# Communication Engineering

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**5-13. Phantom Circuits.** Any means by which the number of communication channels carried by a given number of wires can be increased tends to reduce the relative cost of outside plant, a major charge against long-distance transmission. An extremely simple method by which this can be done is the use of "phantom" circuits. A phantom circuit gives an additional telephone channel for each four wires, thereby increasing the carrying capacity 50 per cent. It works on a balancing principle similar to that of a bridge circuit. The terminal equipment required is very simple, consisting only of a pair of repeating coils (or transformers) at each end of the phantom. The connection is shown in Fig. 5-11.

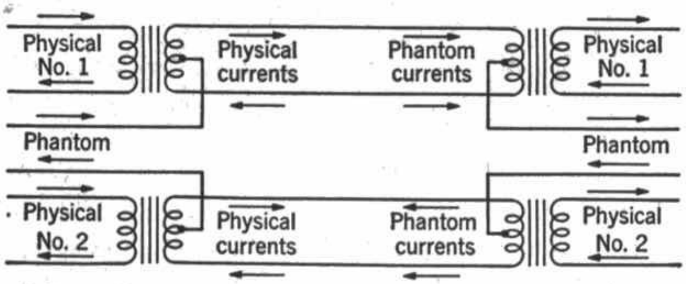

FIG. 5-11. Phantom telephone circuits.

The standard two-wire circuits are usually called "physical," or "side," circuits. The terminals of both physicals and phantoms are brought in to jacks on the long-distance board, so that the operator does not need to treat a phantom circuit any differently from a physical.

By the principle of superposition the signals may be considered one at a time. A voltage impressed on the phantom circuit at the west end of Fig. 5-11 will cause a current to enter at the mid-tap of the secondary winding of each repeating coil. *If the impedances of the two line wires of the physicals* are equal to each other, the current will divide equally and so produce mmfs which cancel each other in each repeating coil. The currents due to the signal impressed on the phantom terminals will flow in the same direction in the two wires of physical 1 and in the opposite direction in the two wires of physical 2. At the far end the two currents will again produce equal and opposing mmfs in the repeating coils, so that no flux will be produced. This absence of flux, due to the currents resulting from the phantom signal, prevents this signal from being transferred to the substations connected to the physicals. It also means that the effective inductance of the repeating coils is negligible for phantom currents. Three conversations, one on each physical and one on the phantom, can therefore be carried on simultaneously without interference.

The directions of the currents at some instant due to the several signals are shown by the arrows in Fig. 5-11.

In order to make sure that the mmfs completely cancel each other, the leakage flux must be made negligible. This is accomplished by winding the two halves of the secondary winding with wires which are adjacent to each other, as illustrated in Fig. 5-12. Toroidal cores are also used to reduce leakage flux.

It is extremely important that the impedances of the two sides of each physical line be made as nearly identical as possible. If this is not done, the phantom currents in the two sides will not be identical and so a mmf will be set up in the repeating coils. This will result in "cross talk," or interference between the unbalanced physical and the phantom. If both physicals should be unbalanced, the phantom would provide a path so that cross talk could also occur between the two physicals, as well as between each physical and the phantom.

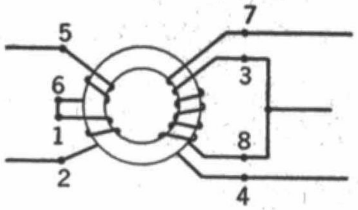

FIG. 5-12. Windings of the repeating coils for use in phantom circuits.

The transmission on the phantom is actually better than on the physicals. Since the phantom uses two wires in parallel for each conductor, the line impedance is cut in half.

In order to prevent the currents flowing in one pair of wires in a cable from inducing a voltage in another pair, the pairs are twisted continuously along their length. On open-wire lines the two wires are transposed at regular intervals for the same purpose.

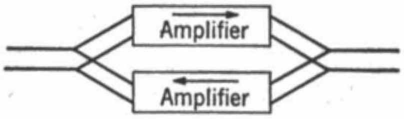

FIG. 5-13. Two-way telephone repeater which will not operate because of "singing."

When two pairs are phantomed, each pair individually must also be treated as a single conductor and the two pairs twisted with each other in a cable or transposed with each other on an open-wire line. Cables in which this is done are called "quadded" cables. Owing to the greater effective separation of the sides of a phantom circuit, its susceptibility to inductive interference is greater.

**5-14. Telephone Repeaters.** One of the most important applications of a bridge balance is in the two-way repeater on telephone lines. As the length of a telephone circuit is increased, the line losses will reach a limit at which the transmission will no longer be commercially feasible. Beyond this point it is necessary to introduce amplification to make up for the line losses. The transmission of a telephone circuit should be the same in both directions. Therefore the amplifier must operate in both directions. The first idea which would occur to the experimenter is to connect two amplifiers side by side as shown in Fig. 5-13, one to operate in one direction and the second to amplify in the opposite direction. The circuit of Fig. 5-13 would not work, because it would oscillate, or "sing."

Inasmuch as the outer conductor of the flexible coaxial cable is not a solid, continuous conducting sheet, the electric and magnetic fields may not be confined to the region surrounded by the outer braid and leakage fields may be present outside the cable, particularly at uhf and above. This condition results from the incomplete shielding by the outer conductor and may be minimized by adding a second grounded shield braid outside the cable. This results in a so-called "shielded coaxial cable."

The common telephone cable consists of a number of wire pairs, insulated with paper and twisted together. The several pairs are also twisted over the entire cable length to minimize cross talk that results from magnetic and capacitive coupling between adjacent pairs. The whole group of pairs is surrounded by a protective outer coating of lead or of corrugated aluminum covered with plastic. The telephone cable and other common transmission-line types are illustrated in Fig. 8-3.

**8-3. Calculation of Line Parameters.** While the concepts of the per unit length line parameters $R$, $L$, $G$, and $C$, were developed for the parallel-wire line, they are by no means peculiar to that configuration. All transmission lines exhibit all four of the line parameters to some extent, though in certain cases one or two of them may be of negligible magnitude. This is notably demonstrated by the common telephone cable. Since each wire pair is twisted and currents flow in opposite directions in the two conductors comprising the pair, the flux linkages are so small that the inductance per unit length, $L$, may be neglected in a number of calculations. Furthermore, the paper serves as an excellent insulator so that $G$, the shunt conductance, is of neglible magnitude. The effect of neglecting $L$ and $G$ in calculations for the telephone cable will be illustrated later in the chapter.

Cable and transmission-line manufacturers publish tables giving the four line parameters of their products. Typical values are listed in Table 8-1. For simple line configurations, such as those of the parallel-wire or coaxial type, $R$, $L$, and $C$ may be calculated from a knowledge of the line geometry and the properties of the materials from which they are made. The necessary equations may be derived by direct application of field theory. They will not be derived[1] here but are summarized in Table 8-2.

**8-4. The Infinite Line, $Z_o$.** Since the equivalent circuit of a length $\Delta x$ of a transmission line and the means of evaluating its components $R$, $L$, $G$, and $C$ have been covered in previous sections, it is now possible to predict the behavior of a line when electrical signals are applied to it. Using the equivalent-circuit idea, let the line be considered as being made up of a large number of incremental lengths, $\Delta x$. Each such length of line then exhibits series loop inductance $L\,\Delta x$, series loop resistance $R\,\Delta x$,

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[1] See, for example, E. C. Jordan, "Electromagnetic Waves and Radiating Systems," Prentice-Hall, Inc., New York, 1950.

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