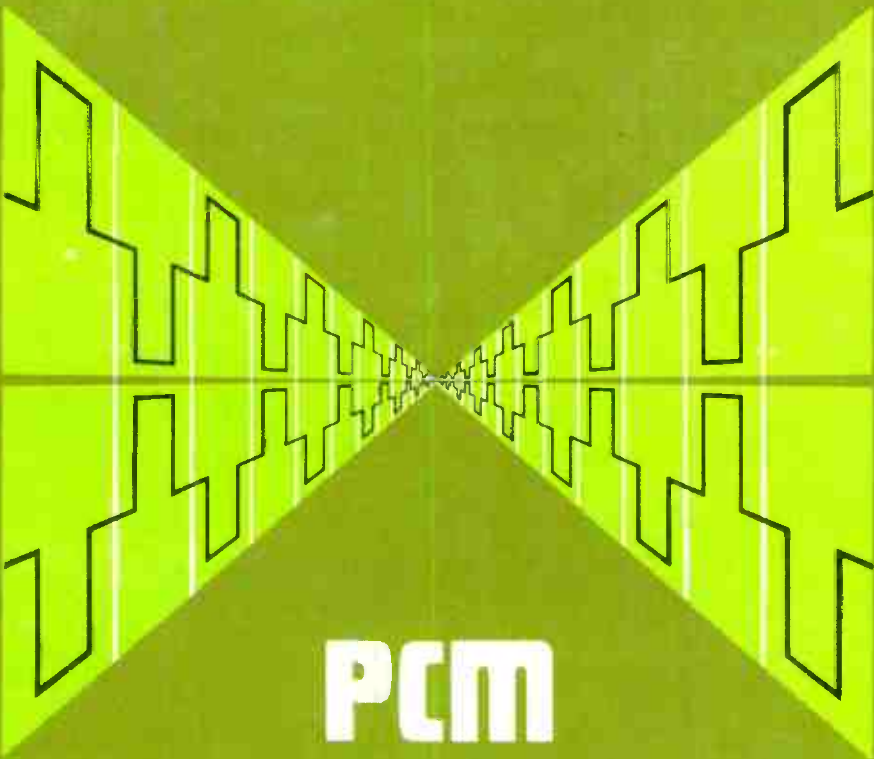
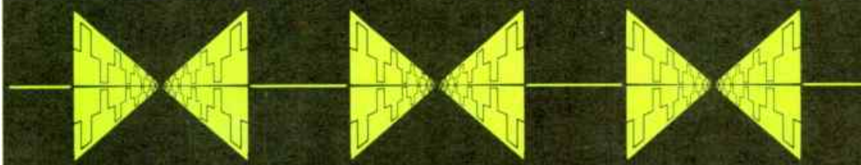
GTE LENKURT

DEMODULATOR

MARCH 1974



PCM Field Study



A field study has substantiated the theory that well designed PCM repeaters may be placed in tandem well in excess of the 50 to 100 miles previously recommended.

Theory indicates that the length of a PCM (pulse code modulation) repeatered line is not limited. But, when several low-speed PCM lines are to be multiplexed into one high-speed line, low-frequency phase jitter, which arises when pulse-pattern changes take place, does limit the line to about 200 repeaters. Since phase jitter has the effect of momentarily speeding up or slowing down the pulse stream, errors will be created in the output bit stream of a PCM multiplexer if the elastic store of the system either overflows (too fast for too long) or empties out (too slow for too long). (See the *GTE Lenkurt Demodulator* for February, 1974.) Accepting these theories, a field study was undertaken to substantiate them.

The particular span that was available for this study afforded an opportunity to build up a tandem system of 650 regenerators (repeaters), extending for 1000 miles. Until this time, no published data was known to exist for systems in excess of about 100 miles, and available recommendations on system design traditionally limited the lengths to between 50 and 100 miles. The opportunity to measure performance in an actual system containing more than 200 regenerators was unique, both as a validation of the theoretical results and as a contribution to new design philosophies for T1-type carrier systems.

Test Line

The span to be used for this study was a dedicated T1 carrier facility between two class 5 offices, twenty miles apart. The cable used was new, 19-gauge, gel-filled, polyethylene-insulated, D-screen cable. It was totally buried except for the end sections, which were in conduit. Two sets of repeaters—one for each direction of transmission—were located in manholes, in pressure-type housings. The repeater spacing, which averaged 8900 feet, allowed for temperature build-up and for the anticipated 100% fill of the cable. Figure 1 shows the repeatered line layout used for the field study.

PCM repeaters, such as the GTE Lenkurt 9101C, are actually two regenerators in one enclosure, each side generally being used for opposite directions of transmission. However, both sides of the repeater can also be made to operate in the same direction. Because of the configuration of the

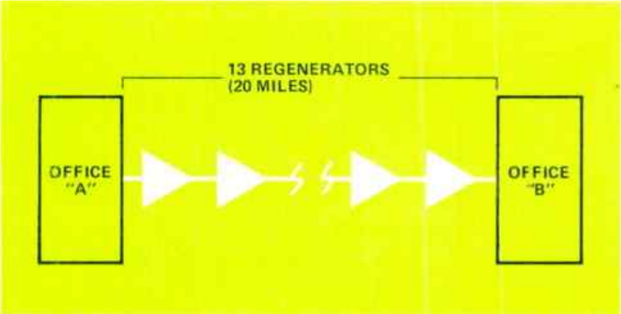


Figure 1. The field study was conducted between two terminals 20 miles apart.

splicing plan, a 500-mile, two-way system (325 repeaters), or a 1000-mile, one-way system (650 regenerators), could be assembled. This permitted measurement of the accumulation of phase jitter as the length of the line was increased.

Test Signal

All the testing was done at office "A", with alternate pairs looped back at office "B". This provided 40-mile increments of 26 regenerators each. The test setup for the facility is shown in Figure 2. Phase jitter was measured from oscilloscope patterns, with a special signal generator providing the driving signal so that jitter caused by pattern changes could be observed. The most prevalent kind of phase distortion in a PCM line is caused by low-frequency phase jitter, which arises when pulse-pattern changes take place.

The special signal generator was constructed to give two pulse-shift patterns. Each output consisted of a 1.544-Mb/s bit stream which had two fixed patterns, with a shift between the patterns at a regular rate. These pulse patterns were as follows (see Figure 3):

1. from one pulse out of eight time slots (1/8) to two pulses out of eight time slots (2/8), shifted at a 2-kHz rate.
2. from one pulse out of eight time slots (1/8) to one pulse out of four time slots (1/4), shifted at a 2 kHz rate.

These pulse-shift patterns were selected to give representative worst-case jitter. With a fixed pattern through all tandem regenerators, each regenerator clock assumes a fixed phase. When the pattern shifts to another fixed pattern, each regenerator clock shifts phase in relation to its previous setting. The phase shift propagates down the line, and is the same for each regenerator.

Study Results

The repeatered line was looped back at office "B" as shown in Figure 2, to allow jitter to be measured in 26-regenerator increments (40 miles), from 26 regenerators to 650 regenerators (1000 miles). The output of the repeatered line at office "A" was displayed on an oscilloscope, with external synchronization supplied by the clock of the signal generator at the input to the line. Low-frequency phase jitter in nanoseconds could be read from the scope as the line length was increased. This would show jitter accumulation. Figure 4 shows a photograph taken from the oscilloscope face which graphically displays the offset of the pulses as the pattern shift takes place (after 26 and 182 regenerators). Figure 5 shows the cumulative jitter as

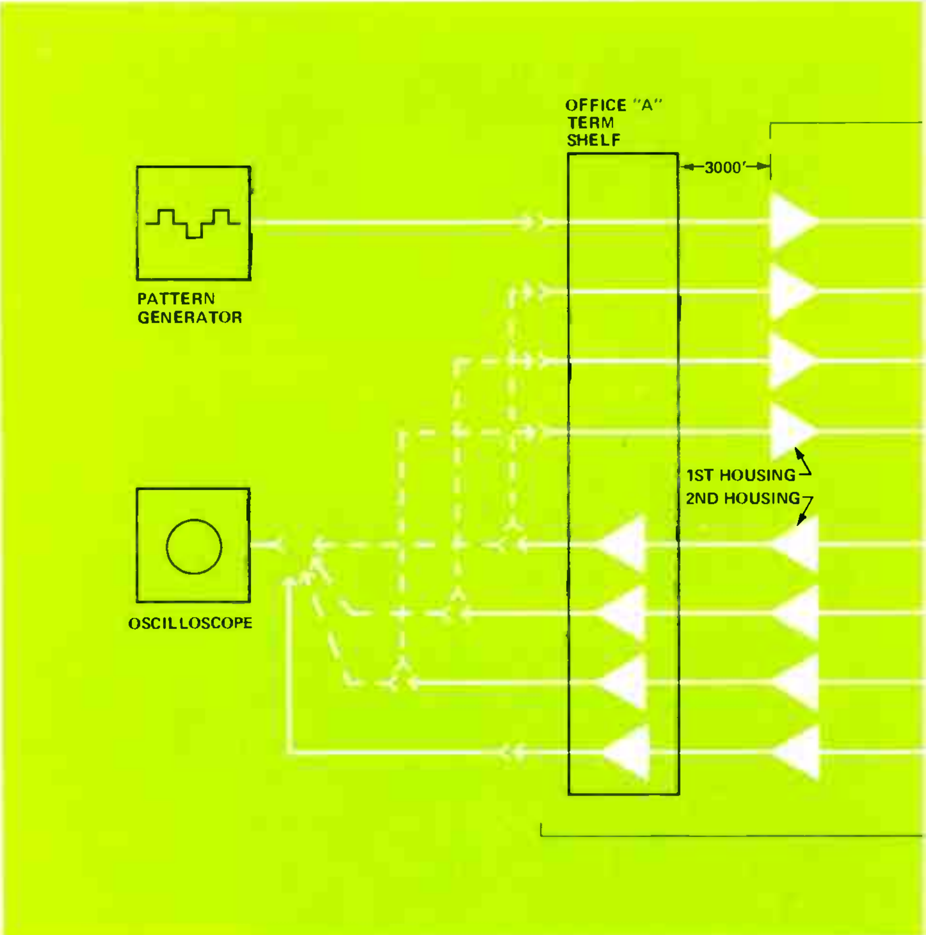
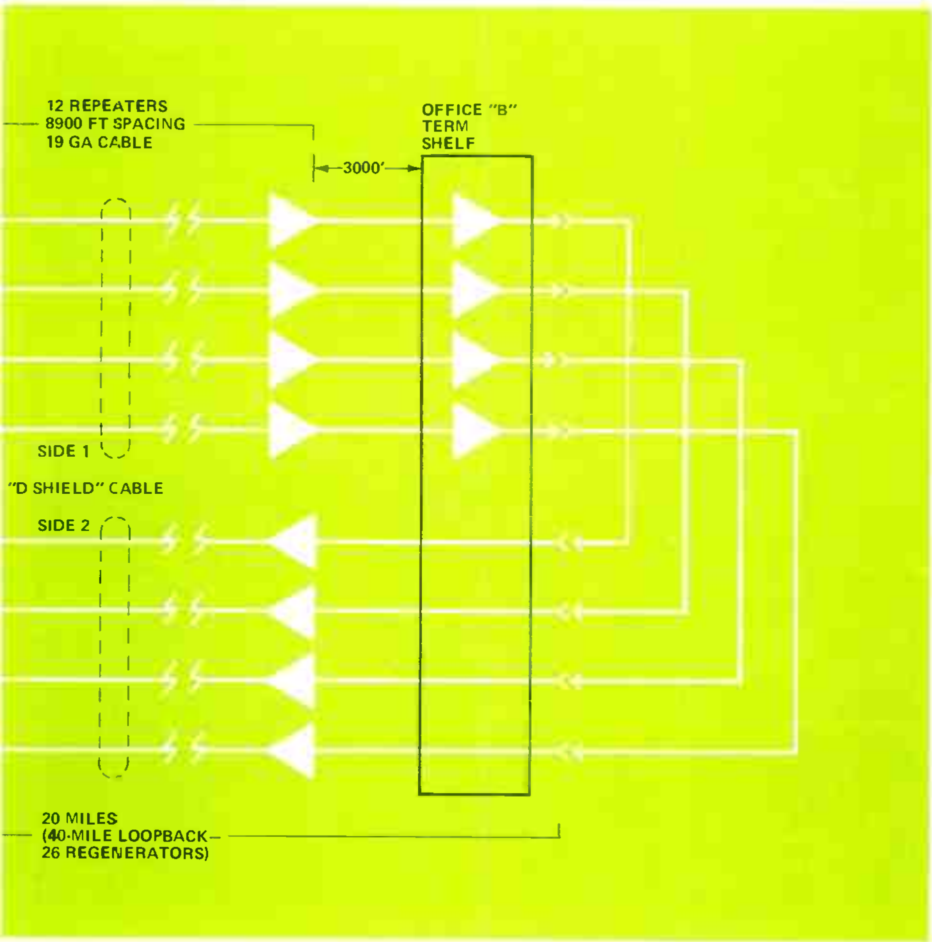


Figure 2. The PCM line was looped back at office "B" to give 40-mile sections in 26-regenerator increments.

the line length increased. Theoretically, low-frequency jitter should be directly additive, with each regenerator adding an equal amount. Calculations made prior to the field study indicated that the worst-case jitter added per GTE Lenkurt 9101C repeater should be about 2-1/2 nanoseconds peak-to-peak, and should add linearly regardless of the number of regenerators in tandem. The measured results in Figure 5 substantiate the expected linearity for the number of tandem regenerators that were measured.

Another cause of phase jitter is the coupling from one side of a repeater (with one pattern) to the other side (with another pattern). A study was made over the 500-mile, two-way system to determine if this effect was significant in the 9101C regenerators. The results of this study showed that any contribution due to this source could be neglected.



Effect on PCM Terminals of Long Repeatered Lines

Theoretically, a PCM terminal should operate without degradation over any length of repeatered line because of the regeneration capability of the line. To test this theory, two 24-channel GTE Lenkurt 9002A terminals were connected end-to-end with a 500-mile repeatered line between them. Idle noise and quantizing distortion were selected as the best figures of merit to indicate whether the terminal was operating properly. Idle noise was measured on all 24 channels at each terminal of the 500-mile system. Compared to a channel bank specification of 23 dBrnc0 maximum, all channels were within 19 to 23 dBrnc0 (averaging approximately 20 dBrnc0). Quantizing distortion was also measured on one channel at each terminal. Quantizing distortion, which is the single most sensitive measurement in a PCM system, proved to be essentially the same as on a looped-back channel bank with no repeatered line connected.

The study conducted showed that (at least for the GTE Lenkurt 9101C

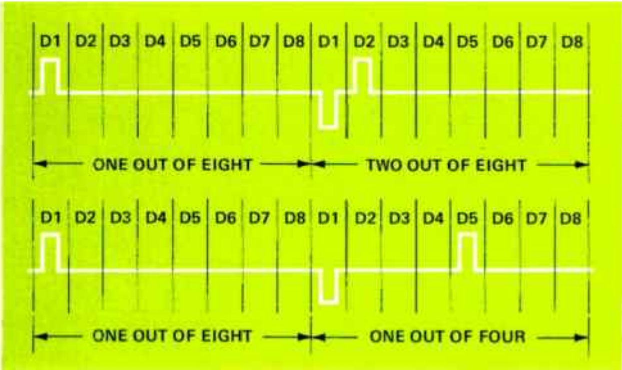


Figure 3. The special signal generator used in the field study had two outputs. One was a pattern shift from one pulse out of eight to two pulses out of eight; the other was from one pulse out of eight to one pulse out of four.

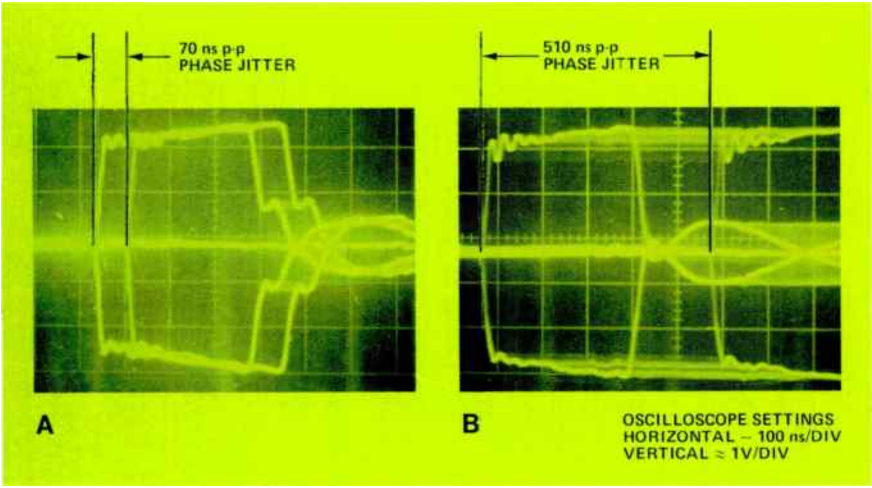


Figure 4. Using the one-out-of-eight to one-out-of-four pattern shift, the cumulative effect of phase jitter can be seen by these two oscilloscope photographs. A is with 26 regenerators and B is with 182 regenerators.

system) channel bank performance is not significantly affected by the number of regenerators placed in tandem, in spite of systematic jitter build up. If indeed there is a practical limit placed on the length of a T1 line between channel banks, it will most likely be imposed by administrative restrictions, not degradation.

The study also verified the calculations that GTE Lenkurt 9101C repeaters contribute some 2-1/2 nanoseconds of phase jitter per regenerator and that it accumulates linearly with the number of tandem repeaters. From this, it has been determined that no more than about 200 repeaters should be used in a single system, if it is anticipated that future multiplexing with multiplexers like the GTE Lenkurt 9120A (3 Mb/s on cable or radio, 6 Mb/s on cable) will take place over T1C (48 channels, 3 Mb/s) or T2 (96 channels, 6 Mb/s) lines.

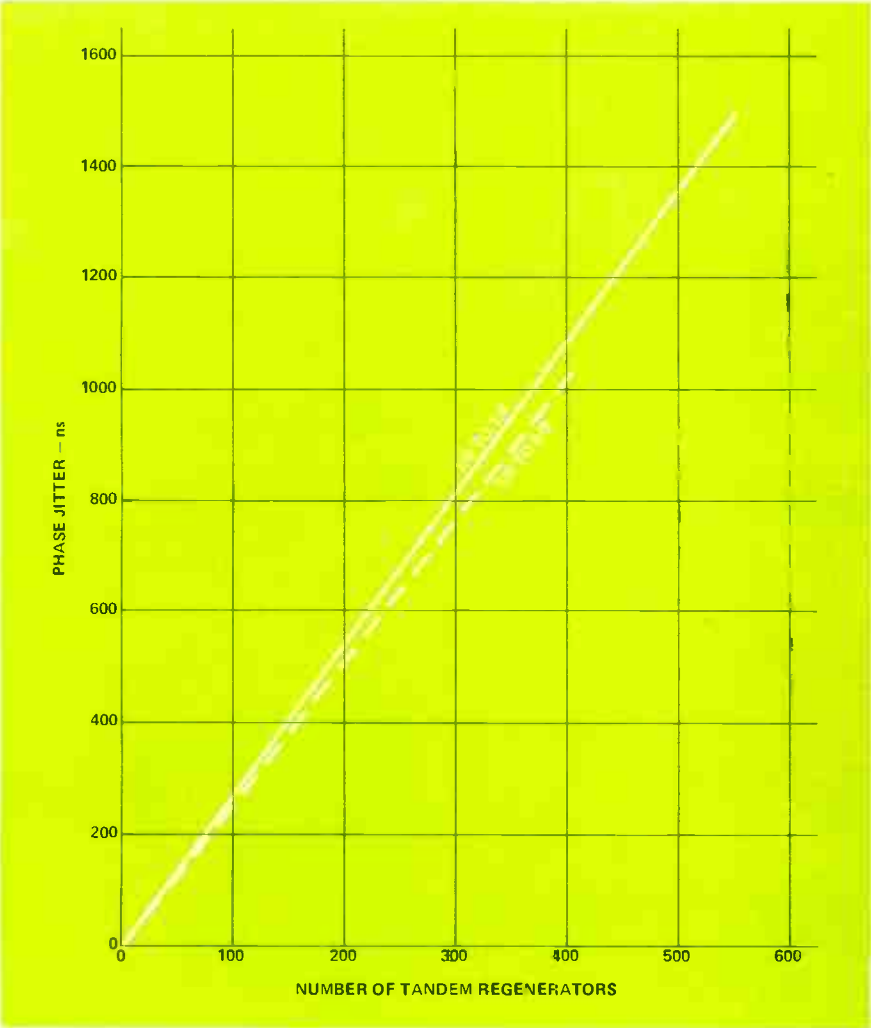


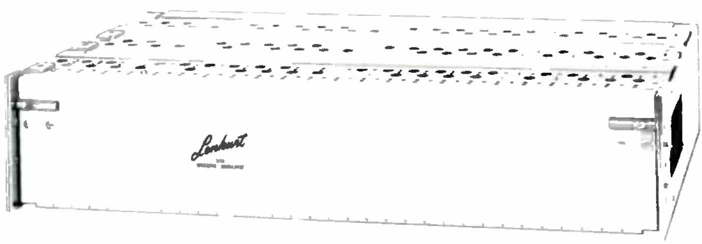
Figure 5. The field study proved that phase jitter adds linearly for both pulse-shift patterns.

BIBLIOGRAPHY

1. Crawforth, L.D. and J.D. Olson. "Maximum T1 Repeatered Line Length Considerations," *International Conference on Communications*, Vol. II, (June 1973), 32-28 32-33.

2. "9101C Repeatered Line Measurements," San Carlos, California: GTE Lenkurt, 1973.

GTE Lenkurt's 970A Wideband Modulator



The 970A Wideband Modulator is an extremely versatile frequency translator that converts the output frequency range of a high-speed data set to a range acceptable to standard carrier and multiplex systems. For more information, write GTE Lenkurt, Dept. C134.

GTE LENKURT

VIDEO, VOICE & DATA
TRANSMISSION SYSTEMS

The GTE Lenkurt Demodulator is circulated monthly to selected technicians, engineers and managers employed by companies or government agencies who use and operate communications systems, and to educational institutions. Permission to reprint granted on request.