The Lenkurt® Demodulator

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6,000 MC RADIO SYSTEMS

Some Equipment and Operating Considerations

The 6,000 mc common carrier and industrial bands are valuable because they can accommodate very large numbers of voice channels. The characteristics of 6,000 mc radio waves, however, call for circuitry which differs in several important respects from conventional radio. Further, propagation is affected more by the atmosphere at this frequency than at lower frequencies.

This article describes two major differences between circuits for 6,000 mc and conventional radio. It also discusses the effect of the atmosphere on propagation at 6,000 mc.

Conventional radio circuits are used for communication at frequencies up to about 2,000 mc. Above this region they will not operate satisfactorily. Components such as standard radio tubes and two-wire or coaxial transmission lines either fail completely or have too much attenuation. In recent years, however, new components have been devised that make microwave communication in the region above 2,000 mc practical and economical.

One of these components, the klystron vacuum tube, is now widely used at frequencies up to 25,000 mc or greater. In some respects it performs more efficiently at microwave frequencies than an ordinary radio tube does at broadcast frequencies.

Another component, the waveguide, makes use of the very short wavelengths of microwaves to provide an effectively shielded transmission line having relatively low loss. The waveguide is not only capable of operating as a transmission line but also can be designed to operate as a capacitance, inductance, filter, or hybrid. When used with auxiliarly devices such as magnets and ferrites, it can be made to operate as an isolator, circulator, modulator, discriminator, or attenuator.

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Besides having different terminal and repeater components, microwave radio systems are affected more by atmospheric conditions than broadcast or other low-frequency radio. Special consideration must be given to 6,000 mc equipment location to overcome the deeper and more frequent fades which occur as frequency increases in the microwave region. Additional importance is also given to the sensitivity and noise figure of receivers because of the deep fading.

Vacuum Tubes

In conventional vacuum tubes operating below microwave frequencies, the time required for an electron to travel from the cathode to plate is very small compared to the time required for a signal on the control grid to go through one cycle. However, if a microwave signal is applied to the grid, its cycle may be short compared to an electron's *transit time,* and will become shorter as the frequency increases. The flow of electrons in transit toward the grid will not be able to follow the signal variations exactly.

The plate-current wave will be very distorted and will be out of phase with the grid voltage. In addition, power will be dissipated at the control grid and, to a lesser extent, at the cathode. The result is distortion of the output signal and loss of gain.

To overcome this problem a klystron vacuum tube uses a stream of electrons to excite a resonant cavity within the tube. The tube output is taken from this cavity at its resonant frequency. Klystrons do not depend on a plate current to create an output voltage.

Klystrons used in microwave transmitters generate the carrier frequency which is modulated and fed to the sending antenna. In receivers they generate the radio frequency which is mixed with the incoming signal to produce an intermediate frequency for amplification and detection. Klystrons have now been developed to the point where they can be made about as reliable as the best standard industrial tubes. Fig. 1 is a schematic representation of the internal and external circuits of a klystron oscillator.

Waveguides

One of the characteristics of electromagnetic waves is that they can be confined in, and propagated along, hollow metal tubes. Such tubes may be circular or rectangular in cross-section, but a rectangular tube is generally the most practical because of its wide frequency range and ability to maintain wave polarization. The power loss in a waveguide is about one-third the loss in a comparable air-insulated coaxial line, and very small compared to the loss in a flexible coaxial cable with solid insulation (rubber, plastic, etc.). Waveguides can be made rigid or flexible and have an infinite life as long as they remain free of corrosion or dents.

One factor limits the use of waveguide. This is the physical dimension required for propagating given frequencies. The lowest frequency a waveguide can transmit is determined by its width. The wavelength at this lowest frequency, or *cut-off frequency,* is twice the width of the waveguide. This means, for example, that a waveguide designed to transmit a 30 mc signal must be at least 17 feet wide. Needless to say, this is impractical.

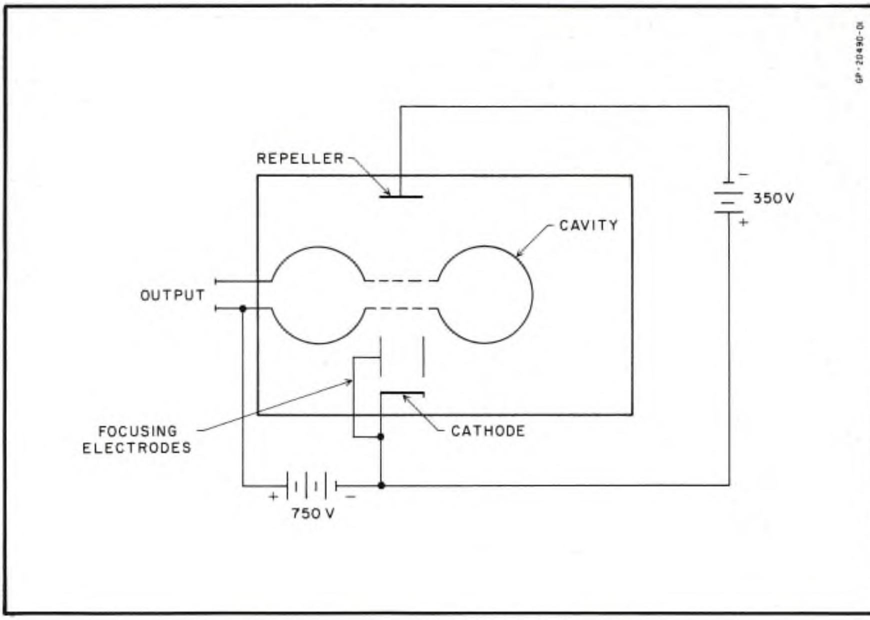

Fig. 1. Diagram of a reflex klystron. Electrons flow from the cathode across the cavity gap toward the repeller. The repeller returns the electrons in bunches to the cavity gap. These electron bunches induce voltages across the cavity at its resonant frequency and maintain a condition of oscillation.

At 2,000 mc, however, half a wavelength is about three inches, and at 6,000 mc only one inch. Waveguides can be built economically to handle these frequency ranges, and they lend themselves to convenient equipment arrangements. Fig. 2 shows the compact waveguide assembly used in Lenkurt Type 74A *Microtel* equipment.

Propagation

Radio signals travel from a transmitter to a receiver by three principal means: *ground waves, sky waves,* and *space waves*. Ground waves cannot be used at microwave frequencies because they are completely attenuated within a few feet of the transmitter. Sky waves are reflected, refracted, or scattered back to earth by ionized layers of the upper atmosphere (the ionosphere), but only to a small extent above 100 mc. At microwave frequencies they are usable only in very high-power expensive systems which must bridge great distances in a single hop. Space waves, which travel through the atmosphere immediately above the earth, are the most practical propagation means for microwaves.

To be usable, the space waves must arrive at the receiver with a certain minimum signal strength. Below this minimum, known as the *threshold level,* the signal is drowned out by receiver noise. When the received signal drops below this threshold in a common carrier radio system, telephone circuits connected to it through a dial exchange will disconnect. To restore service they

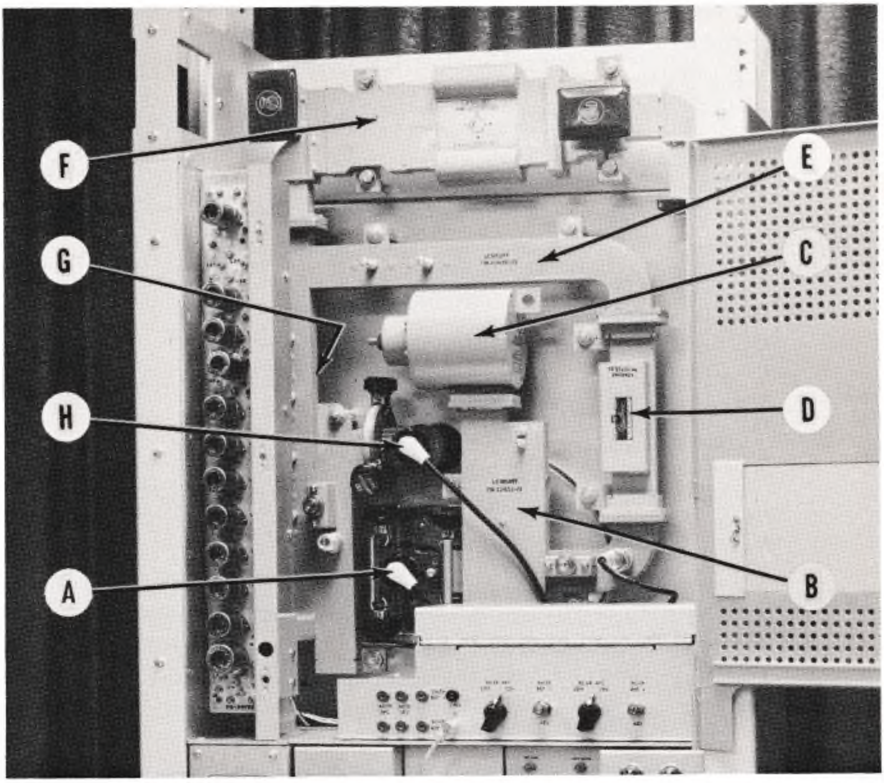

Fig. 2. Type 74A transmitter-receiver with waveguide assembly exposed. The principal microwave components shown are: (A) transmitting klystron; (B) waveguide discriminator; (C) reference cavity for controlling transmitter frequency; (D) isolator; (E) waveguide run to circulator panel; (F) circulator panel; (G) waveguide run to r-f mixer; and (H) local oscillator klystron.

must be redialed. Further, for toll quality communication, the signal must remain several decibels above the threshold level to maintain the desired signal-to-noise ratio.

The maximum distance allowable between transmitter and receiver for toll quality service is determined by transmitter power output, receiver threshold, and the sum of the losses between them. There is a relatively small loss from the transmitter or receiver to its antenna, an appreciable antenna gain, and a varying path loss. Fig. 3 shows gains and losses of a typical radio section.

The total path loss between antennas is made up of two parts: (1) path attenuation and (2) fading. These losses are determined by path length, path clearance above the earth, atmospheric conditions, and frequency.

Path Attenuation

If a space wave is radiated from a point (isotropic) antenna it spreads out equally to all directions in the shape of an ever-expanding sphere. As the surface of the sphere moves farther and farther from the point antenna, the radiated energy is spread over a larger area and the amount of energy per square-foot of wave front decreases. Mathematically speaking, the energy concentration at a point on a wave front is inversely proportional to the square of the distance from the antenna.

The power that can be extracted from a wave front by a similar point antenna is inversely proportional to the square of the frequency. Thus, the power received by a point antenna is inversely proportional to both the square of the distance from the source and the square of the frequency. The ratio of this power to the total power radiated is called *path attenuation.*

When the receiving antenna is something other than a point (a parabola-shaped dish, for example), the amount of power extracted from the wave front is greatly increased. The ratio of the amount of power received by a practical antenna to the amount extracted by a theoretical point antenna is called *antenna gain referred to an isotropic radiator.*

The gain of a parabolic antenna increases with antenna area. It also increases with operating frequency. So, for a given radio path with fixed-size antennas, the path attenuation increases with frequency. But so does the antenna gain. One tends to offset the other. Table 1 compares path attenuation and antenna gain for two radio sections operating at different frequencies over the same path length with antennas of the same size.

Fading

Fading of received signal strength is caused primarily by variations in atmospheric conditions. These variations

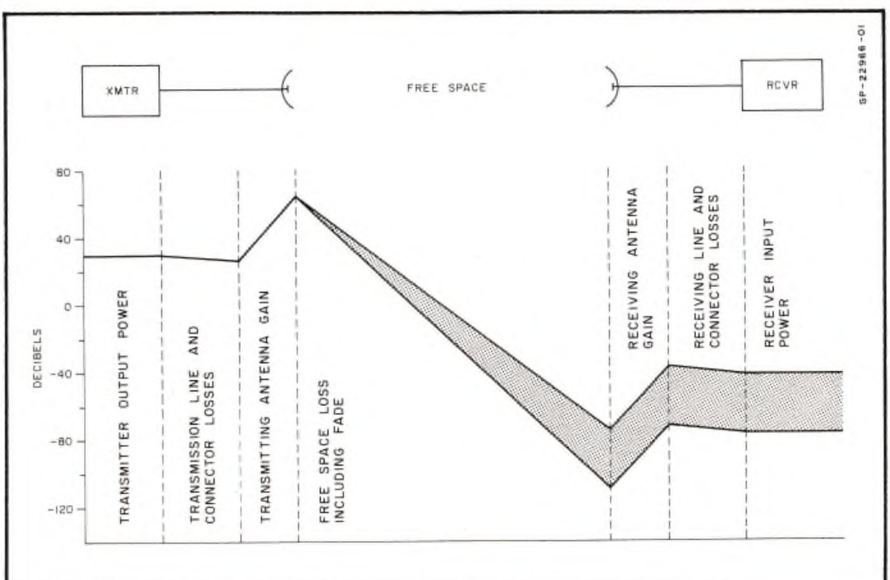

Fig. 3. Gains and losses in a typical radio section. The shaded area indicates the range of losses expected from fading during 99.9% of the time.

TABLE I

COMPARISON OF RADIO SECTION CHARACTERISTICS
AT 1, 000 and 6, 000 MC

	1, 000 MC	6, 000 MC	REMARKS
Path Length	25 mi	25 mi	
Antennas	6' Parabolic	6' Parabolic	
Free-Space Path Loss	124. 5 db	140. 0 db	Computed from: $L = 10 \log f^2d^2$
Antenna Gain (2 antennas)	46. 0 db	77. 0 db	Computed from: $G = 10 \log f^2 + 10 \log D^2 - 52.6$ for one antenna
Normal Transmitter Power	+37 dbm	+30 dbm	
Normal Misc. Losses (trans. lines, combining filters, circulators, etc.)	8 db	5. 2 db	
Net Received Signal Power	-39. 5 dbm	-38. 2 dbm	

cause radio waves to bend away from their normal lines of propagation. The fades resulting under a given set of conditions occur in greater number and greater severity as signal frequency increases. The reasons for more frequent fading at higher frequencies can be explained by examining the mechanics of wave propagation.

A signal beamed toward a receiving antenna consists of a series of wave fronts whose centers are on the line of sight from trasmitting antenna to receiving antenna. The surface of each of these wave fronts consists of an infinite number of isotropic radiators sending signals in all directions away from the wave front. Thus, at any instant there are an infinite number of paths from a given wave front to its receiving antenna.

For example, in Fig. 4 if any two paths differ by one-half wavelength or any odd multiple of a half wavelength, the energies received over the paths will cancel. If they are the same length or differ by any whole number of wavelengths, they will reinforce each other. The paths AR and A′R from the wave front to the receiver R are one-half wavelength longer than the line of sight path OR. All secondary waves emanating from within the area defined by AOA′ as diameter will reinforce the direct wave, OR, at the receiver because they are less than one-half wavelength out of phase with OR. This area is known as the first Fresnel zone and provides one-quarter of the received field energy.

The path lengths BR and B′R are one wavelength longer than the direct path OR. All secondary waves emanating from the shaded area between the first Fresnel zone and the circle whose diameter is BOB′ will act at the receiver to partly cancel the waves from the first Fresnel zone because they are between one-half and one wavelength out of phase with OR. This shaded area is the second Fresnel zone. All odd-numbered Fresnel zones will reinforce the direct wave and all even-numbered Fresnel zones will cancel odd-zone energy.

The third Fresnel zone is defined by diameter COC′, and the fourth by DOD′. There are an unlimited number of Fresnel zones, with each succeeding one contributing less energy than the one before. The area of the Fresnel zones is determined by their distance from the transmitter and receiver, and the operating frequency. The higher the frequency, the smaller is the difference in path lengths which is equal to a half wavelength; hence, the smaller the first Fresnel zone and the others surrounding it. However, each Fresnel zone still contributes the same proportion of energy.

Fresnel zone sizes are important because they determine the effect of wave bending (refraction) on path clearance above the earth and on reflections from smooth earth surfaces. Smaller Fresnel zones cause obstacles in the radio path to obstruct a greater percentage of radiated energy. They also cause more severe and more frequent cancellations of energy between reflected and directly transmitted waves when the latter are bent or *refracted* by the earth's atmosphere.

Refraction

Refraction occurs when a wave changes velocity in passing from one medium into another. This occurs in air when two layers have different densities. As a radio wave travels upward at an angle through the atmosphere it normally encounters air of decreasing density. Since the top of the wave reaches the lighter air first, it increases

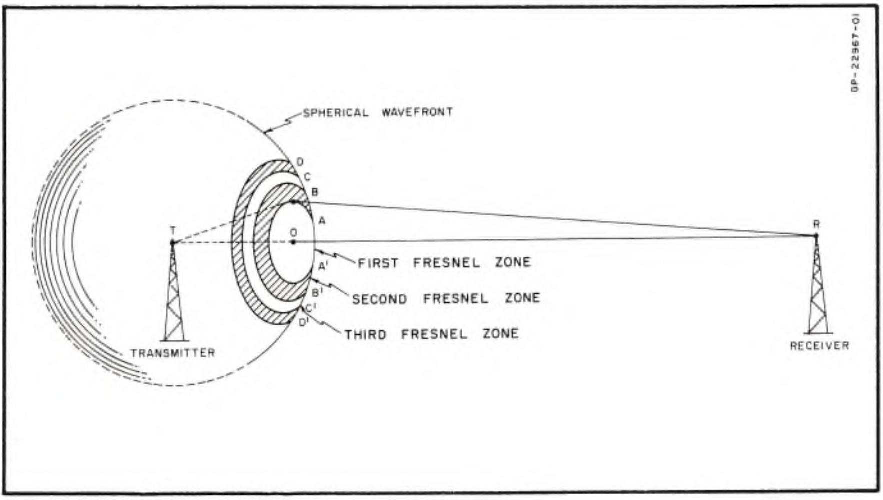

Fig. 4. Fresnel zones of a transmitted signal's wavefront at distance OR from a receiver. The difference in path length to receiver from edge of one zone and edge of adjacent zone is one-half wavelength. Odd-numbered zones reinforce the signal and even-numbered zones cancel it.

its speed first, and the wave bends back toward the earth.

In this way radio waves normally tend to follow the earth or, in effect, the earth appears to flatten and have a larger radius. Correspondingly, if inversion occurs and the air becomes heavier as altitude increases, the wave bends away from the earth.

When atmospheric conditions are such that the air density increases with height, the earth between transmitter and receiver appears to bulge up into the wave fronts. If this effective bulge reaches the line of sight between the transmitter and receiver, microwaves of any frequency will be attenuated about 20 db. However, if the refraction increases so that the earth bulge rises above the line of sight, attenuation will be even greater but no longer equal for all frequencies. Loss in this "shadow zone" increases rapidly with frequency.

For example, Figure 5 shows an effective earth bulge of 67 feet above the line-of-sight caused by atmospheric refraction. The first Fresnel zone radius for a 6,000 mc signal is 81 feet. The 67-foot obstruction results in a −0.83 clearance of the first Fresnel zone at 6,000 mc and causes a loss of 50 db over normal propagation conditions.

In addition to changing the clearance above obstacles, refraction causes fading by changing the relative path length of the direct and reflected waves. As the direct wave is bent above or below the line of sight, its path-length increases so that part of the time the two waves reinforce each other and part of the time they tend to cancel. This is shown in Fig. 6.

If the terrain between the transmitter and receiver is a good reflector, the

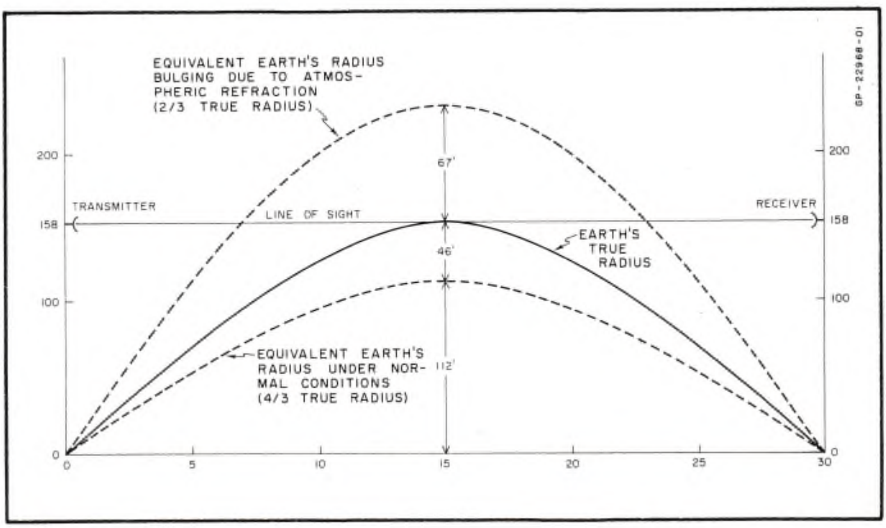

Fig. 5. In this example normal atmospheric refraction permits a signal clearance of 46 ft. above the earth. This is represented by an equivalent flattening of the earth's radius to 4/3 true radius. When atmospheric density increases with height the earth's surface appears to bulge upward. Here a bulge of 67 ft. above line-of-sight gives an equivalent earth's radius of 2/3 true radius.

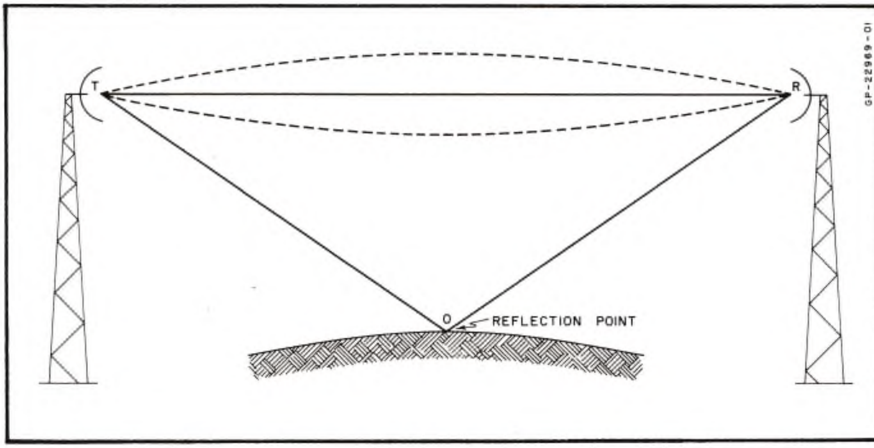

Fig. 6. Refraction of direct wave which results in partial cancellation by reflected wave. TR is the direct path and TOR is the reflected path from transmitter to receiver. Dotted lines show bending of direct wave due to refraction. This changes path length TR and causes alternate canceling and reinforcing by reflected wave TOR.

cancellations may be nearly complete and very deep fades will result. High-frequency waves will cancel each other more frequently than low-frequency waves because smaller changes in refraction are required to cause a difference in paths of one-half wavelength. Thus a 6,000 mc radio system will have more fades than a lower frequency system but they will be of shorter duration.

Fade Margin

To insure that a transmitted signal reaches a receiver with at least a minimum strength for a certain percentage of the time (for example, 99.9%), enough extra signal strength must be available during normal propagation to compensate for most fades. This is called *fade margin,* and is usually determined by actual field experience because there are no reliable formulas for predicting atmospheric conditions.

A fade-margin figure dictated by experience for a typical path at 6,000 mc is 30-40 db. The exact figure used depends on field studies of the particular location. When the signal path is over a good reflecting surface such as water, additional fade margin must normally be allowed.

Conclusions

The frequency bands in the 6,000 mc range available for common carrier and industrial use are valuable because of their high channel capacity. The use of these bands, however, involves special microwave circuitry and increased losses to the space wave. The necessary circuit elements—such as klystrons and waveguides—are readily available and present little difficulty in application. In fact, klystrons and waveguide circuits are more rugged and simpler than low-frequency tubes and coaxial cable. The additional path attenuation and fading at these frequencies can be overcome by shorter sections and antennas of larger gain.

HIGH VOLTAGE PROTECTION

An article in the November issue of The Demodulator discussed the dangerous high voltages that can be induced in telephone lines by power lines or lightning. It also described the operating principles of carbon block protectors. These are widely used in the telephone industry to limit the amount of induced voltage reaching personnel or equipment. Lack of space last month prevented us from including photographs of practical protectors, although these were erroneously referred to as Figs. 4 and 5.

Pictured here are three protectors, typical of those used in the telephone industry. The type shown in Fig. 1 is a fuseless subscriber station protector.

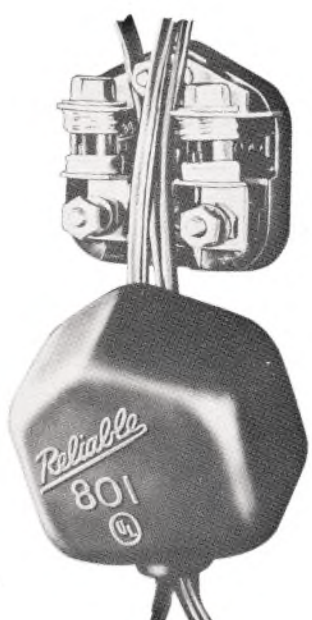

Fig. 1. Fuseless subscriber protector. The carbon buttons are enclosed in removable throw-away cartridges.

Fig. 2. High-voltage protector for open-wire lines.

The air gap between either carbon block and the ground electrode is designed to break down when subjected to more than about 450 volts. Once broken down, considerably less than 450 volts is required to maintain a current path to ground. This further reduces the high-voltage hazard.

Protection of open-wire lines from lightning or power line induction is the purpose of the high-voltage, high-current-capacity style shown in Fig. 2. This protector uses three carbon buttons —one for each line wire and one for ground. They are equally spaced so that if the potential between any two of them exceeds 2,000 or 3,000 volts (depending on the model), the air gap will break down and the induced high-voltage energy will dissipate as heat. These are often used at periodic intervals along pole lines to ground high induced voltages near their source.

Fig. 3 shows a bank of central office protectors. These prevent high voltages reaching a central office from injuring personnel or damaging connected carrier equipment, switchboards, or automatic switching equipment. Breakdown voltage is normally 450 or 750 volts depending on whether the circuits are exchange or toll.

The particular type of central office protector shown in Fig. 3 employs an

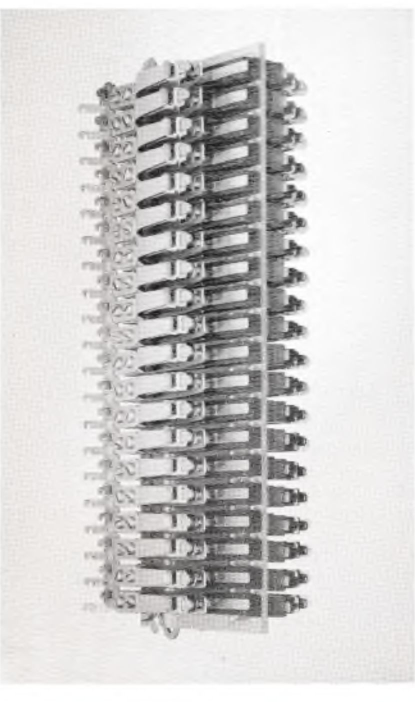

Fig. 3. Automatic Electric Type 675 central office protector.

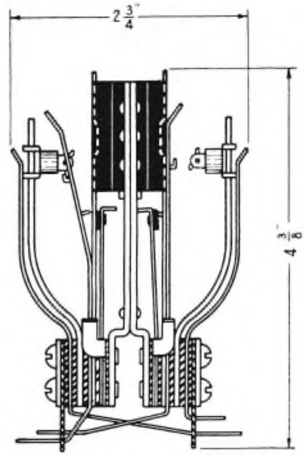

Fig. 4. Cross-section of the Type 675 protector. One heat coil is shown operated.

auxiliary "heat coil" which causes the line to open when the circuit has a steady induced voltage that is dangerous but not high enough to break down the air gap. Heat generated by excessive current in the coil releases a trigger mechanism which releases a spring opening the circuit. At the same time it connects an alarm circuit to the ground electrode. Fig. 4 shows a schematic of this protector with one heat coil operated.

Other types of central office protectors either do not use heat coils or they have heat coils which short circuit the line conductors to ground. This latter type is used extensively in toll offices.

Carbon block protectors are simple devices that cost little but do a big job. They are good insurance against outages caused by high voltage. Subscriber stations and major items such as carrier terminals should never be connected to an unprotected exposed line.

(All Illustrations by Automatic Electric Co.)

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NEW MICROTEL PUBLICATION

A general description of Lenkurt's **TYPE 74A MICROWAVE SYSTEM** is given in a new bulletin, **Form 74A-P4.** General and circuit description, optional arrangements and frequency assignments are contained in this publication. Also provided is a technical summary which lists important design and operating characteristics. Copies of **Form 74A-P4** may be obtained from Lenkurt's offices and distributors.

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