Dec. 24, 1940.

S. DOBA, JR

2,226,238

COUPLING CIRCUIT

Filed Nov. 10, 1939

FIG. 1

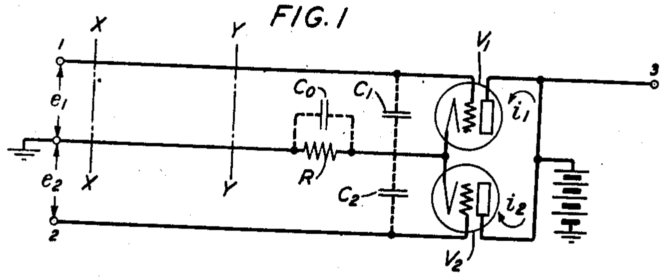


FIG. 2

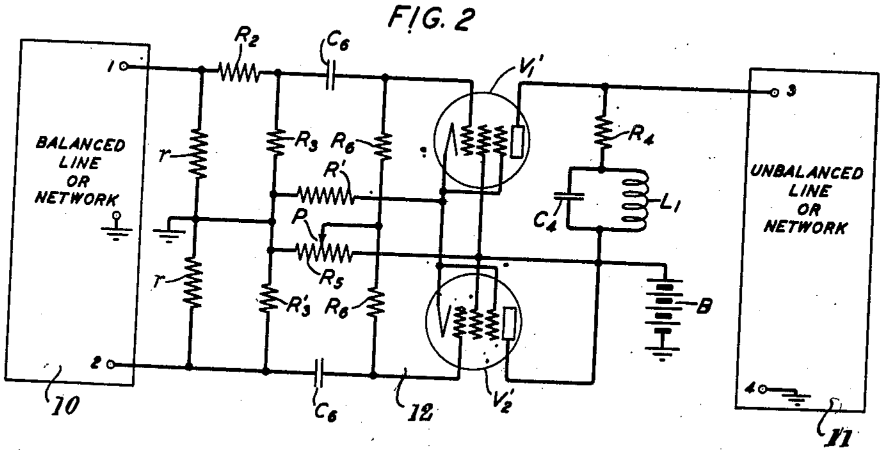


FIG. 3

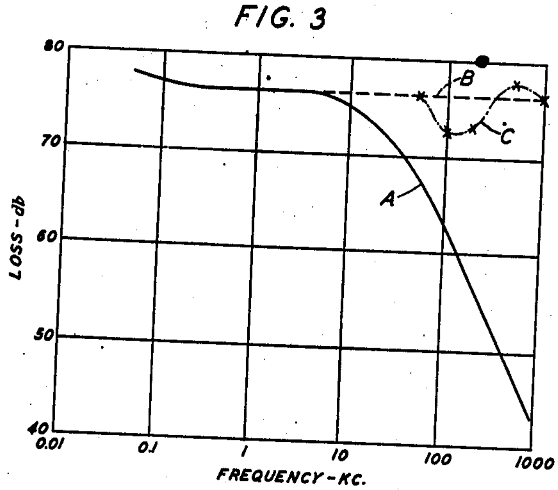
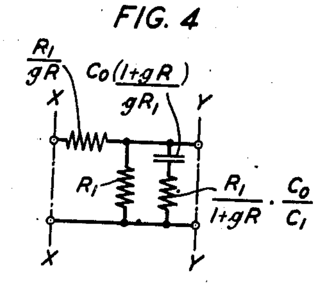


FIG. 4



INVENTOR
S. DOBA, JR.
BY
Robert J. Fluskey
ATTORNEY

Patented Dec. 24, 1940 2,226,238

UNITED STATES PATENT OFFICE

2,226,238

COUPLING CIRCUIT

Stephen Doba, Jr., Long Island City, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application November 10, 1939, Serial No. 303,778

4 Claims. (Cl. 178—44)

This invention relates to coupling circuits and, more particularly, to a circuit for interconnecting a balanced line or network and an unbalanced line or network.

In the connection of a transmission line comprising a coaxial cable in which the outer conductor may be maintained at a fixed potential, for example, ground, to another line comprising an open wire or a cable telephone pair balanced with respect to such fixed potential, a suitable coupling circuit or network is required. At low frequencies or over a very narrow band of frequencies, a transformer or other coil arrangement may be satisfactory. At very high frequencies, however, or over a wide band of frequencies, for example, a few cycles to several millions of cycles, as used in television, such expedients are not satisfactory.

Coupling circuits or networks not employing transformers or coils for connecting balanced and unbalanced lines are known, of course. They have not solved, however, the problem of eliminating the effect of longitudinal currents, nor that of parasitic capacities that become important when the frequencies involved become of a very high order, for example, one or more megacycles.

An object of this invention is to provide an improved circuit or network for coupling together balanced and unbalanced lines or networks, wherein the effect of longitudinal currents is suppressed to a great extent. This suppression is relatively unaffected by variations of the active elements (tubes) in the network caused either by changes in the tubes themselves or by the effect of high voltages due to longitudinal currents.

A further object of this invention is to minimize the effect of parasitic capacities on the suppression of longitudinal currents of high frequencies.

The method whereby longitudinal currents may be suppressed is well known and consists of balancing these currents against each other so as to produce no effect on the unbalanced circuit at which the balanced circuit is connected. This method, however, does not produce a high order of suppression in a practical application for two reasons. These are: First, the active elements, such as vacuum tubes normally used, may vary from their proper adjustment and hence fail to provide a suitable balance. Second, the longitudinal currents themselves may be of such high values as to cause an unbalance due to nonlinearity of these active elements.

The present invention seeks to alleviate both these difficulties by means of negative feedback in the active elements, and to compensate for the effect of parasitic capacities by provision of a corrective or compensatory network in the input circuit to one tube.

One embodiment in accordance with the invention comprises a coupling circuit or network including a pair of electron discharge devices connected in push-pull relation and having an unbypassed common cathode impedance for providing negative feedback to longitudinal currents effective at the input terminals of the coupling circuit connected, for example, to the terminals of the balanced line or network. Any tendency for the magnitude of feedback to diminish with increase in frequency because of parasitic capacity across the feedback impedance, or between the input electrodes of the tubes, may be compensated for or neutralized by introducing a compensating network in the input circuit to one of the discharge devices.

A more complete understanding of this invention will be obtained from the detailed description which follows, read in conjunction with the appended drawing, wherein:

Fig. 1 is a simplified showing of the coupling circuit of the invention;

Fig. 2 shows a circuit embodying a balancing amplifier circuit incorporating the invention;

Fig. 3 shows curves evidencing the longitudinal currents suppression characteristics of the circuit of Fig. 2; and

Fig. 4 shows a network in accordance with this invention for insertion in the input circuit of one tube of the circuit of Fig. 1.

In the transmission of television signals over a telephone cable or open wire pair, one of the problems involved lies in the high noise currents encountered, resulting principally from 60-cycle power interference. Because of the wide frequency band to be transmitted and the rigid requirements on phase shift and loss of the signal, repeating coils which would suppress these noise currents are not now available. The balancing amplifier to be described discriminates between longitudinal and metallic circuit currents, with discrimination of a high order being obtainable at low frequencies and particularly in the range of power frequencies. This loss to longitudinal currents falls off at higher frequencies, but, in a manner also to be described, may be extended to very high frequencies.

The simplified showing of Fig. 1 will facilitate understanding of the invention. The circuit represents two electron discharge devices V_1, V_2 arranged in push-pull relation, adapted to be connected at terminals 1, 2 to the terminals of a line balanced with respect to a fixed potential, specifically, ground, and adapted to be connected at terminal 3 to the ungrounded terminal of a line unbalanced with respect to ground. The tubes may be multigrid devices, specifically pentodes, but inasmuch as the plate current of a pentode is a definite fraction of the total cathode current in any operating condition, for clarity and ease in developing the conditions for suppression of longitudinal currents, V_1 and V_2 are shown as triodes. An unbypassed resistance R is common to the grid-cathode and cathode-anode circuits of the push-pull stage. The input voltages to the balancing amplifier are designated e_1 and e_2, and the respective currents of V_1 and V_2 are designated i_1 and i_2. C_0, C_1, C_2 designate parasitic capacities that become effective only at high frequencies. The operation of the circuit may be explained as follows: When the input voltages are equal and of opposite polarity to ground, the condition for a signal or metallic circuit input, there is no appreciable potential drop appearing across the resistance R. The output circuit current i_1' is then given by

$$i_1' \doteq g_1 e_1 \tag{1}$$

where g_1 is the mutual conductance of V_1.

When, however, the input is due to a longitudinal current, e_1 and e_2 are of the same polarity from ground, and the potential drop across the resistance R is out of phase with e_1. If the effect of the capacitances C_0, C_1, C_2 is neglected, and where g_1, μ_1 and g_2, μ_2 refer to the mutual conductances and amplification factors of V_1 and V_2, respectively, it can be shown that

$$i_1 = \frac{g_1 e_1\left[1+Rg_2\left(1+\frac{1}{\mu_2}\right)\right]}{1+R\left[g_1\left(1+\frac{1}{\mu_1}\right)+g_2\left(1+\frac{1}{\mu_2}\right)\right]}\left[1-\frac{e_2}{e_1}\frac{\left(1+\frac{1}{\mu_1}\right)}{\left(1+\frac{1}{\mu_2}+\frac{1}{Rg_2}\right)}\right]$$

$$\doteq \frac{g_1 e_1}{2}\left[1-\frac{e_2}{e_1}\frac{\left(1+\frac{1}{\mu_1}\right)}{\left(1+\frac{1}{\mu_2}+\frac{1}{Rg_2}\right)}\right] \doteq \frac{g_1 e_1}{2Rg_2} \tag{2}$$

when $e_1=e_2$, and where the approximation is valid if $g_1 \doteq g_2$, $\mu_1 \doteq \mu_2$, $Rg_2>>1$. The current i_1 can be made zero when

$$\frac{e_1}{e_2}=\frac{1+\frac{1}{\mu_1}}{1+\frac{1}{\mu_2}+\frac{1}{Rg_2}} \doteq \frac{1}{1+\frac{1}{Rg_2}} \tag{3}$$

Inasmuch as the suppression of longitudinal currents depends upon the balance of voltages in the grid and cathode circuits of the tube V_1, the amount of suppression actually obtained depends upon the stability of the gain settings. The ratio of output currents i_1'', $1_1'$ for longitudinal and metallic circuit inputs, respectively, can be shown to be equal to

$$\frac{i_1''}{i_1'}=\frac{1}{2Rg_1}\left(\frac{dRg_2}{Rg_2}\right) \tag{4}$$

where

$$\left(\frac{dRg_2}{Rg_2}\right)$$

is the logarithmic differential, or the percentage variation in gain of the tube V_2. The physical meaning of Equation 4 is that the relative output due to longitudinal inputs is proportional to the per cent variation in the gain from the perfect balance point, and inversely proportional to the factor $2Rg_1$. The latter is the feedback stabilizing effect of the resistance R in the common feedback lead.

Fig. 2 shows a coupling circuit actually constructed in accordance with this invention. The balanced line 10 comprised a pair of conductors in a telephone cable, and the unbalanced line 11 comprised a length of coaxial cable with the outer conductor grounded. The coupling circuit 12 comprised the pentodes V_1' and V_2'. The resistances r, r are the terminating resistances for the balanced line. R' is the common cathode resistance and corresponds to R of Fig. 1. The balance requirement as indicated by Equation 2 is obtained by means of the dividing network comprising the resistances R_2 and R_3 at the input of V_1'. The output circuit of the tubes comprises a network constituted by the resistance R_4, capacity C_4 and inductance L_1. Plate power is provided by battery B. The screen grids of the tubes are connected together and to the positive side of plate battery, and also to a resistance R_5 connected in shunt of the battery. The potential drop across R' is quite large, and resistance R_5 provides a means of balancing or bucking-out as much of this voltage as is desired. The potentiometer tap P permits an adjustable control of the bias on the tubes V_1' and V_2'. The balance setting for the push-pull stage is most readily obtained by variation of the grid bias, by means of the potentiometer, on the control grids of V_1' and V_2' simultaneously, Equation 3 being independent of g_1. The resistance of the dividing network may be made as high as desired so that the resistances r may be varied between wide limits to suit different line termination impedances. Condensers C_6 and resistances R_6 are the usual blocking condensers and grid leak resistances, respectively.

Curve A of Fig. 3 shows the suppression in decibels of the longitudinal currents with respect to frequency using the circuit of Fig. 2. This indicates that up to about 10 kilocycles the suppression was of a very high order, and that even up to one megacycle the suppression of longitudinal currents remained of very substantial magnitude.

The use of Equation 2 is valid only for low frequencies inasmuch as its derivation neglected the effect of the parasitic capacities, effectively in shunt of the feedback resistance R and across the grid-cathode circuit of the tubes. The effect of these capacitances upon the balance as a function of frequency is rather complicated, but a close approximation is obtained if $g_1=g_2=g$, $\mu_1=\mu_2$, $C_1=C_2=C$, and the effect of input impedance is negligible. It can be shown then that

$$i_1 \doteq \frac{ge_1}{2}\left[1-\frac{e_2}{e_1}\frac{\left(1+\frac{1}{\mu}\right)}{\left(1+\frac{1}{\mu}+\frac{1}{gR}\right)}\cdot\frac{(1+j\omega C/g)}{(1+j\omega(C_0+C)/g)}\right] \tag{5}$$

For balance, $i_1=0$ when

$$\frac{e_1}{e_2}=\frac{\left(1+\frac{1}{\mu}\right)}{\left(1+\frac{1}{\mu}+\frac{1}{Rg}\right)}\frac{(1+j\omega C/g)}{(1+j\omega(C_0+C)/g)} \tag{6}$$

A circuit for obtaining the condition indicated by Equation 6 would comprise a resistance connected between terminal 1 and the grid of V_1 of Fig. 1; a second resistance connected from the grid terminal of the first resistance to the ground side of resistance R; and a capacitance and a resistance series-connected in shunt of the second resistance. In Fig. 2, R_2 corresponds to the first resistance, and R_3 to the second resistance. The series-connected capacitance and resistance would be connected in shunt of R_3 to provide the complete corrective network. This network with the value of its elements expressed relative to that of resistances R_1 and R to which resistances R_3 and R′ correspond is shown in Fig. 4.

The dotted line B of Fig. 3 shows that theoretically the suppression of unbalance due to longitudinal currents will be substantially constant with frequency when such a corrective network is used. The broken line C, based on measurements made when a condenser and a resistance connected in series were connected in shunt with R_3 of Fig. 2, indicates that a close approximation of the theoretical possibility may be obtained.

Although this invention has been disclosed with reference to a specific embodiment, it is evident that it is not limited thereto, but is of a scope determined by the appended claims.

What is claimed is:

1. A transmission system comprising a transmission line balanced with reference to a fixed potential, a second transmission line unbalanced with reference to said potential, and means coupling said transmission lines, said means comprising a pair of electron discharge devices having a plurality of elements, an impedance common to both of said devices and providing degenerative feedback for the suppression of longitudinal currents present in said first line, and a network in the input circuit of one of said devices to compensate for parasitic capacity effects whereby the suppression of longitudinal currents may be further increased.

2. A wide frequency band transmission system comprising a transmission line balanced with reference to a fixed potential, a second transmission line unbalanced with reference to said potential, and means coupling said transmission lines, said means comprising a pair of electron discharge devices each having a cathode, an anode and a control grid, an impedance common to the cathode-anode and cathode-grid circuits of both of said devices and providing degenerative feedback for the suppression of longitudinal currents present in said first line, said suppression occurring to a preassigned degree up to a frequency at which parasitic capacities between grids and cathodes and that of said impedance become important, and a corrective network in the input circuit of one of said devices to compensate for the effect of said capacities whereby the same order of suppression exists to a substantially higher frequency.

3. A coupling circuit comprising a pair of electron discharge devices each having a cathode, an anode and a control grid arranged with each grid connected to a separate input terminal, the cathodes connected together, and the anodes connected to a common output terminal, an unbypassed resistance common to the input and output circuits of each of said devices, a source of space current for said devices, said common resistance providing degenerative feedback to suppress longitudinal currents impressed on said input terminals, and means connected in the input circuit to one of said devices for compensating for the feedback reducing effect with rising input frequency of the distributed capacity of said common resistance and the interelectrode capacity between the grids and cathodes of said devices.

4. A coupling circuit as claimed in the next preceding claim in which said means comprises a network comprising a resistance connected between one input terminal and the grid of said one device, a second resistance connected at one terminal to said first resistance and at its other terminal to the end of said feedback resistance remote from said cathodes, and a series-connected capacitance and a resistance connected in shunt of said second resistance.

STEPHEN DOBA, Jr.