The Lenkurt® Demodulator

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TIME SHARING

Growing Trend in Communications

The constant search for better communications at lower cost has led to new interest in various forms of time sharing. Although the advantages of time sharing have been long appreciated, only recently have techniques appeared which make it attractive for entire communications networks. This article discusses several applications of time sharing and how it may improve the communications systems of the future.

The concept of time sharing is certainly not new. Actually, time sharing is nothing more than several users of a common facility "taking turns." Traffic lights at a busy intersection provide a form of time sharing. Airplanes approaching a busy airport may be "stacked" to allow a single runway to be used by each in turn. This is certainly more economical and practical than building as many runways as needed to let all aircraft land simultaneously.

Telephone subscribers take turns using toll and trunk circuits. The amount of switching equipment in a telephone office and the number of circuits between offices is carefully restricted to meet the requirements of the normally-expected maximum traffic, rather than the maximum possible traffic. If this idea of "taking turns" is extended to carrier equipment and to the method used in central office switching, even greater economies may be achieved.

Time-Division Multiplexing

Many separate channels may be transmitted over a single wire or radio path if some form of multiplexing is used. Frequency-division multiplexing, or carrier, is the most widely used method for accomplishing this. Another method, used far less, is *time-division multiplexing.* Theoretically, both methods produce equal results, neither one requiring more bandwidth than the other, nor having greater vulnerability to noise, in an ideal system.

Until now, frequency multiplexing has been far more practical because simpler techniques were involved.

Frequency-division multiplexing is accomplished by modulating a carrier frequency with the desired signal. A number of these modulated carriers can be applied to a wire or cable pair, or can, in turn, be used to modulate a wide-band radio carrier of much higher frequency.

Time-division multiplexing requires that all channels "take turns" using the common line. Imagine a situation such as diagrammed in Figure 1, where two talkers require connection to their respective listeners, but have only one line available. If the line is rapidly switched from talker *A* and listener *A* to talker *B* and listener *B*, then back again, both share the line.

If the line is switched between the users at too slow a rate, words or syllables in each conversation may be lost. If the rate is increased slightly, both parties may receive all the words and syllables, but still experience distortion because of the loss of some transient sounds and frequencies during switching. If the switching rate is increased so that each circuit is connected several times during each cycle of the highest frequency that the telephone circuit transmits, neither listener will be able to detect any interruption or distortion. Furthermore, there need be no difference in performance between each of the time-multiplexed signals and a direct, uninterrupted connection.

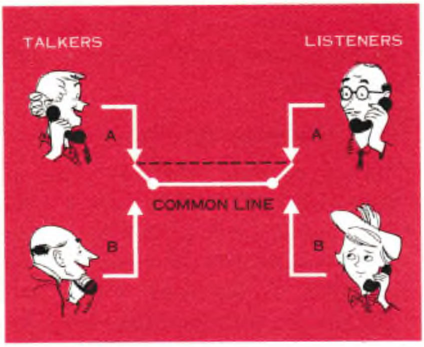

***Figure 1.** Two or more parties may share common line without loss if line is switched to each user at a rate twice the highest frequency that might be transmitted.*

What are the limits to such multiplexing? Researchers have discovered that the necessary sampling rate depends on the highest frequency which must be transmitted. It turns out that a waveform may be perfectly reconstructed if it is sampled at a rate at least twice the highest frequency in the waveform. Thus, a signal may be reconstructed perfectly, without distortion, from samples taken at the rate of 6000 per second. Two samples per cycle allow perfect reproduction because the waveform is inherently unable to assume any surprising or unpredictable values due to the circuit bandwidth limits.

Although telephone channels rarely carry frequencies higher than 3000 cycles per second, the standard telephone channel occupies 4000 cycles. The extra thousand cycles provides a guard band for isolation between channels, and may be used for signaling or other special functions. Therefore, a normal telephone channel would require a sampling rate of 8000 samples per second to completely reproduce all the frequencies it might carry.

A sampling rate of 8000 samples per second requires one sample every 125 microseconds. The shorter the sampling period, the greater the amount of time between samples that might be used for other channels. Shorter pulses, by necessity, have

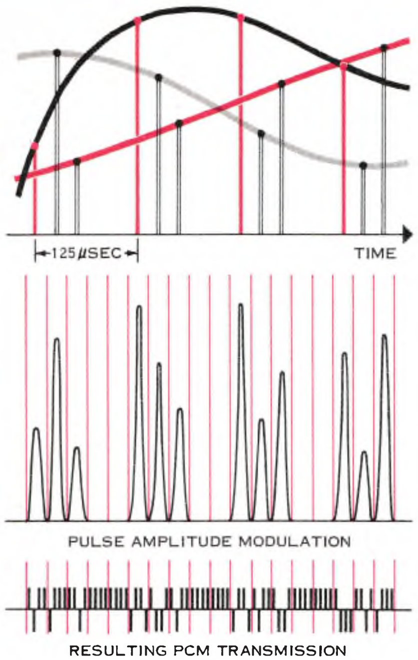

Figure 2. Time between channel samples may be used for carrying samples from other channels. Pulse code transmission increases bandwidth but permits distorted pulses to be completely restored at each repeater.

steeper sides than pulses of longer duration, and this steepness requires more bandwidth for transmission. Insufficient bandwidth tends to "melt" tightly-packed pulses together, thus costing them their identity.

It works out that both time multiplexing and frequency multiplexing require about the same bandwidth. Since the filters of frequency-division systems cannot be made perfect, a guard band must be left between channels to prevent interference. Noise and delay distortion interfere with the transmission of very short pulses, so that they too require operating margin, perhaps a "guard" time interval. Even so, 120 channels might be time-multiplexed by using samples not much briefer than one microsecond, provided that good synchronization is maintained between both ends of the channel.

Pulse Code Modulation

Transmission of such brief pulses presents no particular difficulty over radio, but is considerably more difficult over cable. The very high frequencies involved cause high crosstalk coupling between adjacent cable pairs. Since each pulse represents an amplitude sample, crosstalk tends to change the amplitude of the samples, thus distorting or destroying the message.

A happy solution to this problem is provided by pulse code modulation, a method of converting variable-amplitude signals to digital form. (See DEMODULATOR, *June,* 1959). In this method of modulation, the amplitude range of a signal is divided into a discrete number of steps ("quantized"), and a code combination is assigned to each step. If the code is a binary code, that is, a code having only two states such as mark and space, the transmission is extremely resistant to noise or crosstalk interference, much more so even than frequency-modulated signals. The price paid for this noise advantage is increased bandwidth.

The greater the number of amplitude values or steps to be recognized and transmitted, the greater the number of code elements or digits that must be transmitted for each sample. Since a code combination is used to represent the value of each sample, the number of individual values must be limited, or else the code becomes too long and cumbersome. Accordingly, each code combination is assigned a *range* of values. Naturally, the greater the number of these steps, the smaller the amplitude range that each must cover, and the truer the reproduction of the original signal.

If a binary code is used, the number of amplitude values which may be distinguished is 2^n, where n is the number of digits required for each sample. Thus, a five-digit code can represent 2^5 or 32 amplitude levels, and a six-digit code permits 64 levels. In addition to achieving greater fidelity in reproducing the original signal, each additional digit provides a 6-db noise advantage, but increases bandwidth in proportion to the total number of digits. For instance, a four-digit pulse code could convey sixteen different amplitude values of a signal, but would require four times the bandwidth of an amplitude-modulated transmission. However, it could tolerate 24 db more noise for a given freedom from error. Similarly, a seven-digit code would tolerate 42 db more noise than an AM signal, could transmit 128 different levels, but would require seven times the bandwidth. By contrast, it is interesting to note that an FM transmission must *double* bandwidth for each 3-db noise improvement. Therefore, to obtain a 6-db improvement, an FM transmission requires four times the bandwidth of an AM transmission. To match the 30-db noise advantage of a five-digit pulse-code transmission, FM would require $2^{10}/5$ times the bandwidth of PCM, an increase of more than 200 times!

The tremendous ability of PCM to overcome noise and crosstalk interference has suggested the possibility that a PCM system could be designed that would actually reduce frequency occupancy. Channels could be stacked together without the guard band so necessary in most other modulation methods. Due to the ability of PCM to overcome interference, channels might even overlap to a certain extent. PCM's ability to overcome noise is dramatically illustrated in Figure 3.

ORIGINAL PHOTO AMPLITUDE MODULATION PULSE CODE MODULATION

Figure 3. Comparison of transmission by amplitude modulation and pulse code modulation. Both transmissions were made under identical conditions of noise and transmitting power (4 db signal-to-noise ratio). Improved transmission by PCM is obtained at expense of bandwidth.

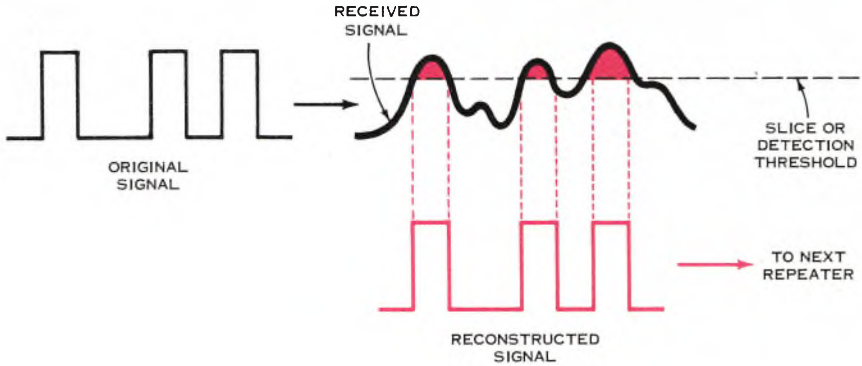

Figure 4. PCM transmission conveys information by presence or absence of pulses, not by pulse shape. Distortion and noise is eliminated by regenerative repeater if it can accurately detect presence or absence of pulses. Reconstructed pulses are synchronously generated to avoid timing errors.

New Pulses for Old

One of the most appealing qualities of PCM is that by using repeaters which regenerate the code pulses, messages can be sent any distance, through any number of repeaters, without acquiring any additional distortion or noise whatsoever. A 3000-mile call would be just as clear and noise-free as a call to a neighbor. All calls would have a standard quality and the distinction between "toll quality" and local or trunk quality equipment would disappear.

Since message information is carried by the presence or absence of pulses, rather than by their shape, regenerative repeaters eliminate the relentless addition of noise and distortion which characterizes all other transmission methods. A regenerative repeater detects only the presence or absence of the distorted pulse and replaces it with a new pulse having the same shape and timing as the one originally transmitted. Repeaters must be spaced close enough that no pulses are so obscured by noise or distortion that they cannot be detected accurately and regenerated.

Electronic Switching

One of the most important factors stimulating interest in time sharing and PCM is their extreme compatibility with electronic switching. The development of semiconductor components having very high reliability and consuming only tiny amounts of current, show the way toward far better and faster service, even while reducing the size and cost of switching equipment. Military communications systems for tactical use already employ electronic switching centers, and several prototype electronic exchanges are going into commercial service.

Most electronic switching centers use the principle of time sharing. Conventional switching methods require that an interconnection be provided for every possible combination of subscriber's lines and trunk circuits, as diagrammed in Figure 5. Note that 45 crosspoints are required to permit any one of the nine telephones to be connected to any one of the five trunk circuits.

An electronic switching network may employ a "memory" to avoid the need for the crosspoints. Instead of 45 crosspoints, only fourteen "gates" are required. In effect, the memory repeatedly scans the gates representing the nine telephones and the five trunk circuits. Each telephone is assigned a specific "time" in each scan. To make a connection between telephone "4" and trunk "B," for instance, the memory has only to open the gate representing trunk B at the regular time that gate "4" opens. It is this recurrent switching that makes the combination of time-division multiplex and electronic switching so compatible. Since certain identical functions, such as synchronization and pulse generation, are required by both, an integrated system would provide substantial savings in equipment and performance over similar systems in which multiplex and switching were provided separately.

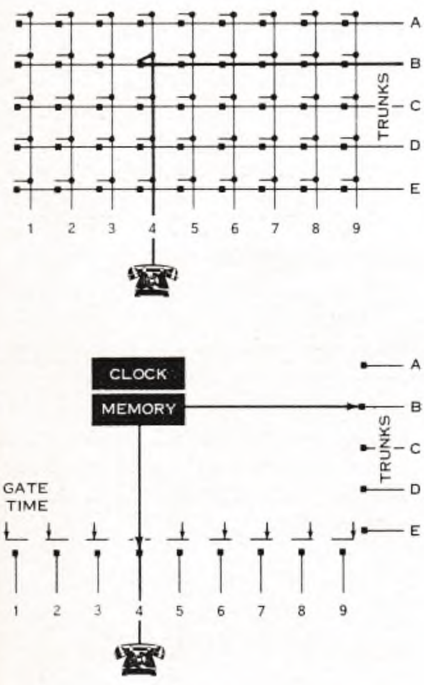

Figure 5. Physical switching requires 45 switches in this example. Electronic system uses only 14 "gates", opened and closed at correct instant by electronic "memory."

The *Bell Laboratories Record* speculates that we might ". . . some day have a 'super' transmission plan based largely on PCM techniques. Fairly small numbers of PCM channels might be assembled into larger and larger groups in coaxial cables, and finally combined for transmission over 'backbone' waveguide routes at information rates perhaps as high as a trillion bits per second. This large capacity would include thousands of telephone conversations, many channels for data, teletypewriter, and other special services."

Despite the special advantage of these new methods, it is not likely that there will be any sudden change in the switching and multiplexing methods now used in telephone systems. New methods will be introduced gradually, in such a way as to be fully compatible with existing plant and transmission methods.

An excellent example of how new methods may be introduced on a fully compatible basis is the time-division signaling used in the new Type 81A Exchange Carrier equipment. Time-division signaling is used in order to reduce the complexity of channelizing equipment, thus increasing reliability and reducing the space required for each system. Each of the 24 channels is assigned a specific "time slot" for signaling. When an individual channel has a signal to transmit, such as a dial

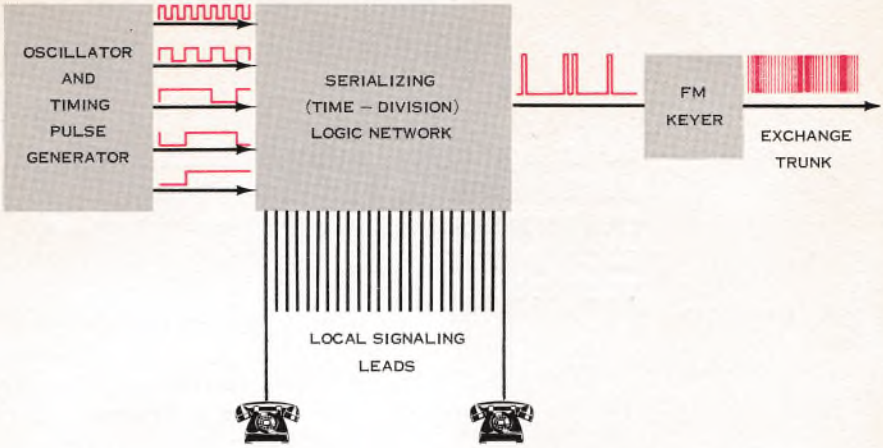

Figure 6. Type 81A Exchange Carrier system employs time-division for signaling. Each local line is assigned its own "time slot." Local signals from all 24 telephones are carried in special binary FM signaling channel.

pulse or ringback signal, a signaling pulse is transmitted only during the time assigned that channel. All 24 channels are scanned 500 times a second, and the resultant signal pulses are transmitted over a single FM binary signaling channel on a frequency slightly above the baseband. Since the fastest dial pulsing rate that might be transmitted over this system is about 20 pulses per second, each dial pulse is scanned at least 25 times, and a signaling pulse is transmitted on each scan. Should a noise "hit" on the line destroy two or three scanning pulses at the beginning or end of a dial pulse, the worst that happens is that dial pulse bias is changed momentarily. If the noise hit occurs in the middle of a dial pulse, nothing at all happens to the signal.

This approach considerably reduces the amount of equipment devoted to signaling in the sytsem. Although the common equipment is somewhat more elaborate, each channel requires fewer components and less space. The use of simple logic circuits and highly reliable semiconductor components, in the fashion of modern computers, provides a high degree of reliability which is in keeping with the best telephone industry traditions. •

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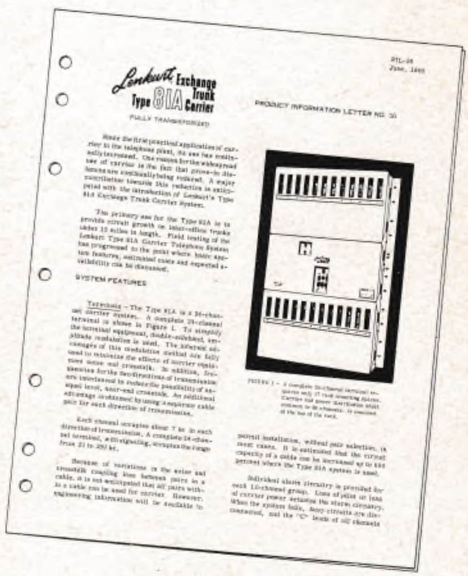
Exchange Carrier Information

Lenkurt's new, low-cost Type 81A Exchange Trunk Carrier System is described in *Product Information Letter No. 30*, just released. The letter provides general descriptive information about 81A, its transmission performance, physical characteristics, and availability. Copies are available on request from Lenkurt or Lenkurt distributors.



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