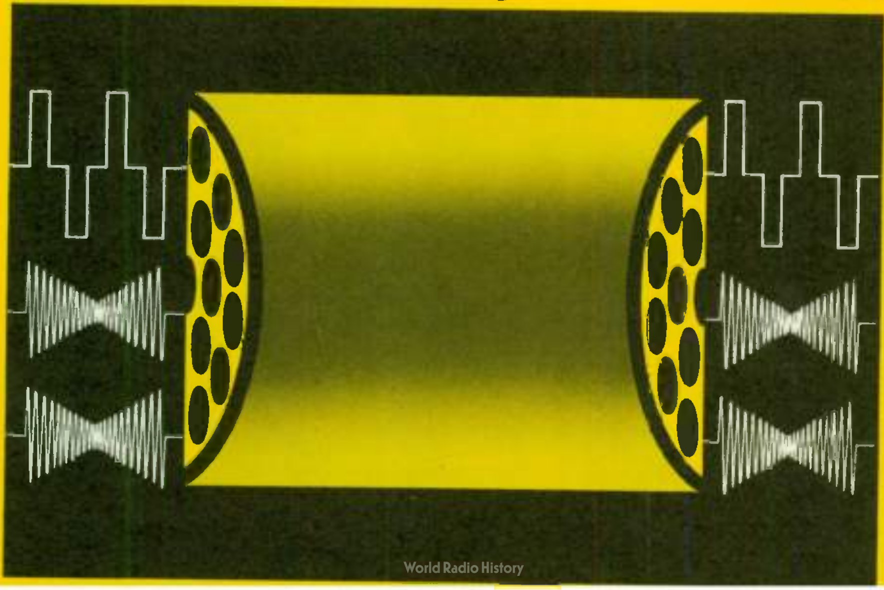
GTE LENKURT

DEMODULATOR

AUGUST 1971

PCM-FDM Compatibility Part 2



The GTE Lenkurt study of PCM-FDM compatibility has yielded useful data in a quantity such that it will require three issues to cover all the information instead of the aforementioned two issues. Part II will deal with the theoretical aspects of PCM-FDM compatibility while Part III will apply these theories to a practical analysis of compatibility using a hypothetical PCM and FDM combination.

In the July issue (PCM-FDM COMPATIBILITY, PART I) of the Demodulator, the focus of attention was mainly on how to use to best advantage the empirical information thus far accumulated by GTE Lenkurt in the study of PCM-FDM compatibility. This included information on direction coordination of cable pairs within the same cable sheath and a discussion of the effects of far-end and near-end crosstalk on an FDM system.

This issue goes one step further in guiding the user toward achieving compatibility between PCM and FDM systems which lie within the same cable sheath.

Sampling, Quantizing and Encoding

The sampling, quantizing and encoding into digital form of an analog signal are the three major functions of a PCM terminal. The information used in this discussion is based on the sampling, quantizing, and encoding scheme used in the GTE Lenkurt 9001A, 9001B (both D1-type) and 9002A (D2-type) PCM channel bank assemblies. These assemblies are end-to end compatible with the Western Electric D1 and D2 channel bank assemblies and to similar terminals produced by other communications equipment manufacturers; hence the designation, "D1- and D2- type."

The level at which a voltage sample is quantized is relevant in evaluating PCM-FDM compatibility and is particularly important at the lower voltage levels since this is where the power spectrum may sometimes be confined to discrete frequencies during quiet and idle conditions in the PCM terminal. An "idle condition" implies that the telephone receiver may be on or off the hook and that no message is being transmitted even though there may be a line open between two parties.

In D1-type systems, each voice frequency channel is sampled 8000 times per second and each voltage sample has 127 discrete voltage levels available for quantization. The zero voltage level is known as level 64. There are 63 levels above level 64 in the positive direction, and 63 levels below level 64 in the negative direction. The number of the quantization level nearest the level sampled is encoded into a sequence of binary pulses and spaces, a pulse corresponding to a "one" and a space to a "zero". Figure 1A gives an example of noise or of low-level voice

NOTE:
The back cover of this issue contains errata for the GTE Lenkurt publication, *Engineering Considerations For Microwave Communications Systems.*

signal sampling and also shows a portion of the level structure of a D1-type PCM system. Figure 1B shows examples of pulse patterns on the line. It should be noted that as the levels get further away from zero (level 64), the steps become progressively larger. This is because most of the information in speech signals is concentrated at low amplitude levels and small quantum steps are thus needed more at the low amplitude levels than at the higher levels in order to maintain a reasonably constant signal-to-noise ratio (in-

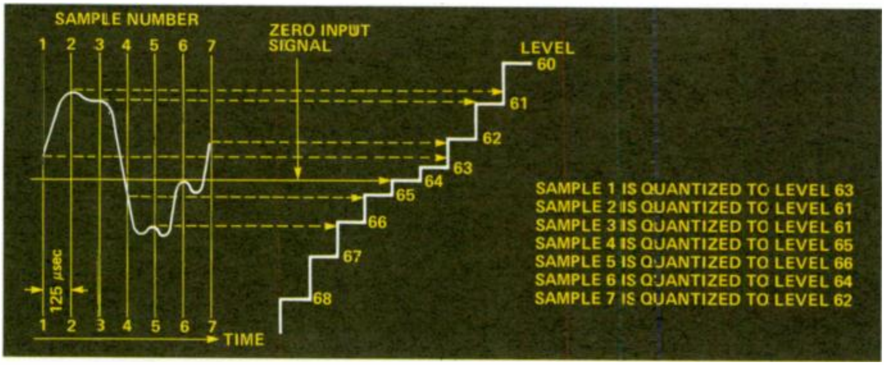


Figure 1A. In a D1-type terminal, each voltage sample is quantized (rounded off) to one of 127 possible levels. The number of the quanitzation level chosen is transmitted to the line as an encoded binary word.

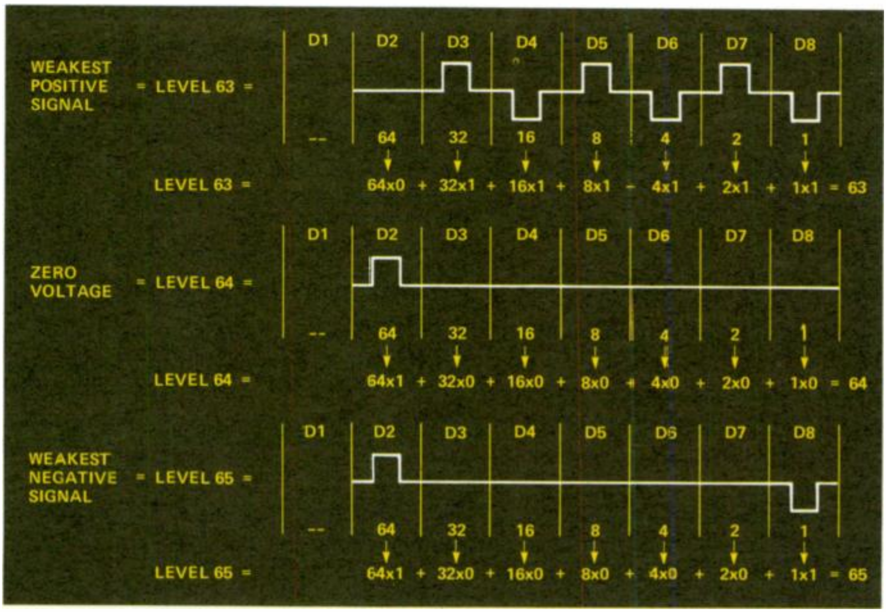


Figure 1B. Resulting pulse patterns on the line and corresponding calculations for small voltage samples in a D1-type terminal. (Positive and negative pulses both represent a binary one.)

dependent of signal level) which is the objective set for speech-loaded PCM telephone systems.

After the voltage is quantized (rounded off to the nearest quantization level), it is encoded into a 7-bit binary pulse pattern or binary word. A binary word consists of eight digits called D1 through D8. *The designation for the eight binary digits of the code word appear as D1 through D8 but should not be confused with the designation for D1- and D2- type terminals, they are two separate entities.* Digit D1 is used for signaling information only, while digits D2 through D8 represent the encoded version of the quantized sample (see Figure 1B). The 24 binary words representing the 24 voice channels plus the framing digit comprise one frame. There are 8000 frames per second and 8x24+1=193 bits per frame. Every other pulse is inverted to produce a bipolar pulse pattern for transmission.

In D2-type systems, the sampling rate is also 8000 times per second, but the number of quantization steps and the encoding method are different. In five frames out of every six all eight digits (D1 through D8) are used for encoding. There are then 255 discrete voltage levels available for quantization. These levels are numbered +0 to +127 and −0 to −127, zero quantization level corresponding to ±127. Figure 1C shows how a noise or low-level voice signal is sampled and quantized in a D2-type PCM system. Figure 1D shows examples of pulse patterns on the line. If the noise level in the terminal is sufficiently low to result in +127 or −127 quantized levels in every sample, a string of binary ones (pulses) broken by a zero (space) on the average only once every sixteen digits will be produced. In the sixth frame, one digit is used for signaling information so that only seven digits (127 levels) are available for quantizing. The availability of eight digits for quantization 5/6ths of the time provides for better signal quality than in a D1-type system.

Power Spectrum Curves

The power spectrum curve is an important tool in evaluating PCM-FDM crosstalk since from it can be derived the amount of potential interference to an FDM system channel which may be transmitted at a certain frequency.

The power spectrum (power as a function of frequency) of a D1/T1-type PCM bipolar pulse train as it would appear during traffic conditions at the output of a regenerator is shown in Figure 2. The curve is calibrated in dBm per 3.1-kHz slot. For this discussion, only a portion of Figure 2 is necessary since the maximum disturbance generated into an FDM line by a PCM system will occur at approximately 710 kHz and the FDM cable carrier systems of most concern for this discussion occupy the frequency range under 400 kHz. Figure 3 shows the significant portion of the power spectrum curve in expanded form. Also shown in expanded form, is the curve for a D2/T1-type system. Although the D1- and D2-type terminals cannot be operated end-to-end, they can both be operated over the T1-type repeatered line.

The power spectrum for a D1/T1-type system is based on a pulse density value of p=0.50, where p is the probability of a binary one (a pulse). This value for p is quite constant with varying loads in a D1/T1-type system provided that there is traffic on at least six of the 24 channels in the terminal. The p=0.50 implies that there is an equal probability of a one or a zero in the pulse train.

The curve for a D2/T1-type power spectrum is based on a pulse density of p=0.55 during busy-hour traffic conditions. When loading decreases, p (pulse density) will increase, resulting in a decrease in P_b (power) at low frequencies (below approximately 420 kHz) and an increase around 710 kHz.

D1A and D1B Signaling

In the study of PCM to FDM interference, the type of signaling used in the PCM system will dictate the fundamental frequency or multiple thereof at which the greatest interference will occur when the PCM system is in the idle condition (no traffic).

Two types of signaling are used with D1-type terminals. These two signaling configurations bear the Western Electric designation of D1A and D1B.

When using D1A (also called "D1/D8") signaling the D1 digit in every binary word is used once in every frame to convey the signaling information. In the on-hook condition there is, then, always a pulse (a binary one) in the D1 time slot in every frame for a given channel. A problem arises when for certain signaling requirements (foreign exchange or revertive pulse signaling, for example) a second signaling channel is required. If this happens during voice transmission

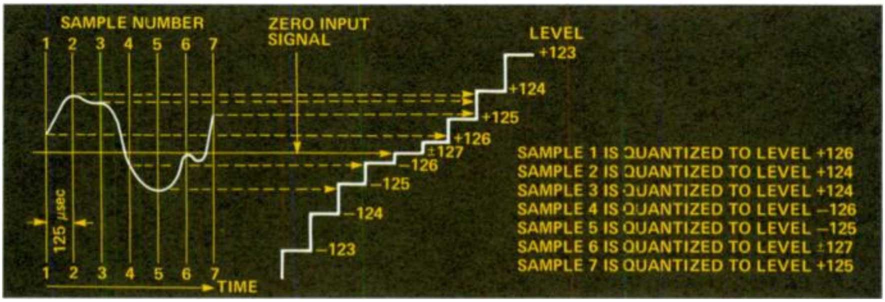


Figure 1C. In a D2-type terminal, each voltage is quantized to one of 255 possible levels.

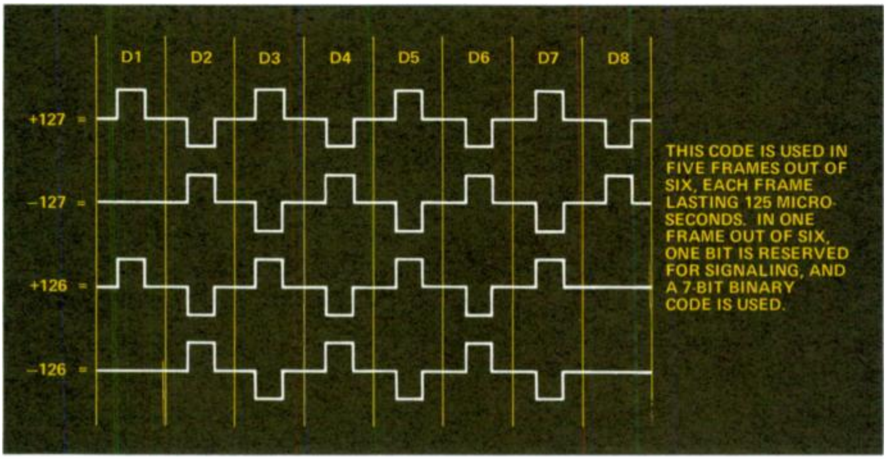


Figure 1D. Pulse patterns resulting from small voltage samples in a D2-type terminal will result in a pulse density close to 100 percent.

(this can happen, for example, when there is no answer supervision), only digits D2 through D7 (six digits) are available for representing the quantized sample. Six-digit encoding corresponds to 63 levels as compared to the usual 127 levels for seven-bit encoding. This six-digit encoding results in larger steps between levels and consequently in greatly increased quantizing noise within the PCM system itself.

To avoid any increase in noise due to requirements for more than one signaling channel, the D1B (also called "D1 only") signaling arrangement was developed. With D1B signaling, the signaling rate is divided by a factor of four so that the D1 digit is used for signaling information only once every fourth frame (per signaling channel). This effectively creates the potential

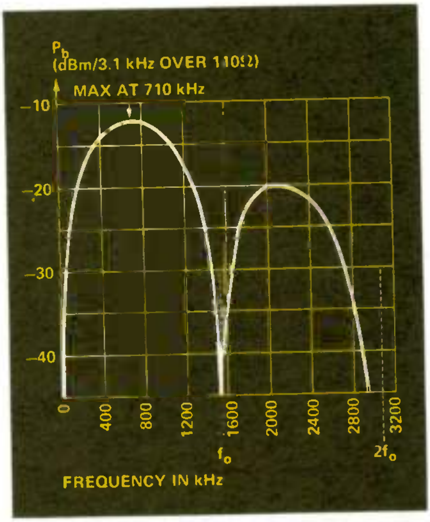


Figure 2. Power spectrum of a D1/T1 type system at the output of a regenerator during traffic conditions.

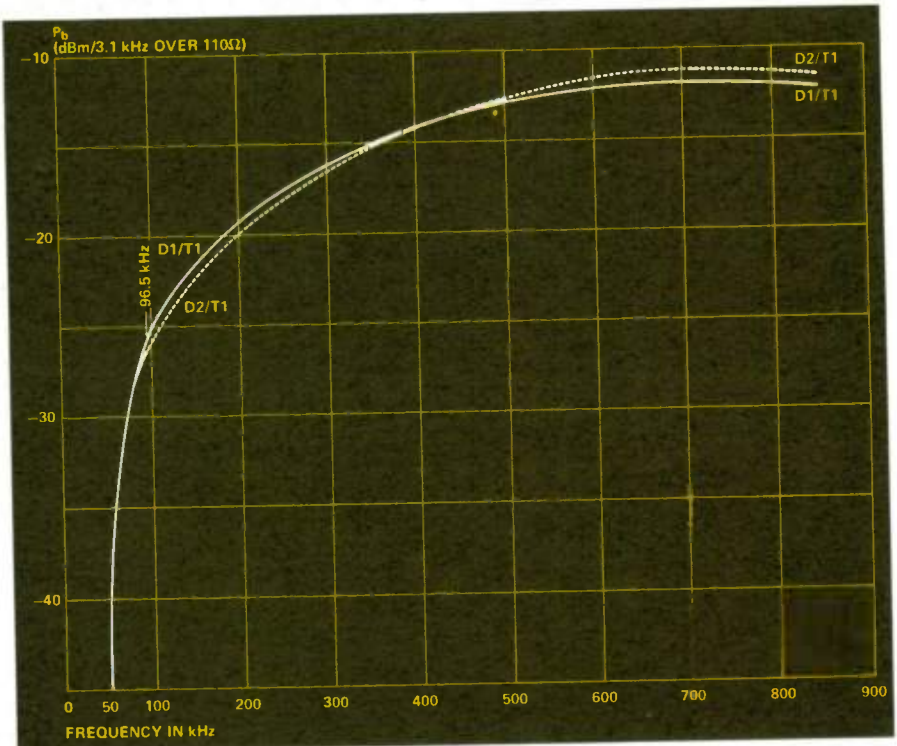


Figure 3. Expanded power spectrum curve of a T1-type pulse train under traffic conditions.

for four signaling channels instead of one, although as a rule, not more than two channels are used. (See the March, 1971, issue of the GTE Lenkurt Demodulator for an extensive treatment of PCM signaling.)

Cable Characteristics

Aside from removing the dc component from the line, conversion of the PCM pulse train to a bipolar format also shifts the power spectrum to lower frequencies. This shift in power spectrum is advantageous for PCM systems because the crosstalk characteristics of cables are better at lower frequencies. Operation at lower frequencies also results in relaxed requirements on cable makeup, pair selection, and/or repeater spacing.

While the impedance of a cable pair is mainly a function of frequency, it also depends on such factors as cable gauge, insulation, and capacitance. Cable impedance falls rapidly from a value of 600-900 ohms at voice frequencies to approximately 100 ohms at 300 kHz and stays relatively constant above that frequency. A compromise value of 110 ohms has been chosen for the 50-400 kHz region which is the band of greatest interest for this study. This compromise impedance is accurate within this frequency range to within approximately 10 percent.

Idle/On-Hook Pulse Pattern

The idle/on-hook pulse pattern is important in the study of interference since an idle and quiet PCM system (all 24 channels idle) can sometimes (if the noise level is sufficiently low) produce a repetitive pulse pattern (resulting in a power spectrum confined to discrete frequencies only) instead of the random distribution of binary ones and zeros normally present when computing the power spectrum. This can cause excessive interference at certain discrete frequencies. A repetitious pulse pattern will appear on digits D2 through D8 in a D1-type system if a very low noise level is present at the terminal. *The value of the D1 digit in the idle condition is determined for the D1-type terminal only by the on-hook or off-hook condition of the channels.*

D1A Idle/On-Hook

If a D1-type system is arranged for D1A signaling, and a condition exists in which all channels are on-hook, with a very low noise level in the PCM terminal, there will be pulses for all D1 and D2 digits in every frame (digits D3 through D8 being zeros or spaces) since this sequence for digits D2 through D8 represents a zero input level (level 64) and since D1 is used strictly for signaling information (the on-hook condition is represented by a binary one). Such a repetitive pulse pattern has a line power spectrum (power concentrated at discrete frequencies). This means that the power in the signal can be represented by components of power at discrete frequencies which are multiples (harmonics) of a fundamental frequency, in this case, 193 kHz. This component may create serious interference in the 36-268 kHz band occupied by an N-type FDM carrier system, for example.

The fundamental frequency is derived for a periodic pulse pattern by the formula:

$$f_o = \frac{1}{T} = \frac{1}{5.18 \times 10^{-6}} = 193 \text{ kHz},$$

where T is the length of one period in seconds.

The periodic idle/on-hook pulse pattern and its corresponding line power spectrum for D1A signaling appear as shown in Figures 4A and 4B. A PCM terminal in a telephone office generally picks up some noise from

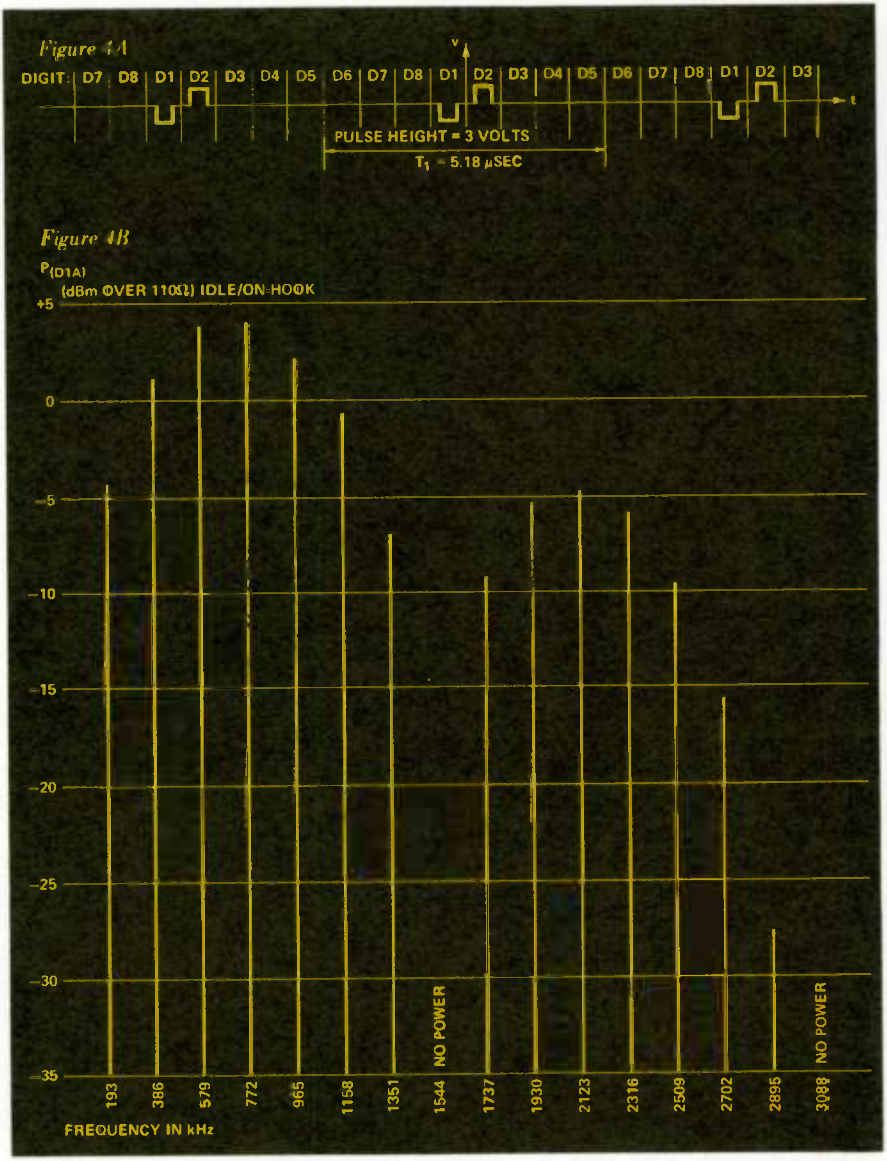


Figure 4A shows the pulse pattern as it appears out of a PCM terminal or regenerator in the idle/on-hook condition when D1A (D1/D8) signaling is used. The resulting line power spectrum is shown in Figure 4B.

Figure 4C represents the pulse pattern in three frames out of four for the idle/on hook condition and D1B signaling.

Figure 4D is the line power spectrum resulting from the idle/on-hook pulse pattern in a D1-type terminal when D1B (D1 only) signaling is used. That pattern is according to Figure 4A every fourth frame; according to Figure 4C the remaining three (out of four) frames.

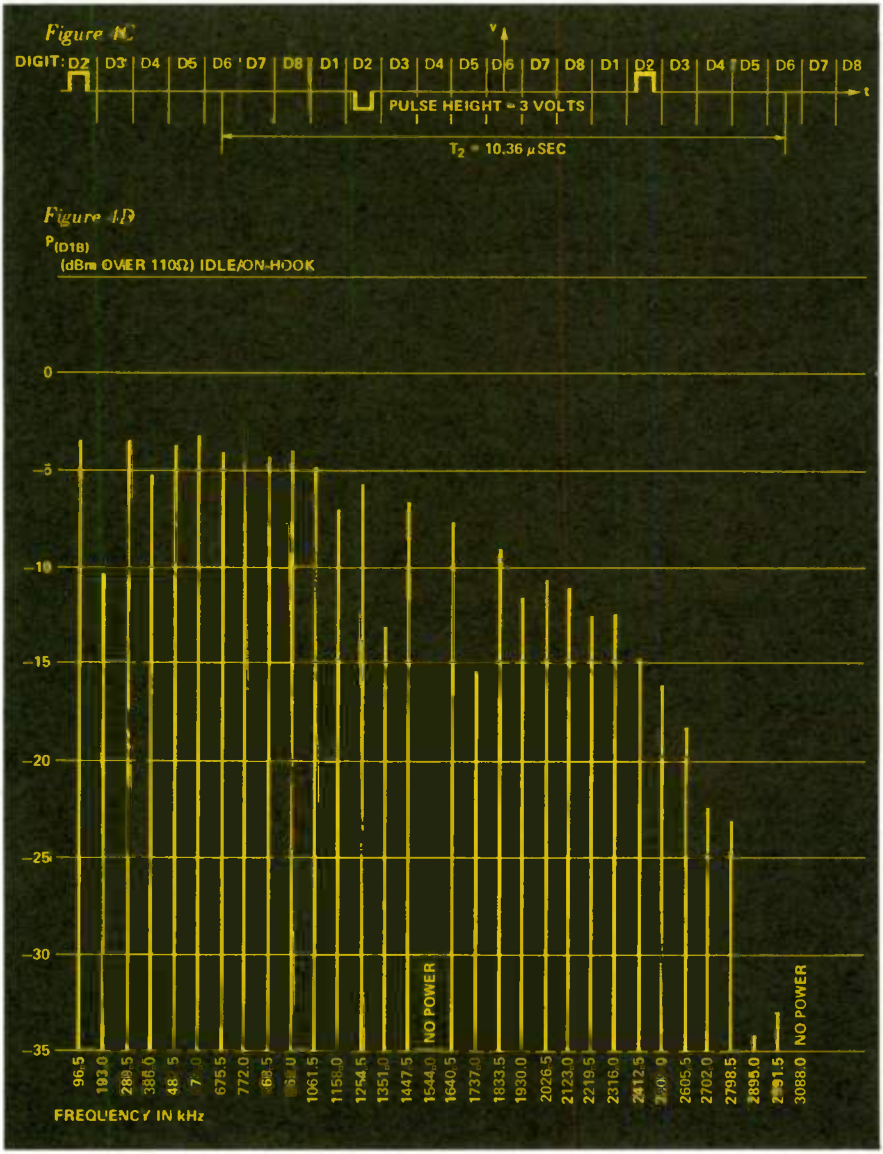


Figure 4C

Figure 4D

switching transients, which causes the power spectrum on the transmission line to be less clean-cut than that shown in Figure 4B. In most working systems, noise will cause the quantized samples of the input signal to fluctuate randomly around level 64. These random fluctuations will introduce more pulses per binary word and thus more high-frequency components to the line. Even rather small noise levels (for example, resulting in levels 63 or 65 most of the time, rather than 64) will result in a pulse density of approximately 50 percent. *Only when all voltage samples are consistently quantized to zero level does the power spectrum become a series of spectral lines.*

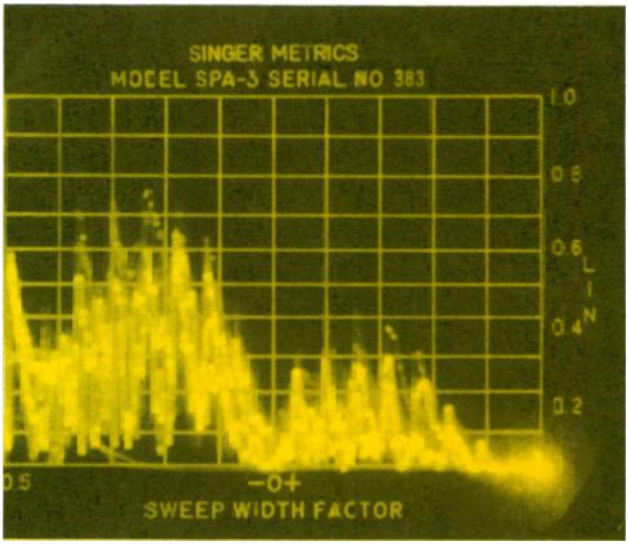


Figure 5. Power spectrum for a working PCM system during a busy-hour condition (10 a.m.) on a week day.

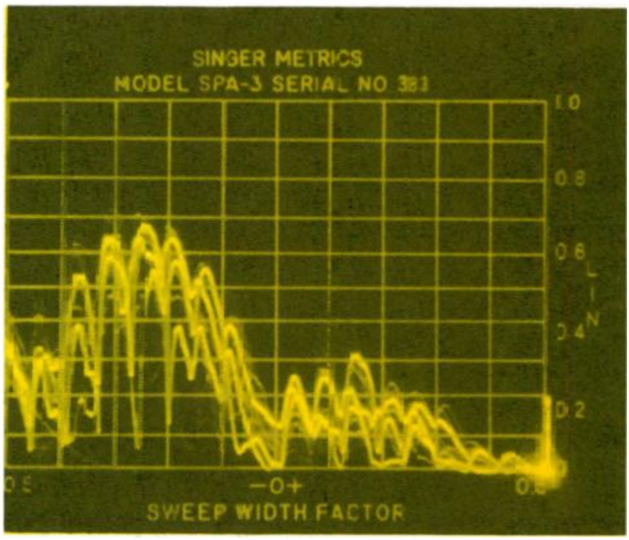


Figure 6. Power spectrum for a working PCM system during a low traffic condition (midnight).

Figures 5 and 6 show the power spectrum of the line signal as it appears at the output of a PCM terminal under different traffic conditions. These photographs were taken in the field on a working 24-channel D1A system. Figure 6 shows that the power spectrum only *approaches* a spectral line condition due to the presence of ambient noise. However, a spectral line condition can be attained in the laboratory where ambient noise is more strictly controlled.

Although a periodic pulse pattern is a rather unusual case since it corresponds to all channels off hook and a very low noise level, it is important because it usually represents the worst interference condition as far as FDM channels in the corresponding discrete frequency slots are concerned. As the pulses occur randomly with traffic, the power spectrum of a PCM system will tend to assume a smooth curvature as shown in Figure 3. Figure 4B represents the worst case for the all channels on-hook condition, as far as crosstalk at low frequencies is concerned.

D1B Idle/On-Hook

When a terminal is arranged for D1B ("D1 only") signaling, the idle/on-hook pulse pattern is somewhat more complicated than for D1A signaling. In one frame out of four the pulse pattern will be as shown in Figure 4A; in three frames out of four it will be as shown in figure 4C. The pulse train in one frame out of four for the idle/on-hook condition is thus identical to that for D1A signaling. This will produce lines in the power spectrum at multiples of 193 kHz as for D1A signaling, but their magnitudes are reduced by a factor of four (6dB) because it represents only the pulse pattern in every fourth frame. The important thing to be noted about the power spectrum for an all channels idle and on-hook condition, (as in Figure 4D) is that it consists of two sets of spectral lines for D1B signaling. One set has lines at all odd multiples of 96.5 kHz caused by the pulse pattern in three out of four frames. The other set has lines at even multiples of 96.5 kHz (which is the same as multiples of 193 kHz) caused by the pulse pattern in one out of every four frames.

D2/T1-Type Idle/On-Hook

The pulse pattern for the idle/on-hook conditions for a D2/T1-type system is a sequence of consecutive pulses (a string of binary ones), broken by an occasional space. If the system is idle with all channels in the on-hook condition, and the noise level is sufficiently low, the voltage samples will all be quantized to +127 or −127 in five frames out of six; to +63 or −63 in one frame out of six. The signaling digit for the on-hook condition is a binary one. For this condition, on the average 15 out of every 16 digits will be binary ones. Analysis of this type of pulse train shows a reduction of single-tone interference below 400 kHz amounting to 11 dB (compared to idle/on-hook D1A) or 7 dB (compared to idle/on-hook D1B).

Crosstalk Evaluation

From a study of idle/on-hook conditions for D1A and D1B signaling it is apparent that PCM to FDM interference will show greatest potential for disturbance at multiples of 96.5 kHz or 193 kHz during the times of the day or night when most of the PCM channels are idle. The value of the worst case component under this condition can be obtained from the applicable diagram in Figure 4. It is possible that this disturbing effect from the PCM system in its idle condition will in some cases necessitate the elimination of FDM channels in baseband slots at or adjacent to multiples of 96.5 kHz.

In Part III of PCM-FDM COMPATIBILITY, the theoretical aspects of compatibility which have been discussed in the previous two issues of the Demodulator will be put to practical application. A hypothetical PCM-FDM combination will be evaluated to determine if the two systems are compatible.

GTE LENKURT
1105 COUNTY ROAD
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Since publication of GTE Lenkurt's *Engineering Considerations for Microwave Communications Systems,* certain text errors have been noted. Corrections for these errors in addition to clarification of a point about reliability calculations in the book are as listed below.

ERRATA

Page 23, Figure 11. — Change "Regular Plan" to "Regular Path"

Page 95, Figure 27B. and Page C22, Figure 27B. — The penultimate and antepenultimate values in the table are incorrect and should be changed as follows:

Change From,

Band GHz	Gain Factor	Distance Factor
8.0	+4.5	.60
11.2	+5.4	.54

To,

Band GHz	Gain Factor	Distance Factor
11.2	+4.5	.60
12.45	+5.4	.54

Page C30 and Page C31 — Log .000621 in the "Distance Calculations" box should be shown as $\bar{6}.793350$ instead of $\bar{4}.793350$. ($\bar{6}$ implies a characteristic of 6.0000 −10)

NOTE:
It is important to note that graphs, formulas and methods for calculating outages throughout the book are all for one way outage. To calculate two way outages it is necessary to double the calculated multipath and equipment outages. Outages due to rain or to non-selective fading do not have to be doubled since they occur simultaneously in both directions of transmission.

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