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A Million-Cycle Telephone System *

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ABOUT two years ago a new wide-band system for multi-channel telephone transmission over coaxial cables was described.[1] An experimental system has now been installed between New York and Philadelphia. The various tests and trials which are planned for this system have not been carried far enough to justify a formal technical paper. Meanwhile, the considerable interest that has been aroused in the system has led to this brief statement of its principal features and its general technical performance as so far measured.

The coaxial cable itself has been installed between the long distance telephone buildings in New York and Philadelphia, a distance of 94.5 miles. It has been equipped with repeaters, at intervals of about 10 miles, capable of handling a frequency band of about 1,000,000 cycles.

This million-cycle system is designed to handle 240 simultaneous two-way telephone conversations. Only a part of the terminal apparatus has been installed, sufficient in this case to enable adequate tests to be made of the performance of the entire system. A general view of the New York terminal is shown in Fig. 2. Some preliminary test conversations have been held over the system, both in its normal arrangement for providing New York-Philadelphia circuits, and with certain special arrangements whereby the circuit is looped back and forth many times to provide an approximate equivalent of a very long cable circuit. The performance has been up to expectations, and no important technical difficulties have arisen to cast doubt upon the future usefulness of such systems. Much work remains to be done, however, before coaxial systems suitable for general commercial service can be produced.

The Coaxial Cable

Figure 1 shows a photograph of the particular cable used in this installation. It contains two coaxial units, each having a 0.265-inch inside diameter, together with four pairs of 19-gauge paper insulated wires, the whole enclosed in a lead sheath of 7/8-inch outside diameter.

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[1] "Systems for Wide-Band Transmission Over Coaxial Lines" by L. Espenschied and M. E. Strieby, *Bell Sys. Tech. Jour.*, October, 1934; *Elec. Engg.* (*A. I. E. E. Transactions*), Vol. 53, 1934, pages 1371–80.

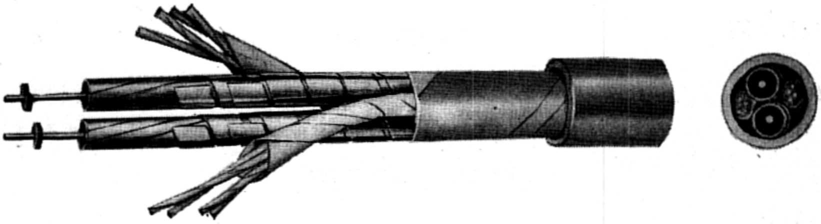

Fig. 1—View showing structure of coaxial cable.

Fig. 2—The New York terminal of the coaxial system.

The central conductor of the coaxial units is a 13-gauge copper wire insulated with hard rubber discs at intervals of 3/4 inch. The outer conductor is made up of nine overlapping copper tapes which form a tube 0.02-inch thick; this is held together with a double wrapping of iron tape.

The transmission losses of this coaxial conductor at various frequencies are shown in Fig. 3. This attenuation is about 4 per cent higher than is calculated for a solid tube of the same dimensions and material. Another matter of importance is the shielding obtained from one conductor to the other or to outside interference. Inasmuch as the most severe requirement is that of crosstalk from one coaxial unit to another, this has been usəd as a criterion of design. Figure 4 shows the average measured high-frequency crosstalk in this particular cable on a 10-mile length without repeaters, both near-end and far-end.

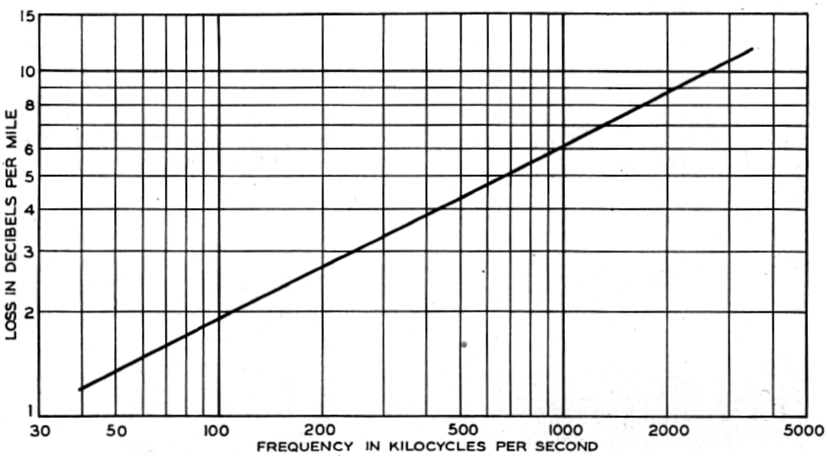

Fig. 3—Attenuation of the coaxial conductor.

Repeaters

The amplifiers used in this system were designed for a 10.5-mile spacing and a frequency range of 60 to 1024 kc. A total of 10 complete two-way repeaters has been provided including those at the terminals. Two of the intermediate repeaters are at existing repeater stations along the route, the other six being at unattended locations along the line. Four of these are in existing manholes, while the other two are placed above ground for a test of such operation. Figure 5 shows a manhole repeater with the cover removed for routine replacement of vacuum tubes. Figure 6 shows one of the installations above ground.

The measured gain of a typical repeater is shown by the points on the curve of Fig. 7. The curve itself is the line loss that the repeater

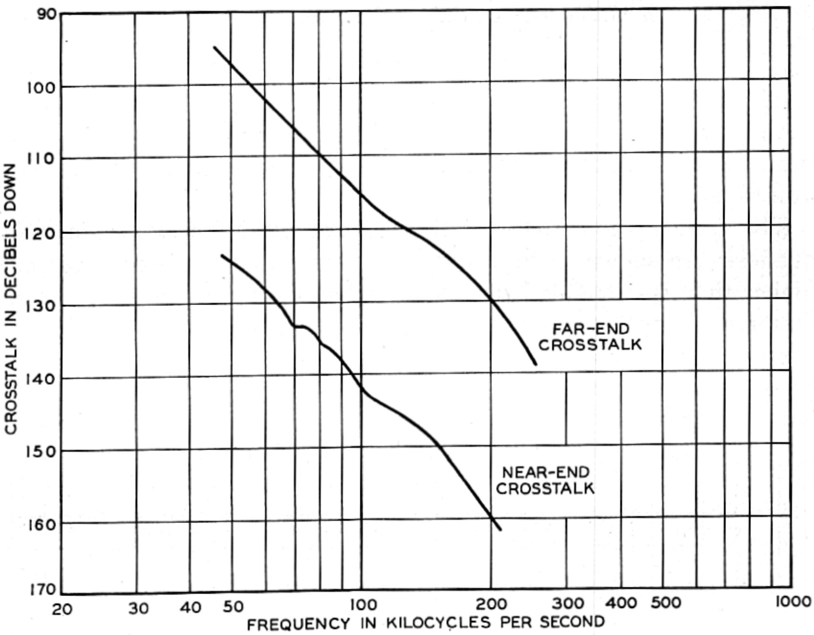

Fig. 4—Crosstalk between the two coaxial conductors in the new cable.

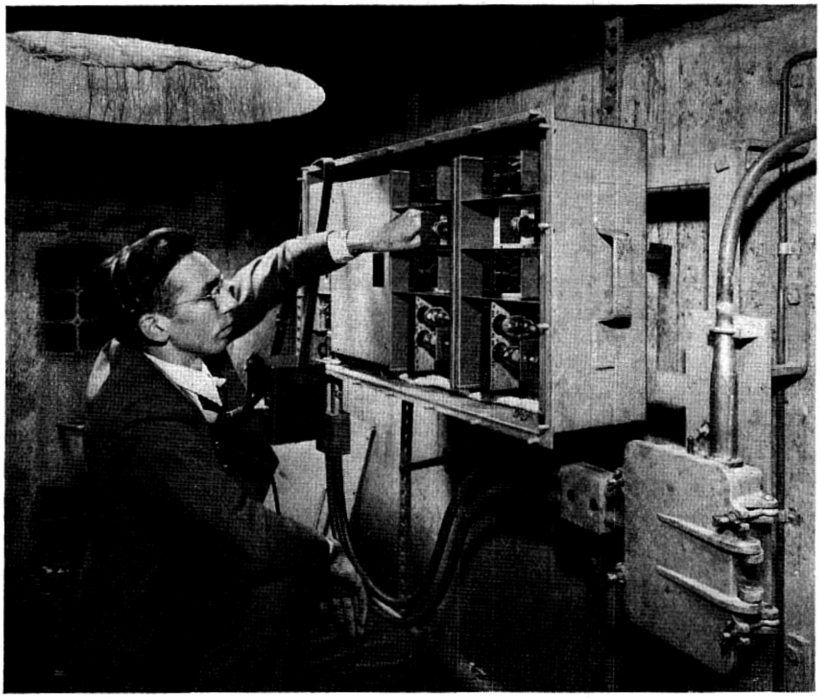
Fig. 5—Million-cycle repeater mounted in a manhole.

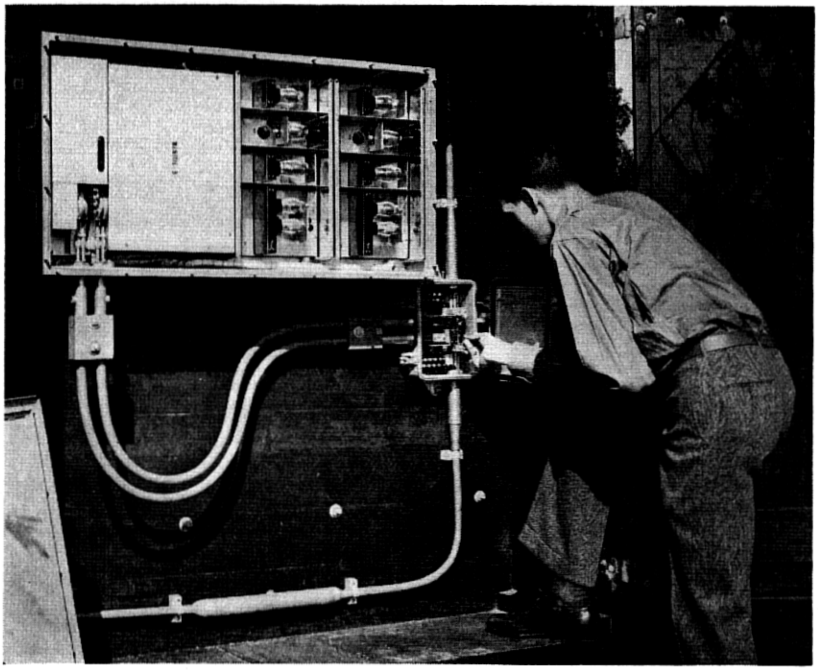

Fig. 6—Installation of coaxial repeater above ground.

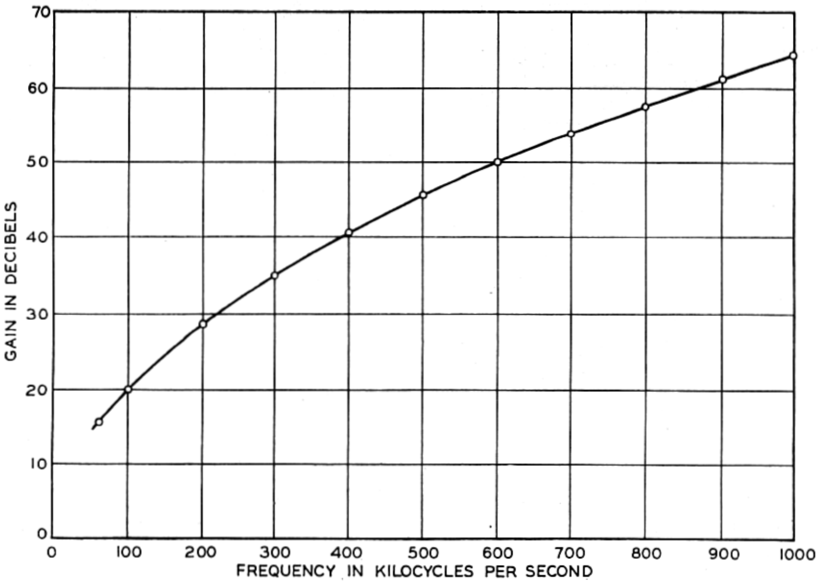

Fig. 7—Gain-frequency characteristic of coaxial repeater.

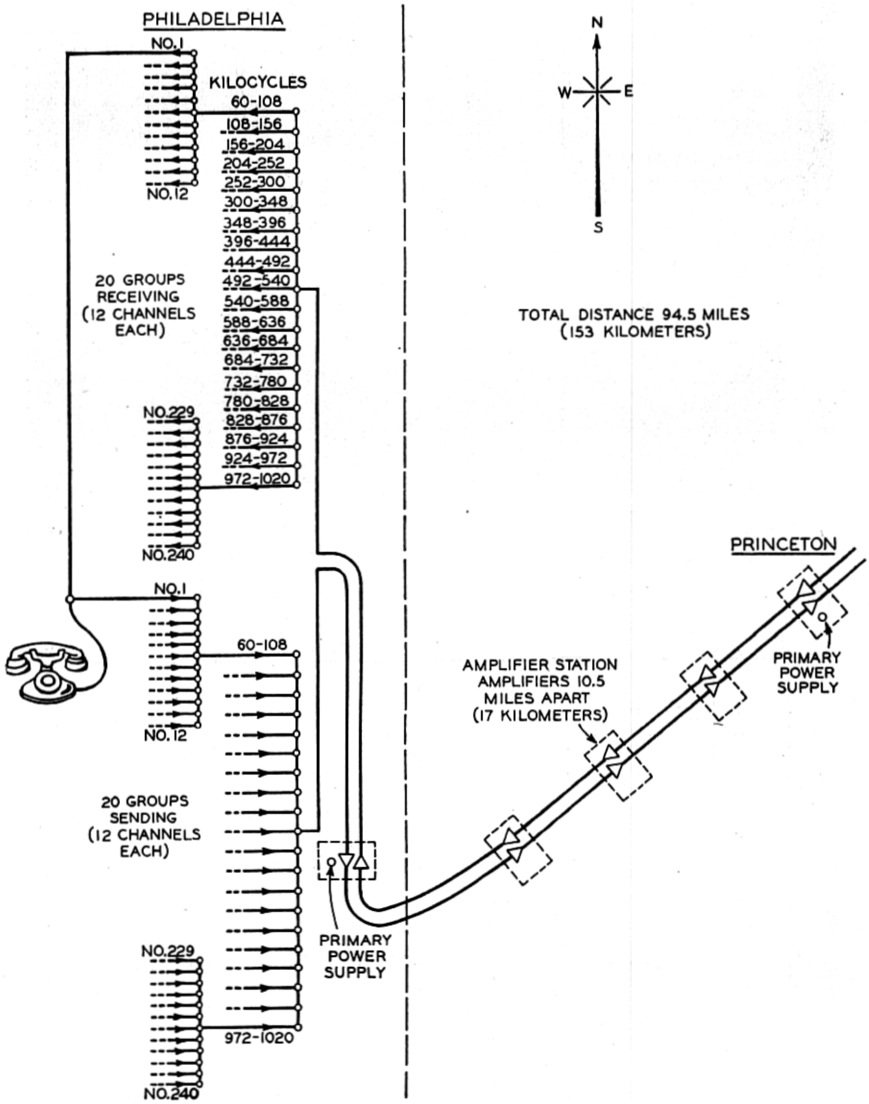

Fig. 8—Frequency characteristic allocation assignments of a typical speech channel. Broad-band system over coaxial cables (240 telephone circuits).—*Continued on page 7.*

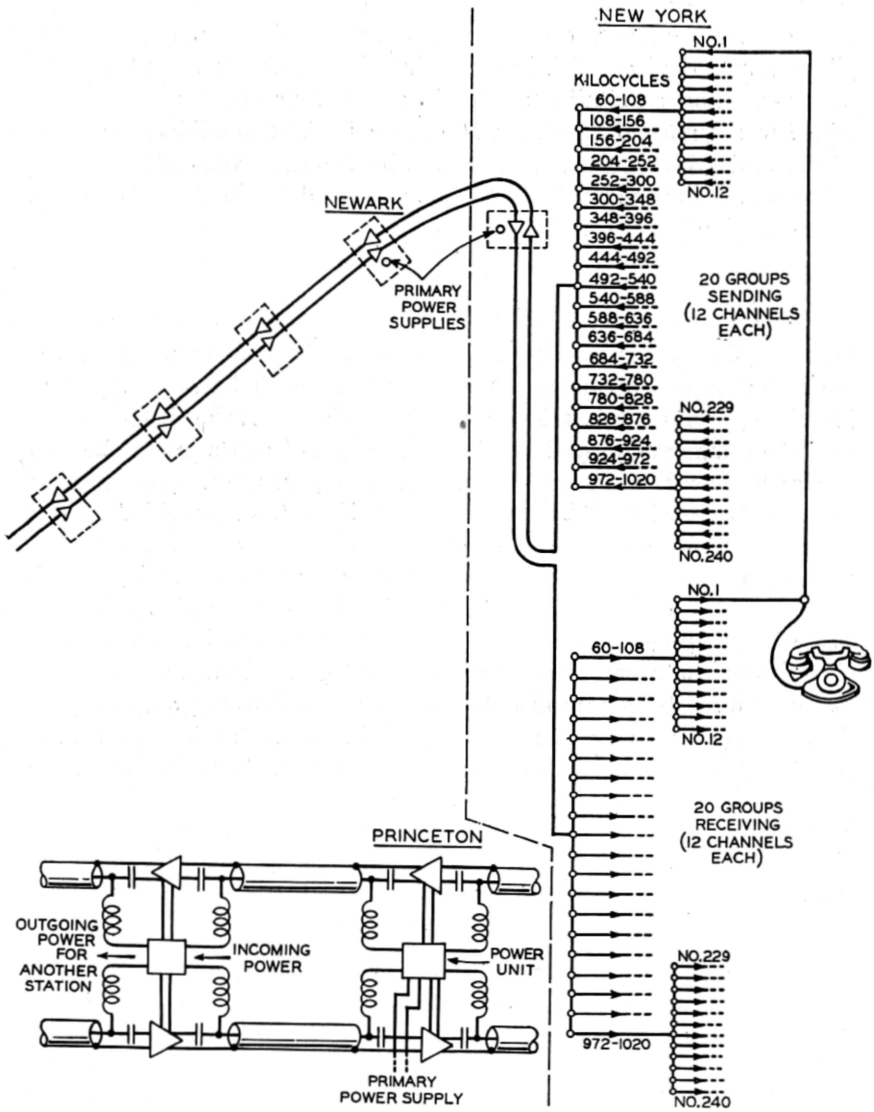

Fig. 8—*Continued from page 6.*

is designed to compensate. Three stages of pentodes are used with negative feedback [2] around the last two stages. Attenuation changes due to temperature of the line are compensated automatically by a pilot channel device which has been installed at every second or third repeater. The regulating mechanism uses four small tubes and is added to the normal repeater when desired. The amplifiers shown in Figs. 5 and 6 are regulating. As the cable is underground, the temperature changes are very slow and but meagre data on the accuracy of compensation are yet available.

Terminals

A schematic diagram of the terminal arrangements for a 240-channel million-cycle system is shown on Fig. 8. In this installation the New York and Philadelphia terminals have each been equipped to handle only 36 two-way telephone conversations. As has been pointed out, the scheme employed involves two steps of modulation, the first of which is used to set up a 12-channel group in the frequency range from 60 to 108 kc. Three such groups have been provided in this installation. In order to transmit at the higher frequencies, a second step of modulation is used in which an entire 12-channel group is moved to the desired frequency location by a "group" modulator. Six such group modulators have been provided at various frequencies throughout the range, including both the top and bottom. Patching facilities have been provided so that any 12-channel group may be transmitted over any one of the high-frequency paths. A typical frequency characteristic of one of the channels is shown in Fig. 9. It may be observed that relatively high quality has been obtained, due largely to the use of quartz crystal electric wave filters, even though the channels are spaced throughout the frequency range at 4000-cycle intervals.

Preliminary Tests

As already noted, various long circuits have been built up by looping back and forth through the coaxial system. One setup over which conversations were successfully carried out consisted of five voice-frequency links in tandem, each link being 760 miles long, giving a total circuit length of 3800 miles. This setup included, in each direction, seventy stages of modulation and the equivalent of 400 line amplifiers, the transmission passing twenty times through each one of the twenty one-way line amplifiers constituting the ten two-way repeaters.

[2] "Stabilized Feedback Amplifiers" by H. S. Black, *Bell Sys. Tech. Jour.*, January, 1934.

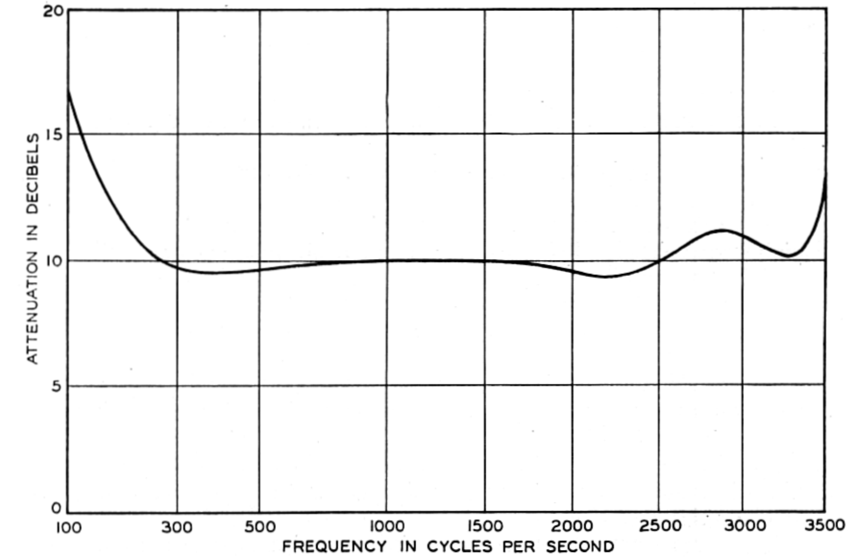

Fig. 9—Schematic diagram of a coaxial million-cycle system showing frequencies assigned to the different channels.

This demonstrated that the complete assemblage of parts, including filters which divide the frequency range into the required bands, modulators which produce the necessary frequency transformations, and amplifiers which counteract the line attenuation, introduced very little distortion. Many problems require further consideration, however, before these systems will be ready for design and production for general use. The final systems must have such refinement that they are suitable for transcontinental distances; the tremendous amplifications needed for such distances must have very precisely designed regulation systems, particularly where aerial construction is involved; noise and crosstalk must not accumulate over the long distances; the repeaters must have such stability and reliability that continuity of service will be assured with hundreds of repeaters operating in series and each repeater handling several hundred different communications simultaneously.