Oct. 23, 1956 C. N. NEBEL 2,768,355

TRANSMISSION LINE WITH IMPEDANCE-MATCHING TERMINATIONS

Filed May 31, 1952

FIG. 1

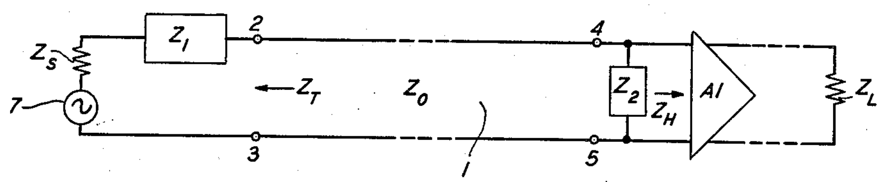



FIG. 2

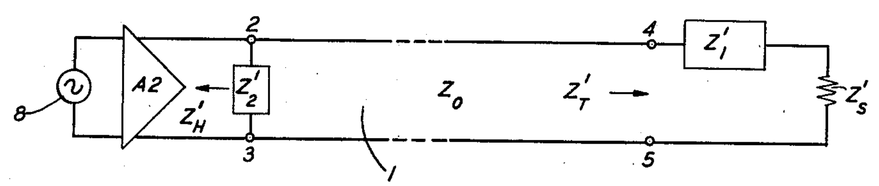
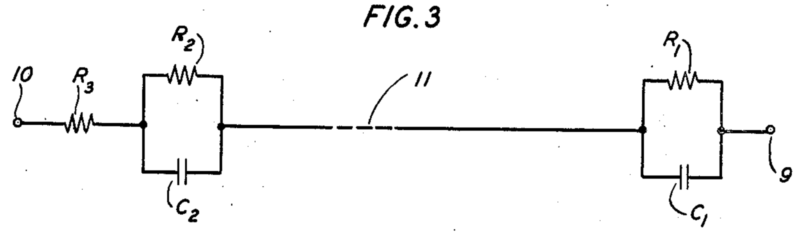



FIG. 3

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## TRANSMISSION LINE WITH IMPEDANCE-MATCHING TERMINATIONS

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3 Claims. (Cl. 333—27)

This invention relates to wave transmission circuits and more particularly to impedance-matching terminations for a transmission line.

An object of the invention is to avoid end reflections in a transmission circuit comprising a transmission line operating between a source and a load, one of which is larger and the other smaller than the characteristic impedance of the line.

More specifically, the object is to introduce into such a circuit terminal impedances which will provide matching terminations for the line without causing transmission distortion due to the added impedances.

In a wave transmission circuit comprising a transmission line interconnecting a wave source and a load neither of which matches the characteristic impedance $Z_0$ of the line, undesired energy reflections will occur at the ends of the line. The impedance of either the source or the load may be either larger or smaller than $Z_0$, which is assumed to have a reactive component. The present invention is applicable to such a circuit when one of these impedances, preferably a pure resistance, has a value $Z_S$ which is smaller than $Z_0$ and the other has a value $Z_H$ which is high compared to $Z_0$. An impedance $Z_1$ approximately equal to $Z_0—Z_S$ is connected in series between the smaller impedance $Z_S$ and the line, and an impedance $Z_2$ approximately equal to $Z_0$ is connected in shunt with the larger impedance $Z_H$. In this way, the line is terminated at each end in an impedance substantially equal to its characteristic impedance, thus greatly reducing or eliminating end reflections. Furthermore, no distortion of the over-all transmission loss characteristic is introduced by the addition of these terminal impedances, because the current through the series impedance $Z_1$ at one end of the line produces a voltage loss characteristic which is entirely nullified by the voltage increase characteristic due to the current through the shunt impedance $Z_2$ at the other end.

The nature of the invention and its various objects, features, and advantages will appear more fully in the following detailed description of typical embodiments illustrated in the accompanying drawing, of which

Fig. 1 shows schematically a wave transmission circuit provided with impedance-matching terminations in accordance with the invention;

Fig. 2 is a schematic circuit showing a second embodiment of the invention; and

Fig. 3 shows schematically one network configuration suitable for the impedances $Z_1$ and $Z_2$ of Figs. 1 and 2.

Taking up the figures in greater detail, Fig. 1 shows a wave transmission circuit comprising a transmission line **1** of characteristic impedance $Z_0$ having a pair of input terminals **2—3** and a pair of output terminals **4—5**. The line **1** may, for example, be a coaxial or other type of cable circuit the characteristic impedance of which has a reactive component. A source **7** of wave energy of impedance $Z_S$ smaller than $Z_0$ is connected through a series impedance $Z_1$ to the input terminals **2—3** of the line **1**. The impedance $Z_1$ has approximately the value

$$Z_1 = Z_0 - Z_S \tag{1}$$

An amplifier **A1** having an input impedance $Z_H$ large compared to $Z_0$ is connected to the output terminals **4—5**. An impedance $Z_2$, approximately equal to $Z_0$, is shunted across the input of the amplifier **A1** between the terminals **4—5** of the line, and the output of the amplifier is connected to a load impedance $Z_L$.

The transmission line **1** is thus terminated at each end in an impedance substantially equal to its characteristic impedance $Z_0$. The terminal impedance $Z_T$ at the sending end is

$$Z_T = Z_S + Z_1 = Z_S + Z_0 - Z_S = Z_0 \tag{2}$$

The impedance match at this end will, of course, depend upon how closely Equation 1 is satisfied. The terminal impedance at the output end of the line is also equal to $Z_0$ if the impedance $Z_H$ is high enough that its shunting effect may be neglected. If this is not the case, the impedance $Z_2$ may be made of such a value that the parallel combination of $Z_2$ and $Z_H$ will be equal to $Z_0$. The reflection of energy at the ends of the line **1** due to impedance mismatch is thus greatly reduced or entirely eliminated. The addition of the impedances $Z_1$ and $Z_2$ will cause no distortion of the over-all loss characteristic of the transmission circuit. The voltage loss characteristic due to the current through the series impedance $Z_1$ is exactly compensated by the voltage increase characteristic caused by the current through the shunt impedance $Z_2$.

Fig. 2 shows another embodiment of the invention in a transmission circuit which is similar to the one shown in Fig. 1 except that the high impedance is here associated with the sending end of the line **1** and the low impedance with the receiving end. In Fig. 2, signal waves from a source **8** are amplified in the amplifier **A2** and impressed upon the input terminals **2—3** of the line **1**, to the receiving end of which is connected a load impedance $Z_S'$. The amplifier **A2** has an output impedance $Z_H'$ which is large compared with the characteristic impedance $Z_0$ of the line **1**. The load impedance $Z_S'$, which may represent receiving equipment or the input impedance of an amplifier, is smaller than $Z_0$. An impedance $Z_2'$ approximately equal to $Z_0$ is connected across the output of the amplifier **A2**, thus terminating the line **1** at the sending end effectively in its characteristic impedance. The line is also terminated in its characteristic impedance at the receiving end by connecting between the load $Z_S'$ and the line a series impedance $Z_1'$ having the value

$$Z_1' = Z_0 - Z_S' \tag{3}$$

The terminal impedance $Z_T'$ at this end is thus

$$Z_T' = Z_S' + Z_1' = Z_S' + Z_0 - Z_S = Z_0 \tag{4}$$

In this circuit, also, the voltage changes caused by the impedances $Z_1'$ and $Z_2'$ are equal but opposite in sign throughout the frequency range of interest and therefore have no net effect on the transmission loss characteristic of the circuit.

Fig. 3 shows a suitable network configuration for the impedance $Z_2$ of Fig. 1. The impedance comprises three resistances $R_1$, $R_2$, and $R_3$ connected in series between the terminals **9** and **10**. The resistance $R_1$ is shunted by a capacitance $C_1$ and the resistance $R_2$ by a capacitance $C_2$. The values of the component resistances and capacitances may be so chosen as to make the impedance between the terminals **9** and **10** simulate quite closely the characteristic impedance $Z_0$ of the line **1** over the useful frequency range of the transmission circuit. This impedance simulation may, in general, be improved by the inclusion of one or more additional parallel combinations of resistance and capacitance, as indicated by the broken connection at **11**. The same type of network may be used also for the impedance $Z_1$. For example, if the impedance $Z_S$ is a pure resistance of value $R_S$, the impedance $Z_2$ may be modified for use as $Z_1$ by substituting for $R_3$ a resistance $R_3'$ having the value

$$R_3' = R_3 - R_S \qquad (5)$$

The type of network shown in Fig. 3 may also be used for the impedances $Z_1'$ and $Z_2'$ in Fig. 2.

Although the transmission circuits in Figs. 1 and 2 have been shown as unbalanced structures, it is to be understood, of course, that they may be balanced. For example, if the circuit of Fig. 1 is balanced, the impedance $Z_1$ is replaced by two series impedances each equal to $Z_1/2$, one of which is connected between the source **7** and the input terminal **2** and the other between the source and the other input terminal **3**.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A wave transmission circuit comprising a transmission line of characteristic impedance $Z_0$ having a reactive component, a first terminal impedance including a wave source connected to one end of said line, a second terminal impedance connected to the other end of said line, one of said terminal impedances being a pure resistance of value $R_S$ smaller than $Z_0$ and the other of said terminal impedances having a large value compared to $Z_0$, an impedance equal over the frequency range of interest to $Z_0 - R_S$ connected in series between said impedance of value $R_S$ and said line, and a two-terminal impedance equal over said range to $Z_0$ connected in shunt with said other terminal impedance.

2. A circuit in accordance with claim 1 in which said first terminal impedance has the value $R_S$.

3. A circuit in accordance with claim 1 in which said second terminal impedance has the value $R_S$.


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