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ANTENNAS FOR RADIO COMMUNICATION, BROADCASTING, AND TELEVISION

by

G. Z. Ayzenberg and S. P. Belousov

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13. ABSTRACT

This article represents a general discussion of various types of antennas for radio communication, radio and television broadcasting, and space communication. The uses and advantages of various antennas are pointed out and antenna parameters are given in many cases.

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ANTENNAS FOR RADIO COMMUNICATION, BROADCASTING, AND TELEVISION

G. Z. Ayzenberg & S. P. Belousov

The first antenna was proposed by our fellow-countryman, the inventor of radio, Aleksandr S. Popov. It had the form of a vertical asymmetrical dipole. To the present day, this antenna is widely used for long-, medium-, short-, and meter-wave applications. Antenna technology, developing concurrently with advances in radio engineering, is now an independent multi-faceted and complex part of the family of radio disciplines. Antenna facility engineering depends largely on the specific area of application (communications, broadcasting, radar, radioastronomy, etc.). Our discussion below will deal primarily with antennas for communications and broadcasting.

Long- and Medium-Wave Antennas for Radio Broadcasting

For transmission on wavelengths longer than 2000-3000 m a variety of wire antennas with highly developed horizontal components of one or another configuration are employed. Essentially, these antennas are not unlike the antennas used in the initial stages of radio engineering when communications were effected on long wavelengths.

Beginning in the thirties, antenna masts and towers with insulated base and developed radial grounding came into use for 200-2000-meter radio broadcasting. An advantageous feature of these antennas is the absence of passive support masts and hoist cables, which distort the radiation pattern and lower the efficiency.

As this type of antenna continued to be developed, a number of new and original configurations were designed and introduced, which differed substantially from the basic versions. The shunt-fed antenna was developed abroad [1], while upper-fed [2], expanded-band [3], and slot antennas [4] were first introduced in the Soviet Union. The distinguishing feature of the shunt-fed and upper-fed antenna is the absence of base insulators, a factor which is oftentimes of great importance. Conventional antenna masts are unsuitable for operation on wavelengths shorter than 1.4 H (H is the mast height). Because of its special driving arrangement, the expanded-waveband antenna is capable of operation at wavelengths from 0.9 H. As a result, one antenna mast can be employed throughout the entire 200—2000-meter broadcast band. The slot antenna is mounted on low supports. For example, an antenna for the 200—600-meter band requires supports 25 to 30 m in height for its installation.

A vitally important achievement of medium-wave antenna engineering was the development of the antifading antenna mast. These antennas are (0.5—0.55) λ in height and, as a consequence, radiate a compressed pattern in the vertical plane with an extremely low side-lobe level and improved gain factor ($\varepsilon \approx 1.6$ as compared with a low-profile vertical dipole). One version of the antifading antenna is the expanded-band antenna which exhibits optimal antifading properties on a wavelength of about 1.25 H. Throughout a considerable portion of the band this antenna features improved gain (as much as 2—3 times that of the low dipole). The use of antifading antennas leads to freedom from deep field attenuation and, especially, pronounced selective fading at greater distances from the transmitter.

A shortcoming of the antifading antenna is the narrow waveband (10—20%) within which the antifading properties are preserved. In many instances there may be a need for an antifading operating mode and high gain in a wider waveband. This requirement can be met by using antenna masts with adjustable current distribution (Russian designation: ARRT*). This type of antenna was proposed in the USSR in 1939 (2). Later on, after undergoing several modifications, the adjustable-current-distribution antenna configuration (Fig. 1) won wide acceptance at the radio centers of the Ministry of Communications (5,6). The current in this antenna is varied by the movement of the shorting device K. By skillfully selecting the installation site for this shorting plug, an antenna mast 250—300 m in height can ensure operation over the entire 200—550 and 750—2000-m broadcast band, with good antifading properties preserved over at least a two-to-one bandwidth (for example, 250—550 m). Maximum gain of the antenna mast is 3.5.

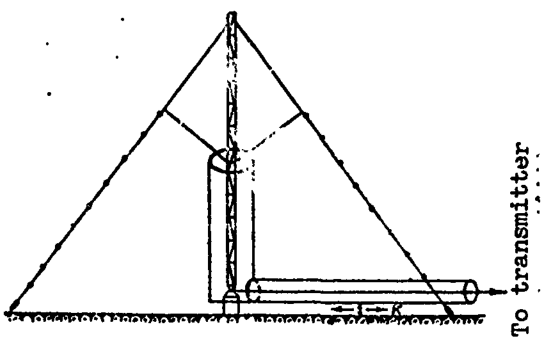


Fig. 1

Gain can be increased twofold by designing the antenna to consist of two antenna masts, one of which is the reflector. Antennas of this type are extensively used in the USSR and abroad. Further gain increases are

* "Antenna-machta s reguliruyemym raspredeleniyem toka" - Translator's Note.

achieved by the creation of cophasal arrays of antenna masts. Through the use of known methods, the antennas' maximum radiation direction can be controlled. In addition to providing increased gain, arrays with relatively narrow radiation patterns are a means of reducing the mutual interference between radio stations.

Within the Ministry of Communications system, medium-wave log-periodic antennas consisting of vertical dipoles [7] have been developed for operation in the 200—600-meter band. Unlike the cophasal arrays, these antennas exhibit a virtually constant radiation pattern throughout the entire working band, in addition to good natural transmission-line matching. The arrangement of such an antenna is shown in Fig. 2. If required, 3—4 antennas, each of which has its own direction of maximum radiation, can be mounted on a single support. Since all the antennas mounted on a support are cophasally driven, nondirectional radiation in the horizontal plane can be achieved.

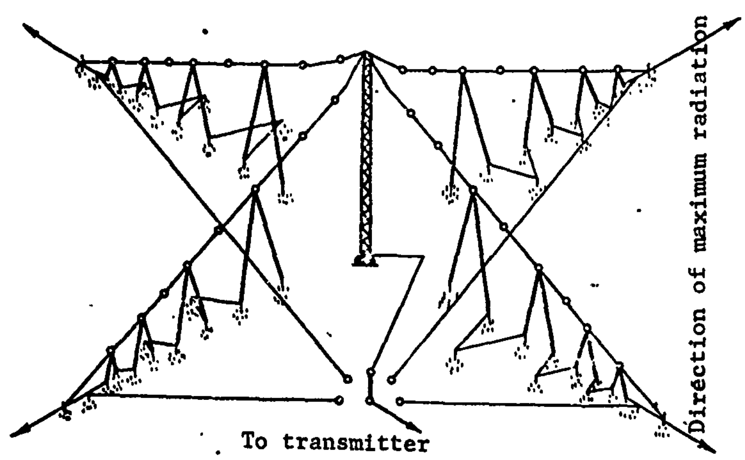


Fig. 2

The development of a strong polymer film technology provides a foundation for the design of new medium-wave antenna structures. Specifically promising is the use of pneumatic antenna masts of polymer material. An antenna of this kind is in effect a cylinder of high-strength film maintained under excess air pressure. Metal guys or a system of vertical wires enveloping the cylinder may be called upon to function as the radiating conductors. Advantages of these antenna masts include rapid installation, a height control capability, and others. Fig. 3 depicts a general view of a pneumatic antenna mast developed under the auspices of the Soviet Ministry of Communications.

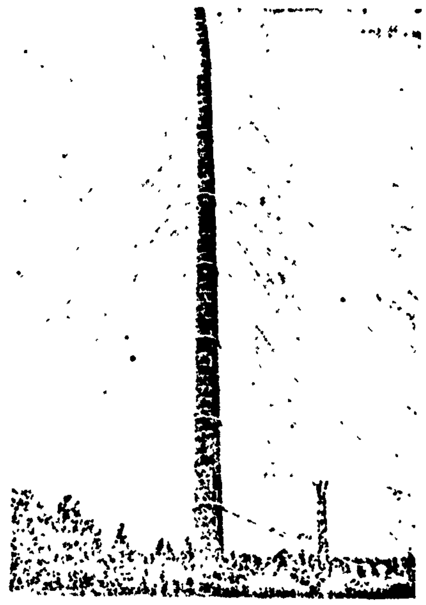


Fig. 3

For professional medium- and long-wave reception, vertical dipoles (with and without a horizontal component), goniometric antennas, and single-conductor traveling-wave antennas are used, while for individual reception, in addition to simple wire antennas, a wide application has been made of ferrite antennas built into the receiver chassis. Recent years, moreover, have witnessed the development of antennas for community radio-broadcasting reception. The use of these facilities makes possible the selection of the most advantageous antenna installation site for optimum audibility and minimum industrial interference level.

Shortwave Antennas for Radio Communications and Broadcasting

Shortwave radio communications are normally handled on wide-band multiple-tuned balanced dipoles and on Soviet-developed double rhombic antennas. For radio broadcasting, the principal transmitting antenna is the wide-band cophasal type with passive reflectors. The number of tiers and sections on these antennas is selected as a function of the broadcast path length. Extensive use has been made of cophasal antennas with aperiodic reflector designed in the form of a wire mesh. An overall view of a twin-section, four-tier, aperiodic-reflector antenna can be seen in Fig. 4.

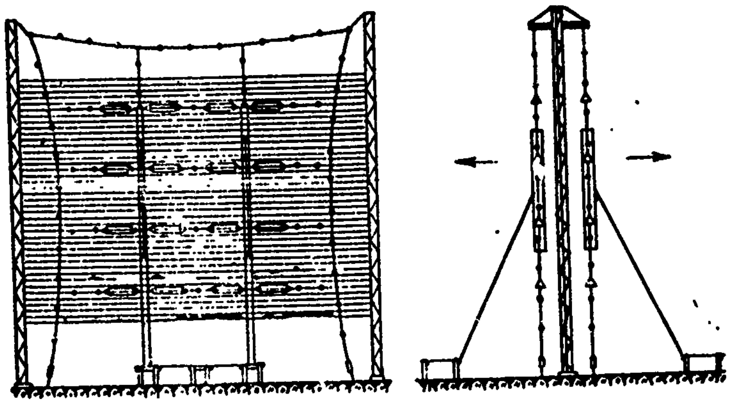


Fig. 4

Among the more important features of these antennas are the absence of tuning elements, the possibility of suspending two antenna curtains on both sides of the reflector, and the extremely low level of radiation in the rear quadrants. The antenna with aperiodic reflector may be effectively used in a two-to-one frequency band and, with certain allowances with respect to the form of the radiation pattern, in a considerably wider waveband.

In recent years there have been developed and introduced in the USSR cophasal antennas with wide-band reflector. These antennas are found in two versions: with a bridge-type reflector feeding arrangement (9, 10) and with the reflector fed across a directional coupler (11, 12). These antennas are distinguished by the retention of tuning in a 1 1/2-to-1 to 2-to-1 band. They show excellent natural matching with transmission lines within the specified working waveband. A deficiency of this type is a 10—30% energy loss in the dissipation lines required for normal performance.

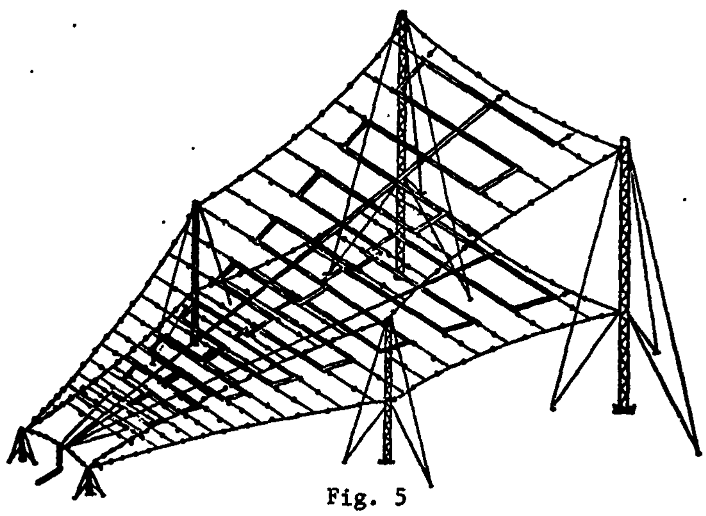


Fig. 5

Log-periodic antennas consisting of horizontal dipoles have gained wide acceptance abroad for shortwave radio broadcasting. Just as the medium-wave log-periodics, the shortwave log-periodic antennas exhibit radiation patterns which are independent of wavelength. This feature of the log-periodic antenna is important in radio broadcasting where normally illumination of a sector of definite width is required. An inclined log-periodic antenna (13) is pictured in Fig. 5.

Soviet specialists have developed an original version of the log-periodic antenna [14]. The curtain of this antenna is vertically oriented. The antenna has an aperiodic reflector permitting the mounting, on the same supports, of two antennas having mutually opposite directions of maximum radiation. The antenna consists of three parallel-connected curtains with an eye toward higher gain.

As shortwave nondirectional vertical radiating elements, pneumatic antennas similar to the medium-wave pneumatics described above are also employed.

Primarily used for professional communication and broadcast reception at receiving centers are double traveling-wave antennas with coupling resistors between dipoles and collecting line [15]. These antennas are distinguished by an extremely low side-lobe level and, correspondingly, high noise-resistance. Further noise-suppression is achieved by the erection of composite antennas consisting of three double traveling-wave antennas [16]. The antenna is generally equipped with a phase-shifter for pattern control in the vertical plane.

Operational experience with traveling-wave antennas having resistance coupling has indicated that in terms of noise-suppression they are far superior to rhombic antennas, including double rhombics as well, and also to the capacitance-coupled traveling-wave antennas used abroad. It is noteworthy that the stable performance of these antennas requires that the coupling resistors be rated for rather high-power dissipation; otherwise, there is a chance that they will burn out in thunder storms. This danger is virtually eliminated by using coupling resistors rated for 10 W dissipation power.

A very interesting trend in shortwave receiving antenna developments is the creation of universal highly directional antenna systems suitable for simultaneous operation with numerous receivers on different wavelengths and in different directions. The use of these antennas will result in financial savings and in territorially smaller antenna fields. One such antenna version is the shortwave Luneberg lens - in essence, a cylinder filled with a medium having a variable phase velocity. The phase velocity increases from the center toward the periphery. When a cylinder of this kind is illuminated by a cylindrical wave source, given a specific law for the phase velocity variation, the wavefront at the lens output becomes flat. Correspondingly, the radiation pattern is made narrow, with this bandwidth narrowing effect the greater, the greater the diameter of the cylinder. The direction of maximum radiation depends on the location of the exicter (primary radiating element) (Fig. 6).

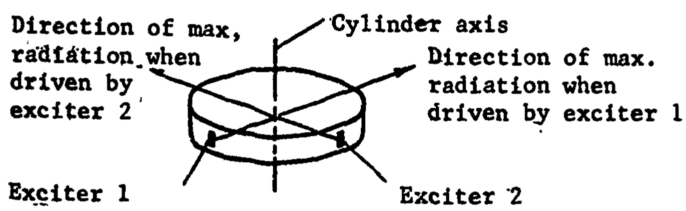


Fig. 6

A lens of this kind can be used for simultaneous independent operation in different directions.

In the United States a Luneberg lens has been developed (17) for the shortwave band. To create the variable-phase-velocity medium, two circular wire-grid disks are used. By appropriately varying the interval between the disks, a variable phase velocity is achieved between them. The disks become part of a cylindrical horn, whose height determines the form of the radiation pattern in the vertical plane. Normal performance by an antenna of this kind requires a high degree of precision in the design of the grids and the unchanged retention of their configuration despite any weather conditions. Moreover, disruption of lens operation may occur should it be coated with a layer of frost or snow.

One version of a receiving antenna capable of simultaneous operation in a variety of directions is a circular antenna consisting of vertical dipoles arranged circumferentially around a cylindrical aperiodic reflector (18). Each dipole is equipped with a wide-band amplifier and decoupler across which the energy is fed to a large number of receivers. Each receiver or parallel-working receiver group has its own system of phase-shifters which give rise to an individualized maximum-reception direction. Such a system permits the concurrent operation of dozens of receivers with a specific maximum-reception direction assigned to each receiver or parallel-operation receiver group. The directional properties of this antenna system increase with increasing cylinder diameter.

The use of polarization-diversity reception is one means of economizing antenna space. Research conducted in the USSR indicates that in the overwhelming majority of cases the fading correlation with polarization diversity differs very little from the fading correlation achieved with spatial diversity. Polarization diversity reception is possible using two traveling-wave antennas, one of which consists of horizontal, the other of vertical dipoles (16). To economize space, the second antenna may be mounted beneath the curtain of the first. A polarization-diversity reception system may also be designed on the basis of cophasal antennas sharing a common aperiodic reflector (16).

There has emerged in recent years a tendency in the shortwave communication area to employ cophasal horizontal antennas with Dolph-Chebyshev sectional amplitude distribution. This kind of amplitude distribution permits a substantial reduction of the side lobe level. Using a system of phase-shifters, such antennas can provide simultaneous reception from various directions.

Attention should also be called to another emerging technique for the side-lobe suppression of cophasal multidipole antennas - this one based on the use of nonequidistant antennas, that is, antennas with unequal spacings between sections. The interval between sections increases from the center out to the edges, resulting in an effect similar to that achieved by reducing the driving amplitudes from the center to the edges.

Meter-Wave Communication Antennas

One form of long-range meter-wave radio communication is communication based on the phenomenon of energy scattering on inhomogeneities in the ionosphere. Severe demands are made of the antennas on these links with respect to side-lobe suppression and maximum major-lobe compression; this, in turn, has determined the character of the antennas themselves. These circuits employ multitier horizontal cophasal antennas, complex antennas of the Yagi type, corner reflector antennas in the form of parabolic cylinders [(19)], and others. Gain may be as much as 400—500. Side-lobe suppression may be improved by appropriate amplitude distribution by antenna sections. Wherever economic considerations militate against the use of these antenna configurations, lower-gain antennas are put up, generally consisting of several Yagi's connected in parallel.

Over the last decade, meter-wave communication based on the phenomenon of meteor-trace reflection has become fairly common. The antenna systems associated with these links are frequently of the Yagi type, so connected that the pattern exhibits two major lobes with their maxima offset by 15°. This latter circumstance derives from the fact that on meteor-trace links the predominant signals reaching the reception site propagate at angles of 6—8° from a direct heading. A radiation pattern of this form can be achieved by, for example, connecting in parallel two diversity antennas of the Yagi type fed with a 180° phase shift.

Wide acceptance for UHF communications has been won by helix antennas, surface-wave antennas, log-periodic antennas, rhombic antennas, cophasal arrays, and others. Helix antennas radiate a field of rotating polarity; this is useful whenever it is not possible to predetermine the most suitable orientation of the field intensity vector.

For "circularized" communications, antennas similar to those employed for UHF FM broadcasting are used (see below).

Moving objects are likely to have slot antennas, dome (cap) antennas, cavity antennas, conventional dipole and reflector antennas, etc..

Antennas for Television and UHF FM Broadcasting

In the early period of television center construction multitier turnstyle antennas were the predominant type used. Each tier of this antenna consisted of two mutually perpendicular dipoles fed with a 90° phase shift, thereby ensuring a virtually circular radiation pattern in the horizontal plane. A serious drawback of the turnstyle antenna is the limited gain which is practicably feasible. This is so because the dipoles are secured to small-diameter metal tubing and adequate mechanical strength is possible only if the total height of the antenna does not exceed 12—15 m. Additional shortcomings of the turnstyle antenna are inconvenience of maintenance and the lack of a stacking capability (i.e., the superpositioning of one antenna atop another).

With the introduction of multiprogram television and the need for mounting more than one antenna on a single support, along with the effort to improve antenna efficiency by increasing the number of tiers, different versions of the panel antenna were developed. In the USSR one such variant was designed, consisting of balanced cylindrical dipoles, supported by metal struts, with a flat aperiodic antenna. By shifting the four panels around the support, nondirectional emission can be achieved in the horizontal plane. Panel antennas can be erected on large-section supports, thus permitting the design of high-gain antennas, as well as the mounting of one antenna above another on a single support. The overlap factor of panel antennas extends from 1—1.4 to 1—1.7, with gain as much as 20—50.

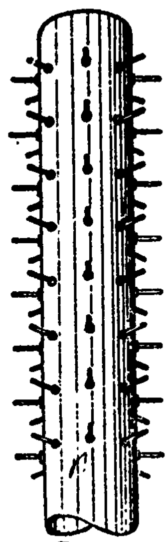
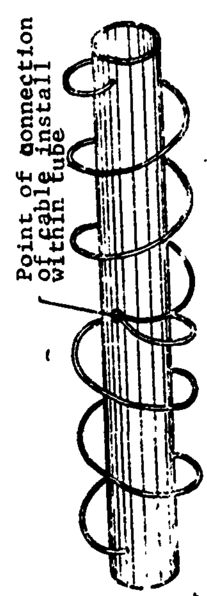


Fig. 7

An operationally very convenient antenna is a Soviet-developed version with radial rod dipoles mounted directly on a support (Fig. 7). By placing on a support, 0.7λ in diameter, eight rod dipoles on one tier, with a rotating-field feed arrangement, adequately uniform horizontal-plane radiation and sufficiently good matching in a frequency band of about ±8% can be achieved. A radial-dipole antenna has been erected at the All-Union Radio-Television Station in Moscow.

Also of interest are antennas in the form of a helix wound around a square or circular support (Fig. 8). Provided the diameter of the turn, the pitch of the winding, and the number of turns are properly selected, an antenna of this kind will give a good pattern in the vertical and uniform radiation in the horizontal plane.



Fig

Slot antennas are frequently employed in the decimeter waveband. The most typical slot antenna, extensively employed abroad, is one which consists of a tube on which have been notched vertical slots. Antennas of this type are extremely light. Compared to half-wave dipoles, slot antennas show gain factors of as much as 20—30. Since slot antennas have a relatively narrow passband, each channel requires a separate antenna.

Major attention in recent years has been directed at the problem of improving the directional properties of antennas in the vertical plane [20]. Unless special measures are taken, only 30—40% of the radiated power strikes the ground, with the remaining emitted energy lost without a trace. Moreover, within a radius of several kilometers from the antenna, fringe reception zones corresponding to the directions of the deep minima in the antenna's patterns are formed. Of the methods devised for acquiring patterns without deep minima and with a groundward direction of maximum radiation, the most advanced involve feeding the tiers of the antenna with the phases so shifted that their fields are cophasally added at an angle of 2θ, where θ is the angle of visibility of the horizon from the antenna installation site. This technique results in 60—70% of the radiated energy striking the surface of the earth. The minima in the antenna's radiation pattern will be satisfactorily filled, provided currents offset 90° in phase are generated in one or two of its tiers.

In feed system and transmission line design major stress is laid on the reduction of reflections. Of great advantage here is the mutual reflection compensation method involving the connection of uniform parallel-fed system elements by line segments differing in length by a quarter-wavelength.

The same antennas are used in UHF FM broadcasting as in television, but with relatively fewer tiers. Television antennas are powered almost exclusively over sealed coaxial transmission lines.

Television reception is effected over balanced dipoles, Yagi antennas, and others, generally installed on the roofs of buildings or on tall support structures. The community television-reception antennas so common in the USSR consist of the antenna proper, the RF amplifier, and the distribution transmission lines which deliver the energy to the individual television sets (21). The foremost advantage of the community antenna is the possibility of selecting for its location an optimum site at which the field strength of the beam incoming directly from the television station will be maximum, with the field strength of beams reflected from nearby buildings minimal. The Yagi is the primary community antenna type used in the Soviet Union. For lowest-loss energy distribution, directional couplers are employed. Recent years have witnessed a trend toward community reception systems servicing a group of homes.

Antennas for Radio-Relay Links

Relatively low-output transmitters (1—10 W) are used on line-of-sight microwave links. This fact, plus the high requirements for the transmission quality of telephony, television, and other information modes demanded of radio-relay circuits, results in the need for antennas with high gain (30—45 dB) and correspondingly large effective surface. Since these facilities must be installed on towers and masts of as much as 100 meters and more in height, the use of antennas with significantly greater gain is made difficult. Frequency modulation requires careful matching of all components of the antenna-transmission line system in order to avoid the occurrence of reflected waves.

Often two frequency bands are used on long-line radio-relay links for transmitter and receiver operation in both directions. This entails extraordinarily severe requirements with respect to the interference protection of the antennas. Receiving antennas must ensure 65—70 dB attenuation for backward-received signals, while transmitting antennas must similarly provide equal attenuation for signals radiated in the opposite direction. This situation has led to the extensive use on Soviet radio-relay links of parabolic horn antennas (22), one of which is shown in a general view in Fig. 9. The horn exciter forms a single structural unit with the parabolic reflector. Because of this, and also because of the presence of two lateral metallic walls ("cheeks"), the antenna provides a good radiation pattern. Rear-quadrant lobes are attenuated to a level of 65—80 dB, with the general level of side emission also held extremely low. The antenna features excellent matching with the waveguide transmission line. The aperture is generally shielded by a sheet of foam-plastic or some other special material to protect it against precipitation and moisture.

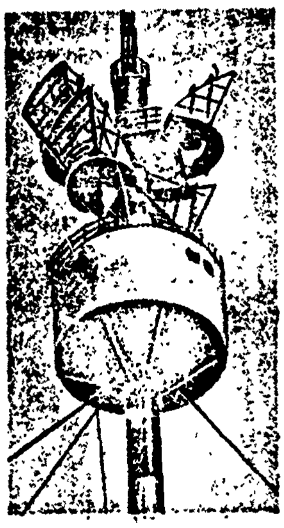


Fig. 9

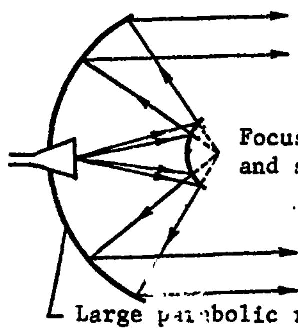


Fig. 10

The waveguide transmission system, and occasionally the antenna itself, is carefully sealed and filled with dry air kept under excess pressure to prevent the penetration of moisture.

In recent years Soviet radio-relay links have begun to be equipped with Cassegrainian-feed twin-reflector antennas of the kind schematically represented in Fig. 10. This antenna consists of a primary parabolic reflector and a small auxiliary reflector. Energy is fed to a horn located at the apex of the paraboloid. The horn radiates against the auxiliary reflector which is generally shaped in the form of a hyperboloid of rotation. Beams reflected from the auxiliary reflector have their phase center at the focus of the hyperboloid. If this center coincides with the focus of the paraboloid, the antenna system will operate as if the phase center of the exciter were coincident with the focus of the paraboloid. By locating the exciter at the apex of the paraboloid, the waveguide transmission line can be more conveniently attached to it. Moreover - and this is of particular importance - the auxiliary reflector facilitates the selection of the most favorable amplitude distribution in the paraboloid aperture, thus ensuring a relatively high surface utilization factor (SUF) for the antenna. The SUF of carefully executed twin-reflector antennas may be as high as 0.55—0.65. In comparison with the conventional parabolic antenna, the twin-reflector antenna has a lower lobe level in the rear quadrants, which, as noted above, is particularly important when operating these antennas on microwave links working on a two-frequency system.

Fig. 11 shows the diagram of an improved twin-reflector antenna [23] which has been developed in recent years in the Soviet Union. This version is one of the twin-reflector antenna class. The primary reflector is a body of rotation of paraboloid segments with a focus located inside a small reflector. The small reflector is a body of rotation of an elliptical line. In each given plane one of the ellipse foci coincides with the phase center of the horn exciter. There is formed in space a focal circumference each point of which is the focus for the corresponding illuminated line of the paraboloid.

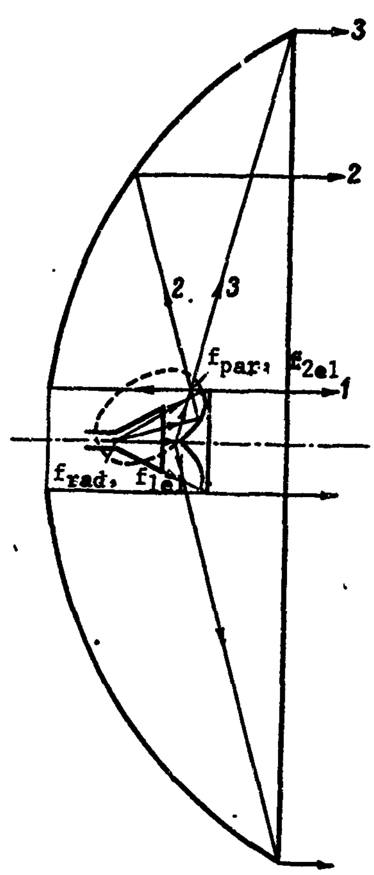


Fig. 11

Fig. 11 indicates the path of the beams striking the extreme points of the elliptical line from the phase center of the exciter. The back flow of energy passes by the exciter and does not strike the transmission line. The absence of energy flowback gives rise to conditions permitting excellent matching of the antenna to the transmission line over a wide frequency band. If the horn exciter provides maximum radiation along its axis, then the configuration selected yields a relatively uniform illumination of the prime reflector since the increase in beam path length to the edges of the prime reflector, and the field intensity attenuation thereby occasioned, is largely compensated by the form of the exciter's amplitude radiation pattern. The more uniform field-intensity amplitude distribution in the reflector aperture makes possible the achievement of a relatively high antenna SUF. This antenna system was independently proposed in the USSR and abroad (France, US).

On radio-relay links utilizing four working frequency bands, decoupling between signals coming from left to right and from right to left is accomplished by the frequency selectivity of the RF filters (24) and receiving equipment. Such links do not pose requirements of the same severity with respect to rear-quandrant lobe suppression. For this reason, low-performance antennas, such as periscopics and paraboloids of rotation, may be used. Research is under way, aimed at upgrading the parameters of periscopic antennas so that they might be employed on two-frequency microwave links.

As a rule, microwave antennas are connected to transmission and reception equipment by means of waveguides. Most frequently encountered are circular-section waveguides, one of which takes the place of two square waveguides designed for transmission and reception channels. In the circular waveguide decoupling between transmission and reception channels is improved because of the mutually perpendicular orientation of the transverse structure of the electromagnetic wave field of the transmission and reception channels.

In recent years, elliptical waveguides have been developed. These have an elliptically shaped section and are produced of corrugated copper ribbon (Fig. 12). A special feature of these waveguides is their mechanical flexibility, permitting their production in the form of one-piece (flangeless) tubing of any length for drum winding. This procedure facilitates the installation of the waveguides at the link.

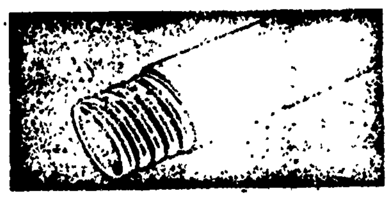


Fig. 12

The distance between adjacent sites on tropospheric radio-relay links is 200—350 km. With no direct line-of-sight between site antennas, communications are maintained by the reception of beams scattered by the troposphere. With this kind of communication system there is no need for elevated antenna installations, as in the case of line-of-sight links. It is sufficient to install the antenna so that the surrounding territory constitutes no obstacle to the passage of the horizontal beams. This makes for greater ease in the use of antennas with a large effective aperture surface - as much as 200—400 m^2. The most commonly encountered types are paraboloids of rotation and parabolic antennas with remote exciter.

Tropospheric links normally employ double reception on two spatially separated antennas, with the result that the intermediate relay sites will mount four antennas. The same antennas are also used for transmission, with the transmission and reception systems decoupled by means of frequency and polarization selection [24]. A general view of a tropospheric communication link antenna may be seen in Fig. 13.

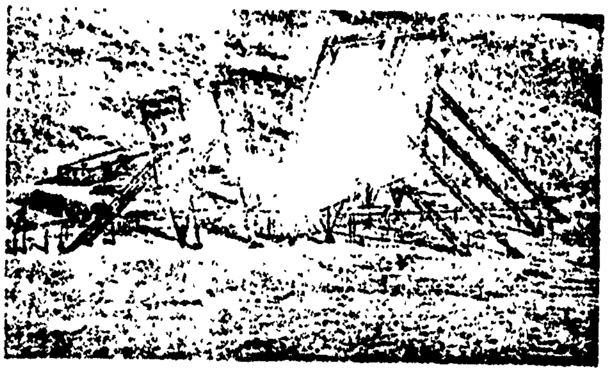


Fig. 13

An extremely important microwave trend is the use of passive relays - that is, sites which lack any transmitting-receiving equipment and at which the signal is received and transmitted by antenna systems alone. The use of such passive relay is of particular interest in mountainous areas where there are frequently virtually unaccessible locations at which the installation of active relay facilities would be extremely undesirable, to say nothing of the prohibitive costs that would be incurred.

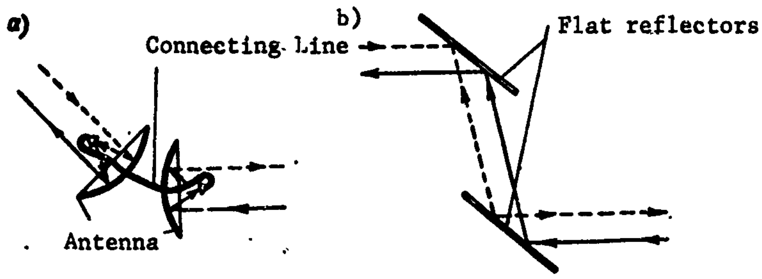


Fig. 14

Passive relays are occasionally designed in the form of two antennas (Fig. 14a). A second version can be seen in Fig. 14b, where the relay effect is achieved by means of two flat reflectors. This form of passive relay is convenient from the design standpoint; however, the use of two passive relays involves great difficulties. In effect, the substitution of a passive for an active site results in a severe reduction of the link's energy potential since transceiving equipment boosts this potential by 60 dB and better. The potential loss is partially compensated by improved antenna efficiency at the active sites, although by and large the compensation must be achieved through the use of high-gain antennas at the passive sites. The gain of passive-site antennas must be many times greater than that of the antennas at the active sites. Accordingly, the surface of the passive relays must also be many times greater. This, however, leads to a sharp jump in the cost of passive relay facilities and so greatly limits their area of application.

An original passive relay configuration that has been proposed in the Soviet Union is the "barrier" ("goalpost") antenna [25, 26], a distinguishing feature of which is its extremely low cost even when its surface area is many times greater than the surface area of active-site antennas. What makes the antennas pictured in Fig. 14 so very costly is the high degree of precision required in their fabrication, as well as the great structural rigidity of both the antenna and the support. The "barrier"-type passive relay configuration, on the other hand, does not require that the antenna be executed precisely or rigidly. As represented schematically in Fig. 15, this version appears as a metallic mesh (the "barrier"), impenetrable to radiowaves, suspended from two supports which are set up between the active sites.

Because of this metallic mesh, in the wavefront traversing its plane a region is formed where the field strength is $E = 0$. According to Babinet's complimentarity principle, such a front radiates in the same manner as a front

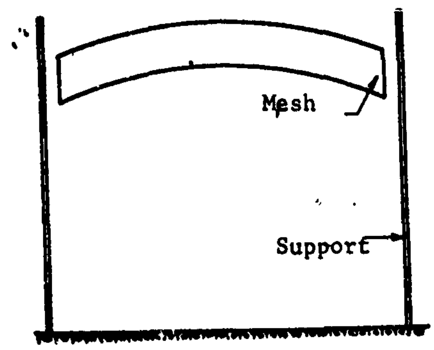


Fig. 15

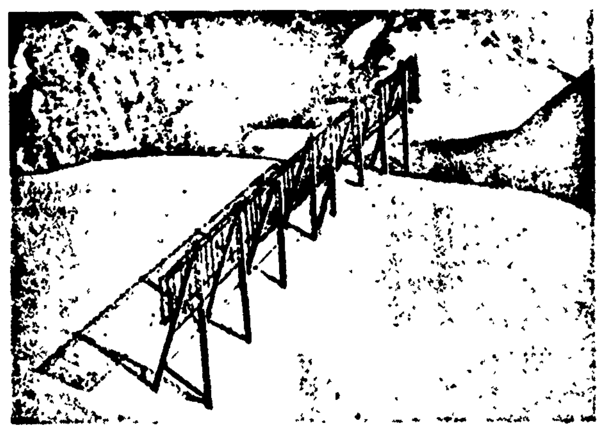


Fig. 16

in which the field strength in the region of the mesh is equal to a certain value of E, while in the remaining plane E = 0. In this way, the shaded region acts as an excited antenna with an area of the same magnitude. Since the only function of the metal mesh is to prevent the wave from getting through, it need not be precisely executed. The height and curvature of the barrier borders are selected so that the shaded region will coincide with one of the Fresnel zones of the active sites between which it is installed.

The area of passive relay facilities may be as much as $S_p = 500\ m^2$ - that is, 50 to 60 times the area of the antenna aperture S_a of the active site - with a gain factor which is greater by the same order of magnitude. Since a single passive relay takes the place of a receiving and a transmitting antenna, the total gain advantage is $(\frac{S_n}{S_a})^2$. Fig. 16 shows a general view of a passive relay installation on a mountain microwave link.

Antennas for Space Communications

On-board antennas for space communications have wide beamwidth and, correspondingly, low gain. This fact, together with the great distance of the space vehicle from the ground antenna, requires the use on the ground of high-power transmitters and high-gain antennas. In actual practice, we find antennas with an area of about 100—450 m^2. As a rule, because of the great costliness of ground antennas for space communications, the same antenna is used for both transmission and reception. The tracking of satellites mounting relay equipment requires steering mechanisms along with an automatic pointing system.

In order to reduce the noise temperature of the antenna and to minimize interference between the satellite communication system and ground communication circuits, the side-lobe emission of the ground antennas must be suppressed. Stability of communications despite the changing polarity on satellite communication links is ensured by employing circularly polarized antennas.

These and other pertinent requirements are most satisfactorily met by parabolic-horn and axiosymmetric twin-reflector antennas (see above). Although the first space communication links used the parabolic horns, subsequently twin-reflector antennas have come to be the only type employed.

In the initial phases of space communication engineering the antennas were equipped with radio-transparent domes for protection against atmospheric precepitation (snow, frost, etc.) and also to cut down the wind stress acting on the antenna (wind pressure may deform the antenna contour, impairing its performance and, in some cases, resulting in a complete loss of signal). However, during actual operation it was found that such domes sharply increase the noise temperature during rainfall, and for this reason they have been abandoned on television and communication space links. This has naturally resulted in a heightened requirement for rigidity in the antenna and steering mechanism.

For the domestic "Orbita" communication system single-reflector antennas have been developed with the radiating element in the form of a helix antenna (27). Careful fabrication of the exciter system along with great precision in the contour of the dish have made it possible to achieve extremely good electrical parameters. The surface utilization factor (SUF) of the "Orbita" antenna is 0.65—0.7, the noise temperature with the antenna pointed at the zenith is 30°K. The antenna lends itself to operation under any climatic conditions.

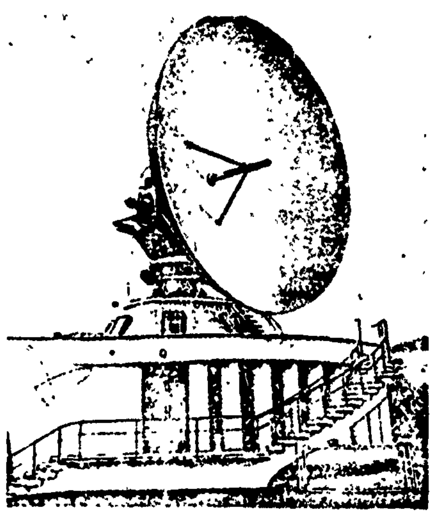


Fig. 17

An overall view of an "Orbita" antenna can be seen in Fig. 17.

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