GTE LENKURT
DEMODULATOR

MARCH 1971

PCM Signaling and Timing

The integration of pulse code modulation (PCM) carrier systems into the telephone plant has left personnel, expert in dealing with the traditional frequency-division multiplex systems, grappling with less familiar terms such as "sampling," "quantizing," and "coding."

The principles of message transmission in a PCM system have been described in a variety of articles and books. (See, for example, *The Lenkurt Demodulator*, November, 1966.) While message transmission is, of course, the objective of such systems, it is not the whole story. A message with no place to go is no message at all.

How, then, do PCM systems carry the various types of signaling and supervisory information that control an ordinary telephone call? And how can a PCM carrier system integrate into an existing plant that already includes such diverse types of signaling as E&M (receive and transmit), loop dial, and foreign exchange? Furthermore, how are these signaling and supervisory functions handled in second generation PCM systems?

The answers to these questions are inextricably bound up with the carrier's nervous system – the timing arrangement that sorts out more than a million-and-a-half information bits each second to form individual message channels and their associated signaling information. A good starting place is a brief review of the transmission techniques used in first-generation PCM systems. These systems are built by several manufacturers. Regardless of their origin, however, they conform to the same general system parameters.

T-Carrier Transmission

For convenience, the entire carrier system is referred to here as a *T-carrier system*, in accordance with the Western Electric Company designation. However, common usage has separated the *T1 repeatered line* from the *D1 channel bank* – the actual multiplex terminal. It is in the D1 bank that sampling, quantizing, and encoding occur. It is also the D1 bank that controls system timing, the all-important brain of the system.

The analog voice signals are first sampled in sequence to form pulse amplitude modulated signals. Each pulse is then quantized – assigned the nearest discrete value to its actual amplitude. Logic circuitry then encodes the pulse into a binary number that defines this discrete value. This binary number is expressed as a series of identical pulses, or spaces. A pulse indicates a binary "1" and a space indicates a binary "0".

The series of pulses and spaces that defines one quantized sample from one channel makes up a PCM word.

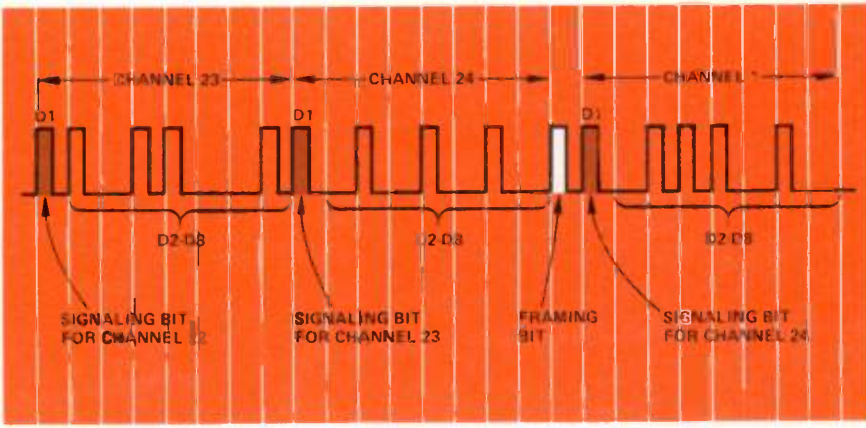


Figure 1. Frame format of D1 channel bank consists of 24 8-bit PCM words plus one framing time slot. The D1 time slot in each word is reserved for signaling information for the previous channel.

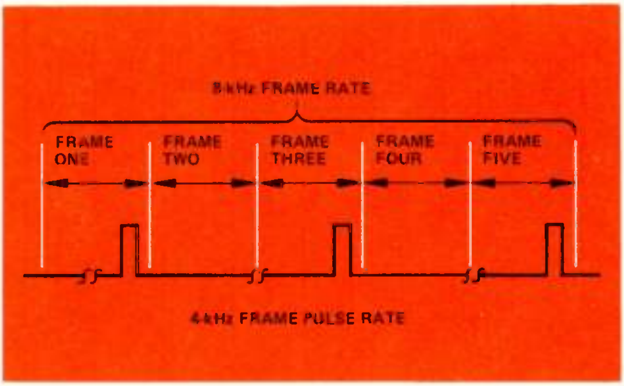
The length of the word limits the number of quantizing steps that can be used, and hence the fidelity with which the original analog signal can be reproduced at the receiving terminal. The D1 bank uses a seven-bit encoding scheme, which permits 2^7, or 128, quantizing steps. (Other considerations preclude the use of 0000000, so 127 steps are actually available for quantizing the voice signal.)

However, there is one necessary ingredient in the PCM word associated with one sample from a single channel. This is some way to carry the signaling and supervisory information. In the D1 bank, this is done by adding one additional bit to form an eight-bit word. The first, or D1, time slot in each word is reserved for signaling and supervisory information for the previous channel.

Since the system handles 24 voice channels, 24 eight-bit words (a total of 192 bits) are contained in one scanning cycle – one word from each channel. These 192 bits make up a "frame." Without a means for the receiving terminal to identify the beginning and end of these frames, the transmitting and receiving terminals will not be synchronized and the receiving terminal will be unable to route the individual words to the appropriate channels. Therefore, a 193rd time slot is inserted in each frame, as shown in Figure 1, to provide timing information.

This framing bit alternates between a "1" and a "0" for succeeding frames. The result is a stable signal component at one-half the frame rate. Since the frames recur at a rate of 8-kHz, the alternating framing pulses produce a 4-kHz component, as shown in Figure 2. The framing circuitry in the receiver locks onto the frame rate. In the event of loss of synchronization, the receiver "slips" one bit per frame until it regains synchronization. If it has not regained the frame rate after checking each bit in two frames, an alarm is initiated. It takes 48.25 milliseconds to check these 386 bits.

Figure 2. Alternating one and zero framing bits produce a 4-kHz pulse rate to establish the synchronization between transmit and receive terminals.



Transmitting Signaling Information

As far as the D1 bank is concerned, there are two types of nonmessage information to be transmitted: supervisory information (on-hook, off-hook) and signaling information (dial pulses and multi-frequency tones). Supervisory information is transmitted using two possible electrical states such as – open or closed loop; potential on either side of the incoming line; or battery or absence of battery on the signaling leads. These two varying electrical states result in a series of either 1's or 0's in the D1 time slot of, say, channel one. When the electrical state changes, the 1's change to 0's, and vice versa. At the receiving terminal, the series of pulses and spaces is used to reconstruct the original DC potential for transmission to the office switching equipment.

Transmission of dial pulses is nearly as simple as transmitting the supervisory information. Assuming, for ease of calculation, a 50/50 make/break percentage, a dial pulse at a nominal 10-pulse-per-second rate has a duration of 50,000 microseconds. Since a sample is taken every 125 microseconds (in the original D1 bank), each pulse is sampled 400 times. (See Figure 3.) Thus, neither the pulse rate nor the make/break ratio is critical. The PCM system sees dial pulses as slowly changing potentials.

Since there are only two possible states in both supervisory information and dial pulses, neither needs to go through the quantizing process used for voice signals. All that is required is sampling at the appropriate time and conversion to the correct voltage level at the receive terminal. Thus, the signaling and supervisory information enters the transmission path just before the bit stream goes on the line. Conversely, this information is extracted from the bit stream as soon as it comes off the line at the receive terminal.

Multi-frequency signaling tones consist of varying AC within the voice band. Therefore, the D1 bank treats them like voice signals. It samples, quantizes, and encodes them. At the receive terminal, they are reconstructed in the same manner as a voice signal. Thus, when multi-frequency signaling is used, the actual signaling path in the carrier system handles only supervisory information.

There are two possible separate signaling paths through the entire common carrier equipment. Not all signal-

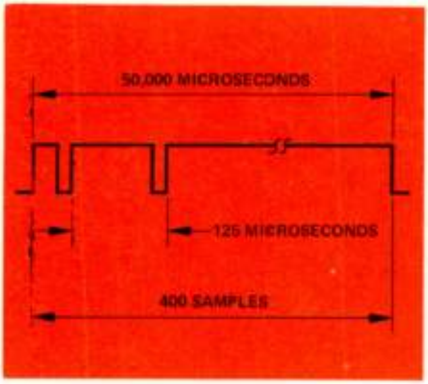


Figure 3. Each dial pulse is sampled approximately 400 times at an 8-kHz sampling rate.

ing arrangements require both paths. Dial pulse and E&M signaling, for instance, each need only one path. However, more complex signaling schemes that must send two types of information simultaneously require both paths.

For example, foreign exchange signaling arranged for forward disconnect must hold the subscriber terminal busy while the office disconnects. It is a matter of controlling two relays, one to hold the subscriber off-hook, and the other to provide on-hook/off-hook information about the office condition. Nevertheless, two separate signaling paths are required for such an arrangement.

Two Paths on One Bit?

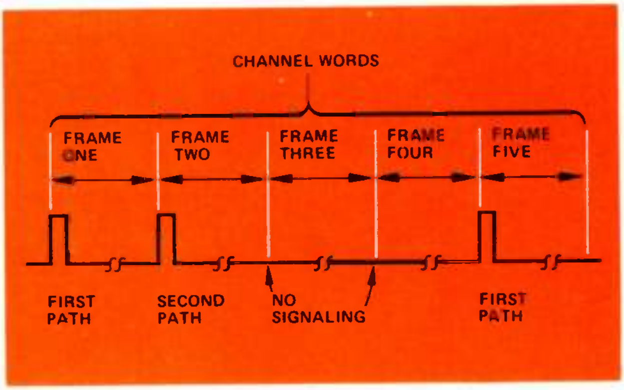
Since two signaling paths are necessary for certain types of signaling, and only one bit in each word is set aside for signaling information, how can the two paths be kept separate? Western Electric Company has developed two separate signaling schemes for the D1 channel bank. These two schemes are called *D1A* and *D1B*.

Although only one digit is set aside for signaling, it is possible to borrow one of the voice digits to provide the second signaling path. The D1A arrangement borrows the eighth bit of the PCM word (the least significant bit) to provide the second signaling path. Hence, this option is often referred to as D1/D8 signaling. Even though this technique uses one of the voice digits, it does not affect the quality of voice transmission through the channel; since once the call is established, D8 is returned for exclusive use in voice encoding. A pulse in D1 indicates the channel is in an on-hook condition. When no pulse appears in the D1 time slot, the called terminal has gone off-hook, and message traffic is imminent. The absence of a D1 pulse inhibits the use of the D8 time slot for signaling, freeing the D8 time slot for full seven-bit voice signal encoding.

This arrangement works out well except in cases where the called terminal sends back no on-hook/off-hook supervisory information. These are the so-called "free" calls (to directory assistance or a test line, for example) where there is no reverse battery supervision. In such a case, a pulse appears in the D1 time slot even when the called terminal goes off-hook. Therefore, D8 would continue to be used for signaling, using a digit that would normally be reserved for voice transmission. As a result, the voice signal is encoded in only six bits instead of the usual seven. The increased quantizing noise with 63 quantizing steps, rather than the usual 127, substantially degrades the quality of the voice channel.

This condition is not a universal problem because it only occurs with certain types of signaling – and then only on free calls. Nevertheless, it can

Figure 4. In D1B signaling, the first signaling path is provided by the D1 time slot on first frame, the second signaling path uses the D1 time slot of the second frame, and neither uses it on third and fourth frames.



be avoided with a different technique for providing two signaling paths. This improved two-path arrangement is referred to as D1B.

Since D1B uses only the D1 time slot for signaling, it is sometimes called "D1 only." The D1 time slot in the first frame provides the first signaling path, the D1 time slot in the second frame provides the second path, and both paths are inhibited during the third and fourth frames. Then the pattern repeats. This four-frame pattern, shown in Figure 4, is necessary to avoid confusing the receiving terminal with false framing information. Suppose, for instance, that the signaling paths were to use the D1 time slot in alternate frames, and one of them produced a series of pulses while the other produced no pulses. The resulting series of alternating 1's and 0's would produce a 4-kHz fundamental component that would be indistinguishable from the framing bits.

Each signaling path for a particular channel is sampled only once every four frames and the entire frame length is 125 microseconds; therefore, samples of signaling information are taken every 500 microseconds — or about 100 samples during a typical dial pulse.

Second-Generation PCM Systems

The second-generation PCM carrier terminal is the *D2 channel bank*. Like the D1 bank, D2 uses an eight-bit PCM word. However, the D2 bank is intended to meet intertoll requirements for lengths up to 500 miles. Seven-bit encoding is not good enough to achieve this objective. The quantizing noise would be too high. Therefore, it is not possible to reserve one digit out of the eight to provide signaling information.

The solution is a second level of time-division multiplexing. In five out of every six frames, the D2 bank encodes the voice signal in eight bits. In the sixth frame, it uses only seven-bit encoding, borrowing the eighth bit for signaling information. The result is an average 7-5/6 bit encoding for the voice signal. This improved performance meets the intertoll objectives.

Two signaling paths, for four-state signaling, are provided in much the same way as in the D1B channel bank. The signaling bit in every other sixth frame carries one two-state channel, while the same bit in alternate sixth frames carries the other two-state channel. In this way, complete information about the condition of both signaling paths can be transmitted in

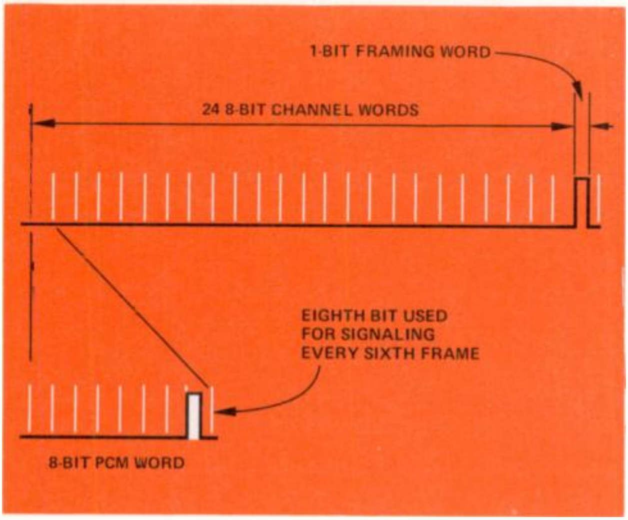


Figure 5. D2 frame format consists of 24 8-bit words plus a 1-bit framing word. Signaling borrows one bit from each channel word, in every sixth frame.

12 frames – about 1.5 milliseconds. If only one signaling path is required, as in the case of E&M signaling, both paths are still used – providing signaling every six frames.

One effect of this time sharing every sixth frame is the necessity for more framing information in the eighth bit of each word. Not only must the receiving terminal recognize the beginning and end of each frame, but it must also determine whether or not a particular frame carries message or signaling information on the eighth bit of each word. Once again the answer is time sharing. The framing bit in every other frame contains the information for terminal synchronization (see Figure 5). This leaves the framing bit in alternate frames free to carry the information necessary to distinguish the one frame in six that carries signaling information.

The net result is a gross frame format and an operating bit rate identical to that of the D1 bank. However, the D1 and D2 banks cannot be operated end-to-end. Not only do their framing and signaling arrangements differ, but they also have different PCM coding schemes and companding characteristics.

While these two channel banks – D1 and D2 – lack such direct compatibility, they can operate over the same repeatered lines. And they are closely related members of the emerging family of digital transmission systems.

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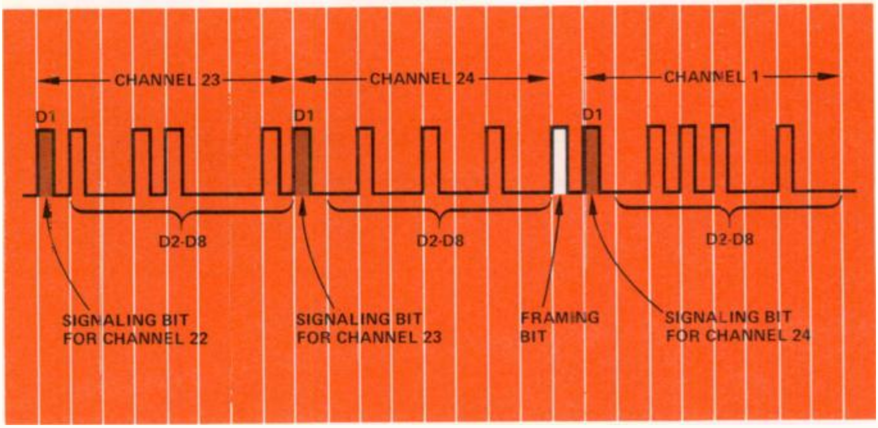

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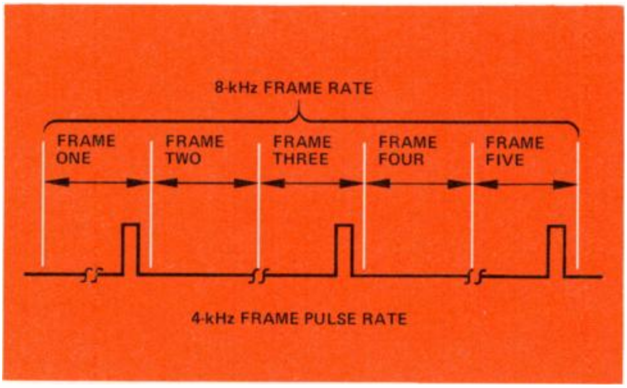

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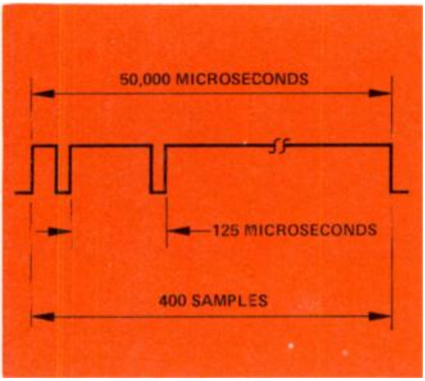

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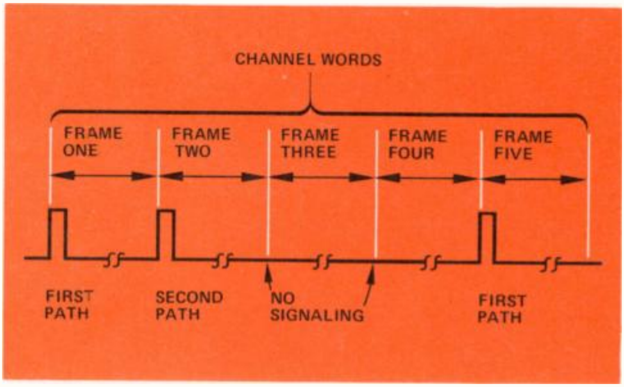

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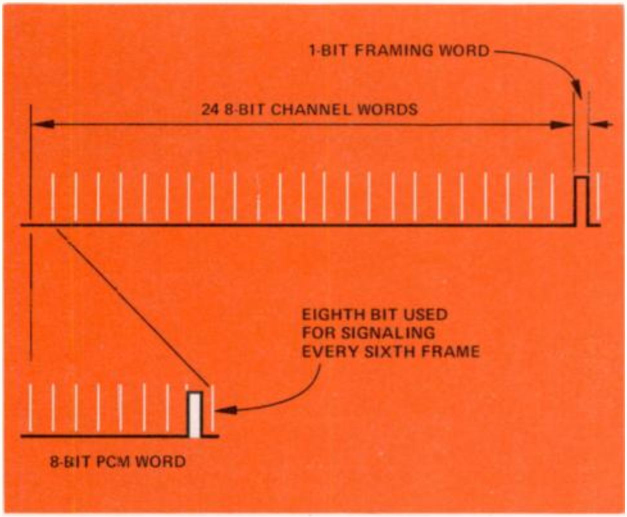

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