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## Longitudinal Noise in Audio Circuits—Part 1

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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.

“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

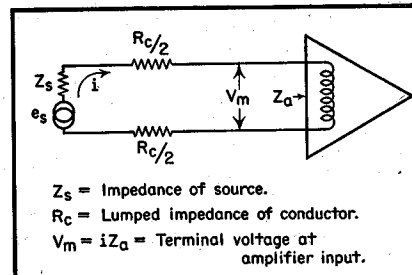


Fig. 1. Example of a metallic circuit voltage.

mainly in the design and application of audio facilities for broadcasting systems, sound reinforcement systems, and similar applications. The principles are general, however, and apply to the general field of communication circuits.

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  $e_s$ , of internal impedance  $Z_s$ , 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  $Z_{ic}$ —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  $Z_{i_a}$  causes a potential difference  $V_{l_a}$  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  $Z_{i_s}$  and  $Z_{i_a}$ .

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,  $Z_{i_s}$  and  $Z_{i_a}$ , 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

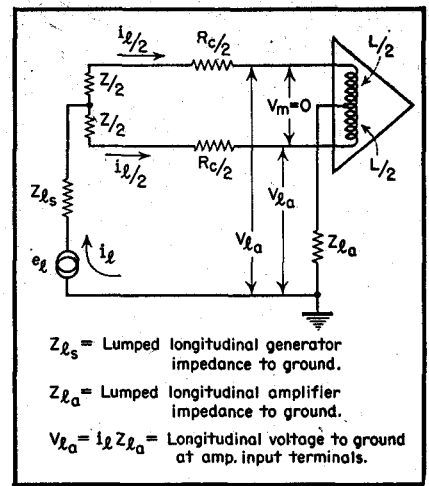


Fig. 2. Example of a longitudinal circuit voltage.

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

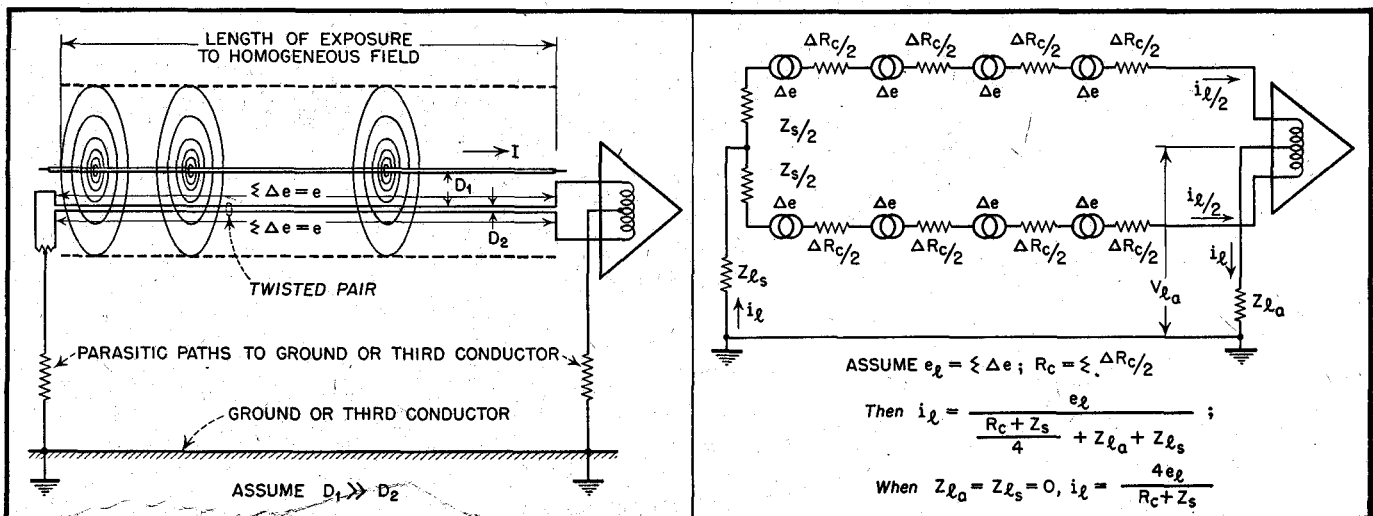


Fig. 3 (left). Example of longitudinal voltage caused by inductive coupling between power circuit and pair connecting source to amplifier. Fig. 4 (right). Schematic representation of longitudinal voltage resulting from magnetic induction.

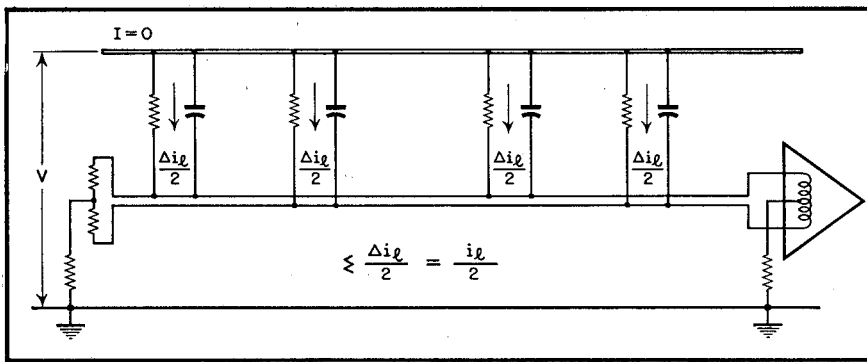


Fig. 5. Example of longitudinal current caused by electrostatic and leakage coupling between power circuit and pair connecting source to amplifier.

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  $Z_{i_s}$  and  $Z_{i_a}$ .

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  $i_l = 4e_l/R_s + Z_s$ . 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 in-

duced 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

$$V_{i_a} = \frac{Z_{i_a} Z_{i_s}}{Z_{i_a} + Z_{i_s}} i_l$$

In the case of a longitudinal noise current, the magnitude of the longitudinal voltage,  $V_{i_a}$ , 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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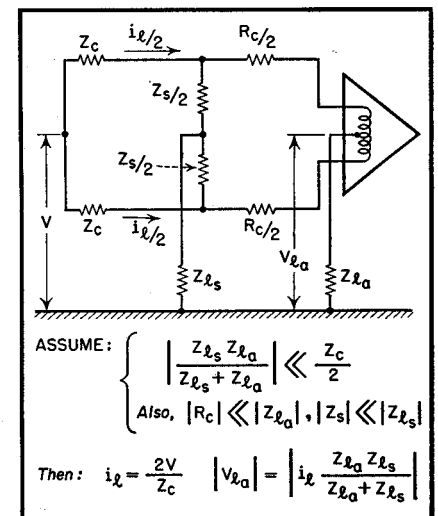


Fig. 6. Schematic representation of a longitudinal current resulting from parasitic coupling to a power circuit.

# LONGITUDINAL NOISE IN AUDIO CIRCUITS

[from page 24]

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)*