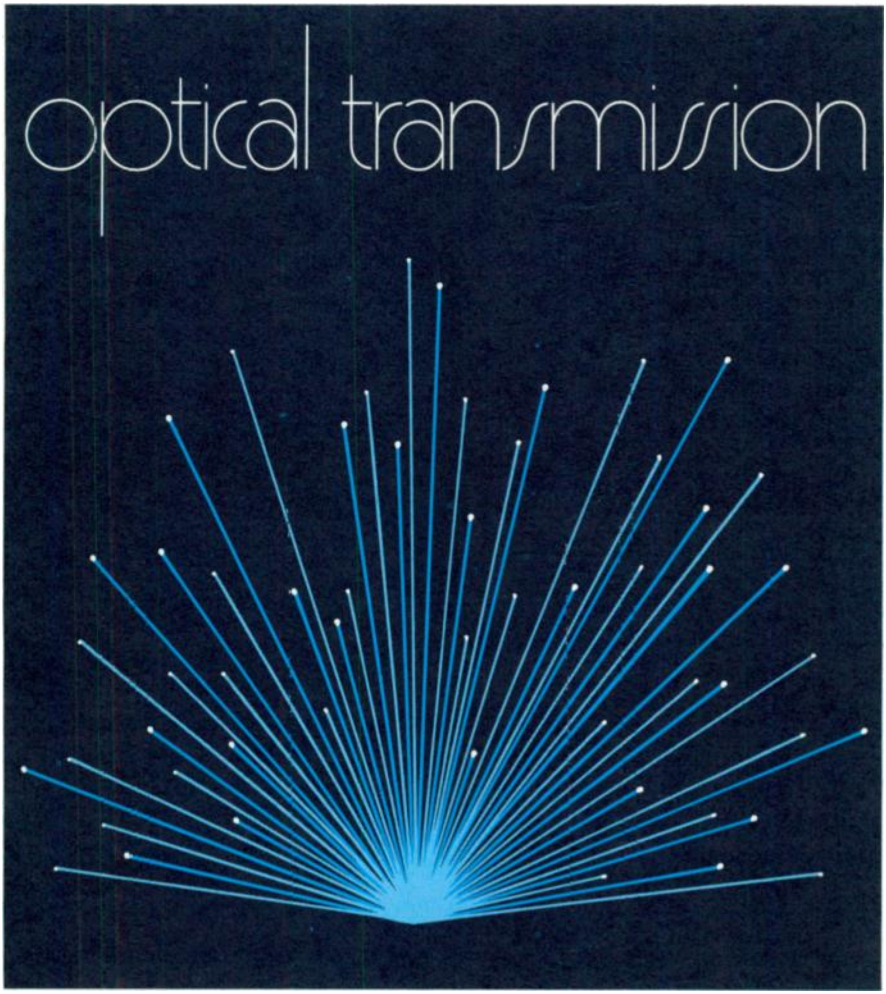
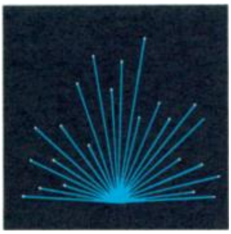
GTE LENKURT
DEMODULATOR
FEBRUARY 1972





Overcrowding of the electromagnetic spectrum, improvements in light sources, and improvements in optical transmission media have been the impetus for development of optical transmission systems.

Optical transmission systems promise bandwidths of approximately 1000 GHz and bit rates of from 100 to 500 Mb/s, or more. Such large capacity transmission systems are presently under development and may be available within the next decade.

Perhaps the two most significant developments in optical transmission are injection light sources and fiber optics. When optical transmission was first investigated it was with the purpose of finding a use for the coherent laser (Light Amplification by Stimulated Emission of Radiation). But, modern developments enable the successful use of injection light sources, in particular, noncoherent light sources such as LED's (light emitting diodes). Also, as first envisioned, optical transmission was to be similar to microwave transmission with free-space propagation. But, free-space propagation is far from ideal, and a closed, guided system such as offered by fiber optics looks more promising.

In addition to the broad bandwidth capability of optical transmission systems, fiber optics can also be used to form a compact system. Individual fibers, which could replace cables (coaxial or paired) in present transmission systems, have a typical outside diameter of 0.02 mm (0.0008 inches) compared to lower capacity 9.5-mm coaxial tubes.

Since optical transmission systems are electrically isolated – no current is transmitted through the system – the crosstalk associated primarily with digital transmission lines is not present with optical transmission. Crosstalk caused by light passing between the optical fibers can be eliminated by placing an opaque jacket around the fiber (see Figure 1). This means that the fibers can be bundled together to keep the system compact.

The electronic equipment being developed for optical transmission should be much smaller than comparable present day radio and cable transmission equipment. Although, the same microelectronic techniques used to miniaturize optical transmission equipment could also be used to miniaturize radio and cable transmission electronics.

One of the biggest advantages that fiber optics offer over cable as a transmission medium is the low cost and plentiful supply of glass compared to copper. Even if there weren't the cost savings for equal quantities of raw material, much less glass than copper is needed for an equivalent transmission link.

For an efficient, long-distance optical transmission system, low-heat light sources, low-loss transmission media, and sensitive detection devices are presently being refined.

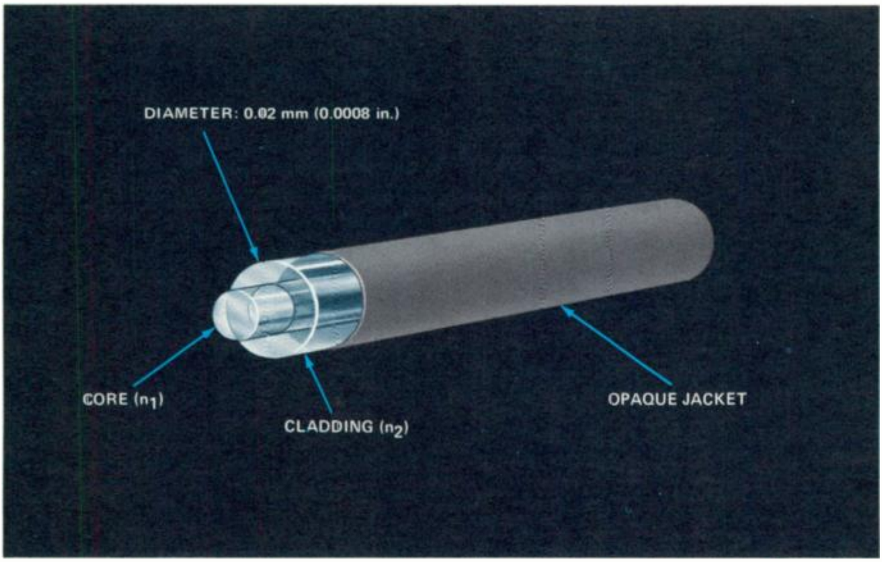


Figure 1. The index of refraction of the fiber optical core (n_1) is greater than the index of the cladding (n_2). An opaque material can be placed around the fiber, like a jacket, to eliminate crosstalk between adjacent fibers.

Light Sources

Generally speaking, a light source is any material or device which gives off energy with a wavelength of from about 300 microns down to 0.5 microns, which includes light bulbs and lasers and everything in between. For optical transmission systems, many solid-state light sources have been investigated and all seem suitable for use with open, line-of-sight systems as well as closed, guided systems. These sources include such things as gallium arsenide (GaAs) injection lasers, light emitting diodes (LED's), and neodymium-doped yttrium arsenide (Nd:YAG) lasers pumped by LED's.

The injection laser, which is composed of more than one semiconductor, has several advantages over other types of lasers for optical communications. Of the laser light sources, injection lasers make the most efficient use of electric energy. And, with an injection laser, it is possible to modulate the light source with the signal without the need for any external modulation devices. Injection lasers do have their drawbacks though. For example, the lasing region for injection lasers is extremely thin and this narrow aperture causes the angular divergence of the emitted beam to be wider than in other lasers. The major disadvantage of injection lasers has been their inability to dissipate the heat generated by the lasing action. Fortunately, special diamond heat sinks have been developed that now make it possible to operate injection lasers continuously at room temperatures.

LED's are essentially tiny light bulbs. These noncoherent, injection light sources are low-cost, low-heat light sources and are the most promising light source for optical transmission. Fabrication techniques have now been developed that accurately manufacture LED's whose power output degrades about 5-10% during the first 100 hours and then changes little, if any, during the following 23,000 hours of operation. Like injection lasers, LED's used as transmission light sources need no external modulation devices. Therefore, LED's seem to have the necessary reliability, life expectancy, and simplicity for optical transmission purposes.

Transmission Media

The transmission media for optical communications can be either open or closed. An open system uses free-space propagation, similar to microwave transmission. Unfortunately, optical transmission using free-space propagation is subject to more interruptions due to atmospheric conditions than is radio propagation. Rain and fog scatter the light and fluctuations in the atmospheric density result in changes in the index of refraction which introduce noise, and opaque bodies prohibit transmission of the light, all in all making open transmission links of limited usefulness. Open transmission systems are presently being field tested for short, direct-hop applications, such as local data distribution.

Closed transmission links make use of optical fibers, or evacuated or dry-gas filled pipes. Any of these closed systems are not subject to the transmission problems associated with open systems. Optical fibers seem to be the most promising transmission media for optical transmission. Optical fibers are essentially hair-like strands of glass with the index of refraction of the center higher than the index of refraction of the outside. The index of refraction can change abruptly as shown in Figure 1 or it can change continuously from the center of the fiber to the outside. To construct a fiber with an abrupt change from the core to the cladding (which appears to be a satisfactory arrangement and is the easiest to manufacture), the fiber is made by placing a glass rod inside a glass cylinder of lower index of refraction and then heating and stretching the combination to form the fiber (see Figure 2).

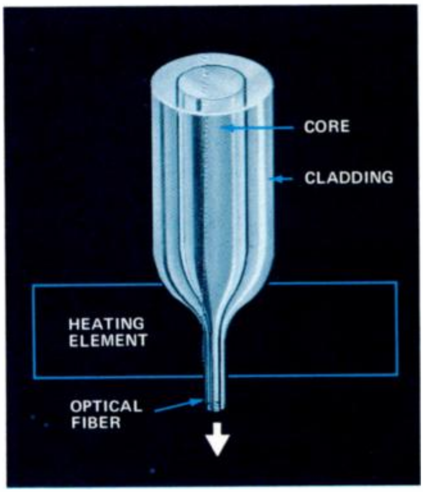


Figure 2. Fiber optics can be made from a glass rod placed inside a glass cylinder of a lower index of refraction.

The difference in index of refraction present in fiber optics "traps" the light within the fiber. As already mentioned, some light can "leak" out of the fiber but this can be controlled by placing opaque jackets around the fibers. Therefore, optical fibers act like waveguide, except for one important feature – optical fibers can be bent in very small radii (as small as 3 cm) without harm to the transmitted signals.

With underground duct space at a premium, any type of space saver is highly desirable and the additional high signal capacity of optical fibers makes them even more desirable. The limit of the signal carrying capacity of optical fibers is dependent upon the multiplex ability of the terminal equipment. Spatial multiplexing, putting fibers into bundles, can be used when the terminal equipment is unable to multiplex any more signals on a single fiber and still greater capacity is needed.

A fiber optic transmission path is not flawless though. The transmitted signal can be attenuated by absorption and by scattering. The most significant absorption losses in fiber optics are caused by metallic ions in the fibers. The most common metallic ions found in fiber optics are iron, copper, cobalt, chromium, nickel, vanadium, and manganese. All these ions have their peak absorptions within the visible and near-infrared spectrum. Purity, then is the primary goal of optical fiber manufacturers. Material purity would minimize the amounts of metallic material present in the fiber, and consequently, minimize the absorption losses. Since scattering is caused primarily by imperfections in the core of the fiber, manufacturing techniques are also at the root of this problem. Fibers are presently being manufactured 200 meters long and with losses of 20 dB.

After manufacturing techniques have been perfected to produce long, low-loss fibers, the single most difficult problem associated with fiber optical transmission may turn out to be splicing the fibers in the field. Techniques that have been tried in the laboratory with relative success are fusing the ends with heat, or using sleeves or grooved alignment blocks for butt joints. Not only is it necessary to splice the fibers to other fibers, but it will also be necessary to have interconnections between the fibers and the terminal equipment.

Total System Concept

In a fiber optical transmission system repeaters are needed for regenerating the optical signals that have become attenuated and distorted in transmission. Of course, terminal equipment for processing the optical signals to make them compatible with non-optical, or electronic, signals are also needed. At the terminals and at the repeaters it is necessary to have light sources, modulators, and detectors. Once a manufacturing technique is perfected for optical fibers, the transmission media will be relatively inexpensive. In order to keep the total system economically compatible, it is necessary to have repeaters and terminal equipment that won't overpower the fibers in size, cost, or reliability.

Toward this end, advanced development labs have been working on networks of microscopically small optical waveguides connecting thin film components. This development is a powerful optical system, comprising conventional lenses, optical waveguides, and signal processing equipment that has been shrunk to a thin chip about the size of an ordinary postage stamp. Such a device could be integrally bonded to the optical fiber and would serve the same function as the large repeater stations (approximately 15 inches in diameter and 26 inches long) presently used with cable systems.

The present goal for fiber manufacturing is to economically produce the fibers with losses of about 20 dB/km. Assuming system losses of between 40 and 60 dB between repeaters, it would be necessary to have repeaters placed every two or three kilometers. The repeater design being developed and the high system capacity offered by optical transmission systems would seem to promise an economical communications system despite the close repeater spacing. And, since the losses in an optical system do not appear to be a function of the number of multiplexed channels on a fiber, repeater

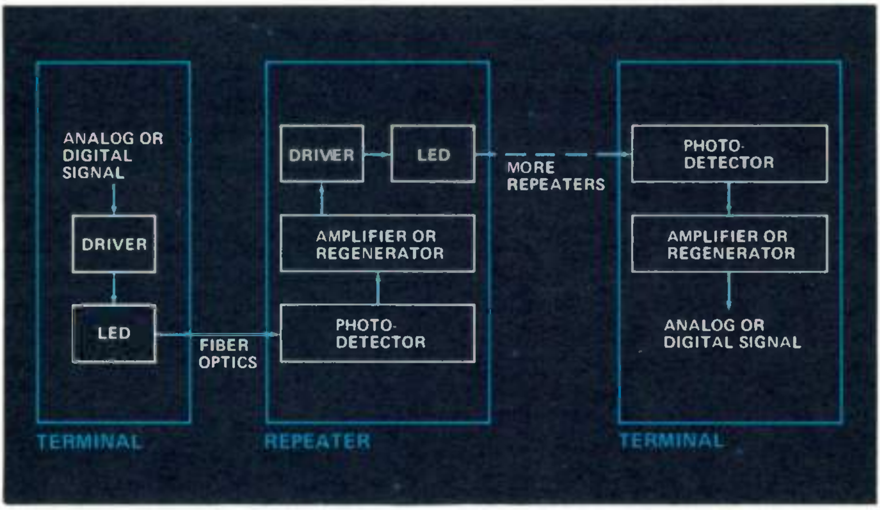


Figure 3. A simple optical transmission system can be designed for analog or digital signals using LED's as the light source.

spacing is practically constant, regardless of channel capacity. The repeaters could therefore be chosen to fit present needs, and economically increased by replacing existing repeaters with larger capacity repeaters at a later date when the system needs change.

Typical optical systems might look like the ones illustrated in Figures 3 and 4. An optical fiber transmission system that uses LED's, or coherent injection lasers, as its source could prove to be quite simple. The signal transmitted would be applied directly to the LED through a driver that would provide the needed current gain. Each fiber in the system would require its own repeater. The repeater would convert the optical signals to baseband frequency and amplify or regenerate the baseband signals and reapply the signals through another driver to modulate the transmitting light source of the repeater.

If a non-injection laser is used, it is necessary to have an optical modulator at the terminal and at each repeater in order to impress the information onto the optical carrier.

Multiplexing

Three types of multiplexing are presently possible for optical communications. These are frequency, time, and spatial multiplexing.

With frequency multiplexing, various frequency subcarriers are modulated. This requires the use of several light sources, each with a different emission frequency (wavelength). One disadvantage of frequency multiplexing is the expensive filters that are required to minimize the crosstalk effects from all the different carrier frequencies present within a single fiber. On the other hand, FSK (frequency-shift keying) is satisfactory for video links, since frequency multiplexed binary data and video signals can be simultaneously transmitted.

For transmitting binary signals, time multiplexing is the ideal scheme since the signals are already in the proper form. Time multiplexing intro-

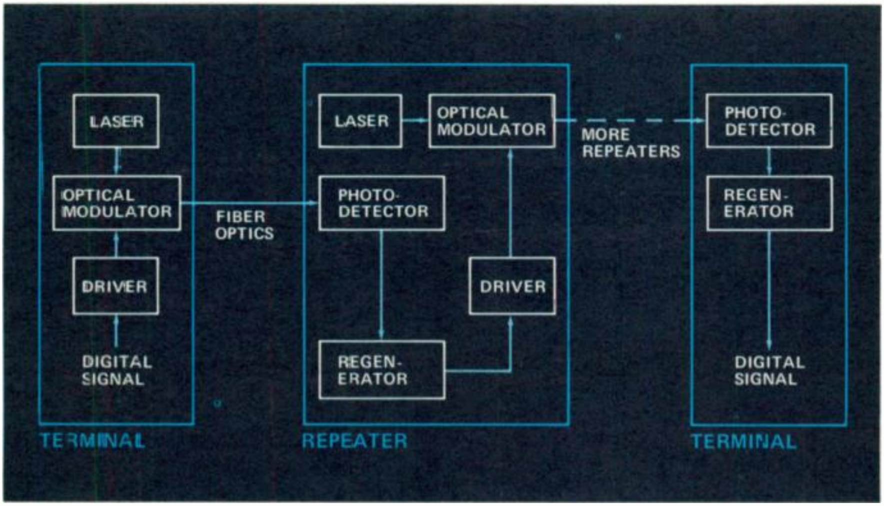


Figure 4. Transmission systems using non-injection laser sources have wider bandwidths than those using injection light sources and are quite suitable for digital transmission, especially PCM.

duces a basic delay of one multiplex period. But, for most applications, this delay is not harmful and the simplicity of time multiplexing makes it attractive for optical data transmission, just as PCM has been successfully used with cable transmission systems.

With spatial multiplexing, or parallel optical transmission, each channel of information has its own fiber optic pair for transmission. For short transmission links such as interoffice trunks, a fiber bundle only a few millimeters thick and containing a few hundred optical fibers, each with a bandwidth of a few megahertz, might provide a simple method of spatial multiplexing that might prove more economical for initial installation than frequency or time multiplexing.

How soon?

Due to their small physical size, large bandwidth capacity, and small bending radius, optical fibers appear to be the most promising transmission media for optical communications. There are many potential applications for such communications systems: interconnections of communications equipment in a building or between buildings over distances of a few hundred feet to up to a few thousand feet; interoffice trunks over distances of a few miles with channels of low to medium capacity; and intercity routes over hundreds of miles requiring medium to high capacity systems. It appears that optical fibers can be used anywhere twisted-wire pairs and coaxial cables are presently being used for communications.

If development continues, optical transmission systems for communications will probably make their formal debut by the early 1980's. And with the system details perfected, the applications are unlimited.

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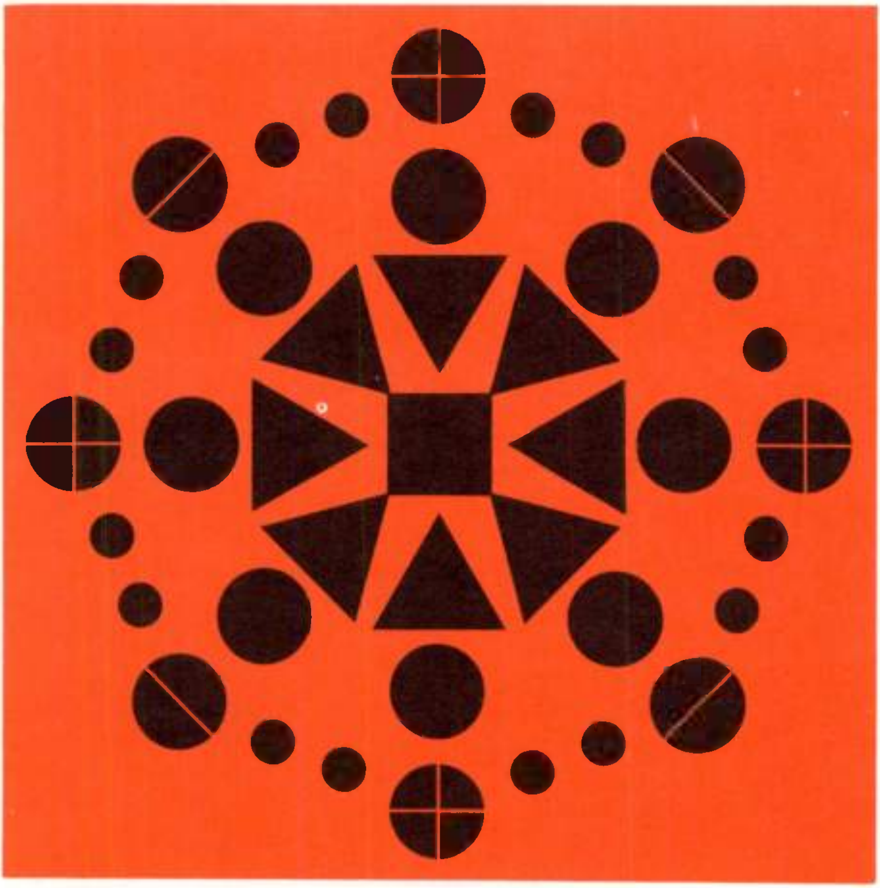
DEMODULATOR

JANUARY 1972

Toll-Quality PCM



The progress in communications equipment development is everchanging. Some years ago the D1-type PCM terminal made its debut in the communications market. Today, a new generation of toll-quality PCM terminals are making their appearance.

The new generation of PCM (pulse code modulation) terminals for the telephone industry are generally referred to as D2-type terminals. They are so designated because they are end-to-end compatible with the D2 terminal manufactured by the Western Electric Company. The earlier D1-type terminal was designed primarily for short inter-office exchange trunks. The D2-type terminal, such as GTE Lenkurt's 9002A, has been designed for use at any level in the switching network of a country. Both D1- and D2-type PCM terminals operate with 24-channel pulse trains (1.544 megabits/second) and can be transmitted over T1-type repeatered lines.

The telephone switching centers of most countries are classified according to a hierarchical structure. The United States has five different classes of telephone offices. These are numbered in decreasing rank from one to five, a class five office being connected to the subscriber telephone and a class one office being of the highest rank. Figure 1 shows the hierarchical structure of the telephone switching network in the United States. This structure applies to all types of communications equipment, not just to PCM.

Trunks

A trunk is a voice-frequency circuit connecting two telephone switching centers and is therefore used by many subscribers. There are different types of trunks some of which can be classified as follows:

(a) direct trunk – interconnects two class five end offices

(b) toll connecting trunk – connects a class five end office to any higher-ranking toll office

(c) intertoll trunk – connects any class one through four toll switching office to any other class one through four office.

The basic objective of telephone companies is to provide similar voice quality for local as well as long distance calls. Since a long distance call such as an interstate call is usually set up using several intertoll-type trunks connected in tandem, the transmission requirements for such trunks are very strict. By contrast, a local call may involve only one direct trunk between two class five offices. Therefore, the transmission requirements for trunks

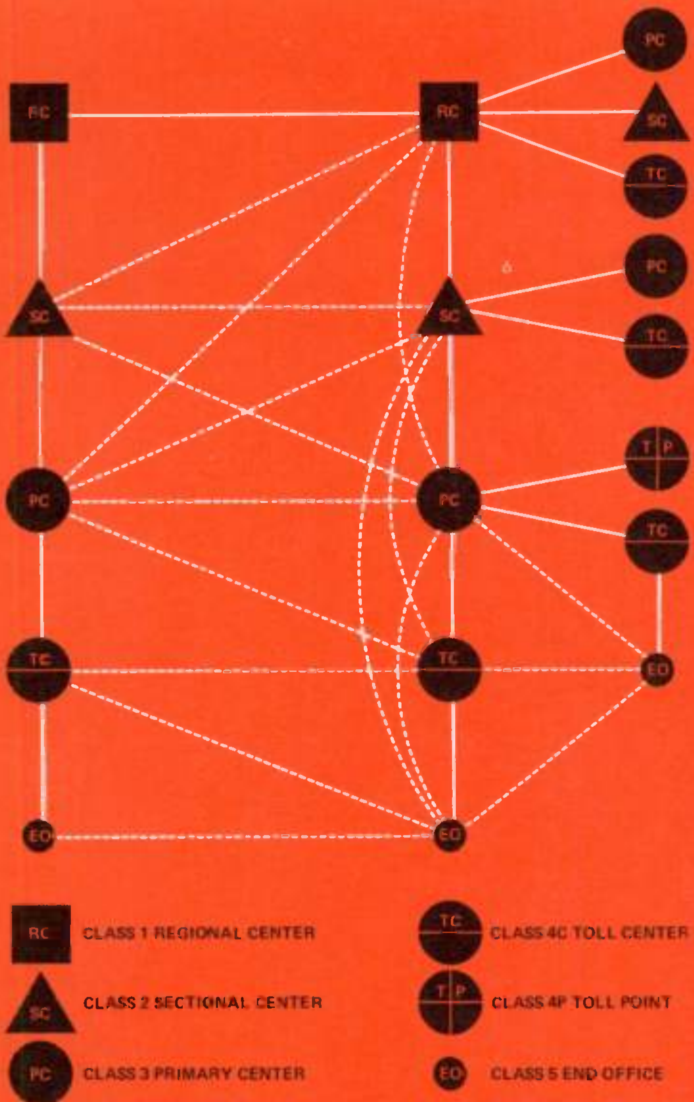


Figure 1. Hierarchical structure of the telephone switching network in the United States. Solid lines indicate main lines of connection within the hierarchy; dashed lines show examples of so-called "high-usage trunks" that can be connected between any two offices (regardless of rank) whenever the traffic volume justifies it.

between lower-ranking offices are less severe than between higher-ranking offices. D1-type terminals can be used for trunks between offices of class five up to class three. The D2-type terminal, because of its improved design, is suitable for use at any level in the switching office hierarchy.

The improved design of the D2-type terminal includes improved return loss, delay, and frequency response characteristics as well as patching jacks and precision attenuators for level adjustment. The most important improvement in D2-type terminals is the use of 8-bit encoding which results in reduction of quantizing distortion.

D2-Type Terminals

The Western Electric D2 channel bank (terminal) is equipped to handle a total of 96 channels. It operates with four input and four output pulse trains, each input-output pair connecting to a 24-channel terminal like the GTE Lenkurt 9002A, a similar D2-type terminal, or another 96-channel D2 terminal. Voice signals coming into the PCM terminal are encoded into a sequence of pulses and spaces, sent out on a T1 line, and received at the distant end by another PCM terminal which decodes the incoming pulse train and restores the original voice information. This voice information is then sent on to its intended destination by means of telephone lines or other carrier systems. Figure 2 shows a PCM voice communication system using D2 and D2-type terminals.

Quantizing Distortion

The noise in a PCM system is largely due to quantizing distortion which is caused by the approximation inherent in the quantizing process. The input signal to a D2-type PCM terminal is sampled 8000 times per second and each sample is rounded off (quantized) to the nearest of a number of specific voltage levels (steps). Theoretically, the largest number of quantizing steps available in a D2-type terminal is 256 since 256 is the largest number that can be encoded with eight binary digits ($2^8 = 256$). Two different numbers are used to designate the voltage when the sample is quantized to zero amplitude. Since two steps are used for zero voltage, there are 255 steps available for quantization of voltage samples. In order to ensure reliable timing information to the regenerators (repeaters) on the line, suppression of the all zeros code (00000000) is usually required. This leaves a total of 254 quantization levels whenever the all-zeros code needs to be suppressed. Figure 3 gives an example of D2-type quantization at low voltage levels. At the distant end of the system, approximation errors occur because each sample can be decoded only to one of the 254 quantization levels.* These quantization errors appear as distortion.

In contrast to D2-type terminals, the D1-types (which are not end-to-end compatible with the D2-type) use 7-bit encoding which allows 127 quantization levels. This gives a greater distance between steps and consequently, a greater error possibility. The smaller quantizing steps of the D2-type terminal allow a smaller distance between steps which results in less error magnitude and therefore, less quantizing distortion.

Figure 3 shows that steps used in quantizing are of unequal size. This represents the technique used for both D1- and D2-type PCM terminals; the

*There are 254 quantization levels used in five frames out of six. In the remaining frame, 7-bit encoding (resulting in 127 quantization levels) is used, one bit being used for signaling.

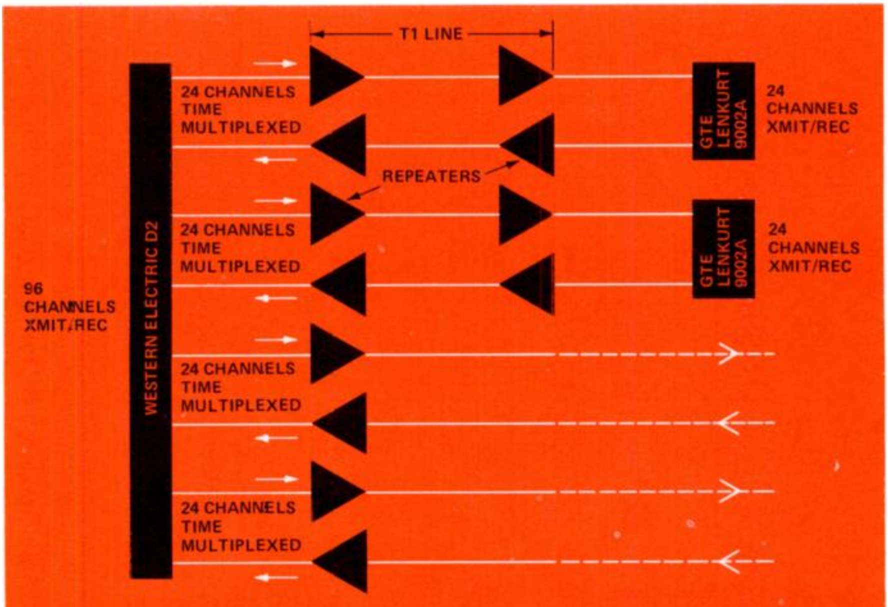


Figure 2. The 96-channel D2 terminal utilizes four input-output signal pairs, each capable of connecting to another D2 or to a D2-type PCM terminal.

steps are always smallest for low power level signals since most speech information is concentrated at low amplitude levels. This results in an improvement in noise performance by virtue of the fact that all signal levels are not equally probable. That is, low voltage signal samples are more likely to occur than high voltage samples in speech signals. The rate at which quantizing steps are allowed to increase is determined by a particular mathematical law especially chosen to optimize the quantizing according to different criteria. For voice communications, the main criterion is a constant signal-to-noise ratio.

Uniform quantizing (equal step sizes throughout the voice range) would introduce distortion with particularly detrimental effects on low amplitude signals. Selection of the most advantageous mathematical law allows the designer of communications equipment to build into his design those properties which are best suited to the required function of the equipment. For example, if signals (such as data signals) of a certain amplitude range and with well-defined statistical properties were to be sent over a communications system, a quantization law could be derived for that system to minimize the error rate. For the transmission of speech signals however, the property desired by telephone companies is a signal-to-noise ratio which is constant over as wide a range as possible. A constant signal-to-noise ratio results in equal quality of

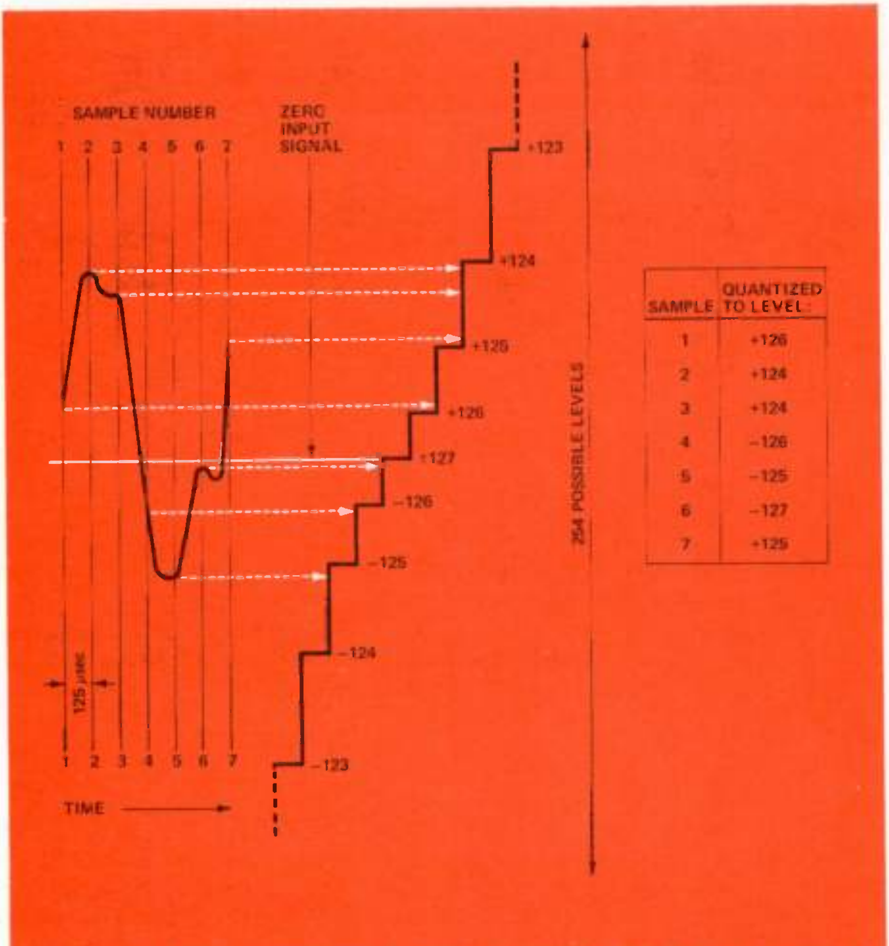
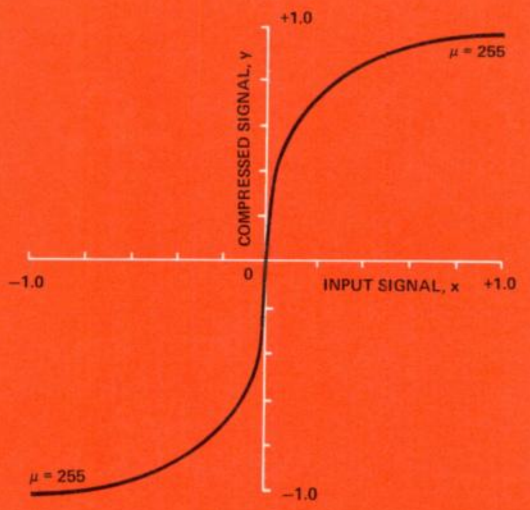


Figure 3. In a D2-type terminal, each voltage sample is quantized to one of 254 possible levels.

service for weak and loud talkers. A quantized rendering of the lower amplitude speech levels necessitates a specific distinction between discrete levels at low amplitudes, while less specific distinction is necessary at the higher speech levels.

The designation S/D is used here to define the theoretical signal-to-quantizing distortion ratio. Quantizing distortion is generally the chief noise contributor in a properly operating PCM system. The *overall* signal-to-noise ratio (S/N) should be within a few dB of the theoretical optimum represented by the signal-to-quantizing distortion ratio (generally 1 to 5 dB below). That is, the overall signal-to-noise radio (S/N), which includes not only quantizing distortion but also all

Figure 4. Quantizing characteristic curve used with D2-type terminals for positive and negative values of x, normalized so that maximum input signal corresponds to x=1, maximum output signal to y=1, and μ to 255.



other noise generated within the terminal, should remain within 1 to 5 dB of the theoretical signal-to-quantizing distortion (S/D).

Quantizing Characteristic

The quantizing characteristic determines the rate of increase in size of the quantizing steps. This characteristic is accomplished in the D2-type terminal through the use of a non-linear coder designed to follow the mathematical quantizing law necessary to approximate a constant signal-to-noise ratio. In D1-type equipment, the quantizing characteristic is often called the *companding characteristic* since it is effected through a combination of an instantaneous compressor-expander (compandor) and a linear coder-decoder (equal quantizing steps). In the D2-type terminal, the compression and encoding functions take place simultaneously in the coder although they may be thought of as separate functions, for simplicity.

The quantizing characteristic for a D2-type terminal such as the GTE Lenkurt 9002A follows the equations:

Equation A

$$y = + \frac{\ln(1 + \mu x)}{\ln(1 + \mu)} \quad \text{for positive x}$$

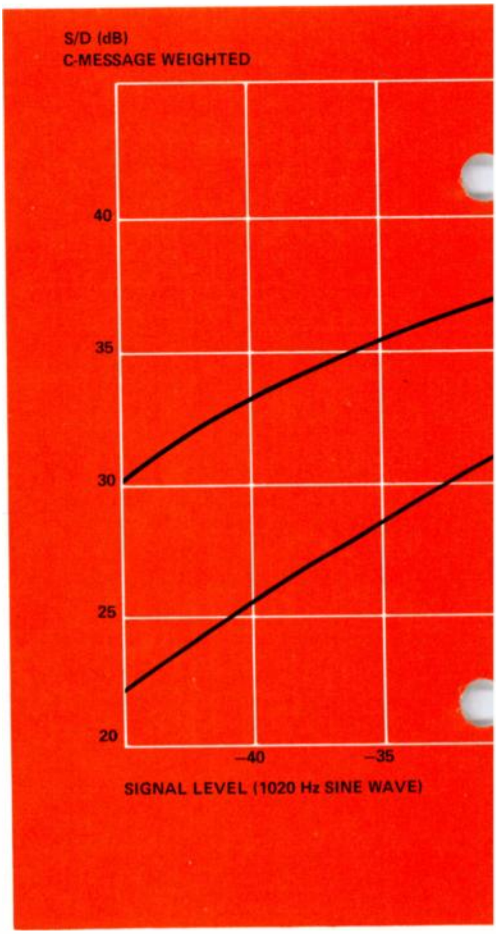
Equation B

$$y = - \frac{\ln(1 - \mu x)}{\ln(1 + \mu)} \quad \text{for negative x}$$

where ln stands for natural logarithms (logarithms to the base e, where e is approximately equal to 2.718), x and y are the input and output voltages from the compressing function and μ is a constant which equals 255 for D2-type terminals and which determines the shape of the quantizing characteristic curve. The 255 value of μ should not be confused with the number of quantizing steps as it is a separate entity. The quantizing curve for D2-type terminals is shown in Figure 4. It is approximately linear for small signal samples, approximately logarithmic for large signal samples (positive or negative), and has a smooth transition between these two limits. In contrast, the D1-type terminal employs a μ value of 100.

Since a logarithmic characteristic is desirable for a constant signal-to-quantizing distortion (S/D), the value of μ = 255 implies an improvement over the D1-type equipment because the characteristic assumes an approximately logarithmic shape at smaller values of input signal x. The net effect is that S/D stays approximately constant over a wider range of input signal values, as shown in Figure 5.

Although quantizing distortion is the predominant noise source in a properly operating PCM system, there are other sources of noise. In the analog section of the terminal, noise from harmonic distortion as well as crosstalk between channels can occur. This is particularly true if several channels are loaded with high power level signals. Errors may also occur in the sampling process (before quantizing) and during encoding and decoding of the signal, as for example, when there is a slight error in dc level in the coder. All of these factors cause the overall signal-to-noise ratios to be somewhat less than the theoretical signal-to-quantizing distortion ratios depicted in Figure 5.



Signal-to-Noise Ratios

The reader who is mainly acquainted with FDM (frequency division multiplex) may wonder why the signal-to-quantizing distortion ratios shown in Figure 5 are relatively small compared with those commonly expected from an FDM system. For example, FDM cable carrier systems have signal-to-noise ratios usually in the range of 55 to 65 dB, and on a single microwave hop, S/N performance is often 75 dB or better. The D2-type curve in Figure 5 shows that the S/D ratio never exceeds 38 dB, C-message weighted, but this does not mean that PCM systems operate at a great dB disadvantage with respect to FDM. The difference lies in that Figure 5 depicts the difference in dB between the *actual* instantaneous level of a sine-wave signal and the quantizing distortion level. In other words, the quantizing distortion varies with the signal; a signal level of 0 dBm0 and a signal level of

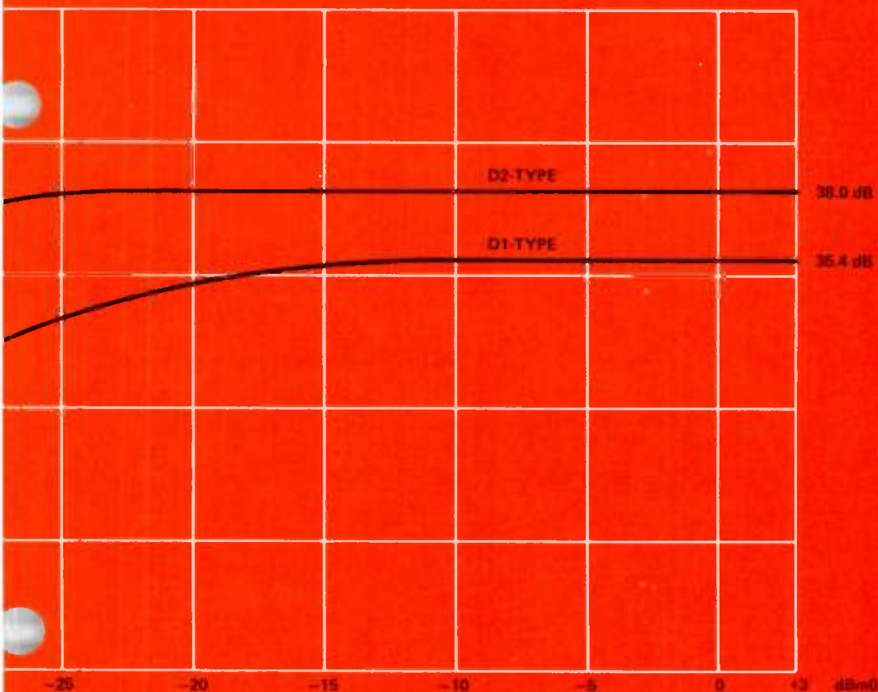


Figure 5. Theoretical signal-to-quantizing distortion ratios (S/D) for D2- and D1-type PCM terminals.

−30 dBm0, looked at separately, result in entirely different levels of distortion (the distortion varies with the signal in such a way that the S/D ratio remains approximately constant between +3 and −30 dBm0). The dB values obtained from Figure 5 are thus representative of the amount of quantizing distortion a talker will actually experience when talking over the system; S/D ratios of 20-30 dB are usually quite adequate.

In contrast, "S/N" in an FDM system nearly always means "test tone-to-noise" ratio *referenced to a test tone level of zero dBm (1 milliwatt) at the zero level point.* The noise in an FDM system is present all the time, whether there is a signal or not. It is only to a small extent dependent on signal level; the noise is practically constant over a wide range of signal levels. In such a system, a S/N performance of 65 dB means that the difference in level between test tone level (inserted with zero dBm level at the zero level point) and noise level is 65 dB. If a weak talker uses this FDM system at a signal level of −45 dBm0 (45 dB weaker than test tone) he will experience an "actual S/N ratio" of only 20 dB (65 dB − 45 dB = 20 dB). It is the obligation to provide satisfactory service to weak as well as loud talkers that requires provision of such wide margins in FDM systems.

Idle Noise and Interchannel Crosstalk

Improvement in signal-to-noise ratios at low signal levels is not the only advantage of a high value of μ such as 255 (as compared to μ = 100). Another advantage of a large μ value is a reduction in idle noise and interchannel crosstalk due to irregular excitation of weak-signal quantum steps.

The idle circuit noise – as well as the crosstalk into an idle channel from a channel with traffic – depends on several factors, but mainly on the quantization step sizes that correspond to very small voltage samples. One reason for this is due to the tolerance in the sampling process. Slight imperfections in the sampling circuitry may cause a small dc offset voltage at the input to the coder. This offset voltage may be large enough that a very small amount of noise or crosstalk can trigger the next (positive or negative) quantization step voltage. This produces an increase in noise or crosstalk. The magnitude of this increase is smaller when the steps are smaller. Idle circuit noise performance as well as interchannel crosstalk performance is improved for D2-type systems because of new circuit design, increased number of steps, and greater μ value (resulting in smaller step sizes) compared to the D1-type terminals.

Seeing that a higher value of μ gives certain advantages, why isn't an even higher value of μ (than μ = 255) selected? There are basically two reasons for this; one is that end-to-end compatibility with other US-manufactured PCM systems would not be possible and the other is that difficulty would arise in designing the appropriate equipment without excessive cost, still retaining the added advantage of a higher μ value.

There are several difficulties in implementing high μ values without adverse results. Some of these difficulties include:

(a) adhering to necessary tolerances while maintaining the reciprocal relationship between the non-linear characteristics of coder and decoder characteristics (between compressor and expander curves in D1-type terminals)

(b) keeping the dc component of the multiplexed signals to a low enough value so as not to offset the advantage of a high μ. To prevent these phenomena from canceling out the advantages gained by a high μ value, smaller, more costly, design tolerances are necessary.

Implementation of the Quantizing Characteristic

In a D1-type PCM terminal, the quantizing characteristic used has a value of μ = 100. This characteristic is achieved through the use of a diode compressor in the transmitter, followed by a uniform coder (giving equal quantizing steps). The end result of these compressing and coding processes is the same as if the quantizing had been implemented directly using unequal steps. The temperature sensitivity of diodes requires that they be mounted in an oven resulting in an increase of total power consumption.

In a D2-type terminal, the quantizing characteristic can be implemented in a non-linear coder through the use of a so-called "piecewise" linear coding process. The desired quantizing characteristic using μ = 255, is approximated by fifteen connected straight lines (covering fifteen different regions of input signal) of varied slopes, the slope of each line segment determining the step sizes in that particular range of input signals. More simply, the quantization curve, shown in Figure 4, and developed from equations A and B, is made up of 15 different connected lines, each with a particular slope. These 15 lines extend from the largest negative to the largest positive signal input voltage which can be sampled by a D2-type PCM terminal without excessive distortion. The result is better accuracy and less power consumption than when diode implementation is utilized.

CCITT and International Standards

The CCITT (International Telegraph and Telephone Consultative Committee) has adopted standards for PCM systems, distinguishing between so-called "primary" and "secondary" PCM multiplex equipment. Primary equipment multiplexes voice or data signals into time-multiplexed sequences of pulses and spaces, whereas a secondary multiplexer accepts several primary PCM pulse trains and multiplexes them into PCM pulse trains with a higher bit rate. Secondary multiplexers have been under development for some time but have only been put into limited service to date.

It would be desirable, from the point of compatibility, if there existed a single world-wide standard for both primary and secondary multiplexers. Although this has not as yet been possible, a step in that direction was taken when the CCITT agreed to recommend two types of primary systems as standards. The two systems standardized were a D2-type system and a European system for 30/32 channels (30 voice channels plus 2 channels for time-shared signaling) using a higher bit rate than the D2-type system. Whether further steps in world-wide standardization will be long or short in coming, only the future can tell. Meanwhile, the D2-type terminal exists as an improvement in the everchanging field of communications.

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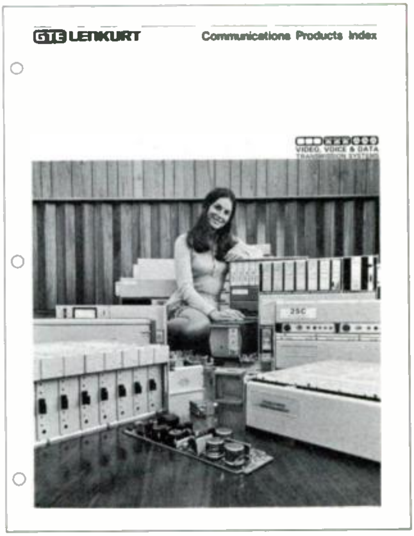

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