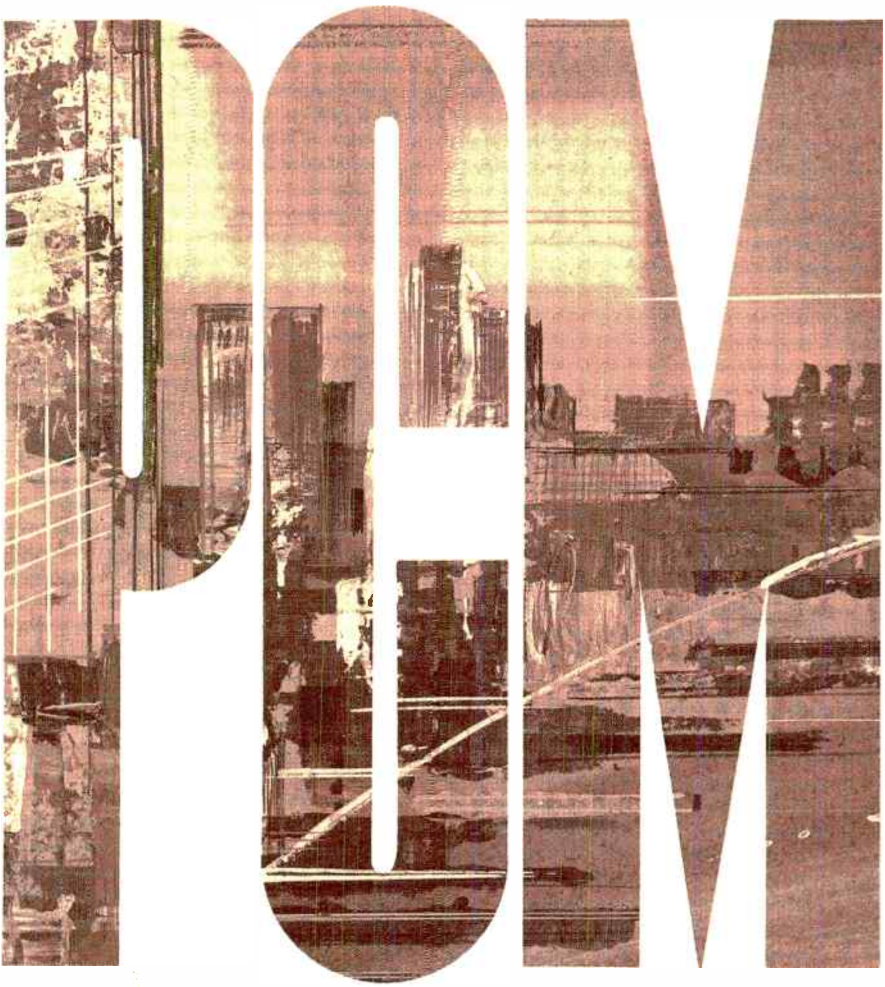
The Lenkurt®
DEMODULATOR
MARCH 1968



Part 1

PCM
PCM
PCM

. . . . a unique family of digital transmission systems for voice, video, or data.

The first serious interest in time division multiplexing came about 1930. Early experiments centered around pulse amplitude modulation, but noise and crosstalk were serious problems.

The invention of pulse code modulation (PCM) occurred in 1937. However, it was so basically different from the contemporary concept of telecommunications that its importance was not widely understood or appreciated. And even if it had been, the components necessary to accomplish the complex processes of sampling, quantizing, and coding were not available. PCM had to wait for transistors, integrated circuits, and a better knowledge of digital devices.

Frequency division multiplex (FDM) has served the telephone industry well for many years, but economic factors have kept engineers on the search for more practical and efficient transmission methods. As interest was renewed in digital communication, the advantages of PCM over FDM became apparent.

Solid State Economy

The economics of solid state technology point to PCM as the transmission method of the future. To the telephone company, this is another means of holding the line against constantly increasing costs; to the telephone user, it is another step toward more efficient and complete communications service.

With transistors as a working tool, and integrated circuits a promise for the future, Bell Telephone Laboratories readied their first PCM systems in the 1950's. The first working system in the United States was installed in 1962. Today there are about a half-million channels in service.

Bell will necessarily establish the system parameters for PCM performance, and as in commonly the case, independent manufacturers and users will find it convenient to refer to Bell nomenclature in describing their own systems.

(To avoid confusion, Bell terminology will be used here rather than Lenkurt equipment types.)

Time multiplexing PCM systems have been designated as T carrier in the Bell System. The first generation, now in service, is the T1. Future systems will expand the T family from T1 to T4. Along with these progressions will come refinements in channel banks and increased available service.

The T1 system can consist of either a D1 channel bank of 24 channels, a D2 channel bank of 96 channels, or several choices of data banks.

The D1 channel bank now in service provides 24 two-way channels on two exchange grade cable pairs, one for each direction of transmission. These may be in the same cable, or in separate cables.

Repeatered Line

Regenerative repeaters are spaced along the cable about every 6000 feet. Because information on a PCM system is transmitted in the form of binary pulses, the repeater need only recognize the presence or absence of a pulse to regenerate a clean, new pulse. Because of the lower signal-to-noise ratio required with regenerative systems relative to FDM systems, large amounts of noise, interference, and distortion can be tolerated.

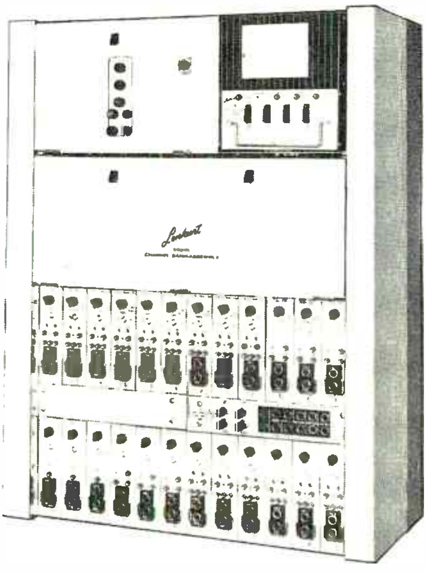


Figure 1. Lenkurt's 24 channel PCM system, the 91A, exhibits space saving design offered by TDM technology.

While noise and distortion do not accumulate along a PCM cable as they do with FDM repeaters, it's not a case of getting something for nothing. The noise appears in a different form, showing up as a jitter on the retransmitted pulse train. If allowed to accumulate, this jitter can prevent perfect retiming of pulses. Hence, special jitter-reducing circuits are needed for long haul PCM transmission systems.

Jitter is not a serious problem in the T1, which is intended for use in systems less than 100 miles in length. But the long haul, high density systems which will someday span the nation must be equipped to handle it.

Time Separation

The translation of an analog signal into PCM begins by switching sequentially from one channel to another at a rapid rate. Each channel occupies the transmission line for a fraction of the total time. Conversations are stacked in time rather than in frequency as in FDM systems, and the method is called time division multiplexing. By synchronizing the sampling rate at the receive end, each channel may be recreated in its original form.

If periodic samples of a waveform are taken often enough, the waveform can be perfectly reconstructed at the end terminal. The necessary sampling rate is just twice that of the highest frequency to be transmitted. Therefore, if 4000 Hz is the highest frequency on a telephone channel, samples taken at the rate of 8000 per second will precisely and exactly duplicate the telephone conversation. This is the sampling rate used in the T1, although in practice the channel bandwidth is 200-3400 Hz.

PCM Coding

Three successive operations are needed to transform the analog speech signal into the series of digitally coded pulses of PCM.

The first operation is to sample the speech signal at a suitable rate (8000

Hz) and measure the amplitude of the signal. This results in a train of pulses roughly analogous to the original waveform.

Next, the amplitude of each sample is compared to a scale of discrete values and assigned the closest value. This rounding off process is called quantizing. Each pulse, now with its discrete value, is then coded into binary form. These binary pulses are what appear on the transmission line.

A 7-digit binary code is used in telephone PCM. That is, each sampled pulse is coded into a combination of seven pulses representing one of 127 different discrete values. To each code group an eighth digit or bit is added for signaling.

Each of the 24 channels in a T1 system is sampled within a 125-microsecond period (1/8000 second), called a frame. To each frame an additional bit is added for synchronization of end terminals.

Eight bits per channel, times 24 channels, plus the synchronizing pulse, brings the total time slots needed per frame to 193. The resulting line bit rate, with 8000-Hz sampling, is 1,544,000 bits per second.

(A more complete analysis of the PCM coding process is found in the November 1966 *Demodulator.*)

The bandwidth required for the T1 system is about 1.5 MHz, or one cycle per bit. This is obviously much more than is needed to transmit 24 channels over an FDM system. On cable, the bandwidth is readily available, but the advisability of PCM on most microwave applications is clearly limited.

The most significant reason more bandwidth is not available to FDM systems on cable is the difficulty of designing wideband amplifiers with sufficiently flat response. In the digital PCM system, where each channel uses the entire system bandwidth and is separated from other channels by time,

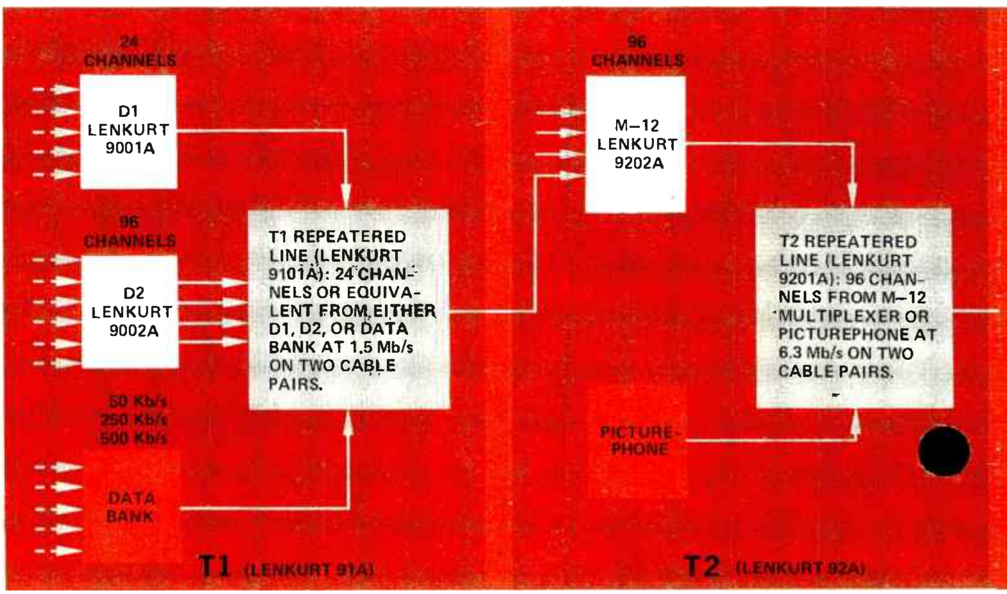


Figure 2. PCM systems, expanding from T1 to T4, will mix voice and other

non-uniform attenuation of the transmission path is not a particular problem. The end terminal, and each repeater along the cable, need only register the presence or absence of pulses to successfully accomplish communication.

T Carrier Family

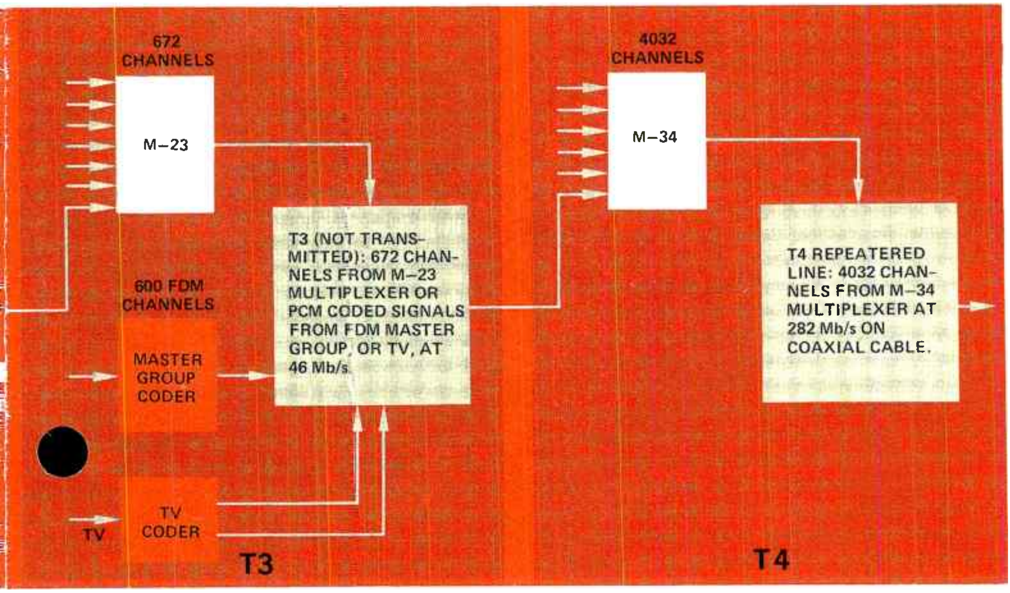
The overall concept of the T carrier family is illustrated in Figure 2. Beginning with the short haul exchange carrier T1 system now in service, the family expands into a transcontinental system capable of carrying voice, data, and television signals simultaneously.

As the network grows, four T1 signals will be combined into a 6.3 Mb/s stream called the T2. Seven T2 signals will be combined into a 46 Mb/s group, sometimes referred to as the T3 section although it is not intended for transmission. The final step in the planned T carrier system will be when six 46 Mb/s signals are multiplexed, forming the T4 signal at 281 Mb/s.

D2 Channel Bank

The first outgrowth of the T1 system will be contained in the channel bank equipment. By combining the common equipment of four 24-channel groups (D1 channel banks) into a 96-channel system, considerable savings in cost and size are promised, along with increased noise performance.

The result is the D2 channel bank. The transmission format is exactly the same as the D1, with each 24-channel group operating over a separate T1 repeatered line. However, some noise improvement is gained by making the eighth digit in each group do double duty. In the D1, this bit is committed to signaling information. But in the D2 the eighth digit will carry VF information most of the time – only occasionally will it be "borrowed" for signaling.



services using time division multiplex. Many T1 systems are now operating.

Current technology will not allow D1 and D2 channel banks to work end to end, but an interface between the two is theoretically possible.

The T1 system, although primarily developed for the transmission of voice, is ideally suited to the increasing data market. Various data banks now being developed will provide service at 50 kb/s, 250 kb/s, or 500 kb/s over the T1 repeatered line. When it is realized that 64 kb/s is the rate used for each voice channel, the hundreds-of-kilobit rates are not surprising.

T2 System

The intermediate speed T2 system will provide 96 channels at roughly four times the T1 speed, or 6.3 Mb/s. A multiplexer, called the M-12 by Bell, will bring together T1 pulse streams from either four D1 channel banks or a single D2 channel bank, retime them, and then transmit them to the T2 repeatered line. Two cable pairs are used, and present planning calls for a system extending out to 500 miles using a more complex repeater.

Bell's Picturephone will also operate at T2 bit rates and could be an alternate use of the system.

The next step in the T carrier hierarchy was originally named the T3 system. But this is no longer considered a necessary step in the logical growth of transmission systems and is now planned to be only a convenient way of gathering groups of signals together within one office.

At this point the M-23 multiplexer will combine seven T2 signals into a 46 Mb/s stream capable of carrying the equivalent of 672 voice channels.

T4 System

Finally, six M-23 signals will be accepted by the M-34 multiplexer to produce a total of 4032 channels in the T4 system at 281 Mb/s.

By its nature, a PCM system can accept almost any mixture of voice, data, or in the T4, television. Once the intelligence has been digitally coded, the pulses are exactly the same. The repeatered line equipment or the multiplexers themselves are no longer concerned with the type of information being transmitted. Likewise, there is virtually no interaction among the various signals.

Experimental systems operating at Bell Laboratories indicate that television signals with 10 Mb/s sampling and a 9-digit code group will produce acceptable picture quality. The total output of the TV encoder at 92 Mb/s will be divided into two 46 Mb/s streams for entrance to the M-34 multiplexer

Another encoder planned for the T4 system will convert an entire FDM master group of 600 voice channels to PCM. The master group will be sampled at 6 Mb/s, and will be transmitted with 9-bit quality. The output of this encoder will also be 46 Mb/s to match the standard M-34 input.

The planned T4 system is unique not only when compared to FDM systems, but to other members of its own PCM family. Because of its design function as a long haul carrier, the T4 must satisfy many special conditions. It should be capable of operating over any distance carrying several thousand telephone calls, several television signals, numerous wideband data signals, or mixtures of all.

To this end, coaxial tubes will be used to attain bandwidths sufficient for the 281 Mb/s signals. And at the toll office, T4 equipment will be called on to provide a number of more critical duties than were earlier systems.

A new code, for instance, has been devised to eliminate a number of limitations inherent in such a long system. A three-level code (minus, zero, or plus pulses) will replace the two-level bipolar code (pulse, no pulse) used in the T1. The new code, called paired selected ternary (PST), primarily conserves bandwidth by adding additional information capability with the same signal-to-noise ratio. PST provides a strong timing signal for repeaters by eliminating long series of zeros, and as in other bipolar PCM transmission, avoids a dc component in the signal and permits errors to be monitored on the repeatered line.

Pulse Stuffing

If the coded pulses of a single channel are to be extracted from over 4000 channels in a 281 Mb/s stream, some method of synchronizing T4 terminals must be available.

In the relatively short T1 system where all pulses originate at the same point and terminate together, the pulse stream itself is satisfactory to lock terminal timing clocks together. But with more complex systems having terminals thousands of miles apart, this is not practical.

Ideally, the various channel banks and coders feeding into the T4 network should be allowed to operate on their own clocks, which will vary slightly from the normal frequency.

One approach being studied at Bell Labs which will allow this independent action is called *pulse stuffing.* At certain intervals an extra time slot is "stuffed" into the digital stream. Because the presence of stuffed pulses is indicated by other coding on the line, these extra pulses are ignored at the receive end. But during transmission they have allowed the incoming signals to get onto the line even though their individual synchronization does not exactly agree. In a way, the stuffed pulses are a buffer between frames of different channel banks. The end terminal is capable of separating these frames and re-creating the synchronization necessary for that particular group of channels.

The basic elements for the implementation of systems beyond the T1 exist – some in operating systems, some in the laboratory. Introduction of the D2 channel bank is imminent, and the T2 transmission system probably is only several years away.

An experimental high-speed system, operating at 224 Mb/s, has been in operation at Bell Labs for over a year. But the T4 system as outlined must still be considered just a concept.

(The April issue of the *Demodulator* will discuss several additional facets of pulse code modulation, including data capabilities, the repeatered line, fault location at repeater sites, and PCM switching.)

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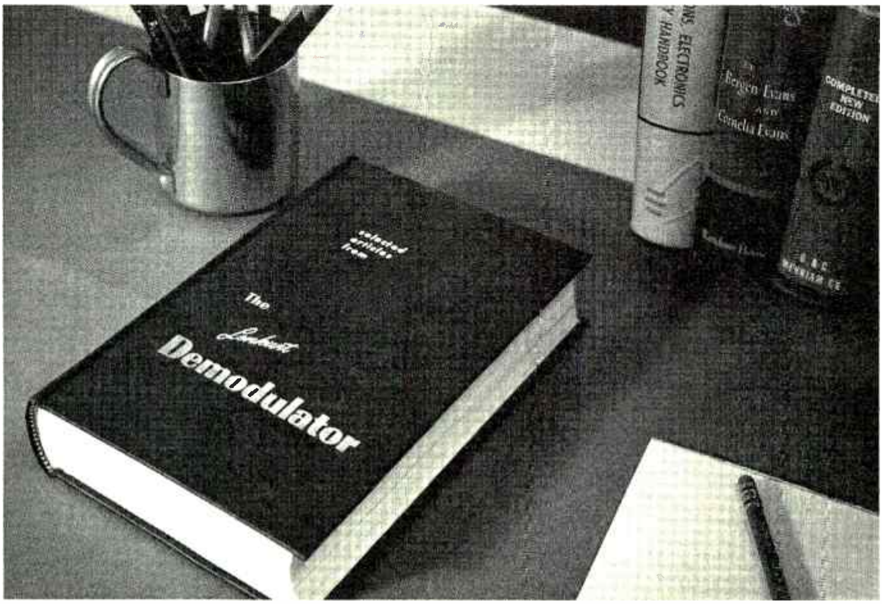

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