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DIGITAL TRANSMISSION IN MOBILE UHF RADIO

by

Aleksy Pankow

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DIGITAL TRANSMISSION IN MOBILE UHF RADIO

by
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Mobile UHF ground communications, or UHF radio communication with objects moving along the ground or inland waters, is an important element in the overall system of public information. The role of mobile UHF communication is increasing as the range and level of its use widens. In the first period of its existence, mobile communication networks were characterized by a very simple structure. They were primarily developed as networks of the dispatcher type. This period was characterized by a rapid quantitative growth in equipment with relatively slight technical progress, both in terms of systems as well as in terms of the fundamental equipment parameters. When radio communication took advantage of the achievements in the "semiconductor revolution", it was able to obtain considerable miniaturization, reliability and high energy efficiency in the equipment.

The next stage of development was characterized by a very cautious approach to problems associated with management of the the frequency spectrum. This is caused by considerable overloading of the frequency bands accepted for mobile UHF radio service. Among the basic steps being taken to overcome this difficulty, we can include the introduction of spatial division of frequency channels on a national and international scale, the stiffening of requirements relating to the technical parameters of the equipment, the adoption of new frequency bands, the increase in efficiency in communication channel employment by creating multichannel group networks. Marked qualitative changes in mobile UHF radio have been taking place in recent years. Theoretical, scientific-research and practical studies aimed at creating promising mobile radio systems that are integrated with both automated telephone networks as well as with telephone information networks are being conducted across a broad front. It is obvious that such systems can only be fully automated systems that permit transmission of analog and digital signals. In this respect, the possibilities and prospects for digital transmission in mobile communication networks are of particular interest.

This problem has yet to find adequate treatment in our own literature. The present article[*)], to a certain extent, has set itself to this purpose.

Among the many reasons for development of digital transmission in mobile communication networks, as might be expected, we can include:

- the possibility of more efficient organization of communication systems, and an increase in their effectiveness,
- the large amount of reliability in information transfer and the possibility of documenting the transmitted text,
- almost unlimited possibilities for concealing transferred information,
- the possibility of cooperation with stationary telephone information networks,
- substantial resistance to interference,
- the possibility of information transfer without the presence of the subscriber.

At the present moment, we can distinguish three basic directions in the development of digital transmission technology in mobile communication networks:

1) transmission of digital signals as the automation element of radiotelephone communication systems,

2) transmission of information in digital form, including:

- transmission of programmed information (of limited content),
- Exchange of any alphanumeric information between network subscribers via teletype,

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*) The article is based on materials ~~of~~ from the topic submitted by the author at the symposium, "Telephone information networks" - Gdansk, 1975.

- access to and communication with computerized data bases;

3) replacement of transmission of analog voice signals by digital transmission.

The directions mentioned will be discussed briefly in subsequent parts of this article.

Digital Transmission as the Autom~~iz~~ation Element for Radiotelephone Communication Systems

An increase in the efficiency of use of radio channels accepted for mobile communication service can be achieved by, among other things, automating the operation of the systems. The principle of automation involves generation and transmission of appropriate signals - administrative or controlling - between the stations that comprise the communication system. Thus, in addition to phonic [voice] signals, digital signals appear on the air.

The first step on the way to automation of communications in mobile networks was selective calling. Generally speaking, selective calling involves ~~the~~ blocking ~~of the level~~ out a number of transmitting radiotelephones operating in a given network, among which only the one to which a special signal is directed is unblocked. Three basic systems of selective calling are distinguished, based on the codes: frequency (parallel), time-frequency (series) and pulsed. The advantages and drawbacks of the individual codes used in selective calling systems have been discussed in detail in the literature [1]. It must merely be emphasized that studies conducted both at home and abroad to compare the selective calling systems in terms of reliability of calling and resistance to interference have shown that for purposes of UHF mobile communications, the most suitable is the time-frequency series code. This code has been recommended for domestic use [2].

A further step on the way to improving operation in mobile communication networks was the introduction of automatic identification of the mobile subscriber. The principle of operation of the identification system consists of the fact that after each transmitter is turned on - in order to establish contact with the base station - a digital signal that identifies the given mobile station is sent automatically. At the base station, the signal received is displayed on a monitor screen or recorded. Thus, both the engagement of the radio channel as well as the time involved for operators in the mobile station and the base station is shortened.

The code used in the identification system, for the most part, is analogous to the code in the selective calling system. This simplifies equipment design considerably in a situation where both systems are used in a network.

The system of mobile subscriber identification also permits simultaneous transmission of additional information. This capability is achieved owing to the use of only part of the digital combinations, e.g., 5 numbers out of 10, for identification purposes. The remaining numbers are used for transmitting any information relating, e.g., to the position of the vehicle, the need for help, etc. A similar system has been designed by the Storno company (the MI system).

In Poland, a system of mobile subscriber identification based on a time-frequency code has been devised at the Institute of Industrial Telecommunication and used in radiotelephone installations of domestic manufacture (ZR RADMOR and WZR WAREL). It is in operation (together with an alarm system), among other places, in the radiotelephone network of the Warsaw taxis.

Automatic localization of a mobile station with the aid of digital transmission can be recognized (after identification) as the next step on the way to automation. This is an important means for improving the operation of law enforcement networks, taxi networks, municipal communication networks, etc. At present, several ideas are known for subscriber localization systems, and they differ from one another quite a bit in terms of operation [3]. Generally, such systems are very expensive and setting them in operation requires a large investment.

Among the very simple, and therefore less expensive systems, we can include the system planned for use by the Washington police [4]. The operating principle of this system is based on the known location of stationary receivers distributed within the area of network operation. Each vehicle is equipped with a low-power transmitter (with a range of 60 m) that emits a continuous identification signal for the given station. The stationary radio receivers, according to the plan, are distributed in street boxes that are in direct telephone contact with police headquarters for the needs of city residents. They can also be placed in fire alarm boxes, in traffic signal control boxes, etc. The accuracy of the system of localization is therefore a function of the feasibility of distributing receivers throughout the city. Fig. 1 depicts the operating principle of a localization system. A new element here is the inclusion of a computer for controlling the system. The identification signals of the mobile stations are transmitted from the individual receivers via telephone lines (special or local lines within the telephone network) to terminal (group) installations, each of which serves a certain area of the city. A block diagram of a terminal installation is shown in Fig. 2. From the group installation, the information signal is transferred to the processor in the form of a pulse. This signal, together with the exact time of its arrival is noted in the memory disc. The system enables an operator to determine instantly the location of every vehicle or to find out how close a vehicle is to a fixed point.

The localization system devised by GTE Sylvania [5] operates on still another principle. Information concerning the location of the vehicle is contained here in the signal sent by the driver (along with the identification signal). A special matrix coder in the form of a flat plate covered with a map of the area serves to generate the localization signal. A code signal, representing a function of matrix coordinates is assigned to each point on the surface. The coder is engaged by touching the surface of the map at the point which represents the location of the vehicle, using a finger. The code signal is transmitted in digital form directly to the base station and from there to the dispatcher center, where it is displayed on a special map and recorded in the memory. At the same time, the identification number of the radio car is displayed.

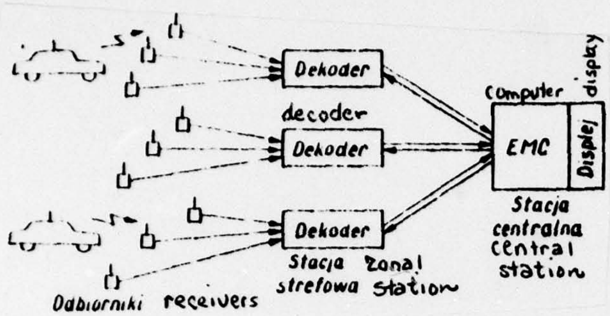

Fig. 1. Operating principle of a localization system

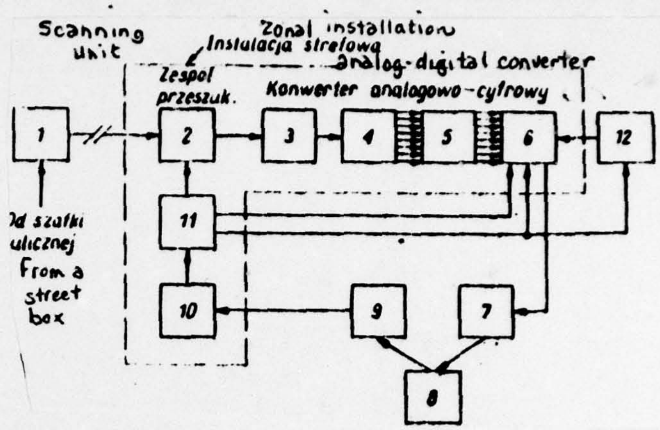

Fig. 2. Zonal station of a localization system; 1 - box terminal, multiplexer, 3 - amplifier and limiter, 4 - filter assembly, 5 - demodulator, 6 - recorder, 7, 9 - modems, 8 - computer terminal, 10 - programming system, 11 - control system, 12 - time generator

Digitial technology has found wide application in equipment and systems for automatic connection of UHF radio networks with telephone networks, especially in multichannel systems with automatic searching for a free radio channel (AWWK). The radiotelephone switchboard plays a major role in such a system. The mobil station equipment should include, in addition to the selective calling, identification, and automatic searching systems (in a multichannel network) mentioned above, units that permit transmission of dialing signals for a subscriber's number in the telephone system. The task of the radiotelephone switchboard consists of automatically arranging contact, coding the dialing signals from the mobile station and transferring them to the telephone exchange, and controlling the operation of the base radiotelephone. The technical ~~solution~~ arrangement of a radiotelephone switchboard can involve different variants, above all, ~~conditioned~~ governed by the method of communication organization in the system or by the method of ~~reaching~~ acquiring a free channel. One of the possible variants for a radiotelephone switchboard is an idea developed at the Institute of Industrial Telecommunications in Warsaw [3].

The 8-channel automatic radiotelephone communication system SMART, developed by the Storno company can serve as an example of a system achieved in practice, where the radio network becomes a natural extension of the local telephone network. A drawback of this system is its limited range. The mobile station here works with but a single base station, only within its radius of operation. In order to increase the range of a network, the system must contain several base stations. Neighboring base stations - in order to eliminate mutual interference - should operate at different frequencies, whereas each mobile station - in order to be able to work with all of the base stations - should possess all of their channels. This leads to considerable expansion and increase in costs for the mobile installation in the case of the conventional multichannel solution, or else suggests that radiotelephone design be based on digital frequency synthesis. Multi-area expansion of a mobile communication network involves the necessity of introducing centralized commutation of the base stations belonging to the network in order to connect conversations carried on between mobile and fixed subscribers at the moment when the mobile subscriber crosses a boundary between zones of separate base stations. A need arises for continuous localization of the mobile subscriber's position and for connection of the localization system with the control system of the communication network. The present world tendency is heading in precisely this direction, in which the superiority of systems with basic zones of small area [6] has been theoretically demonstrated.

Data Transmission in UHF Mobile Communication Networks

From the beginnings of its development, UHF mobile communication was dominated by analog systems of information transmission, based on modulation of the carrier wave in amplitude or frequency (phase) by the signal containing the information - in principle, by the ~~voice~~ audio signal. In order to improve operational quality in mobile communication, systems and installations representing the beginnings of digital transmission were gradually introduced to the systems. These fulfilled a service role relative to the primary task of the system - direct exchange of information between users of the network (its subscribers).

Such systems (e.g., selective calling, subscriber identification, vehicle location, etc.) have been discussed above. The use of code signals in mobile communication networks, which fulfill an auxiliary role, accelerated the process of introduction of information exchange in digital form in these networks. It is now possible to observe the ever more rapid rate at which digital transmission systems are being introduced to UHF mobile communication networks. Digital transmission, understood here as the exchange of information between subscribers (or between a subscriber and a data source) in digital form, does not include digital transmission of sound (or transmission of sound information in digital form), and in this meaning is rather closer to "conventional" data transmission. Problems in digital transmission of sound will be examined later.

The data transmission systems now in use in UHF mobile communication networks can be classified as follows:

- Systems in which the terminal installations contain a strictly limited (determined in advance) supply of information. In principle, this is information of fundamental significance, frequently reproduced and requiring careful transfer. In systems of this type - in addition to digital transmission of the basic information - sound transmission is used, in which the sound transmission remains - in view of the limited supply of digital information - the primary medium of exchange. An example of such a solution is the system in use in the public transportation network of Goteborg (Sweden) developed by the Storno company. We can also include some of the systems mentioned above, to a certain extent, in the systems of this type, for example, the automatic subscriber identification (mobile), the autoalarm, or the localization system, owing to the contents of the signals sent.

- Systems, in which terminal units are connected to the radio installations. These units contain teletype attachments and (for the most part) a monitor screen that permits exchange of any information (alphanumeric) between mobile subscribers and dispatcher points. Sound transmission, which exists in these systems alongside digital transmission, begins to assume a secondary role here. An example of such a system could be the system introduced in the taxi network of New York or the systems used by the police in several American cities (using terminal equipment of the MCT-10 type from the Custom Electronics company or the Vp-1000 from the Motorola company).

- Within the third type we can include mobile communication systems whose users have the capability of collaboration with regional or national telecommunication data transmission networks, connected with EPD, ETO centers, or the appropriate computer card files. Operation of such systems is usually based on computer control. They are presently developed in the U.S., primarily in the police services.

From the point of view of technical progress in mobile communication networks, at present the systems mentioned under point two may have the greatest significance, i.e., systems that permit transmission to and from mobile subscribers of alphanumeric information - in addition to conversations - in the form of digital signals. These systems can obviously be expanded in the direction of incorporation into the stationary telephone information networks. Equipping mobile subscribers with alphanumeric terminal equipment (teletype) ensures documentation of information received in transit or during the absence of the mobile station's subscriber. In addition to the advantages already metnioned for such digital systems: greater speed and reliability of information transfer compared to sound systems, the documentation capability, the substantially higher degree of security, collaboration with computer systems - their use results in greater safety in movement.

On the American market, several mobile designs of alphanumeric terminal equipment are now being offered, e.g., the MCT-10 (Custom Electronics), the IBM 2976 terminal unit, the Xerox keyboard attachment, or the Sylvania alphanumeric keyboard attachment to the Digicom-300 system. Alphanumeric vehicular printers, intended for collaboration with radio installations that operate in mobile networks, have also been developed, e.g., the Vp-100 (Motorola) [7].

Terminal equipment of this type has been permitted in the US for trial use by the FCC decision of May 9, 1972. Vp-100 printers have been installed, among other places, in 418 police cars in the state of California within the scope of the complete communication system for law enforcement agencies in this state that has been accomplished by Motorola's Radiocommunications Division. A MODAT computer was used in this system. After three years of preparatory work, this system began operation in June, 1973. It is based on the cooperation within an automatic dispatching network of about 900 automobile units (8-channel duplex radiotelephones), 120 motorcycle radiotelephones, 225 multichannel mobile (carried) radiotelephones and 6 helicopters. The system provides cooperation with terminal units that permit - by the ordinary push of a button - transmission of information determining the location of a vehicle or a programmed text.

Another example of a network with digital data transmission is the system of two-way digital communication between dispatcher base stations and 250 taxis in New York [8]. The system operates in the 420 MHz area. The transmission of alphanumeric information is accomplished by means of digital coding with error correction. The transmission of information containing 50 words takes about 0.5 sec. In each of the taxis belonging to the network a small console with a monitor screen is installed (above the taximeter). The weight of the console is about 2.5 kg. The monitor comprises a panel with neon lamps and a selector system. 32 different symbols can be obtained on the monitor. The information received can contain up to 8 lines of alphanumeric text. After decoding and correction control the information received is introduced into a buffer store made from MOS transistors. The capacity of the memory is 256 symbols. Next, the information is introduced in turn to the driver's screen by lines.

The console at the dispatcher's position contains an alphanumeric keyboard, a monitor that displays the information with a capacity of 32 symbols, a buffer store and system for arranging and coding the information. At the dispatcher station there is also a CIP2200 minicomputer (32,768 words), a rapid line printer and a magnetic disc memory system for storing information concerning each taxi. The capacity of the memory system is up to 5 Mbit.

The entire area of New York is divided into 12 zones, each of which is served by a dispatcher station. The cabs have their own code number. The dispatcher station automatically calls the cab and determines its location at a given moment, and also determines if it is occupied and if the taximeter is turned on, etc. The address of the passenger who directed his call to the dispatcher point via telephone is transferred to the closest free cab.

The overall value of the system described is over 350 thousand dollars, in which the cost of the base station varies (depending on the equipment) between 3000 and 100,000 dollars, and the cost of a single mobile station (when quantities of more than 100 are ordered) is about 1000 dollars. The Sunrise Electro-Service Corp. played the major role in setting up the system.

As is evident from the above examples, there is an ever increasing trend to equip dispatcher installations in mobile communication networks with the technical means that will enable them (in addition to conducting voice conversations) to rapidly transfer information programmed in advance or any other information in alphanumeric form, and that will offer them direct access to regional telephone information networks, connected to corresponding computerized information sources. In prospect, obviously, is the breaking down of the boundary between digital communication systems classified above (as the second and third types). The greatest progress of such integrated communication systems is observed in the U.S. The greatest "cluttering" of bands allocated to mobile service is occurring in the United States, and in this situation the switch to digital communication is regarded as a remedial measure that will circumvent frequency difficulties. In addition, for many regional services, and above all for law-enforcement agencies, the possibility of a mobile patrol obtaining immediate information from the appropriate card files is of major significance. One of the earliest systems appeared in Kansas City, where in 1965 the chief of police recognized the need to create a computer system suitable for the rapid supply of answers to questions from police patrols on the street. As a result, the ALERT I (Automated Law Enforcement Response Team) system appeared and began operation as early as 1968. The system operates on the basis of IBM 360/40 and 370/155 computers with IBM 3270 screen monitors. ALERT I was expanded into the ALERT II system for use by the public prosecutor and criminal services. In this system they used (in July 1972) vehicular MCT-10 digital terminal units (MCT = Mobile Digital Communications Terminals) from the Custom Electronics company, which enabled the users (mobile subscribers) to obtain direct entry into the telephone information network (without a dispatcher) and to obtain information from the computer within 5 seconds. The information is displayed on a 256-character monitor screen. The transmission of data is based on PSK (phase-shift keying)modulation, which is four times more rapid than the conventional FSK (frequency-shift keying) and is almost error-free even for low signal-to-noise ratios. Practical application has confirmed the high quality of the MCT-10 terminals [9].

Another system of communication between mobile subscribers and telephone information networks, developed by the Sylvania company, under the name Digicom-300,*) should be mentioned. This system was tested in 1970-1971 in San Francisco, Los Angeles, New York and Denver, and has now been put into operation in Oakland (California). In this system, an officer not only can send information - with the help of an alphanumeric keyboard terminal - in digital form through the normal radiotelephone communication channel, but he also has the capability of sending information that identifies a vehicle with simultaneous determination of its location. Such information is sent automatically, after the operator simply touches a coordinate map included with the vehicle terminal equipment (obviously the map must be touched at the point

*) misspelled in original (Digitom).

which corresponds the vehicle's location). Information regarding the location appears automatically on a map placed at the dispatcher position, together with other information that identifies the mobile subscriber [5].

In the U.S. there exist still other "integrated" communication systems for the use of police forces and others. Each such system offers various advantages. A fact that should be emphasized is their continuous modernization, in which one of the elements is miniaturization of vehicle terminal equipment.

Recently on the American market the Arcom MCT-16 (Atlantic Research Corp) vehicle terminal equipment for data transmission appeared. It has a complete alphanumeric keyboard and 10 additional functional keys buttons, which, for programming, permit access to any computer program in the telephone information network. The MCT-16 was designed in principle for police forces, but could be adapted to other uses. The unit contains an 80-character buffer store and a 16-character screen monitor. The information received or prepared for transfer is displayed on the monitor and recorded in the memory. The MCT-16 also contains systems for automatic localization, vehicle identification, automatic confirmation, autoalarm and crossover to sound communication. The unit can be connected to existing types of radio equipment. Dimensions: 133 X 292 X 92 mm. Weight - about 2.5 kg [10].

Digital Sound Transmission

The emphasis on qualitative and quantitative development in radiocommunications has resulted in a situation in which for many years work has been conducted to increase the capacity of radiotelephone channels and to find methods that enable us to restrict their frequency band. Generally speaking, the work has taken two directions. The first direction remains with the analog form of transmitted information, aiming merely at the optimum elimination of speech redundancy contained in the signal. The second direction in improving voice communication consists of converting analog speech signals into digital signals. This direction offers a theoretically ~~vast~~ great possibility in restricting the frequency band needed. Shannon has indicated these possibilities.

The introduction of digital transmission of speech signals in mobile radiocommunication systems is complicated by the fact that severe fading of the signals occurs. This fading is a specific feature that characterizes the communications conditions in mobile radio networks. ~~Their~~ Its source is the interference characteristics in the structure of the electromagnetic field, caused by the multipath propagation of radio waves in the presence of obstacles and the change in position of a moving station during communication. Especially severe variations in the field occur in a built-up area. Statistical measurements have shown that the fluctuation distribution of field amplitudes approximates a Rayleigh distribution quite well. Movement of the mobile station during communication results in the appearance of fluctuations in the amplitude of the received signal at the receiver output, in which the frequency of amplitude ~~changes~~ variations is proportional to the frequency of the carrier wave and the speed of the vehicle.

These fluctuations are considerably more dangerous for digital transmissions than for normal radiotelephone communication. The effect of fluctuations can be reduced only by using special diversity reception units. In recent years - for experimental purposes - several systems of spatial diversity reception have been developed for mobile communications, which enable us to accurately study the relationship between digital transmission reception quality (with various types of modulation, including pulse-code and delta modulation) and the power level of the transmitted signal. As an example, Fig. 3 shows the transmission error rate as a function of the signal-to-noise ratio with fading having a Rayleigh distribution and without fading (delta modulation with unmodulated pulses, the so-called on-off keying, and coherent detection on the reception side) [11].

As tests have shown, for digital transmission of speech with good quality an error rate on the order of 10^{-4} is sufficient. Without fading this corresponds to an average signal-to-noise ratio of about 11.4 dB. In the presence of fading (with a Rayleigh distribution), the signal-to-noise ratio required to obtain the established error rate (10^{-4}) increases to 37 dB. Diversity reception enables us to reduce the effect of rapid fading. Hence, it is important to determine the number of diversity reception channels needed (reception multiplication factor), in order to obtain a result close to conditions without fading. Tests show that this is possible with a reception multiplication factor of 3-4 [11].

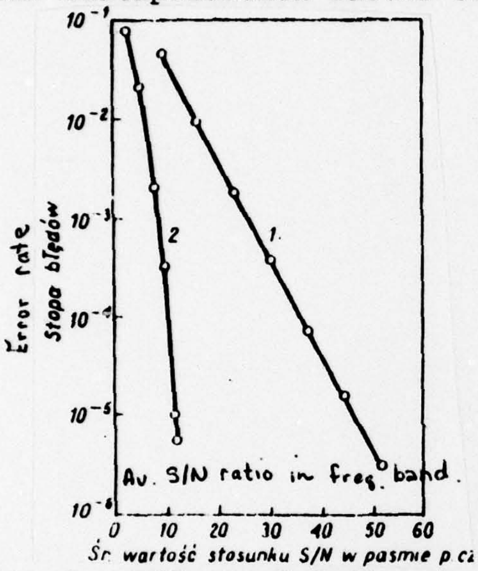

Fig. 3. Effect of fading in the field on the error rate: 1 - in the presence of fading with Rayleigh distribution; 2 - without fading

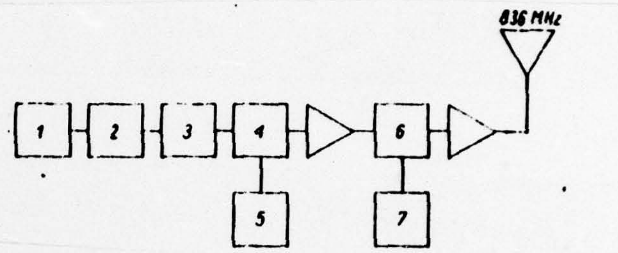

Fig. 4. Block diagram of a base station receiver for digital transmission of sound; 1 - tape recorder; 2 - coder; 3 - cosinusoidal filter; 4, 6 - mixers; 5 - 24 MHz ~~generator~~ oscillator; 7 - 836 MHz ~~generator~~ oscillator

For practical verification of the feasibility of digital transmission of sound in mobile communication networks the Bell Company developed an experimental radiotelephone system with digital modulation [12]. The operating frequency of the system is 836 MHz. The system comprises a transmitting base station and a receiving mobile station. Fig. 4 depicts a block diagram of the transmitting station.

The sound signal, after conversion in the coder to a series of pulses, is supplied to an equalizing mixer through a special filter. A constant 24 MHz signal is sent as well into the mixer from the ~~generator~~ oscillator. The signal from the mixer output, after amplification, is directed to a second mixer, producing a signal with a frequency of 836 MHz. This signal is amplified linearly in a power amplifier to about 2 W. The antenna is a vertical coaxial structure with a gain of 10 dB with respect to a half-wave dipole.

The mobile station contains 4 diversity reception channels. In Fig 5., which shows a block diagram of the mobile station, only one channel is shown, the circuits of the remaining ones being indicated by arrows. A quarter-wave antenna supplies the equalizing mixer with a level of internal noise on the order of 6 dB. A local 866 MHz ~~generator~~ oscillator supplies voltage to all of the channels. Voltage from the mixer is sent to an amplifier with an amplification factor of about 55 dB and a noise factor of about 1.5 dB. Next is a quartz filter with a bandwidth of 100 kHz. After the filter and amplifier with A.G.C. there is a diode system that acts like a square-law detector. The outputs of the detectors of all channels are parallel and connected to the adder input. Upon leaving the adder, the signal is divided into two parts: the first is sent through a low-pass filter, which controls the A.G.C. system of the amplifier, and the second is sent to the decoder. The decoder output is a memory system on magnetic tape.

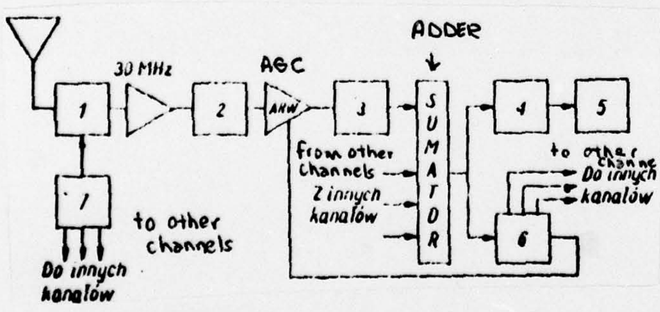

Fig. 5. Block diagram of the receiver in a mobile station for digital transmission of sound; 1 - mixer; 2, 6 - filters; 3 - square-law detector; 4 - decoder; 5 - tape recorder; 7 - 866 MHz ~~generator~~ oscillator

The system was tested both under laboratory conditions using a fading simulator, as well as under field conditions. The field tests were conducted under conditions in a large city and in the suburbs.

The tests consisted of calculating the average frequency of occurrence of disturbance (static) in the sound band of the receiver as a function of signal power and the multiplication factor of diversity reception. The adder used in the laboratory tests supplied several independent sequences of pulsed signals with amplitude fluctuation corresponding to a Rayleigh distribution of 40 dB. The frequency of signal fading in the simulator was equivalent to a vehicle speed of 60 mph and a wave frequency of 836 MHz.

The tests performed showed that a 1-channel system, practically speaking, is unsuitable, whereas a 2-channel system is inadequate. On the other hand, 3- and 4-channel systems function perfectly well.

The tests in suburban areas included areas with residential buildings. The base station was placed at the top of an elevation that was about 75 m above the ground and the antenna was at the top of an 18 meter mast. The transmitter's power was varied between 2 W and 2 mW. The mobile station was installed in a delivery van that moved through the test area at moderate speed. The antennas, in the form of quarter-wave rods, were placed on the delivery van's roof. Their spacing was about 0.75 of the wavelength. The test signal was based on reading the text of a technical article specially prepared for the experiment. At the same time the sound signal was received, measurements of the field intensity were made. In the suburban area the system functioned quite similarly to the laboratory conditions.

The built-up area was characterized by high, single skyscrapers and narrow streets. The base station with an antenna having a 4 dB gain was placed on the roof of a skyscraper. The mobile station was identical to the one used in the suburban tests. The overall quality of the voice signal received (intelligibility) was very good with 3- and 4-channel reception. However, sporadic instances of a drop in the output signal level when the input signal exceeded the threshold value were noted. This might have been caused by disturbances arising from the operation of other pulsed systems or time lags during the multipath propagation of the intrinsic signal. Field tests have shown that digital modulation can be used under conditions of multipath propagation in an area that contains mobile communication.

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