The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 12, NO. 5 MAY, 1963

ANTENNA SYSTEMS for microwave

Part One

An efficient antenna system is a vital part of any successful radio system. This is particularly true of point-to-point microwave, where the low power output and the high propagation losses combine to make highly directive antennas necessary. Many specialized antenna arrangements have been developed to solve specific problems, but compromises are usually necessary. Sometimes the performance of a highly specialized design must be compromised to adapt the antenna to more general usage. And a compromise between performance and cost is almost inevitable. This article discusses the characteristics of several types of microwave antennas used in communications and other applications.

Any radio system requires some sort of transmitting antenna to radiate energy into space and a receiving antenna to collect as much of this energy as possible. The efficiency of the antenna system depends on how much of the transmitted energy can be retrieved by the receiving antenna; and the amount of this received energy depends on the characteristics of both antennas.

Broadcast radio has a low efficiency because it must radiate energy more or less equally in all directions; thus, any one receiving antenna can pick up only a tiny fraction of the radiated energy. To overcome this low efficiency, the broadcast station must transmit a large amount of power. By contrast, a point-to-point microwave system radiates only a small amount of power — but it uses a directional transmitting antenna to concentrate the power into a narrow beam directed toward the receiving antenna. The receiving antenna must also be highly directional to enable it to collect as much of the incoming signal as possible and to reject radiation from other directions.

This directional property of the antenna is of vital importance to the systems engineer and is measured in terms of *gain*. Antenna "gain" results from the directivity of the antenna and is used as a figure of merit for the antenna. It is usually defined as the ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity in the same direction from an *isotropic radiator*. (An isotropic radiator is an "ideal antenna" which radiates equally in all directions; it cannot be realized in practice, but it serves as a convenient performance reference).

Antenna gain increases the effective power of a transmission just as surely as does amplifier gain. A distant observer located along the beam would receive as much signal power from an antenna with a gain of 30 db, radiating 1 watt, as he would from an isotropic radiator at the same distance with an output of 1,000 watts. The effectiveness of the transmission is similarly increased by the gain of the receiving antenna. In fact, all the properties of an antenna are the same whether it is used for transmitting or for receiving.

Closely related to the gain of an antenna is its *beamwidth*, usually defined as the angle between the "half-power points," the points where the radiated power is 3 db down from maximum. The beamwidth may be specified both vertically and horizontally to describe the beam shape in three dimensions. Many different beam shapes are used for various purposes. For example, some radars use a "fan-shaped" beam to increase the volume of the sky covered with each scan of the antenna. Point-to-point communication systems normally use "pencil-shaped" beams to concentrate the power as much as possible toward a single point. Figure 1 illustrates typical radiation patterns of several types of antennas.

Directional Antennas

No directional antenna concentrates *all* its radiated power into the desired beam. For various reasons (such as scattering from feed or supporting structures, diffraction at the antenna edge, and the finite number of wavelengths across the aperture diameter), energy is robbed from the main beam to produce secondary beams or "lobes" which radiate in various directions away from the desired axis — even to the rear. These side lobes and back

Figure 1. Idealized representation of radiation patterns produced by isotropic, dipole, and parabolic reflector antennas.

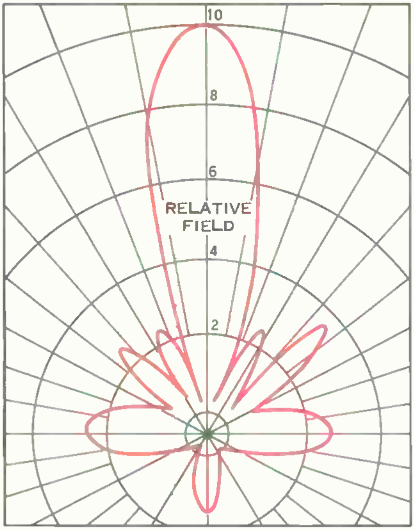


Figure 2. Typical radiation pattern of a parabolic reflector antenna. Majority of the power is concentrated in the main beam, but some power is wasted in the unwanted back and side lobes.

lobes represent wasted power and may be a source of interference with other services.

One method of providing antenna directivity is to use arrays of radiating elements. These are complex arrangements in which the characteristics of many simple radiators add up to achieve directivity. The radiation pattern of an array is controlled by its shape and size (in terms of wavelengths), and by the phase relationship between the individual elements. With careful design, gains of over 30 db are achieved with arrays, but at the expense of very complex distribution arrangements to serve the many elements required.

Arrays are not generally used for point-to-point microwave communication because of the complexity necessary to achieve the required gain and because the mechanical tolerances become difficult to attain at frequencies above 2 gc (2000 mc). Arrays composed of radiating slots cut in a plate or waveguide, rather than of radiating conductors, have recently achieved more prominence. This type of array is sometimes used as a "feed" arrangement to illuminate a microwave reflector.

One of the most attractive properties of microwaves, from the antenna designer's viewpoint, is that they follow many of the rules of optics. Microwaves can be focused into a narrow beam by various lens or reflector arrangements. In both, the lens or reflector must be illuminated by a primary radiator, in the same way that an optical lens or reflector must be illuminated by a light source. In a microwave system this primary illumination is most often accomplished by an electromagnetic horn — a flared end on a waveguide (which itself is an efficient — but sometimes cumbersome — antenna). Waveguide arrays are also used to provide illumination, and, at lower frequencies, dipoles may be used.

A microwave lens is a device for collecting and focusing divergent radiation into a parallel beam by refraction (bending), in much the same way that an optical lens focuses a light beam. Microwave lenses may take a variety of shapes including disks, cylinders, and spheres. Lenses are often constructed of dielectric materials such as polystyrene, but they may also be made of metal plates set parallel (the so-called "waveguide" lens). The main advantage of a lens is that it is fed from the back; thus, there is no front feed structure with its attendant mechanical problems and aperture blocking. A high "front-to-back ratio" (the ratio of power in the beam to the power scattered to the rear) can be achieved with a lens because the rear feed radiates en-

STANFORD UNIVERSITY

Figure 3. An array of 50 log-periodic antennas used for radar explorations of the sun, moon, and planets.

ergy in the same direction as the lens. However, the lens inevitably has reflections at the surfaces and losses in the dielectric material, resulting in an insertion loss of perhaps 1 to 3 db. Thus, the gain is a little lower than that of a reflector and the side lobes of the lens are usually larger. The lens is also more difficult to design, although once designed, it can tolerate greater surface errors than the reflector.

Reflectors

Radio beams can be formed by reflection as well as by refraction. A shaped reflector is used in the majority of communications applications where a high-gain antenna is required; and by far the most widely used reflector shape is the parabola. Many parabolic reflector arrangements are possible, but probably the most common is the paraboloid of revolution illuminated by a center-feed waveguide horn located at the focus of the paraboloid.

The gain of an antenna depends on its size, measured in wavelengths. Gain increases as the wavelength becomes shorter or the antenna becomes larger, according to the relationship

$$Gain = k\left(\pi \frac{diameter}{wavelength}\right)^2,$$

where k is an efficiency factor, usually about 55% in microwave applications. Thus, gain increases very rapidly as the dish diameter is increased or the wavelength is shortened. The practical significance of this is that higher frequencies must be used to attain high gain if the antenna size must be kept small. As an example, assume a 6-foot reflector and an operating frequency of 6 gc (6000 mc). The wavelength at this frequency is 0.164 ft. Then,

$$G = 0.55 \left(\pi \frac{6}{0.164}\right)^2$$

$$= 7270.$$

Expressed in db, this power ratio is 38.6 db. At 1 gc a 36-foot reflector would be required to achieve the same antenna gain.

Figure 5. The center-fed paraboloid of revolution is the antenna most commonly used for point-to-point microwave transmission.

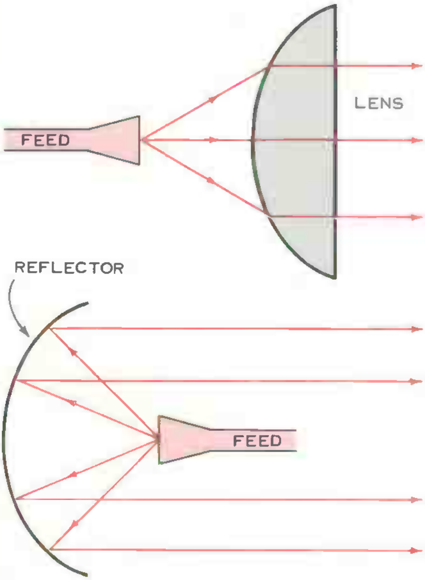


Figure 4. Microwaves follow most of the rules of optics. Lens is illuminated from behind, eliminating aperture blocking by the feed, but energy is lost in passing through the lens.

Since antenna gain is really a result of its directivity, beamwidth can be calculated using a similar formula. Antenna beamwidth, in degrees between the 3-db points, is given by the approximate relationship

$$beamwidth = \frac{(70°)\ (wavelength)}{diameter}.$$

For the same 6-foot antenna and the same 6-gc frequency,

$$beamwidth = \frac{(70°)\ (0.164)}{6}$$

$$= 1.9 \text{ degrees}.$$

The antenna designer strives for a low side lobe level as part of his effort to design an efficient directional antenna. The side lobe levels of a parabolic

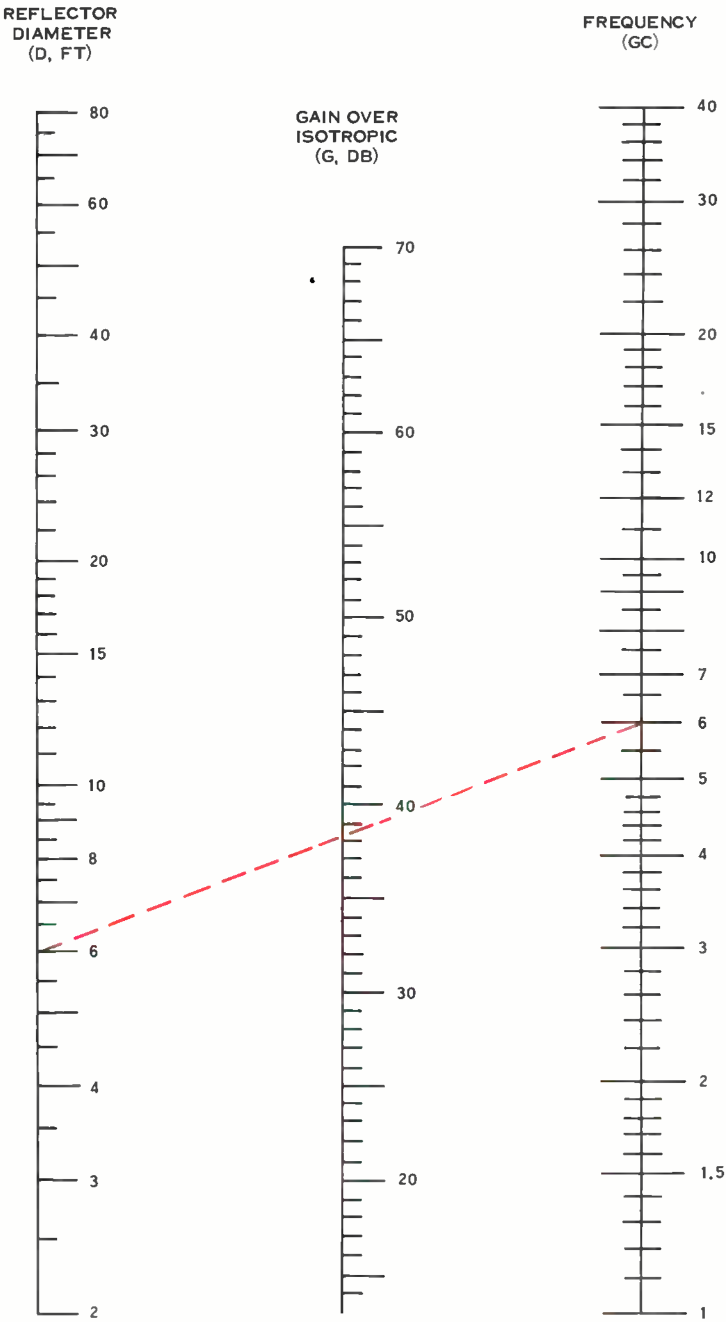


Figure 6. Gain of a parabolic reflector antenna with reference to an isotropic antenna (assumed efficiency of 55%).

reflector are controlled mainly by the feed pattern, not by the dish itself. One method used to reduce the side lobe level is to taper the illumination. That is, the illumination power at the outside edges of the reflector is made lower (usually about 10 db) than that at the center. This reduces the energy scattered to the side and rear by the dish edge, thus improving the front-to-back ratio. Other factors which affect the side lobe level are the scattering produced by the supporting structure, and the shape of the feed horn itself.

There are two main problems which arise from the use of a center-fed horn to illuminate a reflector: (1) the feed horn structure itself blocks a portion of

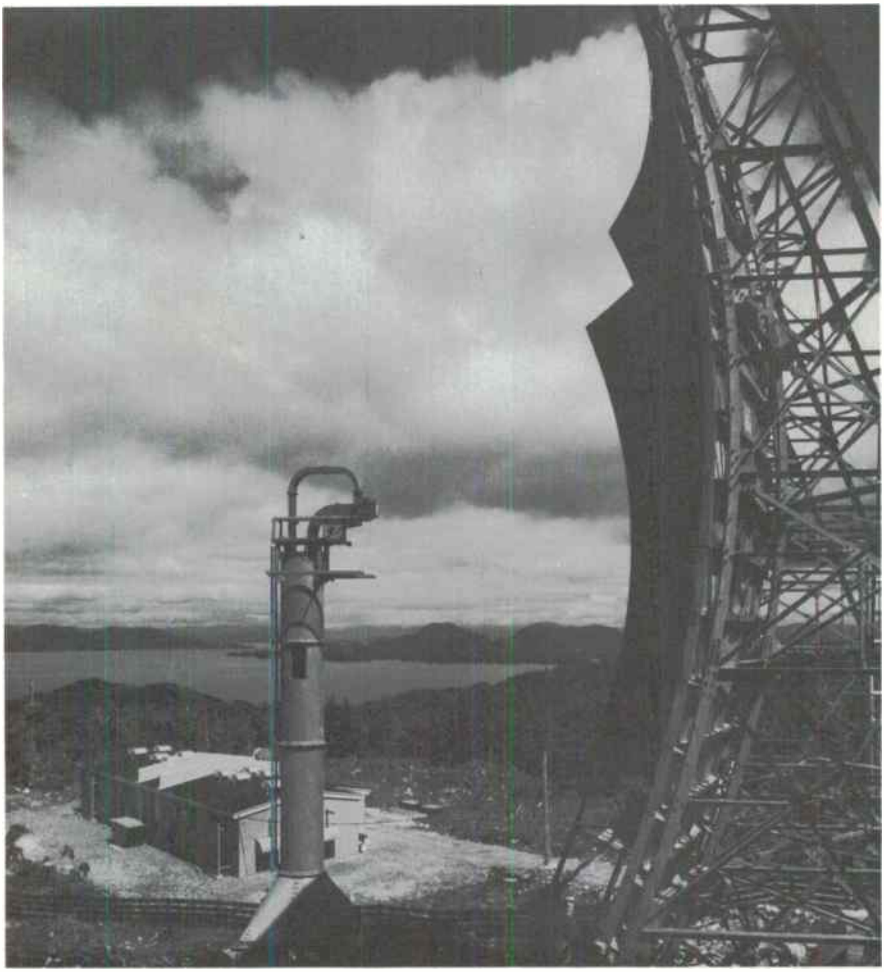


Figure 7. This 60-foot reflector is part of a tropospheric scatter system installed by Lenkurt at Trutch Island, British Columbia. Such antennas, with a gain of 39 db at 900 mc, permit "hops" far longer than line-of-sight distance by using the troposphere as an intermediate reflector.

the reflector aperture, and (2) some of the energy is reflected directly back into the feed horn to create a standing wave, which causes distortion and loss of efficiency. Both these problems, of course, depend on the relative size of the feed horn. One way to eliminate such problems is to use a parabolic section, rather than a paraboloid of revolution, for the reflector. This allows the feed to be located at the focus of the parabola, but offset from the aperture of the antenna. This eliminates both the aperture blocking and the direct reflection of energy back into the feed.

An extreme example of the use of such a parabolic section is becoming increasingly popular for microwave communication systems. This is the horn-reflector antenna (sometimes called the "cornucopia"). In this antenna, the feed horn and the reflector are fabricated as one structure, but it can be considered as simply a horn feeding a parabolic section. One system uses horn-reflectors for the simultaneous transmission of signals in the 4-gc, 6-gc, and 11-gc bands, with gain ranging from about 39 db at the lowest frequency to more than 47 db at the highest frequency. Because the sides of the feed horn extend to the reflector, edge "spill-over" is reduced; this results in lower side lobes and a much higher front-to-back ratio than ordinary parabolic reflectors. This is perhaps the biggest advantage of the horn-reflector; front-to-back ratios of better than 70 db have been reported.

In some applications, the waveguide and feed structure of the antenna system becomes large and complicated. A good example of this occurs in space communications, where low-noise maser or parametric preamplifiers must be placed quite close to the antenna feed in order to avoid the losses which occur in a long waveguide run. These preamplifiers often require elaborate cooling to keep the noise level low. This usually requires a rather large feed structure at the focus of the paraboloid, which may cause excessive scattering and blocking of the beam. It also complicates the mechanical arrangements for running and cooling the amplifiers.

As a way around this problem, antenna designers have borrowed a technique from optical telescope design. This technique, known as the *Cassegrain* design, permits the antenna to be fed from behind the dish, with the horn protruding through the center of the reflector to illuminate the convex side of a hyperbolic subreflector, as shown in Figure 9. The reflection from the

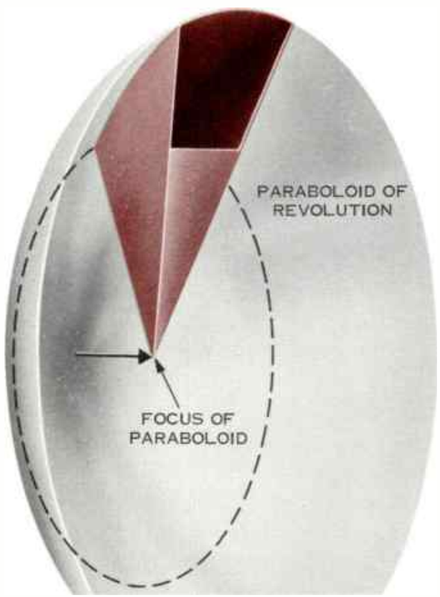
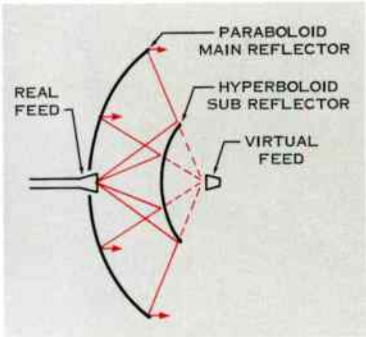


Figure 8. The horn-reflector antenna consists of a parabolic section fed from the focus of the paraboloid. Because the horn extends to the reflector edge, "spill-over" is reduced, side lobe levels are low, and a high front-to-back ratio is achieved.

DALMO VICTOR CO.

Figure 9. The Cassegrain antenna system is used primarily in space communications where low-noise preamplifiers are often placed close to the feed. Cassegrain system permits the antenna to be fed from (and the preamps to be mounted) behind the main reflector.



subreflector illuminates the main dish, which focuses the energy into a beam. With proper design of both the hyperbolic subreflector and the parabolic main reflector, the main dish sees a "virtual feed" located at its focus, and all path lengths are the same from the feed horn to a distant point in space.

The biggest disadvantage of the Cassegrain feed system is the amount of aperture blocking introduced by the subreflector. This can be minimized by enlarging the feed horn and reducing the size of the subreflector. The feed horn is then extended forward so that equal shadows are cast by the feed and the subreflector.

The Mechanics of Antennas

As might be expected from an analogy with light, surface irregularities in the reflector tend to defocus the beam — side lobe levels are increased, gain is reduced, and the beamwidth is increased. The magnitude of these effects depends primarily on the size of the surface errors — in terms of wavelengths at the frequency of interest. Of course, there are limits to machining tolerances, particularly with larger antennas, and some compromising is necessary between performance and economics. As a general rule surface errors should not exceed 1/16 the wavelength. This tolerance is not difficult to achieve

Figure 10. Radomes are sometimes used to protect antennas from weather and debris. The problem is particularly severe where reflectors are mounted horizontally, illuminating a passive reflector which redirects the beam horizontally to a distant site.

at low frequencies or with small reflectors, but it becomes a real problem with large reflectors at high frequencies. For example, at 6 gc the tolerable surface error is of the order of ± 0.12 inch, while at 11 gc it is about ± 0.065 inch. Achievable error tolerance is approximately proportional to the reflector diameter. Thus, a 60-foot reflector (such as might be used for space communications) would be expected to have surface irregularities about 10 times the size of those on a 6-foot dish, even though both were constructed as carefully as possible. Because increased gain achieved by increasing the reflector size is offset to some extent by the gain loss caused by increased surface error, a practical limit on gain is eventually reached. With present techniques, this limit seems to be about 70 db. Of course, this limit might be extended by improved construction techniques.

One such technique has been adapted from telescope-making experiments of half a century ago. In 1908, astronomers experimented with liquid mercury as a reflector. When rotated on a turntable, the liquid was formed by centrifugal force into a "natural" paraboloid, producing an accurate mirror. Although the idea was old, modern chemistry was required to adapt it to antenna making. In modern practice, epoxy resin, catalyzed to harden slowly at room temperature, is placed in a shaped container and spun on a turntable at the correct speed to produce a parabola of the desired focal length. The spinning continues until the material is hard. It is sputtered or sprayed with a thin metallic coating to form the reflector. Very good results have been obtained with small reflectors made this way, and a recent report indicated that a 28-foot "spun" reflector had maximum surface errors of less than 0.02 inch and rms surface errors of less than 0.008 inch. Such close tolerances allowed the use of quite high frequencies. At a test frequency of 35.2 gc (wavelength = 0.336 in.), the reported gain was 67.4 db and the beamwidth was 4.4 minutes of arc.

In some locations antennas must be covered to protect them from the weather or from falling leaves and other debris. Such protection, of course, must be accomplished without impairing the electrical characteristics of the antenna. Ideally, this could be provided by a covering of low-loss dielectric material having the same propagation characteristics as free space. This ideal cannot be realized in practice, but actual coverings, or "radomes," approach it closely. Heating of the radome is sometimes required to prevent formation of ice which would degrade antenna performance.

Point-to-point Systems

Because microwave transmission follows essentially a straight line, path length — or the distance between terminals — tends to be limited by the curvature of the earth and by obstructions such as trees, buildings, and mountains. Actually, microwaves require more than just an optical line-of-sight clearance, to allow for both fading and for certain interference characteristics of the beam itself at microwave frequencies.

In order to obtain adequate clearance, it is often desirable to locate the antennas on buildings or towers. In many cases this may be impractical due to the high signal loss and expense contributed by long waveguide runs. Accordingly, it is common practice to employ antennas located conveniently close to the microwave equipment, and some arrangement of passive reflectors which serve to redirect the radio beam in the desired direction, much as in the case of an optical periscope.

Many variations of these compound antenna systems have been developed to overcome various transmission problems imposed by terrain. However, the engineering of such systems may be more complicated than is apparent from the analogy between microwave transmission and light. Some of the problems encountered in designing such compound antenna-reflector combinations will be discussed in the second article in this series, to appear in the July, 1963 issue of THE DEMODULATOR. •

BIBLIOGRAPHY

1. Henry Jasik, Editor, *Antenna Engineering Handbook;* McGraw-Hill, New York, 1961.
2. S. P. Carter and L. Solomon, "Modern Microwaves," *Electronics;* June 24, 1960.
3. R. W. Friis and A. S. May, "A New Broad-Band Microwave Antenna System," *Communications and Electronics;* March, 1958.
4. J. W. Dawson, "28-Ft Liquid-Spun Radio Reflector for Millimeter Wavelengths," *Proceedings of the IRE;* June, 1962.

Lenkurt Electric Co., Inc.
San Carlos, California

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif.
Permit No. 37

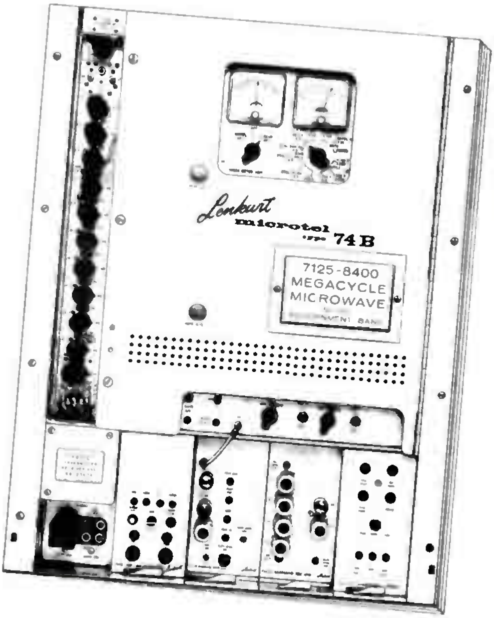
MR. HUGH J. BROWN
KELLOGG SWITCHBOARD & SUPPLY CO.
775 HARD RD.
WEBSTER, NEW YORK

R-25701 21F

RETURN REQUESTED

AN/FRC-84 Microwave Equipment Described

A new Lenkurt publication describes in detail the AN/FRC-84 microwave — the version of the 74B specifically designed for use in the government frequency band. The publication contains information on performance, special equipment features, and optional arrangements. Copies are available on request from Lenkurt or any Lenkurt Field Office.



LENKURT ELECTRIC SAN CARLOS, CALIFORNIA, U.S.A.

GENERAL SYSTEM

LITHO IN USA

District Offices

New York • Minneapolis
Atlanta • Dallas
Chicago • San Carlos
Washington, D.C.

The Lenkurt Demodulator is a monthly publication circulated free to individuals interested in multi-channel carrier, microwave radio systems, and allied electronic products. Permission to reproduce material from the *Demodulator* will be granted upon request. Please address all correspondence to the Editor.