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Longitudinal Noise in Audio Circuits—Part 1

H. W. AUGUSTADT* and W. F. KANNENBERG*

A discussion of the general effect of the presence of longitudinal noise on a transmission circuit, with a description of the differences between metallic circuit noise and longitudinal noise. Test circuits and representative conditions are illustrated and discussed.

"Longitudinals" is a term often used to explain the origin of unknown noise in audio circuits with little actual regard to the source of the noise. In this respect, the usage of these words is similar to the popular usage of the word "gremlins." We attribute to gremlins troubles whose causes are unknown without much attempt to delve deeper into the matter. Similarly, in the audio facilities field, many noise troubles are attributed to "longitudinals," "line noise," or even simply "hum," without a clear understanding of the nature of the trouble or the actual meaning of the terms. However, the noise trouble still persists, irrespective of the name applied to it, until its causes are thoroughly understood and the correct remedial action is applied. This paper describes and illustrates, with representative examples, various types of common noise and in particular those resulting from longitudinal induction, in order to lead to an understanding of their nature. The paper includes, in addition, a discussion of simple remedies which may be employed for representative cases of noise troubles due to longitudinal induction.

The examples used for illustration purposes are shown in terms of amplifier input circuits. This has been done because the article is directed primarily towards people whose interests are mainly in the design and application of audio facilities for broadcasting systems, sound reenforcement systems, and similar applications. The principles are general, however, and apply to the general field of communication circuits.

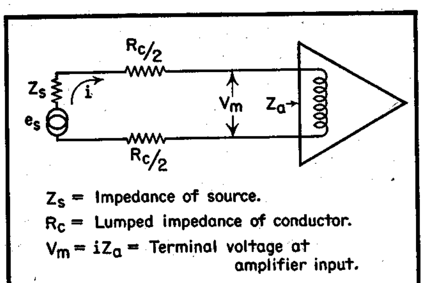

Fig. 1. Example of a metallic circuit voltage.

In order to achieve the objectives of this paper, it is necessary to make clear the meanings of the terms employed in describing various types of noise. It is, therefore, desirable to distinguish clearly between metallic-circuit noise and longitudinal noise. The first step is to distinguish between a metallic-circuit voltage and a longitudinal circuit voltage. The schematic representation of a metallic-circuit voltage is shown in *Fig.* 1 in which a source of constant voltage e_s with internal impedance Z_s impresses, through a conductor resistance R_c, a potential difference V_m across the input terminals of the receiving equipment. Note that the metallic-circuit voltage causes equal and oppositely directed currents to flow in the two conductors connected to the input circuit of the equipment.

The source of the voltage in *Fig.* 1 might equally well have been depicted as a constant-current generator. This generator in the circuit of *Fig.* 1 would likewise have caused currents of equal magnitude and opposite direction to flow in the two conductors of the input of the equipment and thus impress the metallic-circuit voltage V_m on the input terminals of the receiving equipment.

Bearing in mind the conditions represented in *Fig.* 1, a metallic-circuit voltage is a voltage that exists at any point between the two conductors of a pair. It is the metallic-circuit voltage V_m which is amplified by the receiving equipment and affects the performance of the circuit.

Longitudinal Circuit Voltages

In contrast to the condition represented in *Fig.* 1, consider the circuit of *Fig.* 2. In this case, the impressed voltage e_l, of internal impedance Z_l, causes equal *and like directed currents to flow down the two conductors,* out through the centerpoint of the input transformer primary, and through some coupling impedance—represented here as Z_{la}—to a third conductor, and return via the third conductor, which is usually ground. Their flow in the input transformer of the receiving equipment is in such a direction that they mutually oppose one another, and hence, on the assumption that the transformer is perfectly balanced to the midpoint

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ground, they produce no potential difference across the input terminals of the receiving equipment. The flow of this longitudinal current through the coupling impedance Z_{ls} causes a potential difference V_{la} to exist between the input circuit of the amplifier and the third conductor, but no metallic-circuit voltage is produced by this current, and hence the voltage V_m across the input terminals of the receiving equipment is zero.

Note that as in the case of the metallic-circuit voltage condition of *Fig.* 1, the source of the longitudinal voltage may be either a constant-voltage generator as depicted or a constant-current generator. This latter generator may be thought of as a generator which introduces a current $i_l/2$ on each conductor of the input circuit. The longitudinal currents flow to the third conductor via the two impedances Z_{ls} and Z_{la}.

In keeping with the conditions depicted in *Fig.* 2, a longitudinal voltage is a voltage that exists equally on the two conductors of a pair with reference to some third conductor to which it is conductively coupled, generally taken as ground.

When the generators of *Figs.* 1 and 2 are produced by unwanted sources they are designated as *noise generators.* The noise generators in the circuit of *Fig.* 1 may be either of the constant-voltage or constant-current type and produce *metallic-circuit noise voltages* and *metallic-circuit noise currents* respectively. In the longitudinal case of *Fig.* 2, the noise generators produce *longitudinal noise voltages* and *longitudinal noise currents,* depending on whether they are respectively of the constant-voltage or constant-current type. In addition, it should be noted that the generators may be lumped generators as depicted in the figures for ease of illustration, or they may be distributed sources. Likewise, the conductor resistances and the impedances to ground, Z_{ls} and Z_{la}, of *Fig.* 2 may be lumped or distributed.

Source of Longitudinal Noise

The illustrations employed to clarify the definitions of metallic circuit and longitudinal circuit voltages represent conditions which may be set up in the laboratory but do not reflect the conditions likely to be encountered in the normal use of the equipment. Hence, it is of interest to investigate the means by which longitudinal noise is introduced into the input circuits of audio equipment. *Figure* 3 represents one method by which longitudinal induced voltages of electromagnetic origin are introduced on a circuit. In this case, it is assumed that the conductors of the input pair are situated near a power conductor carrying substantial amounts of current. The resulting electromagnetic field from the power conductor cuts the conductors of the amplifier input circuit, and hence introduces distributed e.m.f's of approximately equal magnitude and the same sign on the two conductors of the pair. These e.m.f's cause approximately equal and like directed currents to flow on the conductors of the input pair and return via some third conductor with which they are coupled, indicated in the figure as ground.

Note that the condition represented in *Fig.* 3 may also be one by means of which a metallic-circuit noise voltage is introduced into the circuit. This happens whenever the two conductors of the pair are not linked by the same field. Assuming that changes cannot be made to eliminate the source of the disturbance, the magnitude of the metallic-circuit noise voltage induced in the circuit is reduced by employing

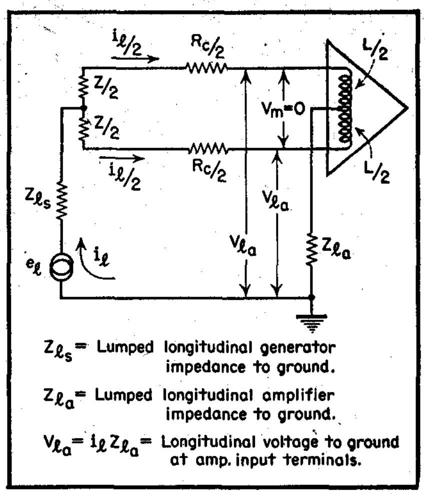
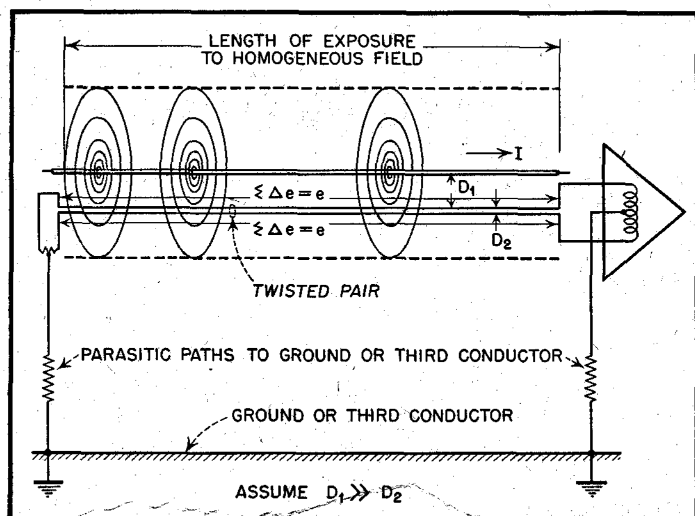


Fig. 2. Example of a longitudinal circuit voltage.

twisted or transposed pair conductors for the input circuit and also by making the distance between the audio pair conductors small compared with the distance of the audio pair from the power circuit. These precautions do not necessarily alter the magnitude of the voltage induced, but rather minimize the magnitude of the metallic-circuit voltage by arranging the circuit in such a way that equal e.m.f's, of like polarity, are induced on both conductors. The sum of these e.m.f's around the input circuit itself is zero, and hence the metallic-circuit voltage at all points of the circuit is zero. Thus, in an exposure of the character represented, protection against metallic-circuit noise voltages is obtained by so arranging the circuit that substantially only longitudinal voltages are induced on the circuit.

For the case depicted in *Fig.* 3, it is quite obvious that in the usual installation the coupling impedance between the power circuit and the audio input



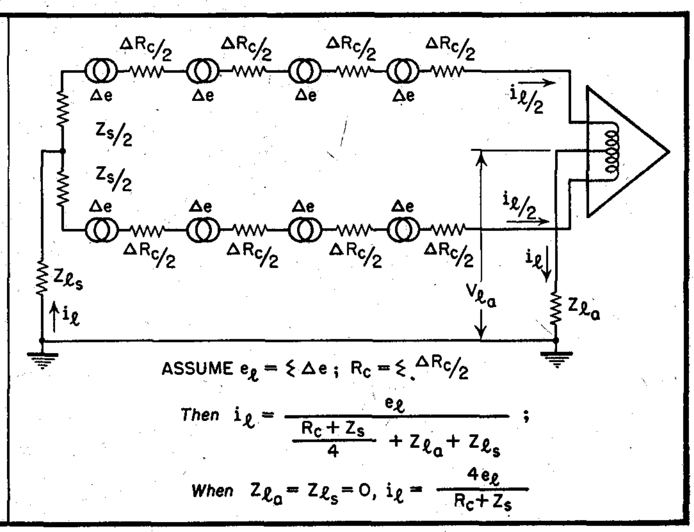


Fig. 3 (left). Example of longitudinal voltage caused by inductive coupling between power circuit and pair connecting source to amplifier. Fig. 4 (right). Schematic representation of longitudinal voltage resulting from magnetic induction.

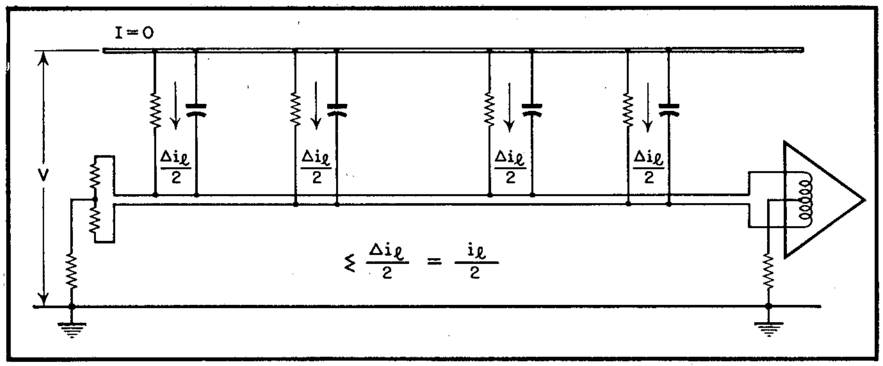


Fig. 5. Example of longitudinal current caused by electrostatic and leakage coupling between power circuit and pair connecting source to amplifier.

circuit is negligible with respect to the magnitude of the longitudinal and metallic-circuit impedances of the amplifier input circuit. This condition may be regarded as one in which the noise is introduced into the circuit by means of a zero-impedance generator. Noise of this type is known in this paper as noise due to a longitudinal noise voltage.

The schematic representation of the longitudinal induced voltage resulting from the conditions of exposure depicted in *Fig.* 3 is shown in *Fig.* 4. The equal incremental distributed voltages of like sign induced on the two conductors of the pair cause equal currents to flow down the conductors to some third conductor via the coupling impedances Z_{ls} and Z_{la}.

The magnitude of the longitudinal current $i_l/2$ on the conductors in *Fig.* 4 is determined by the metallic-circuit impedances and the longitudinal impedances of the circuit to ground. On the assumption that the source and receiving equipments have their center points strapped to ground and that the input transformer of the receiving equipment is an ideal one, the magnitude of the longitudinal current is limited only by the metallic-circuit impedances and becomes $i_l = 4e_l/R_c + Z_s$. This expression for longitudinal current indicates that the effect of a longitudinal induced voltage on a circuit is that of a zero impedance generator.

Longitudinal Currents

The manner in which longitudinal induced currents are introduced in a circuit under representative field conditions is shown schematically in *Fig.* 5. In the case depicted it is assumed that the power-circuit conductor is at a voltage V with respect to ground but that the current flowing on the power circuit is negligible, and, therefore, the associated electromagnetic field is negligible. Parasitic leakages and capacitances are, however, assumed to exist between the power circuit and the input circuit of the amplifier. Under these conditions, incremental longitudinal induced currents flow from the power conductor to ground via the input circuit of the amplifier. In general, for cases of induction of this type, the coupling impedance between the power circuit and the conductors of the input circuit is extremely large with respect to the longitudinal impedances of the input circuit to ground. Hence, the magnitude of the longitudinal induced current is determined by the coupling impedance. Noise of the type depicted in *Fig.* 5 may be regarded as resulting from a constant-current generator and is known in this paper as a longitudinal noise current.

The schematic representation of noise resulting from a longitudinal noise current is shown in *Fig.* 6. The longitudinal impedances of the input circuit to ground are assumed to be negligible in comparison with the magnitude of the coupling impedance Z_c, between the power circuit and the input circuit of the amplifier. Consider the case in which the metallic-circuit impedances are negligible compared with the magnitude of the longitudinal impedances to ground of the input circuit. The longitudinal noise current entering the circuit is then $i_l = 2V/V_c$. Under these conditions, the longitudinal voltage to ground of the input circuit of the amplifier is

$$V_{la} = \frac{Z_{la} \; Z_{ls}}{Z_{la} + Z_{ls}} i_l$$

In the case of a longitudinal noise current, the magnitude of the longitudinal voltage, V_{la}, is determined by the longitudinal impedance to ground of the input circuit of the amplifier.

Recapitulating, the noise introduced in a circuit by electromagnetic coupling is known as a longitudinal noise *voltage* because the noise generator has substantially zero internal impedance. The noise introduced in a circuit by leakage, or by electrostatic coupling, is known as a longitudinal noise *current* because it is due to a substantially constant-current generator.

Method for Identification

The above differentiation in the types of longitudinal noise has been stressed because it will be shown later that the circuit modification required to mitigate the effects of longitudinal induction depends on which type of induction is predominant. Accordingly, it is valuable to be able to identify the type of longitudinal induction to which the circuit is subjected. A test circuit for identification purposes is shown in *Fig.* 7. As shown in this figure, the two conductors of the pair are strapped together and connected to one input terminal of the amplifier; the other input terminal of the amplifier is connected to ground. At the sending end of the pair, the conductors are strapped together and connected to one contact of a single-pole single-throw switch. The other contact of the switch is connected to ground.

Identification of the type of induction is established by using this circuit to demonstrate its predominant characteristics. Assume, for example, that the noise results from electromagnetic induction. Of the two sending end conditions, open-circuit or short-circuit-to-ground, the short-circuit-to-ground condition enables the longitudinal noise voltage to produce the larger current flow, and hence causes most of the induced voltage to appear across the amplifier input terminals. When the sending end is open-circuit-to-ground, the longitudinal current flow is a minimum because of the high impedance to ground at the sending end, and most of the induced voltage appears across the open circuit at the sending end. The voltage across the amplifier input terminals is small because the longitudinal current flow is a minimum.

In the presence of a longitudinal

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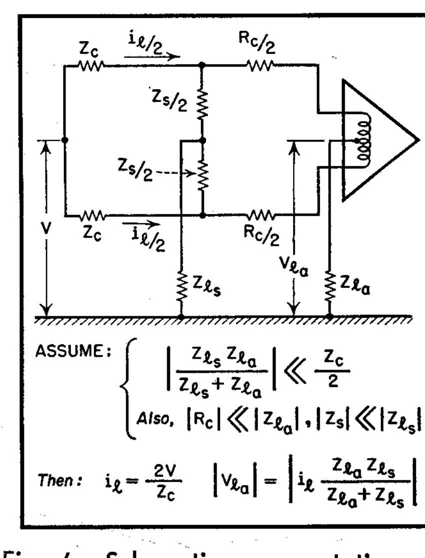

Fig. 6. Schematic representation of a longitudinal current resulting from parasitic coupling to a power circuit.

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noise current, the effects observed with the test circuit are just the reverse from those described above. In this case, the voltage across the amplifier terminals is greater with the switch at the sending end open, because the noise current flows to ground mainly via the input transformer of the amplifier. Closing the switch to ground drains off the longitudinal noise current to ground through a short circuit and causes minimum voltage to appear across the input terminals of the amplifier. As previously explained, the longitudinal voltage to ground of the input circuit depends, in this type of noise induction, mainly on the impedance to ground of the input circuit.

Identification of the type of noise induction is possible by observing the magnitude of the amplifier output. If the output is greater when the switch at the sending end is closed, the noise is of the longitudinal-noise-voltage type. On the other hand, if the output is greater with the sending end switch open, the noise is of the longitudinal-noise-current type. If the output is approximately the same for either switch condition, both forms of induction are present in comparable amounts.

(To be concluded)

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Longitudinal Noise in Audio Circuits—Part 2

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A discussion of the general effect of the presence of longitudinal noise on a transmission circuit, with a description of the differences between metallic circuit noise and longitudinal noise. Test circuits and representative conditions are illustrated and discussed.

Experience shows that, in general, neither a longitudinal noise voltage nor a current can be impressed on the input circuit of an amplifier without degrading the signal-to-noise ratio of the system. It is, therefore, of interest to investigate by what means the longitudinal induced noise is converted into a metallic-circuit voltage in order that it may be amplified and appear in the output circuit of the amplifier.

Shielding

The omission of an electrostatic shield from the input transformer of the receiving equipment is, in general, the greatest single cause of trouble from longitudinal induced noise, especially when the center point of the input circuit is not grounded. Difficulties, in this case, generally will be experienced from longitudinal noise currents. The manner in which the translation from longitudinal to metallic-circuit noise takes place is represented schematically in *Fig.* 8. It is assumed, for the purposes of illustration, that the impedance to ground of the input equipment and interconnecting circuit is large compared to the impedance to ground of the receiving equipment. The impedance to ground of the amplifier results from the interwinding capacitances of the input transformer, represented in the diagram as lumped parasitic capacitors C_1 and C_2. A longitudinal noise current $i_l/2$, whose magnitude is determined by the coupling impedance Z_c, flows along the conductors of the circuit to ground through the capacitors C_1 and C_2. The flow of this current through C_2 causes little difficulty. However, the flow of the longitudinal current through C_1 and the grid-to-ground impedance of the amplifier sets up a metallic-circuit voltage on the grid side of the coil which is amplified and degrades the signal-to-noise ratio of the system.

Figure 8 and its discussion show in fairly simple manner how a longitudinal noise current is converted into a me-

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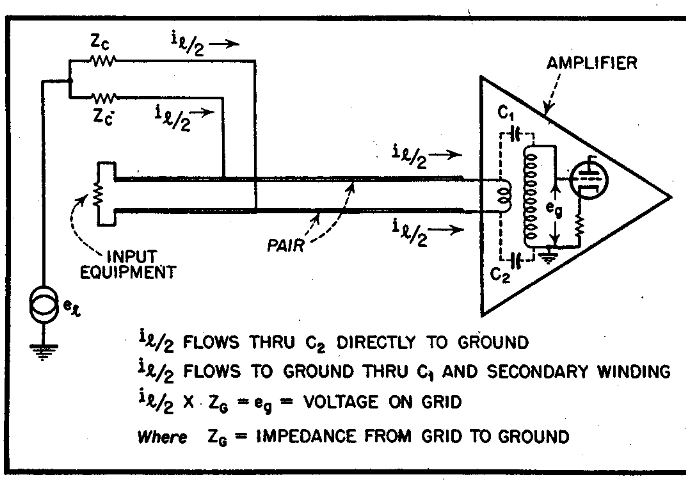

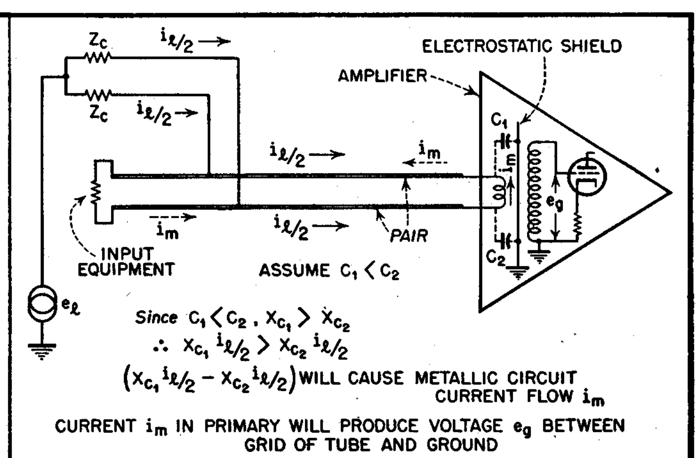

Fig. 8 (left). Conversion of longitudinal current to a metallic circuit voltage by interwinding capacitances in input transformer. Fig. 9 (right). Conversion of longitudinal current to metallic circuit voltage by capacitance unbalance.

tallic-circuit noise voltage and thus becomes a source of noise in an audio system. Whether this noise source is troublesome or not in a particular system depends solely on the magnitude of the longitudinal noise current. The magnitude of the longitudinal noise current is, in turn, determined in part by the size of the coupling impedance Z_c. This example shows the desirability of obtaining a large physical separation between power circuits and the input circuits of audio equipment in order to minimize noise troubles from longitudinal induction.

One method of mitigating difficulties of the type described above is to employ an electrostatic shield in the input transformer of the receiving equipment. Then the disturbing currents will flow down the two conductors to ground through the capacitance between primary winding and shield and will not be able to reach the secondary winding. Note, however, that in order to be effective, the shield must reduce the interwinding capacitances to values so small that only a negligible amount of the longitudinal current flows from the primary to the secondary winding of the transformer.

The introduction of an electrostatic shield in the input transformer of the receiving equipment may greatly reduce the troubles resulting from longitudinal noise, but it does not entirely eliminate them. Another manner in which the longitudinal noise is converted into a metallic circuit voltage is depicted in *Fig.* 9. The conditions assumed here are the same as those discussed in connection with *Fig.* 8. An electrostatic shield has, however, been introduced into the input transformer in order to eliminate the capacitance between the primary and secondary windings. Assume that, due to the physical construction of the coil, the capacitances between the ends of the primary winding and the shield are not identical. This condition will always occur, of course, when the primary windings are layer wound over the electrostatic shield so that one end of the winding is at greater physical distance from the shield than the other. For purposes of illustration and analysis, these distributed capacitances have been assumed to be lumped at the terminals of the coil and C_2 is assumed to be larger than C_1.

Under the assumption that the circuit is subject to a longitudinal noise current, equal longitudinal currents $i_l/2$ flow down the conductors of the circuit to ground through the capacitors C_1 and C_2. Since C_1 does not equal C_2, and by supposition equal currents flow through them to ground, the potential drops across the capacitors will not be equal. Since the two terminals of the input transformer have different potentials to ground, a potential difference must exist across the primary of the coil. This voltage appears on the secondary side of the transformer as the grid to ground voltage e_g and it also produces the small primary metallic circuit current i_m. This metallic circuit current is indicated by a dashed arrow in *Fig.* 9.

Effect of Circuit Balancing

At this point, the question may be raised, "Why not drain the longitudinal current to ground by shorting the center tap of the input coil to ground and thereby eliminate the necessity for an electrostatic shield and also avoid the difficulties due to capacitance unbalances in the input transformer?" Grounding the center point of the input circuit, either at the source or the receiving equipment does, it is true, eliminate most of the troubles resulting from longitudinal noise currents but, under certain conditions, it greatly increases the possibility of noise troubles from longitudinal noise voltages.

The reason for this may be learned from a consideration of *Fig.* 10, in which it will be assumed that the input circuit of the amplifier is subject to a longitudinal noise voltage. The effect of such a voltage on the circuit is simulated by means of the zero-impedance generator e_l. It is further assumed that the source of excitation is connected to the input circuit by means of an ideal repeating coil, between whose center point and ground the longitudinal voltage is introduced, and that the center tap of the input coil on the receiving equipment is strapped to ground.

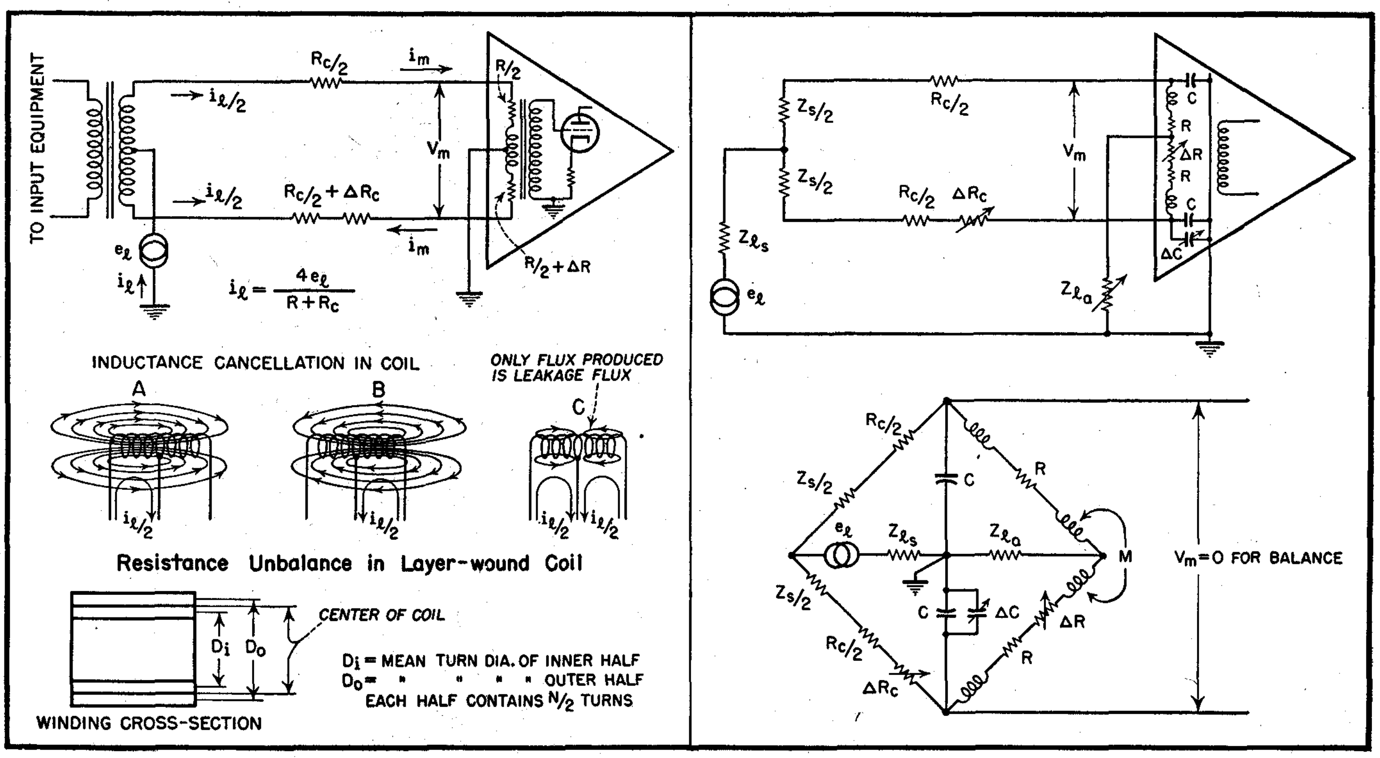

Fig. 10 (left). Conversion of a longitudinal voltage to a metallic circuit current by metallic circuit unbalances. Fig. 11 (right). Circuit elements (above) which may require adjustment to achieve satisfactory equipment performance in the presence of longitudinal noise. Equivalent bridge circuit (below) for analytical purposes.

The longitudinal current produced by the applied voltage is $i_l = 4e_l/(R+R_c)$ in which R_c is the resistance of the conductors of the input circuit and R is the resistance of the primary winding of the input transformer. Note that neither the primary inductance of the input transformer or of the repeating coil, nor the internal input impedance of the amplifier, nor the output impedance of the input equipment appears in this expression. These latter factors cancel out because the longitudinal circuit currents flow in opposing directions to ground through the primary windings of the coils, and hence the associated magnetic fluxes set up by them cancel out, as indicated in *a*, *b*, and *c* of *Fig.* 10. The impedance, due to the residual leakage flux will, in general, be negligible with respect to the winding resistance in the frequency band of interest, i.e. power frequencies and their important harmonics. The repeating coil has, of course, no leakage by the assumption that it is an ideal transformer.

Consider first the consequences of resistance unbalances only on this cir-

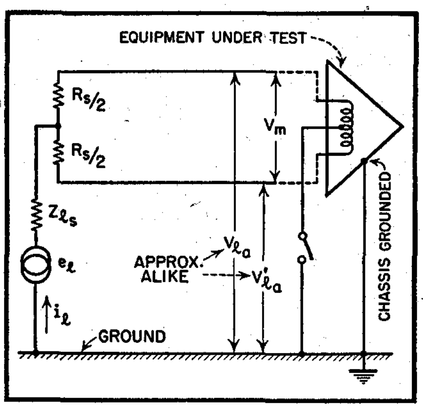

Fig. 12. Test circuit for laboratory evaluation of performance of equipment in the presence of longitudinal voltage or current.

cuit. It is assumed in the illustration that the input transformer is a layer-wound coil, and hence the resistance of its inner winding is less than that of its outer winding. This resistance unbalance in the coil is designated ΔR. It is also assumed that the input conductors are slightly unbalanced, and this conductor resistance unbalance is designated ΔR_c. On the assumption that the unbalances are a small part of their respective resistances, their effect on the circuit may be determined by assuming that equal longitudinal currents $i_l/2$ flow down the two conductors to ground. The flow of these equal currents through resistances which differ slightly in magnitude will produce slightly different potential drops along the two paths to ground. This difference in the two potential drops will cause a metallic-circuit current i_m to flow in the input circuit of the equipment of the correct magnitude to make the potential drops along the two paths to ground equal. However, the flow of the metallic circuit current i_m, indicated by the dashed arrow in the figure, through the primary winding of the input transformer sets up a voltage V_m across the terminals of the receiving amplifier. This then is another means by which longitudinal noise is converted into metallic-circuit noise.

Impedence Unbalance

The actual means for converting the longitudinal noise voltage into metallic-

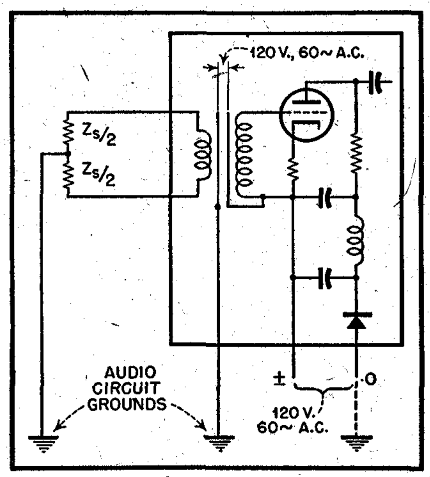

Fig. 13. Analysis of source of noise in an a.c.-d.c. amplifier.

circuit noise, in the general case, is impedance unbalance in the two halves of the input circuit. This impedance unbalance may exist in the input circuit of the receiving equipment, in the connecting pair, or it may originate in the input equipment. Unbalance anywhere in the two halves of the circuit will, under the conditions assumed in *Fig.* 10, convert part of the longitudinal current into a metallic-circuit current. The remedy which this analysis suggests is to reduce the circuit unbalances and so protect the circuit against longitudinal noise voltages.

The magnitude of the metallic-circuit voltage introduced in the input circuit, under the conditions assumed in *Fig.* 10, is a function of the magnitude of the longitudinal current. This, therefore, suggests that an alternate remedy in this case is to remove a center tap ground from the circuit in order to reduce the longitudinal current to a negligible quantity and thereby reduce the metallic-current resulting from circuit unbalances. It is thus apparent that the expedient of operating the input circuit of the equipment with a center-point ground is not a general protective measure against longitudinal

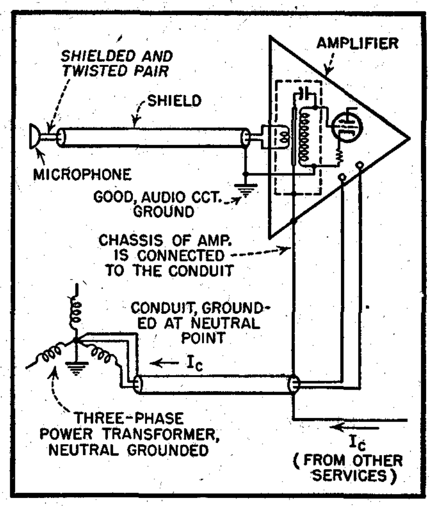

Fig. 14. Multiple grounding method.

noise. The very act of putting center tap grounds on a circuit, while rendering the circuit relatively insensitive to longitudinal noise currents, greatly increases its susceptibility to longitudinal noise voltages. Likewise, operating a circuit without center point grounds makes it relatively insensitive to longitudinal noise voltages and markedly increases its sensitivity to longitudinal noise currents.

In actual conditions of operation, the input circuits of audio systems may be subject simultaneously to both types of longitudinal noise, and the problem is therefore to uncover a general solution that will protect the circuit under both kinds of exposure. The solution, as may have been anticipated, involves the simultaneous adjustment of all the factors discussed so far. The problem which must be solved in a given design may be grasped by a consideration of *Fig.* 11. The metallic circuit voltage V_m must be reduced to a negligible quantity for two conditions of operation: with Z_l equal to zero, representing the case of a longitudinal noise voltage; and with Z_l large compared with the circuit impedance to ground, representing the case of a longitudinal noise current.

The elements of the circuit which must be adjusted to achieve the desired objective are shown as circuit variables (it is assumed that an electrostatic shield is incorporated in the input transformer in order to eliminate the transformer interwinding capacitances). The circuit of *Fig.* 11 is also presented schematically in the alternate Wheatstone bridge form. The problem is then to adjust the circuit variables so as to reduce the bridge output to zero in the presence of the longitudinal voltage e_l. The variables which require adjustment are the series circuit impedance unbalances represented in the figure as conductor and coil resistance unbalances, the impedance unbalances to ground of the circuit represented in the figure as capacitances, and the impedance to ground in the center tap circuit of the input transformer.

The entire input circuit of an audio system must be so designed that it will perform in an acceptable manner in the presence of longitudinal noise. In general, this means that appropriate protective measures against longitudinal induction must be incorporated in all the elements of the input circuit, including input equipment and the connecting pair, as well as the receiving equipment. This is true because both the input equipment and the connecting pair can equally well convert the longitudinal noise into metallic-circuit noise. The problem is not restricted to amplifiers alone as longitudinal conversion sources, but is likewise true for microphones, phonograph pickups and all other types of input equipment.

Equipment Limitations

The limitations of a piece of equipment must be understood in order to use it effectively, and these limitations are generally established by suitable test procedures. From the preceding discussion, it is apparent that data is desired, in appropriate form, on the equipment in the presence of both types of longitudinal induction. This means that the test circuit should provide a measure of the effect of the series impedance unbalances of the two halves of the metallic circuit and of their impedance unbalances to ground, and should also reflect the effect of the other factors such as interwinding capacitances that contribute to poor performance in the presence of longitudinal noise. An appropriate test circuit for this purpose is shown in *Fig.* 12.

The test circuit of *Fig.* 12 is arranged to impress the longitudinal voltage on the equipment under test via the midpoint of the source impedance for which the equipment was designed. The longitudinal voltage may be impressed through an impedance Z_l, whose value is dictated either by the conditions of the test or the sensitivity of the instruments used in making the test. Appropriate precautions should be taken to insure that the test circuit is itself not a source of error.

The test circuit is employed to evaluate the performance of the equipment in the presence of a longitudinal voltage and in the presence of a longitudinal current. The performance of the equipment in the presence of a longitudinal voltage is determined by measuring the metallic-circuit voltage V_m and the longitudinal voltage V_{lo} under the condition of minimum — preferably zero—longitudinal current i_l. The measurement is therefore made with the center point of the input circuit of the equipment open circuit to ground. The longitudinal voltage suppression of the equipment, under these conditions of operation, is the ratio of V_{lo} to V_m. In decibels, it is 20 $\log_{10} V_{lo}/V_m$ and it should be determined over the appropriate frequency band.

The performance of the equipment in the presence of a longitudinal current is determined by measuring the ratio of the metallic circuit voltage V_m to the longitudinal current i_l under the condition of minimum—preferably zero—longitudinal voltage V_{lo}. This measurement is therefore made with the center point of the input circuit of the equipment shorted to ground. The longitudinal current suppression of the equipment, under these conditions of operations, is the ratio of V_m to i_l. It is generally expressed as so many microvolts per ampere and should be determined over the appropriate frequency band.

Field vs Test Performance

The correlation between the performance of a piece of equipment when in a test circuit and when installed in the field is often difficult to establish because of the wide range of field operating conditions. This situation is particularly true when it comes to predicting with accuracy, on the basis of laboratory test data, the longitudinal suppression performance of equipment. Hence, in the remainder of this article, some of the limitations and special conditions encountered will be indicated briefly as a guide to the wide range of problems encountered in the practical application of this information. A source of possible discrepancy between predicted and actual performance resides in the fact that lumped noise sources are employed in both the analysis and test circuits, whereas the noise experienced in the field is usually that due to a distributed source. In the case of the interconnecting pair between the sending and receiving equipment, the metallic-circuit impedances and the impedances to ground are, in addition, distributed rather than lumped elements. It generally will be found, however, that a satisfactory correlation between the longitudinal suppression performance of a piece of equipment in a test circuit and in the field can be established when the effect of these factors are correctly evaluated.

Another factor of importance is that in this discussion it has been assumed that the longitudinal noise is introduced into the input circuit between the sending and receiving equipment. However,

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Employment Register

Positions open and Available personnel may be listed here at no charge to industry or to members of the Society. For insertion in this column, brief announcements should be in the hands of the Secretary, Audio Engineering Society, Box F, Oceanside, N. Y., before the fifth of the month preceding the date of issue.

• **Wanted:** E. E., electronics major, with extensive bkgnd in magnetic and audio cct design and acoustical theory and practice. Must have at least 5 yrs exp. in product design on products now being sold nationally. Must be capable of following product from experimental through production, and be responsible for specifications, quality control, field tests, operation and service manuals on product developed. Must be creative and have an exceptionally high degree of mechanical aptitude. State age, education, and qualifications when answering. Location: Minnesota. Box 102.

• **Communications Engineer** (MIT), 22, single, with good theoretical background and some experience; interested in research, development, or teaching in audio, acoustics, electric circuits, and vacuum-tube circuits. Box 111.

• **Graduate Student** of radio and television desires Junior Engineering position in audio or recording industry. Age 23, married, child. Willing to travel occasionally. Prefer midwest or south. Box 113.

• **Recording Engineer.** Experienced mixer; knowledge of classical music. Knows motion picture and radio mixing techniques, 30, married, presently employed. Graduate of Hollywood Sound Institute. Box 121.

• **Audio Engineer.** Graduate Hollywood Sound Institute, 25, married. Now attending television production school. Desires position with broadcast or recording studio, evenings, N.Y.C. Free to travel for full-time position. Box 122.

• **Graduate:** Advanced Technology course at RCA Institutes, 26, married, with knowledge of music, desires position in audio field; salary secondary. Box 101.

• **Audio Engineer:** M.S. Physics, Electrical Engr; ten years research, development, design experience with sound recording, acoustic measurements, and transducers. Thorough bkgnd in magnetic and mechanical recording including magnetic recording systems for computer applications. Presently employed, prefer firm in which could invest capital, small city or suburban location. Box 201.

• **Graduate VTI:** employed at present. Desires position in audio field. Some experience. Age 20, single, and in good health. Willing to learn, and will go anywhere. Box 202.

• **Audio Engineer:** experienced man with family desires position in recording, broadcasting, film, or TV sound. Excellent operator, troubleshooter, and maintenance man. Superior knowledge of classical music. Studio and equipment design and construction experience. Fluent English, French, and German. Willing to relocate. Box 203.

LONGITUDINAL NOISE

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it often happens that the noise is introduced, by means so far not considered, at other points of the circuit. A well known illustration and one which presents many design difficulties is that of an a.c.-d.c. amplifier operated on a.c. In this case, the amplifier itself is the source of the noise. This is true because the secondary side of the input transformer is directly connected to the a.c. power circuit. Poling of the power plug on the amplifier cannot be relied upon to reduce its noise, because in many areas the so-called low side of the power circuit has a substantial voltage to ground. In addition, this voltage often includes substantial amounts of the higher harmonic and therefore the more disturbing components of the power supply frequency.

The problem in designing a universal a.c.-d.c. amplifier is thus to make a unit with acceptable performance for either polarity of the a.c. power supply. This means that the signal-to-noise ratio of the amplifier must be acceptable when the full power circuit voltage is impressed between the windings of the transformer in the manner shown in *Fig.* 13. One method of solving this problem is by the use of two separate electrostatic shields. One shield encloses the secondary winding and is connected to the low side of this winding. The other shield encloses the primary winding and is connected to the audio circuit ground associated with the input circuit. This arrangement virtually eliminates the parasitic coupling capacitances between the primary and secondary windings of the transformer and thus substantially eliminates the flow of the longitudinal current through the transformer windings from this cause. It also eliminates the flow of the longitudinal current from winding to its associated shield since each winding is at its shield potential, from a longitudinal circuit point of view, by virtue of the connection between them. The longitudinal current flow is thus from one shield to the other, but this current flow will not degrade the signal-to-noise ratio of the amplifier.

Multiple Grounds

Another manner in which longitudinal noise may be introduced in a system at a point other than the interconnecting pair is depicted in *Fig.* 14. In this case, it is assumed that the panel and circuit grounds on the amplifier have been separated for utmost flexibility in application. It is further assumed that on installation the circuit ground has been connected to a quiet audio ground, but that the panel has been connected to the conduit of the power circuit. It is assumed, in addition, that the secondary winding of the input transformer has appreciable capitance to its case and core which are electrically connected to the amplifier panel. Substantial currents originating from external sources are presumed to be returning to ground via the conduit. This condition sets up a potential difference between the amplifier panel and the audio circuit ground and causes noise currents to flow from the conduit to the audio ground via the secondary winding of the transformer and its associated capacitance to core and case. This noise current introduces a voltage into the equipment on the grid side of the input transformer. Installations in which transients on the power circuit appear in the output of the system may be subject to noise trouble of this type. This difficulty may be eliminated by employing the audio circuit ground for both panel and circuit ground purposes.

Summarizing, then, there are two general means by which longitudinal noise is introduced in a circuit, one of high internal impedance so that the noise has the characteristics of a constant current introduced into the circuit, the other of substantially zero internal impedance so that the noise has the characteristics of a constant voltage introduced into the circuit. It has also been shown that these two types of induced noise affect a circuit in different manners and therefore require widely different treatment to avoid their unwanted effect on a circuit. Superficial remedies to render a circuit insensitive to longitudinal noise are as apt to increase the difficulty as to mitigate it because of the diverse character of its two types. However, as outlined in this article, once the nature of longitudinal noise induction is understood, it is as amenable to reduction of its disturbing effects as many of the other sources of noise with which the audio engineer must contend.