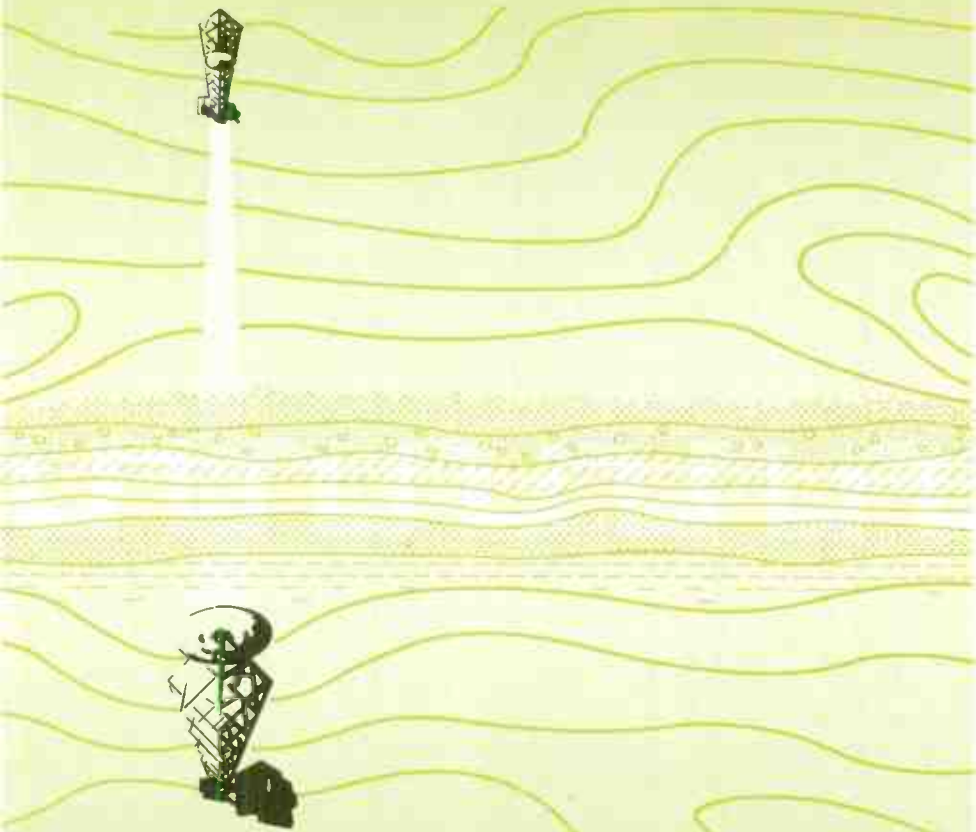
GTE LENKURT

DEMODULATOR

NOVEMBER 1974



PCM OVER MICROWAVE PART 3

The main impairments to good overall performance of a PCM-over-microwave system are far different from those that degrade either PCM cable carrier or FDM-over-microwave systems.

The first two parts of this series on the transmission of PCM over microwave radio have dealt mainly with the internal operation of a digital multiplexer (the GTE Lenkurt 9120A), which processes the PCM information into an analog signal suitable for transmission over a standard FM microwave radio system. This issue discusses the overall performance of a PCM-over-microwave system, using as a hypothetical example, a low density, 2-GHz system intended for short haul local exchange service.

The performance of a PCM cable system may be degraded by such nongausian electrical events as office noise, lightning hits, switching noise, and crosstalk between cable pairs. FDM-over-microwave is affected by delay and linearity inequalities within the radio system, by thermal or fluctuation noise, by path propagation fades to the noise threshold or mute point of the radio receiver, and by low levels of co-channel rf interference. PCM-over-microwave system performance is influenced primarily by multipath propagation fades that introduce excessive hits (errors) into the PCM bit stream, and by high levels of co-channel rf interference.

System Performance Measurement

The most meaningful measure of performance in a digital system is the bit error rate (BER) at the receiver digital demultiplexer output. The bit error rate is given as the number of bits in error, divided by the total number of bits sent. For example, a BER of 10^{-6} means that one error occurs in every one million transmitted bits.

The bit error rate depends primarily on the value of the signal-to-noise (S/N) ratio at the receiver. The S/N ratio is the difference between signal and noise strength in dB. A S/N ratio of 10 dB, for example, means that the rms value of the signal is 10 dB greater than the rms value of the thermal noise. System performance is determined by measuring signal-to-noise ratio at a particular bit error rate. Generally, the voice quality at the receiving end of a typical PCM system carrying voice traffic begins to deteriorate appreciably when the BER exceeds 10^{-3}, a point at which "cracking and popping" sounds may be heard due to bit errors. A BER of 10^{-6} is an acceptable minimum standard for a PCM system carrying 2400-baud data channels. PCM systems are therefore designed so that under normal conditions, the BER lies well below 10^{-9} most of the time and only reaches a 10^{-6} threshold level for very small percentages of the time. The measured value of BER versus S/N ratio is shown in Figure 1. From the graph, it can be seen that a S/N ratio of 20 dB would correspond to a BER of 10^{-6}.

PCM vs. FDM

In a fade-free environment, typical of short paths or paths that traverse rough, nonreflective terrain in dry or elevated climates, low (near threshold) rf received signal levels may be specified for a PCM-over-microwave link. This is contrary to the engineering requirements of an FDM-over-microwave link, whose signal levels must be quite high even in such a suitable environment to provide the thermal noise quieting required to meet the high quality, low noise specifications of a modern communications system. As in cable systems, however, the BER

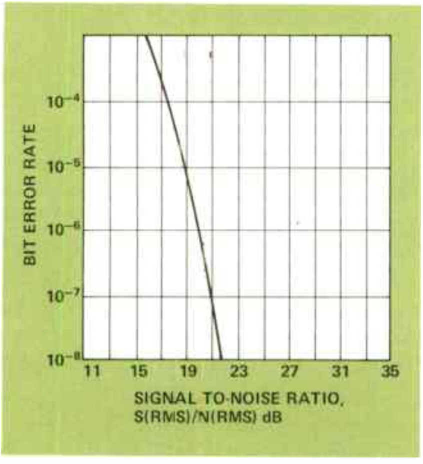


Figure 1. Measured values of BER versus S/N in the receive interface unit of the digital multiplexer.

in a PCM-over-radio system is affected primarily by the introduction of noise spikes or interference pulses into the data stream, which are decoded as legitimate bits of information (bit errors).

In a PCM-over-microwave system, error rates exceeding the 10^{-6} threshold criterion are introduced with a decrease in the signal-to-noise (S/N) ratio either by rf received signal level fading to threshold, or by high level co-channel or in-band rf interference. The S/N ratio related to a 10^{-6} BER assigned threshold, or outage value, is a function of the type of PCM or PCM-to-analog modulation coding (three level duobinary, PSK, QPSK, multilevel PSK, etc.) and the receiver detection techniques (discriminator, coherent detection, etc.) employed. The modulation coding and detection techniques employed in the GTE Lenkurt 2-GHz, PCM-over-microwave system permit the use of a standard analog FM radio system (the 78F2). In a typical BER-vs-S/N characteristic curve such as shown in Figure 1, the S/N ratio is directly related, dB-for-dB, to the rf received signal level and, in PCM radio systems, is of significance only near the radio noise threshold. An unusable BER point is reached only near the receiver threshold, and rf fades to threshold result from changes in the propagation medium (the atmosphere and terrain below it).

Microwave Propagation

The short wavelength of microwaves gives them many of the same properties of light waves; they are therefore refracted or bent by the atmosphere, and are obstructed or reflected by such obstacles as mountains, buildings, bodies of water, and atmospheric layers. While microwaves travel at the speed of light in a vacuum, their speed in air is reduced and varies according to the varying density and moisture content of the air.

Gradual changes in air density may cause the radio wave to refract or bend continuously, so that the beam gradually curves toward the denser atmosphere. Because the atmosphere is increasingly thinner with higher altitudes, radio and, to a lesser degree, light waves, do not follow a straight path but are normally refracted downward. Radio paths extend beyond the visual "line-of-sight" horizon, since radio waves are more significantly affected by all three atmospheric density gradients (pressure, temperature, and humidity) than are light beams. The atmosphere is seldom homogeneous, but may be stratified or constantly changing (as evidenced by the twinkling of stars through what otherwise appears to be a distortion-free atmosphere). These atmospheric irregularities present a varying, nonhomogenous propagation medium to the microwave wavefront, which results in the propagation of not only the main body of energy but also many refracted and reflected secondary rays that arrive at the receive antenna at various phases and amplitudes. The amplitude of the resultant rf received signal—the sum of all of these main and secondary rays—could vary with time from 6 dB above normal to 40 dB or more below normal with signal cancellation. If the fade depth is greater than the fade margin provided in the transmission engineering process, a BER of greater than 10^{-6} is introduced into the PCM channel, resulting in an outage.

Fortunately, most fades of this magnitude result from atmospheric multipath and specular ground reflections, and are of extremely short duration. Only a small percentage of 2-GHz exchange plant PCM microwave paths would ever experience fading severe enough to require adding diversity protection or other special measures. Besides these short-term outages, long-term attenuation fades resulting from partial path obstruction or signal trapping may occur, but usually only in low clearance paths traversing shallow standing bodies of water (swamps, irrigated fields, lakes, etc.). An experienced transmission engineer can usually identify these unusual geographic conditions and route the microwave path over or around the suspected area.

The reliability (or availability) of a 2-GHz microwave path may be approximated with a suitable degree of accuracy from weighted Rayleigh distribution curves as shown in Figures 2A and 2B. These curves show that short 2-GHz microwave links only rarely experience a fade of such depth as to cause an outage, whereas longer paths may be subject to deeper and more frequent fading. The locality is of considerable importance, as shown in Figure 2B: long 2-GHz paths traversing reflective terrain or water in coastal or other highly humid regions will fade far more frequently than long paths over rough terrain in dry regions.

Most applications of the short haul PCM-over-microwave links are configured for single-channel operation, with no need for equipment or propagation redundancy. In longer systems in difficult propagation areas, space diversity may be used. Figure 2B shows that the outage time for a 30-mile path with 35 dB fade margin may be reduced from 48 to less than 2 minutes per year with a 40-foot diversity spacing of the receive antennas.

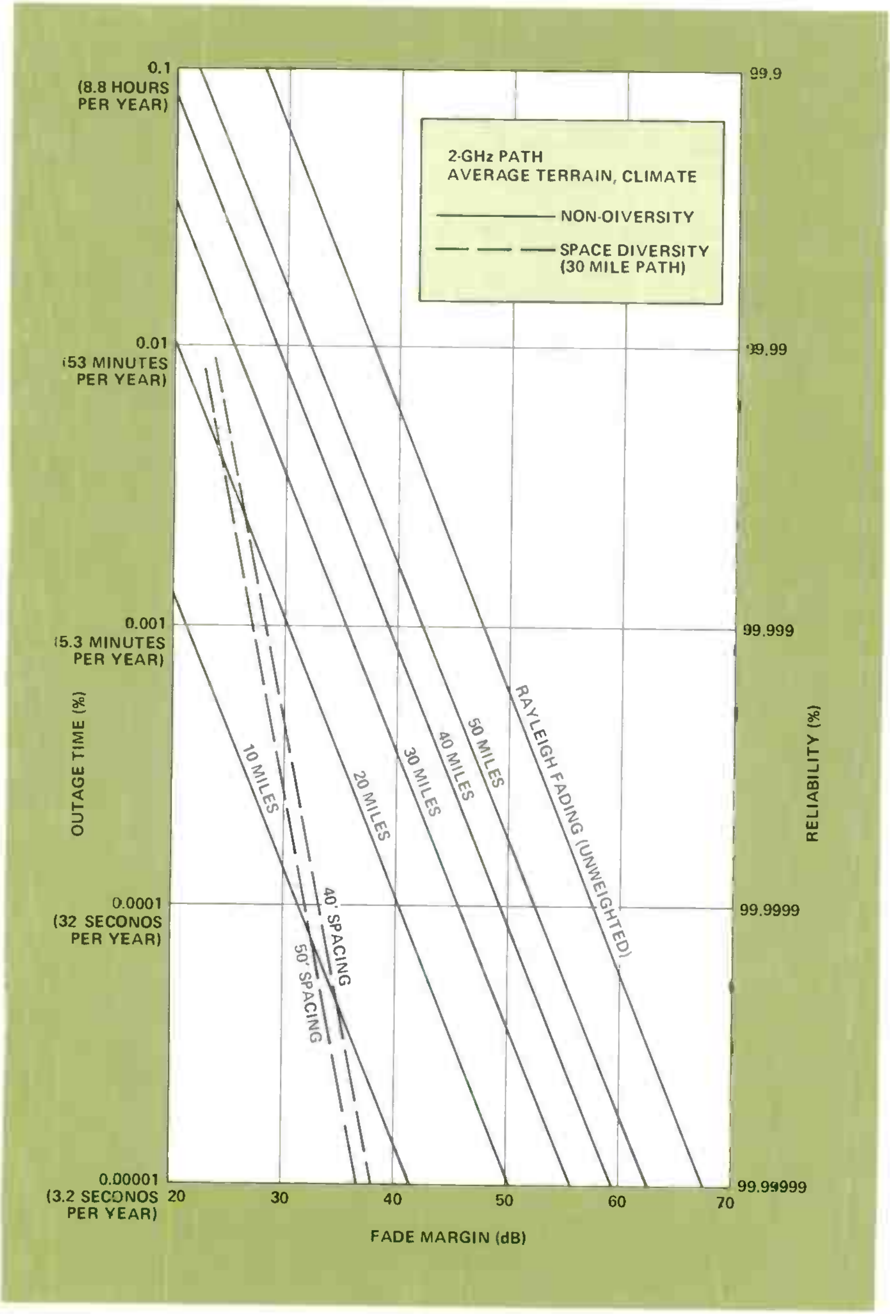


Figure 2A. Outage time due to fading, as a function of path length, can be estimated using weighted Rayleigh distribution curves.

Receiver Noise

In the receiver, the level fluctuations of the received rf signal caused by fading are removed by automatic gain control (agc) circuits before the signal is applied to the demodulator. In most microwave receivers, agc is provided at the intermediate frequency (70 MHz) to which the received signal is converted by the mixer. Thus, the receiver gain varies in accordance with the received signal level, the gain being high when the received signal is faded and low when it is not. Any noise entering the receiver input, as well as noise generated in the input circuit components, is amplified along with the desired signal, so that when the signal fades, the noise is proportionally higher and the signal-to-noise ratio is decreased.

In terrestrial line-of-sight microwave transmission, the limiting noise contributor is the thermal background noise of the warm earth (typically −114 dBm per MHz of receiver bandwidth). Added to this background noise is the receiver front end noise, characterized by the receiver noise figure indicating (in dB) how much more noise is applied to the receiver mixer compared to the −114 dBm/MHz warm earth background. Typical receiver noise figures range from 4 to 12 dB depending on receiver front end design and frequency band. The PCM signal must be 10-20 dB above the thermal noise level (a value determined by PCM coding and detection techniques) for a given threshold error rate of 10^{-6}.

Digital Transmission

A discussion of microwave propagation applies to any type of point-to-point microwave system, whether carrying digital or FDM channels. The information to be transmitted may be carried by the microwave signal in various forms of modulation such as frequency, phase, amplitude, or a combination of these; but, frequency or phase modulation is the preferred method because it facilitates provision of agc, and amplitude linearity is not required in the rf and if circuits.

When the information to be transmitted is in digital form—digital data or PCM voice, for example—the preferred method of modulation of the microwave carrier is still frequency or phase modulation, thereby keeping the envelope of the microwave signal as constant as possible. In this light, it can be seen that FM microwave equipment originally designed to transmit such analog signals as FDM voice or video, should also be suitable for the transmission of digital information. Everything necessary for satisfactory and reliable transmission is already present. All that is required is conversion of the digital signal into a form in which it can take the place of the normal analog modulating signal; that is, make it look similar with respect to level and frequency spectrum.

A typical example of this approach is GTE Lenkurt's 9120A digital multiplexer, which contains facilities to interface two low speed T1 PCM bit streams (24 vf channels each) with an existing FM radio of suitable bandwidth (such as the GTE Lenkurt Type 778F2A microwave radio operating in the 2-GHz common carrier band). A typical arrangement of a 2-GHz, PCM-over-microwave system is shown in Figure 3. At the transmitting end, the 9120A combines two asynchronous DS1 (1.544 Mb/s) bit streams into a single output unipolar digital signal of 3.156 Mb/s. This signal is converted into a "modified duo-

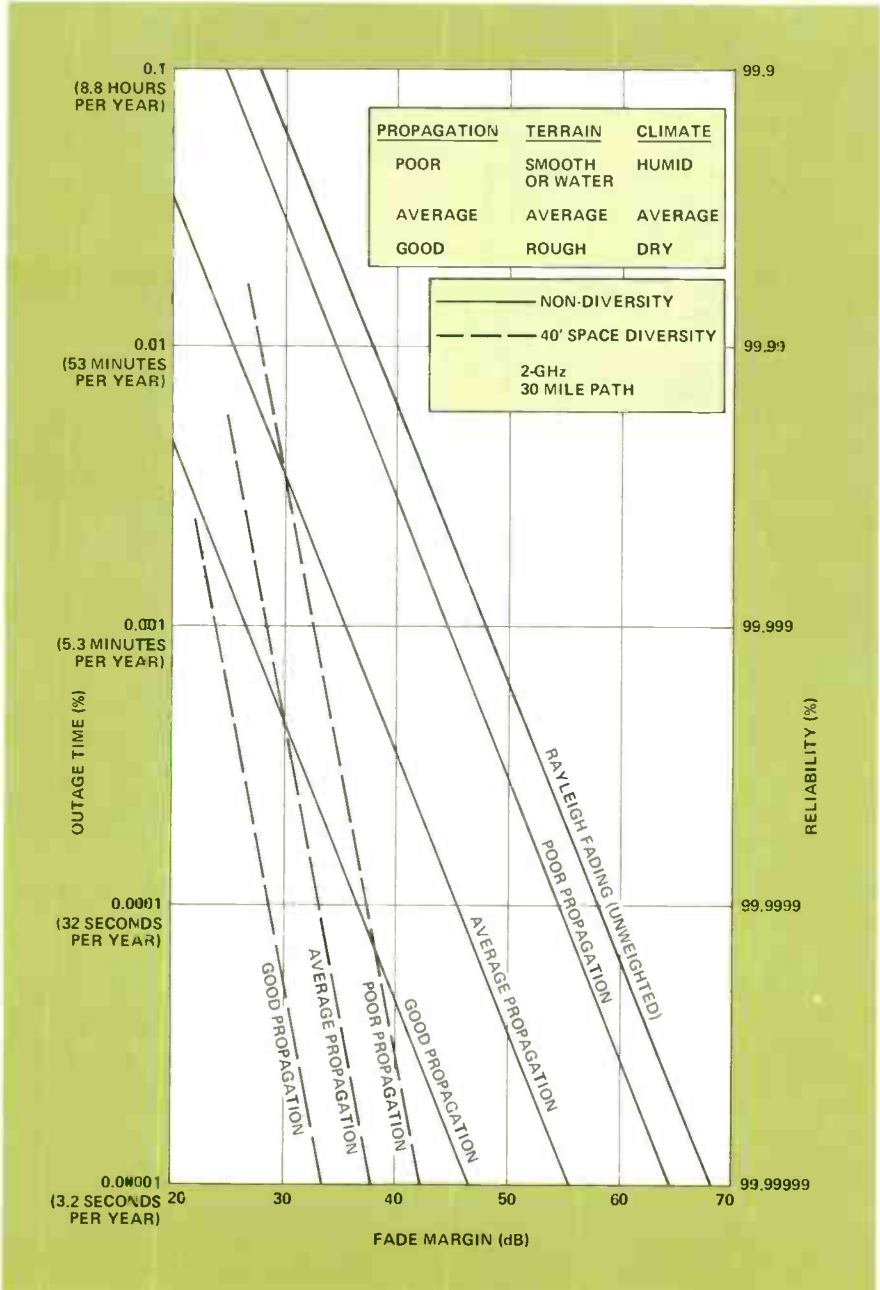


Figure 2B. Climate and terrain are important factors in determining overall microwave system performance.

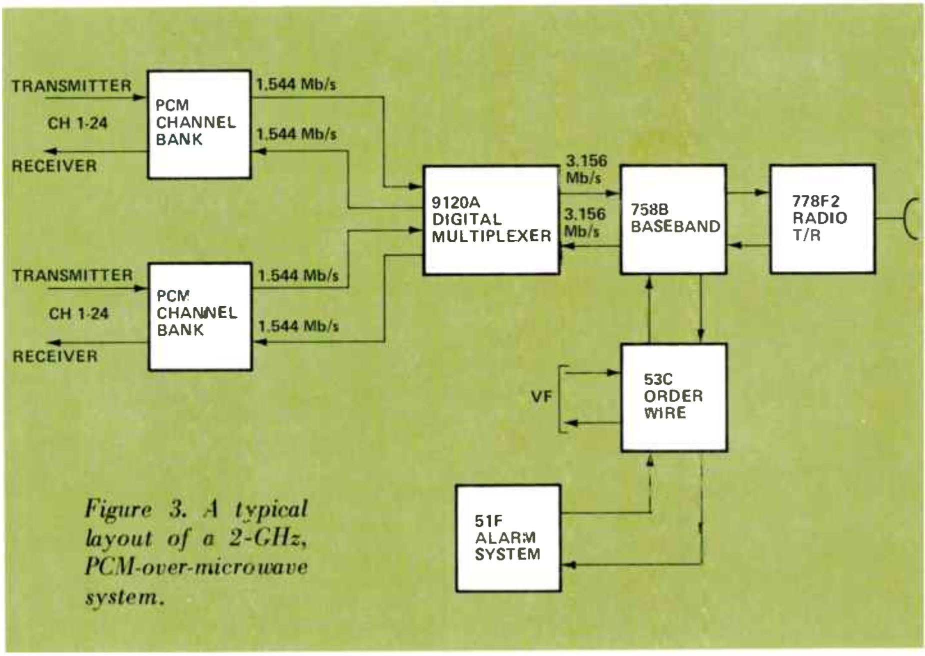


Figure 3. A typical layout of a 2-GHz, PCM-over-microwave system.

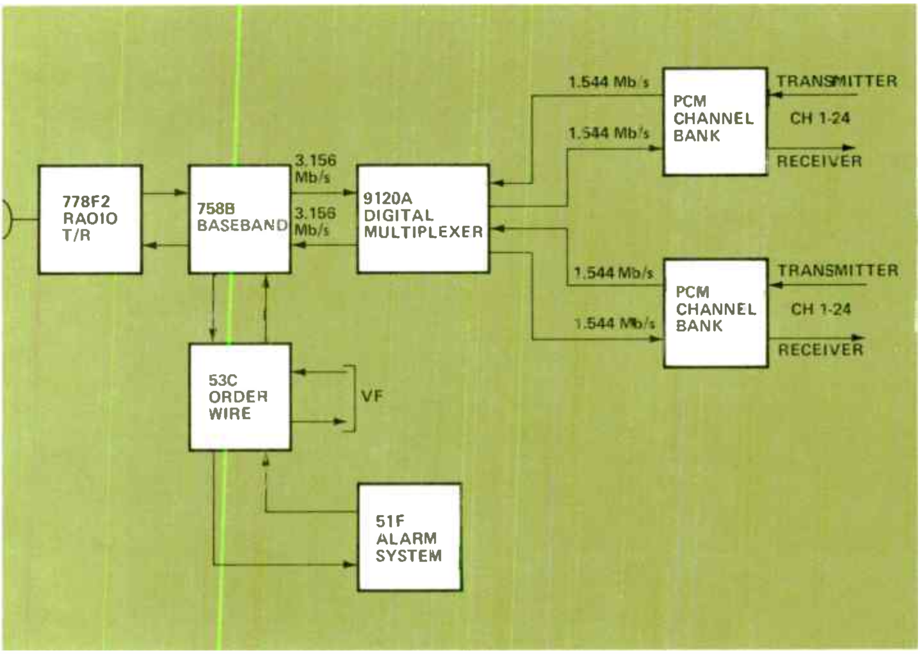
binary" signal in the radio-interface unit and applied to the baseband input of the radio, where it frequency modulates the microwave carrier.

At the receiver, the modulating signal is recovered in the conventional manner by the FM discriminator and then applied to the receive radio interface unit of the multiplexer. The interface unit extracts the clock from the modified duobinary signal and subsequently converts it back into a digital (binary) signal for further processing (de-multiplexing). Finally, the two original 1.544 Mb/s bit streams emerge from the multiplexer for connection to such T1-type equipment as channel banks, data terminals, or repeatered lines.

Fade Margin

Fade margin is one of the important factors that determine microwave system performance. Fade margin is the amount of reserve power in dB available at a receiver to overcome the effects of sudden atmospheric fades. If, for example, the normal receiver input level is −45 dBm, a 30-dB multipath fade will drop the receive level to −75 dBm. If the −75 dBm level corresponds to a S/N ratio in the receive interface unit of 20 dB and a BER of 10^{-6}, then any further increase in the intensity of the fade will exceed the limits of the bit error rate. For the conditions just described, the fade margin is 30 dB.

The fade margin depends on the arrangement of the system. The closer the transmitter is to the receiver, or the more suitable the climate and terrain is for microwave propagation, the smaller the fade margin necessary for required reliability. The minimum rf-transmit output power of the GTE



Lenkurt 778F2A radio transmitter (without hot-standby) is +36 dBm. The net path loss of a system is the total loss inflicted on the signal throughout the microwave path. It includes the loss of the path, the gain of the antennas, the loss in the coax between the antenna and the radio, and anything else in the rf path between the transmitter and receiver antenna ports.

A typical 2-GHz net path loss might be 71 dB if the transmitter and the receiver are approximately 30 miles apart, and 8-foot parabolic antennas are used. Such a loss means that normal receive carrier power will be approximately −35 dBm (+36 dBm − 71 dB = −35 dBm). The fade margin in this example is 40 dB, which means that the signal can drop 40 dB without exceeding 20 dB S/N ratio and a 10^{-6} BER.

The BER of a PCM microwave system is comprised of the total contribution of the digital multiplexer, repeatered line (if used), and the radio. The radio's threshold error contribution varies with the carrier-to-noise (C/N) ratio as well as the signal-to-interference (S/I) ratio at the microwave receiver. The C/N ratio varies with fading, and a 1 dB increase in noise will typically result in a ten-fold increase in errors. A safety or fade margin is required to avoid exceeding the error rate specified in the system reliability objectives more than a certain percentage of the time. The fading characteristics of a particular microwave path, the required propagation reliability, and the use or omission of diversity protection, determine the necessary fade margin.

The detected signal level is held constant by agc and amplitude limiting

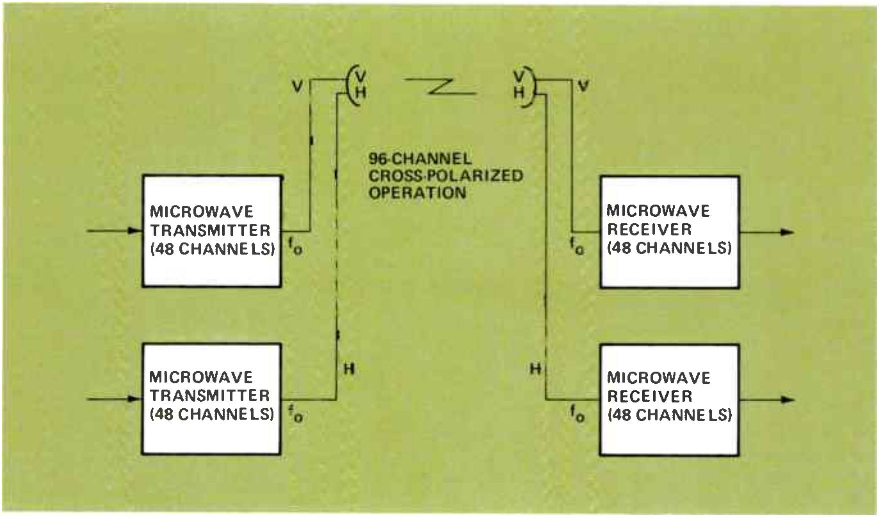


Figure 4. The use of cross-polarization can double the channel capacity of a digital transmission system (Figure shows one direction of transmission only.)

in the if section of the radio, and the noise level may vary over a wide range as a result of microwave signal fading. Over the normal operating range of rf input levels, the error rate is very low. In contrast to a conventional FDM system, noise under unfaded conditions or during moderate fades does not significantly degrade PCM system performance. The digital system is far more tolerant of interference, with error rate being significantly affected only when the power of the interfering signal approaches that of the noise at the error threshold. And, unlike frequency-modulated radio systems carrying FDM channels, the effect of interference on the digital signal is largely independent of the spectral characteristics of the interfering signal.

Cross-Polarization

Because PCM transmission over microwave radio is less sensitive to interference than is FDM transmission, both horizontal and vertical polarization of the same radio frequency can be used for two independent PCM systems over the same path in most propagation conditions, thereby doubling the route capacity. Typically, the value of XPD (cross-polarized discrimination) of a carefully aligned antenna system provides a 25- to 30-dB polarization advantage on a single hop. This means that the vertically polarized signal is attenuated 25 to 30 dB from the horizontally polarized signal (or vice versa). While this separation is unacceptable for transmission of FDM signals, it has an insignificant effect on the transmission of digital signals except near the receiver threshold. Both the horizontal and vertical polarization transmission of a single radio frequency can therefore be used for digital transmission. Thus, two signals from different radios occupying the same rf frequency assignment, but representing two different digital systems, can be transmitted over the same antenna and the same path (see Figure 4). Through the use of cross-polarization, the digital transmission channel capacity over 2-GHz radio using the 9120A digital multiplexer can be increased to 96 channels per radio frequency by using two radios.

While the use of multifrequency cross polarization has been an effective means of transmission for many years, it is not without limitations in single-frequency applications. The XPD may diminish during multipath fading, decreasing the S/I ratio to considerably less than the 20 dB that equates to a threshold of 10^{-6} BER. Similar loss of XPD has also been suspected to result from heavy rainfall, which otherwise is not a factor in 2-GHz propagation characteristics.

Frequency modulation (FM) techniques have been consistently used in commercial microwave radio systems for multichannel voice and data transmission. These systems are used in conjunction with the familiar frequency division multiplex (FDM) carrier system. Proven FM radio equipment can now offer an economically attractive alternative for the extension of digital systems over obstructions or into remote areas where cable plant costs are prohibitive. This three-part series has presented some of the many aspects of a new technique now available to meet the ever-expanding needs of the telecommunications industry.

BIBLIOGRAPHY

1. *Digital Transmission Over 2-GHz Radio System*. San Carlos, California: GTE Lenkurt Inc., 1973.

2. "Microwave Diversity. . .how it improves reliability," *The Lenkurt Demodulator*, March, 1961.

3. Olson, J.D., "A Method of PCM Transmission Over 2-GHz Microwave Radio," *International Conference on Communications*, (June 1974), 33C-1 – 33C-5.

4. Swartz, L.T. "Performance Analysis of a Three-Level Modified Duobinary Digital FM Microwave Radio System," *International Conference on Communications*, (June 1974), 5D-1 – 5D-4.

5. White, Robert F. *Engineering Considerations for Microwave Communications Systems.* 2nd Ed. San Carlos, California: GTE Lenkurt Inc., 1972.

GTE LENKURT
1105 COUNTY ROAD
SAN CARLOS, CALIFORNIA 94070

ADDRESS CORRECTION REQUESTED

Bulk Rate
U. S. Posta
PAID
San Carlos,
Permit No.

The GTE Lenkurt Demodulator is circulated monthly to selected technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.