GTE LENKURT

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EXTENDED LENGTH PCM SYSTEMS

Since PCM carrier systems were introduced several years ago, the recommended maximum length of the 1.5-Mbs, T1-type repeatered line has been held conservatively at approximately 50 miles. Recent calculations and field measurements indicate that this length can be extended to 200 to 300 miles.

The first PCM systems were designed for use as metropolitan, toll-connecting type of carriers. Today, with a need for longer PCM systems, the previous 50-mile PCM line limit is getting a second look by manufacturers of telecommunications equipment.

Recently, telephone operating companies have found it advantageous to design much longer exchange or toll-connecting trunks in rural areas. This has come about as a result of the increasing popularity of PCM systems. Thus PCM is being considered for expansion on routes being served by open wire, older cable carrier systems, or even radio. While this is most prevalent in the more sparsely settled areas, the concept is certain to spread. This has made it necessary to establish the limits by which the proper functioning of a PCM system is bound. In this light, new calculations have been made and experiments conducted by GTE Lenkurt, in an effort to determine the maximum number of PCM repeaters that may be placed in tandem, while still retaining proper operating conditions. Some factors which were considered as possible limiting elements were: (1) powering characteristics, (2) fault location, and (3) phase jitter. The powering characteristics are mainly the problems connected with bringing dc power to the repeaters. This did not prove to be a limiting factor, since power stations are usually available along the line. Location of faults along an extended line was also found not to be a limiting factor. In the final analysis, it was found that phase jitter was the limiting factor to the establishment of extended PCM systems.

Phase Jitter

Phase jitter is an abrupt variation in the phase of the PCM signal, and may be caused by such things as impulse noise, noise from other systems, and pulse pattern changes in the digital bit stream (see Figure 1A). At the input of a repeater, the incoming bit stream is fed into an LC tank circuit. This causes an energy transfer such that the clock can be kept going at a fixed rate, even if there is a series of zeros in between. It is necessary that the incoming pulses and the clock pulse occur at the same time. Phase jitter can offset a PCM pulse far enough that it may not be detected by the clock pulse, thus causing an error in the system.

The timing or clock for the repeatered line is recovered from the incoming PCM signal. This clock is used to generate sampling spikes which should properly sample at the center of the incoming pulse, as shown in Figure 1B. It might be surmised that if the clock stays in the same position, then there is less margin of detecting a pulse, because of the phase jitter on that pulse. This is true in the case of high-frequency jitter (jitter caused by impulse noise, or noise from other

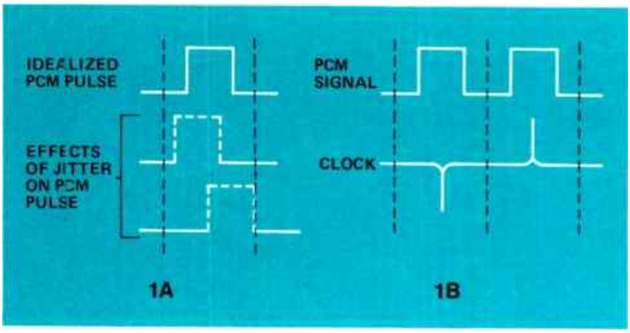

Figure 1A. Phase jitter causes a variation in the phase of the PCM signal.

Figure 1B. Clock timing pulses should sample at the center of the incoming pulses.

systems). But generally, what passes on down the repeatered line is low-frequency jitter. which is the most common type of phase jitter and which is mainly caused by changes in the pulse patterns of a system. Since pulse patterns are constantly changing in a PCM system, there will be a constant source of low frequency jitter. However, this type of jitter is relatively tolerable in an extended length PCM system, since the clock moves back and forth with the change in pulse pattern. This is possible because the clock is a regenerated one, rather than a crystal-controlled internal clock. The result of this is that the clock pulse will sample the incoming pulses at their center, as is desirable. (See the February, 1973 issue of the Demodulator for further information on PCM repeatered line operation.)

Multiplexers and Jitter

Basically, what jitter does is change the instantaneous frequency on the line to some frequency above or below the nominal frequency. According to recent calculations and experiments, it has been found that with stable repeaters, phase jitter on the repeaters does not place a limit on the length of the line between terminals. However, phase jitter does place a limit on the length of a PCM line when two or more lower speed PCM lines are multiplexed to one higher speed PCM line. It is actually the multiplexing that limits the length of the PCM line. At the input to a PCM multiplexer, only a limited range of frequency change above or below the nominal line frequency of 1.544 Mbs can be tolerated. If jitter causes a frequency outside that range, then the multiplexer will cause errors.

When a pattern shift occurs, it will shift the pulses back and forth approximately two nanoseconds per repeater. And, because there are a series of regenerative repeaters in a PCM line, each one of them shifts the same amount. Recent tests have shown that two PCM channel banks, with stable repeaters, such as the GTE Lenkurt 9101C, can operate practically as well with 500 or more miles of repeatered line separating them as they can when operating back-to-back. However, the limit of the length of the repeatered line has been shown to be about 200 repeaters, if a multiplexer is to be used. Since many PCM systems will eventually be used in conjunction with multiplexers, a maximum of 200 repeaters is recommended between terminals, so that an eventual transition to a multiplexed system may be simplified. It should be noted that jitter considerations limit the number of repeaters on a T1 line, and not the length of the line in miles. Thus, with 5360-foot spacing between repeaters, 200 repeaters could extend for 200

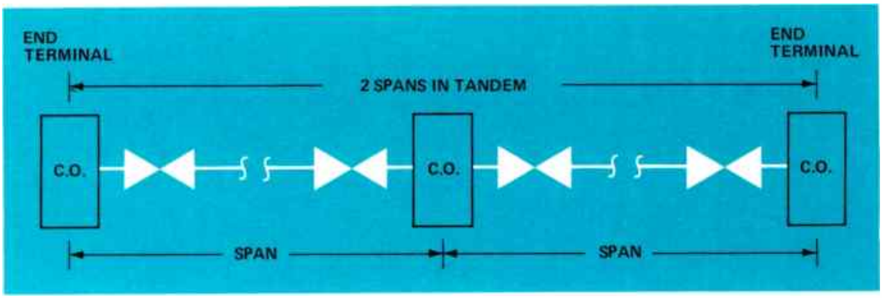

Figure 2. As it becomes necessary to increase the length of repeatered lines, several spans can be placed in tandem.

miles, but with 7900-foot spacing, 200 repeaters could extend for 300 miles.

Limitations in Repeater Spacing

As longer repeatered lines are needed, several "spans" will necessarily be place in tandem. (A span includes all the repeaters between two central offices, which provide powering and maintenance facilities, see Figure 2.)

The maximum repeater spacing within a span is determined by the allowable error rate. This error rate, in turn, is determined by the number of tandem spans, type of cable, placement of transmission pairs within the cable (crosstalk coupling loss), and proximity of repeater pairs to a central office. The total error rate between two end terminals separated by several tandem spans is essentially the sum of the individual span error rates.

The maximum error rate between two end terminals providing good voice communications is generally accepted to be 1×10^{-6}. The error rate is the total amount of information in error that is caused by the transmission media, divided by the total amount of information received. An error rate of 1×10^{-6} would mean that there is one error in one million units of information. A common error rate objective per span has been 3×10^{-7}. Thus, if all span lines were to operate at their maximum error rate, only three spans in tandem could be allowed in a system.

To determine if repeater spacing should be more conservative with many spans in tandem, repeater spacings were calculated for several cable types with 1, 3, and 10 spans in tandem.

A criterion was used which calls for a reduction in error rate per span as tandem spans are added, so that all spans can operate at this error rate without the overall error rate exceeding 1×10^{-6}. Thus, for one span, the allowed span error rate is 1×10^{-6}; for 3 spans in tandem, the allowed error rate is 3×10^{-7} per span; and for 10 spans in tandem, the allowed error rate is 1×10^{-7} per span.

The allowed error rate per span is further apportioned over each span by allowing each of its two end sections (between an office and first repeater) to have 1/3 of the total span error rate and by allowing the section between the first and last repeater in a span to have the remaining 1/3 of the total span error rate.

Once these maximum span section error rates have been calculated for a fixed length system, the maximum repeater spacing allowable to achieve these error rate objectives can be calculated based on the limiting source of line interference. In one-cable operation, near-end crosstalk is the most serious type of line interference encountered on the midsections of a span. In two-cable operation, far-end crosstalk is the most serious type of line interference encountered on mid-sections. In both one and two-cable operation, end-section line interference is due to office impulse noise.

Although each cable is different, a typical result showing maximum mid-section repeater spacing for one of the cable types considered, is shown in Figure 3. This shows that mid-section repeater spacing with up to 10 spans in tandem does not need to be significantly more conservative than when calculated using the present standard method (i.e. span error rate of 3 x 10^{-7}, or 3 spans in tandem). For several types of cable considered, the mid-section spacing for 10 spans in tandem was only between 100 and 150 feet shorter than for 3 spans in tandem. However, more conservative end-section repeater spacing is required with multiple tandem spans. Figure 4 shows the end section of a repeatered line.

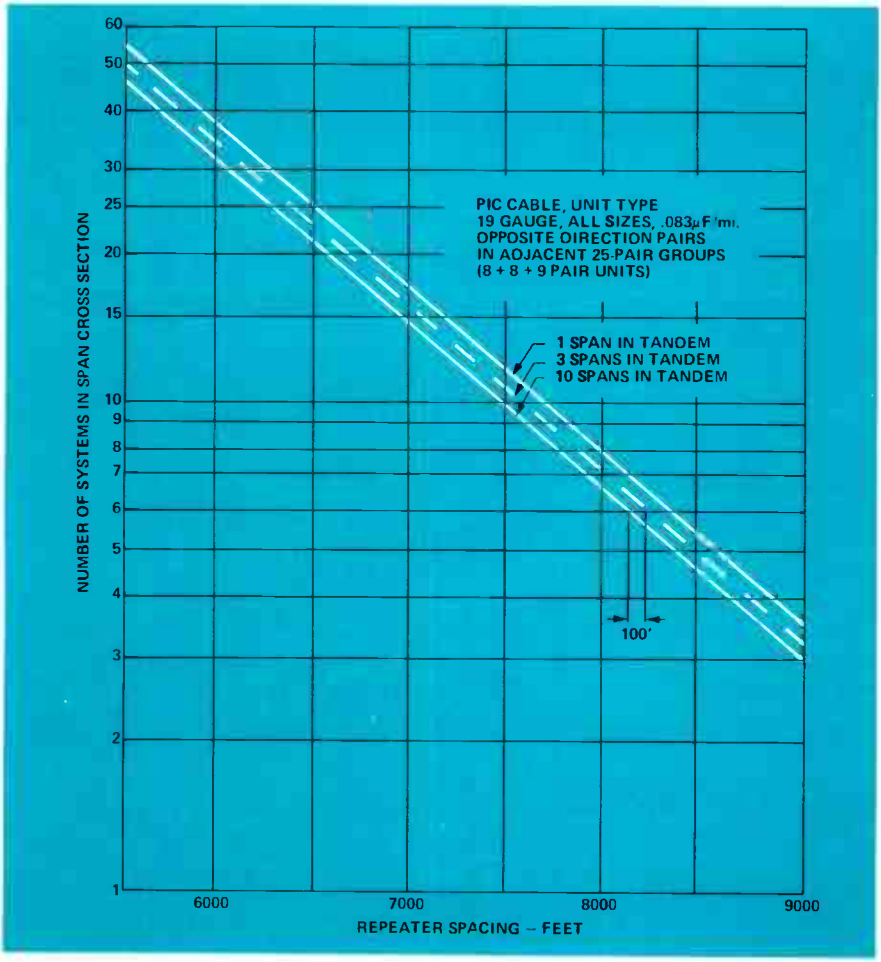

Figure 3. Mid-section repeater spacing with up to 10 spans in tandem does not differ significantly from present standards.

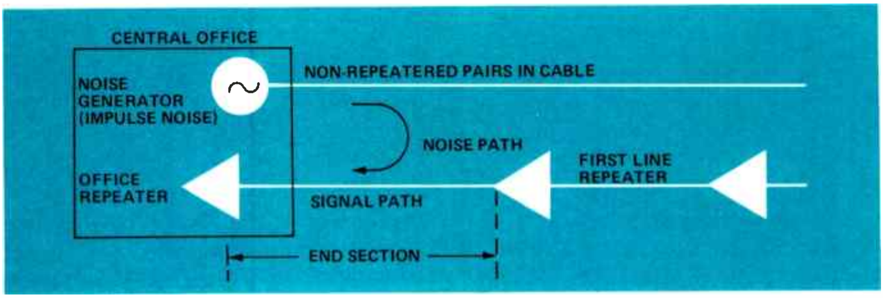

Figure 4. More conservative end-section repeater spacing is required with an increase in tandem spans.

The signal-to-noise ratio and therefore the error rate of an office repeater, is governed by the difference between noise path loss and signal path loss in the end-section of the repeatered line (see Figure 5). With the noise path loss arbitrarily taken to be 75dB for nearly any cable case, the allowable end section loss can be calculated based on the desired error rate. Using the graph of Figure 5 for error rate vs. difference in loss of signal and noise path, the allowable end section loss can be calculated for various error rates. As the number of tandem spans increases, the lower allowed end section error rates cause the end section repeater spacings to be shortened (see in Figure 6). For example, to attain an error rate of 1×10^{-7}, the difference would be approximately 52dB. Since the voice path loss is assumed to be 75dB, then 75dB – 52dB equals an end-section loss of 23dB. Using the same calculation for an end section error rate of 5×10^{-8}, the end section loss would be, 75dB – 55dB = 20dB.

Administrative considerations

With a repeatered line length limitation of about 200 repeaters, the number of spans could become very large (as well as the corresponding number of intermediate offices).

There are several administrative and service quality considerations which must be kept in mind when planning for many spans. These are mainly management problems and are more closely related to the number of intermediate offices in the complete line rather than to the number of repeaters.

Some of these are:

(1) the chance of excessive "down time" during a span failure while the faulty span is located and the system is patched to a spare line

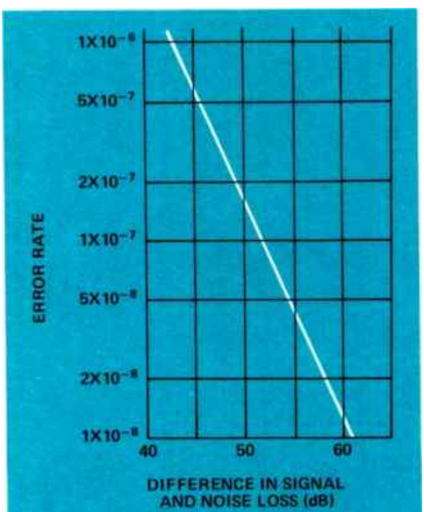

Figure 5. The error rate of an office repeater is governed by the difference between noise path loss and signal path loss in the end-section of a repeatered line.

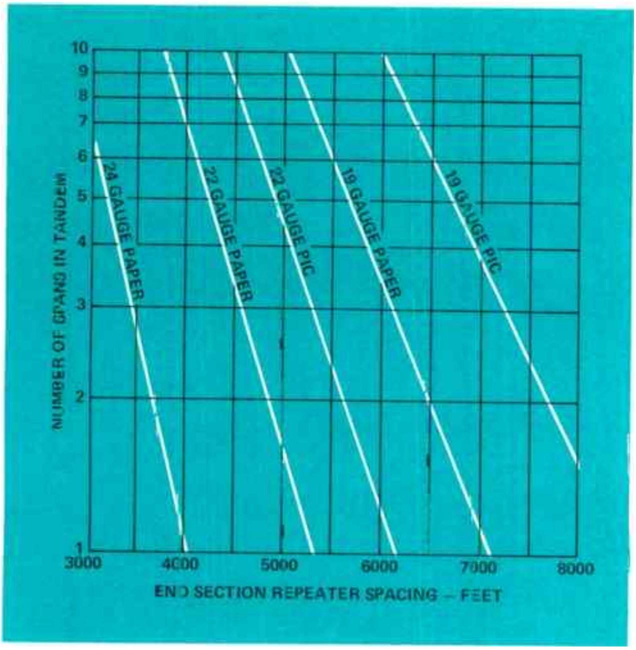

Figure 6. Maximum allowable end-section repeaters spacing for various numbers of spans and cable sizes.

(2) spans have to be divided because of administrative differences in central offices or because of area boundaries

(3) accurate record keeping becomes increasingly difficult as more offices are added, where each office requires a complete set of records for the systems entering and leaving it

(4) the possibility of human error causing system failures increases as intermediate offices (and particularly patching jack facilities) are added

With these and other considerations, it is well to keep the number of intermediate offices to a minimum in a long system, so that the administrative considerations will not impose an undue burden on system lengths.

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GTE LENKURT
1105 COUNTY ROAD
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