TRANSMISSION LOSSES INTRODUCED BY REFLECTION EFFECTS

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1. GENERAL

1.01 By the term reflection effects, is meant the effects upon transmission resulting from changes in the impedance of parts of a telephone circuit. A physical conception of these effects can be readily obtained by considering the propagation of a train of recurrent waves over a circuit where there are abrupt changes in impedance.

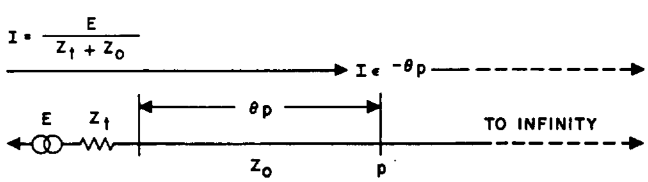

Fig. 1 — Alternating Voltage Impressed on a Constant Impedance

1.02 If an alternating voltage be impressed upon a smooth line such as is indicated in Fig. 1, it produces a steady-state current wave which is attenuated as it proceeds along the line and is propagated indefinitely until it is so completely dissipated that the wave may be considered to have vanished.

1.03 If, however, the circuit is not uniform in impedance throughout, as in Fig. 2, portions of the wave are reflected at each discontinuity.

1.04 Figure 3 gives an idea of the number of such reflections which occur, each reflected wave being considered to be attenuated indefinitely until it has vanished. In the sketch shown, of course, only the first few reflections are indicated as the drawing would become too complicated if a larger number were shown. The steady-state current at any point in the circuit is the sum of the impressed wave reaching this point plus the residuals of all the various reflected waves still persisting at that point.

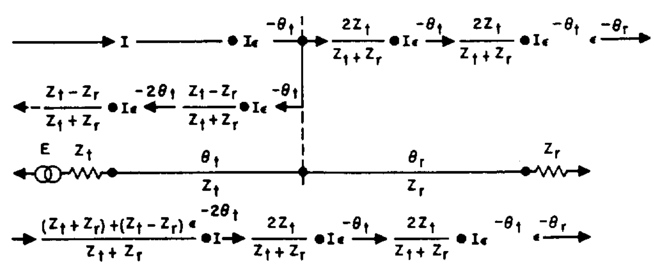

Fig. 2 — Alternating Voltage Impressed on an Impedance Change

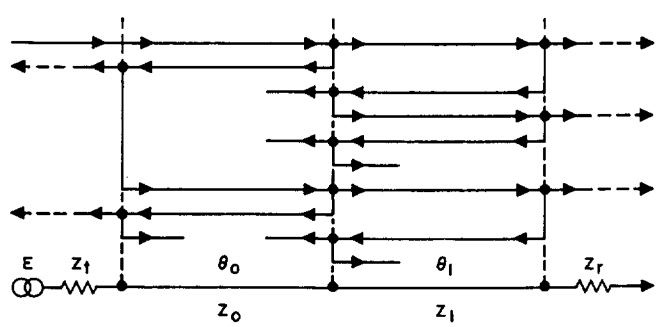

Fig. 3 — Reflections Caused by Impedance Changes

1.05 It will be seen that where there is more than one point of discontinuity in a circuit, the reflection occurring at one discontinuity is reflected again at the next discontinuity. Unless these points at which reflections occur are sufficiently distant from each other so that the attenuation has reduced the reflected wave to a negligible amount by the time it makes a round trip from one junction to the next, there will be additional reflections which will add to or subtract from the original wave.

2. TRANSMISSION LOSSES INTRODUCED BY REFLECTION EFFECTS

2.01 In computations it is convenient to divide the transmission loss resulting from reflection effects into three types of component losses as follows:

(a) Reflections at the terminal junctions of a circuit — reflection loss.

(b) Reflections at intermediate junctions — junction loss.

(c) Interaction between points of reflection — interaction loss.

A. Reflection Loss

2.02 The reflection loss for any two impedances, e.g., Z_t and Z_1, is a function of the ratio

$$\frac{Z_t}{Z_1} = r\underline{/\phi} \qquad (1)$$

where r is the ratio of the magnitudes and ϕ is the difference between the angles of the two impedances. Values of reflection loss in terms of r and ϕ are given by the Reflection Loss Chart of Section 304-008-101.

2.03 A reflection loss between the terminal impedance Z_t and the characteristic impedance Z_1 of the circuit facility terminated by it, is introduced by each of the two terminal junctions of a circuit. These terminal junction reflection effects, however, are taken care of by the terminal reflection loss corrections and end section losses. A reflection loss is also introduced by any intermediate junction at which a long section (or else a section terminated at its other end in substantially its characteristic impedance) of one type of circuit facility is connected to a long or short length of another facility having a different characteristic impedance. This last is discussed further under B. Junction Loss. Unless a circuit is short or is made up of short lengths of circuit facilities having different characteristic impedances, losses, other than the above, resulting from reflection effects, may usually be neglected.

B. Junction Loss

2.04 Reflection loss depends upon only two impedances; junction loss depends upon four impedances. They are the characteristic impedances of the two line sections joined, and the junction impedances i.e., the actual impedances looking in each direction from the junction. A junction loss is introduced by each intermediate junction in a circuit. The junction loss for the intermediate junction of Fig. 4 can be expressed in terms of three reflection losses involving the junction impedances and line impedances as follows.

$$\begin{aligned}\text{Junction Loss} = &\ \text{Reflection Loss } (Z_o, Z_b) \\ &+ \text{Reflection Loss } (Z_1, Z_a) \quad (2) \\ &- \text{Reflection Loss } (Z_a, Z_b)\end{aligned}$$

2.05 As it would be very difficult to set up charts to show junction losses in terms of four different impedances, the best method of determining the junction loss is to determine the three reflection losses which, when added together as noted above, will give the junction loss.

2.06 It should be noted that if either of the junction impedances equals the characteristic impedance of the corresponding line section, the junction loss reduces to the reflection loss for the line impedances of the two sections. Practically this equality between the junction impedance and the corresponding characteristic impedance can be considered to exist when a section is electrically long or when it is connected at its distant end to

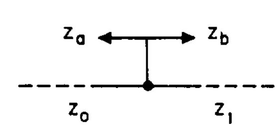

Fig. 4 — Impedances in Junction Loss

an impedance which is closely equal to its characteristic impedance.

C. Interaction Loss

2.07 Similarly, interaction loss depends on four variables, and it is convenient, therefore, to express it in terms of three reflection losses. Referring to Fig. 5, the interaction loss for the section shown can be expressed as follows.

$$\begin{aligned}\text{Interaction Loss} &= \text{Reflection Loss } (Z_c, Z_d)\\ &- \text{Reflection Loss } (Z_o, Z_c)\\ &- \text{Reflection Loss } (Z_o, Z_d)\\ &\quad \text{or} \qquad (3)\\ &= \text{Reflection Loss } (Z_f, Z_e)\\ &- \text{Reflection Loss } (Z_o, Z_f)\\ &- \text{Reflection Loss } (Z_o, Z_e)\end{aligned}$$

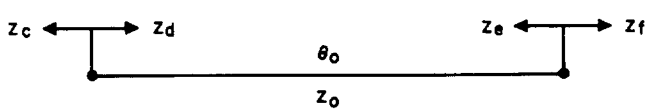

Fig. 5 — Impedances in Interaction Loss

2.08 An interaction loss is introduced by each line section in a circuit; but, referring to the equations above, it will be seen that if either of the junction impedances is equal to the corresponding characteristic impedance, the interaction loss for that section is zero. ***Practically, therefore, the interaction loss may be neglected if any of the four junction impedances associated with that section is closely equal, both in magnitude and angle, to the characteristic impedance of the section.*** Also if the attenuation loss of the section is at least 5 db, the attenuation is sufficiently great so that the interaction loss for that section will not, in general, exceed ±0.5 db.

2.09 In the toll plant, sections are generally long and impedances are closely matched. Interaction losses are usually sufficiently small so that they may be neglected in this case. This leaves only interaction losses for short loaded and nonloaded trunks to be considered.

D. Combination of Junction Losses and Interaction Losses

2.10 It will be found that the addition of a series of junction losses and interaction losses will result in certain of the reflection losses being eliminated by direct subtraction. Referring to Fig. 4, the sum of the junction loss and the interaction loss for the section to the left of the junction reduces to the following simple form,

$$\begin{aligned}\text{Combined Loss} &= \text{Reflection Loss } (Z_1, Z_a)\\ &- \text{Reflection Loss } (Z_o, Z_a)\end{aligned} \qquad (4)$$

and the sum of the junction loss and the interaction loss for the section to the right of the junction reduces to

$$\begin{aligned}\text{Combined Loss} &= \text{Reflection Loss } (Z_o, Z_b)\\ &- \text{Reflection Loss } (Z_1, Z_b).\end{aligned} \qquad (5)$$

The sum of the junction loss and the two interaction losses to the left and right, respectively, of the junction, when added together, reduces to

$$\begin{aligned}\text{Combined Loss} &= \text{Reflection Loss } (Z_a, Z_b)\\ &- \text{Reflection Loss } (Z_o, Z_a) \quad (6)\\ &- \text{Reflection Loss } (Z_1, Z_b).\end{aligned}$$

These equations materially reduce the labor of computing if they are used whenever possible.

3. TYPICAL EXAMPLES

3.01 The use of the information here given will now be illustrated by outlining the method of computing the overall equivalents of some interoffice connections. In the solutions to the following illustrative examples, the component losses which make up the overall equivalent of the circuit are listed at the left; at the right are listed the sections of transmission data and the numbered expressions in this section from which the values of these component losses can be obtained.

3.02 Figure 6 indicates a simple interoffice connection established over a nonloaded trunk. This circuit contains no intermediate junction; the

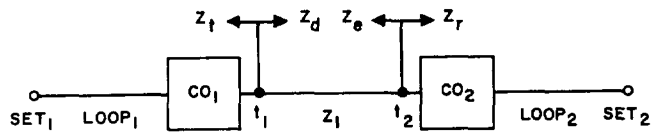

Fig. 6 — Simple Interoffice Connection Over a Nonloaded Trunk

overall equivalent of the circuit, transmitting from Set$_1$ to Set$_2$, is the sum of the following:

Transmitting Loss, Loop$_1$ . . . Section AB22.075
Receiving Loss, Loop$_2$ . . . . . Section AB22.075
Central Office Loss, CO_1 . . . . Section AB22.275
Central Office Loss, CO_2 . . . . Section AB22.275
Terminal Reflection Loss Correction, Junction t_1 . . . . . Section AB22.125
Terminal Reflection Loss Correction, Junction t_2 . . . . . Section AB22.125
Attenuation Loss for Trunk Section AB22.175
Interaction Loss for Trunk . . . . Expression (3)

The interaction loss in this case is given by either of the following combinations of reflection losses:

Ref. Loss (Z_t, Z_d) — Ref. Loss (Z_1, Z_t) — Ref. Loss (Z_1, Z_d)

or

Ref. Loss (Z_r, Z_e) — Ref. Loss (Z_1, Z_r) — Ref. Loss (Z_1, Z_e)

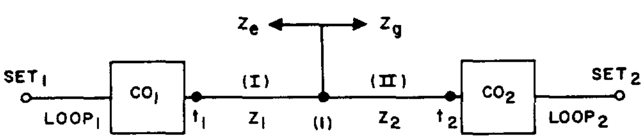

Fig. 7 — Simple Interoffice Connection Over Trunk Containing Two Nonloaded Sections

3.03 Figure 7 indicates an interoffice connection established over a trunk made up of two nonloaded sections. The overall equivalent of this circuit, transmitting from Set$_1$ to Set$_2$, is the sum of the following:

Transmitting Loss, Loop$_1$ . . . Section AB22.075
Receiving Loss, Loop$_2$ . . . . . . Section AB22.075
Central Office Loss, CO_1 . . . . Section AB22.275
Central Office Loss, CO_2 . . . . Section AB22.275
Terminal Reflection Loss Correction, Junction t_1 . . . . . Section AB22.125
Terminal Reflection Loss Correction, Junction t_2 . . . . . Section AB22.125
Attenuation Loss, Section (I) . . . . Section AB22.175
Attenuation Loss, Section (II) . . . . Section AB22.175
Interaction Loss, Section (I) . . Expression (3)
Interaction Loss, Section (II) . Expression (3)
Junction Loss, Junction (1) . . . Expression (2)

In accordance with expression (6), the combined loss for the above junction loss and interaction losses reduces to:

Ref. Loss (Z_e, Z_g) — Ref. Loss (Z_1, Z_e) — Ref. Loss (Z_2, Z_g)

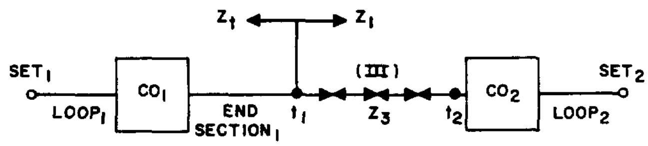

Fig. 8 — Simple Interoffice Connection Over a Partially Loaded Trunk

3.04 Figure 8 indicates an interoffice connection established over a partially loaded trunk terminated at one end in a half section and having a nonloaded end section at the other. The overall equivalent of this circuit, transmitting from Set$_1$ to Set$_2$, is the sum of the following:

Transmitting Loss, Loop$_1$ . . . Section AB22.075
Receiving Loss, Loop$_2$ . . . . . . Section AB22.075
Central Office Loss, CO_1 . . . . Section AB22.275
Central Office Loss, CO_2 . . . . Section AB22.275
End Section Loss, End Section$_1$ . . . . Section AB22.125
Terminal Reflection Loss Correction, Junction t_2 . . . . . Section AB22.125
Attenuation Loss, Section (III) . . . . Section AB22.175
Interaction Loss, Section (III) . . . . Expression (3)

The interaction loss in this case is given by the following combination of reflection losses:

Ref. Loss (Z_t, Z_1) — Ref. Loss (Z_3, Z_t) — Ref. Loss (Z_3, Z_1)