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VHF COMMUNICATIONS IN AIR TRANSPORTATION

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- Czechoslovakia -

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- Czechoslovakia -

/Following is a translation of an article by engineer Karel Zavodsky in the Czech-language periodical Letecky Obzor (Air Review), No 12, Prague, December 1962, pp 390-392./

The use of electromagnetic waves for communications between the crew of an aircraft and ground stations actually is the oldest use of radiotechnology in aeronautics. For this reason the technological process and form of such communication changed with the development of radio engineering and the expansion of aviation.

The oldest communication developmentally was on long waves. Radio engineering of long waves was mastered first, the spread of long waves also is the most regular. Since the frequency band of long waves is comparatively narrow it is practically impossible to use phonics which would permit communication with but a small number of stations. Telegraphy therefore was used which, however, requires longer and more expensive training of employees. A disadvantage of long-wave communications also are strong atmospheric disturbances which can make communications during a thunderstorm practically impossible. Therefore, following later developments in radio engineering the use of short waves was introduced for communications between an aircraft and the ground. On short-wave bands atmospheric disturbance is small. However, the radius of the ground wave which can be counted on under any circumstances decreases rapidly with a growing frequency. On the other hand, it is possible to attain communication by short wave for long distances using very small output, by utilizing the reverberation of waves from the ionosphere. For this communication, however, the correct frequency must be selected with a view to the location and time of communications and the conditions of spread. Radio communication on short waves in aeronautics is used in two ways:

- for communications for short distances (within the area of an airport, at the most within the scope of a district) a ground wave is utilized, communication is always phonic;

- for long distance communications reverberation of waves from the ionosphere is used. Communications to date were, for the most part, carried out telegraphically, but lately phonics have also been used which places fewer demands on the crew.

However, the short wave band is overloaded by broadcasting, commercial, sea, military and other types of stations. Under good conditions of diffusion even weak and remote stations can be heard well and frequent disturbances are the result. In addition the capacity of aeronautical short-wave bands is insufficient for the number of channels to satisfy the needs of intensive aircraft operations.

All these reasons led to the ever increasing use in aviation communications of very short waves in the past few years, and today almost all aeronautical radio communications are carried out on VHF bands which results in a number of operational and technical advantages. Reception on VHF bands is almost without any atmospheric disturbances even when in the immediate vicinity of electrical storms. Aerial VHF bands are sufficiently wide (today 118 to 136 MHz) so that even when using phonics it is possible to operate many communication channels as required by the direction and safeguarding of an intensive aviation program. Antenna systems are small, light, and easily installed on very fast aircraft without excessively increasing aerodynamic resistance. At the same time, such antennas work very effectively since it is easy to fulfill the requirement that their physical dimensions be comparable with at least one quarter of the wave length. As far as VHF spread is concerned the rule more or less applies that communication is assured within range of the direct wave, i.e. within a radius slightly larger than the optical area around the location of the transmitter antenna. In communications between ground stations the reach of communications would be very small, but in an aerial movable service where the aircraft always is one of the stations, the communications range is acceptable and depends primarily on the height of the aircraft. For communications for longer distances it is necessary to install a larger number of ground stations, but on the other hand this permits rectilinear broadcasting of VHF where several stations can work undisturbed on a single channel, provided the distance between aircraft which communicate with these stations, is greater than the range of the VHF. The present development of VHF technological communications processes was made possible by the great progress at-

Topics ... :

tained by radio engineering in the past years. Organization and technology of VHF attained a high degree of perfection, and since we are here concerned with problems which are very important for the present systems of direction and safeguarding of flights we give them greater attention in the following paragraphs.

Basic Characteristics of VHF Communications. → To p 4

Diffusion of very short waves is done according to the same principles as those for longer waves, but certain special characteristics prevail here:

VHF almost do not bend at all, and communication therefore is effected only by direct wave the reach of which is limited by the curvature of the earth surface and the unevenness of the terrain. Approximately, therefore, the use of VHF is limited to the area of optical visibility while in the case of longer waves communication is easily achieved far beyond the optical horizon. VHF waves are not reflected from the ionosphere and we can therefore not count on long distance communications with the air of a space ionospheric wave. If reverberations from the terrain are not present during communications, the surface and type of ground, vegetation etc. have no influence on the VHF range. On the other hand, electrical properties of low strata of the atmosphere make themselves felt when VHF is diffused since most communications are carried out close to the earth surface or under low elevation angles.

Physical properties of the atmosphere (pressure, temperature, humidity) change with altitude and cause the dependence on altitude also of the electrical properties of the atmosphere (dielectric constant). As a result the diffusion of electromagnetic waves in higher altitudes is somewhat greater which manifests itself by the wave not being diffused quite rectilinearly but being curved gently toward the earth surface. To describe this phenomenon in another way, the index of atmospheric refraction continually changes with altitude which results in a continuous refraction of the path of the electromagnetic wave toward the Earth. This phenomenon evidences itself by an increased VHF range on the curved earth surface (see fig.1). We say, therefore, that the VHF range is limited by the so-called radius horizon which is somewhat greater (by about 15%) than the optical horizon. This property therefore is favorable but complicates the analysis of a theoretical VHF range according to the profile of the terrain. Since physical properties of the atmosphere change, especially due to meteorological conditions, the curve and range of the VHF changes also. Therefore, for the sake of uniformity of technological calculations a so-called standard atmosphere is assumed which represents average values of the gradient of physical and electric properties. Since in the planning of a VHF communications system it is more comfortable to draw the path of an electromagnetic wave above the terrain as a straight line, we somewhat increase the radius of the Earth in our calculations so that the altitudes of individual points of the straight path correspond with sufficient accuracy to the altitudes of the curved path above the real radius. For a standard atmosphere this adjusted so-called equivalent radius $R_0 \doteq 8,500$ km compared to the actual value of the earth radius $R = 6,370$ km.

The radius of the radial horizon, or direct radial visibility from a point the altitude of which above the earth is h_1, is expressed thus:

$$d' \doteq 4,12 \sqrt{h_1} \quad (km, m) \qquad (1)$$

(for comparison: size of the optical horizon is $d_0 = 3.57 \sqrt{h_1}$). Maximum distance of communications between two points at an altitude of h_1 and h_2 above the Earth's surface is given by their connecting line which at the same time is a tangent to the earth's surface. It is calculated according to the formula:

$$d \doteq 4.12 (\sqrt{h_1} + \sqrt{h_2}) \quad (km, m, m) \qquad (2)$$

The formulae mentioned may be derived from geometric relations according to figure 2. For a rapid calculation various nomograms are used from which we cite, in figure 3, a graphic solution of relation (1) and in figure 4 a solution of relation (2). These simple dependent calculations of course are valid only for the smooth, round surface of the Earth. The actual range is further limited by differences in altitude in the terrain around the stations and between them. In an ideal terrain the range of VHF communications between a point on Earth and an aircraft at a certain altitude would be graphically represented by a circle circumscribed from that point , and for various altitudes of flight it would be a system of concentric circles resembling contour lines. If, however, we examine the range of VHF in the light of terrain irregularities (this is done by ascertaining height profiles of the terrain from a map, or by measuring the elevation angles of the optical horizon), these graphs are considerably deformed. Figure 5 shows an example of a limited range of VHF communications at the Kosice airport from which range limitations are easily discernible which are caused by mountain ranges in the West, North and East, while in the southerly direction where there is an open landscape the VHF range is considerably greater.

FROM P 3 ⟶ Geographical Separation of VHF Stations; AND, ⟶ TO P 6

When planning and allocating VHF communication channels for services related to the direction of flight operations it is important to make sure that operations in two directed areas working on the same frequency channel do not interfere with one another, and on the other hand, that distances between these spaces are not unnecessarily great, i.e. that the frequency channel be utilized economically. In order to establish such criteria of geographical separation it is advisable to divide individual types of VHF communications into categories for dispatcher services, and establish for them maximum operational ranges as to distance and altitude. An example of such a division of services into categories is given in the following table:

Category	Type of Service	Operational Range distance r (km)	altitude h (m)
A	Airport dispatcher service; landing radiolocator; direction of movements at airport	25	900
B	Approach dispatcher service; area radiolocator	50	3,000
C	Appr. dis.serv. fpr jet aircraft radiolocator control	100	6,000
D	Area dispatcher service, lower space	border of region	6,000
E	Area dis.serv.- upper space area radiolocator	border of region	12,000

By using equation (1) it is possible to calculate for the altitudes cited in individual categories, the following ranges of direct radial visibility:

h = 900 m	d ≐ 125 km
3,000 m	225 km
6,000 m	325 km *)
12,000 m	450 km

*) Adjusted from 320 to 325 to simplify final tables.

The minimum geographical separation of two ground stations operating on the same frequency must be equal (according to figure 6) to the sum of operational ranges r_1 and r_2 and of the ranges of direct radial visibility d_1 and d_2. For various combinations of the previously mentioned categories it is then possible to determine from these values the minimum geographic separations of stations operating on the same channel frequency:

The division into categories mentioned above and the resulting values of geographic separations were used as a basis when establishing VHF frequency plans during meetings of RVHP experts /Rada vzajemne hospodarske pomoci; Council of Mutual Economic Aid/. Similar planning criteria were worked out and utilized when setting up area frequency plans of the ICAO.

It is very difficult to ascertain geographic separations for adjoining frequency channels, i.e. determining the minimum distances between ground stations operating on adjoining channels so that operation may be assued without mutual interference. Here we are concerned with the transmitter power, sensitivity and selectivity of receivers, stability of receivers and transmitters, the level of noise and defects, directional effects of antennas, attenuation during radiation of VHF and other additional factors.

Because these problems are so complicated criteria for adjoining channels have not yet been internationally established for the presently used division of VHF flight band for 100 kHz. However, the introduction of a new division of the flight VHF band with separate channels at 50 kc has forced a more detailed study of this question. A table was worked out for recommended values for the preparation of RVHF frequency plans and some studies also were submitted when the ICAO plan of frequencies was prepared. But because each one of these calculations must be based on a number of simplifying prerequisites which were not selected uniformly the results from various sources are rather different. These problems however are too extensive to be dealt with in the confines of this article.

Systems of VHF Communications for Long Distances

Considerable operational advantages accruing from the introduction of VHF into flight communications were the reason why ways were being sought to use VHF also for greater distances or for lower altitudes than would correspond to the range of waves from the transmitter set up at the airport from which the operation is being directed. Determination of such requirements is possible by more or less complicated methods depending on local conditions.

The situation is most favorable where there is a possibility of finding, near the directing center or in the central part of the territory which is to be covered by VHF signals, a location for a VHF ground station on a dimension dominating the elevation. Then by simply using relation (2) it is possible to considerably expand the communications range. Of course it is essential that the rest of the area be lower and does not substantially limit the radial horizon. An example of such a location is the placement of the Sofia airport stations on the Vitos mountain (2,290m above sea level); or the placement of the station for the Berlin-Schonefeld airport on a mast of a nearby radio transmitter.

Wherever such a simple solution is not possible the network of retransmitting stations located on suitable dimensions in the controlled area so that the diagrams of their coverage mutually complement each other. Control and modulation signals for these stations most often are brought in by underground wire links, in some cases by radio connections. The construction and operation of such a network are very expensive. Also from the technological viewpoint this system is very demanding. It must be expected, after all, that signals in some parts of the area from two or more stations would overlap. At the same time, they must all operate on the same frequency channel. If the nominal frequency of the carrier wave of all transmitters were the same beat interference would be the result since due to instability we must expect displacements among carrier frequencies, and where different beats fall into the acoustical band they make the reception of modulation impossible. This matter therefore is solved by purposely displacing carrier frequencies of the stations of such a ground network so that they will still remain on the band passed through high frequency circuits of the receivers but the resulting beat tones will be so high that they are not passed through low frequency circuits of the receivers. At the same time we must take into consideration the instability of transmitters and receivers and make sure that even maximum fluctuation would not result in the received signal to outside of the passed high frequency band, or that the beat tone does not penetrate into the transferred low frequency band.

Recommended values of selectivity of VHF receivers for presently used separation of channels at 100 kc (according to ICAO) are:

drop of 6 dB during tuning off
o $\pm$ 22.5 kc,
drop of 60 dB during tuning off
o $\pm$ 80 kc.

The transmitted low frequency band usually is limited to 3 to 3.5 kc. Under such circumstances, for example, it is possible to use, for the network of ground VHF stations a nominal carrier frequency f_o and two shifted carrier frequencies (f_o + 11 kc) and (f_o - 11 kc). Another system uses a mutual shift of 7.5 kc so that in one VHF channel it is possible to place as many as five ground stations with carrier frequencies f_o, f_o + 7.5 kc, f_o - 7,5 kc, f_o + 15 kc, f_o - 15 kc. This method naturally places great demands on quality and especially on the stability of the VHF transmitters used but to date is the best solution of the problem mentioned, especially in regions with a varied terrain.

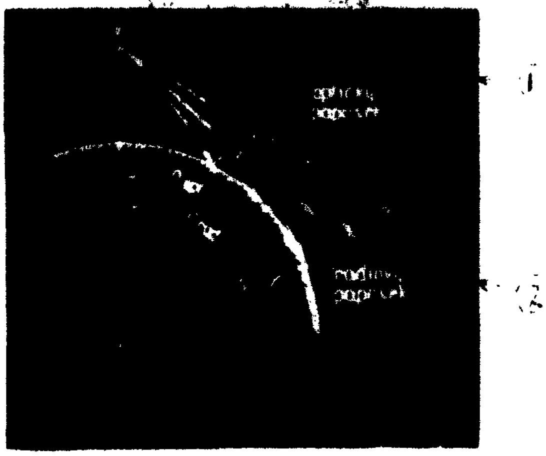
However, this method cannot be used in some cases since it is impossible to place a ground retransmitter station in the direction needed for VHF coverage, for example when establishing lines of flight across the ocean or across inaccessible regions. Elsewhere construction of a ground network might be unnecessarily costly when it is a matter of communications in one direction only, for instance in the case of a radial flight path. In such cases it appears more advantageous to use another system of long-distance VHF communications based on the atmospheric diffusion of strong VHF signals which thus can penetrate far beyond the radial horizon.

While in previously mentioned cases the usual transmitter power in ground VHF stations ranges between 5 and 50 watts, this directional long-distance VHF communications system utilizes power of several kilowatts. A substantial component of the system are gigantic directional antenna systems which multiply the power gain of the system in the established direction. Thus for example, equipment developed for these purposes by the PYE firm uses a 1 kw transmitter power and an antenna system composed of 8 Yagi-ho six-element antennas arranged vertically one above the other. Gain of this system is 20 dB so that the equivalent power in the direction of radiation is 100 kw, a drop of -3 dB occurs in the azimuth sector of 52 deg. The high gain of the antenna together with the use of special receivers with high sensitivity permit the reception of signals of deck stations transmitting far beyond the radial horizon. Such equipment was installed by the firm PYE for P.A.A. at the Shannon airport and now makes possible regular VHF communications on the flight path across the North Atlantic for distances which are more than twice those of the radial horizon.

At the present time the question of VHF long-distance coverage is being intensively tackled in countries with developed aviation. Here too the present unsatisfactory situation of VHF coverage of flight areas will have to be improved. The above informative summary indicates that this is a complicated problem which can be solved in various ways, in the light of local conditions and material and technological possibilities. An important prerequisite which meanwhile causes the greatest difficulties here, is a sufficient number of quality stations, i.e. VHF transmitters and receivers with the needed stability, slectivity, sensitivity and power.

Since we are here dealing with urgent questions the solutions for which are expensive, difficult and time consuming it is essential even now to work for the deepening of the previously made introductory studies and proposals to solve VHF coverage in the CSSR, to ensure the necessary preparation of plans and simultaneously also solve the question of ensuring suitable VHF stations.

Fig. 1



Legend: 1. Optical beam, 2. radial beam

Fig. 2

Maximum Range of VHF Communications Between Two Stations Located at Altitudes h_1 and h_2 above the Earth Surface.

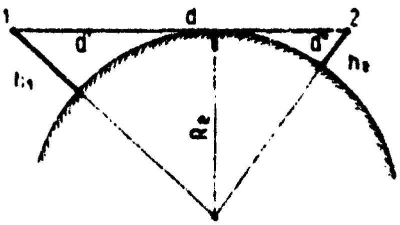


Fig. 3

Nomogram to Calculate the Range of Direct Radial Visibility (d) Dependent on Station Elevation above the Earth Surface (h)

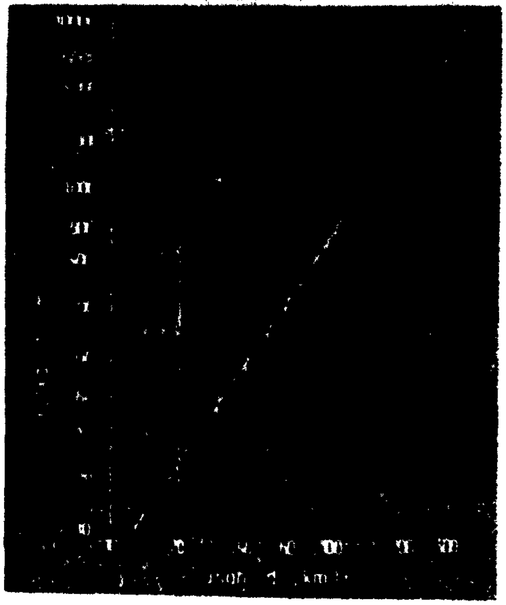


Fig. 4

Nomogram for Calculation of Maximum Range of VHF Communications Between Two Stations Located at Elevations h_1 and h_2 Above the Earth Surface

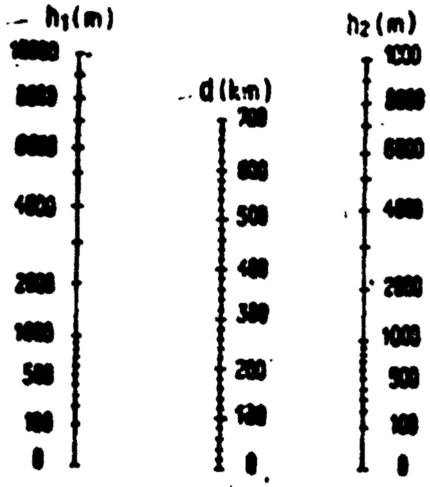
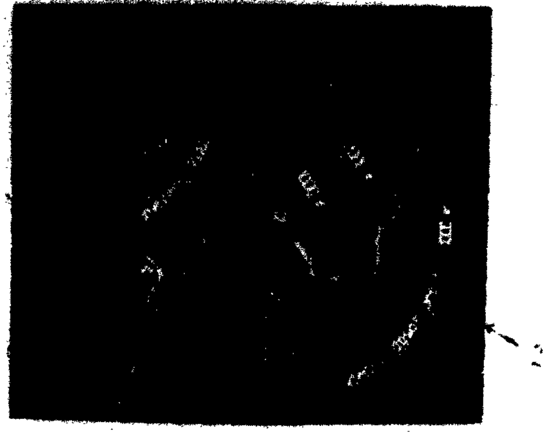


Fig. 5

Example of Range Limitation of VHF Caused by Elevated Terrain Surrounding the Station



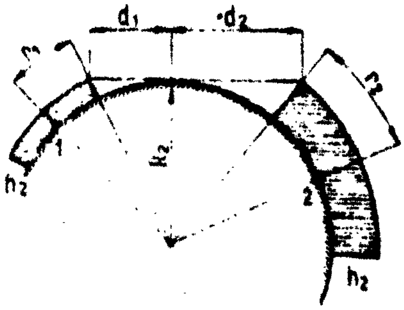
Legend: 1. limited range, 2. ideal range for h = 1000 m

Category	E	D	C	B	A
A	600 x	475 x	575	425	300
B	725 x	600 x	700	650	
C	875 x	750 x	850		
	775 xx	650 xx			
D	900 xx				

x ... from the border of the region
xx .. between the borders of the region

Fig. 6

Derivation of Minimum Geographic Separation of Two Ground VHF Stations for the Direction of Flight Operations



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