equipment of the communication system itself. All interference of this kind is independent on the transmitted signal emf, created in the communication channel or introduced from outside. Consequently, these types of interference are detected in the communication channel even if there is no useful signal available.

The distortions of dependent origin are caused by the imperfection of the communication channel of the system. These include, for example, distortions due to the nonlinearity of the amplitude, frequency, and phase characteristics of the communication channel, as well as distortions due to the presence of parasitic channels of the system, which occur (for example) in multibeam propagation of radio waves. This kind of distortions includes quantization noise created in the process of pulse-code and delta-modulation which, in multichannel radio relay systems, manifest themselves most frequently as additional noises in the channel. The origin of these noises is directly linked to the useful signal; when it is absent, such noises are not detected.

The study of the noises of independent origin in the channels of radio relay systems shows that, in the 100 - 6000 mc frequency band normally used here, atmospheric interference is practically of no importance. Only at the lowest frequencies of this range, during the time of a local thunderstorm, can these disturbances be perceived faintly.

More pronounced in the given frequency region is industrial interference, particularly that due to ignition systems of automatic machines, tractors, aircraft, etc. In the decimeter and especially in the meter wave range, the level of such interference at the point of reception must be taken into account, the more so, if the reception is effected under urban conditions. For evaluating the noise level of this type of interference, experimental data are used. However, modern, high-power radio relay systems operate normally on waves of 20 cm and shorter ones, where the level of industrial interference is so insignificant, that it is usually disregarded in the planning process.

The independent noises include as the most important type for radio relay systems the set noises or inherent noises. These arise mainly at the input stages of the receivers and, to a smaller extent, in other elements of the equipment. On the radio relay lines, these noises are stored from station to station, as shown by the second basic equation of radio relay communication [eqs.(2) and (2a)].

The noises of dependent origin in multichannel radio relay systems manifest themselves for the most part as transient noises. These noises are by no means less important than the fluctuation noises. They are easily detected in each of the individual channels of the system, when useful signals pass in all or part of the other channels.

Modern (theoretical and practical) methods of analysis and calculation of smooth, independent noises in radio relay systems as well as of transient, dependent noises, are based on two fundamental theories, created by Soviet scientists: the theories of stationary random processes established by A.Ya.Khinchin and the theory of potential noiseproof feature by V.A.Kotelnikov. These theories permitted a comparative analysis of numerous radio relay systems with different kinds of modulation, from the point of view of the basic indexes of the given systems - the magnitudes of all kinds of noises. Among other papers in this field should be mentioned those by V.I.Siforov, V.A.Smirnov, S.V.Borodich, I.S.Gonorovskiy, Ya.D.Shirman, and V.I.Bunimovich. Substantial developments in the correlation method of the analysis of random processes, widely used in the analysis of distortions and noises, were created by the Soviet mathematician, V.S.Pugachev.

6. Basic Characteristics of High-Frequency Equipment of Radio Relay Systems

a) Radio Tubes and High-Frequency Equipment

Modern powerful radio relay systems occupy RF and IF band up to several tens of megacycles. The frequency deviation on the carrier may go as high as 5 - 6 mc. The actual efficiency at the transmitter output varies between a few tenths of watts to several watts.

In order to create such broad-band communication systems, corresponding electron tubes and semiconductor converters are required in the first place. At radio frequencies, for generation and amplification special triodes, klystrons, and traveling-wave tubes (TW tubes) are used.

Triodes, capable of operating on centimeter waves of the order 4 - 10 cm, are on the market. Their distinctive characteristics are the extremely small interelectrode distance and their considerable transconductance. For example, in the triode of the type 416A, the transconductance is as high as 50 ma/v, and the grid-cathode distance equals about 15 microns. At 4000 mc frequency, this tube ensures amplification up to 10 db in a band of several tens of megacycles. However, mass production of such types of triodes is difficult; therefore, there is a general trend to use traveling-wave tubes instead.

At present, TW tubes are known which operate on frequencies of several hundred to 48,000 mc. On the waves most frequently utilized for radio relay lines (5-20cm), the TW tube ensures amplification up to 20 - 30 db in a frequency band comprising up to 20% of the operating frequency. For example, at a frequency of 4000 mc, amplification in the band up to 800 mc is feasible. An output power of the TW tube from fractions of watts to tens of watts is readily ensured. The noise factor for quality tubes is smaller than 10 db, but more frequently is of the order of 15 - 20 db. The drawback of these tubes is their rather low total efficiency, due to the substantial energy consumed for magnetization. However, this drawback is eliminated in the TW tube with constant magnets.

Klystrons have found wide application in radio relay systems, mainly in the master FM exciters and as heterodynes for receivers.

As frequency converters (mixer), semiconductor diodes are generally used.

In all modern systems, the basic amplification on the relay stations of a magnitude of 90 - 100 db takes place on the intermediate frequencies. The values of the intermediate frequency recommended by the Ninth Committee of the MKKP are equal to 35, 70, and 105 mc. Known are also attempts to design relay stations with amplification on high frequencies, with application of TW tubes.

The receivers of the terminal stations are designed on the superheterodyne principle.

In order to obtain a high frequency deviation, a high-frequency exciter with subsequent frequency conversion is used.

b) Antennas and Waveguides

Amplification created by the antennas, in the majority of cases, is of the order of 25 - 40 db; with an increase in the number of channels and, consequently, of the width of the band of the system, the amplification of the antennas is increased. The antenna amplification must be such as to (jointly with the amplification in the radio set) compensate for all losses in one section of the radio relay line. The total amplification of the radio relay station will then be of the order of 120 - 140 db.

The main requirements made on antennas of radio relay systems are minimum power of the side lobes and broad-band transmission. The ratio of power in the main direction to power in the side direction should be not less than 40 db. In the more efficient antennas of today, a ratio of the order of 50 - 70 db is obtained.

Since in powerful radio relay systems, six to seven trunks are connected to the antenna array, the bands of such antennas must be up to 400 - 500 mc.

In radio relay systems, various types of antennas are used. The selection of the type of antenna depends mainly on the magnitude of the carrier frequency and on the width of the band of the communication system. For example, on waves of the meter range, in systems with relatively few channels, cophasal multi-oscillator antennas are used. The same antennas are occasionally used in the decimeter range, starting from waves approximately 30 - 40 cm and higher.

The most popular antenna types are the parabolic and the horn-lens antennas. Normally, in systems operating on waves from 15 cm and higher, more often antennas of the first type are used and, on waves of less than 10 cm, antennas of the second type.

To feed the electromagnetic oscillations from the transmitter to the antenna or from the antenna to the receiver, concentrical cables or hollow waveguides are used. The latter are generally used on centimeter waves and have an attenuation up to 40 - 50 db per kilometer. The attenuation of the concentric cable depends on the frequency and, for waves of the order of 15 - 20 cm, reaches 80 - 100 db per kilometer. A very essential problem is the elimination of reflections from the ends of the waveguides, in order to avoid nonlinear distortions in FM systems. With this aim in mind, an attempt is made to create conditions which would exclude the use of long waveguides, for example, by placing the high-frequency equipment in the immediate neighborhood of the antennas on top of the radio relay towers.

In recent times, for systems with relatively few channels, antennas are being systematically replaced by passive relays, installed on top of the towers and having the form of conventional plane reflectors. The antennas themselves are installed on the ground below, near the equipment, and narrow beams are directed on these reflectors, Although the attenuation of such a system may also be of the order of 3 - 4 db, it does not create the same large nonlinear distortions as the waveguide.

Figure 5 shows a version of a terminal office, utilizing an analogous system. In this case, a small horn antenna A_1, connected directly to the high-frequency output unit, radiates in the direction of the elliptic reflector A_2 installed on the ground below. The beam, reflected from A_2, then strikes the plane reflector A_3, installed on top of the tower.

In recent years, waveguides and antennas of a new kind are the subject of active research and it is possible that they may find application in future radio relay systems. Such waveguides include, for example, waveguides in the form of a single wire, sometimes coated with a dielectric or with a special surface finish, waveguides in the form of two parallel strips, separated by the dielectric, hollow waveguides of special design, etc.

The antennas of the new type include also the horn-parabolic antennas.

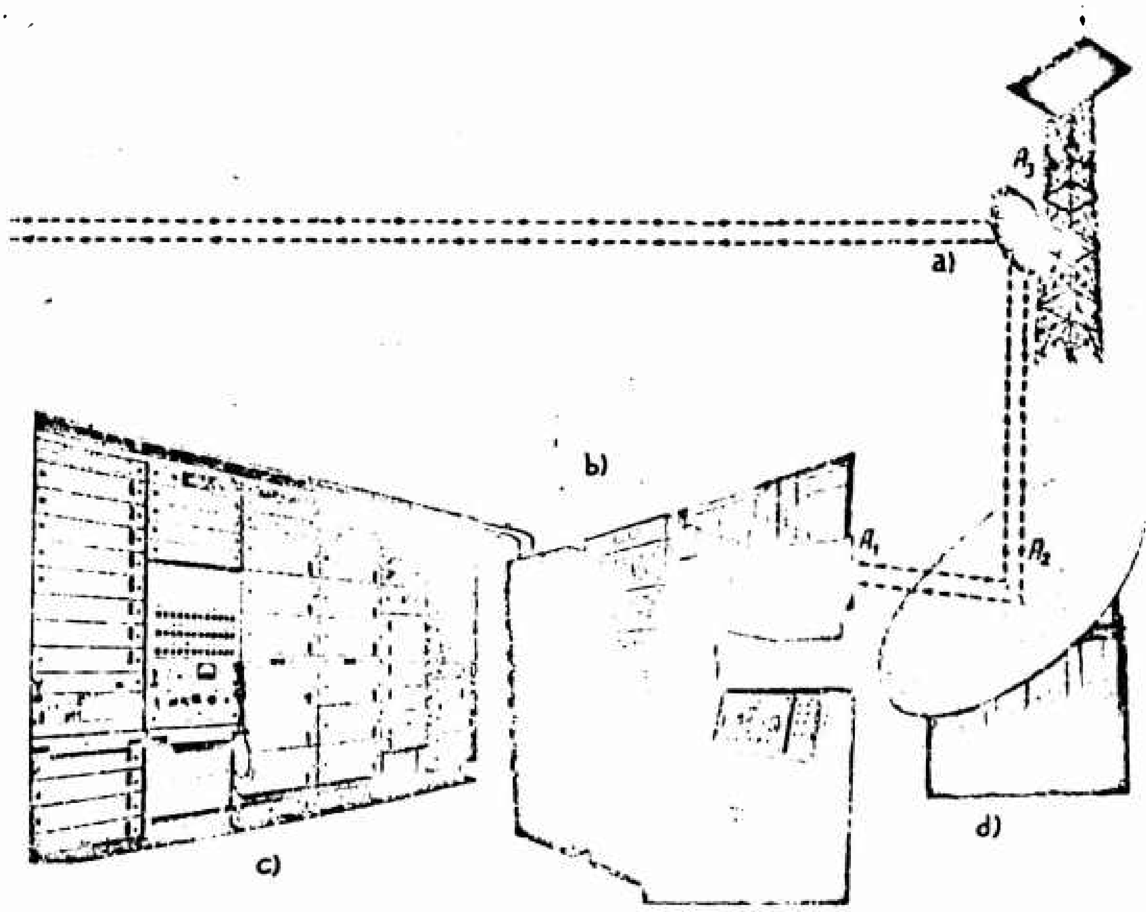

Fig.5 - Appearance of a Station with an Antenna System having a Passive Reflector on Top of the Tower

a) Plane reflector; b) High-frequency equipment; c) Multiplexing equipment; d) Elliptic reflector

c) Equipment for Service Communications, Automatic Devices, and Power Supply

Communication service along the radio relay lines is established in two ways. In high-power radio relay systems, a separate communication line is preferably used, for example, a wire running parallel to the radio relay system, or a separate cheap few-channel radio relay system operating on other waves. When using radio relay systems with relatively few channels, such a method of establishing communication service is uneconomical. In this case, communication service channels are created in the same system, by utilizing the frequency spectrum above or below the multi-channel group spectrum (in frequency division-multiplex systems) or additional time intervals (in time division-multiplex systems).

The majority of radio relay stations of modern systems belong to the nonservice category: the proportion is one service station to 4 - 6 nonservice stations. On all radio relay stations a stand-by high-frequency device is provided, which can automatically replace the operating equipment in case of failure of the latter.

In a typical power supply system for radio relay stations, the feeding is done from the AC network nearest the station. In case of a voltage drop in this network, the load is taken over immediately by a special storage battery, which is charged during normal operation of the network. If the feeding of the equipment is accomplished by alternating current with the aid of rectifiers, then the storage battery rotates a motor-generator set which creates the same AC voltage as the network. On some radio relay lines, self-starting diesels or gasoline engines are installed in each station, which go into action in case of long interruptions in network operation. However, with a reliably operating mains, the probability of its failure for a period longer than a few hours is rather remote so that a storage battery is fully sufficient.

Any kind of trouble in the nonservice stations has to be reported immediately to the staff of the service stations, by means of special signaling devices. Upon receipt of such a signal, the maintenance crew proceeds to the emergency spot, if there is the necessity for it, or other adequate measures are taken. Complicated systems are provided also with a monitoring system of the status of the nonservice equipment from the location points of the technical crew.

RADIO NAVIGATION AND RADAR

by

I.V.Brenev and Ye.Ya.Shchegolev

1. Modern Technique of Radio Navigation

The possibility, in principle, of utilizing stations of wireless telegraph for determining the location of a ship in the absence of visibility, by night or in fog, was pointed out by A.S.Popov as early as 1897. Already ten years after Popov's experiments, devices for determining the direction of radiowaves received (radio direction finders) reached a sufficiently perfected technical form. Radio direction finding as an acknowledged method of determining the location of a wireless telegraph operating station found particularly wide application after World War I. With the history of development of radio direction finding in Russia are closely linked the names of I.I.Rengarten, N.D.Papaleksi, N.N.Tsiklinskiy, D.A.Rozhanskiy, and of other physicists and engineers who were working in those years in still young field of radio.

Later numerous goniometers of the most diverse designs and functions were developed, which found wide application in pilotage as well as in aviation. This group includes airborne, naval, and ground, automatic and nonautomatic direction finders of various wave ranges, various radio landing beacons, glide path facilities ensuring the landing of aircraft, marker beacons of various kinds, etc.

At present, there are radio direction finding devices of some type on every well-equipped aircraft and on every large naval craft.

If a radio direction finder is not available on a ship, but the boat is equipped with a transceiver station, then the location of the ship can be determined with the aid of coastal DF installations. Upon request by the pilot, the ground (shore) DF stations take the bearings of the ship or aircraft and report the data obtained by radio to the pilot. Since the accuracy of taking bearings with the aid of immobile, stationary installations is substantially higher (at night in particular) than with the aid of devices on board; ships equipped with radio direction finders frequently ask the assistance of coastal points.

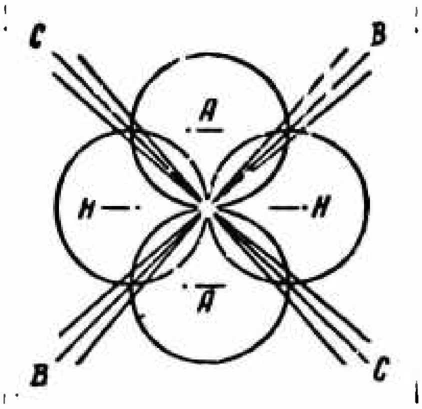

Fig.1 - Radiation Pattern of the Antenna Array of a Radio Range Beacon. Lines B-B and C-C form the axes of the zone of uniform audibility of the signal "A" and "H"

The organization of ground radio direction finding service is comparatively simple, but a large number of small craft without radio transmitters remains without service. For servicing all ships, including small ones, radio beacons with directional radiation patterns are being designed.

Radio beacons with directional action can be of two kinds: some of them are free to move in one or several completely defined directions (these are the so-called radio range beacons), others give the possibility of fixing, at any point, the direction from ship or aircraft to the radio beacon (these are known as radio beacons ensuring reception of the bearings or, as they are sometimes called, bearing projector).

Among the radio range beacons, the most widespread standard beacons are those which create a narrow zone of uniform audibility of signals, usually marks "A" and "H" (or "E" and "T") (Fig.1). The combination of various kinds of antennas in the beacon permit obtaining a different number and a different directivity of zones (courses). Radio range beacons found particularly wide application on air lanes where an airborne aircraft can successively pass from the zone of one beacon to the zone of another, serving as a continuation of the run.

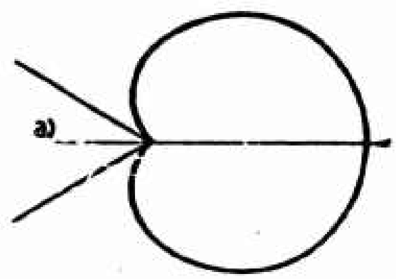

Fig.2 - Diagram of Directed Action of the Cardioid Radio Beacon with Rotating Zone
a) Zone of no reception

Quite widespread, particularly at sea, were radio beacons for reception of bearings. The radiation zone of these beacons rotates, covering within a fixed time the full periphery or sector, serviced by the beacon. The form of the radiation pattern of these beacons may differ, the simplest having the form of a cardioid (Figure 2). The change in the radiation direction is accomplished either by rotation of the antenna array itself or, in more complex installations, by rotation of the rotor of a powerful goniometer, whose field coils are connected with the antennas. In some of the newest beacons, the shifting of the radiation zone is accomplished by changing the phase difference of oscillations in the individual radiators composing the antenna array of the beacon.

The zone, serving for identification of the bearings in a cardioid radiation pattern, is the space where reception of signals is absent; in beacons giving the zone of uniform audibility of the signals "A" and "H" or "E" and "T" (rotating zone of uniform audibility).

To take bearing from ship to beacon is rather simple. At the instant when the RDF zone of the beacon is directed accurately to the north, an initial nondirective signal is emitted, which is received on board ship. The observer, on hearing this signal, places the seconds counter into operation. After some time, the observer will fix the time of passage of the RDF zone through the point of observation. Subtracting the time, by the stopwatch, which elapsed between the moment of reception of the initial signal and the passage of the RDF zone, and knowing the time of a full revolution of the ray, it is easy to determine the bearing.

The basic problem at present in designing navigation devices is to create as simple an apparatus as possible, capable of providing orientation at distances of hundreds and even thousands of kilometers. Particularly important is the maximum simplification of naval radio equipment. In this respect, are particularly worthy of mentioning the so-called sector radio beacons with phase control of the radiation pattern are of special interest. For taking bearing with the aid of such a radio beacon, the ship need be equipped only with an ordinary radio receiver, capable of receiving the sustained oscillations of a conventional radio range beacon.

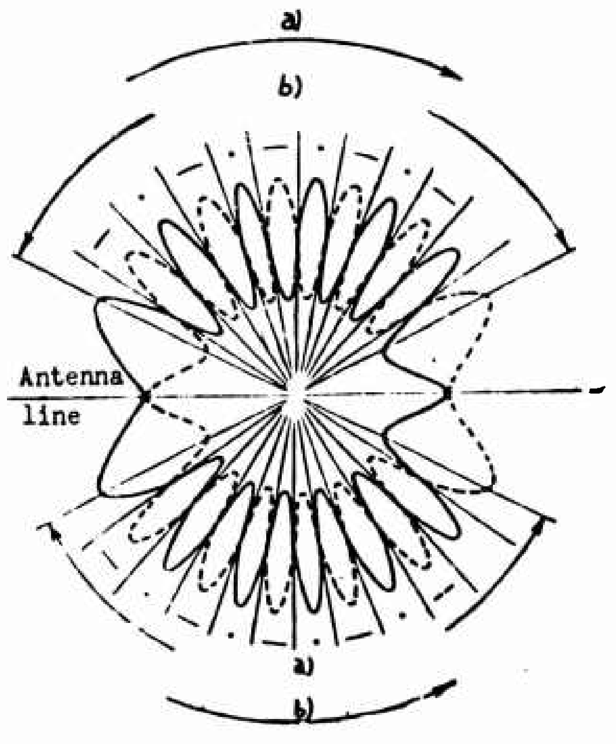

Fig.3 - Radiation Pattern of a Sector Radio Beacon

a) Direction of rotation; b) Service sector

The antenna array of these radio beacons usually consists of three vertical antennas up to 100 m height, arranged on a direct line at equal distances, with spacings of 2 - 3 wavelengths. For different beacons, the distance between the vertical antennas will, differ but the total length of the array will be of the order of 5 - 6 km. The antennas, with the aid of feeders, are fed from the common transmitter with about 1.5 - 2 kw power. Since the distance between the antennas equals several wavelengths, the radiation pattern of such a system has a multilobe character (Fig.3).

Beacons of such type usually service two areas, limited by angles of 120° each, with a bisector perpendicular to the line connecting the antennas of the beacon.

The operating cycle of the radio beacon starts with the sending of calls. After the calls, the observer hears either points or dashes, depending on the sector in which he finds himself. Later, some time after passage of the equisignal zone through the position of the observer, the audibility of this signal decreases sharply and is replaced by the audibility of another signal. The equisignal zone passes a sector in 30 sec. During this time, sixty pairs of signs are emitted.

The signals of the radio beacon follow one another at a uniform rate. These signals replace the function of the seconds counters. While recording the number of signs heard from the beginning of the cycle to the moment of their change, the operator measures the time required for shifting the equisignal zone from the initial position to the direction toward the point of observation. Under good conditions,the metering accuracy is assured up to one sign, which corresponds, for the sectors adjoining the normal, to the metering accuracy of the bearing of the order 10'. In sectors, lying at the edge of the operating area, the accuracy decreases by two times. When there is interference and at night, the accuracy drops substantially. The influence of the nocturnal effect is particularly strong at distances of 500 - 700 km from the beacon. On longer ranges, the accuracy increases again.

In order to make use of the sector beacons, the pilot must have at his disposal special charts or tables, which permit determining the position line of the ship by the number of signs. It is obvious that, in order to fix a position, it is necessary to get the correct bearings relative to two beacons at least. Since the waves propagate along the arcs of a great circle, the most suitable charts for these beacons, as also for all other radio navigation systems, are charts in gnomonic projection. On this projection, the position lines are presented as straight lines coming from the beacon.

As far as the accuracy of location is concerned, sector radio beacons not only are not inferior to the most perfected coastal radio direction finders with respect

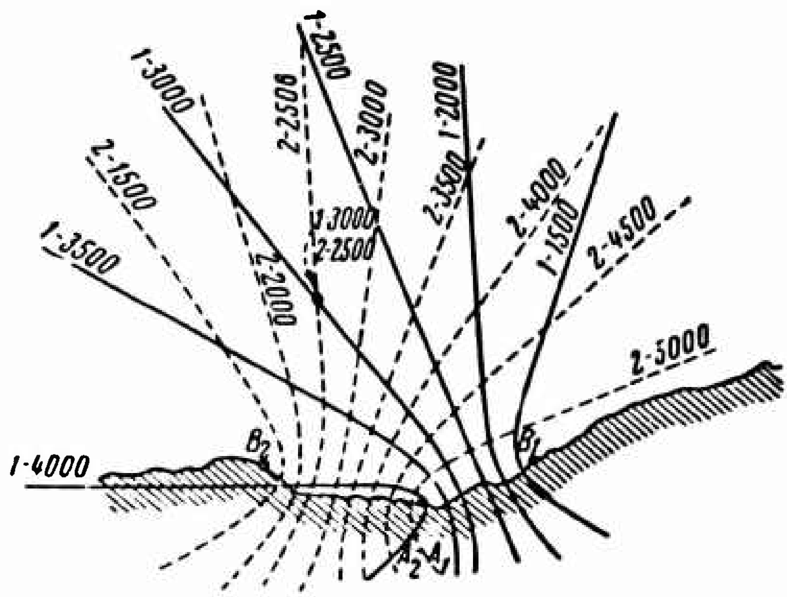

Fig. 4 - Range-Difference Measuring (Hyperbolical) System of Position Fixing by Two Position Lines (in the Diagram: Solid and Broken Lines Correspond to the Groups of Stations $A_1 - B_1$ and $A_2 - B_2$)

to detection, but even exceed these latter. Another important point is the elimination of the necessity of any kind of special shipboard radio navigation equipment. However, the described system also has noticeable drawbacks, the most important of which is the time it takes to obtain a position fix: for defining a locus by two radio beacons (with control), 3 - 5 minutes are necessary. During this period, modern aircraft may cover several tens of kilometers and high-speed aircraft even up to hundreds of kilometers.

The greatest drawback of all goniometric systems (radio beacons and radio direction finders) is the low accuracy of position fixing at large distances from the reference points of the radio beacons or DF points. Actually, at an average operational error in goniometry of $\pm 1^{\circ}$, the linear error at a distance of 600 km will, in daytime, amount to approximately ± 11 km. Here it is necessary to take into account the fact that the most widely applied RDF systems (loop DF) are so sensitive with respect to the nocturnal effect that the range of reliable radio direction finding at night is reduced to distances of the order of 50 km.

If there is a possibility not to limit the measurements of the installation (this is permissible under ground conditions) then as pointed out above, radio beacons can be erected which ensure a substantial range of action, with the simultaneous possibility of receiving linear errors within the permissible limits. There are some RDF systems in existence which, under conditions of nocturnal measurements give satisfactory accuracy, but usually these installations cannot be used on ships and aircraft because of excessive bulk and can be used only under shore conditions.

All goniometric systems permit position fixing of a locality by using as basis the solution of the triangle with two angles (obtained as a result of the measurements) and one side - a known distance between the coastal reference points. In addition, all such systems are based on some manner of using the wavefront. Incidentally, it is known that the position of the wavefront depends greatly on various factors associated with the propagation of radio waves. These factors have much less influence on the length of the path of the radio waves between transmitter and receiver. Therefore, it can be predicted that the solution of the triangle with three sides, two of which are determined by experiment while the third (base) is preset, will give more accurate results than the solution with one side and two angles. Even the replacement of one angle measurement by measuring the distance permits position fix in the polar coordinates and a substantial reduction of the area of the expected locus of the object to be fixed.

Actual experiments did not only confirm these premises but also proved the possibility of practical application, apart from the range finding and polar systems of position fixing, but also of range-difference measuring (hyperbolical) systems (Fig.4).

Fix by position lines according to the difference in azimuth between the point of observation and two difference points is, in principle, less accurate than fixing by distances. However, in view of the substantial accuracy factor of the range-finding systems, the range-difference measuring systems satisfy, as to accuracy, not only the requirements of navigation and hydrography but in many cases also the demands of aerial photography and geodesy.

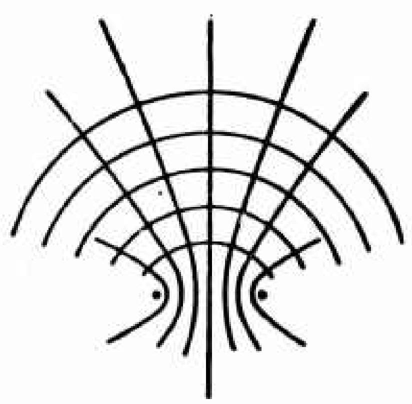

Fig.5 - Position Fixing on the Basis of a Composite (Sum-Difference) Range-Finding System

At present, range measuring methods are utilized in systems operating in the ultra-short wave range. Therefore, position fixing is ensured only for relatively small distances (within the boundaries of propagation of ultra-short waves). The methods of position fixing by the polar coordinates have found wide application in radar. These methods will be described later. The difference-range finding methods are mainly utilized for position fixing of ships or aircraft at large distances from the radio transmitter.

When using difference-range systems for obtaining two position lines, two bases are necessary, i.e., four reference stations. The number of these stations can be reduced to three, on condition of combining the extreme points of the base lines into one, but in this case, the area serviced by such a system is substantially reduced in size.

Apart from the above-described methods, there are also navigation systems, in which the position of the ship or aircraft is fixed on the basis of simultaneous measurements of the sums and differences of the distances from the wanted point to two reference points. Systems of the latter type have two basic advantages over the difference-range finding systems: first, for fixing the position, two coastal reference points are sufficient, since the sum of the distances from the point M to the reference points (i.e., the sum of the radius-vectors) gives only one position line, namely an ellipse, while the difference of these distances gives the second position line, namely a hyperbola (Fig.5). Secondly, the angle of intersection of these position lines remains in all cases the most advantageous, since the confocal ellipses and hyperbolas are always intersected at a right angle.

2. Radio Engineering Methods for Range Determination

Let us next discuss the methods applied when ranging by radio engineering methods.

The basic procedure applied in these measurements is the fixing of the time required by the radio waves for covering the distance to be measured. When measuring the range difference, the retardation of radio waves traveling over longer distances than some reference waves is determined. This explains the recent emphasis in radio engineering on the questions of time measurement. Devices for such measurements (chronometers) must have great accuracy of movement and must permit timing up to hundredths of a microsecond (10^{-8} sec). To ensure the necessary accuracy of such chronometers, modern radio engineering systems use oscillations of quartz plates, which possess a high degree of stability. Such "quartz watches", provided any harmful effect on their movements are eliminated (change in ambient temperature, atmospheric pressure, humidity, and other factors), will ensure the relative accuracy of time measurement required for radio navigation systems.

Another, not less important parameter which determines the accuracy of all radio engineering methods of position fixing, is the magnitude of the rate of propagation of radio waves, taking into account the action of all kinds of influences on it. For this reason, ever since the first radio engineering devices for measuring distances were introduced, special emphasis was placed on the question of measuring the rate of propagation of radio waves.

The first such operations, started in the USSR in 1934 under the guidance of L.I.Mandelshtam and N.D.Papaleksi, were undertaken in the wave range of 150 m up to 360 m. After the end of World War II, numerous experiments on defining the rate of propagation of radio waves were conducted by a group of authors, in ultrashort wave range.

The experiments were based on various methods, for example, direct utilization of radar stations, measurement of the wavelength in waveguides, and hollow resonators, use of the interferometer method, use of absorption spectra, etc. To sum up, it was established that the rate of propagation of radio waves in a vacuum, with accuracy to the fifth significant figure, equals 299,790 km/sec.

At present, all radio-ranging systems are divided into two large groups: the first includes devices, in which long-period (in some devices, continuous) emission of oscillations. The second group includes devices, for whose operation intermittent sending of signals (radio pulses) of a duration equal to infinitesimal fractions of a second are required.

In the systems of the first group, the timing of the retardation of one oscillation as compared with another is done by measuring the phase differences between these oscillations. The given installations are called phase-meter or (for short) phase devices. It should be mentioned that phase or phase-meter systems also include some types of radio direction finding and radio beacon systems, in which phase correlation is used for fixing the direction.

Radio navigation systems of the phase-meter type, in which the problem of position fixing is solved by ranging methods, found particularly wide application during World War II. At present, there are tens of various types of equipment in existence, operating in ranges of ultrashort waves to waves thousands of meters long.

All existing phase radio navigation systems of this type are variants of the basic systems, created in the beginning of the Thirties by L.I.Mandelshtam, N.D.Papaleksi and coworkers, I.M.Borushko, K.E.Viller, E.Ya.Shchegolev, V.I.Yuzvinskiy, and others.

Phase navigation systems, in turn, can be divided into two groups. The first group includes systems, in which the position fixing is based on a phase comparison of two coherent oscillations, whose frequencies are at a fixed, absolutely accurate, rational (in the mathematical sense) relation. The second group is composed of systems, in which the difference of the phase angles, which depends on the distance, is determined from the frequency of a single fundamental oscillation. The radiators of additional frequencies applied in systems of this group play an essential but only accessory role, and the frequency of oscillations emitted by them is not given by the fundamental oscillation. In the systems of this group, the conditions of coherence of the auxiliary oscillations need not be satisfied.

As in optics, these phase systems frequently are called radio interference systems.

The radio interferometer, in its classical form, consists of the "key" or "master" radio transmitting station and a second station playing a role equivalent to that of a mirror in the optical interferometer, of the "reflecting" or "slave" station. The basic difference between these stations lies in the fact that the frequency of oscillations emitted by the master station, is determined by corresponding standard frequencies, whereas in the slave station the role of the master oscillator is played by the frequency transformer of the oscillations received from the first station. The existence of the frequency transformer ensures an absolutely accurate frequency relation of the master and slave stations. The resultant rigid coupling of the oscillations in frequency and phase, i.e., the coherence, permits measurements of the phase difference of these oscillations at any point in the space surrounding both stations.

At constant characteristics of the system, the phase field surrounding the stations remains stable and the phase difference, measured at the point of observation, depends only on the coordinates of this point. The equipment necessary for such fixing of the phase difference of the oscillations at a certain point in space, i.e., for sounding the field at this point, is rather simple: two receivers representing simple high-frequency amplifiers, one tuned to the frequency of the master station, the other tuned to the frequency of the slave station, and a phase-meter installation. As the most simple phase-meter, a cathode-ray tube can be used, which was in fact applied in the initial devices. In newer designs of radio interference systems, special phase-meters often equipped with an attachment for automatic recording of the readings, are used for this purpose.

If such a pickup device, called phase probe, is shifted in the phase field, a change in the reading of the phase-meter will result. To be able to use the phase-meter, the isophases (lines of fixed values of phase differences) must be plotted on the chart in advance. Knowing the initial position of the ship or aircraft and observing further the change in the reading of the phase-meter, it is possible at any time to fix the position of the ship or aircraft. In the described method, the isophases which are position lines, represent hyperbolas and the system itself belongs to the category of range-difference systems.

Another variant of the radio interferometer is possible and is frequently applied, where the indicator arrangement is combined with the master station. As long as the distance between the master and slave station remains constant, the indicator readings remain constant. When the difference changes, these readings also change. In this case, it can be determined with a high degree of accuracy that the phase angle is proportional to the distance. Therefore, it is easy to determine the change in distance between the stations from the readings of the phase indicator. Analogous to the log, which indicates the distance covered by the ship, such a variant of the interferometer became known as radiolog. In difference from the ordinary log, the radiolog shows not the traveled distance, but an increase (or a decrease) of the distance between the stations. In operating principle, the radiolog is closest to the optical interferometer, and among all phase devices, generally distinguished by high accuracy, it is the most accurate. With the aid of the radiolog, in case of necessity, it is readily to measure distances above the sea or in the air up to hundreds of kilometers, with an accuracy of the order of a few tens or even single meters.

The phase probe, like the radiolog, possesses a serious operating drawback: both ground and airborne devices must operate continuously since even a short interruption in their operation may cause a loss of identification and, in any case, exert a considerable influence on the accuracy of position fixing.

There is a possibility to eliminate this drawback and create systems which permit position fixing at any time after connecting the indicator. The principle of action of all these devices, which have been used in practice, is based on changes in the structure of the phase field, surrounding the coastal reference stations, which depends on the frequency change of the applied oscillations. The first installations of this type were the radio range finders MPShch, named in honor of the inventors of these systems (Mandelshtam, Papaleksi, Shchegolev). These range finders (Fig.6) were successfully applied for position fixing of ships on the open sea, shortly after the end of the Thirties.

At present, large areas of the territory of Europe and the surrounding oceans form part of the zone of action of a few phase navigation systems which permit position fixing of aircraft or ship at any moment and at any time, immediately upon connecting the pickup on board, after its brief heating period.

It is interesting to note that in all installations in which incoherent oscillations are applied, and also in all devices without exception which permit position fixing without preliminary tying-in to a known point, a rather important role is played by the phenomenon of maintaining the differences of the phase oscillations when converting their frequency by heterodyning. This phenomenon permits at will to switch the process of measuring the phase difference into the range of low frequencies (for example, acoustic) while maintaining the accuracy of the high-frequency radio interferometers, or to change the grid scale of the position lines

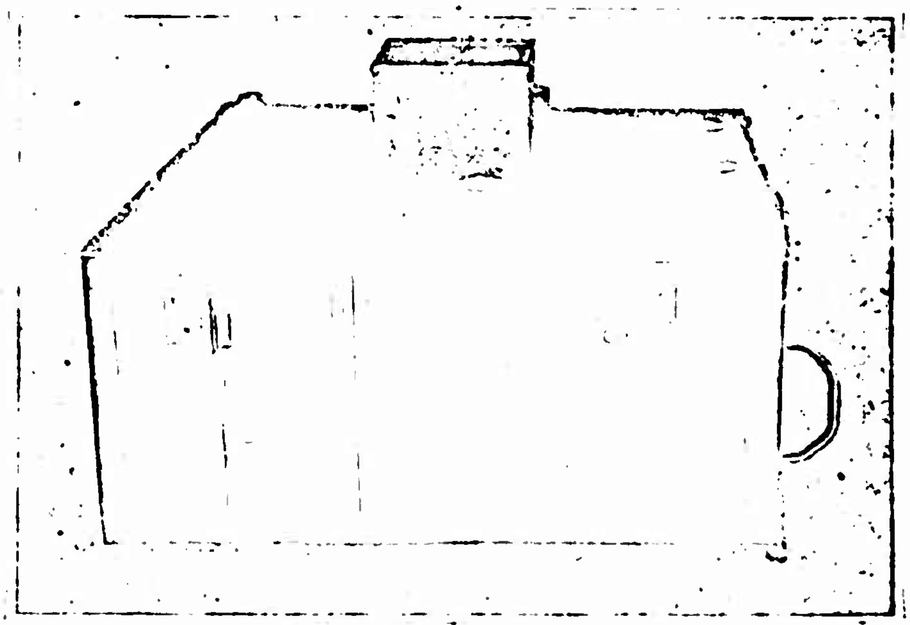

Fig.6 - Slave Station of the MPShch Radio Range Finder

into any number of times with the aim of obtaining more coarse detection. As early as 1925, at the All-Union Radio Engineering Exposition, an installation was exhibited which had been erected by the Central Radio Laboratory ETZST according to the ideas of L.I.Mandelshtam; this device demonstrated the phenomenon, discovered by him, of the preservation of the phase difference in the heterodyning process with recording of the phase difference on the telegraph tape. Some time later the same phenomenon was described in one of the foreign publications.

The process of obtaining an accurate fix by position lines by phase installations consists of successive stages (two or three), carried out automatically. Initially, the zone of detecting a ship or aircraft is delineated on the rough isophase grid, created as a result of utilizing, for example, the differential frequency in the heterodyning process. Then, the position is more accurately defined on the phase-meter operating on a higher frequency (a "path" is fixed), and, finally, in some systems, the accurate position line is found by utilizing oscillations of still higher total frequency. The numbers of zones, paths, and position lines are counted off by the pilot directly on the indicator scale.

The accuracy of position fixing with the aid of hyperbolic phase systems meets the practical requirements for distances from the control points up to 2000 km, with a transmitter power of the order of $1\frac{1}{2}$ - 2 kw and antenna towers of 100 m height. However, such accuracy can be obtained only under stable propagation conditions of radio waves by day. At night, as a result of the influence of waves reflected from the ionosphere, the phase of the received oscillations changes substantially and scatters in time. Consequently, the reading of the phase-meters become unreliable at distances on which the reflected waves have a substantial effect. The decrease of the zone of action of the phase systems at night time is the basic and practically the only important drawback of modern installations of this type.

The second group includes devices, for fixing the distance by direct measurement of the time needed by the radio wave to travel the given distance. In these systems, called pulse systems, sending of rather short signals consisting of a comparatively small number of oscillations is used. The duration of such signals (radio pulses), depending on the design of the system, has a magnitude of some tens of microseconds up to smallest fractions of a microsecond. Typical examples of pulse systems are the widespread types of radar stations and a large number of navigation range finding, difference-range finding, and sum-difference systems.

All radio navigation systems reviewed until now are characterized, as shown, by their high sensitivity to the harmful influence of the waves reflected from the ionosphere. Even in devices, specially designated for operation over large distances, the accuracy at night drops considerably. Many types of systems cannot be used at all during the night, on distances exceeding 50 - 60 km. To eliminate the influence of the reflected waves on the reading of the devices, the waves arriving at the point of reception along the surface of the earth must be separated from the waves, initially reaching the ionosphere and returning to the earth upon being reflected. Here, time selection comes to the aid.

Under any conditions and at any distances, the path of the ray traveling along the earth is always shorter than the path traveled by the reflected ray. This difference, for the maximum ranges of the order 2000 km, constitutes about 25 - 30 km; for smaller ranges, the difference is substantially higher. Thus, a signal sent by the master station will be received at the point of reception twice: once after the receiver records the arrival of the direct ray, and for the second time, when the reflected ray arrives at the receiver. The minimum interval of time between these signals amounts to 100 microseconds. If the signal has a shorter duration, for example, 40 or 50 microseconds, then the direct and reflected signals will be received separately. This circumstance, when utilizing pulse transmission, permits elimination of the harmful influence of the nocturnal effect.

The described method of elimination of the nocturnal effect can be applied not only in range systems, but also in goniometric devices. For example, if the optical method instead of the acoustic method of position fixing is used in radio direction finding and if the change in the reception power is observed on an electron oscillograph, then, at the moment of disappearance of the pulse image (received thanks to the direct ray) the correct reading will be obtained on the scale of the radio goniometer, despite the fact that the images of the reflected pulses may have a larger size and that a much louder sound may be heard on the telephone.

In the following, we will only give a brief review of the operating principle of the pulse difference-range finding system. To obtain a position line in this case as well as in all hyperbolic systems, two reference transmitting stations are necessary. One of them is the master station, the other a slave station.

The operation of the system proceeds as follows: The master station emits the radio pulse. This signal reaches the slave station after an interval of time determined by the distance between the stations. Normally, this time equals ten thousandths of a second. The pulse which had reached the slave station serves as a signal for this station to send a return pulse. The slave station always sends the signals with some lag relative to the signals of the master station. This delay is primarily caused by the necessity for the key signal to travel the distance between the stations and, secondly, by some delay in the circuit operation of the slave station. This delay must be constant and fixed for correct operation of the system, but, in size, equal to infinitesimal fractions of a second.

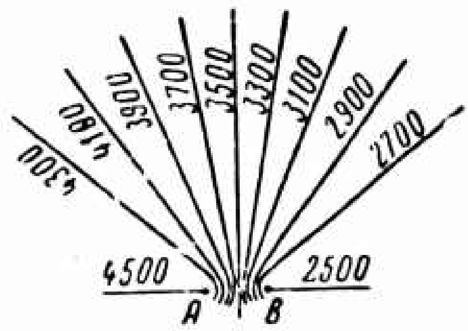

Fig.7 - Lines of Equal Delay of the Pulse for the Distance AB = 300 km

The fact that the signals are not received simultaneously by both stations, at a correct time selection of the delay in sending the pulses, readily permits determining which of the stations is nearer and which is farther from the observer. Figure 7 shows a family of hyperbolas, designed for a distance of 300 km between the stations (the time of propagation of the signal from the master station to the slave station is 1000 microsec), and with metering the time of operation of the slave station (2500 microsec). The total delay equals 3500 microsec. Near each hyperbola the time (in microseconds) between the instants of reception of the signals is entered. Evidently, the largest interval of time will be on the extension of the base line beyond the master station. In our case, this equals 4500 microsec.

To obtain a fix, the measurements by two pairs of stations must be available. These two pairs of stations can be independent or can be formed by one master station and two correspondingly located slave stations. The accuracy of position fixing depends on the accuracy of the time measurement, on the quality of operation of the ground stations, and on their location. An error of 1 microsec causes an error of 300 m in the fixing of the position line on the base line. With an increase in distance from the base line, the linear error increases considerably. Due to the extensive range of action of the support stations, the area serviced by the pulse system may be quite large. The support stations may be as far away as hundreds and even thousands of kilometers from the area of navigation or flight; however, the greater the distance, the less the accuracy.

The pulse system, operating according to the described principle, is largely free of the harmful influence of the nocturnal effect. However, obtaining a fix with this system is by far inferior in accuracy of fix to phase devices. In addition, the cost of coastal installations and board indicators of receivers is substantially higher.

Experience shows that the time measurement can be done with an accuracy equal to 1/10 - 1/20 of the duration of the received pulse. The shorter the pulses the more accurately can the position lines be determined, provided all other conditions are equal. Therefore, it is preferable to use the shortest possible waves within whose range the formation of very short pulses is admissible.

There exist pulse systems of great accuracy, which are not inferior to the phase systems with respect of accuracy but which are applied (in connection with the fact that ultrashort waves are utilized) only within the boundaries of a few tens of kilometers at sea and 200 - 250 km in aviation. For navigation purposes, a particularly high degree of accuracy is not always required, but such kind of systems find wide application in other cases, for example, in aerial photography, when a position fix of the aircraft is required at the moment of exposure with maximum accuracy. The same high accuracy is required for devices serving the needs of military aviation, for example, for solution of the problem of bombing an invisible target.

The literature contains numerous indications pointing to the rather important advantages of navigation systems which would combine the merits of both phase and pulse systems (so-called phase-pulse systems).

3. Modern Radar Methods

In navigation, along with the above-described methods, radar methods found wide application. Usually stations with circular scanning are used for this purpose. Such stations are used both in aviation and on ships of the naval and river fleets.

The essence of the method of circular scanning lies in the fact that the antenna of the radar station which gives a sufficiently narrow beam of rays in the horizontal plane, rotates continuously about an axis perpendicular to this plane, and sweeps the entire area to be observed. The signals reflected from the swept area of the earth's surface are reproduced only in that sector of the cathode-ray tube of the PPI of the radar station, which corresponds to the given direction of the antenna. Since the rotation of the antenna proceeds at high speed, while the screen of the cathode-ray tube is capable of retaining for some time the received image, the eye will perceive the picture on the screen as a whole.

Fig.8 - Image on the PPI of an Airborne Radar Station

Figure 8 shows a photograph of the screen of a cathode-ray tube of an airborne radar station. The scope shows images of islands, of the sea shore, and the water surface. The islands and the shore area are reproduced on the scope brighter than the sea surface. This is explained by the fact that the water surface acts almost as a mirror with respect to the incident rays, i.e., the rays directed toward this surface at a certain angle are reflected from it at the same angle, but to the side of the aircraft. In rough seas, the law of mirror reflection is naturally somewhat disturbed but not to such an extent that the reflection from the sea would exceed the reflection from the earth's surface. Further, if there are on the earth's surface any objects which reflect the radio waves stronger than the terrestrial envelope, they will be received on the screen in the form of still brighter light spots. Thus, individual coastal installations, railway trunk lines, bridges, etc. can be spotted by radar, in view of the fact that they possess a better reflecting quality than the reflecting background. On the same principle, radar stations can spot ships, buoys, and other objects on the water surface.

Fig.9 - Image of a Coastal Dispatcher Radar Station on the PPI

For convenience in counting off the distance on the circular scan PPI, space rings corresponding to fixed distances from the position of the radar station are created, corresponding, as a rule, to the center of the circular screen. The luminous line on the photograph in Fig.8 is the lubber line indicating the direction of flight of the aircraft or of the movement of the ship.

The scale of the images on the screen of the cathode-ray tube is variable. This allows, depending on the requirements, either to conduct scanning of a large area, resulting in small-scale images or to confine the scanning to a small area, resulting in large-scale images.

Figure 9 shows a picture from the PPI of a coastal radar station, designated for dispatcher service in the harbor. The picture shows a channel marked by buoys with two ships in succession whose images of which on the tube screen appear in the form of two traces of streamlined form.

Rather often, the circular scanning stations, used for navigation, are combined with devices permitting an adjuncture of radar images of the location with its images on the geographical maps.

The basic principle of all these devices is the reduction of scale and position of the images. This is done with the aid of some optical projection devices. However, from the point of view of design, such devices are either too complicated or not entirely satisfactory with respect to practical requirements. When designing such devices, it must be remembered that the image of the locality on the map is constant and that the chart itself is stationary, whereas the image of the same locality on the PPI varies in proportion to the movement of the ship or aircraft. This presents the basic difficulty of designing simple and well-performing compound devices.

Fig.10 - Image on the PPI of a Naval Radar Station

The described principle of circular scanning itself was developed in the years of World War II, but recently its development was extended in the direction of improving the resolving power and increasing the accuracy of reproduction of the objects scanned. This was achieved by shortening the duration of the radar signals (pulses) to values of some hundredths of a microsecond and by lessening the lengths of the waves applied. During the war, the basic range of such stations was 10-3 cm, while this range has been widened to limits including the millimeter waves.

Figure 10 shows the picture of the PPI of a circular scanning naval radar station with a high resolving power. On this photograph, the ship is at the center of the picture. Due to the high resolving power of the station as to distance (a very short pulse is used), the bow and stern of the ship can be discerned on the picture. The outline of the coast is also well defined.

A further development of the described radar method tends toward a solution of the problem of radiovision. This process is the possibility to reproduce, on the screen of the cathode-ray tube, the image of the observed object by direct utilization of the reflection effect of the radio waves without applying electro-optical converters, as is the case in modern television. Thus far, however, this is a matter for the future.

4. Practical Applications of Radar

It is obvious that the utilization of radar is far from being exhausted by its application in navigation. To be more accurate, one would have to say that utilization of radar for navigation is a rather negligible part of the multitude of its applications. Let us discuss some of these.

Radar, which came into existence shortly before World War II was intended primarily to serve the war effort. In those years, the development of aviation made great strides. The flying speeds of aircraft have increased from year to year. The old aeroacoustic methods of spotting aircraft began gradually losing importance. This very circumstance posed the problem for radio engineering to find reliable methods of spotting airplanes at large distances. The solution of this complex task by radiotechnics became a reality only in the mid-thirties, when ultrashort waves came into use, when methods of observation and recording of high-speed processes were developed (electron oscillography), and the basic principles of position fixing with the aid of radio waves and the principle of radio direction finding.

The radar development in the USSR is linked with the names of many of our researchers who, by their works in related fields of radio engineering, ensured the possibility of development and realization of the first radar stations. These researchers include M.V.Shuleykin, B.A.Vvedenskiy, M.A.Bonch-Bruyevich, A.A.Chernyshev, and many others. The creation of the first domestic models of radar stations operating on the pulse method, which subsequently were widely applied in radar, is linked with the names of Yu.B.Kobzarev, P.A.Pogorelko, and N.Ya.Chernetsov.

Rather widespread use and further development was experienced by radar during World War II. Military applications of radar, which basically became better defined during the course of the war, have grown in diversity more than anticipated. Apart from ground stations, intended for the needs of antiaircraft defense, stations were erected for spotting ships and controlling the fire of coastal batteries. Almost simultaneously, radar stations came into increasing use on airplanes and warships. Further development of radar led to the creation of special types of stations, in conformity with their various purposes. Thus, in aviation, there appeared radio bombsights (operating on the principle of circular scanning), aircraft interception stations which spot enemy aircraft in the air; fire control stations for aircraft artillery; defense radar located in the tail section which spot enemy aircraft in the rear hemisphere; radio altimeters; etc. Warships were equipped with stations for detection of air and surface targets, stations for artillery and torpedo armament of ships, navigation stations, and a number of others. The installation of airborne and ship stations, with the aircraft and ship in motion, under conditions of rolling, turning, etc., demanded the realization of special stabilization devices for the antenna arrays of these stations. Improved performance of the stations with respect to moving objects (flying aircraft, moving ships) demanded the development of methods of automatic tracking, i.e., methods where the station, having spotted a target, automatically tracks its movement. During the war, methods of radar reconnaissance were developed and widely used, i.e., methods which permitted with the aid of radar stations to establish, by means of "interrogation" and "response", whether the ships or aircraft in question belonged to friend or foe military forces.

Still during World War II, many methods of navigation and radar came into use for control of flight of the aircraft or projectile along a given course, for guiding the aircraft, projectile, or ship to a designated place with maximum accuracy. The development of radar permitted such devices as homing of missiles on the target or radio detonators which detonate the projectile not only when it strikes the target directly but also when it flies wide of the mark, at a fixed distance.

The successful utilization of radar during the war resulted in the development of a whole series of countermeasures against radar observation. This started radar reconnaissance, use of jamming stations, antiradar screens in the form of light metal foil or metallized strips (windows) scattered in the air from aircraft, various methods for simulating of targets and methods of antiradar camouflaging, which render the real targets hardly noticeable or completely invisible against the surrounding background. However, the radar countermeasures did not rob radar of its inherent valuable strategic qualities but rather forced the improvement of the technical methods of designing radar stations, bringing them up to such a state that, for every radar countermeasure, new defensive measures were developed. Modern radar in this respect is much more advanced than radar of the war years.

The rapid and successful development of radar during the last two decades and the resultant improvement in ultrashort-wave technique opened possibilities of a wider use of radar systems not only for war purposes but also in a number of other fields. Such fields where, in the recent past, the achievements of the ultrashort-wave technique and radar were utilized, include radioastronomy, radiometeorology, and radiogeodesy.

The rudiments of radioastronomy date back to the beginning of the Thirties of our century when, during studies of the nature of atmospheric interference, the existence of cosmic radio radiation on short waves ($\lambda = 14 - 17$ m) was first discovered. However, the transformation of this new branch of astronomy into a sufficiently developed scientific discipline, was realized only in the mid-forties after it had become possible to create rather sensitive receivers in the ultrashort-wave range.

At present, radioastronomy is being developed in two directions. The basis of one of these is the utilization of the method to receive the natural radiation of cosmic bodies (sun, moon, stars), the basis of the other is the application of the radar method of reflection of radio waves from the objects observed.

For the first time, radio radiation of the sun was discovered in 1944 on the 187-cm wave. Subsequently, the existence of solar radio radiation was established also on other waves, beginning with waves of 8 mm length and ending with waves of 12 m length. The exploration of the radio radiation from the sun gave the possibility to obtain a whole series of new data about it. For example, it is quite established that solar radio radiation, unlike light radio, does not possess constancy. Thus, it was established that longer (meter) waves are radiated by the lower layers of the solar atmosphere - the chromosphere - and the shorter ones (centimeter waves) by its upper, more rarefied, layers - the solar corona. Further investigations have established a direct connection between the flux of radio radiation and the area of sunspots. With the aid of radioastronomy methods, it became possible to ascertain the kinetic temperature of the corona, i.e., the temperature determined by the mean velocity of the thermal motion of the particles composing the corona. This temperature was found equal to approximately one million degrees.

At present, the radiotechnical methods of solar radiation are firmly entrenched in the operational practice of the so-called Sun Service, having the task to conduct regular observations of the sun, to develop and evaluate the results obtained, and to predict the appearance on the earth of certain effects of solar disturbances.

Extensive scientific material is obtained from radio observations of the sun during eclipses. In this connection, the USSR Academy of Sciences organized in 1947 a special expedition for carrying out such explorations during the total eclipse of the sun in Brazil. The radioastronomic observations were organized on board the

Soviet Diesel-propelled ship, the "Griboyedov", and were conducted on the 1.5 m wavelength.

Apart from the sun, radio waves are also emitted by the moon. The lunar radio radiation on the 1.25 cm wave was first detected in 1946. An analysis of the observations confirmed that the temperature of the moon changes during the transition from moon "day" to moon "night". However, these temperature fluctuations are smaller than the diurnal variation, detected earlier in studies of the infrared radiation of the moon. This led to the conclusion that the radio radiation of the moon, unlike the infrared radiation, is not created by the lunar outer envelope but in much deeper layers. The same observations confirmed the correctness of the supposition that the surface of the moon is covered with a thin layer of "cosmic dust", preserved there due to the fact that, in the absence of an atmosphere on the moon, there are no rains or winds there.

Still more interesting results of radioastronomical observations were obtained in recent years in connection with the discovery of galactic and extragalactic radiation. It was established, in particular, that radio radiation arriving at the earth from spaces in the universe, covers almost the total range of meter waves. Hidden sources of such radio radiation were detected. Until 1952, over a hundred such sources were counted. Finally, with the aid of radioastronomic methods, the boundaries of our Galaxy were penetrated. In particular, in 1950 on the 190 cm wave, radio radiation from a source lying in the direction of the cosmic fog of Andromede, located at a distance of 750,000 light years (!) from the earth, was detected.

Unfortunately, the nature of these cosmic radiations is still guesswork. It is not clear, for example, what formations in the universe serve as their sources: the interstellar ionized gas, or the comparatively dense gaseous hot bodies, capable of intense radiation in the radio range. One point seems clear and that is that radioastronomy, owing its existence to the progress in the technique of ultrashort waves, is one of the most powerful and promising tools for investigating the universe surrounding us.

Not only purely scientific interest attracts our attention to radioastronomy. The possibility of observation of radio radiation from cosmic bodies opens prospects of creating new methods for position fixing of ships or aircraft in navigation and in flight, similar to the use of existing astronomical methods for these purposes. It is true, the technical realization of this new concept is connected with considerable difficulties (reception of very weak signals, necessity of stabilization of antenna systems, development of tracking systems, accurate fixing of the coordinates of the sources of cosmic radiations, etc.). However, the first attempts to create radio sextants have already been made.

The use of radio in astronomy necessitated the development of special radio equipment. Having considerable similarity in many respects with radar devices, radioastronomical devices nevertheless differ by some characteristic features.

The necessity for detecting rather weak cosmic radio radiation demanded the development of rather complicated receiving installations. The special characteristics and difficulties of their manufacture are due to the fact that the cosmic radiations and the receiver noise have, in both cases, a very similar fluctuating structure. The separation of the weak cosmic signal from the background of receiver noise would have been impossible, without modulation of the received signal. The operating principle of such receiving installations with local modulation of the cosmic signals received (radiometers) is as follows:

The waveguide, connecting the receiving antenna with the receiver, is provided with a device which alternately passes the received energy or prevents it from reaching the receiver. In practice, this is done by placing into the waveguide a disk, one half of which passes the radio waves while the other half blocks the passage. Rotating this disk at a speed of 20 - 30 rps permits modulation of the received signal with a desired frequency. Then, this frequency is separated by means of the LF resonance amplifier and the synchronous detector, which permits to receive the incoming signal.

In the most sensitive modern radiometers, cosmic radio radiation can be detected even when their energy constitutes a magnitude approaching hundredths of the energy percentage of the receiver noise. It is interesting to note that the signals of cosmic origin thus received, judging by the absolute quantity of radiant energy striking the receiver, have a few hundred times less energy than is required for photographing stars with modern large optical telescopes.

In order to achieve directed reception of cosmic radio radiation, radiotelescopes and radio interferometers are used. Both types operate with directive antennas, usually applied in radar multidipole antennas, antenna arrays with parabolic reflectors, etc. In radiotelescopes directive antennas are used, which ensure relatively nigh angles of radiation (rarely less than 1^{o}), and, consequently, give a rather low resolving power. In order to increase the resolving power of the radio-astronomical devices, antenna systems operating on the principle of interference are used. This is achieved by using two or more antennas, spaced at distances exceeding the wavelength used. In such a case, the radiation patterns of the described antennas will have a multilobe character with the width of the lobes reaching a few minutes.

It was mentioned earlier that apart from receiving cosmic radiations, radio-astronomy makes direct use of radar methods. These methods have permitted experiments such as radar contact with the moon and meteors, and have opened the possibility of obtaining reflections from the sun and other planets.

The possibility of radar contact with the moon was theoretically proved by L.I.Mandelshtam and N.D.Papaleksi as early as 1943. In 1946, such an experiment was carried out in the USA. The basic difficulty was the necessity to increase the sensitivity of the receiver by approximately 1000 times, as compared with receivers normally used for this purpose by radar stations. In the first experiments of radar contact with the moon, the required increase of the sensitivity of the receiver was achieved by increasing the duration of the main pulse (in various installations pulses of 10 - 250 microsec were used) and by narrowing the pass band of the receiver (in various receiving devices, this fluctuated within the limits of 10 to 100 cycles). Such a narrowing of the band, however, required raising the frequency stability of the transmitter and heterodyne of the receiver to values of the order of 10^{-6}, which constituted an additional difficulty in the erection of such stations. In addition, the manifestations of the Doppler-Belopolskiy effect, due to the rotation of the earth and the moon's elliptical orbit, had to be taken into account, which led to a change in the distance between the moon and earth during the experiment. When the signal is emitted with a frequency of 100 mc, the frequency variation, due to the above effect, reaches a value of 250 c.

Nevertheless, despite these difficulties, the first and subsequent experiments were successfully carried out and proved the practical possibility of solving such a task.

Apart from the scientific value of these experiments, they contributed to the conception of new technical ideas. One of these is the utilization of the moon as a passive reflector for establishing long-distance communication on ultrashort waves. Of interest are also the prospects of utilizing radar contact with the moon for celestial position fixing of a ship at sea. However, for a practical realization of these ideas a large amount of work is still to be done.

Another example of the utilization of radar methods in astronomy is the observation of meteors.

Without discussing the first radio observations of meteors (in the years 1928 - 1930), based on the discovery of changes in the propagation of radio waves under the influence of ionospheric disturbances caused by meteor showers, we will record only the more typical examples of direct observations of meteors with the aid of radar stations. Such observations were originally conducted in 1945. Particularly interesting was the observation of a meteor shower in the night of 10 October 1946. This phenomenon was connected with the transit of the Giacobini-Tsinner comet in proximity of the earth. The phenomenon itself had been predicted by astronomers, which made it possible to prepare the radar equipment necessary for the observations. The observations were conducted in various countries, basically on 4 - 5 m waves and gave rather clear results. During the transit of the earth through the orbit of the comet (approximately three hours), the number of radio echoes increased to such an extent that there was no doubt as to the true origin of these signals.

Radar methods of studying meteor phenomena are valuable in this respect, since they permit conducting such observations not only at night but also during the day as well as under conditions of zero visibility (for example, in fog and on days of overcast). It is essential to note also that radar methods permit determining the velocity of meteors, the orbits of the meteor streams, and their other properties.

No less meaningful and diverse is the application of radar methods in radiometeorology.

During World War II, the essential influence of meteorological factors was discovered in the range of radar observation. It was established that, due to refraction in the lower layers of the atmosphere, the range of the radar stations varied substantially from large to small, other conditions being equal. The investigations showed that these aspects of radar observation depend on the characteristic of the vertical distribution of temperature, humidity, and atmospheric pressure in the lower layers of the atmosphere. Laws were established which permitted, by studying the data on the status of the weather, to determine and forecast the appearance of favorable or unfavorable conditions for operation of the radar stations. On the other hand, observations of the change in visibility of certain invariable targets, at positions fixed with respect to the radar station, opened possibilities for formulation and solution of the reverse task - determination of the meteorological parameters according to radar data which, in turn, proved useful for weather forecasts.

The possibility of obtaining reflections from various heterogeneities in the atmosphere opened new ways of applying radar in meteorology, in particular, for fixing the points of formation of hurricanes, establishment of the position and movement of atmospheric fronts, recording of lightning, creation of radar pluviographs, and for other purposes.

All these applications of radar in meteorology have practical value. For example, as soon as it is possible to fix the point of formation of a hurricane, it can be dispersed by detonations before it assumes a dangerous character. The observation of atmospheric fronts is useful for almost instantaneous forecasts (within a few hours), which became of great importance recently in aviation in connection with the terrific growth of speed of modern airplanes. The recording of lightning gives the possibility to fix the position of areas of electric activity, which is important for meteorologists and dispatchers of airports and for pilots.

Let us point to one more radar application in meteorology - the use of radar stations for observing flights of balloons equipped by the radio stations, transmitting data on temperature, pressure, and humidity in the upper layers of the atmosphere. The observation coverage of such balloons reaches distances of 50 - 65 km. If they are fitted with responder devices (similar to those used for identification), then the observation range of such balloons reaches 150 - 160 km.

For experimental fixing of the refractive index of the air, an airborne radio refractometer can be used.

This device is based on the principle of measuring the frequencies of two cavity resonators, through one of which the air to be tested is passed, while the other, hermetically sealed, serves as standard. Naturally, when utilizing this device on an aircraft, measures must be taken to compensate for the inaccuracy of measurements produced by the influence of temperature, pressure, vortexes, and flying speed.

To conclude, we will touch briefly on still another radar application - in radiogeodesy.

Many years ago, L.I.Mandelshtam and N.D.Papaleksi laid the foundation for the application of radio range methods for the production of geodetic photographs and for the carrying out of geographical work. But these methods do not permit fixing the topography of the locality. Therefore, whenever it becomes necessary, particularly when sufficiently accurate data on the topographic details of large areas are required, aerial surveying and photography was used. However, in some cases it is more practical to use radar photography for the given purpose. The advantages of the latter lie in the possibility of conducting operations at zero visibility, for example, at night or in fog, which is completely out of the question in aerial photography.

To produce radar photographs, it is necessary to use radar stations with a narrow beam, directed at an angle of 45^{o} to the horizon and rotating about a vertical axis. Such a station is capable of irradiating a circular area of the locality. The time of transit of the pulse to the earth and back, together with the data on the angle of the locus, the azimuth, and the altitude of flight, serve as reference values for determining the topography of the locality. In the described devices, the shortest waves of the radar range (about 1 cm) are used. The photographic speeds of the installations, known from the literature, reach 750 km^2/hr. The resolving power of such stations equals 45 m, which gives the possibility, when taking topographic pictures, of maintaining the distances between the horizontals at the same order. To couple the aircraft to the control points, the most accurate radio navigation systems of those described above are used.

Radar and its methods find also numerous other applications. To this category should be added applications such as radar reconnaissance of icebergs, observations of drifts and currents, devices for the blind, devices for locating defects in electrical networks, cables, etc. Further development in this field of the technique will lead to a still wider utilization of radio in various fields of human endeavor.

RELAY SYSTEMS OF BROADCASTING

by

I.A.Shamshin

1. Introduction

The broadcast receiving network in the USSR bases its development on the utilization of a wide complex of technical means and relay methods of broadcasting programs to the subscribers.

The combination of individual radio reception by radio receivers with installations relaying the broadcasting programs to the wire networks permitted a rather efficient solution of the problem of wide coverage of broadcasting to the multimillion population of the huge territory of the country and particularly its large industrial, administrative, and cultural centers.

The first installations of wire relay broadcasting appeared in the USSR. In 1925 they began to come into ever increasing use in the country. Thus, commemorating 60 years of radio in 1955, we also note the 30 year old domestic development of the system of wire relay broadcasting. Some time later, wire relay broadcasting found application in a number of countries in Europe; however, it could never reach in these countries such an advanced scale and rate of development as in the USSR, since the development of the system of wire relay broadcasting in the USSR was promoted by the socialist character and the planned development of the national economy.

The system of wire relay broadcasting (wire broadcasting, in short) is characterized by its extreme simplicity and efficiency. Its development, practically speaking, is not limited by such essential factors as the necessity to ensure everywhere power supply sources for the individual receiving installations; it is free from the effect of all kinds of disturbances, ensures in this way a high quality of transmission and solves the problem of achieving local broadcasting with a small number of radio waves utilized for this purpose.

The insignificant energy losses of broadcast transmission in wire relay broadcasting networks permits the use of extremely simple receivers for the subscribers of these networks. The centralization of technical means, requiring special sources of power supply and containing various complicated and expensive devices, simplifies the solution of the problem of guaranteeing the power supply of the system and increasing its operational stability.

A sufficiently high efficiency factor of the distribution channels permits transmitting the electric energy of audio frequencies on a high level and to apply, as receiving devices, loudspeakers without additional amplifiers, thus leading to a high efficiency of the system and, consequently, to its large-scale production.

It is known that, as distribution channels, both specially erected networks and existing telephone and electric power lines can be used. A sufficiently thorough analysis of the possibilities of using these networks for wire broadcasting, supported by extensive experimental work, was carried out in the USSR in the first years of the development of radiobroadcasting. Thus, already during 1925 - 1926 an experimental installation for broadcasting over telephone networks was erected in Moscow. Similar work was conducted in Germany and in a number of other countries in Europe, where broadcasting over telephone networks is still in partial use.

In 1930 - 1932, experiments were carried out in the USSR on using electric power lines for broadcasting. Somewhat later, similar developments took place in Japan, England, and some other countries.

Then, the possibility of channeling energy by audio frequencies as well as by modulated high frequencies was tested, efforts were made to channel modulated high frequencies on a high level, excluding the necessity of signal amplification at the point of reception; a whole series of other experimental work was carried out, which permitted selection of the most practical methods of distribution and designing systems of wire broadcasting which, under the conditions prevailing in the USSR, were systems with special networks.

The growth of wire broadcasting networks and the ever increasing demands made as to quality of the broadcasting transmissions in the first stage of its development, are closely linked with the necessity to increase everywhere the adjusting and specific power (power to the receiving installation) of the stations, feeding these networks. The increase in specific power, in turn, required a review of the system of designing networks and the formation of branch points of the station installations. Thus, the formerly applied centralized power distribution of audio-frequency transmission from one booster point (station) for the entire territory serviced by this station was replaced by a decentralized distribution within individual houses and dwellings by means of creating several small-power booster points (substations). The initial construction of booster stations and substations of small power (2 - 3 volt-amp), due to the increase of load, had to be expanded to more powerful stations and substations (200, 500, 1300, 5000, and even 60,000 and more volt-amp).

The rise in the capacitances of stations and substations and the increase in their effective radius caused a transition from the usual single-link distributing network, for which the electric energy voltage (of audio frequency) transmitted by the network, equals the excitation voltage of the loudspeakers (30 v), to the two-link network with one transformation stage (240:30 v or 120:30 v); However, even this measure did not solve the problem of channeling large capacitances, over sufficiently large distances, with high quality; as a result, since 1939, the introduction of three-link distributing networks of wire broadcasting with two transformation stages of the transmission was started in a number of large cities.

Developing gradually, large wire broadcasting networks were transformed into powerful systems equipped with all technical facilities, with extensively developed automatic mechanisms of monitoring and remote control. Wire broadcasting became an independent technical field as a result of widespread and critical utilization of technical methods, applied in a number of related fields of the communications and broadcasting techniques.

The development of relay wire broadcasting networks in the USSR was promoted by intensive development of a vast complex of questions of calculating and designing elements and equipment of wire broadcasting routes, calculation and projection of networks with specific features, sharply distinct from regular communication lines, calculation and designing of elements of automatic devices and tele-mechanics, whose wide application permitted, in its early years of development, to create rather efficient automated and remote-control systems.

Among the "first generation" of Soviet radio engineers and scientific workers, who laid the scientific and technical foundations of the wire broadcasting technique and who organized the training of qualified nuclei for this new field of technics, one must mention particularly: L.A.Meyerovich, I.P.Vaks, I.Ye.Goron, A.N.Barashkov, V.V.Furduyev, and others. As far as the organization of industrial manufacture of equipment, planning, designing, and operation of wire broadcasting systems is concerned, excellent work was done by G.S.Tsykin, A.A.Nikolaev, P.Ya.Gertsenshteyn, B.G.Pozdeyev, N.L.Bezlednov, M.S.Orlov, and others.

2. Urban Systems

In the majority of towns in the USSR with up to 50,000 inhabitants and about 8 - 10,000 subscribers, the design of mainly two-link networks of wire broadcasting is the rule. Hereby, two-link networks are erected even when their full load is not planned for the first year of construction but for subsequent years. In populated points of this type, depending on their layout, usually one or two booster stations are erected. In larger towns with a population of 250 - 300,000, both two-link and three-link networks are in use. The selection of a certain design variant for a network is usually accompanied by corresponding techno-economical calculation, carried out during exploration and planning. The networks are usually fed from several booster stations and substations, composing a single, interconnected complex of installations. For cities with a population exceeding 300,000 it is practical to apply, as experience has shown, three-link networks, where the route between the booster station or substation and the subscribers' installations is supplemented by a third link, high-voltage main feeder lines.

The system utilizing three-link circuits is accepted as fundamental for projecting and designing wire broadcasting installations in the towns of the USSR. This system ensures: increase in quality factors of the routes, increase in operational stability of the installations of wire broadcasting in towns with difficult decomposition of the power systems, operation of powerful booster substations (up to 60 kva) and transformers of substations (up to 10 kva) with remote control and monitoring and possibility of a flexible range composition of various circuits of the system elements; instant automatic reserve during failure of basic elements (booster substations, main high-voltage networks, transformer substations); supervisory control of the status of all booster devices, main and distributing feeder lines for rapid detection of trouble in the most branched-out sections of the route with a minimum of service personnel; minimum outlay for construction (the saving in cost in comparison with two-link systems is about 25 - 30%), etc.

In the process of development and introduction of the three-link system and equipment, a number of original technical solutions was accepted. These include, for example, automatic shielding devices for powerful amplification channels at a drastic change in their load; automatic limiters - compression of the transmission level while maintaining high quality indexes of the route; devices for forced air-cooling of powerful radio tubes with air filtration by automatic filters, ventilation and heating of the buildings of stations and substations; switches and devices of automatic shielding of the networks operating on audio frequencies; original devices of consolidating the monitoring, signaling, control, etc. circuits.

A simplified schematic of the transmission route of a large urban system of wire broadcasting is shown in Fig.1. The central monitoring station TsS is linked

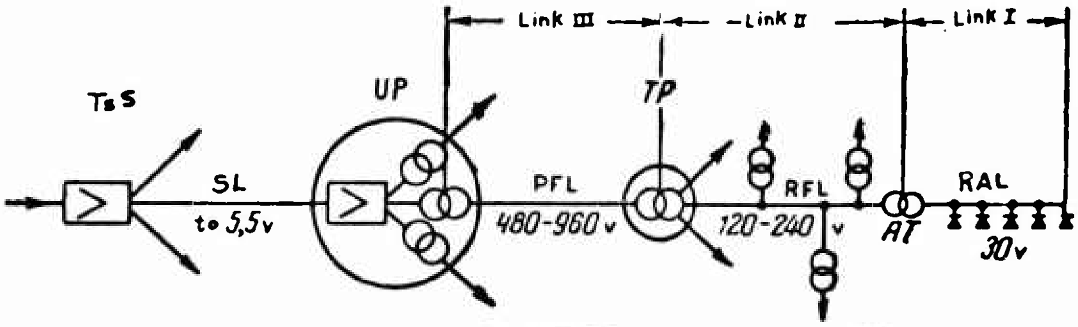

Fig.1 - Simplified Schematic of the Transmission Route of a Wire Broadcasting System

by a connecting line SL to the booster substation UP, which supplies the audio-frequency power to the transformer substation TP via the feeder lines PFL. From the substation, the energy, traveling along the distributing feeder lines RFL, arrives at the subscribers' transformers AT, feeding the distributing subscribers' lines RAL, to which the loudspeakers of the subscribers are subconnected.

The presence of a third link in the network increases the radius of action of the stations or substations, thus reducing their number in the system, increasing its operational stability, and considerably reducing the cost of designing and operating the installations. Depending on the planning of the town and its size, density of population and built-up area, the number and interconnection of booster stations and substations and also of the transformer substations may vary from 2 to 10 - 15 booster stations and from 4 - 5 to 40 - 50 and more transformer substations. In all cases the possibility is provided for interchangeability of individual station objects and feeder networks.

As experience in concrete planning has shown, the extension of the high-voltage link of the network can be shortened in some cases by supplementing the three-link relay network with feeder points FP, which permit considerable branching out of the feeder lines.

The increase in operational stability of the system is usually ensured by the use of damage localizers in its distributing links and reserve units in the feeding links. The correlation between the distributing and feeding links and the stage of

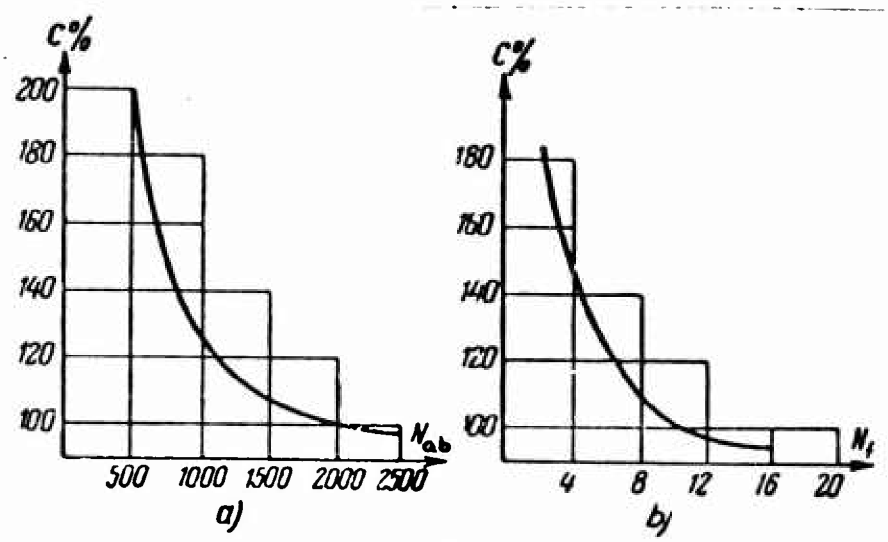

Fig.2 - Dependence of the Cost of the System on the Number of Subscribers' Sets (a) and the Number of Distributing Feeder Lines (b)

localization and reservation are determined by special requirements and capital outlay. These optimum correlations are based on a compromise between the given qualitative and economic requirements.

The dependence of the cost of the system on the number of subscribers' installations, arriving at the distributor feeder line of the distributing link, is shown in Fig.2; here the relation of cost of the entire system to the cost of the variation in which the number of subscribers' installations on the distributing feeder line equals 2000, is denoted by the letter C, and the number of subscribers' installations arriving at one feeder line, by the letter N_{ab}.

The dependence of the cost of the system on the number of distributing feeder lines, belonging to a single transformer substation of the supplying link, is plotted in Fig.2b.

Here, the cost of the entire system refers to the cost of the variation, where the transformer substation is subconnected with 10 distributing feeder lines of the distributing link, with the number of subscribers' sets on each of these lines amounting to 1500. The quantity of distributing feeder lines subconnected to the transformer substation is equal to N_r.

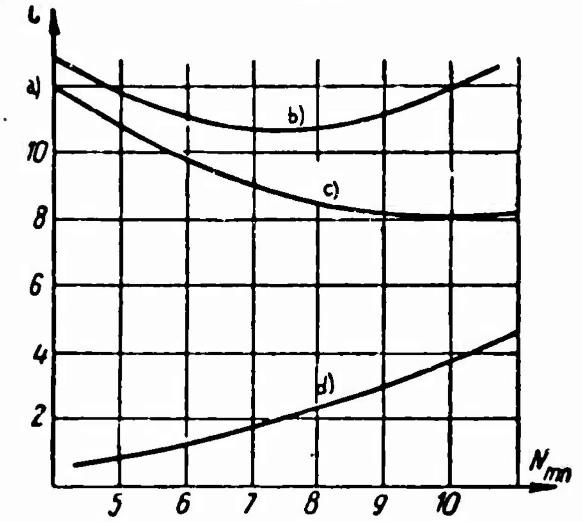

Fig.3 - Dependence of the Cost of the System on the Number of Transformer Substations

a) Conventional unit; b) Total cost;
c) Cost of stations and substations;
d) Cost of supplying network

Figures 2 a and b indicate that an increase in the number of subscribers' sets subconnected to the distributing feeder line, to more than 1700 - 2000 makes the system somewhat cheaper but simultaneously sharply decreases its operational stability. An increase in the number of distributing feeder lines, subconnected to the transformer substation, to more than 10, leads to an insignificant reduction in the cost of the system but to a complication of the network topology and the consequent unavoidable increase in the parallel spacing of the feeder line circuits, i.e., to an uneven load.

The dependence of the cost of the system on the number of transformer substations of the supplying link, subconnected to one booster substation, is shown in Fig.3. Here the cost of the system is given in conventional units, and the number of transformer substations alloted to one booster substation, equals N_{mn}.

Figure 3 shows that, with a growing number of transformer substations subconnected to one booster substation, the cost of the high-voltage supply network grows proportionally with the extent of the latter. However, simultaneously the cost of the station installations decreases, due to an increase in the capacitance of the booster substations and a decrease of their number in the system.

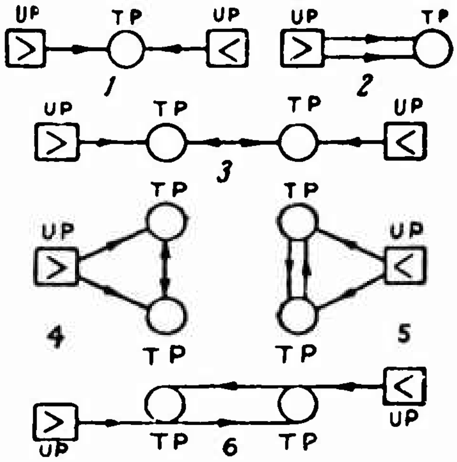

Fig.4 - Variations of Supply of Sound Transformer Substations

The total cost of all the installations has a certain optimum. The graphs shown in Figs.2 a, b, and 3 are the result of techno-economic calculation, carried out for one of the large cities; these graphs have a rather conventional character and are used for illustrating the methods of the techno-economic investigations.

It should be mentioned that, in some cases, on the outskirts of large cities and also in towns with low buildings and less densely built-up areas, the realization of the optimum correlations, obtained by calculations, is limited by the admissible fading and frequency distortions in the distributing feeder lines. In this case, the size of the distributing bunch TP may be slightly different from the calculated one. The same may occur in the center of a town, where the establishment of the optimum size of the bunch is hindered by natural boundaries (canals, main streets).

Since the system of power supply to towns, as a rule, imposes certain limitations as to the selection of a location for the booster substations, in the overwhelming majority of cases the possibility of direct link-up to the booster substation of the distributing bunch is excluded.

Apart from this, in a system where trouble occurs in the elements of pcwer supply of the booster substation or where its connection with the central station is impaired, the transmission would stop in the whole bunch of the distributing link.

Sufficient operational stability is achieved by subconnecting the distributing bunch to two sources of transmission. Such sources can be either direct booster substations or sources supplying high-voltage feeder lines.

Figure 4 shows possible variations of feeding the audio-transformer substations TP. Sufficient operational stability of the system, when utilizing the variants 2, 4, and 5, is possible only when using feeder lines of two-way supply, interconnecting the booster substations ("feeders of power exchange"). However, in this case, the system becomes complicated and, at a substantial power, it becomes necessary to apply high voltages to the power exchange feeders, which can be achieved only by the use of cable lines. The greatest operational stability is shown by circuits designed in the variants 1, 3, 6. In connection with the necessity of automatic change-over of the supply of the transformer substation from basic to standby, the systems 3 and 6, which have no permanent break point of the standby ring, even in the presence of two step-down substations in the supply ring, a highly complicated automatic monitoring system is required. The best system is the subconnection of the transformer substation to two different booster substations and the connection of supply feeder lines into the one-way supply system, as is shown in the variant 1. This variant finds application everywhere.

It is also practical, for supply standby of transformer substations on the outskirts of towns and some other special situations, to introduce a block substation BP into the system booster substations, which operates only when standby operation is required.

The basic diagram of the urban wire broadcasting system, described in general outline, accurately determines the links, in which localization of defects and standby must be applied. The requirement of high operational stability of the system necessitates extensive use of automatic devices for localizing damage. As trouble finders, together with safety fuses, automatic limiters of the changes of full load resistances, are used. In particular, in the distributing and supplying feeder lines, special relays are utilized, operating from the transformed energy of the broadcast transmission; in the subscribers' network, limiting inductive resistances of the house transformers and active limiters are used.

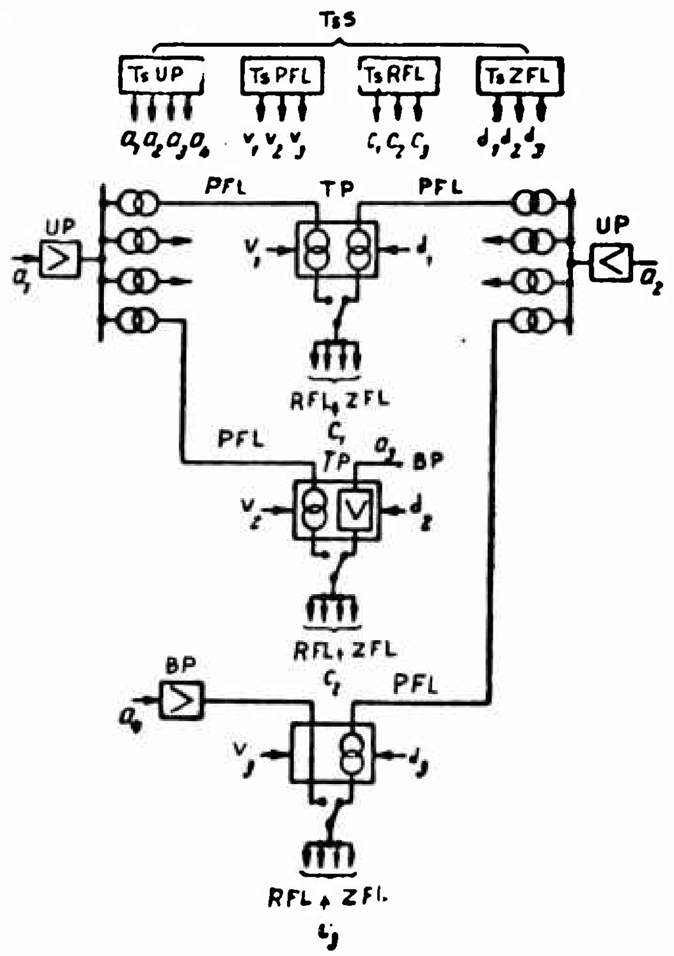

Fig.5 - Example of a Basic Diagram of Monitoring of Elements of the System

The accepted system of standby (two independent supply sources) governs the technical demands as to the standby equipment. In particular, there is no necessity in a number of cases for reserve amplifiers and other elements on the booster substation. The basic standby device is an automatic switch on the transformer substation.

The operation of modern large wire broadcasting systems, which presents a difficult complex of technical facilities, is impossible without extensive automation and centralized dispatcher control. This fact was responsible for the wide application of monitoring and control devices as well as systems of automatic control and safety.

The devices of monitoring control ensure: acknowledgment signals for operation of remote-control elements, automatic signalization as to status and coordination of the individual parts of the system, telemetering and remote control of the quality of transmission. As channels of telecontrol and monitoring, and also for supplying the programs to the station points in urban wire broadcasting systems, pairs of telephone cables of the city telephone networks are used.

The monitoring and control elements of the system are usually divided according to their functional principle. Operators' positions are in existence for supervising the booster substations, for supervising the high-voltage supply network and TP, for control of the distributing feeder lines, and for supervision of the network of the public address system. The questions of territorial layout and quantitative breakdown of these operators' positions are solved individually for each town. For example, for medium-size towns, all the operators' positions can be placed in the same building; for very large cities, with multi-office line service, the switchboard monitoring positions of the distributing feeder lines can be organized in each zonal line-technical center, whereas the control of the booster substations and the high-voltage network is centralized. The supervision of street loudspeaker systems, independent on the size of the wire broadcasting system can be effected from the central station of wire broadcasting or from another point, upon request of town organizations, etc.

Figure 5 shows an example of a basic diagram of supervision of the individual elements of the system. In the central station TsS are concentrated all the control devices of the booster substations TsUP; the control devices for the supply feeder lines TsPFL and TP, the control devices for the distributing feeder lines TsRFL, as well as the installations serving for control and supervision of the distributing feeder lines of the street public address system TsZFL.

Figure 6 shows the master diagram of a toll-switching layout for station installations of the wire broadcasting of a city.

Stable supply sources in the central station and booster substations are usually obtained without difficulties, whereas stable sources for the local supply of the automatic devices and telecontrol in all the other links of the system are extremely difficult to obtain and are expensive. In connection with this, the power supply for all important elements of the telecontrol system is obtained by electric energy

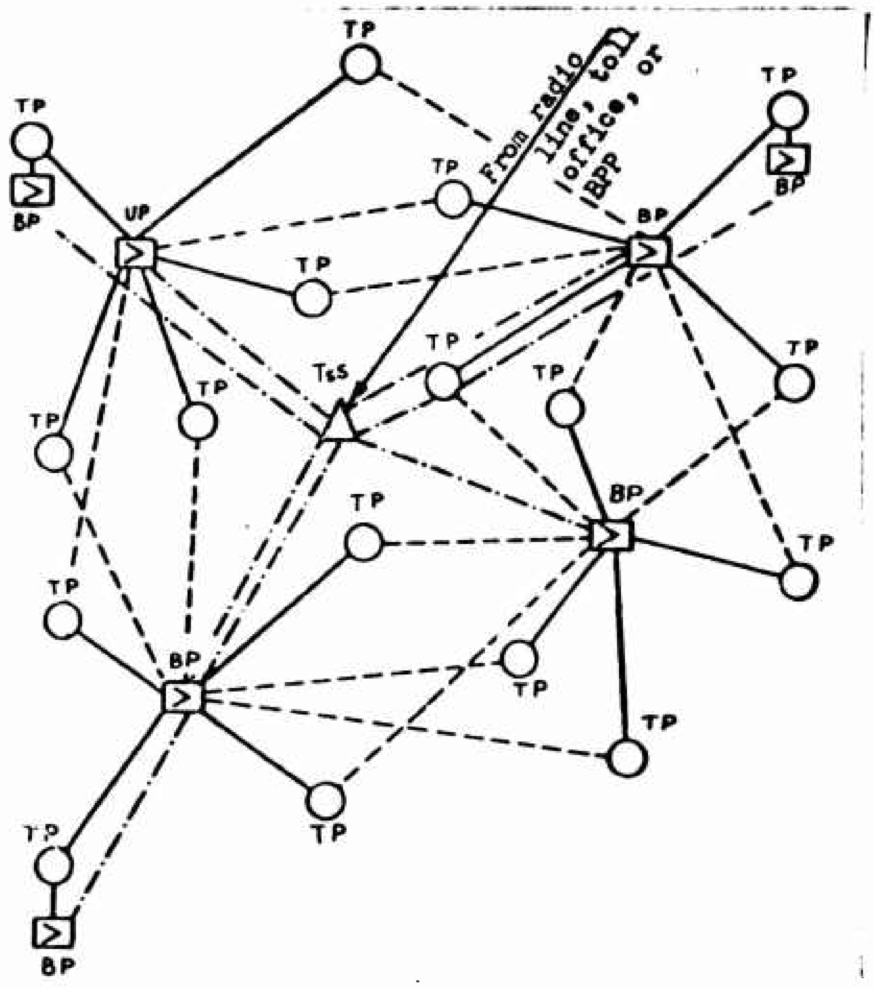

Fig.6 - Master Diagram of Toll-Switching Planning of Station Installations of Urban Wire Broadcasting

transported from the central station and booster substations along special channels. These channels are located within the broadcasting circuits and connecting lines.

The highly developed automation of supervision and telecontrol permit maintaining the operation of the system with minimum service personnel, which represents a substantial saving.

The basic complex of the apparatus and equipment for urban wire broadcasting systems, manufactured by the industry, permits both two-link and three-link systems.

For small and medium towns, equipment sets for booster stations of the type TY-600, TY-5, CBK, STP, and CTR find application. More powerful amplifier and switching equipment for the largest town centers is produced in smaller numbers. Thus, the

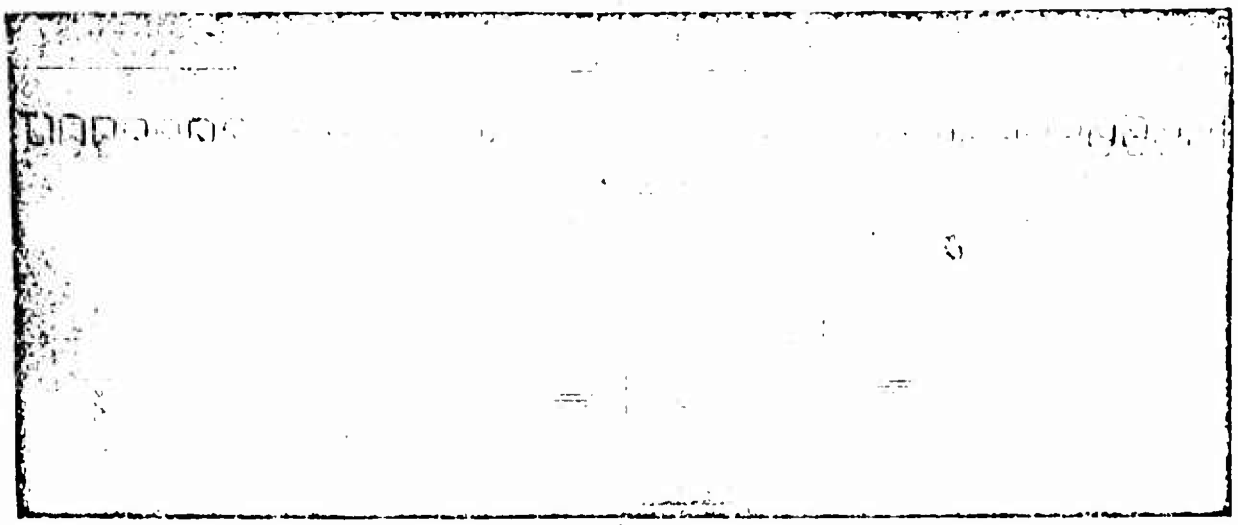

Fig.7 - General Aspects of the Sets of Typical Apparatus of a Remote Control 60-Kilowatt Booster Substation

administration of the Moscow town radio relay network manufactures equipment sets and apparatus for remote-controlled 60-kilowatt booster substations. The manufacture of equipment components for remote control, control, and metering for the central stations of the large wire broadcasting systems, is arranged along similar lines.

The general aspects of the sets of typical apparatus and equipment of a remote-control 60-kilowatt booster substation of wire broadcasting is shown in Fig.7.

3. Rural Systems

The rural wire broadcasting network is designed either on the centralized or the decentralized principle. The centralized system is based on a relatively powerful radio center, supplying the far-flung networks which serve a large number of populated places. A typical example of such a system is the "raion" or district central office, which, with the aid of several lines of considerable extension, supplies the entire zone or part of it. In large administrative areas, several centers may be installed. One is usually located in the district central office itself and covers the adjoining populated points, while the others are located in large settlements (primarily kept running by continuously-operating electric power sources) which represent geographical as well as administrative centers of separate parts of the zone. The decentralized system is based on small radio centers or receiver-booster installations, each of which serves from one to three small populated points of the given zone.

A technico-economical analysis shows that the centralized system should be primarily used for coverage of small rural populated points, located within a radius of 15 - 20 km from the station of the radio center and gravitating toward the district central office or a larger town of a more extensive area.

The decentralized system may be used efficiently in cases where the broadcast coverage of populated rural points by the centralized system is technically impossible or impractical from the economical view point, in particular, at distances from the stations of the radio center exceeding 15 - 20 km and at a low number of subscribers' sets per 1 km length of the line.

In each individual case, the limits and scope of application of a given system are determined by investigation; however, in areas with a large density of population and small distances between the populated points, preference is usually given to the centralized system. The use of this system is particularly effective in the presence of continuously-operating electric-power sources at the point of installation of the station.

The centralized system simplifies the transmission of programs and the realization of local broadcasting on the scale of the administrative area. In the case of undeveloped electrification, this system is more stable from the operational viewpoint than the decentralized system and, apart from that, requires a smaller technical staff for its servicing.

In recent years, a combination system has been used, where the drawbacks of the decentralization of station equipment are partly eliminated by automated supervision. The combination system provides for the development, along with relatively powerful stations, of small-power remote-controlled substations, similar to the system used in towns. Primarily, this system is introduced in districts with highly developed inter-area telephone networks where the utilization of the circuits of the latter permits establishing the required automation (telecontrol) and the transmission of the broadcast programs to the booster substations.

In this case, local broadcasting becomes accessible for even smaller administrative and agricultural sections of the area (rural soviet, kholkhoz, sovkhoz).

The combination system with rural booster substations is sufficiently effective, whenever the substations are located in populated points having constantly operating electric power sources or when there is the possibility of supplying electric power to the substations via the artificial circuits of telephone communication. As shown by experiment, such a method of power supply for small-power equipment yields positive results.

The degree of decentralization of station installations cannot have a well-defined solution for all of the various rural areas. However, in the majority of cases, the decentralization is usually limited by the size of the kholkhoz. When the kholkhoz unites populated points spaced at considerable distances, the scale of decentralization increases. In the opposite case, in areas with considerable density of population and closely spaced populated points of various kholkhozes, inter-kholkhoz radio centers are used. The construction of inter-kholkhoz centers has a considerable economical influence and ensures the creation of stable and high-quality rural broadcasting systems.

All above methods of designing rural radio relay broadcasting systems are applied in the USSR along with the advanced introduction of reception in individual receivers which came into particularly increasing use in electrified localities.

In rural radio relay broadcasting systems, lines of various types are utilized: local aerial lines, mainly pole supports (in large rural populated points, lightened strut supports), zonal telephone poles, low-voltage power-line poles, and as an experiment - high-voltage lines, ground cable lines, made of cables with nonmetal (polyvinyl chloride) sheaths.

It should be mentioned that in all cases of transmission of broadcasting programs to subscribers only special circuits are used and their combination with the circuits of other services is attempted only on master supports. Thus, suspension of broadcasting wires from the supports of low-voltage power lines and also from local telephone poles is widely applied at present and is regulated by special rules and norms.

In connection with the great progress made in the construction in rural localities of branched electric network, the use of its poles for wire broadcasting presents great economic advantages. The considerable telephone effect permits also the use of the poles of the zonal telephone communication system. Therefore, the designing of low-voltage electric transmission lines, communication lines, and wire broadcasting already takes into consideration the joint utilization of their poles.

For the transmission of broadcasting programs to the stations and substations, joint utilization of the electric circuits is achieved with the aid of different frequency spectra (condensation of the circuits). Multiplexing of the communication lines and, partially as an experiment, of the electric power lines is widely used for the purposes of wire broadcasting.

Of great importance is also the reverse task: the development of multiplexing means of the broadcasting circuits by communication channels. With the existing branched wire broadcasting network and its planned substantial development, this measure would open considerable additional possibilities for the organization of the local inter-production communications in toll offices, kholkhozes, and sovkhozes.

The utilization of the electric power circuits for sending broadcasting programs of high frequency and at a high level, directly to the subscribers, is economically not recommended, as proved by the following considerations:

Placing high-frequency amplifier devices alongside high voltage requires substantial power of these devices. Arranging detector-amplifier devices alongside low voltage requires a large number of these. In case of relaying low-level high-frequency programs to the subscriber, the latter must have special receiving equipment; use of such equipment in an electrified locality cannot compete with conventional radio reception, whereas in localities without electrification, such special installations are completely ineconomical.

For all broadcasting systems in rural localities the question of continuously operating power sources is of tremendous importance. This question, in conjunction with a number of other local factors, basically determines the limits and scope of application of a given broadcasting system.

By determining the municipal expenditure for the entire equipment complex of the reviewed systems (stations and networks), composed of the amortized cost of the installations and the cost of their operation, all other conditions being equal, an adequate economic comparison can be made. In this case, the total outlay for the network depends on the radius of action of the network and its extension, based on one populated point covered by broadcasting (load density per 1 km of the line). In turn, the total expenditure for the station depends on the load of this station, i.e., on the utilization of its installation power.

The economic advantages of a given system depend largely on the size of the serviced populated points (number of yards or courts). Thus, when the number of yards (low density) is small, the advantages of a decentralized system are reduced even for cases in which the populated points are widely scattered.

On the whole, the limits of efficient use of a given system can be determined on the basis of technico-economic calculations, based on local cost data, available technical means, and the geographic features of the locality.

Figure 8 gives the results of such calculations, applied to the local conditions of one of the objects, relative to the erection of radio communication facilities. Despite the fact that these calculations have, to a certain extent, a conventional character, they are nevertheless suitable for illustrating the procedure and analysis of the question. In the diagram, the length of the feeder line ℓ, referring to one populated point, is laid off on the abscissa, while the relation between the yearly cost per subscriber installation n in the centralized and the decentralized systems is plotted on the ordinate. The diagrams are designed for populated points with 50 yards, with full broadcasting coverage and for a 50 and 100% station load, as well as for the case where no continuously operating power sources are available in the populated point to be equipped with radio facilities, but where such sources are available at the point of location of the station (in the centralized system).

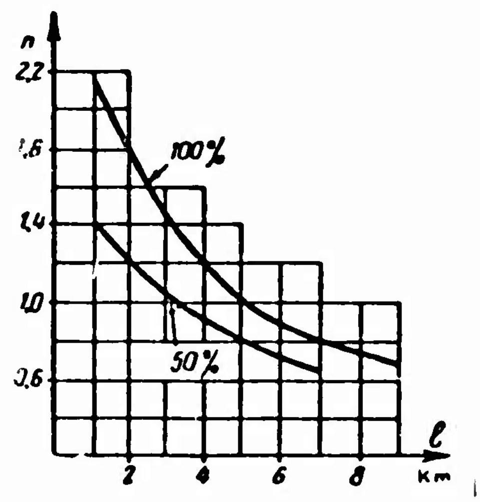

Fig.8 - Technico-Economic Calculations of the Usefulness of Various Rural Wire Broadcasting Systems

The segments of the curves lying in the area where n > 1 show the advantages of the centralized system, and those lying in the area where n < 1 show the advantages of the decentralized system.

In those rural populated points where, in conformity with the data of the findings and planning, the erection of a low-power local radio center has been authorized, the use of a single-link network is permissible (with the operating voltage equal to the excitation voltage of the loudspeakers). If the center is to service also one or more neighboring populated points, a two-link network is utilized. In a number of cases three-link networks are used in the larger rural systems. Servicing of a given district or of a considerable portion of it by one

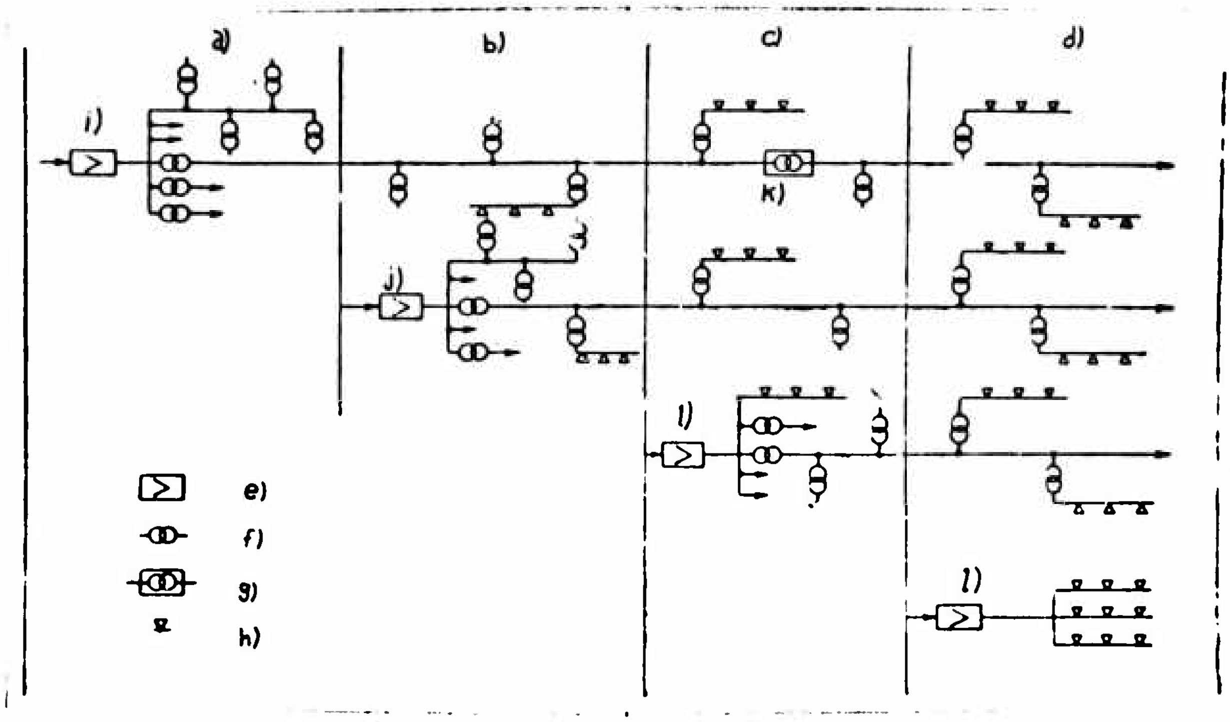

Fig.9 - Diagrams of Designing Wire Broadcasting Networks in Rural Localities

a) Radio center; b) Rural soviet; c) Large populated point; d) Small populated point; e) Station or substation; f) Feeder or subscriber's radio; g) Correction; h) Loudspeaker; i) From toll office; j) Through "raion" telephone office; k) Corrector; l) Through "raion" office or radio

powerful station is usually achieved with the aid of two independent networks - one for the district central office itself (network of urban type) and another for the hookup with the central office of rural populated points (network of the rural type).

Possible diagrams for designing wire broadcasting networks in rural localities are shown in Fig.9.

As far as the rural broadcasting systems are concerned, a very important requirement is the securing of high-quality transmission of the broadcasting programs to the stations and substations. For the given purpose, wherever possible, the lines of the intercity or interzone telephone system are used, by selecting special circuits or channels of high-frequency condensation for broadcasting. However, frequently, because of the little advanced electrification of the intercity and interzone communication system of the district, meeting this requirement is connected with rather high material expenditures and proves generally not feasible. In such cases, the broadcasting programs are transmitted to the stations over the radio on long, medium, and occasionally (when very urgent) on short waves. The high quality of the program transmission at relatively small material outlays is due to the use of meter waves.

Thus, in rural broadcasting systems, the complex of methods of program transmission is put into practical use. The scope of application of a given method is dictated by local conditions, special requirements, and economic expediency.

In view of the fact that not all rural districts have at their disposal continuously operating power sources, a very essential, if not basic question is that of the selection of local power sources. Above, when discussing the economic expediency of using centralized and decentralized broadcasting systems, the extent of the influence of the electrification factor on the economic indexes of the systems was demonstrated. The vigorous progress in electrification, together with the wide utilization of various local power sources substantially simplifies the solution of the problem of continuous electrification of the rural localities in the USSR.

As local power sources various technical facilities are used: galvanic elements, batteries, charged by generators (the generators are put into operation by liquid-fuel internal combustion engines, wind-driven generators and/or hydraulic motors and gas-generator engines). Recently, thermogenerators came into use. The list of equipment of local power sources comprises a large range of power and thus permits supply of the rural stations and substations of the broadcasting centers, both in the centralized and decentralized systems.

The powerful stations of the centers, requiring relatively powerful current sources, are usually supplied by local power stations, using internal combustion engines. The stations of small-power centers are supplied by power stations using wind-driven generators and low-power internal combustion engines. Receiver-amplifier systems as well as radio receivers are supplied by galvanic elements, in individual cases by batteries with wind generators and, experimentally, by thermogenerators.

The tremendous undertaking to establish radio facilities in the rural areas makes the problem of automation of the rural broadcasting systems particularly acute. In this connection, extensive work is being done in the last few years to create the technical means of automation; automated systems are being erected, which, in view of the intensive combination of servicing the communication and broadcasting facilities, have a large overall influence and contribute to successful erection of radio communication facilities all over the country within the next few years.

Remote control of the rural substations of the broadcasting centers is realized on artificial lines of the "raion" communication service (BPC), using the connecting and subscribers' circuits BPC. The equipment designed for this purpose permits range control of the typical sets of the radio center equipment (TUB-100, MGSRTU-100, TU-600, and others). The remote-control equipment can be connected to the BPC circuits with a resistance of the two-wire circuit up to 2000 ohms and an insulation resistance of each wire to ground exceeding 20,000 ohms, which ensures operation of this equipment on the 3-mm steel aerial circuits BPC with an extension up to 40 - 50 km and, on cable PRVPM circuits with a core diameter of 1.2 mm, with an extension of 50 km.

Simultaneously with the solution of the problem of remote control by rural broadcasting installations, the question of transmission of broadcasting programs to the stations has been successfully solved.

The apparatus designed for this purpose ensures the possibility of overlapping the fading of the BPC circuit at 5 nepers at a minimum signal level of 3 nepers, which, in turn, ensures the operation range of the equipment without intermediate amplifiers: for 4-mm steel circuits - up to 30 km, for 3-mm steel circuits - up to 25 km and for 1.2 mm PRVPM cable - up to 10 km.

In recent years, broadcasting technicians have introduced new methods of designing and operating rural radio stations and networks. For small kholkhoz centers, equipment with universal supply - KPY-2 and KPY-10 is being produced and for radio relay centers of the zones, central offices, and inter-kholkhoz centers - TY-600 equipment, wind-driven electric units, centers with remote feeding RDP-51, economic loudspeakers of various types. Joint suspension on the same supports of the broadcasting circuits and toll office poles found wide application; cables with nonmetal sheaths were introduced, their laying was mechanized, and efficient methods were developed for tying and repairing these cables.

4. Multiprogram Systems

The relay wire broadcasting systems created in the USSR are single-program systems. In the field of creating multiprogram systems, exploratory work has been started in the USSR.

Multiprogram broadcasting, as is known, can be accomplished:

1) Over special cable networks - transmission to each subscriber on a cable with a number of pairs equal to the number of programs, or over intermediate automatic stations, enabling the subscriber to select a program from the limited number of pairs, using a device of remote dialing;

2) Over conventional two-wire circuits - by multiplexing in the 60 - 250 kc spectrum, transmission of programs on a low level and their subsequent amplification at the subscriber (transmission on a high level is excluded because of power considerations);

3) Over telephone networks - by multiplexing in the 60 - 300 kc spectrum as well as by utilizing automation equipment. In the latter case, a pair of telephone cable can be used either for telephone calls or for broadcasting. In either case, the transmission must be done on a low level;

4) Over light networks - by multiplexing in the above frequency spectrum and transmission of the broadcasting programs on a low level. Transmission on a high level is excluded.

Cable systems are complicated, bulky in metal requirement and high in cost; their mass use is ineconomical so that they can find application only for individual objectives. All other versions cannot be used for channeling energy on a high level, which eliminates the basic advantage of wire broadcasting: simplicity and low cost. Low-level high-frequency systems can be used in combination with a radio receiving network, as a means of perfecting the quality of radio broadcasting.

These variants cannot always compete with conventional radio broadcasting, particularly, with broadcasting on ultrashort waves.

The extensive development of the semiconductor technique opens new possibilities for the solution of the problem of multiprograms over wire broadcasting systems.

HIGH-FREQUENCY COMMUNICATION ON WIRES

by

B.C.Anosovich

During the postwar years, a large amount of work was done in the USSR on restoration and further development of electric communication means.

As a result of the fruitful works of Soviet scientists, engineers and technicians, a vast network of nation-wide and trunk telephone lines was created in the USSR. Outside plants and office facilities of the intercity telephone network now permit communications inside the country between points spaced at more than 10,000 km, i.e., practically between any points of the intercity telephone system in the USSR and also communications with any other country whose lines are hooked up with the international telephone network.

A characteristic feature of the technique of long-distance wire communication is the wide use of multiple telephoning and telegraphing on cable and aerial circuits, with application of electron tubes and semiconductor elements. This creates a large pool of passive and active, linear and nonlinear quadripoles and other elements of the high-frequency telephone system on the one hand and the radio communication and radiobroadcasting systems on the other.

In view of this, the development of the technique of telecommunication at the present time is linked in many respects to the technical progress in all fields of radio engineering. Therefore, it can be stated the name of our great compatriot, the inventor of radio, Aleksandr Stepanovich Popov, is closely connected with the birth and development of another, exceptionally important, field of communications technique - high-frequency telephony on wires.

The basic task of the technique of telecommunication is the achievement, in the most economical way, of the required telephony range with simultaneous stable electrical characteristics of the communication channels, to ensure good quality. This problem is solved by applying corresponding communication systems and by using repeaters for compensating for the fading of circuits. At present, four-wire and two-wire communication systems find wide application.

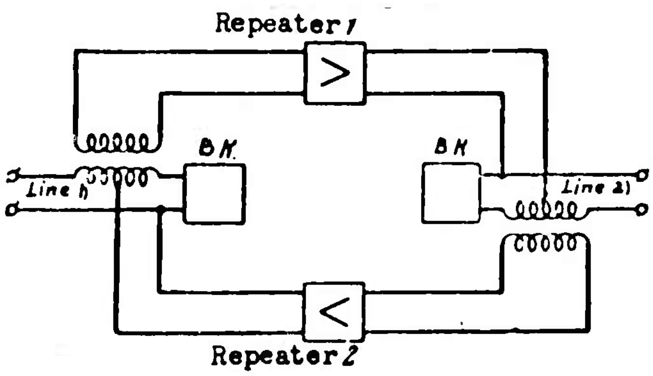

Fig.1 - Schematic of Telephone Two-Way Repeater

Two-wire communication systems are utilized mainly for intercommunication service, i.e., on relatively short sections of the intercity telephone network.

For increasing the operating range of such communication systems, two-way repeaters are used.

The first to develop the basic diagram of a two-way repeater - telephone relay - was a pupil of A.S.Popov, now member-correspondent of the Academy of Sciences of the USSR, laureate of the Stalin Prize, V.I.Kovalenkov, who on 2 August 1919, obtained two patents for the invention of the telephone relay.

In the circuit of the amplifier, as shown in the diagram in Fig.1, feedback is obtained by mismatch of the line impedance and the balancing network (BK). The magnitude of the resultant feedback current is higher, the smaller the balanced fadings of the differential systems and the larger the number of series-connected repeaters.

Figure 2, for a particular case, shows the reduction in the critical amplification of the audio-frequency amplifier, under the most unfavorable conditions, obtained by series-connected two-way repeaters. The critical amplification, which actuates the repeater, decreases with increasing number of connected repeaters and thus decreases the margin of stability of the telephone communication channel. This circumstance results in a limited application of two-wire systems of telephone communication on relatively short sections with few repeaters whose number depends on the number of the admissible feedback circuits in the master tandem communication system of the country, taking into consideration the securing of the necessary coverage of internal and external through service.

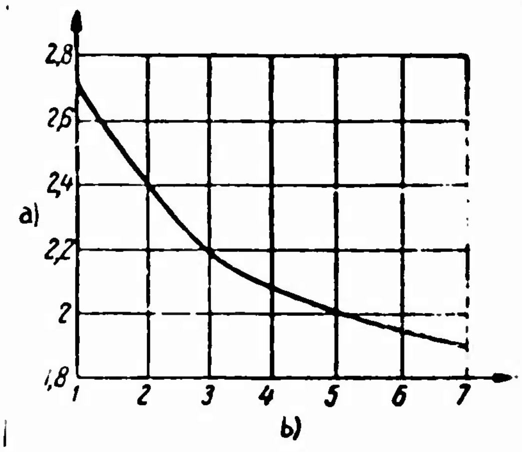

Fig.2 - Change in Critical Amplification as a Function of the Number of Series-Connected Telephone Repeaters

a) Critical amplification, in nepers; b) Number of series-connected boosters

The tendency toward increasing the coverage of the communications led to the application of four-wire systems, whose basic diagram is shown in Fig.3. In this case, different pairs of wires are used for direct and reverse directions of transmission, which gives the possibility of using one-way repeaters for boosting, which compensate for the fading of the preceding line sections. The four-wire communication system which can easily be replaced by an equivalent circuit of a single two-way repeater, has only one feedback circuit and thus ensures the operational stability of the telephone communication, no matter at what length of line. N.A.Bayev devoted his work to the development of the stability theory of telephone communication channels in the USSR and his work served as a basis for projecting a number of nation-wide trunk line service in the Soviet Union.

The problems of stability of the telephone channels are not the only factors limiting the operating range of intercity telephone communication. The operating

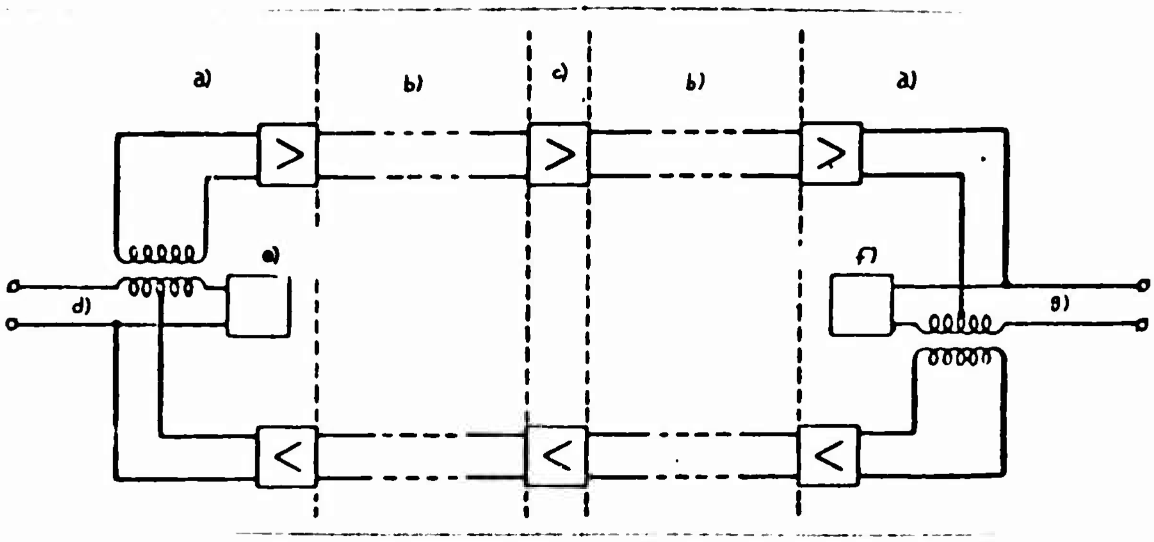

Fig.3 - Basic Diagram of a Four-Wire Communication System

a) Terminal repeater; b) Line; c) Line repeater; d) To subscriber 1; e) Balancing network line 1; f) Balancing-network line 2; g) To subscriber 2

range of the system is also influenced by the total time of the current distribution between two conversing subscribers, which depends on the special features and construction of the line installations and on the frequency spectrum, used in establishing the communication (aerial or cable line, method of coil loading or pupinizing of the cable line, diameter and material of the wires, etc.) and also the time of propagation of the current echo. On continental connection between two subscribers, the time of propagation of the signal is limited to the value of 250 msec while, in each national receiving or transmitting system, the time is fixed at the value of 50 msec.

The influence by the current echo increases with increasing time of propagation of these currents in the telephone circuit. Figure 4 gives the minimum values of the fading of the current echo, as a function of the time of their propagation in telephone circuits not equipped with echo suppressors.

The development of the technique of high-frequency communication on wires ensured the required operating range of the intercity telephone service by the most economical method.

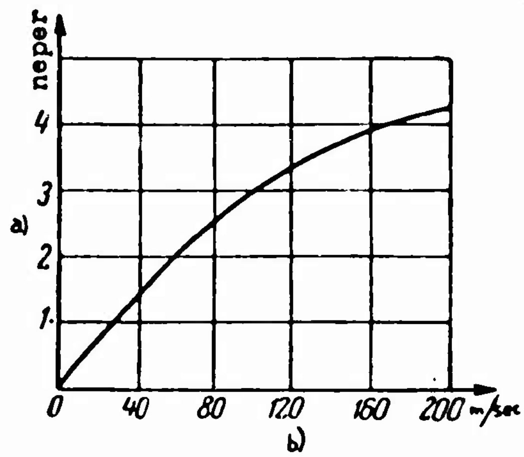

Fig.4 - Minimum Fading of the Current Echo

a) Minimum permissible fading of the current echo; b) Time of propagation

High-frequency telephone communication is based on the principle of using either two different frequency bands for direct and return transmission when establishing communication on one pair of wires, or one frequency band when establishing communication on two pairs of wires. In either case, such a communication is electrically equivalent to a four-wire communication system and, therefore, possesses all the merits of this system from the point of view of increasing the margin of stability of the telephone channels over that of the two-wire communication system.

Multiple use of expensive aerial and cable symmetric circuits, not to mention concentric cables, permitted to reduce by tens of times the requirement of nonferfous metals for establishing one channel-kilometer of telephone communication.

The rate of propagation of speech currents in modern high-frequency telephone channels is so extremely high that it practically does not limit the operating range and does not require installation of echo suppressors for elimination of the echo phenomenon. For example, the rate of propagation of currents in the high-frequency channels, operating on nonpupinized and concentric cables, exceeds 200,000 km per second.

The above-described brief technico-economic considerations indicate the reason for the fact that high-frequency telephone channels, at the present time, are basic for the establishment of trunk telephone service, i.e., service between district and Republics centers and the capital of the USSR - Moscow.

Characteristic for the contemporary status of the technique of high-frequency telephony on cable lines is the widespread utilization of nonpupinized and coaxial cables. Equipping cable circuits with Pupin coils, at its time, was a sign of progress since it lowered the fading of these circuits and thus increased somewhat the range of telephoning without repeaters or increased the lengths of the amplifier sections in the case of application of repeaters. In proportion to the development of the technique of high-frequency telephony, it became expedient and possible to multiplex not only the aerial but also the cable lines. The use of cables in the higher frequency range led to the necessity of increasing the limiting frequency of coil-loaded cables, above which the fading of the coil-loaded line increases sharply, which renders it impossible to make use of the range beyond the limiting frequency. The increase in the limiting frequency of the coil-loaded cable is correlated with the decrease in inductivity of the sections of the coil-loaded line. Later, lightened systems of coil loading were developed: light, very light, and frequency coil loading.

The tendency to use cable lines in the still higher frequency range led to abandonment of coil loading and erection of high-frequency telephone networks on cables without coil loading.

For establishing communication on symmetric cable lines without coil loading, cables with braided paper or styroflex insulation are used.

Soviet engineers devoted considerable attention to the creation of various types of long-distance cables, to the problems of the theory of interference between circuits in the cable and elimination of this influence. As a result, new methods of electrical symmetric balancing of the cable circuits were developed, which permitted the use of symmetric cables in the broad frequency band, reaching hundreds of kilocycles.

The most widespread systems of multiple telephony on symmetric cable lines, at the present time, are the 12-channel and the 24-channel systems. With these systems,

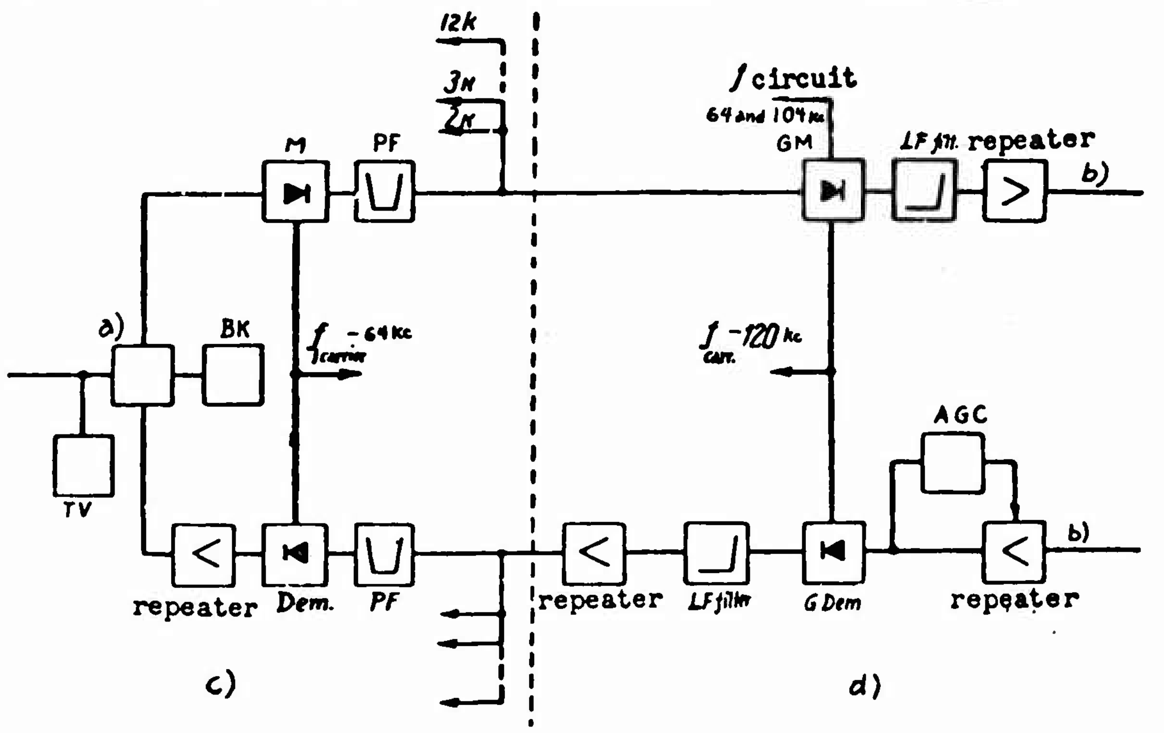

Fig.5 - Simplified Diagram of a Terminal Station of a 12-Channel System of High-Frequency Telephony on Cable Lines

a) Differential circuit; b) Cable; c) Individual equipment channel; d) Group equipment channel

12 high-frequency telephone communications in the 12 - 60 kc frequency range or 24 communications in the 12 - 108 kc frequency range can be obtained on two pairs of cable. For the direct and return voltage of the transmission the same frequency bands are used. Usually the connection in this case is established on two cables (two-cable system), each of which contains concentrated pairs for identical direction of the transmission. It is also possible to use one cable, but with well-shielded pairs of different directions of transmission, with the aim of eliminating

cross talk due to mutual interference of the pairs.

Figure 5 gives the basic diagram for a terminal station of a 12-channel high-frequency telephony unit on symmetric cable lines.

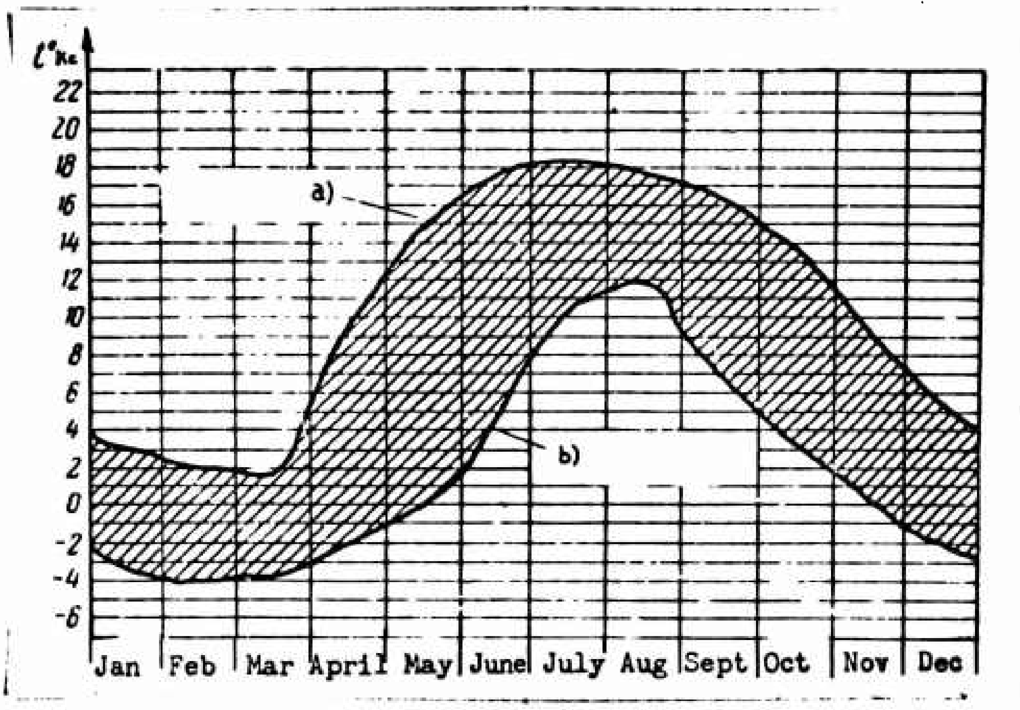

Fig.6 - Change of the Soil Temperature as a Function of the Seasons

a) Maximum temperature; b) Minimum temperature

Voice-frequency speaking currents, coming from each of the 12 subscribers in the 300 - 3400 cycle frequency range, are transferred into the corresponding range of the common spectrum at the output of the 12-channel 60 - 108 kc unit, by separate frequency conversion in each of the channels. For this purpose, the individual modulators (M) from the first to the twelfth channel are supplied with corresponding carrier frequencies 64, 68, 72 .... 108 kc, spaced at a distance of 4 kc. Upon repeat conversion in the group modulator (GM) with a carrier frequency of 120 kc behind the filter, currents in the frequency range 12 - 60 kc enter the line. As long as the line spectrum does not coincide, even partially, with the frequency spectrum coming from the individual elements of the 12-channel unit, it is sufficient to use one stage of group frequency conversion. At the receiving end, by means of corresponding frequency conversion, the line spectrum is transferred into the 60 - 108 kc range which, after individual conversion in the 12-channel unit, is

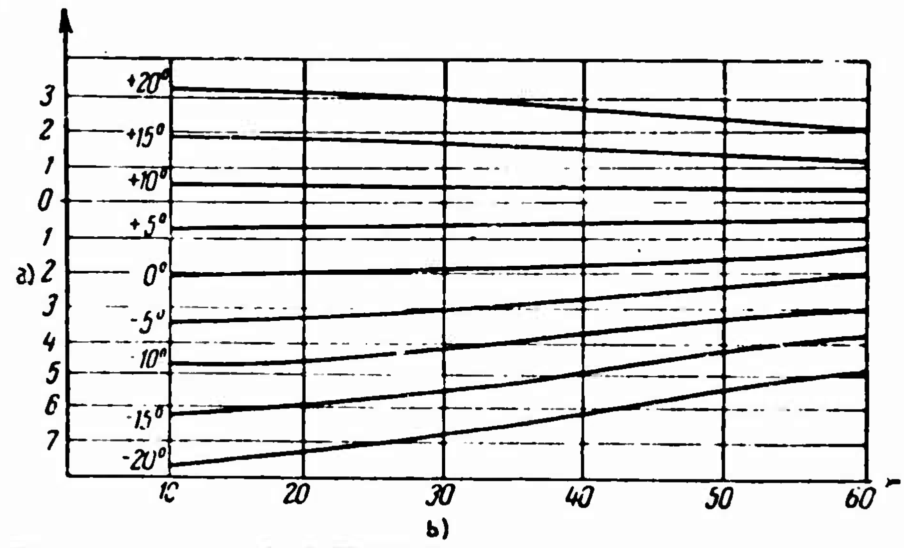

Fig.7 - Frequency Characteristics of Temperature Changes of the Fading of the Cable with Paper-"Kordel" Isolation

a) Attenuation, mnep/km; b) Frequency, kc

converted in each of the 12 channels into the voice-frequency spectrum of 300 - 3400 cycles.

The indicated schematic of the individual equipment of the 12-channel unit is common also to other systems of modern high-frequency telephony equipment. The 12-channel unit is used in the terminal equipment of the concentrical cable, in the multiplexing systems of aerial circuits of nonferrous metal, and in the equipment for radio relay lines.

Communication on cable lines is much less subject to the influence of external meteorological factors than that on aerial lines; nevertheless, the electric properties of the cable will considerably change in the course of a year, depending on the temperature of the soil. The change in soil temperature at the depth of the buried cable (0.8 m for the European portion of the USSR) is shown in Fig.6.

Maximum temperature fluctuations during the year may reach 20 - 22°C. This causes considerable temperature fluctuations of the fading of the cable circuits, which are not equal for the various frequencies. In Fig.7 the frequency characteristics of the temperature changes on attenuation of cables with paper-cord insulation are plotted; the diameter of the linear core is 1.2 mm, with spiral quad.

The increases in the attenuation of cable circuits are given for the various temperature deviations from +8 °C, accepted as average. At a frequency of 12 kc, for example, the fluctuations in the attenuation of a cable circuit of 1000 km length, in the course of a year, will amount to a value of the order of 5 nepers. Therefore, in order to ensure normal operation of telephone service on cable circuits in the 12-channel equipment, automatic control of the transmission level is provided, operated with the aid of heat-regulated or thermosensitive resistors, so-called thermistors. Automatic gain control (AGC) of the transmission compensates for the attenuation fluctuations of the corresponding line sections, due to changes in the amplification of the line repeaters and terminal offices in the entire range of transmitted frequencies. Repeaters equipped with the AGC device, are not connected to every amplifier point of the main cable. Instead, repeaters with plane automatic gain control of the transmission, in which the amplification change has the same value over the entire operating spectrum, are connected after each two repeaters without AGC. After every eight repeater stations, a repeater is connected which compensates for the attenuation fluctuations over the entire frequency range, by varying the slope of the frequency characteristics of amplification. The AGC devices are controlled by the currents of the pilot frequencies, continuously fed by the terminal stations into the line. Repeater stations are erected every 40 km, on the average.

In the 24-channel high-frequency telephony equipment, two 12-channel units are used: After the first unit, as in the 12-channel system, a group modulator is inserted which converts the frequencies of the 60 - 108 kc spectrum into a 12 - 60 kc spectrum, while the 60 - 108 kc frequencies from the second 12-channel unit strike the line directly. Thus, the line spectrum in the 24-channel system is 12 - 108 kc.

In a similar manner, other systems can be designed, in which the number of channels will be a multiple of 12.

The possibility of multiplexing in the broad frequency range of symmetric cables yields large bunches of channels at relatively small capacitances of these cables. For example, on two cables with a capacity of eight pairs of cores in each, multiplexing of these cables will give 192 high-frequency telephone connections for the 24-channel system.

Still more profitable from the point of view of savings in nonferrous metal per channel-kilometer of communication, at a large number of communications, is the communication system via concentric cable. This type of cable, due to its unusual design, permits its use over a very broad frequency range.

The concentric pair consists of an inner solid copper conductor and an outer

Fig.8 - Cable with Four Concentric Pairs

conductor in the form of a cylindrical tube, with the axis of the cylinder forming the axis of the inner conductor. The inner conductor and outer tube are insulated from each other. Figure 8 gives a photograph of a cable containing four concentric pairs. This type of cable, in addition, contains the usual symmetric pairs for signaling.

In Fig.9, the curves for attenuation per kilometer are plotted for two types of concentric cable: the curve 2.6/9.4 shows the attenuation of a cable with a 2.6 mm inner conductor and a 9.4 mm (inside diameter) outer conductor; the curve 5/18 gives the attenuation of a cable with inner and outer conductor diameters of 5 and 18 mm, respectively.

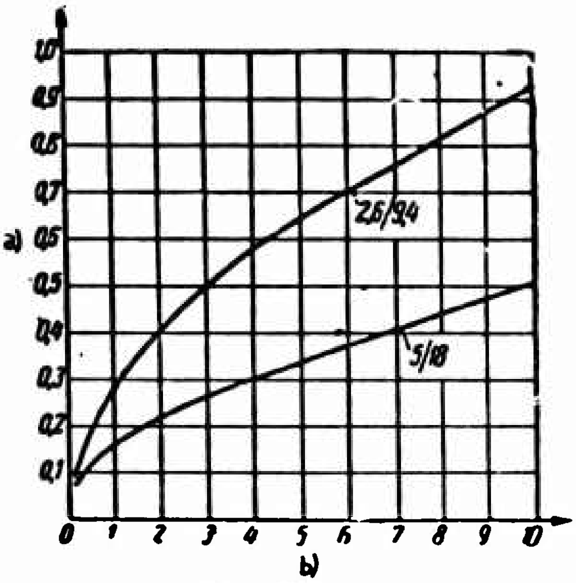

Fig.9 - Attenuation per Kilometer of Concentric Cable

a) Attenuation, neper/km; b) Frequency, mc

Both these types of cable can be used not only for telephony, but also for the transmission of intercity television programs. For establishing telephone communication, two concentric pairs are used: one for the transmission in one direction, and the other for transmission in another direction.

The base of the primary groups in the terminal equipment is provided with a 12-channel unit, of the type described above. In this equipment two stages of group frequency conversion are used, which finally transfer the voice-frequency 300 - 3400 cycle spectra to the corresponding point of the common line spectrum.

As an example, Fig.10 shows a diagram of frequency conversion for a 900-channel system, laid out on the basis of the recommendations of the International Consulting Committee on Telephony.

The speaking currents of the audio frequencies from 900 subscribers enter a total of seventy-five 12-channel units. After individual frequency conversion at the output of each of these, frequencies of the 12-channel primary group are formed in the 60 - 108 kc spectrum. Then, in the first group modulators with carrier frequencies of 420, 468, 516, 564, and 612 kc, these frequency spectra are converted into 60-channel groups, occupying the 312 - 552 kc spectrum. Fifteen such groups are formed in all. After this, in the second group modulators with carrier fre-

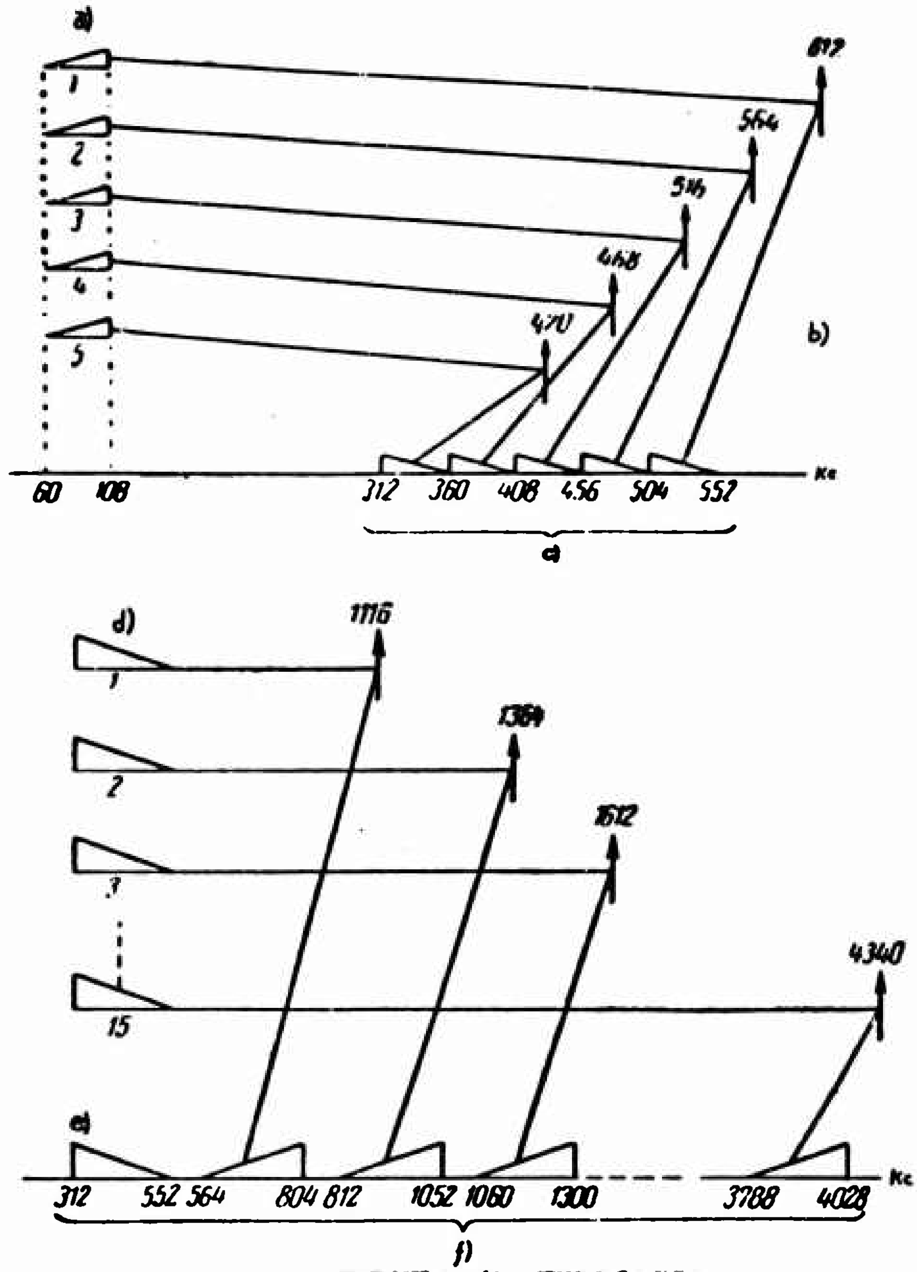

Fig.10 - Diagram of Frequency Conversion for a 900-Channel Communication System via Concentric Cable

a) 12-Channel primary groups; b) Carrier frequencies of the first group frequency converters; c) Five groups of 12 channels: 60 channels; d) 60-channel groups; e) Without conversion; f) Fifteen groups of 60 channels: 900 channels quencies of 1116, 1364, 1612 ..., 4340 kc, the spectra of the 60-channel groups are converted into a corresponding range of the common line spectrum from 312 to 4028 kc. At the receiving end, the reverse frequency conversion takes place, as a result of which the speaking currents of the 300 - 3400 cycle audio frequencies reach the subscriber.

The number of channels that can be established via concentric cables is not limited to 900 channels. By utilizing a still higher frequency range, after analogous frequency conversions, the number of channels can be doubled, bringing them to 1800; however, this would necessitate a decrease in the distance between the amplifying points, in proportion with the increase in attenuation on the higher frequencies.

The transmission of intercity television programs via concentric pairs can be accomplished in the 0.5 - 7 mc frequency range, while the sound accompaniment of television is transmitted in the frequency range below 0.5 mc.

The distance between the amplifiers for the cable 2.6/9.4 is from 6 to 8 km, depending on the number of channels transmitted. In the repeaters, automatic gain control of the transmission is used in order to compensate for the attenuation changes produced by temperature fluctuations of the soil at the depth of the buried cable.

The above-discussed principles of establishing communications via cables without Pupin coils and concentric cable lines show that, in modern long-distance communication, the multichannel systems utilizing broad frequency ranges are of basic importance. This circumstance, as was shown, resulted in a considerable reduction of the lengths of amplifier sections and, consequently, to an increase in the number of amplifier points. Such frequent positioning of the amplifier points would have caused a sharp increase in the cost of operation, as well as an increase in the primary capital outlay for construction of the main cable lines (if the high-frequency main cable lines are equipped along the same principles, which had been applied formerly in the construction and servicing of the voice-frequency amplifier points of multipair, intercity coil-loaded cables). A more economical solution of this problem was found by creating repeater stations that did not require constant technical servicing; the majority of these receive their power from amplifier points equipped with power sources. In this case, there is no need for permanent technicians to be on duty in remote-supplied amplifier points, the industrial areas of the repeater stations are reduced to a minimum and there is no necessity for power supply installations, which usually form a substantial part of the equipment of repeater stations.

In balanced cables, the remote feeding is usually done at the center point of the circuit by direct current. A special feature of this method of supply is the protection of the lead sheath of the cable from corrosion by stray currents. Depending on the magnitude of the DC voltage, the feeding amplifier point can remote-supply from 1 to 5 - 6 unattended repeater stations for each party.

In concentric cables, the supply of remote-fed repeater stations by alternate current is realized via the inner conductor. By filling the cable with a special gas between conductor and ground, voltages up to 2000 v can be built up, which gives a possibility of simultaneously supplying up to 20 unattended repeater stations on either side of the feeding amplifier point. If the concentric cable is not filled by a special gas, then the permissible AC voltage between the inner conductor and ground for remote supply is reduced approximately to 800 v.

Normal operation of such main cables is ensured by the use of complicated systems of telecontrol and telesignaling between the supplying and remote-supplied points.

With the installation of hundreds of unattended amplifier stations on the main lines, the demands made as to quality and useful life of electron tubes substantially increased, despite the existence of standby amplifiers in the amplifier points.

High-frequency telephone communication via aerial circuits of nonferrous metal and steel circuits gained acceptance in the erection of intercity connections much sooner than that via cable circuits. The history of the development of high-frequency telephony technique actually began with the multiplexing of aerial circuits of nonferrous metal. In this case, inasmuch as one pair of wires is used for establishing the communication, different frequency bands are used for different transmission directions.

Modern high-frequency telephony equipment permits 16 telephone calls in the 140 - 143 kc range, on one copper or bimetal circuit (possessing, on high frequencies, the same electric parameters as the copper circuit). The spectrum from 300 to 2400 cycles is occupied by the voice-frequency channel. The spectrum from 3200 to 5200 cycles is set aside for four ultrasonic telegraph communications. In the 6-27 kc and 36-143 kc spectra, multiple telephony is achieved by application of the 3-channel and 12-channel high-frequency telephone equipment.

The frequency distribution of the main spectrum in the 3-channel equipment is shown in the Table, given below.

Table

No. of Channel	Direction of Transmissions A-B		Direction of Transmissions B-A	
	Carrier Frequency, kc	Upper Sideband, kc	Carrier Frequency, kc	Lower Sideband, kc
1	6	6.3 - 8.7	27	26.7 - 24.3
2	9	9.3 - 11.7	24	23.7 - 21.3
3	12	12.3 - 14.7	21	20.7 - 18.3

For operation on parallel circuits, suspended on one pole line, the equipment of an additional spectrum can be used, in whose channels frequency inversion relative to the channels of the main spectrum equipment is applied.

The repeaters form a pool - one group for each of t' directions of transmission. The efficiently transmitted frequency band in the communication channels lies within 300 - 2700 cycles.

The 12-channel system occupies the line spectrum of 36 - 84 kc for one transmission direction and of 92 - 140 kc for the other transmission direction. Other

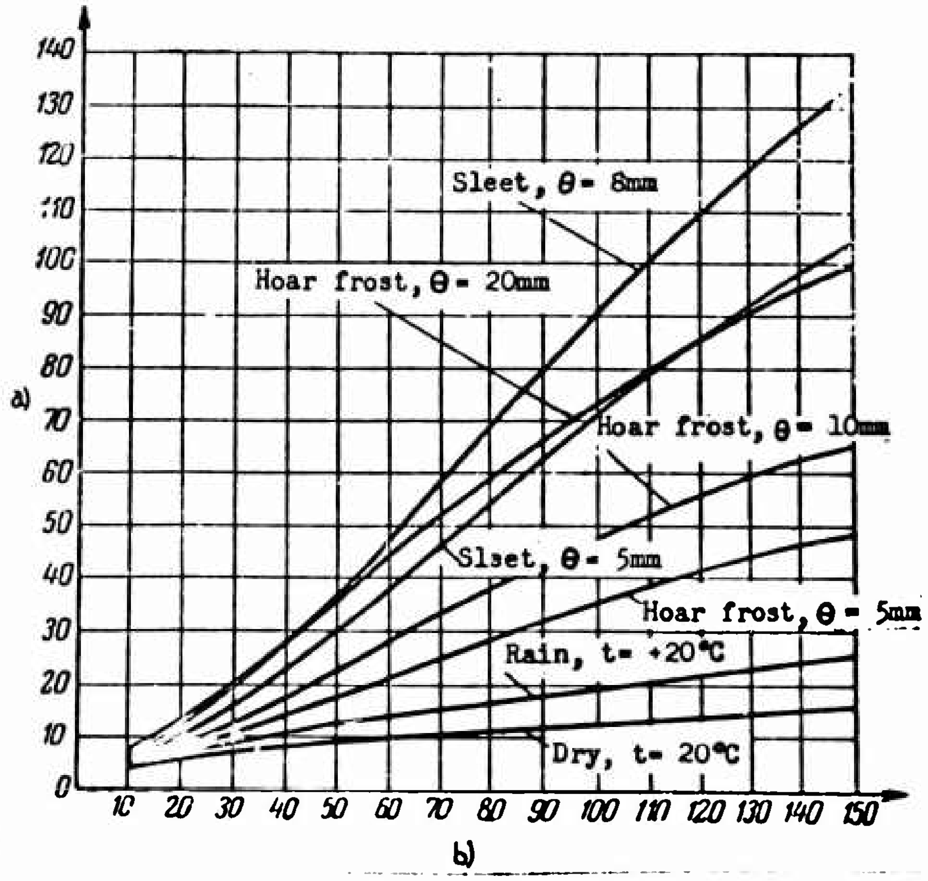

Fig.11 - Attenuation per Kilometer of a Copper Telephone Circuit, as a Function of the Current Frequency and Atmospheric Conditions

a) Attenuation, $\beta 10^{-3}$ nep/km; b) Frequency, kc

versions are possible, which provide for frequency shifts and inversion of the line spectrum in order to ensure better operating conditions of the equipment on parallel circuits. Into the base of the equipment, a 12-channel unit is inserted, of the type already known from the description of other high-frequency telephone systems.

The electric parameters of the aerial circuits change within considerable limits, depending upon temperature and weather conditions.

In Fig.11, curves are plotted for the attenuation per kilometer of a copper circuit with 4 mm wire diameter and 20 cm distance between the wires, under different atmospheric conditions depending on the frequency of the current.

The attenuation of the circuit increases steeply when there is hoar-frost and sleet on the wires, which is a frequent occurrence in winter in a large sector of the territory of the Soviet Union.

The greater the thickness of hoar-frost and ice deposit on the wires (θ), the greater will be the attenuation of the circuit; this has an extremely detrimental effect on the efficiency of high-frequency communications via aerial lines. This unfavorable effect is particularly apparent in the operation on the 12-channel system, which occupies a higher frequency spectrum than the 3-channel system. Maintenance of stability of the electric properties of the channels during changes in the attenuation of the circuits requires the application, in the 3- and 12-channel systems, of an automatic gain control for transmission at the repeater and terminal stations in each direction of transmission. But even these devices cannot ensure the efficiency of high-frequency communications when there is considerable hoar-frost and sleet, since the attenuation of the amplifier section increases so much that it can no longer be compensated by the booster capacity of the amplifier.

To maintain communications under unfavorable winter conditions, auxiliary repeater stations are used. These stations are erected between the main stations and are connected to the circuit as the necessity arises. They are remote-supplied via the same copper circuit over which the communication itself is established. These measures, at correct planning of the main lines, ensure almost uninterrupted operation under winter conditions with minimum expenditure for construction and operation of the main lines.

Considerable work has been done by Soviet specialists in the field of developing and designing equipment for high-frequency telephony in the postwar period.

For development of the multichannel system of high-frequency telephony, the following workers in science and industry received the 1952 Stalin Prize: G.G.Borodzyuk, I.A.Babenko, A.F.Beletskiy, N.M.Driatskiy, I.S.Stipakov, G.N.Stepanov, G.A.Nikolayev, B.V.Khalezov, A.S.Blokhin, I.V.Basik, Ya.I.Velikin, and S.A.Adzhemov.

Multiplexing of steel telephone circuits, which find wide application in establishing interdistrict communications, gives the possibility of sharply increasing the amount of telephone and telegraph communications between the district and area main office centers and of creating channels for transmission of broadcasting programs via wires.

The use of aerial circuits in the frequency range up to 150 kc greatly complicated the parallel operation of the multiplexed circuits, suspended on one pole line. To maintain the required degree of mutual shielding between the circuits, excluding the influence of one circuit on the other due to cross talk, it was necessary to theoretically develop very complicated explanations for the electric effect between communication circuits. The practical devices for crossing of telephone circuits and the arrangements of lead-ins of the multiplexed circuits into amplifier points, developed on the basis of this theory, ensure parallel operation of the multiplexed circuits in the frequency range up to 150 kc.

In the amplifiers, special filters are used for eliminating interference of the radio stations with operation of the 12-channel system of high-frequency telephony.

Extensive work in the USSR in the field of exploration and study of the problems of mutual electric interference between the circuits was carried out by P.K.Akulshin.

The developed network of high-frequency channels in the Soviet Union is the basis not only for intercity telephone communication. The same network is used for establishing communications of voice-frequency telegraphy and phototelegraphy and channels for transmission of broadcasting programs.

The voice-frequency telegraph equipment gives a possibility to obtain, via the four-wire communication system, up to 18 telegraph connections when operating on channels with an efficiently transmitted frequency band from 300 to 2700 cycles, and up to 24 connections when operating on channels with a frequency band from 300 to 3400 cycles.

The telegraph communications obtained in this manner greatly increase the maneuverability of the telegraph network, since the telephone communication channels can always be used for establishing new or bypass communications. Such a system of establishing telegraph communication is at the same time the most economical type, since it does not require any additional outlays for line and station installations of the telephone communication system. The main capital outlay is the cost of the voice-frequency telegraphy equipment, connected at the ends of the telephone channel. Powerful bunches of telegraph channels obtained in this way not only met the requirement of the electrocommunication agency as to telegraph channels but yielded a new form of communication - subscriber's telegraph communication.

For the qualitative transmission of broadcasting programs, a broader efficiently transmitted frequency band is required than for telephone communications. Therefore, the broadcasting channels on high frequency are formed by combining two to three telephone communication channels.

Simultaneous use of high-frequency channels for telephone, telegraph, and phototelegraph communications as well as for broadcast transmissions, opens interesting possibilities for the complex development of all kinds of communications and broadcasting.

The technique of designing long-distance communication equipment is now at such a high level of development that it pays to use high-frequency telephone equipment not only for multiplexing of intercity lines but also of shorter lines - suburban and urban telephone service. Primarily, such equipment is to be used for multiplexing of suburban cables and cable links between automatic raion or district telephone offices. This will save large amounts of nonferrous metals and money in laying out an urban telephone communication system.

High-frequency multichannel equipment permits the creation of large bunches of stable telephone channels. This gives all the prerequisites for the automation of intercity telephone communication systems.

Each year, new scientific inventions, developments, technical perfections in the radio technique and in the field of long-distance communication by wire narrow the margin between these related technical fields. Already now, the multichannel systems of high-frequency telephony via wires and via radio relay lines are equally useful for establishing an intercity telephone communication system.

It can be expected that, in the near future, new and still more progressive technical means will be developed, with whose aid the problems of establishing intercity telephone and telegraph communication in the Soviet Union will be even more successfully solved.

RADIO-ENGINEERING METHODS IN SCIENCE AND THE NATIONAL ECONOMY

by

S.I.Nadenenko

1. Basic Principles

Despite the fact that long-distance transmission of signals remains the basic and main problem of radio engineering, the entire complex of technical means, which is combined under the term "Radiotechnique", comprises and solves a substantially wider range of problems.

The middle of the current Century is characterized by achievements of science which opened vast prospects for the development of the productive capacity of society. The utilization of subatomic energy, principles of reactive motion in transportation, high-frequency technique of communication facilities, new materials and new methods of their treatment, permit to speak about the creation of a new foundation for further technical progress.

The part played by the facilities at the disposal of radio engineering is exceptionally important in this process. It is sufficient to mention that, in the production of atomic raw material such purely radiotechnical devices as cyclotrons, betatrons, and synchrotrons are being used. The control of all kinds of air and sea traffic is inconceivable with application of radiotechnique. The manufacture and development of new materials also require the use of radiotechnical methods. Thus, the characteristic feature of the development of modern radiotechnique, apart from the continuous improvement of the equipment and methods, is its constantly increasing daily use in various and widely differing fields of science, culture, and national economy.

An analysis of the development of radiotechnique during the 60 years from A.S.Popov up to the present time, distinctly shows three basic lines of this development, with well-defined classified criterions:

1) The field of radiotechnique, in the true sense of the word, which utilizes electromagnetic waves with their basic properties for the purpose of transmitting signals at a distance without wires.

During the 60 years of its existence, radiotechnique has made terrific progress in the field of generation, radiation, and reception of electromagnetic waves in a rather broad frequency range from 20,000 cycles to 10^{11} cycles. The laws of propagation of the waves in all ranges, under the complex conditions of the earth's atmosphere, underwent a full and thorough study. The transmission of signals by means of radio waves finds wide and successful application in radio communication, radiobroadcasting, television, radiotelemechanics, radar, radio navigation, radiogeophysics, radiometeorology, and radioastronomy.

2) The field of various applications of strong magnetic and electric fields of high frequency. This field, due to sheer inertia, is still designated as "radiotechnique" only because of the fact that high-frequency generators and devices channeling high-frequency energy (feeders, cables, waveguides) are widely used here. In essence, there is no transmission of signals involved here nor is there any excitation of the waves in space (unless one considers spurious radiation).

Thus, the absence of radiation and reception of radio waves, i.e., the absence of antennas and receivers, is a well-defined classification criterion for this field of application of radiotechnical methods, which can be considered an independent branch of high-frequency electrotechnique.

Strong high-frequency electric and magnetic fields are used in many branches of industry, particularly for inductive heating of metals, as semiconductors and dielectrics, and in other technological processes, opening new revolutionary manufacturing processes for treatment of materials, with tremendous technico-economic effect. Specifically, induction heating is applied in metallurgy (induction furnaces), machine construction (tempering of steel products), plastics industry (preheating of raw material), building industry (drying of materials), food industry (sterilization and pasteurization of food products). Induction heating finds also wide application in medicine for therapeutic purposes.

3) The exceptionally broad field of electronics - application of electron-ion devices (electron tubes, photocells, ion devices) in different measuring and control devices, and automation and remote-control installations.

PRESENT STATUS AND PRACTICAL UTILIZATION OF HIGH-FREQUENCY ELECTROTECHNIQUE

1. Physical Principles

The utilization of high-frequency electrotechnique in the above-mentioned various fields of the national economy is linked, in the majority of cases, with the specific action of high-frequency electric and magnetic fields on the materials placed in these fields.

As is well known, when placing any kind of body into a strong magnetic or into a strong electric field, the influence of the field on the body will differ; this difference will be mainly determined by the electrophysical characteristics of the material subjected to the action of the field: its dielectrical permeability ε, its magnetic permeability μ and its specific electric conductivity σ. If the body possesses metallic conductivity, it will warm up considerably in the magnetic field and hardly experience any thermal effect in the electric field. However, if the body possesses the properties of a dielectric, it will warm up in the electric field and will remain cold in the magnetic field. This difference is explained by the fact that the forces of the magnetic field act only upon the moving charge, whereas the forces of the electric field act on both the moving and the quiescent charge.

The structural lattice of bodies with metallic conductivity contains free electrons in disordered thermal motion. The magnetic field regulates the motion of the charges and imparts high accelerations to these charges. Under the action of the magnetic field, eddy currents are generated in the metal bodies, which result in heating of the body.

In dielectrics there are no free charges, and the bound positive and negative charges form elastic or ductile dipoles. These charges cannot move freely but are capable of either shifting somewhat from the position of their equilibrium or rotating under the action of the forces of the electric field. Therefore, despite the fact that conduction currents cannot develop in dielectrics, the movement of the paired charges in the viscous medium is accompanied by substantial losses of energy by friction, which leads to heating of the medium. Metal bodies in an electric field hardly warm up, because of the fact that under usual experimental conditions (for example, placing a solid body into a capacitor), the current density is rather small and the heating of the body, proportional to the square of the current density, will be insignificant.

The character of the heating in both fields will also differ.

The heating of metal bodies in the magnetic field, due to the surface effect, takes place only on the surface while the center may remain cold. If the time of heating is short, the depth of heating will be proportional to the depth of penetration of the current S, which depends on the frequency of the current, the electric conductivity of the body, and its magnetic permeability in the following manner:

$$S = \frac{1}{\sqrt{\mu \sigma f \pi}} \text{ m}$$

where μ is the magnetic permeability, in gm/m;

σ is the conductance, in mho/m;

f is the frequency, in cycles.

The above formula shows that the higher the frequency of the current, the smaller will be the depth of penetration of the current and the smaller the depth of heating of the metal. By proper selection of the current frequency, the depth of heating of the metal surface can be regulated.

When placing the dielectric in an electric field, its heating will take place uniformly throughout the entire volume, and in each cubic meter of the body an equal quantity (equal power P) of heat will be generated, determined by the function

$$P = E^2 \varepsilon f \tan \delta \frac{w}{m^3}$$

where E is the strength of the electric field, in v/m;

f is the frequency of the field, in cycles;

ε is the dielectric permeability of the material, in far- ;

δ is the angle of loss in the material.

The uniformity of losses in volume is a characteristic property of dielectric heating. In all other heating methods (by convection), the heat is transferred from the peripherical layers of the body to its center, and for heating of the entire body to the same temperature a known and sufficiently long time is required, determined by the thermal conductivity of the material. In bodies of low thermal conductivity, with heating by convection, local overheating is not impossible (charring). The difference between the conventional heating methods and heating in a high-frequency electric field manifests itself particularly in laminated dielectrics. When the layers are arranged along the electric field (Fig.1a) the quantity of heat, liberated in each case, is proportional to their electric conductivity. When the layers are arranged crosswise in the field (Fig.1b), their relative heating is different for different frequencies (thermoselective heating). In this case, the field frequency can be so selected that one dielectric is heated very strongly and the other less strongly. For example, one can cook an egg in a block of ice.

High-frequency heating of materials has the following properties in comparison with all other heating methods:

1) Possibility of high rate of temperature increase of the material without the risk of harmful effects (charring and fusing).

2) Thermoselective heating of heterogeneous (stratified) structures.

3) Uniformity of temperature distribution as to volume (selection of field frequency).

4) Simple methods of regulation and control of the heating process of materials.

For the purpose of high-frequency heating, almost the entire known spectrum of electromagnetic oscillations is used, from audio frequencies (500 cycles) up to decimeter and, in the future, also centimeter waves (3×10^{10} cycles).

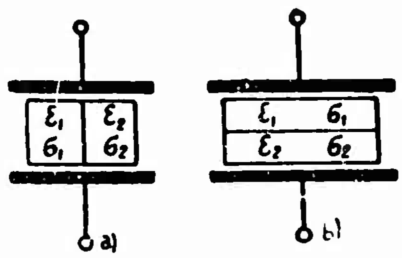

Fig.1 - High-Frequency Heating of Laminated Dielectrics, with Arrangement of Layers:
a) Along the Electric Field;
b) Across the Electric Field

The study of the interaction between the high-frequency electromagnetic field and organic or inorganic nature opens new, at times unexpected, ways of solving a number of urgent problems. Particularly extensive possibilities are given by the mastering of high radio-frequency ranges. Already now, the range of the highest frequencies utilized in the technique is approaching the natural frequencies of the oscillations of large molecules of organic substances. The resonant excitation of the molecules may furnish new qualitative and quantitative concepts on the behavior of substances in an electromagnetic field.

Our scientists and designers made large contributions to the development of high-frequency electrotechnique. As early as 1912, V.P.Vologdin created a machine generator, and in the Twenties high-frequency machines of large power - up to 300 kw in one unit were produced. The laboratory of the Leningrad Electrotechnical Institute, under the direction of V.P.Vologdin, was the first to develop equipment for high-frequency smelting of metals and for surface-hardening of steel products.

The papers by M.A.Bonch-Bruyevich in the Twenties on creation of powerful generator tubes and the development of high-frequency generators have created the foundation for the designing of powerful vacuum-tube generators in all frequency ranges. The theoretical foundations of this branch of electrotechnique were laid by V.K.Arkad'yev and generalized in his monograph "Electromagnetic Processes in Metals" (1936).

2. Fields of Practical Application

Metal Smelting. The metal to be smelted is placed in an induction furnace (crucible) located in the magnetic field of the circuit coil (inductor). The current frequency selected is kept at a moderate value so as to allow the field to penetrate into the depth of the metal. The smelting is carried out by heating the body by induction currents and takes place in absolutely clean surroundings, excluding the possibility of harmful admixtures to the metal, gases, etc. In furnaces of two-ton capacity field frequencies of 500 cycles are used, while for lower-capacity furnaces the field frequency is increased up to 3000 - 5000 cycles. In small furnaces, calculated for a few kilograms of metal, the field frequency may reach 100,000 - 500,000 cycles. The power of induction furnaces reaches thousand and more kilowatt in one unit.

Surface-Hardening of Steel Products. The surface-hardening of steel products is achieved by placing the parts (neck of shafts, axles, cogwheels, instruments, etc.) into the high-frequency magnetic field, created in the inductor. At sufficient power and at an accurate selection of the field frequency and the heating time, the surface of the part can be heated to the required depth and to the necessary temperature. Immediate rapid cooling will harden the surface layer and permit the center to retain its plastic properties. Such a hardening will decrease the surface wear of the part but will not lower the general strength.

The hardening of heavy articles requires the use of high-power generators and complicated equipment. To simplify the technology, successive hardening of individual sections along their length, is applied as far as possible; for this, the inductor is shifted along the part and heats one section after another. The inductor is followed by the quenching bath.

To generate the necessary power, machine as well as vacuum-tube generators are used. In the advanced technology of the machine-building industry, high-frequency heating for tempering of steel products received full recognition. In the larger plants, special electric-heating sections have been established.

The hardening of steel products in high-frequency magnetic fields, in comparison with the usual tempering methods, has the following advantages: absence of warping during the heating process, due to the small volume of heating; increased production as a result of the high rate of heating; small power consumption and reduced cost of operation; homogeneity of the structure of the hardened layer; possibility of regulating the depth of hardening; improvement of the product quality and improvement of the working conditions; possibility of automation of the hardening process and establishment of assembly-line mass production. In addition, the hardening of steel products with the aid of high-frequency currents, obsoletes the necessity for further treatment of the part, its cleaning and polishing.

Thus, surface hardening of steel products increases their useful life, yields a tremendous saving in metal consumption, improves the quality of production, and eases the working conditions.

The heating of metals in magnetic fields is also utilized for contact welding, brazing, annealing, and normalizing of steel, high-speed gas cementation of steel, forging, and stamping. Lately, high-frequency heating came into increasing use in the manufacture of enameled products (china, wires, etc.)

Drying of Building Materials. Drying of lumber in the woodworking industry and in the building industry presents a complicated technological process. In large drying workshops, the lumber is loaded into chambers with steam installation and the drying proceeds at high temperatures over a period of 100 - 500 hours. When drying large boards, containing the pith of the wood, the rejects reach 90 - 95%, due to breaking and cracking of the pith. When drying wood in the high-frequency field, the drying time is shortened to 3 - 8 hrs, and the quality of the wood remains high: the rejects are reduced to a few percent. The application of high-frequency heating to the process of impregnating and splicing of wood under pressure yields new high-quality materials. High mechanical strength, not inferior to the strength of metal, wear resistance of the surface, resistance to corrosion and swelling, high surface toughness, low specific weight, and simplicity of treatment permit replacement of metal by wood in certain constructions. This material is used in the manufacture of aircraft propellers, cogwheels, boats, hoods, insulators, etc.

Dielectric heating and drying in high-frequency fields results in a substantial improvement of the quality of ceramics products in the building and electrotechnical industry and in the manufacture of artistic ceramic products.

Production of Plastics. High-frequency heating also finds wide application in the manufacture of articles from plastic masses by molding. Since plastic materials are good dielectrics, having a small loss angle, a substantial increase in the frequency of the electric field is required for their heating. Here generators with current frequencies of the order of 10^7 - 10^8 cycles (waves of the meter range) are used.

Induction Heating in the Food Industry. Powerful high-frequency installations are utilized with high efficiency for the melting out of fat from the waste in slaughter houses and for sterilization and pasteurization of food products and canned goods. Placing products, contaminated by bacteria, for a few seconds into a sufficiently strong high-frequency electric field makes the product sterile. Thus, the high-frequency field is used for sterilizing jams, canned fruits and vegetables, tomatoes and other products of the food industry, resulting in a substantially higher quality than with the old sterilization methods in which steam baths were used; the fruit is not cooked to a pulp, keeps its vitamins, flavor, and natural savory qualities.

High-frequency heating can be successfully applied for the drying of macaroni, tea, and tobacco and also for baking bread and bread articles. As shown by calculations, the baking of one ton of bread requires about 60 kg of conventional fuel (7000 calories) or approximately 490 kw-hr. With a high-frequency conveyer baking and generator efficiency of 50%, this consumption amounts to a total of 250 kw-hr, i.e., to two times less.

High-Frequency Electrotechnique in Agriculture. In agriculture, high-frequency electrotechnique has not been used as widely as in industry; however, the results of actual experiments, carried out on a large scale, show that the high-frequency technique in agriculture has great possibilities. Thus, under laboratory conditions, highly favorable results were obtained with high-frequency fields, in stimulating the growth and development of plants and in fighting agricultural pests (weevils and mites). Significant is also the increase by about 20 - 30% of the yield of silk by exposing the larvae of the silkworm to high-frequency fields.

High-Frequency Heating in Therapeutics. For a long time, heat has been the most widespread and efficacious therapeutic method. Local heating not only soothes pain in many illnesses but also contributes to the localization and limitation of the disease process, and helps the organism in fighting the disease. Because of the presence, in living organisms, of heat-control centers and because of the heat-regulating action of the skin, the heating of deep tissues and organs of the body by conventional methods (via the skin) is difficult. Here medicine is assisted by the high-frequency field by which any organ of any living organism can be heated to any temperature. Therefore, high-frequency diathermy equipment is being increasingly used in the clinic. Many illnesses which do not respond to surgical or therapeutical treatment, are cured by high-frequency heating.

Recently, interesting experiments were made in medicine to ascertain the influence on the human organism of short pulses of the high-frequency field from radar transmitters. Another insufficiently explored point is the question of the sterilizing action of the high-frequency field. This property of the field, in particular, can be utilized in surgery and manufacture of surgical material.

3. Present-Day Application of Electronics and Radio Methods

The application of electric circuits containing electron tubes, electron tubing, photocells, and other electron-ion devices, is increasing every day. These circuits present a very delicate but powerful means in the hands of a scientific worker-naturalist and in the hands of a technologist-organizer of industrial production.

The number of circuits with electron devices used in various fields of science, technique, and industrial production probably has reached several thousand by now. Let us examine the main trends of application of electronics and radio methods.

Electron amplifiers by themselves as well as in combination with every possible transmitter-converter of mechanical strains, temperature changes, and other non-electrical quantities into electrical currents and voltages, permit to carry out accurate measurements in such numbers and in such fields that were for a long time inaccessible to researchers.

A typical example is the use of amplifiers in biology and medicine. It appears that the cells of living tissues, in the process of their vital activity, function as electrically active elements. The charges of the cells change under the influence of mechanical, thermal, chemical, and other kinds of stimuli. The variations in these charges create currents inside the organism, known as biocurrents.

The measurement of biocurrents and their visual observation on the oscillograph screen permit the physician(physiologist) to judge the proper functioning of various organs of the body. Thus, the recording of the heart currents (cardiogram) and the recording of the brain currents (encephalogram) are of tremendous help to the physician in the diagnostics of diseases of these organs.

Combination of amplifiers with transmitters of mechanical pressures and strains is widening the possibilities of measuring deformation of loaded mechanisms in an unlimited way. With the aid of devices of a similar kind in the construction field, stresses in load-carrying members of huge installations: dams, bridges, foundations of buildings, wavebreakers, etc., in the machine construction the service conditions of individual units and parts of complicated machines and mechanisms can be studied. The same devices permit observation, measurement, and study of oscillations of equipment and machines.

The results of tensometric measurements give a possibility of an accurate determination of the dynamic-mechanical stresses in various kinds of equipment and machines, and assist in finding the most economical engineering solutions in their planning.

The use of amplifiers in conjunction with seismographs increases the sensitivity of the seismographs and permits recording the seismic oscillations, which is of particular importance in the seismic prospecting for mineral resources.

Circuits with electron tubes have been developed for counting the electrical pulses and for "remembering" the count.

These devices find wide application in various kinds of analytical computers. Due to the utilization of electron tubes, the technique of machine computing made a big stride forward. In modern digital computers (some of them contain up to 20,000 electron tubes) any mathematical calculations down to the solution of differential and integro-differential equations can be carried out. Electronic computers, speeding up calculations by hundreds and thousands of times, increase the accuracy of the calculations and free highly qualified workers from laborious calculating processes.

Electron circuits find wide application in the measuring technique of nonelectric quantities by electric methods. For example, circuits for accurate measurement of short intervals of time permit measuring time intervals from 0 to 100 microsec and higher, with an accuracy no less than 2 microsec.

Electron circuits for temperature measurement permit regulation of temperature with a very high degree of accuracy. Thus, a circuit with nickel resistance ensures maintenance of the rated temperature of the oven or bath at 100°C, with an accuracy of ± 0.00055°C.

An electron micrometer can be used for detecting displacements of one angstrom (10^{-8} cm). Measurement devices of mechanical displacements of the order of 10^{-5} cm do not present much difficulty and are often applied in the practice of precision measurements.

All devices of this kind as well as the circuits with electron tubes for automatic control and telemechanical control increase the production output, contribute to the increase in quality of production, and free operators from tedious mechanical work.

The combination of electron tubes with photocells and electron pipes permits widening of the frequency and dynamic range of such important sensory organs as sight and hearing, and opens a path into the invisible and inaudible. The most interesting achievement of electronics in this field of human knowledge is the electron microscope.

It is known that a conventional optical microscope can magnify to the order of 1500 - 2000 times, the same microscope in ultraviolet rays can magnify 3000 times, which is the limit for optical microscopes. In the electron microscope, the illumination of the observed object, effected by the flow of electrons, substantially increases the resolving power of the device. Under the electron microscope, magnifications of 30,000 times and, with successive photomagnifying, up to 100,000 to

200,000 times, can be obtained.

Under the electron microscopes large molecules of complicated organic compounds can be studied, the inner structure of bacteria and viruses, can be made visible and the structure of metallic surfaces, etc. can be examined.

Fig.2 - External View of an Electron Microscope

The tremendous importance of the electron microscope in biology and bacteriology lies in the fact that it gives the possibility of direct observation of the action of various chemical and medicinal agents on live bacteria. There is no doubt that the application of the electron microscope will help develop efficient means of combating disease-carrying microorganisms.

Figure 2 gives the external view of an electron microscope, developed by A.A.Lebedev, V.N.Vertsner, and N.G.Zandin.

Figure 3 shows an interesting photograph of the attack of a microbe by bacteriophages (magnification 28,000 x).

Sounds lower and higher than the audibility threshold beyond the boundaries of the 16 - 16,000 cycle range remained inaudible until recently despite the fact that their world is very rich and diverse. Electron-ion circuits permit conversion of the spectra and rendering inaudible sounds audible. On the basis of the achievements of radiotechnique and electronics, a new and powerful field of the technique of ultrasound was developed. Ultrasonics find wide application in hydroacoustics for sounding the depths of oceans, for studying the profile of sea and ocean bottoms, for spotting of vessels, submarines, and obstacles in the path of ships (hydrolocation). The Soviet scientist, S.Ya.Sokolov developed methods of ultrasound fault detection in machine construction, which permit detecting, in solid metal parts of machines, the most minute structural defects: flaws, cracks, foreign inclusions.

Fig.3 - Attack of a Microbe by Bacteriophages

In speaking of the development of radiotechnique, high-frequency electrotechnique, and electronics, the beneficial influence of their ideas and methods on the development of related field of science and technique should be mentioned. Thus, radiophysics finds wide application, in particular, in the study of the structure of the high layers of the atmosphere. Radioastronomy studies the structure of the universe by analysis of the electromagnetic waves, radiated or reflected by cosmic bodies. Radiometeorology is exploring the meteorological processes in the earth's atmosphere on the basis of observation of the propagation of radio waves.

The successes of radiotechnique and electronics stimulated the development of electroacoustics and the technique of sound recording and sound reproduction.

The achievements of radiotechnique are also used in the development and manufacture of musical radio instruments of various systems.

The list of applications of radiotechnique and its methods could be increased manifold; however, those mentioned suffice to illustrate the importance of radio in the life of modern society.

LITERATURE ON RADIOTECHNIQUE

by

B.S.Grigor'yev

Ten years ago, our country commemorated the fiftieth anniversary of the invention of radio by A.S.Popov, and for the first time celebrated Radio Day. This holiday coincided with the end of the Great Patriotic War. Bringing to a victorious end the most difficult of wars humanity has ever known, the Soviet people resumed peaceful construction. Industry, agriculture, science, technique, and art were given new, unlimited, possibilities of development. Over the last ten years, the Soviet people recorded great achievements in all fields of the national economy. Extensive work was also done in the development of radiotechnique and its practical utilization.

The success of radiotechnique found expression in the radiotechnical literature and contributed to the publication of valuable books. In turn, the literature helped and continues to help the further development of radiotechnique and the education of qualified specialists.

During the Great Patriotic War, publications of radio literature were comparatively few. Some books and leaflets were published, devoted mainly to a description of practical devices and equipment and individual problems of using the means of radio communication and radiobroadcasting. Such literature, in those years, was extremely necessary for the young, still inexperienced, workers who had to service radio sets. The publication of textbooks and school manuals for high and medium special schools was limited, almost no monographs or engineering-technical literature were issued, the publication of radio amateur pamphlets stopped. The edition of the popular magazine "Radiofront" and the scientific-technical journal "Electrocommunication" ceased as well, which had previously published papers on questions of radiotechnique.

After 1945, the publications in the field of radio literature started to increase again, listing numerous documents on the invention of radio for the first time. To mark the occasion of the fiftieth anniversary of the invention of radio, the Soviet of Peoples' Commissars of the USSR decreed a number of measures and the publication of a compilation of historic documents relating to the invention of radio by A.S.Popov, of a biography of A.S.Popov, of a scientific-technical collection "50 Years of Radio" and of a popular booklet on the development of radio. All these books were published in time for Radio Day and laid the foundation for the systematic publication of material pertaining to the invention of radio and its development. The most interesting and valuable publication is the collection of documents on the inventor of radio, prepared and issued by the Academy of Sciences, and the scientific-technical compilation "50 Years of Radio", composed by leading Soviet radio specialists and edited by Svyaz'izdat. Other publications, which have appeared for the fiftieth jubilee, include a collection of documents "A.S.Popov", prepared by the Archives Section of the UNKVD in the Leningrad district and published by Lenizdat.

From that time on, it became a tradition to mark the Radio Day by publishing material devoted to the invention of radio and its contemporary status. Each year, such material forms the basis of the May issues of radiotechnical and radiocommunication magazines. Besides, also nonperiodical scientific-technical and historical publications, devoted to the development of radio, made their appearance. Many brochures and books on the inventor of radio were published in the years that followed, not only by the central publishing houses but also by local ones (Gorki, Saratov, Stalingrad, and others). These popularized the name of the great scientist, a fame well-deserved as proved by indisputable documentation. Material was also printed in the periodical literature. It is of interest to note that in the first edition of the list of papers and literature on the life and activities of A.S.Popov, prepared by the library workers of the USSR Academy of Sciences and published in 1945, only 431 papers are listed, whereas the second edition of this list (1951) enumerates already 904 papers.

A whole series of editions during the last decade illuminates the question of priority of Russian scientists and engineers in the development of important questions of theory and practice of radiotechnique. To this group belong the books by N.A.Nikitin "Nizhegorodskaya Radio Laboratory" (Svyaz'izdat, 1954), a collection of papers "Mikhail Vasil'yevich Shuleykin" (Sovetskoye Radio, 1952), a booklet by one of the oldest radio operators, P.A.Ostryakov "Mikhail Aleksandrovich Bonch-Bruyevich" (Svyaz'izdat, 1953), the book by V.I.Shamshur "The First Years of Soviet Radiotechnique and Radio Amateur Activities" (Gosenergoizdat, 1954) and others. The life and activities of A.S.Popov are also described in the books "Men of Russian Science" (Gostekhizdat, 1948), M.A.Shatelen's "Russian Electrotechnicians" (Gosenergoizdat, 1950), and others.

A rather important feature, characterizing radio literature and issued during the past ten years, is the steady growth of its ideological level, greatly promoted the decisions of the Central Committee of the Party on ideological questions. The cultural level of the readers increased sharply, which led to an increase of the requirements with respect to authors, critics, and editors. As a result, the probability of appearance of rough-style, undeveloped, or uninteresting editions was reduced. Now, as far as contents is concerned, the Soviet radiotechnical literature occupies one of the foremost places in the world.

The planned character of socialist economy ensures the most practical utilization of the possibilities of technical publishers, excludes parallelism in their work, and helps satisfy to the fullest possible extent the requirements of the reader.

Publishing of radio literature in the USSR is done mainly by three publishing houses. Literature on general questions of radiotechnique, textbooks, and manuals for high and medium special schools, information, production-technical, and radio amateur literature is published by Svyaz'izdat, forming part of the system of the Ministry of Communications of the USSR. Radio literature, intended for designers of equipment, workers in plants and laboratories, and specialists in the radio-technical industry is published by Gosenergoizdat, which also edits many books for radio amateurs. Finally, literature devoted to the technique of superhigh frequencies and related fields is published mainly by the publishing house "Sovetskoye Radio". Some books are also published by other central publishers (Gostekhizdat, Transzheldorizdat, Oborongiz, and others) and peripherical houses (Gostekhizdat of the Ukraine, and others) which, however, do not systematically publish radio literature.

To coordinate the activities of the publishers of radio literature, the scientific council for radiophysics and radiotechnique of the USSR Academy of Sciences created a special committee in May 1952, which was given the task of reviewing the program of the publishers and make recommendations. The Soviet sent inquiries to the user agencies in the ministries and departments, to teaching faculties of various departments, to scientific research institutes, and other users as to their requirements of radio literature. After deleting repetitions in the individual replies, a list of ninety books was compiled, mainly textbooks and teaching manuals, necessary for the normal preparation of engineering-technical nuclei in universities and technical schools for radio-engineering degrees, as well as monographs dealing with individual questions of radiotechnique, which are needed by the staff of scientific research institutes and laboratories. Subjects, not represented in the programs of the publishing houses, were divided into topical groups and then, on recommendation of the radio Soviet, introduced into the planned programs of the trade publishing houses. The participation in the formation of the publishing programs of such an authoritative organization as the Scientific Soviet for radiophysics and radiotechnique, and the attraction to this matter of broad scientific-engineering publicity has a very beneficial effect on the activities of the publishing houses.

In order to form an idea of the work accomplished by the publishing houses, let us review, in a most general form, a number of questions treated in the Soviet radio literature during the last decade.

Quite extensive literature appeared on general radiotechnique. For electric engineering colleges and faculties, a textbook by V.A.Kotel'nikov and A.M.Nikolayev "Basic Principles of Radiotechnique" was published in two parts (Svyaz'izdat, Part I, 1950; Part II, 1954); for higher technical schools, a textbook by B.P.Aseyev, "Basic Principles of Radiotechnique" (Svyaz'izdat, 1947); for the physico-mathematical faculties of pedagogical institutes, a teaching manual by N.N.Malov, "Course of Electrotechnique and Radiotechnique" (Gostekhizdat, Second edition, 1948*; third edition, 1952); for the institutes of railway transportation, a textbook by P.N.Ramlau "Radiotechnique" (Transzheldorizdat, first edition, 1946; second edition, 1950); for the radiotechnical faculties of the higher naval schools, a manual by N.N.Krylov, "Theoretical Foundations of Radiotechnique" ("Sea Commerce", first edition, 1951, second edition, 1953); for the navigation departments of naval academies, a textbook by A.M.Bayrashevskiy, "Naval Radiotechnique" (second edition, "Sea Commerce", 1949; third edition, Vodtransizdat, 1953); for colleges teaching courses in applied radiotechnique, a book by G.V.Voyshvillo, "General Course of Radiotechnique" (Voyenizdat, first edition, 1948; second edition, 1950); for electrotechnical communications schools, a textbook by M.V.Amalitzkiy, "Basic Princi-

* This book was also published in Ukrainian ("Radyan'ska Shkola", 1950)

ples of Radiotechnique" (Svyaz'izdat, Part I, 1949; Part II, 1948); for military signal schools, textbooks by N.M.Izyumov, "Radiotechnique" (Voyenizdat, 1946) and "A Course in Radiotechnique" (Voyenizdat, first ed. 1947; second ed. 1950*) and a manual by N.I.Chistyakov and V.D.Zharov, "Radiotechnique" (Voyenizdat, 1953); and others.

Papers on radiotechnique by L.I.Mandelshtam and N.D.Papaleksi have been published in collections of their works (Published by the USSR Academy of Sciences).

The publishing house "Tekhnika da Shroma" published in the Georgian language "Basic Principles of Radiotechnique" by K.I.Kontrikadze (1949).

Worth mentioning in the literature on general radiotechnique for radio amateurs is the book "Radiotechnique" by I.P.Zherebtsov (Svyaz'izdat), which had a few editions.

The basic teaching manual on electronics at present is the book "Electronics" by N.A.Kaptsov, published in 1953 and 1954 by Gostekhizdat as a teaching manual for colleges. The same publishing house published basic books on the physics of electron emission: L.N.Dobretsov's "Electron and Ion Emission" (1950 and 1951), S.V.Ptitsyn's "Physical Phenomena in Oxide-Coated Cathodes" (1949), B.M.Tsarev's "Contact Potential Difference and its Influence on the Operation of Electric Vacuum Devices" (1949).

In 1949, a second edition of the book "Electric Vacuum Devices" by B.F.Vlasov appeared (Svyaz'izdat), which was approved as a textbook for colleges. The foundations of industrial electronics are treated in a textbook by I.L.Kaganov "Electron and Ion Converters", Part I: "Electron Technique" (Gosenergoizdat, 1950), for power engineering and electrotechnical colleges and faculties.

For students of communications institutes, electrotechnical and power engineering institutes, engineers of scientific and research institutes and plants who have

* This book was published also in Esthonian (Estgosizdat, 1951)

to do with the application of electronic devices, the book by A.A.Shaposhnikov "Electron and Ion Devices" (Gosenergoizdat, 1952) was published.

Some colleges published their own manuals on this course, for example, the Leningrad Electrotechnical Institute imeni M.A.Bonch-Bruyevich, a manual by N.N.Khlebnikov "A Summary of Lectures on the Course of Electron Devices" (1950); the Leningrad Red Banner Military Aviation-Engineering Academy, a manual by V.I.Rakov "Electric Vacuum Devices" (1949); the Military Aviation-Engineering Academy imeni N.Ye.Zhukovskiy, a manual by A.I.Dugin "Electron and Electron-Ion Devices (1949).

A series of teaching charts by G.A.Tyagunov and A.A.Zhigarev: "Electron Tubes" (1948), "Electron Devices" (1949), and Ion Devices" (1950) was published by Gosenergoizdat. In 1954, Gosenergoizdat published a book by B.M.Shaposhnikov "Guidance for the Laboratory of Electron and Ion Devices".

In Tallin, a book in the Esthonian language by A.Pydrus "Electric Vacuum Devices" was published (first ed. 1949; second ed. 1952).

As a textbook for the technical schools of the radiotechnical industry the book by G.A.Tyagunov "Electric Vacuum Devices" (Gosenergoizdat, 1949) was used, and as a manual for the technical signal schools a book by V.S.Grigoryev and B.S.Grigoryev "Electron and Ion Devices" (Svyaz'izdat, first ed. 1950; second ed. 1954).

The monographs and engineering books on electronics include the interesting books of S.Yu.Lukyanov "Photoelectric Cells" (published by the USSR Academy of Sciences, 1948); N.O.Chechik, S.M.Faynshteyn, and T.M.Lifshits "Electron Multipliers" (Gostekhizdat, 1954); Ye.A.Vaynrib and V.I.Milyutin "Electron Optics" (Gosenergoizdat, 1951); M.Ya.Mulyarov"Electron-Beam Devices" (Gosenergoizdat, 1954); A.V.Moskvin "Cathode Luminescence" (Gostekhizdat, Part I, 1948; Part II, 1949).

The great success of Soviet physicists in the development of semiconductors was reflected in the book by A.F.Ioffe "Semiconductors in Modern Physics" (published by the USSR Academy of Sciences, 1954). These questions are also treated in other Soviet publications, in particular, in the books by A.Z.Levinson "Semiconductor Rectifiers" (Gosenergoizdat, 1948) and K.B.Karandeyev "Semiconductor Rectifiers in Measuring Technique" (published by the USSR Academy of Sciences, 1954).

An important contribution to the development of the science of propagation of radio waves was the publication of the book by V.N.Kessenikh "Propagation of Radio Waves" (Gostekhizdat, 1952), approved as a teaching manual for physics and physico-technical faculties of universities and the books by Ya.L.Al'pert, V.L.Ginzburg, and E.L.Faynberg "Propagation of Radio Waves" (Gostekhizdat, 1953). As a textbook for higher technical signal schools a book by M.P.Dolukhanov "Propagation of Radio Waves" (Svyaz'izdat, 1951 and 1952) is used. A number of papers was devoted to the examination of individual questions on the propagation of radio waves. These were collected in the books by B.A.Vvedenskiy and A.G.Arenberg "Questions of the Propagation of Ultrashort Waves", Part I ("Sovetskoye Radio", 1948), Ya.L.Al'pert "Propagation of Radio Waves in the Ionosphere" (Gostekhizdat, 1947), V.L.Ginzburg "The Theory of Propagation of Radio Waves in the Ionosphere" (Gostekhizdat, 1949), V.A.Fok "Diffraction of Radiowaves over the Earth's Surface" (published by the USSR Academy of Sciences, 1946), P.Ye.Krasnushkin "Method of Normal Waves in the Application to the Problem of Long-Distance Communications" (Publishing House of the Moscow Order of Lenin of the State University imeni M.V.Lomonosov, 1947), A.I.Potekhin "Some Problems of Diffraction of Electromagnetic Waves" ("Sovetskoye Radio", 1949) and in the collection of lectures "Newest Explorations of the Propagation of Radio Waves over the Earth's Surface" (Gostekhizdat, 1945).

The collection of papers "Research on Propagation of Radio Waves", prepared by the All-Union Soviet for radiophysics and radiotechnique of the USSR Academy of Sciences, was issued by the USSR Academy of Sciences (1948).

Antenna technique was treated in the textbook for higher technical signal schools by A.A.Pistol'kors "Antennas" (Svyaz'izdat, 1947) and in the monographs by I.A.Dombrovskiy "Antennas" (Svyaz'izdat, 1951 and 1952), G.Z.Ayzenberg's "Antennas for Main Line Shortwave Radio Communications" (Svyaz'izdat, 1949) and Ya.N.Fel'd's

"Basic Principles of the Theory of Slot Antennas" (Sovetskoye Radio, 1948). Standartgiz issued in 1950 a collection of lectures and annotations of author's certificates and patents "Centimeter Wave Antennas", prepared by the All-Union Institute of Technical Information.

The mechanical part of antennas is covered in a textbook for the higher technical signal schools by G.A.Savitskiy "Antenna Arrays" (Svyaz'izdat, 1947) and in his monograph "Principles of Calculation of Radiomasts" (Statics and Dynamics), (Svyaz'izdat, 1953).

The monograph by B.A.Vvedenskiy and A.G. Arenberg "Radio Waveguides", published by Gostekhizdat in 1946, was the first Soviet book devoted to the new method of transmission of electric power. In subsequent years, a few more important papers on this question were published. These include the books by L.A.Vaynshteyn "The Diffraction of Electromagnetic and Sound Waves at the Open End of a Waveguide" (Sovetskoye Radio, 1953), A.G.Gurevich "Hollow Resonators and Waveguides" (Sovietskoye Radio, 1952), presenting an introduction to the theory, and Ye.M.Studenkov's "Experimental Studies of the Propagation of Electromagnetic Waves in Hollow Conductors" (Published by the Moscow State Pedagogical Institute, imeni V.I.Lenin, 1947).

Many books on radiotransmitting devices were published during the last decade. The basic textbook for power engineering and electrotechnical colleges is the book by S.I.Yevtyanov "Radiotransmitting Devices" (Svyaz'izdat, 1950) which received the Stalin prize. The fundamental work by S.A.Drobov "Radiotransmitting Devices" was published in two editions (by the Leningrad Red Banner Military-Air Engineering Academy, 1947; Voyenizdat, 1951). A book bearing the same title by A.D.Yepifanov was published by Voyenizdat in 1945. The Military Red Banner Academy of Communications, imeni Budenniy published a manual by A.M.Semenov "Radiotransmitting Devices" (1950

For technical signal schools a teaching manual by Z.I.Model' and I.Kh.Nevyazhskiy "Radiotransmitting Devices" was published (Svyaz'izadt, 1949 and 1950). For the technical colleges of the radiotechnical industry, Gosenergoizdat published a textbook by B.M.Betin "Radiotransmitting Devices" (1951).

A series of monographs was published, including the books by B.S.Agafonov "Theory and Calculation of the Radiotelegraph Systems of Generator Tubes" (Sovetskoye Radio, 1954), by Z.I.Model' "Problems of Designing Powerful Radio Stations" (Gosenergoizdat, 1947), by S.V.Person "Circuits of Radiobroadcasting Transmitters with Frequency Modulation" (Sovietskoye Radio, 1951), by A.I.Eylenkrig and S.Ye.Glikman "Modulator Devices for Transmitters with Amplitude Modulation" (Sovetskoye Radio, 1954), by S.S.Arshinov "Temperature Stability of the Frequency of Vacuum-Tube Generators" (Gosenergoizdat, 1952), by S.S.Arshinov, S.V.Person, and A.I.Eylenkrig "Engineering Calculations of Circuits of Ultrashort-Wave and Short-Wave Generators" (Sections of Long Lines and Cavity Resonators) (Sovetskoye Radio, 1951).

The problems of equipment and operation of transmitting systems were treated in the books by L.A.Kopytin "Transmitting Radio Centers" (1951), A.T.Kholin "Control, Blocking, and Signaling on Radio Stations" (1953), P.A.Ostryakov and N.V.Zaryanov "Heat-Dissipating Devices of Powerful Radio Stations" (1954), L.A.Kopytin "Technical Functioning of Transmitting Radio Centers" (1954), A.S.Repin "Establishment and Operation of Enterprises of Radio Communication and Radiobroadcasting" (1953). All these books have been issued by Svyaz'izdat.

The most popular textbook on receiving devices - the book by V.I.Siforov "Radio Receiving Devices" - was reprinted three times in the postwar period. Originally published by Svyaz'izdat, it was published in the last few years by Voyenizdat (fourth ed. 1951; fifth ed. 1954). A manual for higher technical schools is the book by A.A.Kolosov "Resonator Systems and Resonator Amplifiers" (Svyaz'izdat,1949).

A book of the character of a teaching manual is the book by B.V.Plisov "Radio Receivers" (Editorial-Publishing Division of the Air Force, 1949). The electrotechnical institutes of communications use as a textbook the book by V.L.Lebedev "Radio Receiving Devices" (Svyaz'izdat, 1949).

Military schools and colleges use the books by N.M.Izyumov "Radio Reception" (Voyenizdat, 1954) and N.I.Chistyakov "Radio Reception and Operation of Receivers" (first ed., Voenmorizdat, 1951; second ed, Voyenizdat, 1953).

On individual problems of the radio receiving technique, the following monographs have been published: N.N.Krylov's "Electrical Processes in the Nonlinear Elements of the Receivers" (Svyaz'izdat, 1949) L.S.Gutkin's "The Conversion of Superhigh Frequencies and Detection" (Gosenergoizdat, 1953), M.R.Kaplanov's and V.A.Levin's "Automatic Frequency Tuning" (Gosenergoizdat, 1953), V.I.Bunimovich's "Fluctuation Processes in Radio Receiving Installations" (Sovetskoye Radio, 1951), M.L.Volin's "Intermediate-Frequency Amplifiers" (Sovetskoye Radio, 1950).

The practice of equipping and operating receiving centers was treated in the teaching manual for radio faculties of universities "Radio Receiving Centers" by V.K.Adamskiy (Svyaz'izdat, 1949).

The books on repair and maintenance of receivers include as the most fundamental the book by Ye.A.Levitin "Radiobroadcasting Receivers" (KOIZ, 1953).

The change-over to ultrashort-wave broadcasting and radio-relay communication system necessitated the publication of literature on the radiotechnique of superhigh frequencies. At present, many questions linked to this technique have been covered in the literature. The questions of the generation of superhigh-frequency oscillations are treated in the books by V.I.Kalinin "Generation of Decimeter and Centimeter Waves (Microwaves)" (Svyaz'izdat, 1948) and by M.S.Neyman "Triode and Tetrode Generators of Superhigh Frequencies" (Sovetskoye Radio, 1950). For this book, M.S.Neyman received the Stalin prize. Electronics was reviewed also in the books by V.F.Kovalenko "Introduction to the Electronics of Superhigh Frequencies" (Sovetskoye Radio, Part I, 1950; Part II, 1951) and V.M.Lopukhin "Excitation of Electromagnetic Oscillations by Electron Streams" (Gostekhizdat, 1953). In 1952, Sudpromgiz published a book by V.P.Blagoveshchenskiy "Foundations of the Radiotechnique of Superhigh Frequencies", intended for engineering-technical operators.

The first Soviet books on frequency modulation were the monographs by S.V.Novakovskiy "Frequency Modulation" (Svyaz'izdat, 1946) and A.A.Kulikovskiy "Frequency Modulation in Radiobroadcasting and Radio Communications" (Gosenergoizdat, 1947). This was followed by the books by I.S.Gonorovskiy "Frequency Modulation and Its Applications" (Svyaz'izdat, 1948) and S.V.Novakovskiy and G.P.Samoylov "Technique of Frequency Modulation in Radiobroadcasting" (Gosenergoizdat, 1952).

The specific features of electrical measurements at superhigh frequencies are analyzed in the books by B.A.Dobrokhotov "Radiotechnical Measurements on Centimeter Waves" (Sovetskoye Radio, 1948), R.A.Valitov and V.N.Sretenskiy "Radiotechnical Measurements at Superhigh Frequency" (Voyenizdat, 1951), R.A.Valitov "Radio Measurements on Ultrashort Waves" (Voyenizdat, second ed., 1948).

Publications on general radio measurements included a textbook for electrotechnical signal schools "Radio Measurements" by G.A.Remez (Svyazizdat, 1948) and a textbook for technical schools of the radiotechnical industry "Radio Measurements" by S.F.Korndorf, A.S.Bernshteyn, and M.I.Yaroslavskiy (Gosenergoizdat, 1953) and also a book by G.A.Remez and S.G.Itkin "Radio Measurements and Radiomeasuring Apparatus" (Voyenizdat, 1947), A.K.Balikhin's "Radio Measurements" (Voyenizdat, 1949), G.P.Shkurin's "Electric and Radio Testing Devices" (Voyenizdat, 1948), and "Handbook of Electric and Radio Testing Devices" (Voyenmorizdat, 1950).

The first Soviet books on pulse technique were the books by Ya.S.Itskhoki "Pulse Technique" (Sovetskoye Radio, 1949) and N.N.Krylov "Pulse Technique" (Svyaz'izdat, 1950) approved as a teaching manual for electrotechnical colleges. Now the basic book on these questions is "Pulse Technique" by L.A.Meyerovich and L.G.Zelichenko (Sovetskoye Radio, first ed., 1953; second ed. 1954). Pulse communication systems are described in N.M.Izyumov's book "Pulse Systems of Multichannel Radio Communication Systems" (Voyenizdat, 1947). Sovetskoye Radio published in 1954 a book by N.T.Petrovich and A.V.Kozyrev "Generation and Conversion of Electric Pulses".

Equipment operating on the pulse system is covered in books by S.A.Drobov "Ultrashort-Wave Pulse Generators" (Svyaz'izdat, 1946) and V.I.Siforov "Ultrashort-Wave Radio Receivers of Pulse Signals" (Svyaz'izdat, 1947) and D.V.Stepanov "Pulse Amplifiers" (Gosenergoizdat, 1954).

The results of studies on transient processes are summarized in the books by S.I.Evtyanov "Transient Processes in Receiver-Amplifier Circuits" (Svyaz'izdat, 1948), F.V.Lukin "Transient Processes in Linear Elements of Radiotechnical Devices" (Oborongiz, 1950), I.S.Gonorovskiy "Radio Signals and Transient Phenomena in Radio Circuits" (Svyaz'izdat, 1954) and I.I.Teumin "Handbook on Transient Electric Processes" (Svyaz'izdat, 1951 and 1952).

A number of books was devoted to television technique. These are books by A.Ya.Klopov and Ye.I.Rassadnikov "Foundations of Television Technique" (Gosenergoizdat, 1951), a textbook for technical signal schools by N.K.Ignat'yev "Television" (Svyaz'izdat, 1951 and 1952), A.Ya.Klopov "Foundations of Television Technique" (Sovetskoye Radio, 1953), P.V.Shmakov's "Color Television" (Gosenergoizdat, 1948) and "Foundations of Color and Volume Television" (Sovetskoye Radio, 1954), V.L.Kreytser's "Video Amplifiers" (Sovetskoye Radio, 1952) and S.I.Katayev's "Pulse Generators of Television Scanning" (Gosenergoizdat, 1951). Together with these editions, intended for the advanced reader, there appeared popular booklets telling about the principles of television transmission, and booklets with a description of concrete types of television receivers, intended for televiewers.

The literature on wire broadcasting was overwhelmingly operational-technical and was intended mainly for workers engaged in installations and operations of radio relay centers. Among literature of this kind should be mentioned the manual for trade schools of A.K.Chernyavskaya "Stations of Radio Relay Centers" (Svyaz'izdat, 1948) and V.N.Dogadin's "Installation and Servicing of Radio Relay Networks" (Trudrezervizdat, 1947), "Illustrated Handbook on Equipment for Radio Relay Centers" (Svyaz'izdat, 1948), the books by Yu.I.Avramenko "Monitor of Establishment of Radio

Communication Facilities" (Svyaz'izdat, 1952) and by V.N.Dogadin and A.K.Chernyavskaya "Manual for the Kolkhoz Radio Operator" (Svyaz'izdat, 1954).

The subject of some books was amplifiers. Problems of amplifier technique are treated in the books by A.A.Rizkin "Foundations of the Theory of Amplifying Circuits" (Sovetskoye Radio, first ed., 1951; second ed. 1954), S.N.Krize "Low-Frequency Voltage Amplifiers" (Gosenergoizdat, 1953), in the textbook for technical signal schools by S.N.Krize "Low-Frequency Amplifiers" (Svyaz'izdat, 1948), in the important textbook for motion-picture technical schools by I.Ya.Chudnovskiy "Amplifier and Rectifier Devices" (Goskinoizdat, 1949), in the textbook for motion-picture technical schools by B.A.Mal't "Rectifier and Amplifier Equipment" (Goskinoizdat, 1949) and in the textbook for schools and courses for cinemechanics by V.V.Muromtsev "Amplifier Devices and Electroacoustics" (Goskinoizdat, 1951).

S.A.Lyutov's book "Industrial Interference of Radio Reception and its Elimination", appeared in three editions (Gosenergoizdat, first ed. 1945; second ed. 1951; third ed. 1952) and is used as teaching manual for electrotechnical and power engineering colleges and faculties.

General questions on radar are treated in the books by I.V.Brenev "Basic Principles of Radar" (Military-Naval Academy of Shipbuilding and Armament imeni A.N.Krylov, 1947), A.F.Bogomolov "Basic Principles of Radar" (Sovetskoye Radio, 1954), and in the teaching manual for technical schools relating to the design and construction of devices and installations "Basic Principles of Radar", written by V.S.Nelepets and G.B.Belotserkovskiy (Oborongiz, 1954). A popular presentation of the foundations of radar is contained in the book by S.A.Bazhanov "What is Radar?" (Voyenizdat, 1948). The calculations and planning of radar receivers are presented in the book by A.P.Sivers "Radar Receivers" (Sovetskoye Radio, first ed. 1952; second ed. 1953).

The theory and practice of radio navigation is treated in the books by V.V.Shirkov "Ground Radio Navigation" (Voyenizdat, second ed. 1945), T.B.Asatur'yan "Radio

Navigation" (Redizdat Aeroflota, second ed. 1945; third ed. 1950), S.V.Kurinov "Radio Direction Finding of Aircraft" (Voyenizdat, second ed. 1945), T.M.Paliyevskiy "Utilization of Radio Direction Finders in Air Navigation" (Redizdat Aeroflota, 1953), G.N.Gordeyev "Radio Air Navigation Problems" (Voyenizdat, 1948), P.V.Karmalin "Physical and Technical Foundations of Naval Radio Direction Finding" (Morskoy Transport, 1945), Ye.Ya.Shchegolev "Radiotechnique in Ship Navigation" (Morskoy Transport, 1950) and "Naval Radio Navigation Systems" (Vodtransizdat, 1954), Yu.K.Baranov "Use of Sector Radio Beacons for Position Fixing of Ships at Sea" (Vodtransizdat, 1953), I.N.Dmitriyev "Position Fixing of Ships by Radio" (Voyenizdat, 1947) and I.N.Terekhov "Brief Course on Radio Deviation" (Voyenizdat, 1947).

On radioastronomy a popular essay by I.S.Shklovskiy "Radioastronomy" (Gostekhizdat, 1953) was published.

The large-scale introduction of electronic concepts into science and the national economy resulted in the publication of numerous books on this field of technique. These included books by: A.A.Sanin "Radiotechnical Methods of Radiation Research" (Gostekhizdat, 1951), A.M.Bonch-Bruyevich "Application of Electron Tubes to Experimental Physics" (Gostekhizdat, first ed. 1950; second ed. 1954), A.A.Bulgakov "Electronic Devices for Automatic Control" (Gosenergoizdat, 1951), A.L.Gorelik "Industrial Electronics" (Gosenergoizdat, 1951), V.A.Mikhaylov "Electronic Automation in Communal Economy" (published by the Ministry of Communal Economy RSFSR, 1953), A.V.Yerofeyev "Electronic Devices for Heat Control and Regulation" (Gosenergoizdat, 1951), I.A.Ibragimov "Electronic Devices for Control and Regulation in Oil Refining and Processing" (Aznefteizdat, 1954).

For the planning of electric vacuum devices and radio equipment and for the workers in the radiotechnical industry, Gosenergoizdat published during the last several years books by K.I.Krylov "Physical Foundations of the Electric Vacuum Technique" (1949), Yu.A.Katsman "Foundations of the Calculation of Radio Tubes" (1952), B.M.Tsarev "Calculation and Design of Electron Tubes" (1952), S.A.Yamanov and S.A.Smirnov "Handbook on Insulation Materials for the Radio Industry" (1947), D.M.Kazarnovskiy "Testing of Radiotechnical Materials and Parts (1953), V.A.Volgov "Circuit Elements of Radio Sets" (1954), V.B.Pestryakov and D.D.Sachkov "Design of Radio Equipment" (1947), D.D.Sachkov "Design of Radio Equipment" (1951), A.D.Frolov "Handbook for Designers of Radiobroadcasting Receivers" (1951), Ye.Yevteyev and V.A.Zhukov "Technology of Radio Equipment" (1952), S.M.Plakhotnik "Manufacturing Technology of Radio Equipment" (1949), S.A.Yamanov and D.D.Sachkov "Methods of Protection of Radio Parts from Humidity" (1951).

Calculations and planning of converters for radio sets are treated in the book by G.S.Tsykin "Low-Frequency Converters", published by Svyaz'izdat (1950).

Special mention should be made of the compilation and publication of textbooks on individual questions of radiotechnique. The Voyenizdat published "Problems of Radiotechnique" by D.F.Masanov (first ed., 1948; second ed., 1949), while the "Morskoy Transport" published "Problems of Naval Radiotechnique" by N.N.Krylov (1950) and the Leningrad Red Banner Military-Air Engineering Academy published a manual by Yu.I.Sokolovskiy "Problems of Theoretical Radiotechnique Part I: Linear Systems" (1948).

Gosenergoizdat published a teaching manual for the higher technical signal schools by Yu.S.Bykov, R.A.Valitov, and L.S.Gutkin "Problems in the Course of Radio Receiving Devices" (1947), while the Svyaz'izdat published a teaching manual for colleges by Ye.R.Gal'perin, V.P.Godelevich, S.I.Yevtyanov, P.Zh.Kriss, S.I.Kunina and I.A.Popov "Problems of Radiotransmitting Devices" (1951). The Military Red Banner Academy of Communications, imeni S.M.Budenniy issued a manual by N.N.Khlebnikov "Collection of problems and exercises for the Courses on Electric Vacuum Devices" (1948).

Questions of international control of operation of radio stations were covered in a publication by Svyaz'izdat "Rules on Radio Communications" (1949) and in a book by S.B.Krylov "International Law on Radio Communications and Radiobroadcasting"

(1950).

Several publishing outfits are engaged in the publication of popular scientific and radio amateur literature, with a leading position occupied by Gosenergoizdat. This publishing house, by issuing a booklet by S.A.Bazharov "How Does a Radio Tube Operate. Classes of Amplification", started in 1947 with publications of a serial radio library under the general editorship of Academician A.I.Berg. Since then more than two hundred booklets and books of this series were published, devoted to widely differing topics. These include books by A.D.Batrakov and S.Kin "Elementary Radiotechnique" in two parts (Part I, 1951; Part II, 1952), S.Khaykin "Dictionary of the Radio Amateur" (1952), A.A.Kulikovskiy "The newest in the Technique of Radio Reception" (first ed., 1950; second ed., 1954) Ye.Ya.Pumper "Crystal Diodes and Triodes" (1953), A.S.Presman "Centimeter Waves" (1954), V.N.Loginov "Radio Measurements" (1954), S.M.Gerasimov "How to Read Radio Circuits" (1948), F.I.Tarasov "The Practice of Radio Assembly" (1949), G.G.Sitnikov "Handbook of the Radio Listener in Questions and Answers" (1949), V.V.Yenyutin "A Guide to Radio Amateur Magazines" (1950), G.V.Pankov "Principles of Frequency Modulation " (1949), S.V.Novakovskiy and G.P.Samoylov "Reception of Television Transmissions" (1953), S.A.Yel'yashkevich "Industrial Television Receivers and Their Operation" (1951), V.G.Korol'kov "Magnetic Recording of Sound" (1949), V.Yu.Roginskiy "Semiconductor Rectifiers" (1952), A.Ya.Korniyenko "Radio-Relay Television Center" (1950), G.A.Ryabchinskiy "Radiotechnical Materials" (1950), D.A.Konashinskiy and S.Ya.Turlygin "Introduction to the Technique of Ultrahigh Frequencies (1951), and others.

The total circulation of booklets of the serial radio library exceeded seven million copies up to the present time.

Radiotechnique and its application are covered in several books of the popular scientific library of the Gostekhizdat. They are "Radio Navigation" by Ye.Ya.Shchegolev (1946), "Radar" by G.S.Gorelik and M.L.Levin (1947 and 1948) and F.I.Chestnov (1952), "Radio" by A.F.Plonskiy (1954), "Television" by K.A.Gladkov (first ed., 1950; second ed., 1951; third ed., 1952) and others. Such booklets have also been published by Svyaz'izdat, Voyenizdat, Goskul't-prosvetizdat and other publishers.

Toward the end of 1954, Svyaz'izdat started publishing booklets in a series "Manual for Rural Installation Crews of Radio Communication Facilities" ("Coil Loading of Rural Underground Lines of Radio Communications" by M.S.Orlov, "Wind-Driven Generator VE-2 and Its Operation" by G.M.Sabinin and V.R.Sektorov, and others).

In 1951, the technical administration of the Ministry of Communications prepared lectures on communications technique for engineers and technicians. Some lectures during the past years were devoted to radiotechnique and its practical utilization. These are lectures by I.F.Agapov "Two-Channel Frequency Radiotelegraphy with Active Spacing - TFT" (1953), S.V.Borodich's "Multichannel Radio Relay Lines" (1953), V.S.Mel'nikov's "Frequency Radiotelegraphy" (1952), I.V.Ostrovskiy's "Radio Communication on a Single Frequency Sideband" (1952), B.A.Shvarts's "Duplex Radio Communication with Combined Installation of Transmitters and Receivers" (1953) and others.

In a series of informative books on the new technique, which are also being compiled by the technical administration of the Ministry of Communications and published by Svyaz'izdat, the following collections were issued: "Technique of Establishing Radio Communications in a Village" (1954), "System and Equipment for Wirebroadcasting in Cities" (1951), "Inter-District and Inter-Raion Radio Communication" (1949), "Frequency Keying in Radiotelegraph Communication Systems" (1949), "Radio Communications and Radiobroadcasting" (1947), "Establishment of Radio Communications" (1949).

Another series to be mentioned is the operation-technical literature of the Ministry of Communications. The installation and operation of radio communication and radio broadcasting stations must be carried out in conformity with fixed rules. The development and perfection of these rules are of great importance for improving the operation of radio stations. This is the reason for the considerable attention devoted to the publication of operation-technical manuals. The most popular forms of radio stations are radio-relay centers. For these, electric standards of projecting networks, rules of design and maintenance and repair of radio-relay networks, rules of technical operation of radio-relay centers, typical projects of centers of various power and other literature were compiled and published. Operation-technical literature is also issued for enterprises of radio communications and radiobroadcasting. This kind of literature is published by Svyaz'izdat.

Apart from the publishing houses, some teaching and scientific-research institutes as well as social organizations engage in publishing activities. Over a number of years (1947 - 1949) a "Collection of Works of the Leningrad Electrotechnical Institute of Communications imeni M.A.Bonch-Bruyevich" was published. In addition, separate collections of the works of the Moscow and Odessa Electrotechnical Institutes of Communications and other teaching establishments were published.

In 1954, works of the All-Union Scientific Research Institute of Radiobroadcasting Reception and Acoustics of the Ministry of Radiotechnical Industry began to be issued. Questions of radiotechnique are also reviewed in the collection of works of the Electrotechnical Institute of the USSR Academy of Sciences.

Sections of the All-Union Scientific Technical Society for Radiotechnique and Electrocommunications, imeni A.S.Popov, published results of their work. They published the booklets by I.S.Dzhigita "Contemporary Radar Systems"; V.A.Smirnov "Theory and Calculation of Small Nonlinear Distortions, with Amplification of the Frequency-Modulated Oscillations"; A.I.Lebedev-Karmanov "Comparison of the Modulation Circuits in Ultrashort Wave Television Transmitters"; A.M.Pisarevskiy "Analysis of Nonlinear Distortions Due to Transient Processes in Powerful Class C Amplifiers"; B.A.Vvedenskiy and M.I.Ponomarev "Application of the Methods of Geometrical Optics to the Fixing of Trajectories of Ultrashort Waves in a Heterogeneous Atmosphere"; Ye.Ya.Shchegolev "Radio Interference Methods and the Study of the Propagation of

Radio Waves"; S.I.Katayev "Some Questions on the Formation of Electric Pulses in Television and Other Technical Fields"; G.V.Braude "Fluctuation Noise in Amplification of Television Signals and Sensitivity of the Transmitting Television Tubes", and many others.

Together with books by native specialists, we issue regularly translated literature. The larger portion of such literature is published by the specialized "Publishing House of Foreign Literature". This outfit published, in particular, the books by G.Bode* "Theory of Circuits and Projection of Amplifiers with Feedback" (1948), by L.Levin "Contemporary Theory of Waveguides" (1954), of Ya.Groshkovskiy "Generation of High-Frequency Oscillations and Frequency Stabilization" (1953), by Louis de Breuille "Electromagnetic Waves in Waveguides and Hollow Resonators" (1948), by S.Goldman "Harmonic Analysis, Modulation, and Noise" (1951), by A.F.Harvey "High-Frequency Electron Tubes" (1948), of J.Markus and V.Zellhof "Technical Applications of Electron Tube Circuits" (ed. 1, 1953; ed. 2, 1954), by V.Schokle "Theory of Electronic Semiconductors" (1953), by S.Deshman "Scientific Foundations of the Vacuum Technique" (1950), of K.Hering and M.Nichols "Thermoelectronic Emission" (1951), of P.Gerlick "Application of Photocells" (1952), by A.Rustergol "Electron Optics" (1952), by L.Kedi "Piezoelectricity and its Practical Applications" (1949), by B.Lowell and J.Klegg "Radioastronomy" (1953), Collections of Translations "Propagation of Centimeter Radiowaves in the Troposphere" (1950), "Semiconductor Electron Devices" and "Theory of the Transmission of Electric Signals in the Presence of Interference" (1953).

Extensive work was done by the publishing house "Sovetskoye Radio" in publishing translated literature. This outfit issued the books by A.E.Harrison "Klystron" (1946), by E.Schneider "Radar" (1947), by J.Slater "Electronics of Superhigh Frequencies" (1948), by G.Colman "Generation and Amplification of Decimeter and Centimeter Waves" (1948), by D.Fisk, G.Cagstrom and P.Gateman "Magnetrons" (1948),

*Translator's note: Not all of the Western authors' names have been verified.

"The Principles of Radar" (Part I, 1948; Part II, 1949), "Radar Technique" in two parts (1949), "Principles of the Technique of Centimeter Waves in Radar" (1951), "Generation of Electric Oscillations of Special Form" (1951), "Tube Circuits for Time Measurements" in two parts (1951), "Antennas of Centimeter Waves" in two parts (1950), "Radiotechnical Navigation Means" (1948), "Printing Technique of Circuits" (1948), "Handbook on Waveguides" (1952), "Crystal Detectors" (Part I, 1950; Part II, 1951), "Measurements on Superhigh Frequencies" (1952), and many other publications. The publishing house translated and issued the best books from the series of the Massachusetts Institute of Technology.

A number of translated books was published also by other publishers. For example, Gostekhizdat issued the books by F.B.Levellin "Inertia of Electrons" (1946), by S.Ramo and J.Yinneri "The Fields and Waves in Contemporary Radiotechnique" (first ed., 1948; second ed., 1950), of J.Slater "The Transmission of Ultrashort Radiowaves" (first ed., 1946; second ed., 1947), of J.Stratton "The Theory of Electromagnetism" (1948), by S.Herman and S.Wegener "The Oxide Cathode" (1949), by I.Schintelmeister "The Electron Tube as a Device for Physical Measurements" (1949). Gosenergoizdat published the books by Barton Cog "Elements of Radiotechnique" (1947), by O.S.Packel "Scanning Oscillators" (1948), by S.Ramo "Introduction to the Radiotechnique of Superhigh Frequencies" (1948), by J.G.Reich "Theory and Application of Electron Devices" (1948), by P.King, G.Mimno, and A.Young "Transmitting Lines, Antennas, and Waveguides" (1948), by G.Keller, G.Reich and L.Woodruff "The Technique of Ultrahigh Frequencies" (1948), by Brucke and Reknagel "Electron Devices" (1949). Svyaz'izdat published books by R.Sarbacher and V.Edson "Technique of Superhigh Frequencies" (1947) and by G.G.Skilling "Introduction to the Theory of Electromagnetic Waves" (1947), Voyenizdat published a collection "The Theory and the Technique of Radar" (1947) and the book by D.Fink "The Technique of Radar" in two parts (1950). Oborongiz published "The Foundations of Radar" in two parts (first ed., 1950; second ed., 1951).

A great deal of attention is devoted to collections of translations and reviews of foreign periodicals. The management of the scientific information center of "Publishing House of Foreign Literature" is issuing a series "Questions of Radar Technique" (six issues a year) and "Problems of Modern Physics" (twelve issues a year) whose individual issues are devoted to questions of radiotechnique. For example, this series contains the collections "Propagation of Radio Waves in the Ionosphere" (1953), "Physics of the Ionosphere and the Propagation of Radiowaves" (1954) and "Radioastronomy" (1953).

During the past decade, the publication of domestic periodicals on radiotechnique also increased. In April 1946 began to appear a monthly scientific-technical and theoretical magazine "Radiotechnique", the organ of the All-Union Scientific-Technical Society of Radiotechnique and Electrocommunications, imeni A.S.Popov. The function of this magazine is a generalization of the working experience of scientific research institutes, laboratories, colleges, and individual specialists and clarification of the newest theoretical questions of radiotechnique.

In this magazine, up to the beginning of 1955, over four hundred technical articles of the most diverse topics were published. These manifold articles included: I.Ye.Goron's "Restoration of the Recorded Speeches of V.I.Lenin" (No.2, 1949), A.A.Kharkevich's "The Basic Features of the General Theory of Communications" (No.5, 1954), M.S.Neyman's "The Mechanism of Radiation of Electromagnetic Energy by Metal Antennas" (No.5, 1951), A.A.Pistol'kors "On the Theory of a Wire Parallel to the Horizontal Boundary of the Dividing Line between Two Media" (No.3, 1953), I.F.Agapov's "Two-Channel Frequency Radiotelegraphy" (No.3, 1954), S.N.Losyakov's "The Basic Relationship between Signal Power, Frequency Band, and Signal-To-Noise Ratio in Radio Communications" (No.1, 1950), N.G.Kruglov's "Plate Self-Modulation of Radio Transmitters" (No.2, 1949), and "Some Questions on Plate Self-Modulations" (No.2, 1954), B.P.Terent'yev's and N.V.Kovalenko's "Bridge Circuits of Additional Transmitter Power (No.1, 1952), Yu.B.Kobzarev's "Theory of Vacuum-Tube

Oscillators with Two Idling Stages" (No.2, 1950), S.I.Yevtyanov's "Theory of the Quartz Self-Oscillator" (Nos. 1 and 5, 1949), G.A.Zeytlyenok's "Parameters of Electron Tubes on Ultrahigh Frequency" (No. 1, 1953), B.S.Agafonov's "Loading Characteristics of Modern Vacuum-Tube Generators" (Nos.2 and 4, 1953), S.S.Arshinov's "Thermocompensation at changing TKI" (No.5, 1950), V.M.Vol'f's "Dynamic Study Method of Nonlinear Distortions" (No.2, 1953), S.V.Person's "Nonlinear Distortions when Amplifying Frequency-Modulated Signals" (No.6, 1951), I.S.Gonorovskiy's "Relationship between Frequency and Phase Characteristics of a Linear Circuit" (No.1, 1954), S.V.Novakovskiy's "Modern Color Television Systems" (Nos.4 and 5, 1952), V.D.Kuznetsov's "A Collective Antenna for Television" (No.4, 1952), L.V.Mitel'man's "Television Measuring Apparatus" (No.6, 1951), S.A.Lyutov's "The Calculations of L-Network Inductance-Capacitance Filters, for Suppression of Industrial Radio Interferences" (No.5, 1949), G.S.Tsykin's "Calculations of the Cascades of Broad-Band and Pulse Amplification with a Correction RC Network in the Plate Circuit" (No.3, 1952), Ye.L.Faynberg's "Soviet Radiophysics and Theory of the Propagation of Radio Waves Along the Earth's Surface" (No.4, 1947), A.V.Netushil's "Calculations of the Load of a High-Frequency Generator when Heating Plane Dielectric Plates and Slabs" (No.6, 1950), G.V.Voyshvillo's "Present Status of Radiotechnical Terminology and Conventional Designations in the Field of Radiotechnique and Electrocommunications" (No.1, 1951), and others.

In connection with the thirtieth anniversary of Soviet power, one of the issues of the magazine (No.8, 1947) was devoted to a survey of scientific-technical work by Soviet scientists and engineers in the field of radio during the thirty years since the day of the Great Socialist October Revolution. In this issue are printed articles by A.L.Mints "The Success of the Technique of Radiotransmitting Systems in the USSR", by V.I.Siforov "The Works of Soviet Scientists on the Theory of Radio Reception", by P.N.Kuksenko "The Development of Soviet Trunk Line and Radiobroadcasting Radio Receivers over a Period of 30 Years", by I.G.Klyatskin "The Beginning of the Soviet Theory of Antennas", by G.Z.Ayzenberg "Development of the Technique of Short-Wave Antennas in the USSR", by A.A.Pistol'kors "Contemporary Status of the Theory of Slot Antennas", by I.S.Dzhigit "History of the Development and Achievements of Soviet Television", by S.N.Rzhevkin and V.V.Furduyev "The Development of Works on Electroacoustics in the USSR", by V.N.Kessenikh "Ionospheric Investigations in the USSR", by B.A.Vvedenskiy and M.I.Ponomarev "About the Work of Soviet Scientists on the Propagation of Ultrashort Waves", and by S.M.Rytov "The development of the Theory of Nonlinear Oscillations in the USSR".

Later on, a few topical issues of the magazine appeared. Thus, No.2 of "The Radiotechnique" for 1952 was devoted to basic theoretical and some applied questions of magnetic sound recording, and No.4 of the magazine - to questions of television technique.

In 1946 (April), publication of the popular monthly radiotechnical magazine "Radio" was resumed (formerly "Radiofront"), this being the official organ of the Committee on the Establishment of Radio Communication Facilities and Radiobroadcasting of the Council of Ministers of the USSR and of the Central Soviet Osoaviakhim of the USSR. The first issue of this magazine had a circulation of 20,000 copies and then increased by several times. In 1955, the magazine has a circulation of 150,000 copies, two and a half times more than prior to the war; however, the demands for the magazine are not yet fully satisfied.

From No.7, 1950, the magazine "Radio" became the official organ of the Ministry of Communications of the USSR and of the All-Union Voluntary Society of Assistance to the Army (now DOSAAF).

The magazine publishes theoretical and general technical articles, gives descriptions of electron tubes and industrial radio equipment, and furnishes schematics and designs for amateur receivers, television sets, and parts. Papers are published regularly on short and ultrashort waves, sound recording and electroacoustics, measurements, measuring apparatus, supply sources, application of radio in the national economy, establishment of radio communication facilities and radiobroadcasting in the countries of the peoples' democracies. The experience of Soviet radio amateurs is described in the section "Exchange of Experiences". Apart from this, the magazine prints articles, surveys, and notes on the development of radiotechnique, on the establishment of radio communication facilities and radio amateur work, as well as annotations of new books on radiotechnique and critical reviews.

Many outstanding scientists and radio specialists are collaborating in the magazine: A.I.Berg, B.A.Vvedenskiy, V.I.Siforov, A.L.Mints, S.E.Khaykin, P.V.Shmakov, M.P.Dolukhanov, Z.V.Topuria, N.G.Kruglov, V.S.Mel'nikov, S.N.Krize, and others.

The problem of large-scale introduction of the newest domestic technique and improvements of operation of all communication means demanded a reorganization of the magazine of the Ministry of Communications of the USSR "Vestnik Zvyazi" (Herald of Communications), which appeared in two issues - "Electrocommunications" and "Post". In the old layout of the magazine, the questions of establishment and operation of means of communications, economics, planning, the struggle for fulfilment of the State plan, were spread over two issues, which made an interchange of experience and application of the achievements of some branches of communications to other branches more difficult. Therefore, starting January 1, 1949, the issue "Electrocommunications" was replaced by the issue "Tekhnika Zvyazi"(Communications Technique) and the issue "Post" was replaced by "Organization and Utilization of Communications Facilities". In both issues, articles were systematically published on questions of radiotechnique and operation of communications and radiobroadcasting facilities.

However, the editing of the magazine "Herald of Communications" in two issues led a division, between the two issues, of the closely interrelated questions of acceptance and introduction of the new technique, of the organization and utilization of communications means and of economics and planning. To eliminate this drawback, both issues of the magazine "Herald of Communications" were combined, at the beginning of 1951, in one monthly engineering-technical magazine "Herald of Communications".

From 1951 to 1953 a monthly mass-produced magazine "The Soviet Communicator" was published, which was the publication of the Ministry of Communications of the USSR and the Central Committee for the Trade Union of Communication Workers. The journal published material of advanced experience in operation, organization of socialist competition, newest achievements and communication technique, history of domestic technique, etc.

From No.6, 1953 onwards, "The Herald of Communications" and the "Soviet Communicator" were united into one monthly production-technical magazine "Herald of Communications", the publication of the Ministry of Communications of the USSR. This magazine is intended for supervisory engineering-technical and intermediate operational staff of administrations, enterprises, and district offices of communications. The magazine outlines the technical policy of the Ministry of Communications, describes the new technique of communications, and discusses questions of operation of the means of communications, rationalization and development of inventions, history of domestic technique, etc.

During 1954 alone, the magazine published over 30 technical articles on questions of radio communication, radiobroadcasting, and television and over 20 articles on questions of organization and operation of radio economy. The published articles include the following: S.V.Borodich's "Frequency Densification of Radio-Relay Lines of Communication" (No.3) and "Densification of the Radio Relay Lines of Communication as to Time" (No.7), I.A.Gusyatinskiy's "Experience of Operation of Radio Relay Main Lines of Communications" (No.5), K.M.Kosikov's "Phenomena in the Ionosphere and Ways of Weakening their Influence on Radio Communications" (No.8), A.A.Magazanik's "Device for Frequency Control in Frequency Telegraphy Channels" (No.5), I.P.Agapov's "Experience in Utilization of Two-Channel Systems of Frequency Radio-Telegraphy" (No.3), A.I.Miroshin's "Plate Self-Modulation on Short-Wave Transmitters" (No.5), A.Ya.Stukman's "Amplitude Selectivity in Double Reception" (No.9), E.S.Soberayskiy's "Increase in the Stability of the Action of Phototelegraphic Radio Communications" (No.4), N.A.Savina's and B.Ya.Gertsenshteyn's "Projecting of Long Feeder Lines for Wire Broadcasting" (No.9), P.S.Mozharovskiy's "Some Questions on the Improvement of the Quality of Operation and the Reduction in Initial Cost of Operation in Radio Enterprises" (No.8), N.V.Zaryanov's "Cooling Systems of Radio Stations" (No.12), A.M.Lokshin's and P.M.Kolpakov's "Selection of Inductance of Cathode Chokes and Capacitance of Coupling Capacitors for the Transmitter Stages Designed on the Principle of Inverted Circuits" (No.10), A.V.Radziyevskiy's and Ye.A.Shapiro's "How to Improve the Operation of Kolkhoz Radio Centers" (No.8), N.A.Savinov's "Experience of Designing and Operating Lines of Joint Suspension of Feeder Radio Relay Circuits and of Circuits of Inter-District Telephone Communication" (No.1), etc.

Articles on radiotechnique are also being published by the magazines of the Academy of Sciences of the USSR: "Reports of the USSR Academy of Sciences", "News of the USSR Academy of Sciences, Department of Technical Sciences", "Journal of Technical Physics".

In the postwar years, Soviet radiotechnical literature was being exported abroad in substantial quantity. This literature is used in the countries of the peoples' democracies, in particular. The technical publishing houses of these countries proceeded to republish the best Soviet radiotechnical books in the native tongue of the respective country. These republications include: teaching manuals for higher and medium special schools, engineering-technical monographs, radio amateur literature, etc. The popular radio amateur textbook "Radiotechnique" by I.P.Zherebtsov was issued in Bulgaria (two editions), Czechoslovakia, the German Democratic Republic, and Rumania, while the textbook for technical signal schools "Radiotransmitting Devices" by Z.I.Model' and I.Kh.Nevyazhskiy was republished in Poland, Hungary, and the German Democratic Republic, the monograph by G.S.Tsykin

"Low-Frequency Converters" is translated into Hungarian, Rumanian, and Polish, the book by G.Z.Ayzenberg "Antennas for Main Line Short-Wave Radio Communications" has been republished in the Chinese Peoples' Republic, etc.

The Communist Party and the Soviet government devote a great deal of attention to the development of book publishing in our country. The production of paper is being increased, new polygraphic combines are being created, equipped with the most modern technique, and the bookselling market is being broadened.

In 1952 a fixed system of establishing rates for book production was introduced by Government decree. Previously, before this resolution was accepted, the prices for books were fixed by each publishing house on the basis of its own norms. Therefore, a great discrepancy in prices existed. Prices for books were determined not only by the character of the edition, but mainly by the special features of the publishing house: the volume of its activity, cost of wages, polygraphy, overhead, etc. As a result, the consumer had to pay for the poor organizational work of the publishing houses, and books of absolutely the same type differed sharply in price only because they were issued not by one but by different publishers.

The Government decision motivated by concern with the interest of the people put an end to this abnormal situation. Starting in 1952, the prices for books were determined by one single indicator, namely the type of book. For example, each sheet of copy of a textbook for technical disciplines for a medium special school can be sold for no more than 35 kopeks, a sheet of copy of strictly special information literature for engineers and technicians for no more than 50 kopeks, classical science productions for no more than 30 kopeks, etc. Identical prices have been established for binding, graphic production, etc. To get an idea as to the advantage to the user as a result of the introduction of maximum ratings, a few comparisons will suffice: The book by N.I.Chistyakov "Radio Reception and Operation of the Radio Receiver", published by Voyenmorizdat in 1951 was selling at 8 rubels, 50 kopeks. The same book, in the same size, republished in 1953, sold at 6 rubels.

The book by S.A.Lyutov "Industrial Interference in Radio Reception and Its Elimination" (State Publishing House for Electric Power) published in 1951, was priced at 13 rubels, 35 kopeks, whereas its next edition, published in 1952, was selling at 9 rubels, 05 kopeks, despite the fact that the size of the book had increased by more than 30%. The selling price of the booklet by A.P.Gorshkov "How to Install a Radio Receiver", published in 1950 by the State Publishing House for Electrocommunication, was 1 rubel, 10 kopeks, while the price of the second edition of this booklet, published in 1952, amounted to only 90 kopeks, despite the fact that the size of the booklet had increased by almost 50%.

Simultaneously with the fixing of new uniform rates for book production, a reevaluation of books issued in former years and still available in the bookseller's market was carried out. On the average, this reduction was about 18%.

Despite certain success achieved by the technical publishing houses during the last several years, their operation still shows shortcomings. The publishers do not amply satisfy the inquiries of readers as to literature, a number of books does not correspond in contents to the present status of science, does not meet the basic concept of the contents, or language and form do not satisfy the increased demands of the Soviet reader. Sometimes dull, carelessly written, unfinished books are put on the market, of excessive size with predominantly descriptive material, and of unsatisfactory polygraphic quality.

The publishing houses must work intensively and diligently in order to give the Soviet readers the very best what has been created by man in the fields of science and technique, as demanded by the interests of the communist structure.

HISTORICAL SKETCH OF DOMESTIC RADIOTECHNIQUE

(Some Chronological Data, 1895 - 1940)

by

V.I.Shamshur

1895 (7 May) A.S.Popov delivered a lecture "The Relation of Metal Powders to Electric Oscillations" at the conference of the Russian Physico-Chemical Society in St.Petersburg and demonstrated the first radio receiver in the world.

1896 (24 March) At the next conference of the Russian Physico-Chemical Society, A.S.Popov realized the first, in the history of mankind, transmission of a wireless communication. Over a distance of 250 m, a radiogram consisting of two words: "Heinrich Hertz" was transmitted.

1897 (June) During experiments in radio communication, a range of 5 km was reached on ships of the Baltic fleet in the summer of 1897, and reflection of electromagnetic waves from ships was detected. In a report on these experiments, A.S.Popov pointed out the particular features of the propagation of radio waves, which later on became the basis of radio navigation and radar.

1900 (6 Feb.) The first practical radio communication line in the world was opened, 50 km long between the islands of Gogland and Kotka on the coast of the Gulf of Finland for servicing the rescue operations in connection with the removal from the rocks of the foundered armor-clad "General-Admiral Apraksin". The first radiogram sent by A.S.Popov to Gogland contained an order to the icebreaker "Ermak" to put to sea and try to find the fishermen carried out to sea on a broken-off ice floe. "Ermak" carried out the order and rescued 27 fishermen.

1900 (6 July - 9 Aug.) Under the guidance of A.S.Popov, successful experiments on the use of portable radio stations were carried out during maneuvers of the 148th Caspian Regiment.

1901 (summer) In experiments on radiocommunication on the Black Sea, A.S.Popov used complicated devices of transmitting and receiving radio stations: a range of radiocommunication of 150 km was achieved (by receiving radiograms on telephone receivers).

1901 (Sept.) A.S.Popov organized the construction of civilian radio stations for transmitting messages to the Rostov Harbor on the water level in the arms of the river Don.

1902 A.S.Popov started his first lecture series in the Electrotechnical Institute of St.Petersburg, which he gave the name: "Wireless Telegraphy". A lithographed edition of these lectures formed the first textbook on radiotechnique in Russia.

1907 (25 July) Professor B.L.Rozing of the St.Petersburg Polytechnic Institute obtained a patent on a method of "electric telescopy" (Transmission of images at a distance). The basis of the patent was the use of electron-beam tube for reception.

1908 V.V.Subbotin designed a generator of the inductor type with reversible poles for 500 cycle frequency and 0.5 kw power.

1911 (9 May) B.L.Rozing obtained on the screen of a cathode-ray tube the simplest image (a square).

1911 D.A.Rozhanskiy perfected the construction of the cathode-ray tube by using magnetic focusing and electrostatic deflection of the electron beam.

1912 V.P.Vologdin (1881 - 1953) designed the first high-frequency machine in St.Petersburg, on orders of the Department of the Navy. The power of the machine was 2 kw, the frequency 60 kc. The rotor of the machine was making 20,000 rpm with a peripheral speed of about 314 m/sec.

1913 (16 Jan.) A "Radiotelegraph Station" of the Navy department was officially opened in St.Petersburg, created at the Kronstadt radio laboratory of A.S.Popov.

1914 (Sept. - Dec.) Two powerful spark-transmitter radio stations were erected in Tsarskoe (Detskoe) Selo near St.Petersburg and on the Khodyn field in Moscow, as well as a receiving station "The Tver radiostation of international communication". The Khodyn radiostation began operating on 6 December, 1914. Both transmitting stations were single-type spark transmitters with rotary discharger.

1914 N.D.Papaleksi began an experiment to produce cathode tubes (with gas) for the amplification and generation of oscillations. The first tubes were ready by the end of 1914. N.D.Papaleksi contributed a substantial improvement to the technology of tube production by applying high-frequency induction heating for lighting of the electrodes during the exhaustion. This invention was substantially ahead of the patent, obtained in 1918 by the German firm "Hut", on the use of high-frequency currents for the induction heating of electrode tubes.

1915 With the aid of N.D.Papaleksi's generator tubes (Power about 200 w, oxide-coated cathode with direct heating and platinum base), and with his cooperation, radiotelephone communication was established between Petrograd and Tsarskoe Selo.

1915 (June) The radiotelegraph station of the Navy Department was transformed into the radiotelegraph plant of the Navy Department, which executed all the basic constructions of radiotelegraph stations for the warships of the Russian Navy.

1915 At the end of the year, under the guidance of V.I.Volynkin, at the radiotelegraph plant, began the development and manufacture of electron tubes, interrupted in 1917 and resumed in 1922. The first lot of tubes made by the radiotelegraph plant was delivered to the Navy on 8 December, 1922, and the last on 9 August, 1924. The tubes of the radiotelegraph plant bore the designation LK1 and were intended for operation in vacuum-tube amplifiers, manufactured by the same plant for the Navy.

1915 At the end of the year, M.A.Bonch-Bruyevich, at the Tver receiving radiostation, produced the first gas radio tubes and, with their aid, began to realize reception of signals of radio stations which operated with undamped oscillations, applying for this purpose a tube heterodyne.

1916 (spring) M.A.Bonch-Bruyevich developed the technology of manufacturing tube amplifiers with purely electron dischargers.

1916 (23-29 Sept.) M.V.Shuleykin carried out a series of experiments on the battleship "Andrey Pervozvanny" with a high-frequency machine, designed by V.P.Vologdin, and succeeded in establishing radiotelegraph communication between Petrograd and Helsinki.

1916 The "News on Mine Matters", published an article by M.V.Shuleykin "The Conditions of Application of High-Frequency Generators for Radiotelephony", which gave a mathematical treatise, including a formula for proving that, in the process of modulation of undamped oscillations, "side" frequencies arise in addition to the carrier frequency.

1917 (7 Nov.) The radio station of the cruiser "Aurora" transmitted an address by V.I.Lenin "To the People of Russia", informing them about the downfall of the Temporary Government and the transfer of power into the hands of the Petrograd Soviet of Workers and Soldier Deputies - War Revolutionary Committee.

1917 (Dec.) A trade union of radio specialists was formed, which took part in the creation of a network of radio receiving stations and of first radio courses for the training of qualified radio specialists.

1918 (spring) A network of civilian radio receiving stations NKPiT began to function and develop, intended for the reception of omnidirectional transmissions, addressed "CQ, CQ, CQ". Radiograms for this network were transmitted by the radio stations of Khodyn, Detskosel'skaya and Tashkent. In the fall of 1918, the texts of radio messages from Moscow were posted in all towns and large railway centers.

1918 (spring) In Moscow, on Myasnitskaya Street (now Kirov Street) courses on radio were opened. Later on, with these courses as basis, a radiotechnical school of national communication was created (on Gorokhov Street). In 1921, the technical school was reorganized into the Institute of Communication imeni V.N.Podbel'skiy.

1918 (21 July) A decree by the Soviet of the People's Commissars was promulgated "Centralization of Radiotechnical Affairs", which laid the foundation for Soviet radio construction. The decree provided for the transfer of several powerful radio stations from the War Department to NKPiT and the establishment of Radiosoviet NKPiT, whose task it was to develop the organization of installation and operation of a network of permanent radio stations, to coordinate the entire national economic and technical activities in the field of radio of the various commissariats.

1918 (Sept.) The first issue of the scientific-technical magazine "Wireless Telegraphy and Telephony" appeared. The issue had the following foreword by its editor, V.K.Lebedinskiy "Russian Radiotechnical Literature Already has a History". It began in the magazine "Electricity" with an article by A.S.Popov, which contained the first graphic expression, in the world, of the idea of the possibility of radiotelegraphy (1896). Simultaneously with "TiTb/p" (Wireless Telegraphy and Telephony) appeared the initial issue of the more popular magazine "Radiotechnique", which was also edited by V.K.Lebedinskiy.

1918 (2 Dec.) V.I.Lenin signed "The Status of the Radio Laboratory with Workshop in the System NKPiT in Nizhnii Novgorod", in which it was stated that "the radio laboratory is the first stage toward establishment in Russia of a State Socialist radiotechnical institute".

1918 - 1924 During lectures in the Moscow Polytechnic Institute, where the training of radio specialists was organized, M.V.Shuleykin explained his analytical method of calculations with respect to generators, based on the linear idealization of the characteristics of vacuum-tube generators.

1918 At the end of the year, the first batches of electron tubes PR1 were manufactured and delivered to NKPiT, developed in the radio laboratory of Nizhnii Novgorod.

1919 (Feb.) M.A.Bonch-Bruyevich delivered a lecture in the radio laboratory of Nizhnii Novgorod on the three-electrode tubes theory developed by him, based on extensive experimental work.

1919 (March) Series manufacture of tubes of the type PR1 began (approximately 1000 units a year).

1919 K.I.Ostyrkin recommended to establish radio centers of communication and concentrate there the control of transmitting and receiving stations. The stations themselves would have to be located outside of towns and be connected with the radio centers by wire or cable lines. This recommendation, after its realization in Soviet Russia, came into ever increasing use in the whole world.

1919 (fall) M.A.Bonch-Bruyevich developed the design of kenotrons with voltages of 1500 v, with the aim of utilizing them for supplying the plate circuits of radiotelephone transmitters.

1919 (Dec.) M.A.Bonch-Bruyevich developed the design of a transmitting tube with water cooling.

1920 (11 Jan.) The first experiment of radiotelephone transmission from the walls of the Nizhnii Novgorod radio laboratory was realized. The transmission started at 10 p.m. on the 1200 and 1500 m wave; the reception of the experimental transmission took place at the Nizhnii Novgorod receiving station at a distance of about 4 km from the laboratory.

1920 (16 Jan.) Radiotelephone transmission was accomplished from Nizhnii Novgorod to Moscow with an antenna power of 50 w.

1920 (5 Feb.) V.I.Lenin wrote a letter to M.A.Bonch-Bruyevich, in which he stated:

"I am taking this opportunity to express my deep gratitude and sympathy on the occasion of the great work on radio inventions, which you are carrying out. A newspaper without paper and 'without distances', which you are creating will be a great thing. I promise to give you every possible assistance in this and other work".

1920 (17 March) V.I.Lenin received a report on the successful experiments of the Nizhnii Novgorod radio laboratory in radiotelephony, and had the Soviet of Labor and Defense promulgate a decree, the first points of which read as follows:

"1. To commission the Nizhnii Novgorod radio laboratory to produce with extreme urgency, not later than in two and a half months, a Central Radiotelephone Station with a radius of action of 2000 versts.

2. To designate Moscow as the site of installation and to proceed with the preliminary work forthwith."

The same decree provided for the manufacture of high-frequency machines, based on the V.P.Vologdin system.

1920 (April) In the laboratory of the Khazan base of radio formations, a radiotelephone transmitter was designed, in whose three stages up to 50 - 100 amplifier tubes were used. The test transmissions of this station were received in Astrakhan, Leningrad, and Rostov-on-Don.

1920 (21 July) V.I.Lenin signed the decree of the Soviet of Labor and Defense concerning the establishment of radiotelegraphy in the RSFSR. The decree provides for the construction near Moscow of a radio station with arc transmitters and high-frequency machines, powerful enough to ensure direct communication with America; the reconstruction of the Detskosel'skaya radio transmitting station, dismantled during the attack of Yudenich; the establishment there of an arc transmitter and high-frequency machines; the manufacture and assembly of high-frequency machines at the radio stations of Moscow, (Khodyn), Tashkent, Odessa, and Omsk.

1920 (10-13 Sept.) In Nizhnii Novgorod the first All-Russian Radio Technical Conference was held.

1920 (Dec.) On the premises of the Khodyn radiotransmitting station a prototype of a radiotelephone transmitter with 5 kw power was installed, produced in the Nizhnii Novgorod radio laboratory. Radiotelephone communication tests were carried out with Berlin, where the reception of these transmissions in Potsdam (near Berlin) was effected with a loop antenna. Not until March 1921 did they succeed in Germany to realize a return radiotelephone transmission.

1920 The first powerful Soviet radiotelegraph transmitting station of undamped oscillations with an arc generator was erected in Moscow on the Shabolovka. After a year, V.G.Shukhov designed for this station a metal tower of his own construction, 150 m high.

1921 (27 Jan.) By a decree of the SNK, signed by V.I.Lenin, the People's Commissariat for Post and Telegraph was instructed to install, in Moscow and in the more important centers of the Republic, radio equipment for intertelephone communications.

1921 (May) The Khazan base of radio formations delivered a three-stage 12-tube amplifier of low-frequency oscillations to Moscow. The amplifier showed good operational results on the intercity wire lines Moscow-Kharkov, Moscow-Tula, and also during tests of public address transmissions from the Square in front of the Moscow Soviet.

1921 (3 June) A STO resolution was accepted on the establishment in Moscow of a permanent radio newscast with the use of street loudspeakers. After two weeks, loudspeakers were erected on six Moscow Squares, and in the evenings (after 9 p.m.) the "oral paper" of ROSTA was transmitted daily, including sometimes reports and popular lectures.

1921 (summer) In the laboratory of V.P.Vologdin in Nizhnii Novgorod, mercury rectifiers were developed, intended for plate feed of the tubes of radio transmitters.

1921 (2 Aug.) Completion of the construction in Lyubertsy of the first discriminator radio receiving station in the world. Its equipment consisted of long-wave tube receivers, with large loop antennas suspended on a tower of 60 m height.

1921 (25 Sept.) In Moscow, the foundation was laid of the building for a central radiotelephone station, constructed during the winter 1921 - 1922.

1921 (5 Oct.) The Soviet of Labor and Defense passed a resolution regarding the use of the vacuum-tube rediffusion device of V.I.Kovalyenkov for intercity telephone communication on wires Moscow (Kremlin) - Petrograd (Smolny).

1921 N.D.Papaleksi organized the production of electron tubes in the Odessa State radio factory. Technicians for this production were recruited from the students of the Odessa Polytechnical Institute.

1921 V.P.Vologdin developed in the Nizhnii Novgorod radio laboratory the first high-voltage tubes for rectification of alternate current, which he used in creating the design of a rectifier, which found application in a number of Soviet radio stations. The mercury rectifier of V.P.Vologdin was applied for the first time for supplying the plate circuits of the tubes of the radiotelegraph station, designed in 1923 by the Nizhnii Novgorod radio laboratory.

1922 (Jan.) O.V.Losev discovered the amplifying properties of a crystal detector made of zincite, as well as the possibility of its application for generating oscillations. The semiconductor amplifier (oscillating-crystal receiver) of O.V.Losev forms the basis for the development of modern semiconductor diodes, triodes, tetrodes, etc. (transistors).

1922 (spring) A.F.Shorin of the Nizhnii Novgorod radio laboratory carried out successful tests in the application of Baudot and Whitestone printing telegraphs for radiotelegraphy between Moscow and Nizhnii Novgorod.

1922 (summer) On the site of the central radiotelegraph station, a mast was installed before 1 May and another mast toward the beginning of July, followed by a complete checkup and assembly of the electric equipment was undertaken. In June, the manufacture of a transmitter of 12 kw power was completed, and on 12 August the first experimental radiotelephone transmission took place.

1922 (16 Sept.) A government resolution was passed to award the Nizhnii Novgorod radio laboratory the Order of Labor of the Red Banner. In the resolution, special mention was made of the merits of V.P.Vologdin, M.A.Bonch-Bruyevich and

A.F.Shorin, to whom the VZIK expressed recognition.

1922 (17 Sept.) The first concert via the central radiotelephone station in Moscow took place, thus initiating Soviet radiobroadcasting. NKPiT was given charge of organizing the radiobroadcasting programs, on the first floor.

1922 (fall) In a specially constructed building on the site of the Khodyn radio station the assembly of a high-frequency V.P.Vologdin machine of 50 kw power, manufactured in the Nizhnii Novgorod radio laboratory, was accomplished.

1922 (fall) A combine of weak-current industry on the site of the former plant ROBTiT in Petrograd established an electricvacuum factory, where a group of scientific workers and designers under the leadership of M.M.Bogoslovskiy, and with the cooperation of S.A.Vekshinskiy, A.A.Shaposhnikov, S.A.Zusmanovskiy and others, proceeded to manufacture amplifier and oscillator electron tubes.

1922 (Nov.) The Upper Quay in Nizhnii Novgorod was renamed Radio Quay; the central radiotelephone station in Moscow was designated: "Radiotelephone Station, imeni Komintern", the Khodyn radiotransmitting station was renamed the October Radiotransmitting Station, and Voznesenskiy Street in Moscow was named the Street of Radio.

1922 B.A.Vvedenskiy and A.I.Danilevskiy made successful tests of radiotelegraph transmission on wave 3.8 m.

1923 (Jan.) P.N.Kuksenko and A.L.Mints obtained an authors' certificate for a ferroresonance device of a receiver.

1923 P.N.Kuksenko achieved a transcribed reception of radio signals at high speeds, utilizing for the first time an electron relay for this purpose.

1923 M.V.Shuleykin, in exploring the question of the propagation of radio waves above the plane earth with terminal conductance, derived formulas and diagrams for practical calculations, 8 years ahead of van der Pol, who solved a similar problem only in 1931.

1923 (spring) M.A.Bonch-Bruyevich achieved a substantial increase in the power of oscillator tubes. The new design with an external brass anode and water cooling yielded 25 kw.

1923 (12 Sept.) A decree of the SNK was promulgated on special-purpose radio stations, which gave the right to State and public agencies to organize and operate industrial-commercial, cultural-instructive, and amateur radio stations.

1923 S.I.Shaposhnikov, under the guidance of M.A.Bonch-Bruyevich, began to develop the design of a radiobroadcasting transmitter of small capacitance for district towns.

1924 (May) V.V.Tatarinov, in the Nizhnii Novgorod radio laboratory, began experiments with telephony on short waves (30 m).

1924 (24 May) A.A.Chernyshev obtained a certificate for an equipotential cathode, in which, between the heater and the cathode, an electrically insulated substance which conducted heat was inserted.

1924 (28 July) The Soviet of the People's Commissars of the USSR passed a resolution with respect to private radio receiving stations. This resolution of the Soviet government which initiated broad organization of radio communication facilities all over the country, the development of radiobroadcasting, and a mass radio amateur movement, received the name "Law on the Freedom of the Ether".

1924 (15 Aug.) The first issue of the magazine "Radioamateur" came out.

1924 (2 Oct.) A special "Joint-Stock Company for Radiobroadcasting" - "Radiotransmission" was established.

1924 The radio laboratory of the combine of weak-current industry was reorganized into the Central Radio Laboratory (TsRL).

1924 The combine of weak-current industry began to issue the first radiobroadcasting receiver "Radiolina".

1925 (15 Jan.) Radio signals of the first Soviet short-wave radio ham, F.A.Lbov, are received abroad in a number of countries.

1925 In the beginning of the year, M.A.Bonch-Bruyevich and V.V.Tatrinov of the Nizhnii Novgorod radio laboratory began the study of the directive properties of radiation on short waves. At the same time, a two-tube oscillator on the 76 m wave with an antenna power of 15 kw was designed.

1925 A group of specialists, headed by L.I.Mandel'shtam and N.D.Papaleksi began to work on the theory of nonlinear oscillations, on the study of parametric phenomena, in particular.

1925 (summer) In the Nizhnii Novgorod radio laboratory, experiments were conducted on establishing communication on short waves Moscow - Tashkent and Moscow - Tomsk.

1925 (June - Nov.) In Moscow, at the polytechnical museum, the first All-Union Radio Exhibit was organized.

1925 (Aug.) At the radiobroadcasting station, imeni A.S.Popov (in Sokolniki) the first short-wave telephone transmitter in the world, with a power of 1 kw (wave 77 m), started operating.

1925 A.I.Berg published an analytical calculation method for generators, which he had developed.

1925 P.N.Kuksenko recommended a circuit for a low-frequency amplifier with application of a cathode repeater as the penultimate stage.

1925 In the building of the House of Unions in Moscow, a radio relay center of 40 w power was erected, which, a special network of wires, operated 80 loudspeakers installed on public squares and workers' clubs in the metropolis.

1925 V.P.Vologdin completed the manufacture of a high-frequency machine of 150 kw power.

1925 I.A.Adaman recommended a system of color television with sequence transmission of colors.

1926 (5 Feb.) A resolution by the SNK of the USSR was passed, on radio stations for private use, which gives the right to radio amateurs to design and operate their own short-wave transmitters.

1926 (March) A scientific-technical conference of the electrotechnical institutes, forming part of the scientific-technical department of the VSNKh, was held. A decision was taken to mark the achievements of the Nizhnii Novgorod radio laboratory in the field of short waves and to recommend intensification of this work on a larger scale.

1926 V.P.Vologdin, in collaboration with engineer Belyayev, realized the first experiments on the application of high-frequency currents for surface hardening of metal products.

1926 At the radio station, imeni A.S.Popov in Sokolniki, a 20-kw radio broadcasting transmitter was installed, at that time the most powerful in Europe.

1927 (2 Feb.) In the combine of weak-current industry, an office for powerful radio construction was established, headed by A.L.Mints, which designed a number of high-power radio stations in the USSR.

1927 (18 March) Operation was started of a 40-kilowatt radiobroadcasting station, imeni Komintern, the most powerful (at that time) in Europe, whose transmitter was installed in the building of the former Shabolovskaya station.

1927 (March) The Nizhnii Novgorod radio laboratory put into operation the first short-wave line of nation-wide radio communication service Moscow - Tashkent.

1928 (16 Jan.) A government resolution was passed to reward the Nizhnii Novgorod radiolaboratory with a second Order of Labor of the Red Banner.

1928 A resolution was passed on the transfer of the basic scientific-technical research and development projects, together with the organized body of leading engineers and coworkers of the Nizhnii Novogorod radio laboratory, to the Central Radio Laboratory of the combine of weak-current industry. The reorganization took effect in December 1928 to January 1929.

1929 (5-9 Sept.) The first All-Union Conference on organization of radio communication services in rural areas was held.

1929 (28 Nov.) The radiobroadcasting station VTsSPS with 100 kw power began operations.

1929 M.A.Bonch-Bruyevich recommended an amplification circuit, now widely known under the name "Amplification circuit with grounded-grid tube", used for amplifying superhigh-frequency oscillations.

1930 (12 Jan.) Radio operator E.T.Krenkel', during his wintering on Franz Josef Land, used a low-power short-wave transmitter in establishing radio communication with Byrd's expedition in the Antarctica, covering a distance of 20,000 km.

1930 (30 Jan.) A radiosonde, invented by P.A.Molchanov, rose in the air.

1930 (4 Aug.) L.A.Kubetskiy applied for an author's certificate for an "electronic multiplier" - a device using the phenomenon of secondary radiation of electrons for signal amplification.

1930 In the Leningrad Electrophysical Institute (group of L.I.Mandel'shtam and N.D.Papaleksi) work was started on the interference method for direction finding.

1930 (Dec.) The Soviet physicist A.P.Konstantinov suggested the idea of a television transmitting tube, utilizing the principle of simultaneous formation of video signals and charge storage (a tube with multicellular mosaic).

1931 (24 Sept.) S.I.Katayev received an author's certificate for a television transmitting tube with a mosaic photocathode, now called an iconoscope.

1931 (1 Oct.) The television laboratory of the All-Union Electrotechnical Institute started television transmissions of images by the mechanical system with 30-line definition. The transmissions were carried out by the radio stations MOSPS and the experimental transmitter NKPiT.

1931 Radiobroadcasting on ultrashort waves began via radiobroadcasting station on meter waves (PB-61), the first in the world and designed (at the VEI) by A.V.Astaf'yev and A.V.Cherenkov, under the guidance of B.A.Vvedenskiy.

1931 A.L.Mints recommended the application of the block system in the design of high-power transmitters, realized by him later in the erection of a 500-kw radiobroadcasting station.

1932 D.A.Rozhanskiy achieved the first development of tubes with electron velocity modulation.

1932 A.N.Shchukin made public the calculating method developed by him with respect to the voltage of the electromagnetic field on short waves (the method of Namba and Tsukada was published in 1933, Ekkersleya's method in 1934).

1933 (31 Jan.) An All-Union Committee was created for establishing radio communication facilities and radiobroadcasting at SNK SSSR.

1933 (1 May) The 500-kw Moscow radiobroadcasting station began operations.

1933 M.A.Bonch-Bruyevich designed and operated an ionospheric station, using the pulse method for altitude fixing of the reflecting layers of the ionosphere.

1933 P.V.Shmakov and P.V.Timofeyev applied for an author's certificate for a television transmitting tube with projection of the optical image on a semitransparent photocathode and with subsequent transfer of the electron image on the mosaic.

1933 (Oct.) Production started of small radio transceiver stations of the political department, intended for establishing radiocommunications in toll offices, sovkhozes, and kolkhozes.

1933 - 1934 A.L.Mints, in collaboration with N.I.Oganov and M.I.Basalayev, developed the design of a demountable oscillator tube with actual power of 250 kw.

1935 I.F.Agapov developed circuits of electronic relays with feedback, which ensure radiotelegraph communications at speeds up to 600 words per minute.

1935 (fall) The expedition LEFI was carried out under the guidance of L.I.Mandel'shtam and N.D.Papaleksi, for measuring the rate of propagation of radio waves.

1936 N.F.Alekseyev and D.Ye.Malyarov developed the design of a multichamber magnetron-generator of centimeter waves.

1938 (Aug.) The world's most powerful (at that time) 120-kilowatt short-wave radiobroadcasting station RV-96 was erected.

1938 (1 Sept.) Operation began of the Leningrad television center with 240-line definition. For transmission of movies, the cathode-ray transmitting tube of G.V.Braude's design was used.

1938 (Oct.) Operation began of the Moscow television center with 343-line definition.

1938 V.I.Kerby and V.V.Novikov developed the sextuple Baudot telegraph.

1939 In the October Transmitting Radio Center, a system of single-band multi-channel radiocommunication (ORM) was installed, developed by V.A.Kotel'nikov, A.V.Cherenkov, and A.F.Ganin.

1940 N.D.Devyatkov, M.A.Sliozberg and Ye.N.Danil'tsev developed the design of a two-circuit klystron with plane radial electron stream.

1940 N.D.Devyatkov, Ye.N.Danil'tsev and I.V.Piskunov obtained an author's certificate for a reflector klystron (called by the inventors "electron tubes with retarding field").

1940 V.F.Kovalenko received an author's certificate for the method of electron tuning of reflector klystrons.