

Disturbances on Telephone Lines and Their Remedies.

by

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and

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Outline.

Disturbances.

Leakage.

- (a) Earth Disturbances
- (b) Electric Storms
- (c) Electric Light and Railways

Electro-magnetic Induction.

- (a) Ground Lines
- (b) Metallic Circuits
- (c) Sources

Electro-static Induction.

- (a) Grounded Lines
- (b) Metallic Circuits
- (c) Sources

Remedies.

Leakage.

- (a) Metallic Circuits
- (b) Insulation
- (c) Partial Metallic Circuits Through Repeater Coils

Electro-magnetic Induction.

- (a) Insulation
- (b) Metallic Circuits
- (c) Transposition
- (d) Removing from Inducing Wire

Electro-static Induction.

- (a) Separation of Circuits
- (b) Transposition, etc.
- (c) Cables

Disturbances on Telephone Lines and Their Remedies.

F. E. Brown.

Telephone lines were first built with only one wire, the earth being used as a return circuit. It was soon found that the telephone receiver was so sensitive to electrical disturbances of all kinds that lines so constructed were rarely free from noises, and were often so seriously affected thereby as to render conversation almost impracticable. As other electrical industries multiplied the troubles increased, especially after the coming of the street railway that insisted upon using the earth as a return circuit for very large currents. The disturbances became so great that the telephonists were confronted with a serious problem in an endeavor to render their circuits commercially quiet.

A careful study of the origin of noises upon the telephone line revealed them to be due to several causes,- leakage, electro-magnetic induction, and electro-static induction.

The first that we will take up is leakage. It has been found from experience that few instruments have been invented which are as sensitive a detector for a varying current as the telephone receiver. It has been found that a current of less than a millionth of an ampere will readily effect a telephone receiver. If therefore a telephone line is so situated with respect to other electrical circuits that there can be an actual leakage of electricity to the telephone line, it is certain to produce so much disturbance as to render the use of the line impracticable. When telephones are operated as grounded circuits, one end of the line is connected to the earth at one station and the other at some distant point.

If there is a difference of potential between the earth at the two stations there is a tendency for foreign currents to flow over the

line in an endeavor to equalize this difference of potential. This difference of potential between two points on the earth may arise from a great many natural causes as well as from the operation of other electrical plants. The earth is frequently visited by magnetic storms, which effect compass needles all over the globe and often produce so serious electrical disturbances as to render telegraph lines inoperative; apparently the effect of such a magnetic storm is to create a difference of potential between various localities.

Telegraph messages have been sent by the use of currents caused by these differences of potential. It is no wonder that under such circumstances all telephone lines are rendered so noisy as to be thrown out of use. Even a summer thunder storm will often produce such a variation of potential over a line as to render conversation impossible, and in almost any thunder storm the listener may hear in the receiver a snapping for every flash of lightning. Such disturbances particularly effect grounded lines, for the differences of potential created tend to equalize themselves over the telephone wires.

With the invention of the electric light came circuits carrying considerable current at relatively high voltage. These circuits designed to carry electricity to the lights had to be run over various streets. These circuits are at times more or less leaky, and permit a sensible fraction of their current to escape. In its attempt to find its way back to the generator it selects the grounded telephone line as furnishing the easiest path to travel. Next came the street railway that discharges into the earth thousands of amperes. While the ground is a very good conductor for the small currents of the telephone and telegraph it presents a marked resistance when it is proposed to use it for the large currents used by railways, and no sooner did the railway come into use than telephonists found that it

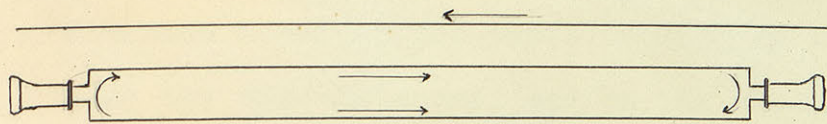


Fig. 2

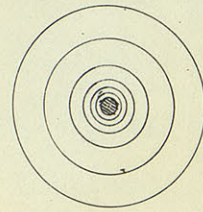


Fig. 1

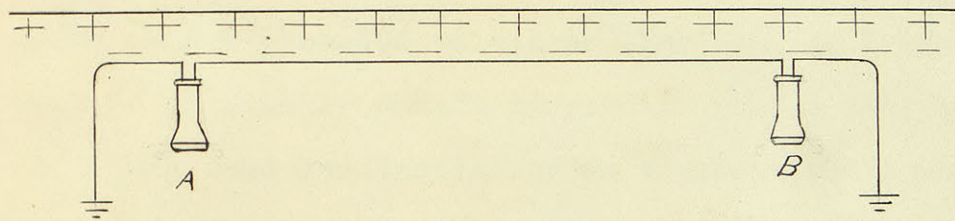


Fig. 3

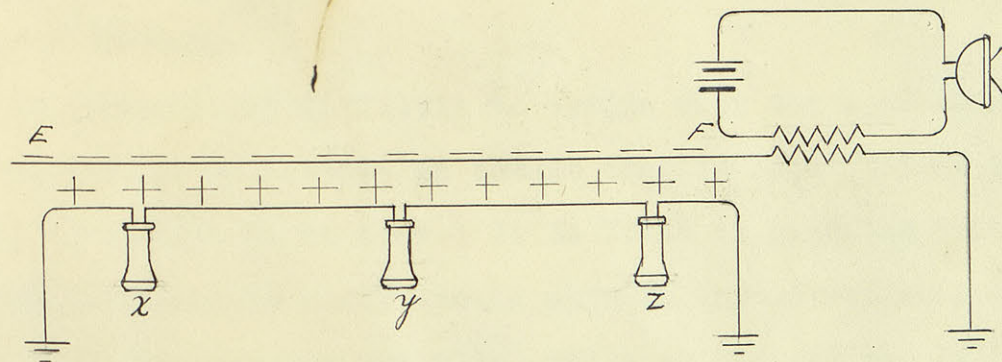


Fig. 4

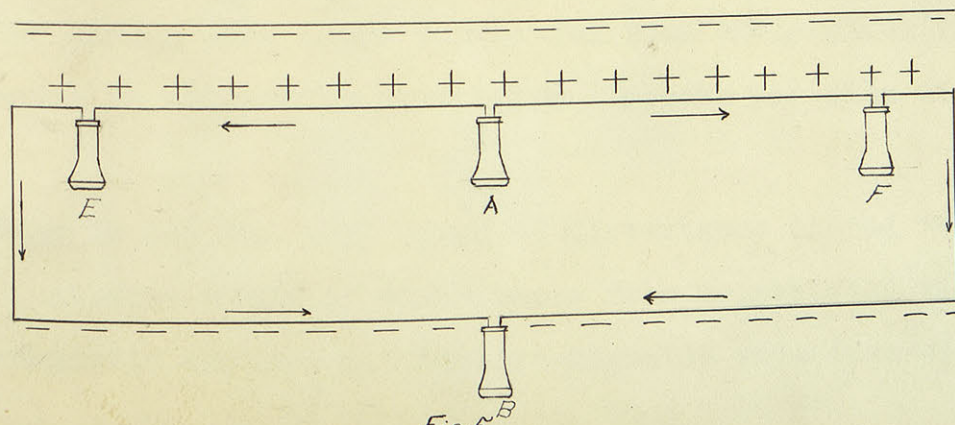


Fig. 5

was impractical to continue the use of grounded lines.

It is safe to say that no telephone company of magnitude can now for a moment consider the installation, or operation of, grounded lines, under any circumstances; and on the other hand, it must use the utmost care to see that its entire wire plant is constantly maintained in the very highest and best state of insulation. If therefore a telephone line becomes noisy the first step to be taken is to ascertain whether or not the line is leaky. It should therefore be carefully tested from end to end, and the remotest suspension of insulation immediately taken into hand and cured. It is by no means safe to state that a grounded telephone line will be noisy, and on the contrary it is equally unsafe to predict that a well insulated one will be quiet, but low insulation is frequent and a prolific source of disturbance. It is the easiest of all possible causes of noise to detect and remedy, and therefore comes first upon the list of diseases to cure.

It is exceedingly difficult to define what the best telephone insulation should be because an amount that is insufficient in one case will be enough in another. It is found in practice that in good insulation a new cable plant should show an insulation resistance of not less than 500 megohms per mile, while an old one may fall to 10 megohms per mile and yet give good service, but it is quite certain that less than 10 megohms per mile is likely to give trouble. Open wire lines always show lower insulation than cable circuits, but should never be allowed to fall below 1 megohm per mile even in bad weather.

Leakage is not the only cause of disturbance in the telephone circuit. Another cause of disturbance from neighboring wires is electro-magnetic induction. Electro-magnetic induction on a telephone line is due to the fact that the line wire lies in the field of

force set up by current flowing in the disturbing wire. About every wire carrying a current there is a field of force or magnetic whirl consisting of closed lines of force surrounding the conductors. Such a condition is represented in the accompanying Fig. I.

If the current is a continuous one, the line's force will not vary after being once set up, and the telephone wire lying in this field will not be affected. If the current in the disturbing wire is fluctuating, the number of lines of force in this field will vary, that is the field of force will expand and contract accordingly. This expansion and contraction of the field will cause its lines of force to be cut by the telephone wire and will by the law of electro-magnetic induction cause current to flow in the telephone wire.

If the current in the disturbing wire is an alternating one, the field of force around it will be established in one direction, destroyed and established in the reverse direction and again destroyed, with every complete cycle of the current. This would be a condition of maximum disturbance in the telephone wire. This trouble caused by electro-magnetic induction is found in the metallic as well as in grounded circuits. Merely making the line a metallic circuit, as in Fig. II. does not give complete freedom from inductive troubles from other wires. Considering the electro-magnetic induction, a current flowing in the disturbing wire, Fig. II. would set up a field of force, the lines of which would cut conductors A and B, A being closer however, would be cut by more lines than B, and therefore any currents induced in A by changes in this field will be stronger than those in B. If a current starts to flow in the disturbing wire from right to left, as shown by the arrow, by the law of induction, then there will be a current flowing in both A and B and from left to right, as indicated. If these currents were the same they would neutralize each other, but that in A being stronger will overcome that

in B and the resultant current will flow in the circuit in the direction indicated by the curved arrows. Such a disturbance would be caused by electric light and power wires running parallel to a telephone circuit, and as a telephone wire carries a varying current during the time it is in use it is evident that the same effect will be produced by two telephone circuits running parallel and very close to each other.

Next, taking up the third and greatest cause of cross-talk, which is the greatest bugbear in a telephonists business.

In Fig.III. is illustrated the nature of electro-static induction. Suppose the disturbing wire is carrying an alternating current, under which conditions the medium around it will receive alternate positive and negative charges. First taking the instant when it is charged positively, as shown in the diagram, the medium surrounding the telephone wire will by static induction receive a negative charge, the positive charge being repelled by that on the disturbing wire, will flow to the ground in the direction indicated. With each change of direction in the disturbing current, the direction of flow of the repelled current is changed also, with a resultant noise in a receiver connected at A or B. Such a disturbance will be caused by neighboring electric light or power wires and the same effect will also be produced by two telephone lines running parallel. In this case the effect of the induced current will be not only to produce noise but to repeat on one line, more or less distinctly the conversation carried on over the other line - this is called cross-talk. This phenomenon is explained in some articles on the subject by the supposition that it is chiefly if not entirely due to electro-magnetic induction. A series of experiments were carried on by Mr. J. J. Carty, chief engineer of the New York Telephone Company, to prove that cross-talk was

not the result of electro-magnetic induction, but wholly due to electro-static induction.

The arrangement of circuits in one of his experiments is shown in Fig. IV., in which E F and C D are two well insulated lines each 200 feet long and placed parallel with each other through the whole length, at a distance of one-eighth inch apart. E F is the disturbing line and is open at E. At F it is connected through a secondary with the ground. In the primary circuit was a battery and a transmitter. A tuning fork vibrating before the transmitter acted on the diaphragm and caused impulses on the line E F of practically the same strength as voice currents, these impulses are of course alternately positive and negative and are the same as impulses on the disturbing line. Three receivers, x, y and z, were placed in the line C D, the receiver y at the middle point in the line. Upon operating the tuning fork its musical notes could be heard in receivers x and z while not in y. The silence of the receiver y shows that the flow of the induced current would be either toward or from the middle point of the wire, showing the central point to be neutral. If this were electro-magnetic induction the induced current would flow the whole length of the wire. It was also found that opening the central point of the line C D produced no effect on the existing conditions; the noises in the receivers x and z were plainly heard and of equal loudness.

So far in electro-static induction grounded circuits only have been considered. If the telephone circuit is metallic, and the disturbing wire is placed so as to be at equal distance from the two conductors of the telephone circuit, no induced current will be produced in the latter since if the disturbing wire has positive charge at any time the surface of the two wires nearest will have negative charges, while those most remote will have a positive. As the charge on the disturbing wire changes to negative, that on the adjacent surface

will change to positive, while that on the remote surface will change to negative. Since the telephone circuit is not grounded it is obvious that the only way for this charge to take place is by the current flowing across the wire which produces no noise.

When two conductors of a telephone circuit are at unequal distances from the disturbing line we have a different condition. This is shown in Fig. V. As soon as the disturbing wire receives a negative charge a positive charge is induced on the adjacent surface of the nearest telephone wire, and the negative charge repelled to the farthest conductor, causing a flow away from the receiver and towards the receiver B, in the direction indicated, with a resultant noise in the receivers E and F. Cross-talk may be caused by other than inductive causes. Say there are two grounded circuits of two different exchanges and they are grounded near the same point. Now they may be run on opposite sides of the road for several miles to a town and both 'phones placed in the same building for toll business, both 'phones being grounded close together again. Now, from the position of the grounds it can be seen that the resistance between the two lines would be less than to return through the ground: for this reason the current could return through the other line, in which case there would be cross-talk.

Also, in the case of metallic circuits where a common return is used there is danger of cross-talk if lines are not properly constructed, if the return wire was too small, and resistance too great the current might return through the other lines, and with this condition cross-talk could be heard on all the lines using the same return. Also, if the connections on the return wire were poor the current would return over the other lines rather than through the resistance of a poor connection.

This practically covers the field of natural disturbances and next to be taken up will be how to remedy these disturbances on the line.

Remedies for Disturbances on Telephone Lines.

E. M. Wilson.

A knowledge of the many and varied faults and disturbing factors or influences that are liable to exist in connection with every telephone system, and their effects on the system, is an essential part of every telephone engineer's education, and armed with this knowledge it is a comparatively easy task for the engineer to ascertain the existence of any such faults. Further it is quite possible in most cases to determine the exact location of the fault or disturbing factor, but this is a small part of the engineer's task. It is one thing to discover and locate a fault and a far different thing to remedy or eliminate that fault.

The existence of faults and disturbances in telephone systems has given rise to much experimental work and lead to the suggestion and adoption of many remedies and means of correction. Since, however, every system is subject to disturbances peculiar to itself, its location and manner of construction, it is impossible for practical purposes to lay down any fixed set of rules by which the engineer may be governed; but he must take into consideration all local conditions in applying any remedy to a fault.

There are however certain general disturbing conditions that are liable to exist in connection with every telephone system and it is the purpose of this paper to suggest, and discuss the application of, remedies to these general conditions only. As set forth in the first section of this paper, the disturbing condition most commonly met with

in telephone lines is that due to leakage currents, especially is this true in the so-called single wire, or grounded system. As has been stated, these leakage currents originate from many sources and are beyond the control of the telephone engineer. Since then, he cannot remove the cause of the disturbance he must eliminate its effect. At present it seems that the only remedy for this evil is the adoption of a complete and well insulated metallic circuit, which means the abandonment of the grounded system. This system seems fairly well adapted for rural lines but has proven impractical for use in cities where the lines are subject to influences from so many outside electrical sources. In some cases however, in which the ground system is subject to a disturbing influence over part of its length, say a transmission line paralleling it for a distance, a method somewhat as follows has been pursued with success. The part of the line in which the disturbance takes place is made double or metallic, and connected to the rest of the line through repeater coils, as shown in Fig. V. The metallic circuit being connected to one side of the coil while on the other side of the coil one end is connected to the line and the other end grounded. Several transpositions may be made in the metallic circuit as explained later and the inductive effect entirely eliminated. Thus in many cases the fault may be eliminated with a small cost, whereas making the entire circuit metallic would necessitate considerable expense.

Second among the common disturbing factors are currents due to electro-magnetic induction, due to the line being parallel with another line carrying alternating current. The currents thus induced are very troublesome on a grounded circuit and cause a noisy line even on a metallic circuit. In some cases it is quite possible and convenient to remove the line from the magnetic influence of the disturbing wire, but usually this is impossible. The only recourse in such a case is

to make the circuit entirely metallic if it is a single wire line, for it is impossible to in any way annul the effects of these currents on a grounded circuit. If then the circuit is entirely metallic there are two courses to pursue in affecting a remedy. If it is possible to place the two wires at the same relative distance from the disturbing wire, that is if the two lines can be placed so that they are in induced magnetic fields of the same strength, the induced current in each line will be of the same magnitude, and since they are in the same direction they will exactly neutralize each other through the receivers at the end of the line, and there will be no flow of current through the receivers and consequently no noise produced. If however it is impossible, as it usually is, to so place the two sides of the circuit that they will be in fields of equal strength, a method of transposition may be pursued which will tend to neutralize the induced currents. If one side of the circuit is nearer to the disturbing wire throughout its length than the other, there will of course be a higher potential induced in the one than the other, and there will always be a flow of current from the one of higher potential to the one of lower potential. If however, the two sides of the circuit be crossed or transposed as nearly as possible in the center of the part in which the disturbing influence occurs then for one-half of the distance one side of the circuit will be the nearer and for the other half the other side will be the nearer, and thus the inductive effect will be practically the same on both sides of the circuit, and the induced currents will neutralize through the receivers with no flow from one side to the other.

The theory of this remedy is very good, but practice has brought out the fact that while single transposition does have a quieting effect on a noisy line it does not entirely stop the noise. This lead to much experimenting by Mr. J. J. Carty and others, and it developed

that much of the noise and cross-talk on lines was due not to electro-magnetic induction but to electro-static induction. As explained in Section I. of this paper, when a circuit is paralleled by a line carrying alternating current there is alternately a charge of one sign induced and bound on the nearer of the two wires and charge of the other sign repelled to the farther wire. Then as the inducing current dies away the bound charge is released and there is a flow of current from one side of the line through the receiver to the other side in an attempt of the two charges to neutralize each other, and this occurs at each reversal of the inducing current. It was further found that the current divided in both wires and flowed from the center of the disturbing section in both directions toward the ends of the line, as shown in Fig. II. These points were found to be neutral with respect to flow of current, and if a receiver ^{be} inserted at this point it will be silent, while the receivers at the ends of the line are noisy. Now if we transpose the two wires at this point, as shown in Fig. VI., it will be seen that instead of two paths as before, there are now four paths through which the current may flow in neutralizing, and that there are two neutral points, one between each end and the point of transposition. It will also be seen that since the impedance through the receivers is much greater than that through the point of transposition most of the current will flow through that point instead of the receivers, and the quieting effect on the line will be considerable.

If now we insert two more transpositions in the line, as shown in Fig. VII., there will be eight paths instead of four as before, and the amount of current flowing through the receivers is still further reduced. Theoretically it would take an infinite number of transpositions to entirely eliminate the flow of current through the receivers, but practice has shown that a transposition, say every

quarter or even half mile, is usually sufficient to eliminate cross-talk and render lines comparatively quiet.

Fig. VIII. shows a method of transposition used by the American Telegraph & Telephone Company on their long distance line between New York and Chicago. There are five circuits on each cross arm and it will be seen that the center circuit is transposed every mile while the two adjacent circuits on either side are transposed every half mile and the two outside circuits are transposed every mile again, but their transpositions are staggered with respect to that of the center circuit. The reason for this staggering is that if two circuits were transposed at the same time their inductive relation to each other would be unchanged. The method of transposition is the same on each crossarm, if there be more than one, but the transpositions on each arm are staggered with respect to those on the arm immediately above or below it.

Perhaps the best illustration of the beneficial effect of transposition is that of the telephone cables which are being used extensively today. In these cables each circuit is twisted together and then the several circuits twisted about each other, the direction of the twist being reversed at short intervals. In this way although the cable contains many wires lying very close together the inductive effect of the several circuits on each other is practically neutralized and all cross-talk is eliminated.

There are of course many minor difficulties that arise in connection with every telephone line, but they are usually mechanical defects and require little skill to remedy. The troubles herein discussed are the chief ones which the telephone engineer meets with, and the great problem with the engineer today is to be able to construct lines free from noises and cross-talk and yet keep the cost of construction within commercial limits.