The Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

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ANTENNA SYSTEMS for microwave

Part Two

Without highly directional antennas, modern microwave systems could not achieve their high propagation reliability with such low power outputs. However, just as some antennas are more efficient than others, compound arrangements of antenna elements often provide a more effective and less expensive means of linking the transmitter to the receiver than do simple antennas. Some of the factors involved in the use of these compound systems are considered in this article.

Because microwave transmission follows essentially a straight line, the path between transmitter and receiver must clear any intervening obstructions. The limiting factor may be the curvature of the earth or it may be an obstruction such as a mountain. In either case, one way to achieve additional path clearance is simply to raise the antenna systems at the ends of the path. This can be done in several ways, but they all cost money. If the antenna is placed at the top of a tower, the expense and the transmission impairments of a long waveguide run must be considered, in addition to the cost of the tower.

Of course, if the terminal is located on a mountain top it may not require a tower. Usually, however, the cost is still there — it is no less real because it takes the form of an access road instead of a steel tower. Thus, terminals are placed for convenient access to roads and power lines, and the antenna system must get the signal over or around all obstructions.

This does not mean, however, that the path between transmitter and re-

Figure 1. A "periscope" antenna system can provide path clearance without the expense and transmission impairments of a long section of waveguide.

ceiver must be a single straight line. Since microwaves follow most of the rules of conventional optics, a system of "mirrors," similar to an optical mirror system, can be constructed to reflect the beam over or around an obstruction. Such a system often provides a solution to the antenna system problem, which is essentially one of balancing path clearance, directivity, and transmission loss against economic factors.

"Periscope" Antenna Systems

The simplest and most common reflector system consists of a parabolic antenna mounted at ground level and directed vertically to illuminate a passive reflector at the top of a tower. This reflector, inclined at 45°, redirects the beam horizontally to a distant site, where a similar "periscope" system may be used to reflect the signal back to ground level. The vertical separation between antenna and reflector may be provided by a specially constructed tower or the reflector may be mounted on a building or other convenient structure, providing two factors are considered: (1) the structure must be high enough to provide adequate path clearance; and (2) there should be an optimum separation between antenna and reflector — signal strength is impaired by either too small or too great a separation. This second point is not obvious, but it has an important effect on the efficiency of the system. In fact, a properly laid out antenna-reflector combination can produce more gain than the antenna alone, even when reflector losses and scattering are considered. ("Gain" results from increased directivity — a "sharper" beam).

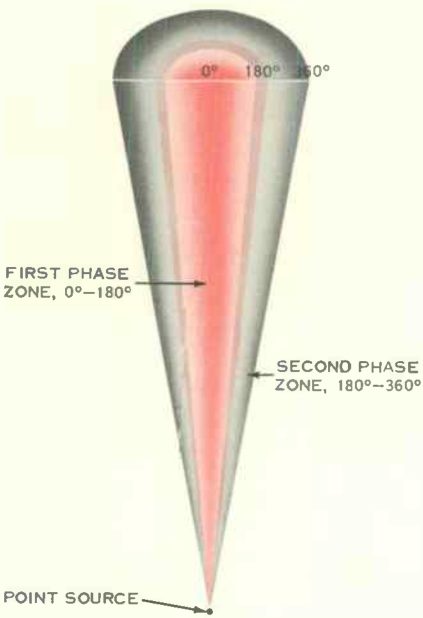


Figure 2. When a plane intersects radiation from a point source, phase addition occurs throughout first phase zone (red). When second zone energy (gray) is intercepted, phase cancellation occurs.

This seemingly paradoxical situation occurs because of a complex interrelationship between the size and shape of both antenna and reflector, the distance between them, and the operating frequency. These are the factors which control the phase relationship of the energy striking the reflector — and this phase relationship is the key to an effective system.

The phase variation at the reflector is illustrated in Figure 2, which shows a flat plane intersecting the radiation emitted by a point source. As the distance from the center of the plane increases, so does the distance from the source, until some point on the plane is reached where the distance from the source is a half wavelength longer than the distance from the source to the center of the plane. At this point the wavefront is 180° out of phase with the energy at the center of the beam. A line joining all such points describes a circle about the center, and all the energy within this circle has an in-phase component. That is, all the energy between 0° and 180° has a common in-phase component at some intermediate angle. As the phase difference exceeds 180°, all the energy has a component which is out of phase with the energy in the first phase zone (0° to 180°). This second phase zone, consisting of out-of-phase energy, extends from 180° to 360°. Additional zones exist, but most of the energy is concentrated in the first two.

Effectively, this means that the reflector will have maximum gain when it intercepts all the energy in the first phase zone, because phase *addition* occurs throughout this zone. If, however, some of the energy from the second zone is also intercepted, phase *cancellation* occurs and the effective signal power is reduced. Because the maximum in-phase reflection occurs when all of the energy in the first zone — but none of the second-zone energy — is reflected, the optimum reflector size corresponds to the size of the first phase zone. A smaller reflector will not intercept all the in-phase energy, and a larger one will intercept some of the out-of-phase energy, producing cancellation.

But choosing the proper reflector size is not the whole problem. The first phase zone expands as the distance from the antenna increases. (Its diameter is approximately proportional to the square root of the distance.) This means that if antenna and reflector size are fixed, there is an optimum separation. Increasing this separation has the same effect as reducing the size of the reflector.

Furthermore, antenna size also affects the performance. The preceeding discussion considered the antenna as a

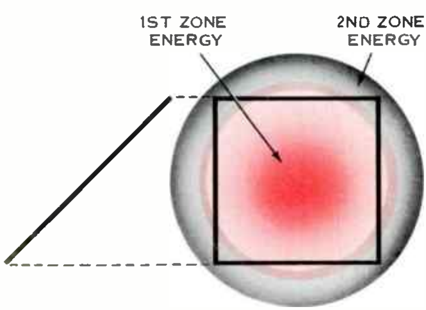


Figure 3. Rectangular reflector illumination seen from antenna. A small reflector misses some first zone energy, while corners of larger reflector catch some second zone energy, thus reducing gain.

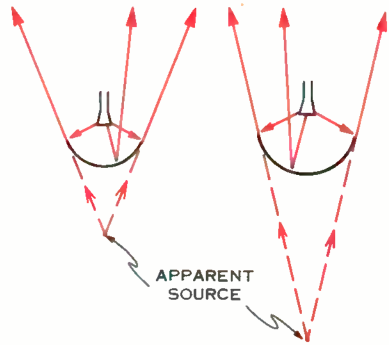


Figure 4. A smaller antenna produces a more divergent beam, causing phase zones to spread more. Hence, a smaller antenna requires a larger reflector to intercept entire first phase zone for maximum gain.

point source, but in reality the area of the antenna may be a sizeable fraction of the reflector area. The significance of this is that the point source becomes an apparent source somewhere behind the antenna, as shown in Figure 4. This is the point from which the radiation appears to be emanating. Because a larger antenna produces a more nearly parallel beam, this point is farther back and the first phase zone does not expand as rapidly. In other words, for any given antenna-reflector separation, a larger antenna provides a better focus, and a smaller reflector must be used to achieve maximum gain.

Another aspect of the problem is the *shape* of the reflector. Since the desired first phase zone is round, the reflector should present a circular area to the antenna; corners may project into the second phase zone, catching some out-of-phase energy, and straight sides may miss some of the in-phase energy of the first zone. Because a reflector is normally inclined at 45°, it must be elliptical to project a circular area. In actual practice, however, reflectors are seldom elliptical because rectangular ones are less expensive. A rectangular reflector is proportioned to project a square area both vertically and horizontally. The inefficiency of this square shape can cost 1 or 2 db of gain if the corners extend into the second phase zone. In practice, however, a reflector usually does not occupy the entire first zone, and the corners increase the effective reflecting area, thereby slightly increasing the gain.

Square corners also have an adverse effect on the side lobe level. An elliptical reflector has a high side lobe level, but the corners of a rectangular reflector increase the scattering, producing an even higher side lobe level. Because of these undesirable effects, it is common practice to remove the corners, forming an octagonal projected area — or two corners only may be removed to form the familiar "fly swatter."

A properly designed antenna-reflector system can produce 2 or 3 db more gain than the antenna alone. This comes about not only because just the in-phase energy is reflected, but also because of another factor. The surface of the re-

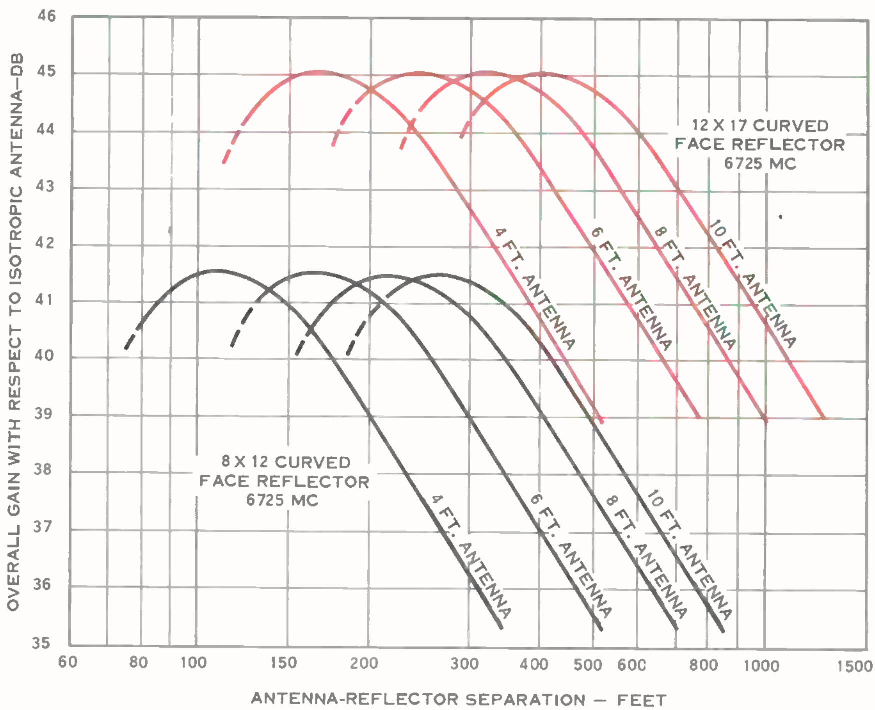


Figure 5. Gain variation of curved-face reflectors with respect to separation between antenna and reflector. The red curves are for various sizes of antennas used with a 12 by 17 foot reflector. Black curves are for an 8 by 12 foot reflector. Larger antenna requires smaller reflector or higher tower for maximum gain.

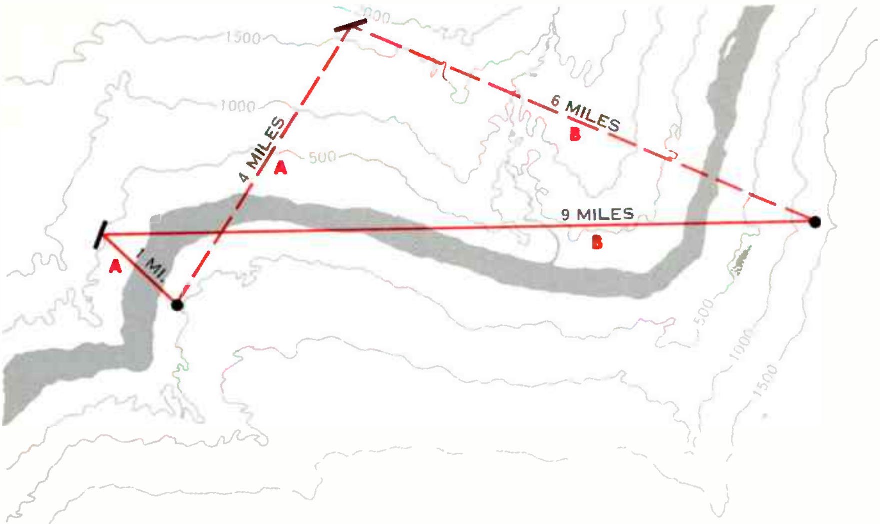


Figure 6. Topographical map showing two possible locations for a passive repeater. The total path length is the same for both locations, but placing the reflector much closer to one terminal results in 7.5 db less path attenuation.

flector is larger than that of the antenna (in most cases) so it acts effectively as an antenna of larger aperture; that is, it produces a "sharper" beam at a distant point. Replacing the reflector with an antenna of similar aperture will provide just as much gain — but the antenna and the long waveguide run would cost much more and would also introduce additional waveguide losses and reflections.

One way to realize more gain from a compound antenna system is to curve the reflector to provide additional focusing. Regardless of the size of the antenna, the beam striking the reflector is always divergent. A reflector with a parabolic curvature acts much like an extension of the antenna — it makes the beam more nearly parallel. Such a reflector would be a small section of a very large paraboloid, with the antenna feeding it from the focus. In actual practice, however, the cost of carefully fabricating and installing a parabolic section of the required size is likely to be prohibitive. One effective technique is to install a flat, but flexible, reflector. Once this is in place, and the system is operating, the reflector is curved by pulling the center of it back with tension fittings. An ideal curvature can be approximated by experimental adjustment to produce maximum gain.

The effect of antenna and reflector sizes and separations on system gain is indicated by the curves of Figure 5. Such curves may be plotted in terms of the relative gain with respect to the antenna alone, but a more useful method is to plot them to show the gain of the combination at various separations, relative to the gain of an isotropic antenna. The antenna and reflector together can then be treated as one large antenna. Figure 5 indicates that for an

8 by 12 foot curved reflector operating at 6725 mc, a maximum gain of 41.5 db can be obtained by using a 4-foot antenna separated from the reflector by 120 feet. The same gain can also be achieved with a 10-foot antenna at 265 feet or with other sizes at various distances.

For comparison, a similar series of curves is shown for a 12 by 17 foot reflector at the same frequency. These curves indicate that the maximum gain of 45 db occurs with a 4-foot antenna at 160 feet or with a 10-foot antenna at 405 feet. Thus, the higher gain available with the larger reflector must be paid for in additional tower height. Or, conversely, if path clearance demands a higher tower, a larger reflector is required for the best performance.

Passive Repeaters

Sometimes a tower cannot provide clearance over an obstruction. For example, if two sites are separated by a mountain, the microwave beam may have to be redirected at one or more intermediate points to get it around or over the mountain. Although repeater stations could be used at these points to amplify and retransmit the signal, *passive repeaters* may be used to merely change the path direction without amplification. These passive repeaters contribute no signal amplification, but they require no power and very little maintenance, so they can be located in places where access is very difficult.

One type of passive repeater uses two parabolic antennas connected back-to-back through a short length of wave-

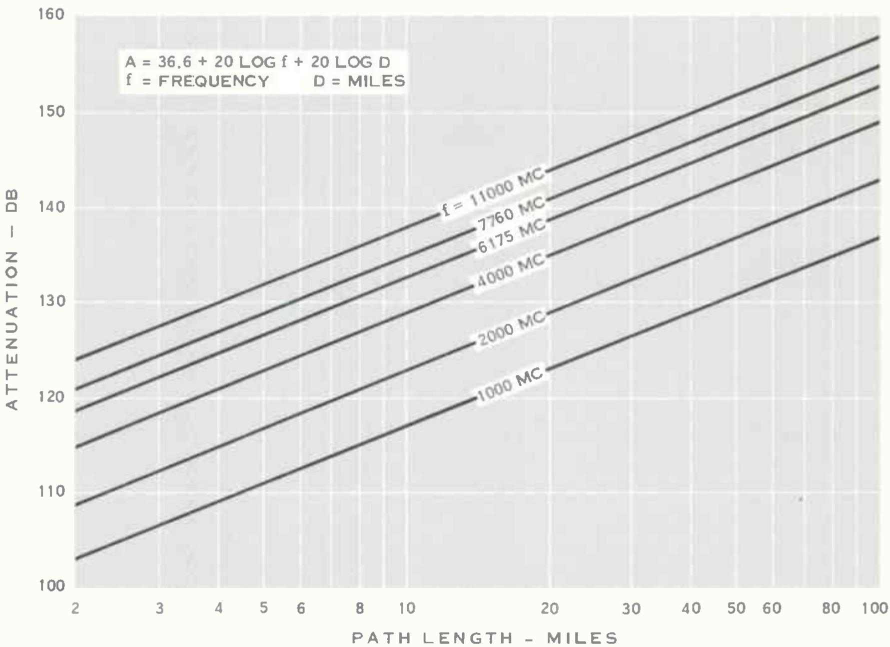


Figure 7. Free space attenuation between isotropic antennas. Attenuation increases by 6 db when path length is doubled, regardless of actual distance increase.

guide. With this arrangement, the beam can be redirected in virtually any direction simply by using an appropriately curved waveguide section. However, this type passive repeater is not widely used because of the losses encountered. The efficiency of each parabolic antenna is typically only about 55 percent, and the waveguide inevitably contributes some loss and reflection, resulting in considerable signal impairment.

A more common type of passive repeater for situations like this is the so-called "billboard" — a large, flat surface which acts simply as a reflector. In a typical system, a billboard repeater might be located at a turn in a valley, effectively "bending" the beam to follow the valley. Such reflectors may be illuminated by a periscope antenna system and may reflect the beam to another periscope system, forming, in effect, an arrangement which resembles a huge mirror system.

The size of a billboard reflector is not subject to the same limitations as the size of the reflector in a periscope system because the passive repeater is usually located far enough from the transmitter so that all the energy intercepted by any manageable size reflector is essentially in phase. Typical reflector sizes range from 6 by 8 feet to 24 by 30 feet.

In contrast to open wire or cable, where the attenuation per mile is con-

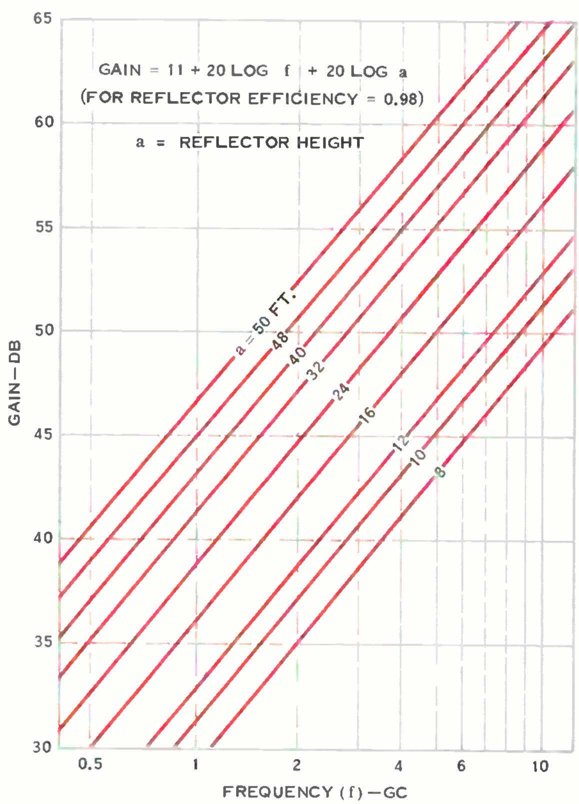


Figure 8. Passive reflector produces gain with respect to an isotropic antenna. Gain depends on size of reflector as well as on frequency of operation.

stant regardless of the number of miles, the attenuation per mile of a radio signal depends on the path length. Signal strength is inversely proportional to the square of the distance from the transmitter. Thus, each time the path length is doubled, the signal strength is reduced to 1/4 of its previous value. This means that path attenuation increases by 6 db each time the path length doubles, whether the actual distance increase is 1 mile or 10 miles.

Because the attenuation is greatest in the first few feet of the path, the relative lengths of the paths have an important effect on the location of a reflector. As an example, consider a passive repeater placed as shown in Figure 6 so that path A is 1 mile long and path B is 9 miles, for a total length of 10 miles. If the repeater is then relocated to give path A a length of 4 miles and path B a length of 6 miles, the total is still 10 miles — but the loss in path A has been increased by a factor of 16, while the loss in path B has been reduced only to 4/9 of the original value. The effect of this is to make it highly desirable to place a passive repeater much closer to one terminal than to the other because the total attenuation for the two paths is highest when they are of equal length.

The same example might be calculated in terms of db, using the formula

$$A = 36.6 + 20 \log F + 20 \log D,$$

where

A = free space attenuation between isotropic antennas in db,

F = frequency in mc,

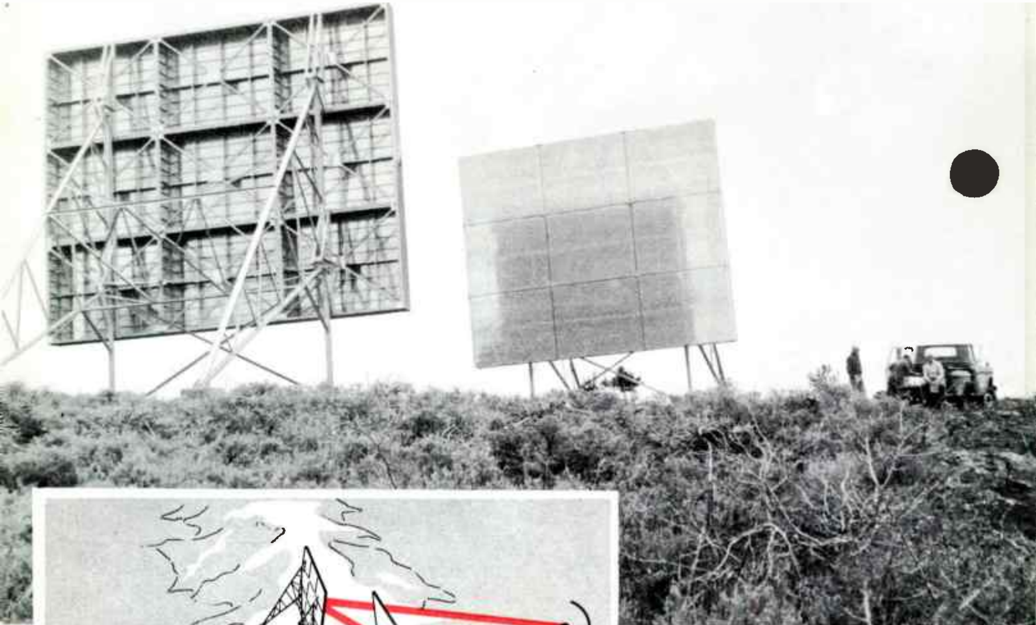
and

D = path length in miles.

For an operating frequency of 6,000 mc, path A would originally have an attenuation of 112.2 db and path B would have 131.3 db, making a total attenuation of 243.5 db. After the relocation, path A would have 124.2 db and path B would have 127.8 db, for a total of 251.0 db. Thus, moving the reflector 3 miles closer to the midpoint has increased the total path loss by 7.5 db, even though the total path length has not changed. This means that the power reaching the receiver has been reduced by 82 percent.

If the choice between these two locations for the passive repeater is made entirely on the basis of path loss, the reflector will be located to make the two paths 1 mile and 9 miles long, respectively. The path loss of 243.5 db represents the loss between two isotropic antennas, without considering the directivity of either of the antennas at the terminals or of the billboard reflector. If the terminal antennas are 6-foot parabolas, each will have a gain of about 38 db, thus reducing the path loss by a total of 76 db. From the curves of Figure 8, a passive reflector with a projected area of 14 by 14 feet is shown to have a gain of 50 db. This effect occurs because the reflector is considered to receive and retransmit the energy. Since the gain is a measure of directivity, the billboard is 50 db better than an isotropic antenna at receiving and 50 db better at transmitting. Thus, the reflector subtracts another 100 db from the path loss. The result, 243.5 db minus 76 db minus 100 db, is 67.5 db — the actual difference between the transmitting level and the receiving level.

Such path loss calculations really amount to an "accounting" procedure — a convenient way of calculating the performance of a reflector in a transmission path. Another way to look at is to consider the entire distance as one path. In this case the reflector is *not* considered as a receiver and retrans-



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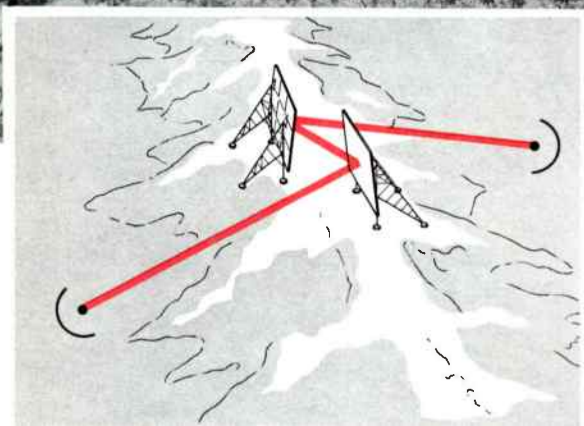

Figure 9. A double reflector arrangement is often used where path direction is to be changed only slightly. Second reflector contributes little extra loss.

mitter. For a 10-mile path, the isotropic attenuation is 132.2 db, only about 1 db more than for a 9-mile path. Subtracting the gain of the antennas (76 db), the transmission loss is 56.2 db. Because this method does not consider the reflector, a comparison with the two-path method gives the loss contributed by the reflector: 56.2 db subtracted from 67.5 db indicates an actual reflector loss of 11.3 db.

Since passive reflectors have a high efficiency (typically about 98%), the high loss in this one is almost certainly due simply to its small size. It may not reflect enough energy for some applications. A 24-foot reflector would contribute about 9 db more gain (or less loss, depending on the viewpoint), reducing the reflector loss to a more tolerable 2.3 db.

For some applications, normally where the microwave path requires only a slight bend, a double reflector installation such as that shown in Figure 9 is used. In this case a single reflector cannot be used because the beam would strike it at an extreme angle, resulting in almost an "end-on shot," and severely limiting the effective reflecting area. In such an arrangement, the two reflectors are installed nearly parallel and quite close together so that virtually all the energy reflected by one is intercepted by the other. But since they are not 100% efficient, inevitably they introduce slightly more loss than a single reflector.

The Future of Reflectors

The antenna system is becoming more and more important to the performance of modern microwave equipment. In a high-performance system such as the Lenkurt Type 76, the antenna and waveguide system is the limiting factor in intermodulation distortion. The reflections caused by a long waveguide run can raise the intermodulation level considerably, even with high-quality waveguide, unless the installation is done with extreme care. Here a reflector system has the advantage because it requires only a short waveguide run.

Reflectors however, are used primarily to save money. Nearly any job that can be done by a reflector system can also be done by other means — but usually at a higher cost. This does not mean that reflectors are inferior. It simply means that where there is a choice of acceptable methods the least expensive one is usually chosen. In antenna systems this often proves to be a reflector.

But reflectors have their limitations. High side lobe levels, low front-to-back ratios, and cross illumination (unwanted illumination of a reflector by the antenna of another system), for example, make periscope antenna systems especially vulnerable to crosstalk. This makes it particularly necessary to use different frequencies in each direction of transmission from a repeater station. This is a satisfactory solution when the frequencies are available. But economic considerations are being overridden more and more by the fact that frequencies are becoming scarcer. Using the same frequency in both directions usually demands performance which cannot be provided by a reflector, or even by a simple parabolic antenna.

The passive repeater's big advantage is its suitability for remote and inaccessible locations. And the very remoteness of the installations usually makes the scattering from a billboard relatively unimportant because it is not likely to cause mutual interference with other services.

Reflectors are definitely here to stay, but they undoubtedly will be used more selectively in the future as more situations arise where the controlling factor is not one of economics. ●

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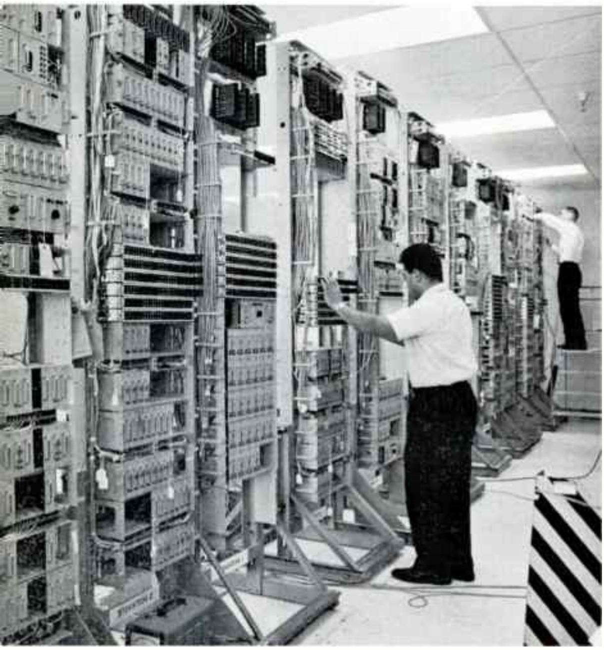

400 Miles in One Room

Eight multiplex terminals of a major railroad's communication system are shown undergoing complete systems testing before shipment. Delay lines link the *Type 46A* terminals to simulate the transmission conditions which will be encountered in the field. The complex system, which uses Lenkurt microwave for transmission, has an ultimate capacity of 600 channels.

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