The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

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Microwave Diversity . . .
how it improves reliability

Microwave radio, promising infant of 1951, has become the dependable, durable worker of 1961. No longer limited to such special-purpose uses as transcontinental television and very long telephone circuits, microwave is already demonstrating a remarkable versatility in filling the diverse, ever-growing communications needs of the world.

Microwave's extremely high information capacity provides a communications bargain, but places extra importance on the need for reliability. With today's improved equipment, the greatest cause of signal failure is no longer the equipment, but the characteristic fading encountered in the transmission path itself. This article discusses microwave fading and how it may be overcome.

Today's microwave equipment has become so dependable that the most important single cause of transmission failure is the propagation characteristics of the radio waves themselves. Because of their very short wavelength, microwaves have many of the properties of light. Microwave signals can be concentrated by suitable reflectors into tight beams which conserve power and increase privacy of transmission. Like light, microwaves are refracted by the atmosphere through which they travel, and are subject to obstruction or reflection by intervening objects. These particular phenomena often result in *microwave fading,* an important cause of transmission failure.

Although fading occurs in many different ways, only two types have much importance in microwave transmission. These are *multipath fading* and *inverse beam bending* or *ducting*. Of the two, multipath fading is much more common and troublesome.

Multipath Fading

Microwaves travel at the ultimate speed of light only in a vacuum. Through air, radio waves are slowed

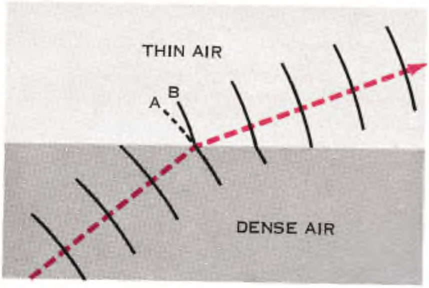


Figure 1. Wave direction is shifted by change in propagation velocity. Wavefront at B would have only reached A had it continued in slower medium.

down very slightly. The denser the air and the greater its moisture content, the slower the velocity of the radio or light rays. When the wavefront passes diagonally from a dense layer to a thinner layer of air, the direction of travel of the wave is altered. The first part of the wavefront to enter the thinner layer begins traveling slightly faster than the portion of the wave still in the denser medium. As the remainder of the wavefront passes into the thinner air, it increases velocity, but cannot overtake those parts of the wavefront which entered the thin air first. As a result, the direction of travel of the wavefront is deflected slightly, and the amount of this deflection or refraction is proportional to the difference in the velocity of the wave through the two masses of air.

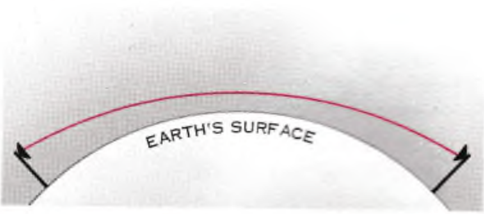
If the change in air density is gradual, the refraction or bending of the radio beam may be continuous, so that the beam is gently curved away from the thinner toward the denser atmosphere. Since the atmosphere is normally more dense near the earth, and usually thins out with increased altitude, radio and light rays do not follow a true straight-line path, but are usually deflected downward and tend to follow the curvature of the earth. For this reason, so-called line-of-sight radio paths often extend beyond the visual horizon.

Frequently, atmospheric irregularities cause a portion of the radio beam to be bent away from the most direct path, so that one part continues on the direct path to the receiving antenna, and other parts are deflected upward or downward. As a result, two or more separate components of the original transmission may arrive at the receiving antenna, each having traveled a path slightly different from the others. This is called multipath transmission.

When the component traveling the longer path reaches the receiving antenna, it arrives slightly later than the direct beam because of the difference in path length. Consequently, the different components of the signal will be somewhat out of phase with each other, because of the difference in the length of path each has traveled.

If two equal signal components travel paths having a difference of ½ wavelength, they will arrive at the receiving antenna 180° out of phase and will cancel each other. This, of course, destroys the signal. If several components reach

Figure 2. In normal atmosphere, beam is gently deflected toward earth by gradual change in density of atmosphere above the earth's surface.



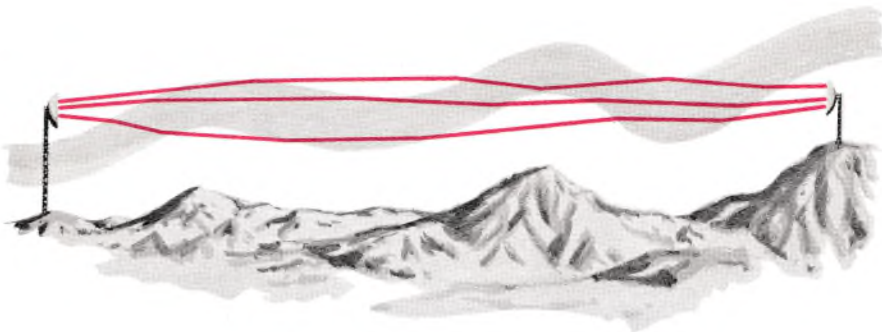


Figure 3. Irregularities in atmosphere cause radio beam to break up into several components traveling different paths. Those which manage to reach receiving antenna will have traveled paths of different lengths, causing phase cancellation.

the antenna *in* phase, they add and increase the received signal. It should be noted that a 6000 mc signal has a wave length of only about two inches. Thus, a one-inch difference in the path length of two signal components makes the difference between a very strong signal and one that cancels itself out.

Where partial signal cancellation occurs due to atmospheric multipath transmission, the message content or modulation of the signal is essentially unaffected, so long as enough signal power remains to be detected by the receiver. Differences in path length due to atmospheric refraction and reflection usually vary from a fraction of an inch to not much more than six or seven feet. Although this much difference provides many opportunities for phase cancellation of the *RF* signal, it is only a very tiny fraction of a wavelength of the *modulating* signal. For instance, the highest modulating frequency in a 600-channel carrier system is about 2.4 mc, and has a wavelength of about 410 feet. If path-length variations of ten feet are experienced, this represents a phase shift of only about eight degrees — not enough to produce significant distortion. Since microwaves are transmitted as very narrow, concentrated beams, it is unlikely that path differences greater than a few feet will occur.

Physical Causes of Multipath

Multipath transmission can result from any of several different causes. One path may be the direct optical path, while one or more other paths may result from reflection off the surface of the earth or water lying in the transmission path. Reflection and refraction from layers of air having different densities are most common.

Where there is constant wind and continuous mixing of air, multiple transmission paths rarely occur. Where the air is very still, it tends to collect in layers, each layer having a different temperature and usually a different moisture content. Sometimes the division between layers is quite sharp, and a microwave beam may be reflected from this interface as though it were a mirror.

Frequently, the air is particularly still during the night and just before dawn. Under these conditions, there is a great difference in the transmission characteristics of air close to the surface and air some distance above the surface. Heavy, moisture-laden air collects close to the

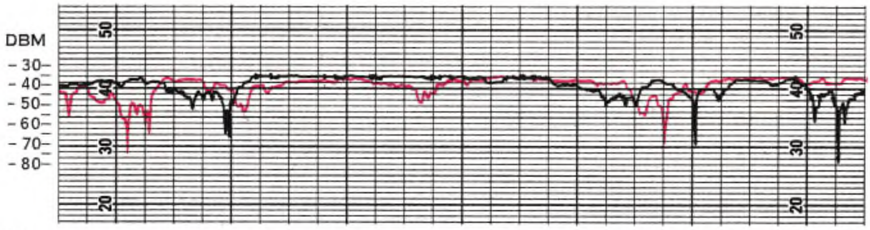


Figure 4. Actual recording of frequency-diversity transmission. Signals followed identical paths, were spaced 180 mc (3%) apart. Note that deep fades never occurred simultaneously. Small simultaneous fades are accommodated by fade margin.

ground. Humidity rises and may reach 100%, thus producing a ground fog. At various heights above the earth, the air will have different temperature and moisture characteristics, and each region will have a different index of refraction. Under these circumstances, a microwave signal may be split into many paths.

Ducts

Occasionally, a temperature or humidity inversion will occur so that instead of thinning with increased altitude, the atmosphere may actually become denser at some point above the earth. Instead of being deflected toward the earth, microwaves will experience less downward deflection, and may actually be bent upward. This is known as *inverse beam bending.* Although relatively rare, it may cause very long, deep fades. These fades do not result from multipath interference, but from the deflection of the signal above the antenna. If additional path clearance is provided between the signal path and possible obstructions, some rays may reach the receiving antenna despite the inverse beam bending. Fades due to inverse beam bending are also said to be caused by *earth bulge,* since the effect is analogous to the earth bulging upward so as to obstruct the transmission path.

Above the inversion, the normal thinning of the air with increased altitude is restored. Microwaves deflected upward by the temperature inversion are again deflected downward when the air begins to thin with increased altitude. As they reach the temperature inversion, they are again refracted or reflected upward, so that they are trapped within a

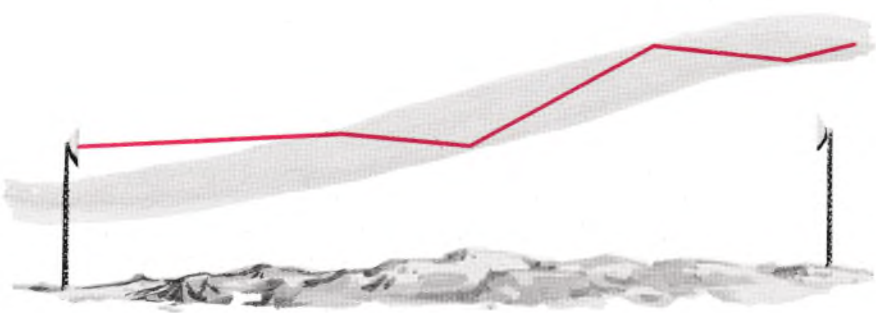


Figure 5. Temperature or humidity inversion may cause duct which traps signal.

narrow layer or "duct" of air. This is known as *trapping* or *ducting* of the signal. If both the transmitting and receiving antennas lie within the duct, the received signal strength may be considerably increased. Normally, however, such ducting or trapping usually results in a deep fade which may block communications for hours. This type of fading is much less common than atmospheric multipath fading.

Overcoming Microwave Fading

Since multipath fading is an almost perfectly random phenomenon, it occurs on a chance basis. Lord Rayleigh, in his important work on sound, showed that random phase cancellations occurred in a predictable manner, and followed the relationship shown in Figure 6. This curve has been shown to describe the likelihood of microwave fades of various degrees of severity. As shown in the curve, fades of 35 db or more may be expected .02% of the time. In the course of a year, this amounts to about an hour and 45 minutes during which transmission is interrupted.

One way of overcoming this loss is to design the system with enough performance reserve to offset all but the very deepest fades — those of 40 db or more. This approach is useful, but can become quite costly. Larger antennas, reflectors, and towers are required to obtain enough system gain to offset the deep fades. In addition, the distance between microwave repeaters may have to be decreased substantially.

Increased transmitter power will also provide additional reserve against deep fades. If a 20 db fade margin is considered ample, a 100-watt output signal is required to assure continuous performance of the quality obtained by a 1-watt output signal in the absence of fades.

One objection to this approach concerns interference. Although there is far more available bandwidth at microwave frequencies than at lower frequencies, the supply is not unlimited. One of the very desirable features of microwave transmission is that low powers and narrow beams permit the use of the same frequency spectrum by many different communications systems, so long as they are separated physically. With microwave, this separation need not be great.

A far more practical approach to overcoming microwave fading is to use some form of *diversity transmission*. In general communications experience, three types of diversity have been found useful in overcoming fading: *polarization* diversity, *space* diversity, and *frequency* diversity. The first of these, polarization diversity, while effective in systems where propagation is largely by sky wave, has been found to provide no advantage in point-to-point, line-of-sight microwave systems.

Space Diversity

Space diversity takes advantage of the fact that simultaneous fading is not likely over two well-separated paths. In a typical microwave space diversity system, the signal from a single transmitter is received at two antennas having a large vertical separation. The two independently-received signals are connected to a diversity combiner which selects the signal having the greater freedom from noise.

This method of diversity has the advantage of conserving frequency spectrum, since only one transmitting frequency is used. Its greatest value is in overcoming multipath fading in which one of the paths is caused by a specular or direct reflection such as from water, a building, or the earth itself.

A major objection to space diversity is its cost. Since vertical separation is required, additional antennas and waveguide are necessary. If a single tower is

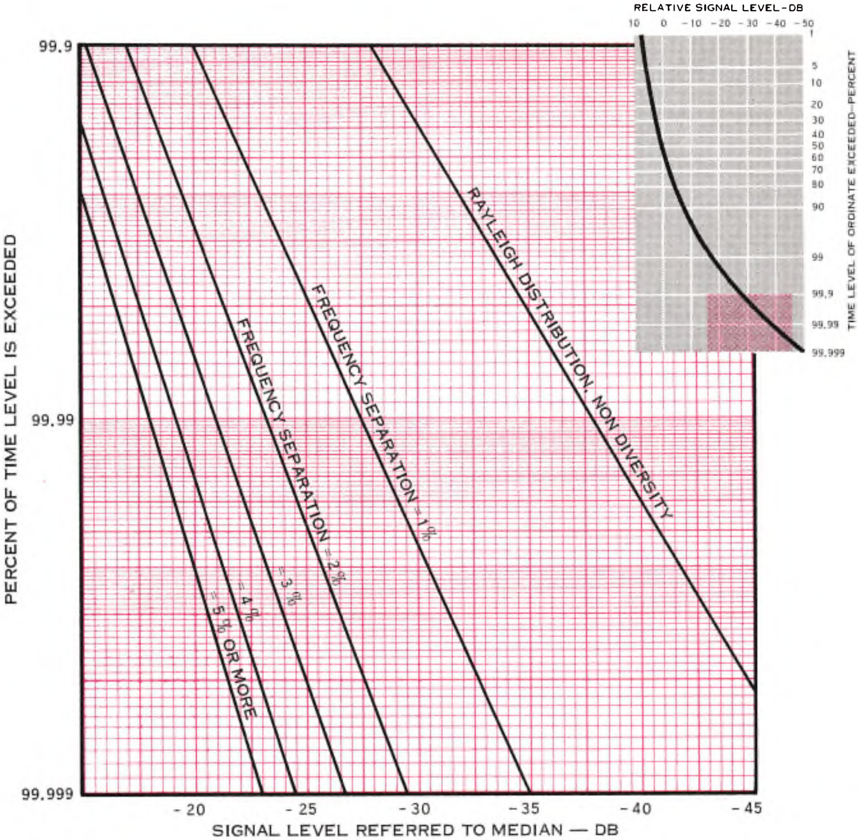


Figure 6. Rayleigh distribution curve (inset) shows probability of fades of various depths. Expanded section shows diversity improvement for various frequency spacings.

used, it must be much stronger than one designed for a single antenna, and will need to be much higher to achieve enough vertical separation between antennas.

Another objection is that space diversity does not provide nearly as much freedom from fading as does frequency diversity, for instance. Although separate paths are involved, they may or may not experience simultaneous fading. The greater the vertical separation (and the higher the tower), the less likely that the two signals will fade together. Although only a single transmitter is needed, two receivers are required.

Frequency Diversity

For all practical purposes, the refraction or deflection of a microwave signal is independent of its frequency; signals of even quite widely separated frequencies are refracted about the same amount under the same transmission conditions. Thus, several microwave signals of different frequencies will experience identical refraction and splitting into separate components. If a single pair of antennas is used for transmitting these frequencies, all components of both signals will follow identical paths.

One might expect that all signals traveling exactly the same paths would experience identical phase cancellations and would therefore tend to fade simultaneously. This is not so, however. Microwave signals of different frequencies fade independently of each other if they travel identical paths. The greater the frequency separation, the less chance the two frequencies will fade simultaneously. If the frequencies of the two signals are brought closer together, they will tend to fade more and more nearly simultaneously.

The reason for this frequency-selective fading is that signals having different frequencies also have different wavelengths. A signal of *x* frequency may have components that arrive exactly out of phase at a given moment. Since signals of *y* frequency (of longer wavelength) travel over the identical paths as those of *x* frequency, they *cannot* be exactly out of phase with each other at the same moment as the components of *x* frequency. When one frequency fades, the other will usually be at near-normal strength.

As in the case of space diversity, a diversity combiner is required to select the better signal and reject the faded transmission. (Diversity combiners were discussed in the DEMODULATOR, *March,* 1959 and *September,* 1959.)

Although two complete transmitters and receivers are required at each diversity terminal, this is much less costly than a space diversity system which would be required to provide comparable protection from equipment failure and fading. Since both transmitters operate continuously, no switching equipment is required to substitute one transmitter for another in case of equipment failure. The requirements for towers, reflectors, antennas, and waveguide are the same as for non-diversity systems.

Conclusions

Most microwave communications systems operate full-time carrying important data and other information vital to business and industry. The many needs which efficient communications satisfy make it imperative that interruption be held to an absolute minimum.

Of the many ways for increasing transmission reliability, frequency diversity has been found to provide the best protection at the lowest overall cost. Not only does it provide almost sure protection against atmospheric fading, it is the only system which permits ready maintenance of the microwave equipment without withdrawing the system from service. Single-frequency hot-standby systems, are generally unsatisfactory for continuous-duty service in systems requiring very high reliability because they provide no protection from fading. In addition, their protection against equipment failure is reduced because complete periodic maintenance is impractical without rerouting the communications and taking the system out of service. This same objection, while not true of the receiving end of a space diversity system, is true of the transmitting portion. ●

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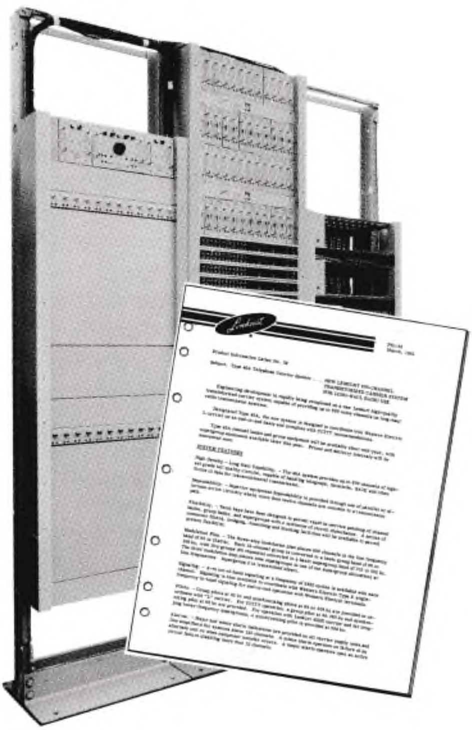

New 600-Channel Carrier System Described

Newly-released Product Information Letter No. 32 describes Lenkurt's Type 46A Carrier System. The 46A is a transistorized 600-channel system of original design suitable for high-density, long-haul applications. Copies of PIL-32 may be obtained by writing

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