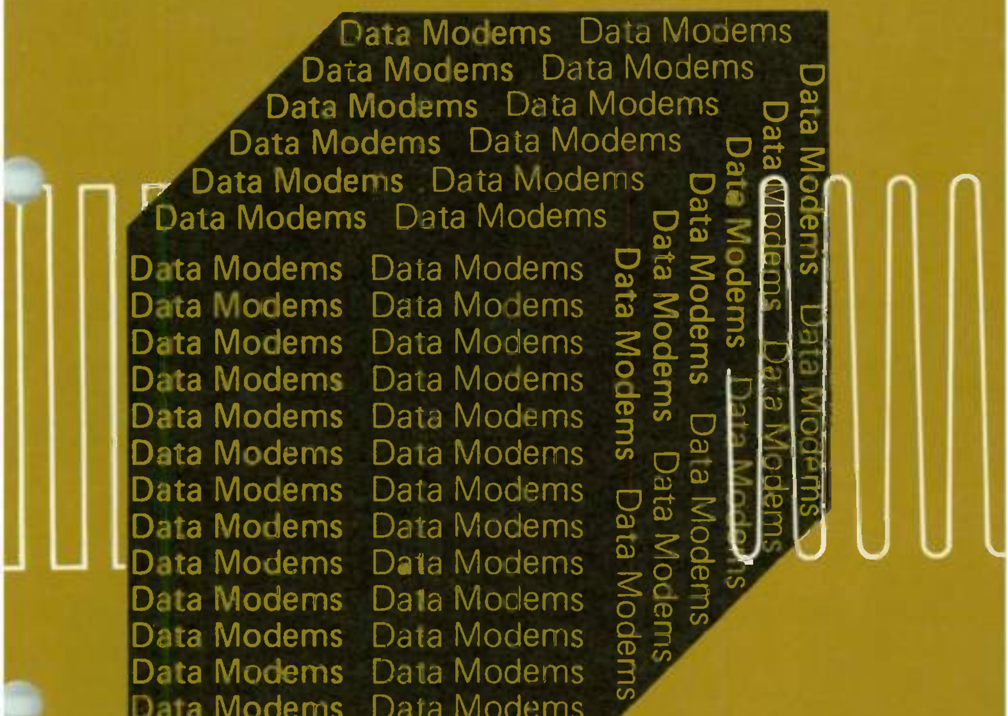
GTE LENKURT

# DEMODULATOR

OCTOBER 1971




**Modems . . . those unglamorous but vital "black boxes" that form the interfaces between digital machines and the communications network.**

Modems have been referred to as data sets, line adapters, modulators, or subsets. Regardless of the name used, the purpose of each of these black boxes is to convert digital pulses into analog signals, such as audible tones, suitable for transmission over the telephone network.

If two machines – such as computers, data terminals, or facsimile machines – are communicating via the telephone network, it is necessary to have a modem at each end of the line to act as the interface between the machine and the communications line. These black boxes must be capable of modulating and then demodulating the signals – hence, the contraction modem from *mo*dulate and *dem*odulate.

A pair of modems are considered "transparent" since the signals into the first (the input) are identical to the demodulated signals (the output) from the second modem. Figure 1 illustrates the position of the modems in a data link and the signals into and out of each element of the link.

The modem and the communications line can be connected directly (hardwire) or indirectly (acoustic or inductive coupling). Acoustically coupled modems are portable since they can be used with any available telephone. With acoustic coupling, the dc data signals are converted to audible sounds which are picked up by the microphone (or transmitter) in an ordinary telephone handset. The audible signal is converted to electrical signals, and transmitted over the telephone network. The process is reversed at the receiving end.

Inductive coupling, like acoustic coupling, requires no direct connection. With inductive coupling a data signal passes to the telephone through an electromagnetic field by way of a hybrid coil.

Acoustic/inductive couplers generally do not operate as reliably as direct electrically connected modems, because they involve an extra conversion step (for example, digital to audible to electrical) where noise and distortions may be introduced. For this reason acoustic/inductive modems are presently limited to transmission speeds below 1200 bps (bits per second).

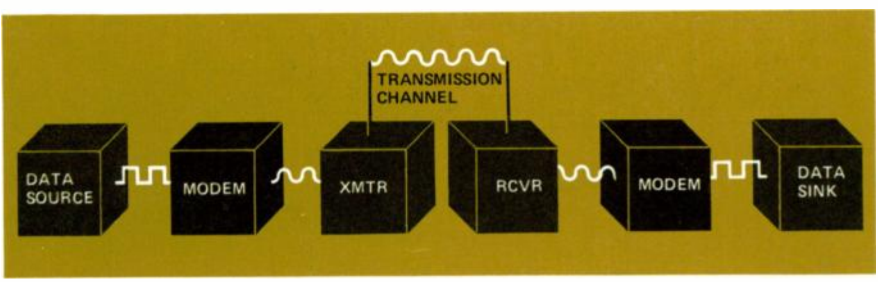



*Figure 1. A data link requires a modem on each end of the transmission channel.*

A direct hook-up to the communications channel, therefore, is preferable, since it is less error-prone and not limited to low speed transmission.

## Asynchronous or Synchronous

Having connected the digital machine to the communications line it is necessary to coordinate the data received with the data sent. This coordination or synchronization can be accomplished in two ways. If start and stop bits are used to "frame" each character, the transmission is asynchronous. Synchronous modems require the use of clocking devices which lock the transmitted signal of the modem and the terminal device together at a fixed transmission rate.

High-speed data generally uses synchronous transmission since for identical data coding levels and transmission bit speeds, a higher data speed can be achieved. Asynchronous transmission requires the use of two or three start- and stop-bits for each character depending upon the type of machine generating the digital signal. Consequently, if an eight-bit code is being used, asynchronous transmission requires 10 or 11 bits per character and synchronous requires only 8. Synchronous modems can therefore transmit at least 25% more characters than asynchronous modems at the same bit speed (see Figure 2).

Although synchronous transmission is efficient, the clocking mechanism requires added circuitry which makes the equipment more costly than asynchronous modems for the same speed.

Asynchronous modems have a specified maximum transmission speed, but they can be used to transmit data at any speed up to this maximum. Asynchronous modems are used for low- and medium-speed transmission up to approximately 1800 bps.

High-speed modems, on the other hand, are intended for synchronous operation at a fixed transmission rate. The transmission speed of a synchronous modem is established by the clocking source which is generally a crystal oscillator. If a synchronous modem has more than one speed, the speeds are generally multiples of the oscillator frequency.

## Parallel or Serial

Another way to classify data modems is according to the type of bit stream used – parallel or serial. Figure 3 illustrates the difference between serial and parallel bit streams. Serial bit streams are most commonly used since the digital information can be modulated as it comes from the digital machine. As long as sufficient bandwidth is available for transmission without degradation, a serial bit stream may be used.

If, however, transmission is to take place over bandwidths which do not have uniform transmission characteristics, a serial bit stream can be converted to a parallel bit stream. At the receiver, a parallel-to-serial conversion

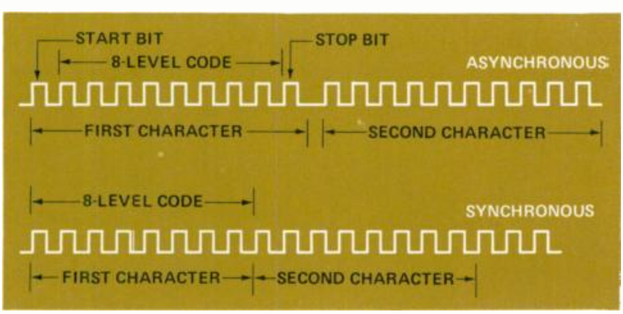



*Figure 2. Each character is at least 25% longer with an asynchronous system than with a synchronous system.*

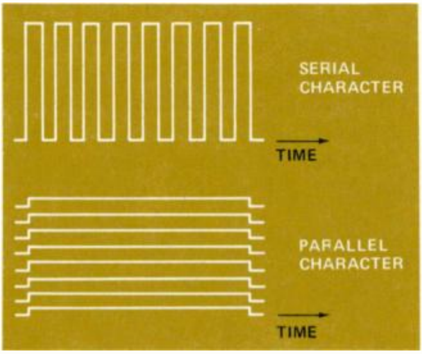



*Figure 3. With parallel transmission, longer bits are used to transmit the same amount of data in a given period.*

takes place. This technique is often used to transmit data at 4800 bps and higher over a voice channel.

Parallel channels with their longer symbols provide better correlation of fade and phase factors and multipath delay distortion in the propagation medium – radio or cable. (See September, 1970, *Demodulator* for discussion of transmission impairments.) However, the complex circuitry for parallel transmission makes parallel modems more costly. They are also less efficient since bandwidth is used for flanking of the bandpass filters in each channel. For these reasons serial modems have been accepted as an industry standard.

## Modulation

Modems can also be classified according to the analog signal generated in the D/A (digital to analog) conversion. These analog signals may be amplitude, frequency, and phase modulated. Four types of modulation are used extensively in digital data transmission: amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), or AM combined with either FM or PM.

With an AM modem, the sinusoidal carrier wave is varied in amplitude to correspond to the digital information being transmitted. Upper and lower sidebands equal to the carrier plus the modulating signal and the carrier minus the modulating signal, respectively, occupy a total bandwidth of twice the modulation rate (see Figure 4). The entire double-sideband AM signal, a single-sideband AM signal, or a vestigial-sideband AM signal can be transmitted depending upon how the signal is processed at the receiving end.

In single-sideband only, one sideband is transmitted with or without the carrier, and the required transmission bandwidth is only half that required by double-sideband AM. But, if it is necessary to transmit a dc component for signal processing, vestigial-sideband AM must be used – transmitting the wanted sideband, part of the carrier, and the low frequency end of the unwanted sideband.

Single-sideband AM gives the best bandwidth economy, but not the best equipment economy. The filtering necessary for single-sideband AM is difficult to achieve; consequently, the technique is used primarily for high-speed data transmission over a band-limited channel where the advantages outweigh the disadvantages.

Vestigial-sideband AM systems require a bandwidth approximately 1.3 times that required for single-sideband AM systems, and the technique is typically used in data modems operating at speeds of up to 7200 bps over voice-grade lines.

In AM transmission the amplitude of the carrier is varied but with FM transmission the carrier frequency varies proportionally to the instantaneous value of the modulating signal – the data bit stream. When transmitting binary data, the frequency of the transmitted wave shifts between two discrete values (determined by the channel bandwidth), one representing binary one and the other, binary zero. This is a double-sideband system called frequency shift keying (FSK) and re-

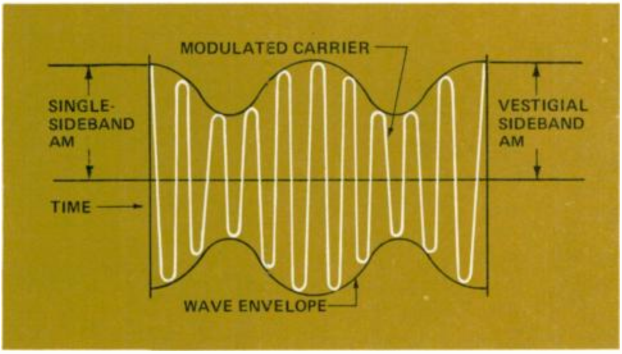



*Figure 4. The wave envelope is the same as the modulating data signal. The bandwidth of the double-sideband AM signal is twice the bandwidth of the modulating signal.*

quires approximately the same bandwidth as double-sideband AM.

For phase modulation the phase of the transmitted carrier varies proportionally to the instantaneous value of the modulating signal. For binary data transmission the phase is shifted 180° for each transition between one and zero, or zero and one. Phase shift keying (PSK) is extensively used for synchronous high-speed data transmission systems up to 2400 bps. However to transmit at 2400 bps and above, it is necessary to resort to a four-phase system utilizing 90° shifts. PSK, like FSK, is a double-sideband system.

In a special form of FSK called duobinary, FSK modulation is used in conjunction with duobinary coding which uses a three-level code to represent the binary data. The duobinary coding technique, developed at GTE Lenkurt, is used in the GTE Lenkurt 26C data modem. Assuming a constant bandwidth data channel, duobinary FSK transmits at twice the speed of FSK. Figure 5 shows the difference between FSK and duobinary FSK.

Factors to consider when selecting a modulation scheme are complexity of electronic circuits, required bandwidth, quality of transmission channel, signal-to-noise ratio, tolerance to delay distortions, tolerance to amplitude changes, tolerance to jitter, and reliability. Each system has some advantages relative to the other systems.

## Compared to Voice Band

Another way to classify modems is by their required transmission bandwidth. Modems can be divided into three categories: sub-voice, voice, and greater-than-voice band (or wideband). The chart in Figure 6 relates bandwidth to transmission speed, and illustrates that transmission speed is generally proportional to bandwidth.

Sub-voice band modems use only a fraction of the 4-kHz voice band for each data channel. These modems generally serve slow digital devices with speeds of up to 600 bps. Frequency division (FDM) or time division (TDM)

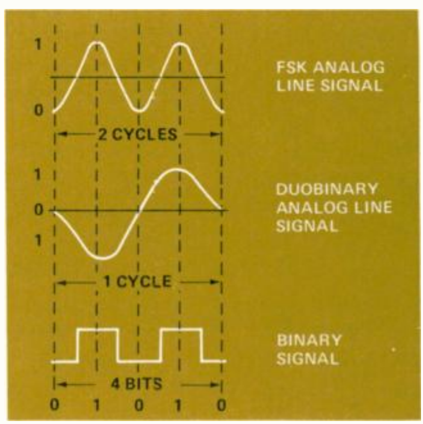



*Figure 5. Duobinary FSK transmission is twice as fast as FSK transmission showing four binary bits compressed into one cycle of the line signal.*

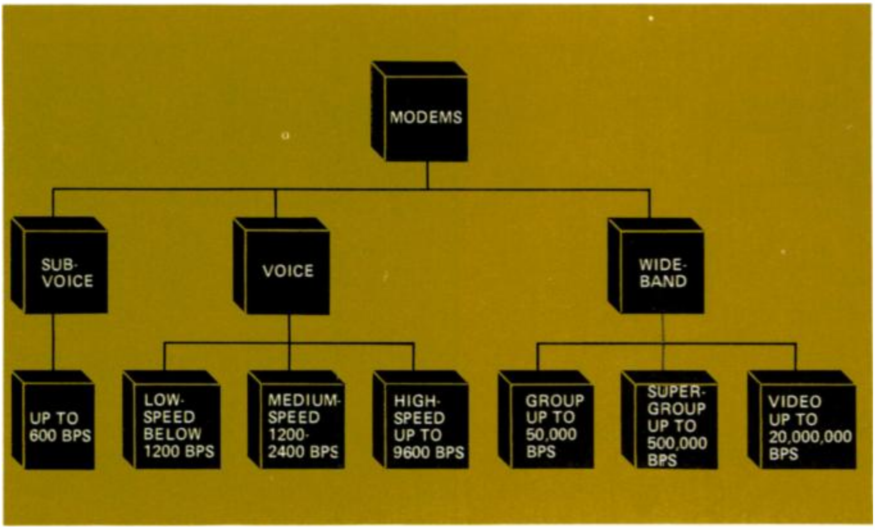



*Figure 6. Bandwidth and transmission speed are generally related as shown in this chart – the wider the bandwidth, the higher the speed.*

multiplex techniques are used to fill the voice band. With FDM, a multiplexer is not needed because the modem conditions the data signal for transmission in its proper frequency slot on the telephone line – the signal is in essence frequency modulated and translated. GTE Lenkurt's 25C data modem performs such a multiplexing function. But, with TDM, a multiplexer combines the digital signals in time. This new high-speed, serial bit stream then goes to a modem for digital to analog conversion and transmission over the telephone circuit. Figure 7 illustrates the difference between FDM and TDM systems.

FDM and TDM are equally suitable for voice grade channels. However, TDM is more efficient in bandwidth utilization; therefore, more channels can be multiplexed on a single channel. Conversely, FDM is best suited where few circuits are dropped off and picked up at scattered points, and where the greater reliability of individual channel modems is desired.

Since voice band modems range in speed from as low as 300 up to 9600 bps or higher, they are not defined as much by speed as by the facility and means of transmission. Voice band data is the most efficient means of utilizing the telephone network.

Satisfactory modem performance at 3600 bps and above generally requires complex equalization circuitry to precondition the signal for non-linear or varying line parameters – such as delay distortion and attenuation. Some high-speed modems, generally used over leased lines with relatively constant characteristics, use manually adjusted equalizers. Other high-speed modems use automatic or adaptive equalizers to continually adjust to the line characteristics.

Medium-speed voice band modems operating in the 1200- to 2400-bps range have been in general use for over ten years and have achieved a degree of reliability and low-error performance adequate for most data transmission applications. Most of these medium-speed modems tolerate or pre-condition the signal for minor changes in telephone line characteristics without error or interruption of

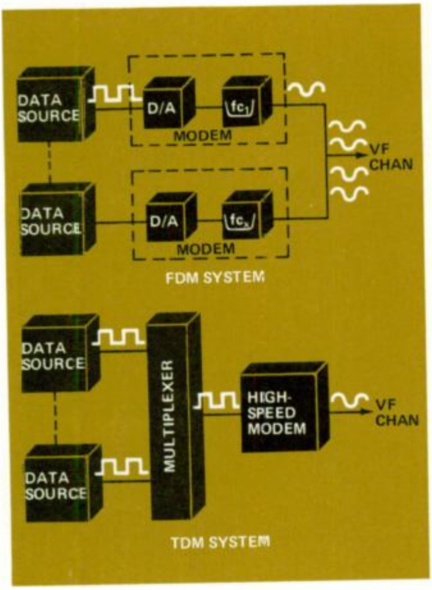



*Figure 7. A time division multiplex system requires the use of a multiplexer and a modem.*

transmission. Medium- to high-speed modems at 4800, 7200, and 9600 bps are finding wider use as transmission speeds continue to increase.

The telephone network is designed such that when the signal bandwidth exceeds one voice channel, the next transmission channel has a group bandwidth or supergroup bandwidth – equivalent to 12 or 60 voice channels. Greater-than-voice band or wideband modems operate at speeds from 18,750 to 500,000 bps. Top speed is presently limited by the expense of leasing wider bandwidths and the limited need to move much larger volumes of data at these rates.

Wideband modems are not true modems since they do not contain a modulator or demodulator, but they do condition a digital signal for transmission over the telephone network. In wideband data sets, the digital signal is first put through a scrambler which inverts every other pulse to eliminate sustained intervals of ones or zeros that might create an undesirable dc component in the line. Next the signal is filtered to remove low- and high-frequency components. The result is an ac signal which, for 50,000 bps data, has a 25-kHz fundamental frequency – since two bits complete a cycle, the fundamental frequency is half the bit rate. There is no need to translate the wideband signal in frequency, as there is for sub-voice and voice band modems.

This ac signal readily passes through transformer-coupled circuits and over non-loaded physical cable pairs with reasonable equalization and amplification. The signal can also be fit into a twelve-channel bandwidth for analog exchange and trunk carrier systems.

High-speed modems may be frequency division multiplexed to put a number of them in parallel on a single wideband circuit.

The great advantage of digital transmission via wideband systems is that high data transmission rates may be obtained while keeping the data stream in serial form. In the multiplexing equipment it is not necessary to come down to the nominal voice channels (4-kHz), but the serial data streams may be modulated on a group bandwidth (48-kHz) with a data rate capability of 50,000 bps, or a supergroup bandwidth (240-kHz) at up to 500,000 bps.

## All-Digital Network

All-digital transmission networks which would not require data modems are being designed, developed, and tested, but it will be a long time before the sub-voice and voice band data systems requiring modems are eliminated from the telephone network – if they ever are.

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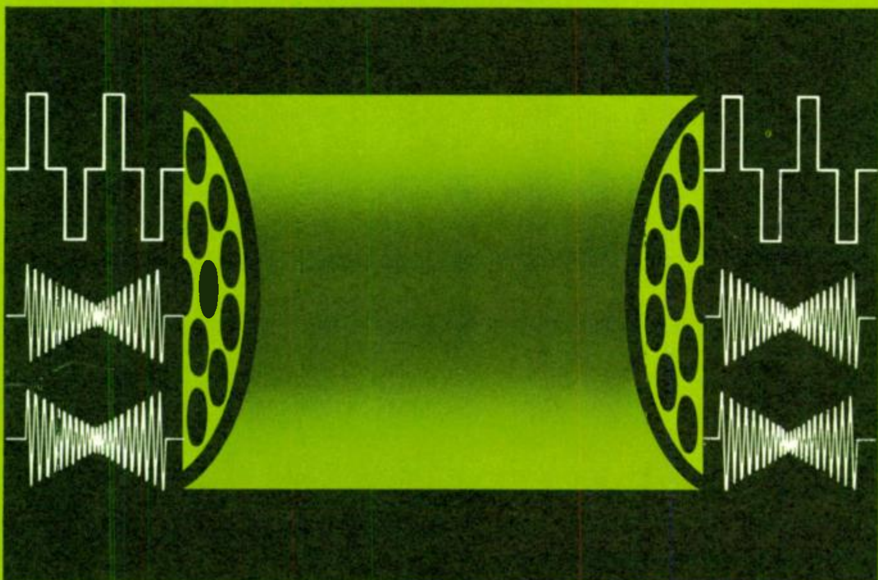
GTE LENKURT

# DEMODULATOR

SEPTEMBER 1971

## PCM-FDM Compatibility Part 3



Subjection of an FDM system to interference from PCM signals is the major factor which discourages the user of communications equipment from placing PCM and FDM systems in the same cable sheath. By giving careful consideration to direction coordination of cable, and by evaluating the effects of PCM to FDM crosstalk, single-tone interference, and length of repeater sections, the user may find his FDM system compatible with PCM without extensive modifications.

Parts I and II of the PCM-FDM compatibility series dealt with the empirical and theoretical aspects of PCM and FDM systems which lie in the same cable sheath. Some of the factors influencing the amount of interference between these two types of systems are crosstalk coupling loss, length of exposure of FDM to PCM, the frequency band occupied by the FDM system, and the type of PCM signaling utilized. The discussion of these subjects brings to light a way of evaluating the amount of interference which the FDM system receives from the PCM system.

A series of steps may be taken to evaluate the possibility of compatibility between PCM and FDM systems which operate on pairs within the same cable sheath. To demonstrate how this series of steps can be useful to the communications equipment user, an example is given in this issue (using a hypothetical PCM-FDM combination) on the process of estimating the minimum crosstalk coupling loss required if two systems are to be compatible.

The example for crosstalk evaluation will employ a GTE Lenkurt 24-channel 91A PCM system (D1/T1-type) equipped for D1A signaling and a GTE Lenkurt 47A (an N-type FDM system) equipped with compandors. The calculations are valid for any D1/T1-type PCM system and any N1 or N2-type FDM system.

The 47A is a 12-channel, double-sideband, amplitude-modulated carrier system which operates over two cable pairs, one for each direction of transmission. It is end-to-end compatible with Western Electric N1 or N2 systems (depending on the option of 47A used). Compandors are optional for these systems. On any section of the cable, the two directions of transmission utilize different frequency line groups. The low-frequency group extends from 40 to 128 kHz and the high-frequency group from 176 to 264 kHz as shown in Figure 1. In each repeater there is a modulator which shifts the signal from one band to the other (frequency frogging) in order to combat near-end crosstalk.

For this example it is assumed that maximum-length repeater section lengths are used for the 47A system (40 dB at 176 kHz) and that end sections (or any sections adjacent to a telephone switching office) do not exceed 25 dB at 176 kHz. The 40-dB value is the maximum allowable power loss over an intermediate repeater section where little interference will be encountered from external sources; for this discussion an intermediate repeater location not at a switching center will be referred to as a "low-noise point." The 25-dB value is the maximum allowable power loss over a repeater section adjacent to an office (an end section, for example). At an office the repeater is subject to interference from office switching equipment; for this discussion offices will be referred to as "high noise points." For 22-gauge PIC (polyethylene insulated

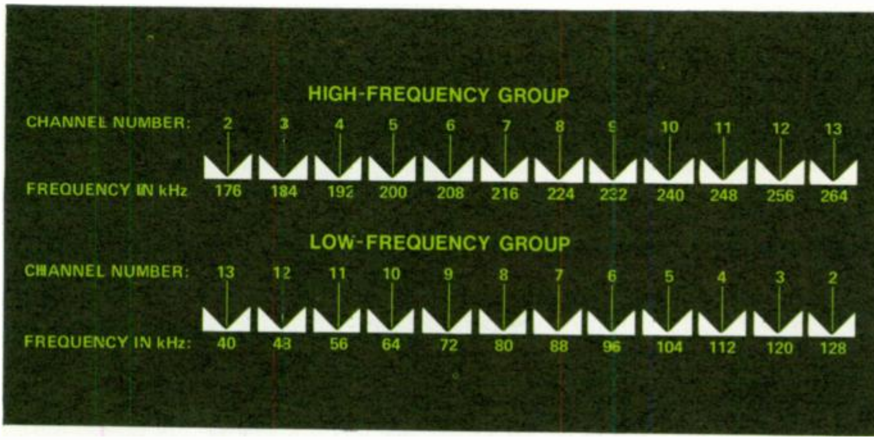



*Figure 1. Frequency designations for the GTE Lenkurt 47A FDM System. Channel 1 (not shown) is an optional channel which is seldom used due to performance limitations at that frequency although it may be used in lieu of any of the other available channels.*

cable) with a capacitance of 0.083 μF per mile, the 40- and 25-dB values correspond to repeater section lengths of 3.88 miles and 2.42 miles, respectively. The loss at 772 kHz (the loss at this frequency determines the PCM repeater spacing) is 90 dB over a 3.88-mile section of such cable. Assuming that the PCM intermediate repeater sections are exactly one third of the 47A repeater section (this corresponds to 30 dB at 772 kHz), that the 47A repeater locations within the section exposed to PCM interference always coincide with a PCM repeater point, and that the exposure to PCM occurs over three 47A intermediate repeater sections plus one end section, the system layout will appear as in Figure 2.

## Noise Interference

The interference from a PCM system consists either of noise or single-tone interference depending on the traffic loading of the PCM system and the noise level at each PCM terminal. The first consideration will be that of noise interference from a traffic-loaded PCM system.

The near-end crosstalk interference from a PCM system to an FDM system is shown in Figure 2 by the green arrows which indicate the near-end crosstalk paths of importance. The interference from PCM is most severe at the high-level outputs of the PCM repeaters (regenerators). However, the only near-end crosstalk of importance occurs on the PCM repeater sections adjacent to FDM repeater receive-inputs, as the green arrows in Figure 2 indicate. This is because the level of the received signal on the FDM system is the lowest and most noise-sensitive at that point. The PCM to FDM near-end crosstalk originating on PCM repeater sections not adjacent to an FDM repeater receive-input will be attenuated by 10 dB or more before reaching the FDM repeater input and can be neglected.

The allowable degradation of noise performance in the 47A system has been chosen such that the presence of PCM carrier interference should not cause the noise performance to deteriorate to worse than 27 dBrnc. This is one dB worse than the worst line-up

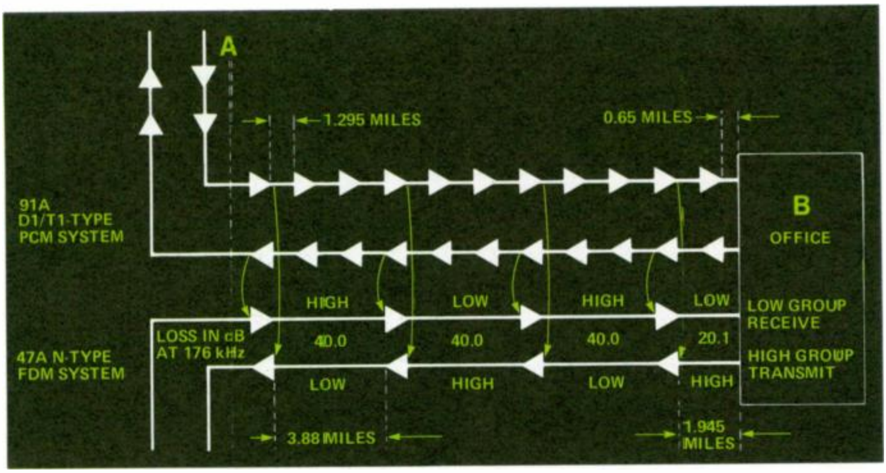



*Figure 2. PCM-FDM combination showing three intermediate repeater sections and one end section of the FDM system exposed to PCM interference.*

noise performance allowed for a long distance 47A system without PCM interference (26 dBrnc). Based on this requirement, the total noise contribution originating from PCM carrier systems must not exceed 20 dBrnc, since by dB addition laws, 26 dBrnc + 20 dBrnc = 27 dBrnc. The dBrnc unit is used to measure absolute noise and from the conversion table shown in Figure 3, a 20-dBrnc value converts to 100 pW psophometrically weighted (100 pWp).

A performance requirement of 20 dBrnc for PCM interference corresponds to an FDM signal-to-PCM interference noise ratio (test tone-to-PCM interference noise ratio) of 68 dB (as shown in Figure 3). The expression "signal-to-noise ratio" generally used in FDM system terminology actually means test tone-to-noise ratio since it refers to a test tone which is injected into the system from a signal generator for measurement purposes. At test tone level, a 47A non-compressed carrier is amplitude-modulated with a modulation index of 0.35 (35 percent). This 35% value was chosen in the initial system design to avoid exceeding 100 percent modulation at even the highest speech volumes.

Figure 4 shows the relationship between carrier and test tone signals in one channel of an FDM system. In order to solve for unknown noise levels a meaningful relationship must be established between the carrier-to-noise and signal-to-noise ratios. For this non-compressed, double-sideband, amplitude-modulated, 47A FDM system, in which a test tone modulates the carrier 35 percent, the following equation is true:

Equation 1

$$\left(\frac{C}{N}\right)_{6.2\text{ kHz}} = \left(\frac{S}{N}\right)_{3.1\text{ kHz}} + 9\text{ dB}$$

where C/N stands for FDM carrier-to-PCM interference noise ratio (where the carrier is at one specific frequency and the PCM noise is over 6.2 kHz) and S/N for FDM test tone-to-PCM interference noise ratio, with reference to the voice frequency drop point. The 3.1-kHz value, corresponds to the usable sideband bandwidths in a voice channel. Since the 47A uses double

| dBrnc | pWp | S/N (dB) |
|---|---|---|
| 6 | 4.0 | 82 |
| 7 | 5.0 | 81 |
| 8 | 6.3 | 80 |
| 9 | 8.0 | 79 |
| 10 | 10.0 | 78 |
| 11 | 12.6 | 77 |
| 12 | 15.9 | 76 |
| 13 | 20.0 | 75 |
| 14 | 25.1 | 74 |
| 15 | 31.6 | 73 |
| 16 | 39.8 | 72 |
| 17 | 50.0 | 71 |
| 18 | 63.0 | 70 |
| 19 | 79.5 | 69 |
| 20 | 100.0 | 68 |
| 21 | 126.0 | 67 |
| 22 | 159.0 | 66 |
| 23 | 200.0 | 65 |
| 24 | 251.0 | 64 |
| 25 | 316.0 | 63 |
| 26 | 398.0 | 62 |
| 27 | 500.0 | 61 |
| 28 | 630.0 | 60 |
| 29 | 795.0 | 59 |
| 30 | 1000.0 | 58 |
| 31 | 1260.0 | 57 |

All units are given with reference to test tone level of zero dBm.
dBrnc – C-message weighted.
pWp – Picowatts psophometrically weighted.

*Figure 3. Noise measurement conversion table.*

sideband operation, each carrier is associated with noise interference over a bandwidth of 6.2 kHz. Equation 1 states that carrier-to-noise is equal to the signal-to-noise + 9 dB.

The maximum allowable noise performance for a GTE Lenkurt 47A system is 26 dBrnc. In a case where the repeater sections are of acceptable lengths and good cable and line-up procedures are used, the noise performance will usually be much better than 26 dBrnc. However, this discussion will proceed as if the noise performance on the system was at the 26-dBrnc point (worst case) before the addition of PCM interference. In order to allow for this PCM interference, one additional dB of interference will be accepted which will make the total noise performance 27 dBrnc. For this discussion the 20-dBrnc value will be regarded as the total noise interference to the FDM system although it must be remembered that a 26-dBrnc noise value *does* exist in addition to the 20 dBrnc.

The 20-dBrnc PCM noise requirement previously calculated corre-

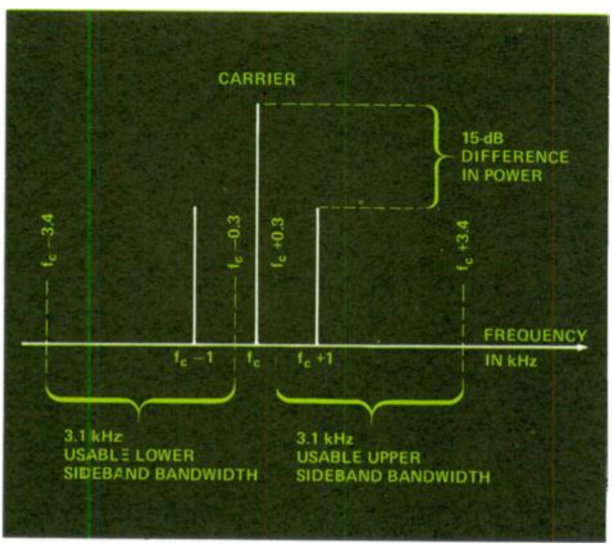



*Figure 4. When a carrier of frequency $f_c$ is modulated by a sinusodial 1-kHz test tone, sideband frequencies appear at frequencies ($f_c$−1) kHz and ($f_c$+1) kHz. Each one of these two sideband frequency components are of a power level 15 dB below the level of the carrier. This is based on the test tone modulating the carrier with a modulation index of 0.35 (such as in a non-compandored 47A system).*

sponds to an FDM signal-to-PCM interference noise ratio of 68 dB, and thus converts to a requirement for FDM carrier-to-PCM interference noise ratio of:

$$\left(\frac{C}{N}\right)_{6.2\ \text{kHz}} = \left(\frac{S}{N}\right)_{3.1\ \text{kHz}} + 9\ \text{dB}$$

$$\left(\frac{C}{N}\right)_{6.2\ \text{kHz}} = 68 + 9\ \text{dB}$$

$$\left(\frac{C}{N}\right)_{6.2\ \text{kHz}} = 77\ \text{dB; (non-compressed).}$$

For this discussion a compandor will be inserted in accordance with the original conditions at the beginning of this example. This produces a 20-dB compandor advantage and results in a requirement of:

$$\left(\frac{C}{N}\right)_{6.2\ \text{kHz}} = 57\ \text{dB (compressed).}$$

The carrier with the lowest power level will differ in level and frequency depending upon the 47A repeater section length and whether the low-group or the high-group is being observed. Levels will thus be different on repeater sections adjacent to switching centers (as in end sections) compared to intermediate sections adjacent to low-noise points. If the spacing rules for N-type carrier are adhered to (end-sections not to exceed 25 dB at 176 kHz, intermediate sections not exceeding 40 dB), the lowest carrier levels on a 47A system have been calculated to be approximately:

(a) At a high-group repeater input at the high-frequency end of the band (264 kHz) . . . . –48 dBm

(b) At a low-group repeater input at the high-frequency end of the band (128 kHz) . . . . –42 dBm

(c) At a high- or low-group repeater input or terminal input located in or adjacent to a switching center . . . . . . . –28 dBm.

These "lowest" FDM carrier power levels are significant when evaluating PCM to FDM interference since it is at these levels that an interfering PCM system will have the greatest effect on FDM. It is assumed throughout the following calculations that the spacing rules quoted above were followed when laying out the N-type carrier system.

A repeater input on a section adjacent to a switching center is at least 14 dB less sensitive to PCM interference than other intermediate sections due to its shorter length (compare values –28 dBm versus –42 dBm and –28 dBm versus –48 dBm). End-sections and other sections adjacent to high-noise points can thus be neglected for the purpose of these interference calculations if there are at least as many normal (adjacent to low-noise points) intermediate 47A repeater sections in the section being exposed to PCM interference as there are 47A repeater sections adjacent to high-noise points. The approximation error thus incurred is no more than 0.2 dB.

If a 47A carrier system is exposed to PCM interference over several intermediate sections (as in this example), about half the number of sections exposed (for any direction of transmission) are high-group sections and half are low-group sections. Consideration must therefore be given to the relative effects of interference into these two groups.

## High-Group Repeater Input

The minimum FDM carrier-to-PCM noise ratio requirement has been calculated to be 57 dB (68 dB + 9 dB – 20 dB = 57 dB). The lowest power level (this is the worst acceptable case condition) of the highest-frequency carrier (at 264 kHz) is –48 dBm as previously mentioned. The maximum allowable noise level due to PCM carrier interference in the 47A FDM system is then calculated as follows:

$$\left(\frac{C}{N_{max}}\right)_{6.2\ kHz} = 57\ dB.$$

By virtue of the fact that C is –48 dBm in the worst case, and that the dB division rules state that division of two values effectively means subtraction of these values when expressed in dB form, it follows that,

$$-48\ dBm - \left(N_{max}\right)_{6.2\ kHz} = 57\ dB$$

$$\left(N_{max}\right)_{6.2\ kHz} = -48\ dB - 57\ dB$$

$$= -105\ dBm$$

or

$$\left(N_{max}\right)_{3.1\ kHz} = -108\ dBm$$

where $N_{max}$ is the maximum allowable noise level in the 6.2-kHz or 3.1-kHz slots at 264 kHz. Dividing the bandwidth by 2 makes the requirement more severe by 3 dB and hence, $N_{max}$ in a 3.1 kHz slot becomes –108 dBm.

The noise power in a 3.1 kHz slot centered at 264 kHz of the PCM system is –17 dBm according to the power spectrum curve of Figure 5. The difference between –17 dBm and –108 dBm is 91 dB. This would be the requirement for near-end crosstalk coupling loss at 264 kHz between PCM and FDM cable pairs in this example if the following were true:

(a) The effect of far-end PCM to FDM crosstalk could be neglected

(b) Only one PCM system interfered with the FDM system

(c) Only one 47A repeater section were exposed to PCM interference.

Also, the effects of single-tone interference have been neglected up to this point but will be covered in following paragraphs along with the effects of a PCM system interfering with more than one FDM repeater section.

## Low-Group Repeater Input

The lowest power level of the highest-frequency carrier (at 128 kHz) as previously stated is –42 dBm. A carrier-to-PCM noise requirement of 57 dBm thus corresponds to a maximum allowable noise level, due to PCM interference, of:

$$\left(N_{max}\right)_{6.2\ kHz} = -42\ dBm - 57\ dB$$

$$= -99\ dBm.$$

This value is derived from the subtraction of the carrier-to-noise level (57 dB) from the lowest carrier level (–42 dBm).

or

$$\left(N_{max}\right)_{3.1\ kHz} = -102\ dBm$$

where $N_{max}$ is the lowest allowable noise level in the 6.2-kHz or 3.1-kHz slots at 128 kHz. Dividing the bandwidth by 2 makes the requirement more severe by 3 dB and hence it becomes –102 dBm.

The maximum allowable level of PCM interference is thus 6 dB (108 dB – 102 dB = 6 dB) greater (less severe) at a low-group intermediate repeater input than at an input using the high frequency line-group. Also, the noise power in a 3.1-kHz slot centered at 128 kHz (the highest carrier frequency in the low group) of the interfering PCM signal is 6 dB lower than in such a slot centered at 264 kHz (–23 dBm compared to –17 dBm as shown in

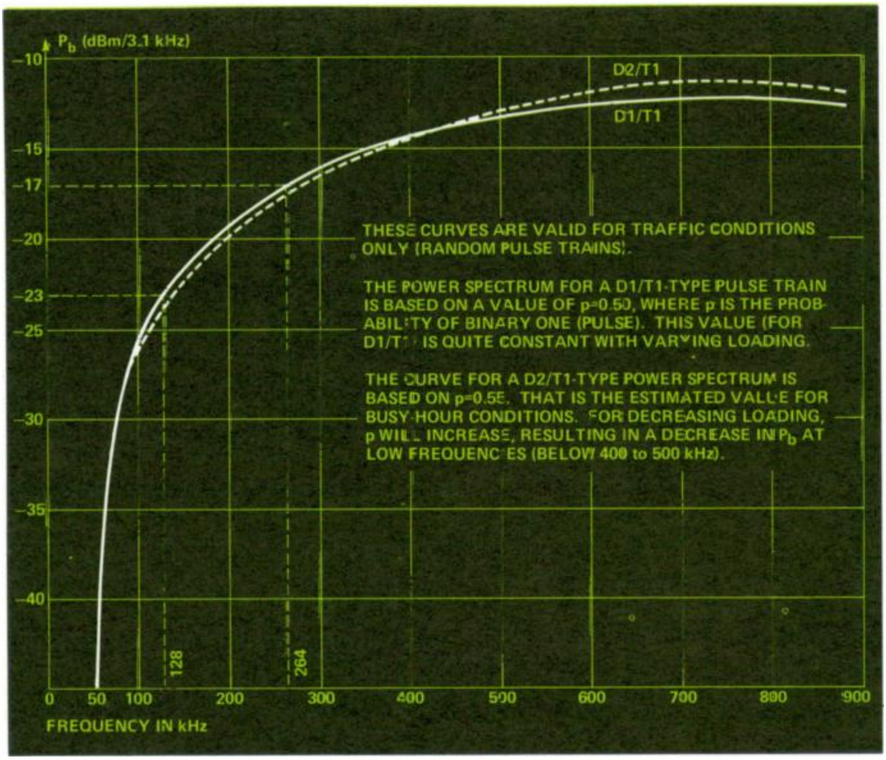



*Figure 5. Power Spectrum of a T1-type PCM pulse train under traffic conditions at the output of a regenerator.*

Figure 5). A low-group intermediate repeater input is thus 12 dB less sensitive to interference from a PCM system with traffic than such an input using the high line-group (due to two 6-dB advantage factors).

Based on the above calculations, it can be concluded that only the high-group intermediate repeater inputs, being the ones most sensitive to interference, are going to determine the required value of near-end or far-end crosstalk coupling loss between PCM and FDM cable pairs. Therefore, in this example the effects of all low-group repeater inputs may be neglected. The error incurred by this approximation does not exceed 0.5 dB provided that the section of the 47A system exposed to PCM interference contains more than one intermediate 47A repeater section.

## PCM Noise Conclusion

For this example, in the A to B direction of transmission shown in Figure 2, two high-group intermediate repeater sections are exposed to PCM interference. Had only one such section been exposed, the near-end crosstalk coupling loss requirement would have been 91 dB at 264 kHz. Since there are two exposed high-group intermediate FDM repeater sections, the requirement is 91 + 10 log 2 dB, or 94 dB, for near-end crosstalk coupling loss at 264 kHz. This is based on one interfering PCM system and the length of its exposure to the FDM system as shown in Figure 2.

The value of 94 dB for near-end-crosstalk coupling loss is based on total PCM to FDM noise crosstalk contributions. The assumption is made here that near-end crosstalk contributions will be much more likely to cause interference than the contributions of PCM to FDM interference due to far-end crosstalk. If this assumption cannot be made, half of the crosstalk contribution can be assigned to near-end crosstalk (making that requirement 3 dB more severe, or 97 dB), and half to far-end crosstalk. The requirements for coupling losses between PCM and FDM cable pairs are then as follows:

(a) Near-end crosstalk coupling loss requirement at 264 kHz is 97 dB

(b) Far-end crosstalk coupling loss requirement at 264 kHz (as measured over one PCM repeater section length) is (97 – C dB), where C is the loss in dB at 264 kHz of the cable pair over one PCM repeater section length.

In the B to A direction of transmission shown in Figure 2, there is only one intermediate high-group repeater section exposed to PCM interference that is not adjacent to a high-noise point. For simplicity, this example has considered only the worst direction of transmission (the A to B direction).

## Single-Tone Interference

The next problem to consider is that of single-tone near-end interference (between opposite directions of transmission) from the PCM system into the 47A FDM system. Figure 6 shows that the only frequency of concern in this case is 193 kHz (D1A-type signaling, and highest frequency in the FDM system of 264 kHz).

An interfering tone at 193 kHz will fall at the 1-kHz point (1 kHz on one side of the carrier) in the upper sideband of Channel 4 of the high group of the 47A system (see Channel 4, Figure 1). The maximum allowable level of such a 1-kHz tone is set to –70 dBm0, that is, 70 dB below test tone level. This is consistent with previous assumptions since this corresponds to 100 pWp at the zero-level test-tone point. The maximum allowable PCM noise level in the previous calculations was 20 dBrnc, which corresponds to 100 pW psophometrically weighted (see Figure 3). It should be remembered that the PCM to FDM interference occurs *either* as noise *or* single-tone interference, never both types simultaneously.

In this case (D1A-type signaling) only the high-group repeater inputs are of interest, since the interfering tone falls within the high-group frequency range. End sections or repeater sections adjacent to high-noise points can be disregarded as before if the length of the 47A system section being exposed to PCM interference contains at least as many normal (adjacent to low-noise points) intermediate 47A repeater sections as there are 47A repeater sections adjacent to high-noise points.

The lowest carrier level encountered at a high-group repeater input is –48 dBm, in accordance with the value used earlier in this example. This value is for the highest-frequency carrier (Channel 13) at 264 kHz. For Channel 4, the lowest level encountered is –41 dBm. Since in a 47A system without compandors the level of each sideband of a test tone is 15 dB below the carrier level (see Figure 4), the lowest such sideband level encountered is –56 dBm (–41 dBm – 15 dB). The interfering tone must be at least 70 dB below that, in other words, less than –126 dBm.

For the 47A system in this discussion, the compandor advantage allows

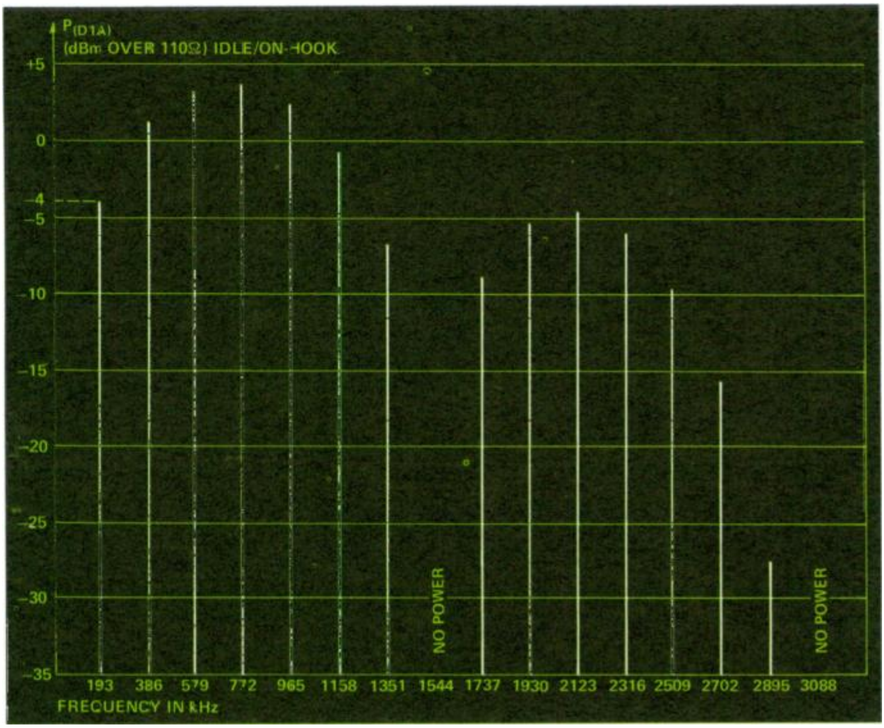



*Figure 6. The line power spectrum which results in a D1-type terminal under idle/on-hook conditions when D1A (D1/D8) signaling is used.*

this requirement to be relaxed by 20 dB to −106 dBm.

The level of the 193-kHz tone of an idle PCM system with D1A-type signaling is −4 dBm as shown in Figure 6. The difference between −4 dBm and −106 dBm is 102 dB. The requirement for near-end crosstalk coupling loss at 193 kHz between PCM and FDM cable pairs thus becomes 102 dB per exposed high-group 47A intermediate repeater section. Since there are two such sections exposed in the A to B direction of transmission as shown in Figure 2, this requirement becomes 105 dB (102 + 10 log 2 dB = 105 dB) for this direction. (The requirement for the other direction is 3 dB less, but for simplicity only the worst case will be considered here.) This 105-dB value is based *only* on single-tone interference and on the assumption that the following additional circumstances are true:

(a) the effect of far-end PCM to FDM crosstalk can be neglected

(b) only one PCM system is involved.

If far-end PCM to FDM crosstalk can for some reason not be neglected, 3 dB should be added to the requirement above. This new value (108 dB at 193 kHz) becomes the new near-end crosstalk requirement; (108-D) dB is the far-end crosstalk requirement as measured over one PCM repeater section length. (D is the loss in dB of the cable pair at 193 kHz over one repeater section length of the PCM system.) This assumption effectively assigns half of the single-tone interference to near-end crosstalk and half to far-end crosstalk contributions.

## Overall Conclusion For This Example

In this example, the resulting requirements on near-end and far-end crosstalk were:

(a) *For near-end crosstalk over one repeater section length of the PCM system,*
97 dB at 264 kHz
108 dB at 193 kHz

(b) *For far-end crosstalk over one repeater section length of the PCM system,*
(97-C) dB at 264 kHz
(108-D) dB at 193 kHz

where, C and D are the losses in dB of the cable pair at 264 and 193 kHz, respectively, over one PCM system repeater section length.

If the requirements at 264 kHz can be met (this is necessary to combat noise across the band coming from the PCM system when it is loaded with traffic) but the requirements at 193 kHz cannot be simultaneously met, consideration should be given to removing the 47A channel affected (Channel 4) from service.

## Conclusions Regarding "T to N" PCM-FDM Interference

The results and conclusions of the example just discussed are valid for any D1/T1-type PCM system equipped for D1A-type signaling, disturbing an N1 or N2-type FDM system equipped with compandors.

If the D1/T1 system is equipped for D1B signaling there will be an additional component of single-tone interference falling at 96.5 kHz, corresponding to the 500-Hz point (on one side of the carrier) of one of the sidebands of Channel 6 in the lower line group. This will produce an additional requirement (at that frequency) for near-end and far-end crosstalk coupling loss, respectively.

If the PCM system is a D2/T1-type system, the single-tone interference problem is reduced significantly.

The calculations regarding noise interference from a traffic-loaded PCM system are the same for a D1B as for a D1A-type PCM system. For a D2/T1-type system, a separate curve is used (see Figure 5).

If a D1/T1- or D2/T1-type PCM system is disturbing an N3-type system such as the GTE Lenkurt 46B, there is a 3-dB disadvantage since the single-sideband 46B system does not have the advantage of coherent detection of a double-sideband signal (as the 47A does) since,

Equation 2

$$\left(\frac{P}{N}\right)_{6.2\ \text{kHz}} = \left(\frac{S}{N}\right)_{3.1\ \text{kHz}} + 12\ \text{dB}$$

where P/N is the pilot-to-PCM interference noise ratio, and S/N is the test tone-to-PCM interference noise ratio. In equation 2, the 3-dB disadvantage shows up in the +12-dB value when compared to the +9-dB value of Equation 1.

This three part series on PCM-FDM compatibility has endeavored to provide the user of communications equipment with as much information as has been gathered to date by GTE Lenkurt on the problem of combining PCM and FDM within the same cable sheath. Adherence to the ground-rules laid out in this series should enable the user to systematically phase out an old FDM system while using PCM, or permanently combine PCM and FDM within the same cable sheath.

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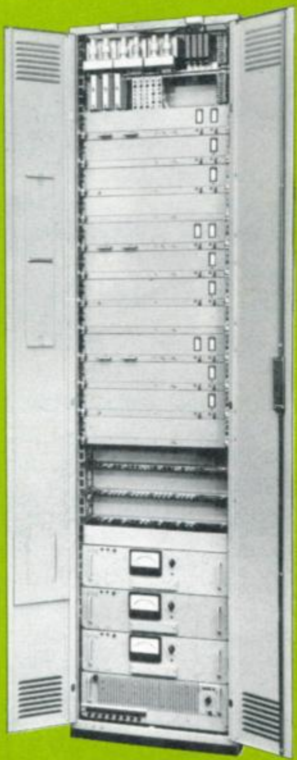

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