Sept. 27, 1938. A. L. STILLWELL 2,131,393

ELECTRIC WAVE AMPLIFYING SYSTEM

Filed Dec. 5, 1936

FIG. 1

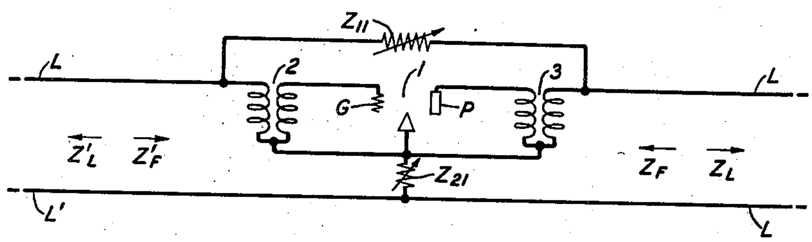


FIG. 2

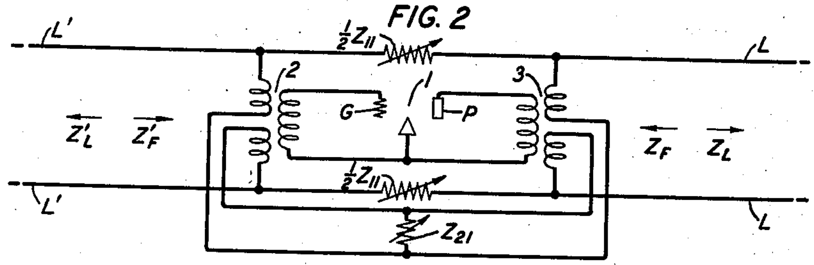


FIG. 3

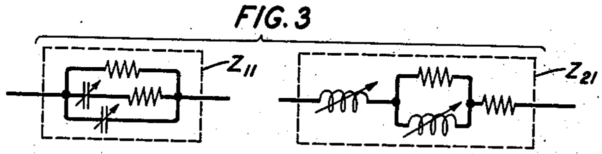


FIG. 4

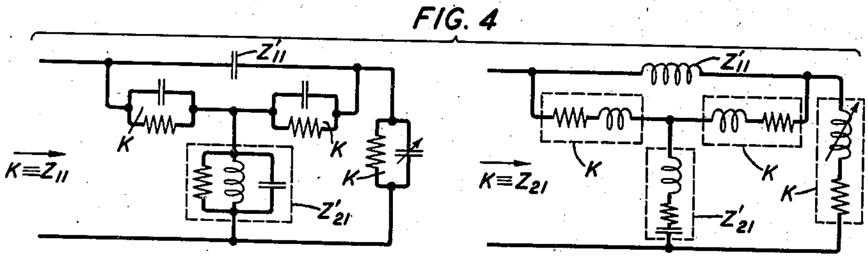
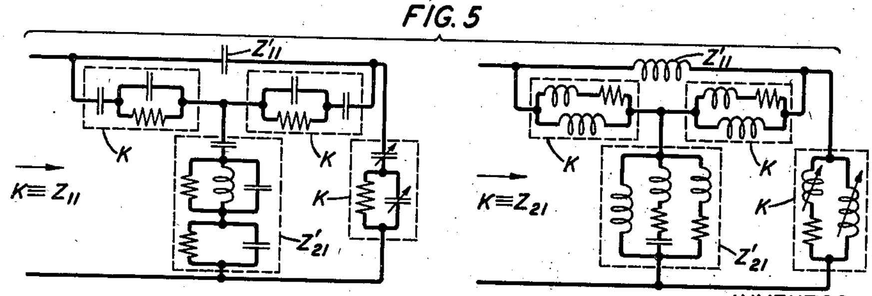


FIG. 5



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ELECTRIC WAVE AMPLIFYING SYSTEM

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18 Claims. (Cl. 179—171)

This invention relates to wave amplifying systems.

An object of the invention is to adjust feedback in an amplifier, for example for gain adjustment or transmission equalization, without producing undesired variation of the amplifier input or output impedance.

One specific aspect of the invention is an amplifier having two impedances connected alternately between its grid and load circuits and also alternately between its incoming and plate circuits. (Connecting two impedances alternately between two circuits signifies connecting one of the impedances, one of the circuits, the other impedance and the other circuit successively in a closed loop, the impedances thus alternating as to their connection between the circuits.)

The impedances may be caused to vary inversely, to control feedback in the amplifier, for example to vary negative feedback for adjusting gain or equalizing transmission while maintaining constancy of the amplifier impedances faced by the load and incoming circuits.

With sufficient feedback these amplifier impedances can be made to approach asymptotically a constant resistance (matching the resistances of the attached load and incoming circuits, respectively) even when their values without feedback would vary considerably with frequency, for example because of variation with frequency in transmission efficiency of input and output transformers in the grid and plate circuits, respectively.

In another specific aspect the invention is an amplifier with two feedback circuits, each symmetrical or balanced with respect to ground, and each by its feedback, affecting the gain in the same sense as the other, but feedback through one tending to produce a given variation of the amplifier input or output impedance with frequency and feedback through the other tending to produce a complementary or neutralizing variation, so that the amplifier input and output impedances are unchanged upon variation of frequency. For example, the feedback through one feedback circuit may be series-series negative feedback and the feedback through the other may be shunt-shunt negative feedback, and two inverse reactive networks may be connected in the two feedback circuits, respectively, for giving a desired variation of the amplifier gain with frequency while maintaining the amplifier input and output impedances constant.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 is a schematic diagram of an amplifier circuit embodying a form of the invention;

Fig. 2 shows a modified form of amplifier circuit; and

Figs. 3 to 5 show specific forms of networks that may be used as impedance elements in circuits such as those of Figs. 1 and 2.

The amplifier shown may be, for example, a stabilized feedback amplifier of the general type in which a portion of the output wave is fed back in gain-reducing phase and in amount sufficient to reduce distortion below the distortion level without feedback. Such feedback is disclosed, for example, in the copending application of H. S. Black, 606,871, filed April 22, 1932, for Wave translation system, now Patent No. 2,102,671, Dec. 21, 1937, and in the article by Black on Stabilized feedback amplifiers, published in Electrical Engineering, January 1934, pages 114 to 120.

The amplifier 1 is shown as of the vacuum tube type and may have a single stage or any desired number of the tandem connected stages, G and P designating the grid of the first tube and the plate of the last tube. The amplifier may have in its input circuit an input transformer 2, and may have in its output circuit an output transformer 3. Waves to be amplified by the amplifier are supplied by incoming line or circuit L′; and the amplified waves are transmitted to outgoing line or circuit L. The amplifier circuit has two feedback paths Z_{11} and Z_{21}, shown as two-terminal transmission control networks of generalized impedances. The amplifying path of the amplifier may be referred to as the μ-circuit, and the feedback circuits may be referred to as the β-circuits, or the β_1-circuit and the β_2-circuit, respectively, the significance of μ and β being as indicated in the Black application and article mentioned above.

The feedback through path Z_{11} may be, for example, negative feedback with $\mu\beta_1>>1$ and the feedback through path Z_{21} may be, for example, negative feedback with $\mu\beta_2>>1$. The feedbacks are applied to the amplifier through the input and output coils or transformers. This procedure includes the coils within the μ-circuit of the feedback loops, thus reducing their distortion by feedback. As a result their modulation and distortion requirements will be less severe, and in general they will be cheaper to build and will be able to provide much higher gains when desired.

It is seen that the path Z_{21} is in serial relation to the line L′ with respect to the amplifier input and is in serial relation to the line L with respect to the amplifier output. Thus, the feedback through path Z_{21} is a series feedback at the input side of the amplifier and a series feedback at the output side of the amplifier. Therefore, the feedback through path Z_{21} will be referred to as a series-series feedback, and path Z_{21} will be referred to as a series-series feedback path or circuit.

It is seen that the path Z_{11} is in shunt relation to the line L′ with respect to the amplifier input and is in shunt relation to the line L with respect to the amplifier output. Thus, the feedback through path Z_{11} is a shunt feedback at the input side of the amplifier and a shunt feedback at the output side of the amplifier. Therefore, the feedback through path Z_{11} will be referred to as a shunt-shunt feedback, and path Z_{11} will be referred to as a shunt-shunt feedback path or circuit.

The amplifier circuit forms a bridged T network connecting lines L′ and L. The transformers **2** and **3** are two of the arms of the T, and they are bridged by an arm Z_{11} of the bridged T network. The third arm of the T is the arm Z_{21}. Whenever, in the passive condition of the amplifier circuit, each of the four arms of the bridged T network has its impedance equal to that of each of the circuits L and L′, (or in other words, whenever the primary-to-secondary impedance of transformer **2**, the secondary-to-primary impedance of transformer **3**, the impedances Z'_L and Z_L of the lines L′ and L, and the impedances Z_{11} and Z_{21} are all equal and, indeed, whenever $Z_{11}.Z_{21}$ is equal to the product of the impedance of L′ and the impedance of the amplifier output circuit and also equal to the product of the impedance of the load circuit L and the impedance of the amplifier input circuit, then the system is in a condition which may be called the condition of passive balance. In this condition, conjugacies exist between the incoming circuit L′ or source of waves to be amplified and the output transformer **3** or amplifier output circuit, and between the load circuit or receiving circuit L and the amplifier input circuit or input transformer **2**, and between impedance Z_{21} and impedance Z_{11}. Thus, these conjugacies can be maintained even if Z_{21} and Z_{11} are varied, provided they are varied inversely (i. e., so that their product remains constant). Further, with considerable amounts of negative feed-back in the amplifier and relatively large value for Z_{11}, these conjugacies practically are maintained even when the values of the amplifier input and output impedances without feedback vary widely from their values for the passive condition of passive balance, the feedback tending to restore the conjugacies and maintain the amplifier input and output impedances Z'_F and Z_F (or impedances facing lines L′ and L) at the values they would have if the impedance of the amplifier input circuit (i. e., the primary-to-secondary impedance of transformer **2**) and the impedance of the amplifier output circuit (i. e., the secondary-to-primary impedance of transformer **3**) were at their values for passive balance of the system.

With considerable amounts of negative feedback, if $Z_{11}\cdot Z_{21}=Z'_L\cdot Z_L$, the amplifier input and output impedances Z'_F and Z_F closely approach

$$\frac{Z_{11}\cdot Z_{21}}{Z_L} \text{ and } \frac{Z_{11}\cdot Z_{21}}{Z'_L}$$

respectively; and then if Z'_L and Z_L are equal resistances R_o, Z'_F and Z_F each substantially equals R_o.

Thus, the impedances Z_{11} and Z_{21} may be caused to vary inversely, to control feedback in the amplifier, for example, for adjusting gain or equalizing transmission while maintaining constancy of the amplifier input and output impedances faced by the incoming circuit and the load.

With considerable negative feedback the amplifier input and output impedances can be made to remain respectively substantially equal to the impedances of the incoming and outgoing lines, notwithstanding inverse variation of Z_{11} and Z_{21} and notwithstanding variation of the amplification from the amplifier input circuit to the amplifier output circuit (due, for example, to variation of the impedances or amplification constants of the amplifier tubes as a result of changing tubes or types of tubes, or to variation of the transmission efficiency of transformers **2** and **3** with frequency).

Z_{11} and Z_{21} may be inversely variable resistances when they are to be used for gain adjustments in which the gain changes are the same for all frequencies in the frequency range of interest and Z'_L and Z_L are resistances.

When Z_{11} and Z_{21} are to serve for varying amplifier gain with frequency, for example, for transmission equalization, they may be suitable reactive inverse impedances, for instance, as shown in Figs. 3 to 5 described hereinafter. With considerable negative feedback in the amplifier, the amplifier gain in decibels will be

$$20 \log_{10}|Z_{11}|.$$

The equalizer can effectively replace both input and output bridges of an amplifier using such bridges to maintain constant amplifier input and output impedances with varying feedback, yet it is incorporated in a single bridge network and the line loss (i. e., the loss in transmission between the amplifier and the lines) is correspondingly less. In addition, assuming that a variable network is used between fixed input and output bridges, these must be designed to minimum feedback loss to allow maximum feedback. This corresponds to maximum line loss which is present also for maximum gain. However, with the equalizer in accordance with this invention the maximum gain corresponds to maximum feedback loss and hence minimum line loss. For a 30 decibel maximum gain requirement the corresponding line loss would be of the order of 0.3 decibel, for example.

The amplifier circuit of Fig. 1 is unbalanced with respect to ground. That is, one side can be grounded so that there are no longitudinal transmission problems.

Fig. 2 shows a modified form of the circuit which is balanced with respect to ground. That is, each side of the line is above ground by the same impedance. In Fig. 2 the impedance Z_{11} is shown divided into two equal parts, and the impedance Z_{21} is shown connected between the two halves of the primary winding of the input transformer **2** and also connected between the two halves of the secondary winding of the output transformer **3**. As in the case of Fig. 1, with $Z_{11}\cdot Z_{21}$ equal to $Z'_L\cdot Z_L$, the amplifier input impedance is

$$Z'_F=\frac{Z_{11}\cdot Z_{21}}{Z_L}$$

and the amplifier output impedance is

$$Z_F=\frac{Z_{11}\cdot Z_{21}}{Z'_L}$$

and then if $Z'_L=Z_L=R_o$, we have: $Z_{11}\cdot Z_{21}=(R_o)^2$ and $Z'_F=R_o$ and $Z_F=R_o$.

Where the gain of the feedback amplifier is to be varied by different amounts at different frequencies, for example, to compensate for changes of line attenuation which vary with frequency, this may be accomplished, for example, by adjusting continuously variable reactances, such as air condensers or variometers or both, in inverse networks Z_{11} and Z_{21}, while maintaining the relation $Z_{11}\cdot Z_{21}=(R_0)^2$ or $Z_{11}\cdot Z_{21}=Z'_L\cdot Z_L$. For instance, the networks Z_{11} and Z_{21} of Fig. 1 or Fig. 2 may be composed of resistances, inductances and capacities, with the capacities of network Z_{11} adjustable and the inductances of network Z_{21} adjustable, as indicated in Fig. 3. The adjustments may be made manually; or they may be made automatically, for example, by pilot wire or pilot channel controlled operating means in response to effects produced by temperature or weather changes that produce the line attenuation changes.

Figs. 4 and 5 show examples of another type of variable network that can be used for the networks Z_{11} and Z_{21}, for instance, in the manner just described for the networks of Fig. 3. This type is a terminated bridged T constant impedance structure, which can be used as a two terminal network, for example, in the bridged T network of Fig. 1 or Fig. 2. In the networks Z_{11} and Z_{21} of Figs. 4 and 5 the inverse impedances are designated Z_{11}' and Z_{21}'. The impedances designated K in these networks have the value K, K being a complex quantity, and $Z_{11}'\cdot Z_{21}'=K^2$. The amplifier gain adjustments, for example, for compensating for line attenuation changes that vary with frequency, may be made for instance, as indicated by the arrows in Figs. 4 and 5. These figures show the networks Z_{11} and Z_{21} composed of resistances, inductances and capacities; and in Fig. 4 the arrows indicate a capacity in network Z_{11} and an inductance in network Z_{21} as adjustable; and in Fig. 5 the arrows indicate two of the capacities of network Z_{11} and two of the inductances of network Z_{21} as adjustable. The impedance product K can be chosen to give a prescribed or desired average slope of the amplifier gain-frequency characteristic for the normal setting of these adjustable elements, and then the characteristic can be raised and lowered by adjustment of these elements. If necessary for obtaining the desired characteristics, resistance as well as reactance elements of the networks Z_{11} and Z_{21} can be made adjustable.

What is claimed is:

1. Wave amplifying means having input and output circuits, a wave source for association with said input circuit, a load circuit for association with said output circuit, and two impedances connected alternately between said input and load circuits and also alternately between said source and said output circuit, said load circuit being in shunt relation to one of said impedances and in serial relation to the other impedance, with respect to said output circuit, and said source being in shunt relation to said one impedance and in serial relation to the other, with respect to said input circuit.

2. The method of operating a transmission controlling system including an amplifier and two impedance networks connected alternately between its input and receiving circuits and also alternately between its output and sending circuits, which comprises causing the impedances of said networks to vary inversely.

3. A system comprising wave amplifying means having an input circuit and an output circuit, a wave source and a load circuit, and means connecting said source and said load circuit in bilaterally transmitting relation to each other with said source in conjugate relation to said output circuit and in transmitting relation to said input circuit, and with said output circuit in transmitting relation to said input circuit and said load circuit.

4. A system comprising wave amplifying means having an input circuit and an output circuit, two wave transmission circuits, and means connecting said transmission circuits in bilaterally transmitting relation to each other with said output circuit conjugate to one and said input circuit conjugate to the other.

5. A system comprising wave amplifying means having an input circuit and an output circuit, two transmission circuits, and means connecting one in conjugate relation to said output circuit and connecting said input circuit in conjugate relation to the other, said means comprising passive means connecting said two transmission circuits in transmitting relation.

6. A system comprising wave amplifying means having an input circuit and an output circuit, a wave source and a load circuit, and a single bridge circuit including said source and said circuits and connecting said output circuit in conjugate relation to said source and said input circuit in conjugate relation to said load circuit.

7. A wave amplifying system comprising a bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, and a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, the branches including said input circuit and said source having a common junction point, and the branches including said output circuit and said load circuit having a common junction point.

8. A bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, and a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, the remaining two branches respectively consisting of two inverse networks comprising reactances, one of said remaining two branches connecting said input and output circuits and the other connecting said two junction points.

9. A bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, the remaining two branches respectively consisting of two inversely adjustable impedances, one of said remaining two branches connecting said input and output circuits and the other connecting said two junction points.

10. A bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, and a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, the product of the impedances of the latter two branches being equal to the product of the impedances of the remain-

ing two of said six branches, one of said remaining two branches connecting said input and output circuits and the other connecting said two junction points.

11. A bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, and a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, one of the latter two branches having its impedance equal to the square root of the product of the impedances of the two remaining branches, one of said two remaining branches connecting said input and output circuits and the other connecting said two junction points.

12. A bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, and a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, each of the latter two branches having its impedance equal to a given resistance, and the remaining two branches having the product of their impedances equal to the square of said resistance, one of said remaining two branches connecting said input and output circuits and the other connecting said two junction points.

13. A wave amplifying system comprising a bridge circuit composed of six branches, an amplifier having its input and output circuits respectively connected in two of said branches having a common junction point, and a source of waves to be amplified by said amplifier and a load circuit for said amplifier respectively connected in two others of said branches having a common junction point, the remaining two branches providing feedback that changes the gain of the system for transmission from said source to said load circuit without changing the impedances presented to said source and said load circuit, one of said remaining two branches connecting said input and output circuits and the other connecting said two junction points.

14. A bridge network comprising a line having a frequency selective transmission characteristic and having sending and receiving sections and an amplifier circuit connecting said sections, said amplifier circuit comprising an amplifier with input and output circuits connected for transmitting waves from said output circuit to said input circuit that produce variation of gain of said amplifier circuit compensating for variation of the line attenuation with frequency, and said bridge network having said output section in one of its arms and having said input section in a branch connected across that arm and an adjacent arm.

15. The combination of a wave source, a load circuit, and a bridged T network for connecting said source for transmission through said network to said load circuit, said network comprising an amplifier and having the amplifier input circuit as one arm, the amplifier output circuit as an adjacent arm, and two inversely variable impedances as the remaining arms, one connected across the amplifier input and output circuits, and one connected from the junction of the amplifier input and output circuits to the junction of the source and the load circuit.

16. In a transmission system, a transmitting medium having a varying efficiency dependent upon the frequency of the wave transmitted therethrough, an amplifier for off-setting at least a portion of the transmission loss of said medium, said amplifier having input and output circuits, incoming and outgoing lines for connecting said amplifier into said medium, and a network comprising said circuits and two general impedances, one of said circuits and one of said impedances being serially connected across one of said lines, the other circuit being bridged across said one circuit and the other of said general impedances in serial relation, the other of said lines being connected across the whole of said network, the network being designed to simulate the varying efficiency of at least a portion of said medium and match the attached impedances of said lines.

17. A system comprising wave amplifying means having an input transformer and an output transformer, a wave source and a load circuit, and means connecting said source and said load circuit in bilaterally transmitting relation to each other with said source in conjugate relation to said output transformer and in transmitting relation to said input transformer, and with said output transformer in transmitting relation to said input transformer and said load circuit.

18. A negative feedback amplifier having input and output circuits and having input and output impedances, a wave source attached to said input impedance, a load circuit attached to said output impedance, and two inversely variable impedances with their product approaching that of said input and output impedances, one of said inverse impedances and the load circuit being in serial relation with respect to the amplifier output circuit, and the amplifier input circuit and said one inverse impedance being in serial relation with respect to the source, and the source, in parallel with the amplifier input impedance and said one inverse impedance in series, being connected across the other inverse impedance and the load in series.

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