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2,166,929

ELECTRIC WAVE AMPLIFYING SYSTEM

Filed Dec. 5, 1936

FIG. 1

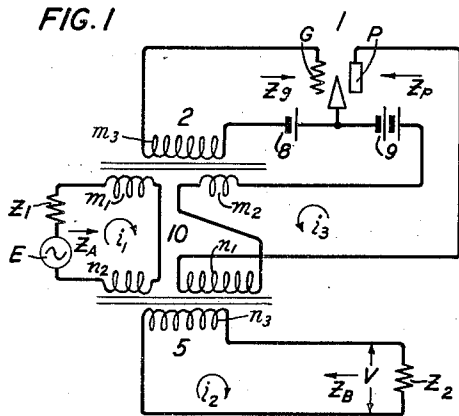


FIG. 2

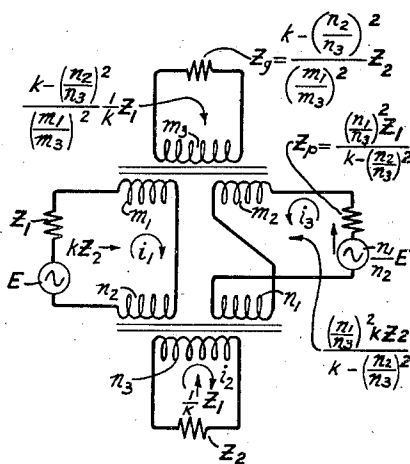


FIG. 3

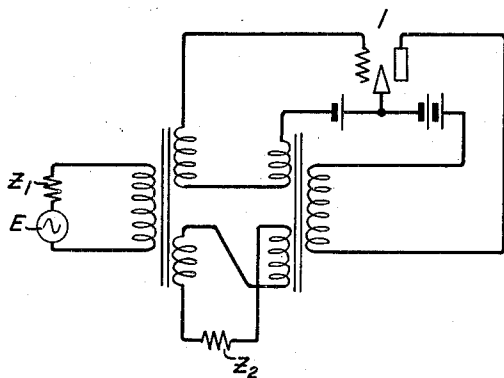


FIG. 4

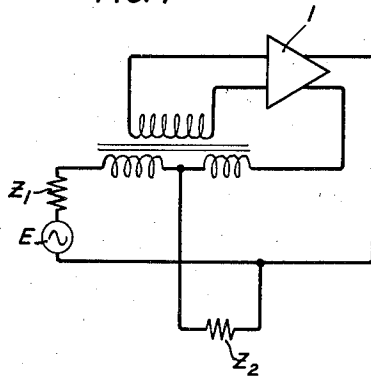


FIG. 5

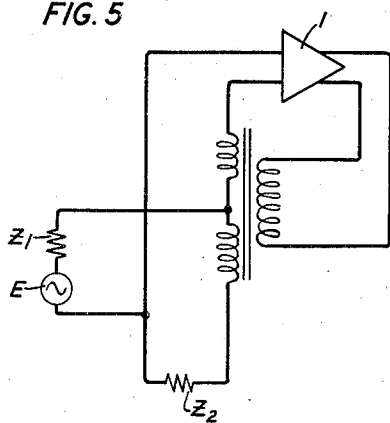
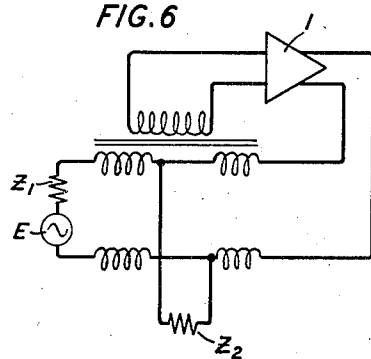


FIG. 6



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ELECTRIC WAVE AMPLIFYING SYSTEM

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15 Claims. (Cl. 179—171)

This invention relates to wave amplifying systems.

An object of the invention is to control transmission properties of such systems, as for example, transmission efficiency, distortion, longitudinal currents and impedances in such systems.

In one specific aspect the invention is an amplifier with feedback rendering the amplifier transparent as to impedance so that the amplifier input impedance is determined by and proportional to the load impedance and the amplifier output impedance is determined by and proportional to the impedance of the incoming line or circuit. Thus the amplifier can readily be connected in a circuit such as a filter or long transmission line without disturbing the impedance conditions.

In another aspect the invention is an amplifier with feedback rendering the insertion gain of the amplifier independent of frequency. Thus, the amplifier can readily be inserted in a circuit without changing the shape of the transmission-frequency characteristic of the circuit.

Another aspect of the invention is an amplifier with feedback rendering its insertion gain for transmission in one direction equal to its loss for transmission in the opposite direction.

The feedback may be, for example, series negative feedback proportional to the load voltage and shunt negative feedback proportional to the load current, such feedbacks also reducing distortion in the amplifier and stabilizing the amplifier gain. The feedback may be provided, for instance, by a bridge transformer network connecting the incoming circuit and the amplifier output circuit each in transmitting relation to the amplifier input circuit and the load circuit, with the amplifier output and input circuits conjugate respectively to the incoming circuit and the load circuit.

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

Fig. 1 of the drawing shows a circuit embodying a form of the invention;

Fig. 2 is a circuit diagram facilitating explanation of the operation of the circuit of Fig. 1; and

Figs. 3, 4, 5 and 6 show four circuits that are modifications of the circuit of Fig. 1.

In Fig. 1 is shown a system embodying a form of the invention comprising an amplifier whose amplifying path may be, for example, an amplifying element 1 of the vacuum tube type having a single vacuum tube stage or any desired number of tandem connected stages, G and P designating

the grid of the first tube and the plate of the last tube.

The amplifier 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 H. S. Black Patent No. 2,102,671, December 21, 1937, for Wave translation system, and in the article by Black on Stabilized feedback amplifiers, published in Electrical Engineering, January 1934, pages 114 to 120.

The amplifier of Fig. 1 has an input transformer 2 with a primary winding m_1 of m_1 turns and a secondary winding m_3 of m_3 turns, and has an output transformer 5 with a primary winding n_1 of n_1 turns and a secondary winding n_3 of n_3 turns.

Waves to be amplified by the amplifier, as for example, speech current waves or speech modulated carrier waves, are supplied from an incoming line or circuit Z_1 of impedance value Z_1 comprising a wave source E of voltage E. The amplified waves are transmitted to the outgoing line or circuit Z_2 of impedance value Z_2 .

The amplifier comprises a feedback coil m_2 of m_2 turns on transformer 2. This coil m_2 is in series with winding n_1 and provides shunt-series negative feedback, or in other words shunt negative feedback proportional to the load current. The amplifier also comprises a feedback coil n_2 of n_2 turns on transformer 5. This coil n_2 is in series with winding m_1 and provides series-shunt negative feedback, or in other words series negative feedback proportional to the load voltage. A C-battery 8 for providing negative grid bias is shown. A B-battery 9 is shown for supplying space current.

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 circuit, or the β_1 circuit in the case of the feedback path through the feedback coil m_2 and the β_2 circuit in the case of the feedback path through the coil n_2 , the significance of μ and β being as indicated in the patent and article mentioned above. The feedback through the coil m_2 may be, for example, negative feedback with $\mu\beta_1$ much greater than one; and the feedbacks through the coil n_2 may be, for example, negative feedback with $\mu\beta_2$ much greater than one.

The two three-winding transformers 2 and 5 are connected to operate as biconjugate circuit or

bridge transformer network 10 or in other words to form a hybrid coil 10. The hybrid coil 10 connects Z_1 and the amplifier output or plate circuit each in transmitting relation to the amplifier input or grid circuit and the load circuit Z_2 , with the amplifier output and input circuits conjugate respectively to Z_1 and Z_2 .

Transmission from Z_1 arriving at the network 10 is partly transmitted through windings n_2 and n_3 to Z_2 and partly transmitted through windings m_1 and m_3 to the grid circuit of tube 1. Transmission from the plate circuit of the tube is partly transmitted through windings n_1 and n_3 to Z_2 , partly fed through windings m_2 and m_3 back to the grid circuit of the tube, and partly fed through windings n_1 and n_2 and windings m_1 and m_3 back to the grid circuit.

It can readily be seen that the negative feedback action causes the flux set up by the turns m_2 to oppose the flux set up by the turns m_1 . Stability will be reached when the differential flux from windings m_1 and m_2 produce a voltage in winding m_3 on the grid of the tube which when amplified to the plate circuit causes a current i_3 to flow in m_2 of the magnitude necessary for the stabilized value of the differential flux.

For large gain between grid of the first tube and plate of the last tube, stability will be reached with the voltage across the grid relatively zero. The voltages across m_1 and m_2 are consequently zero, or in other words $i_3 m_2 = i_1 m_1$, and

$$i_3 Z_2 = \frac{n_3}{n_2} (E - i_1 Z_1) \quad (1)$$

Also

$$i_2 n_3 = i_1 n_2 + i_1 \frac{m_1}{m_2} n_1 \quad (2)$$

It follows that

$$i_1 = \frac{E}{Z_1 + Z_2 \left[\left(\frac{n_2}{n_3} \right)^2 \left(1 + \frac{m_1 n_1}{m_2 n_2} \right) \right]} \quad (3)$$

$$i_2 = \frac{\frac{n_3}{n_2} \left[\left(\frac{n_2}{n_3} \right)^2 \left(1 + \frac{m_1 n_1}{m_2 n_2} \right) \right] E}{Z_1 + Z_2 \left[\left(\frac{n_2}{n_3} \right)^2 \left(1 + \frac{m_1 n_1}{m_2 n_2} \right) \right]} \quad (4)$$

Since

$$i_3 = \frac{m_1}{m_2} i_1$$

$$i_3 = \frac{\frac{m_1}{m_2} E}{Z_1 + \left(\frac{n_2}{n_3} \right)^2 \left(1 + \frac{n_1 m_1}{n_2 m_2} \right) Z_2} \quad (5)$$

It is apparent from Equations 4 and 5 that i_3 is proportional to the load current i_2 , the proportionality depending only on the turns ratios of the windings.

If

$$\left(\frac{n_2}{n_3} \right)^2 \left(1 + \frac{m_1 n_1}{m_2 n_2} \right)$$

is made equal to unity, it follows that $Z_A = Z_2$, that is, the input impedance equals the load impedance, and $Z_B = Z_1$, or the output impedance equals the incoming line impedance and

$$i_2 = \frac{n_3}{n_2} i_1$$

It is apparent here that the insertion of the feedback amplifier device between Z_1 and Z_2 results in an amplified picture of the current that would flow out of Z_1 into Z_2 with these two

impedances directly connected together. This means that the amplifier is transparent as to impedance.

It is also apparent that a current traversing the circuit in the reverse direction to that assumed in Fig. 1, i. e., flowing out of Z_2 into Z_B , will encounter a loss equal to the gain of the device in the assumed positive direction. This may be viewed as a result of symmetry, but in a broader sense, it is a fundamental characteristic of transparent amplifiers.

A further characteristic of the circuit shown in Fig. 1 is that the turns ratios may be so chosen that Z_A will equal a constant (k) times Z_2 while Z_B equals the reciprocal of this constant

$$\left(\frac{1}{k} \right)$$

times Z_1 . The gain introduced by the device is at the same time independent of the turns ratios assigned to give the desired impedance values. This point is illustrated by Equations 3 and 4. With the assumption that it is desired that $Z_A = k Z_2$

$$\left(\frac{n_2}{n_3} \right)^2 \left(1 + \frac{m_1 n_1}{m_2 n_2} \right) = k$$

$$i_1 = \frac{E}{Z_1 + k Z_2}$$

$$i_2 = \frac{\frac{n_3}{n_2} k E}{Z_1 + k Z_2}$$

The gain on a power basis is

$$k \left(\frac{n_3}{n_2} \right)^2$$

It can readily be seen that in none of the foregoing equations does m_3 appear. The stabilized performance of the amplifying system is independent of the turns on m_3 , as μ is directly proportional to m_3 and β independent of it.

In Fig. 2, the impedances and conjugacies existing in the stabilized amplifier are shown. Z_g and Z_p represent the stabilized grid and plate circuit impedances respectively. The generator in series with Z_p is the stabilized magnitude of the plate circuit voltage. It can be easily proven in this diagram that the input circuit of the amplifier is conjugate to the load circuit and that the source is conjugate to the output circuit of the amplifier. As indicating in a simple way why, in Fig. 1, a source of E. M. F. inserted in the load impedance Z_2 , for example, causes substantially no energy to be transmitted to the input impedance Z_g , it may be noted that (1) without the feedback, since Z_p is large the voltage induced in n_1 by n_3 produces little current flow in m_2 , and the voltage induced in the circuit n_2, Z_1, m_1 by n_3 would appear principally across m_1 (since the impedance attached to m_3 is high), but (2) the negative feedback current through m_2 opposes the flux created in 2 by m_1 , causing the voltage across m_1 to decrease and the voltage across n_2 to increase, and with high amplification in the tube, at the condition at which the operation becomes stabilized the voltages across m_1 and m_2 are substantially zero, so the voltage transmitted to Z_g is very small.

It is often desired that an amplifier work on a matched impedance basis between two impedances Z_1 and Z_2 , have a fixed gain, have a flat gain-frequency characteristic, and have good longitudinal balance (low metallic current per volt applied longitudinally). The amplifier cir-

cuit shown can readily be made to satisfy all of these requirements. For example, if a 20 decibel gain amplifier is desired with Z_1 an impedance of 150 ohms and Z_2 an impedance of 600 ohms,

$$\frac{n_3}{n_2} = 20$$

and

$$\frac{m_1}{m_2}$$

can be made equal to

$$\frac{n_1}{n_2} = \sqrt{99}$$

Then Z_A will equal

$$\frac{Z_2}{4}$$

and will match Z_1 , and Z_B will equal $4Z_1$ and will match Z_2 . Not only will the circuit satisfy the requirements noted above, but all transmission performance requirements will be either improved or stabilized by the negative feedback action.

As indicated above, in an amplifier circuit such as that shown, the negative feedback can render the insertion gain of the amplifier independent of frequency, so that, for example, even if Z_2 be reactive or include reactance, the insertion of the amplifier will change the transmission efficiency of the circuit, for transmission between Z_1 and Z_2 , by the same amount at all frequencies, or in other words, the amplifier can be inserted without changing the shape of the transmission-frequency characteristic of the circuit.

In Fig. 3 to Fig. 6, inclusive, circuits are shown that perform in a similar manner to the amplifier in Fig. 1. The circuit of Fig. 3 like that of Fig. 1 is adapted to working between balanced to ground impedances of arbitrary impedance ratio and with arbitrary gain.

Figs. 4, 5 and 6 show modifications of the circuit of Fig. 1 adapted for operation only between unlike impedances. Figs. 4 and 5 are circuits adapted for grounded circuit operation. Fig. 6 is suitable for balanced-to-ground operation.

What is claimed is:

1. A wave translating system comprising a wave amplifying device having input and output impedances, and means feeding back in said device waves that cause said input and output impedances to be determined by and proportional to the receiving and sending impedances, respectively, connected to said input and output impedances, said device comprising an amplifying element having input and output circuits and said means comprising an impedance in shunt relation to said input circuit with respect to said sending impedance and in serial relation to the receiving impedance with respect to said output circuit, and an impedance in serial relation to said input circuit with respect to the sending impedance and in shunt relation to the receiving impedance with respect to said output circuit.

2. A wave translating system comprising a wave amplifying device having input and output impedances, sending and receiving impedances attached to said input and output impedances, respectively, and subject to variations, and means producing negative feedback in said device of waves that cause said input and output impedances to maintain fixed ratios to said varying receiving and sending impedances, respectively, said device comprising an amplifying element

having input and output circuits and said means comprising means for producing shunt feedback to said input circuit proportional to current flowing in said output circuit and series feedback to said input circuit proportional to the voltage across said receiving impedance.

3. A system comprising wave amplifying means and a load impedance therefor variable with frequency, said amplifying means comprising an amplifying device and a network feeding waves back in said device in gain-reducing phase and rendering the input impedance of said amplifying means equal to a constant times said load impedance, said network comprising input and output transformers for said amplifying device having primary and secondary windings, a feedback coil in series with the primary winding of said input transformer and inductively related to said windings of said output transformer, and a feedback coil in series with the primary winding of said output transformer and inductively related to said windings of said input transformer.

4. A wave translating system comprising wave amplifying means, a sending impedance therefor variable with frequency, said amplifying means comprising an amplifying device and a network for feeding waves back in said device in gain-reducing phase and rendering the output impedance of said amplifying means equal to a constant times said sending impedance, said network comprising input and output transformers for said amplifying device having primary and secondary windings, a feedback coil in series with the primary winding of said input transformer and inductively related to said windings of said output transformer, and a feedback coil in series with the primary winding of said output transformer and inductively related to said windings of said input transformer.

5. A wave translating system comprising a wave amplifying device, two wave transmission circuits, and a network interconnecting said device and said circuits and producing negative feedback in said device of waves that cause the impedance of one of said circuits to appear as the impedance facing the other circuit, said network comprising input and output transformers for said amplifying device having primary and secondary windings, a feedback coil in series with one of said windings of said output transformer and inductively related to said windings of said input transformer, and a feedback coil in series with one of the two first-mentioned windings of said input transformer and inductively related to said windings of said output transformer.

6. A wave amplifying device having input and output circuits, a wave source for association with said input circuit, a load circuit for association with said output circuit, and means for producing gain-reducing feedback in said device, said means comprising an impedance in shunt relation to said input circuit with respect to said source and in serial relation to said load circuit with respect to said output circuit, and an impedance in serial relation to said input circuit with respect to said source and in shunt relation to said load circuit with respect to said output circuit.

7. A wave amplifying system having means for producing shunt feedback to the input of the system proportional to current flowing in the load impedance and series feedback to the input of the system proportional to the voltage across the load impedance.

8. A wave transmission system comprising a wave amplifying circuit and attached incoming and outgoing circuits therefor, one of said attached circuits comprising reactance, and said amplifying circuit having means feeding back therein waves that reduce its gain and render its insertion gain independent of frequency, said means producing shunt feedback to the input of said amplifying circuit proportional to the amplified output current of said amplifying circuit and series feedback to the input of said amplifying circuit proportional to the voltage across the load impedance.

9. A wave translating system comprising a wave amplifying device, incoming and outgoing circuits, and a network comprising two three-winding transformers interconnecting said device and said circuits and producing negative feedback in said device of waves that cause the impedance of said network facing one of said two circuits to equal a constant times the impedance of the other of said two circuits and cause the impedance of said network facing said other circuit to equal a constant times the impedance of said one circuit, one of said transformers having primary and secondary windings connected respectively to said incoming circuit and said device, the other of said transformers having primary and secondary windings connected respectively to said device and said outgoing circuit, said one transformer having a feedback winding inductively related to its primary and secondary windings and carrying a feedback current proportional to the current in one of said windings of said other transformer, and said other transformer having a feedback winding inductively related to its primary and secondary windings and carrying a feedback current proportional to the current in one of the two first-mentioned windings of said one transformer.

10. A wave translating system comprising a wave amplifying device having an input circuit and an output transformer with a primary winding and a secondary winding for coupling said device to a load impedance, means for producing negative feedback in said device comprising a feedback impedance in shunt relation to said input circuit and in serial relation to said primary winding of said output transformer, and means for producing series negative feedback in said device proportional to the voltage across the load impedance.

11. An amplifier with an input transformer having a primary winding and a secondary winding, a load impedance for the amplifier, means comprising a feedback coil in series with said

primary winding of said transformer for producing negative feedback in said amplifier proportional to the voltage across the load impedance, and means for producing shunt negative feedback in said amplifier proportional to the current in the load impedance.

12. An amplifier with input and output transformers each having a primary winding and a secondary winding, a feedback coil in serial relation to said primary winding of said output transformer and inductively related to said windings of said input transformer, and a feedback coil in serial relation to said primary winding of said input transformer and inductively related to said windings of said output transformer.

13. A system comprising wave amplifying means having an input circuit and an output circuit, a wave source and a load circuit, and a network connecting said load circuit for transmission to said source and connecting said output circuit for transmitting to said load circuit, said network having inductively related branches which are connected respectively to said source and said output circuit in opposing relation with respect to said input circuit and which substantially prevent transmission from said load circuit to said input circuit.

14. A wave translating system comprising a wave amplifying device and means for feeding back in said device waves that render the insertion gain introduced in traversing said system in one direction equal to the loss introduced in traversing said system in the opposite direction, said means comprising input and output transformers for said amplifying device having primary and secondary windings, a feedback coil inductively related to said windings of said input transformer and carrying current proportional to the load current of the amplifier, and a second feedback coil inductively related to said windings of said output transformer and carrying current proportional to that in one of the two first-mentioned windings of said input transformer.

15. An amplifier with an input transformer and an output transformer each having a primary winding and a secondary winding, and means for producing negative feedback in said amplifier comprising a feedback coil inductively related to said windings of said input transformer and carrying a current proportional to the current in one of said windings of said output transformer, and a second feedback coil inductively related to said windings of said output transformer and carrying a current proportional to the current flowing in one of the windings of said input transformer.

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