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Telephone Transmission

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Telephone Transmission

By C. A. Wright

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The electric current in a telephone circuit during conversation is alternating at frequencies between 50 and 5,000 cycles per second. Figure 1 shows a sine wave alternating current, and Figure 2 shows the character of the current in a telephone circuit (part of vowel sound "E").

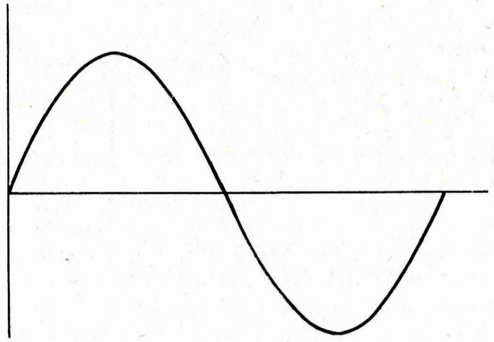

Fig. 1.

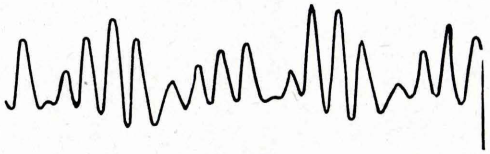

Fig. 2.

Electromotive force forcing current through an electric circuit has to overcome the effects of resistance, leakage, capacity, and inductance.

The effects of resistance in an electric circuit are well known. Leakage is the escape of current through or over the insulation.

A condenser forming capacity in a circuit permits current to flow through it. If a constant e. m. f. is applied at its terminals, current flows for a short time and then stops. If the e. m. f. is alternating, current flows first in one direction and then in the other, the condenser alternately charging and discharging. The higher the frequency, the greater is the current that flows. The capacity is increased by increasing the area of the plates, by increasing the dielectric constant of the dielectric, or by decreasing the distance between the plates.

Figure 3 shows a circuit in which there is a condenser, and Figure 4 shows a section of a cable. It is to be noted that any two conductors of a cable with the insulation between them form a condenser, and that the capacity between these wires is increased, as they are placed closer together, or as the dielectric constant of the insulation is increased by the use of an impregnating compound.

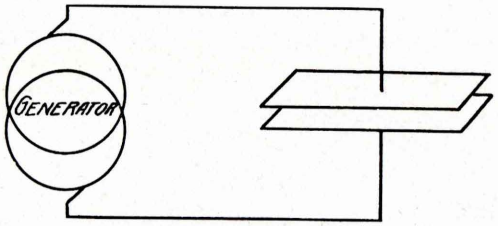

Fig. 3.

When current flows through a conductor, lines of force are set up around that conductor, and when the current changes, the building up or the collapsing of these lines of force induces an e. m. f. in the conductor in such a direction as to tend to prevent the change in the current. The effect of this induced e. m. f. in a conductor is referred to as "inductance." The combination of resistance and inductance effects is known as "reactance." Reactance retards the flow of alternating current just as resistance does, but the energy used up in the circuit is only that used up in overcoming resistance. The inductance of a circuit gives back all the energy it absorbs. Figure 5 shows the inductive effect of current in a circuit. The inductive effects of two adjacent wires neutralize each other.

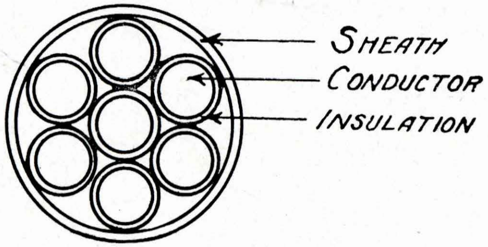

Fig. 4.

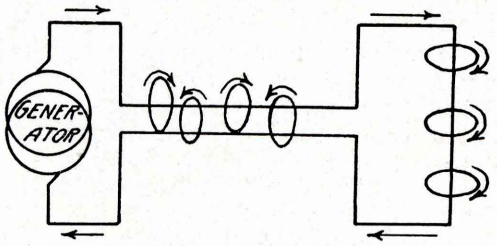

Fig. 5.

In Tables 1 and 2 are given the constants of several types of commonly used telephone lines, which have been taken from the Standard Handbook for Electrical Engineers, 4th edition.

TABLE 1.

Constants Per Loop Mile.

Kinds of Non-Loaded Open Wire Lines.	Effective Resistance (Ohms).	Effective Inductance (Henries)	Effective Capacity (m. f.)	Transmission Equivalent	Miles Equivalent to 30 Miles of Standard Cable
No. 8 B. W. G. Bare Copper, pairs...	4.08	.00337	.00898	.035	860
No. 8 B. W. G. Bare Copper, phantoms	2.04	.....	.....	.029	1,035
No. 8 B. W. G. Bare Iron, (BB) pairs	...	.....	.....	.22	135
No. 12 B. W. G. Bare Iron (BB) pairs	.85	.0150	.....	.32	93

TABLE 2.

Constants Per Loop Mile.

Kinds of Non-Loaded Cable Circuits	Resistance (Ohms).	Capacity (m. f.).	Insulation (Megohms).	Transmission Equivalent	Miles Equivalent to 30 Miles of Standard Cable
No. 19 A. W. G. Dry Core Paper Cable, pairs	88	.060	500	1.00	30
No. 22 A. W. G. Dry Core Paper Cable, pairs	176	.083	500	1.66	18
No. 19 A. W. G. Dry Core Paper Cable, pairs	88	.074	500	1.11	27
No. 22 A. W. G. Sw. Bd. Cable (s and c) pairs	176	...	100	2.2	14
No. 16 A. W. G. Sw. Bd. Cable (wool), pairs	44	...	100	1.1	27

As the wires of an open wire line are widely separated the distributed capacity is small and the inductance is comparatively high. Therefore, such a line may be represented by a number of resistances and reactances in series. On the other hand, the wires of a cable pair are close together. the inductance is negligible, and the capacity between wires is high. It may best be represented, therefore, by a number of resistances in series, with condensers bridged across the line. It is to be remembered that the frequency of the current in a telephone circuit varies, and that the higher the frequency the more of it will flow through the distributed capacity of the circuit. Therefore, more of the high frequency current of the high notes is shunted off from the receiving end of the circuit than the low frequency current of the low notes. The low notes are received more strongly than the high notes, and the "quality" of the tone is affected. As both low and high frequency currents are shunted the current at the receiving end is "attenuated" and the "quantity" of the sound is affected. Also attenuation results from the e. m. f. in the circuit being used up in overcoming the resistance of the circuit.

Where there is a discontinuity in the circuit, a piling up of the current and voltage waves occurs in such a way that losses in transmission occur. These losses are known as "reflection" losses.

Circuits are loaded by inserting reactances in series in them at intervals so short that appreciable reflection losses are avoided. These reactances decrease the energy loss in the circuit by their tendency to neutralize the bad effects of the capacity. They make it possible to apply a higher voltage to the line without increasing the current proportionally. In this way they decrease the attenuation. By changing the relation between the resistance, leakage, capacity, and inductance of the circuit, they decrease the distortion. Thus, they better the received sound both in quantity and quality.

In addition to the above high-frequency losses, there occur what are known as battery-supply losses. The greater the direct current supplied to the transmitter, the greater will be the energy which that transmitter sends out into the circuit, but the amount of this current is limited by the heat radiating qualities of the transmitter. The transmitter is, therefore, used most efficiently when the amount of direct current supplied to it normally is the greatest possible without unduly heating the carbon path in the transmitter. A loss due to a decrease in the direct current normally supplied to the transmitter is known as a "battery-supply" loss.

The quantity of sound transmitted over a telephone line under various conditions might be indicated by delicate apparatus, but this would not take account of the distortion of current or quality of the sound received. What it is necessary to measure is "transmission" or a combination of quantity and quality of received sound, and in order to do this a unit of transmission must be chosen and a standard of transmission devised.

A unit is an arbitrary division for measurement. A standard is the means of making the measurement; for example, a foot and a foot rule, or an ampere and an ammeter.

A primary standard is one from which secondary standards are calibrated. It should be, first, Constant for specified conditions, and, second, Reproducible from written instructions—but not necessarily cheap or portable. A secondary standard must be, first, Cheap; second, Portable, and third, Constant for specified conditions.

It was necessary to choose a unit and standard of transmission because "transmission" had never been measured before. The

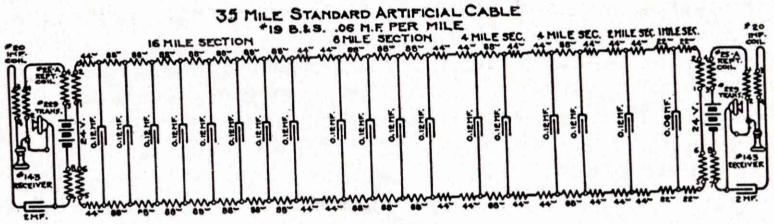

Fig. 6.

unit chosen was a "mile of transmission" over "the standard circuit." The primary standard chosen was the No. 19 gauge non-loaded cable then in use, having a mutual capacity of .06 microfarads per mile and a loop resistance of 88 ohms per mile, with the common battery central office and sub-station circuits then in use. Artificial lines made up of resistances and condensers mounted in a box with the above central office and sub-station circuits at both ends have been used as secondary standards.

The standard circuit is shown in Figure 6. The designations shown refer to apparatus manufactured by the Western Electric Company. Figure 7 shows a commonly used artificial cable with the associated apparatus.

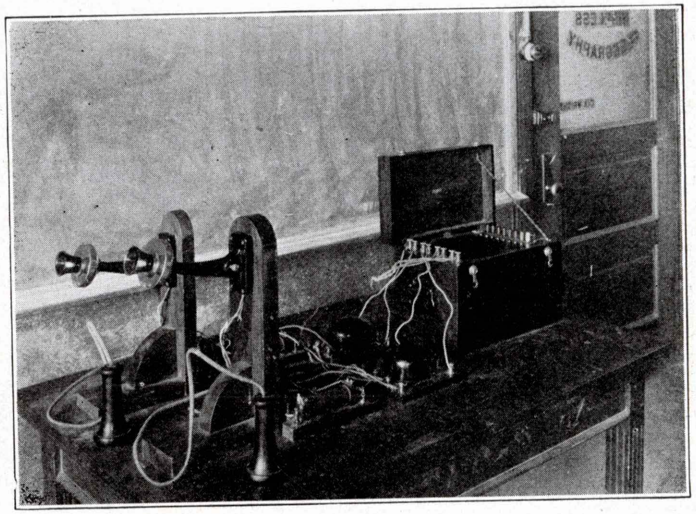

Fig. 7.

In testing transmission it is necessary to find the number of miles of No. 19 gauge standard cable which in the standard circuit will give the same transmission when talking over the standard circuit, as when talking over the circuit under test. The transmission over a circuit may be different when talking in one direction than when talking in the other.

When testing transmission the tester who is talking should be careful not to vary his voice or the distance of his mouth from the transmitter mouthpiece. He should do all necessary switching, keeping the tester who is receiving always in ignorance of the condition of the circuit. This is necessary in order to avoid any error due to the personal equation or opinion of the receiving tester.

If it is desired to test a transmitter or other unit of the terminal apparatus, such as the induction coil or battery, the artificial cable with standard terminal apparatus at one end is arranged so that it may be switched to standard terminal apparatus, or terminal apparatus, all units of which are standard except the transmitter or other unit under test at the other end. It is then determined by careful trial what length of artificial cable with the terminal apparatus under test will give the same transmission as the standard terminal apparatus with 20 miles of artificial cable. If this length of cable should be 16 miles, the transmitter under test is said to be 4 miles poorer in transmission efficiency than the standard. If it should be 24 miles, the transmitter is said to be 4 miles better than the standard.

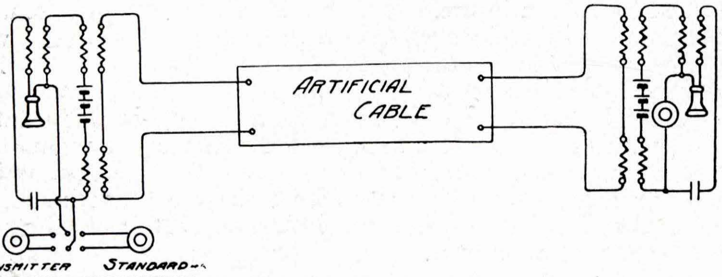

Fig. 8.

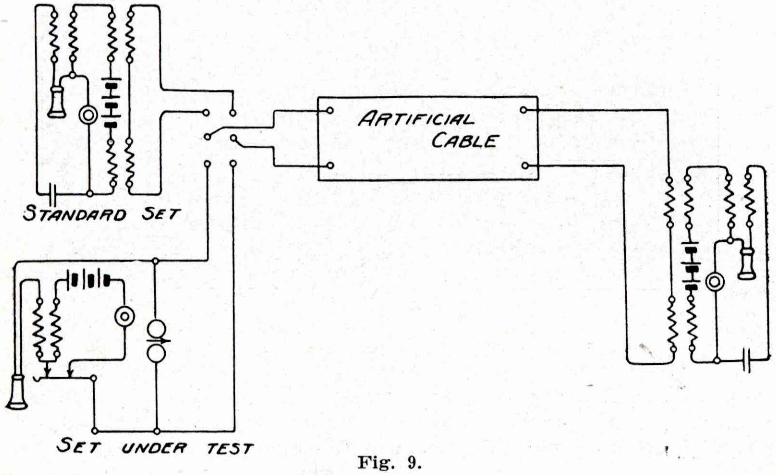

Fig. 9.

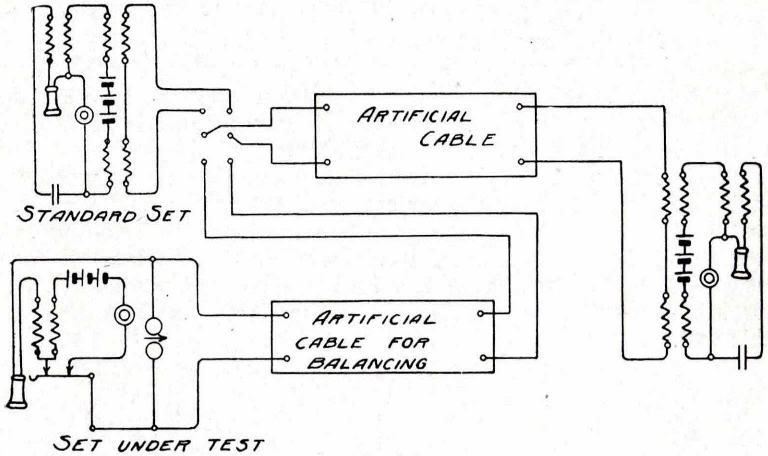

Fig. 10.

In Figure 8 is shown the circuit used in comparing a transmitter with a standard transmitter. A similar circuit may be used for testing induction coils or other elements of the substation set. Figure 9 shows a circuit for comparing two substation sets.

If two artificial cables are available, a balancing cable is used as shown in Figure 10. This avoids the operation of one or more switching keys each time the standard or test apparatus is cut into circuit.

The effect on transmission of holding the mouth at varying distances from the mouthpiece of the transmitter may be determined in approximately the same way. However only the standard terminal apparatus need be used in this case.

The following losses in miles of standard cable determined by a prominent telephone engineer, result from talking with the mouth at the given distances from the mouthpiece of the transmitter:

Distance of mouth from mouthpiece of transmitter, in inches.	Loss in miles of standard cable. Microphonic type of transmitter.
.5	3.5
1.0	5.5
1.5	8.0
2.0	11.0

If it is desired to test the transmission efficiency of a length of cable or a line, and if only one circuit is available, it is necessary to connect one of the sub-station circuits at the distant end of the line, and arrange with the wire chief or someone else at that point to aid in the test. The transmission over the above sub-station circuits with 35 miles of No. 19 gauge cable is generally regarded as the limit of commercial transmission. It is possible to determine this amount of transmission from memory more definitely than any other amount. Artificial cable is added to the circuit under test until 35-mile transmission is obtained. Then the number of miles of artificial cable thus necessary, subtracted from 35, will give the transmission equivalent of the circuit under test. Figure 11 shows the circuit used in making this test.

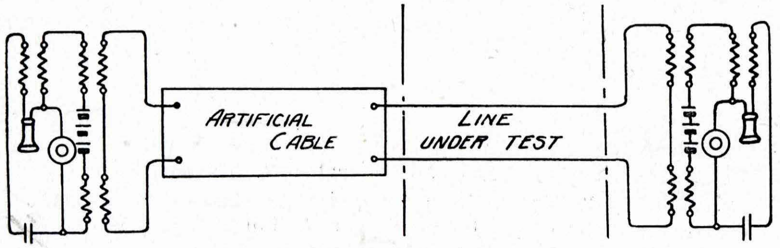

Fig. 11.

If two circuits to a distant point are available, which follow the same course and which are so nearly the same that their transmission equivalents may be assumed to be equal, the simplest way to test them is to loop them as in Figure 12, find the transmission equivalent of the two circuits in series, and divide the result by 2 to obtain the transmission equivalent of either circuit.

If the circuits to be tested follow different courses, and it is probable that their transmission equivalents are different, they should first be looped together as in Figure 12, and their series transmission equivalent found. Then one of the sub-station sets should be transferred to the other end, as in Figure 13, and it should be carefully determined what amount of artificial cable it is necessary to insert in the circuit, the transmission of which is the better in order to make the transmission over the two circuits the same. This amount of artificial cable is the difference in the transmission equivalents of the two circuits. If a and b represent the equivalents obtained in these two tests, and if x and y represent the transmission equivalents of the two circuits, then from the relations $x+y=a$, and $x-y=b$, the transmission equivalents desired may be easily obtained. It will be found that

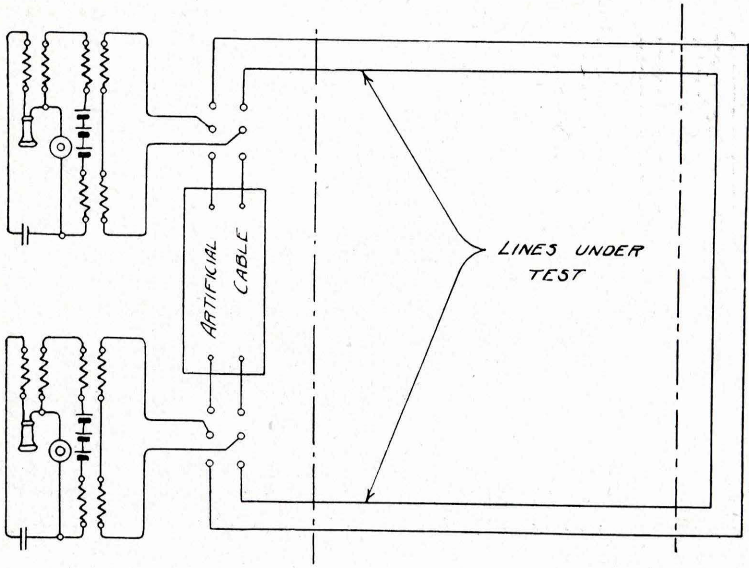

Fig. 12.

$x=\frac{a+b}{2}$, and $y=\frac{a-b}{2}$

If x, y, and z represent the transmission equivalents of three circuits, none of which follow the same course, the tests may be made with all the sub-station apparatus and the artificial cable at one end of the circuit. The aid of a wire chief or a maintenance man in changing connections is all the aid that is necessary at the distant end of the circuit. If we find from using the method of testing described for Figure 12 that $x+y=a$, $y+z=b$, and $z+x=c$, the transmission equivalents of x, y and z may be determined. It will be found that $x=\frac{a+c-b}{2}$, $y=\frac{a+b-c}{2}$ and $z=\frac{b+c-a}{2}$

A transmission equivalent of a piece of apparatus or a section of a circuit is the loss in miles of transmission which that apparatus or section of circuit will cause when inserted in a telephone connection. Values of transmission equivalents for various types of telephone lines and apparatus have been determined by the various manufacturers and users of telephone equipment.

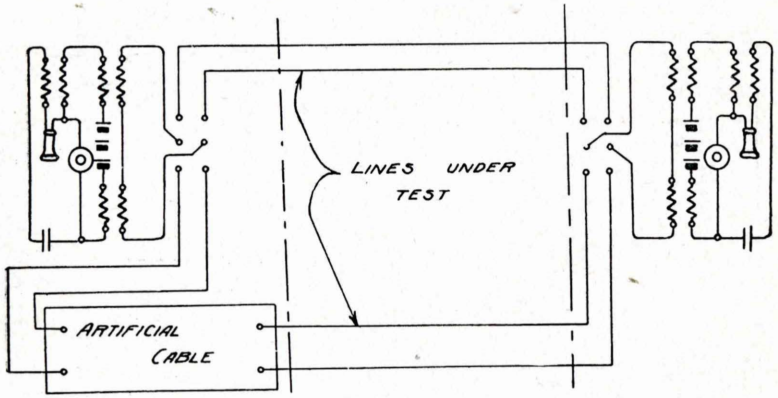

Fig. 13.

The transmission equivalents of various types of circuits are given in Tables 1 and 2. In Table 3 are given approximate transmission equivalents of various typical pieces of apparatus. (Published in an article in Telephone Engineer, August, 1915, by C. J. Larsen.)

TABLE 3.

Apparatus	Approximate Transmission Equivalent.
Average wire wound heat coils	0.500
Tinsel cords, per pair	0.030
Steel cords, per pair	0.250
1,000-ohm bridged drop	0.150
500-ohm bridged drop	0.975
200-ohm bridged drop	2.000
2 m. f. condenser	0.160
Early type, repeating coil	5.000
Subsequent, improved repeating coils	2.000
Present-day repeating coil	0.500

To these transmission equivalents may be added several others taken from the Standard Handbook for Electrical Engineers, 4th edition, which are of common interest:

1,000 ohm bridging bell		Less than 0.1
Efficient phantom repeating coil	on side circuit	0.25 to 2.0
	on phantom	0.05 to 0.15
Operator's set, bridged across line		0.5 to 5.0

"Reflection losses between non-loaded open wires of different sizes or side circuits and phantoms, or open wires and cables are usually but a fraction of a mile of standard cable. In the case of a loaded open-wire circuit, connected to an open-wire non-loaded circuit, the reflection loss may become equal to 3 or 4 miles of standard cable."

The transmission equivalents (miles of standard cable which give the same transmission loss as one mile of the cable in question) of various types of cable are given in Table 4. These data are taken from "Gibson's Manual of Telephone Troubles." Because of the slightly different characteristics of the cables and wire tested, these data do not exactly check with those of Tables 1 and 2.

TABLE 4.

Transmission Equivalents of Telephone Cables and Wires.

	Loaded Cable			Non-Loaded Cable
	Heavy	Medium	Light	
Underground Cable, No. 22 B. and S. Gauge	.53	.70	.95	1.61
Underground Cable, No. 19 B. and S. Gauge	.278	.348	.455	1.0
Underground Cable, No. 16 B. and S. Gauge	.170	.195	.248	.74
Underground Cable, No. 14 B. and S. Gauge	.132	.14	.160	.60
Underground Cable, No. 13 B. and S. Gauge	.113	.117	.135	.53
Open Wire No. 12 N. B. S.	...	...	...	.03
Open Wire, No. 8 B. W. G.	...	...	...	.035
Dry Core, No. 16 B. and S. Gauge	...	...	...	1.05
Dry Core, No. 13 B. and S. Gauge	...	...	...	.75
Bridle Wire, No. 14 B. and S. Gauge	...	...	...	.86
Swbd. Cable, No. 22 B. and S. Gauge	...	...	...	2.16
Swbd. Cable, No. 19 B. and S. Gauge	...	...	...	1.65

The insertion of such a resistance in a common battery loop that the current through the transmitter is decreased from its value in a zero loop to one-tenth of this value may cause a loss of ten miles of standard cable or more, while a loss of the same amount may result in a local battery set from decreasing the voltage across the transmitter to one-third its normal value.

Loose connections, or "high joints," and grounds may cause losses which are negligible or of such a value as to make conversation over a telephone impossible.

As the various losses given above are additive, the occurrence of many such losses, each small in itself, may prevent the use of a telephone line.

The various values of transmission given above are approximate, as they vary with the conditions in the rest of the circuit and the position of the apparatus in the circuit.

The cost of such transmission losses is determined by the cost of improving other parts of the connection, as the lines, by loading or by the installation of telephone repeaters, to bring the transmission over the whole connection up to the standard which is being maintained. It is to be remembered, however, that if at the start the transmission loss does not make the transmission equivalent of the circuit poorer than this standard, it is generally considered that such a transmission loss has no value, just as air, water, or sand have no value when there is a superabundance of them available. The transmission may even be so good that it is disagreeable to the subscriber.

The addition of a traffic feature to a circuit which causes a loss in transmission will "prove in" if the saving in operation, plus the value of the betterment in service, will balance the cost of the apparatus plus the cost of the transmission loss.

If transmission is too poor, people will not use the telephone, and the income will be decreased. If transmission is too good, the cost of the circuits and lines will make the cost of service too high. Balancing the amount of service against the cost of circuits, we can determine the proper quality of transmission to maintain in order to give the greatest return to the telephone company. A standard of 20 miles has been generally maintained for local service, and 30 miles for toll service. With the cheapening of telephone apparatus the standards of telephone transmission which it is economical to maintain are constantly becoming better.

In five towns in western Pennsylvania, in an effort to better telephone transmission, inefficient repeating coils, cords, heat coils, and other apparatus were replaced by better apparatus, old transmitters were replaced, run down batteries were renewed, and other similar changes in plant were made. The result was that in eight months the commercial transmission areas were increased between 50 and 100 per cent, and the amount of toll and long distance business in this territory increased about 25 per cent.

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