

July 25, 1939.

S. T. MEYERS

2,167,368

ELECTRIC WAVE AMPLIFYING SYSTEM

Original Filed Dec. 5, 1936

2 Sheets-Sheet 1

FIG. 1

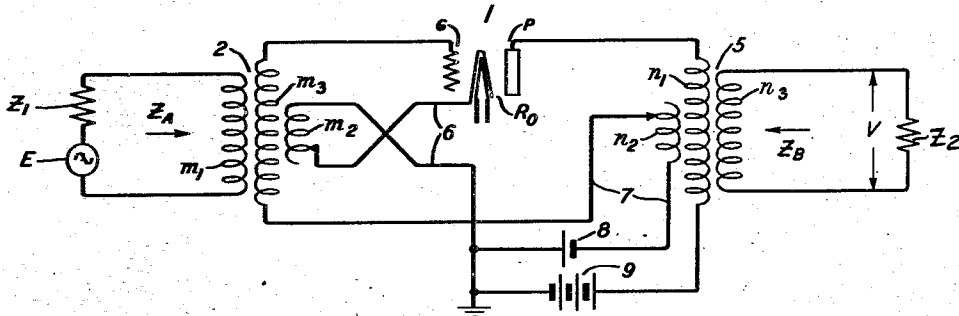


FIG. 1A

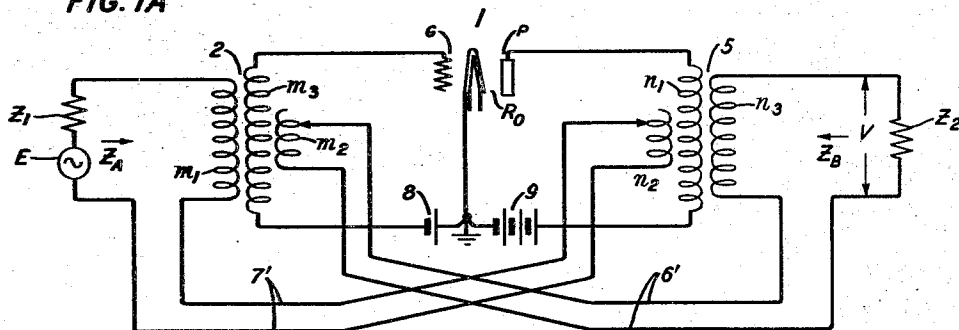
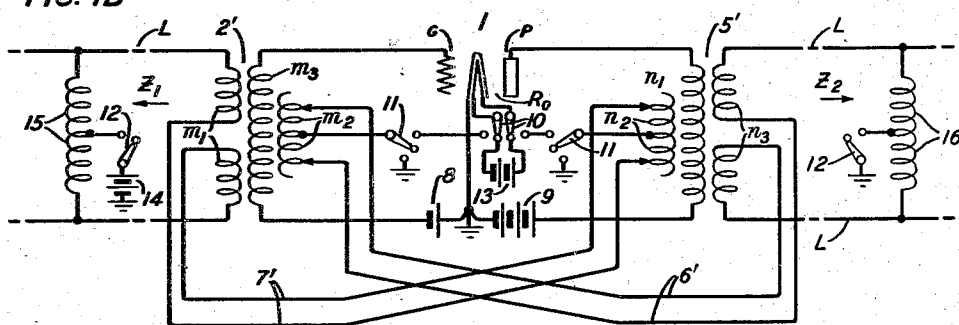


FIG. 1B



INVENTOR
S. T. MEYERS
BY
B. L. Leger
ATTORNEY

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S. T. MEYERS

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FIG. 2

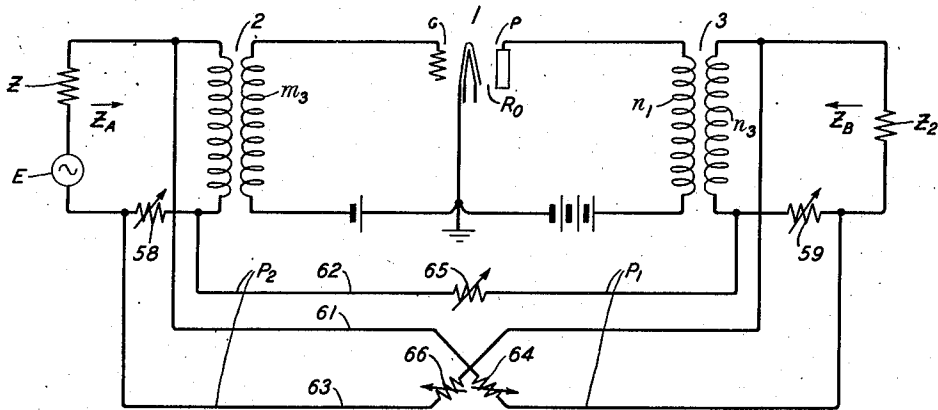
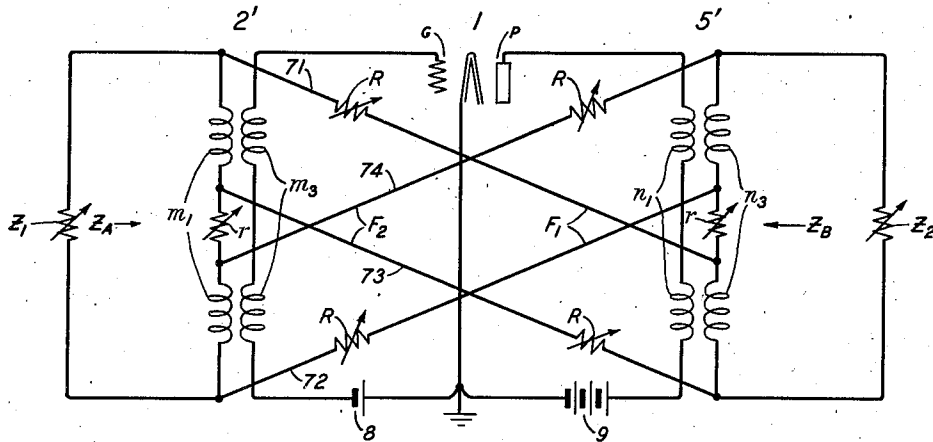


FIG. 2A



INVENTOR
S. T. MEYERS
BY
B. C. Leger
ATTORNEY

UNITED STATES PATENT OFFICE

2,167,368

ELECTRIC WAVE AMPLIFYING SYSTEM

Stanley T. Meyers, East Orange, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Original application December 5, 1936, Serial No.
114,400. Divided and this application October
15, 1937, Serial No. 169,116

2 Claims. (Cl. 179—171)

This application is a division of my prior application Serial No. 114,400, filed December 5, 1936, for Electric wave amplifying system.

This invention relates to wave amplifying systems.

Objects of the invention are to control transmission properties of such systems, as for example, transmission efficiency, distortion, feedback, and impedances, and relations of such properties in such systems.

It is also an object of the invention to provide simple systems affording such control.

In one specific aspect the invention is a system comprising a simple amplifier which has negative or gain-reducing feedbacks that reduce distortion and render the insertion gain of the amplifier independent of frequency.

The feedbacks may be, for example, a shunt-series negative feedback and a series-shunt negative feedback. (A shunt-series feedback here refers to a feedback that is shunt feedback at the amplifier input and series feedback at the amplifier output; a series-shunt feedback refers to a feedback that is series feedback at the amplifier input and shunt feedback at the amplifier output.)

The shunt-series feedback may be obtained, for example, by a feedback coils in series in the output circuit and inductively related to the windings of an input transformer for the amplifier, and the series-shunt feedback may be obtained, for example, by a feedback coil in series in the input circuit and inductively related to the windings of an output transformer for the amplifier.

If desired, with considerable amounts of negative feedback of both types (i. e., shunt-series and series-shunt) the insertion gain of the amplifier can be made independent of frequency and the amplifier can be transparent as to impedance, i. e., can have its input and output impedances Z_A and Z_B determined by and equal to the attached impedances Z_2 and Z_1 , respectively, of the outgoing and incoming lines or circuits.

The transparency is a very useful property, for example, where it is desired to insert amplification in a circuit such as a filter or a long transmission line without disturbing the impedance conditions. This is especially desirable in the case of resistance or inductance loaded transmission circuits, where, ordinarily, when an amplifier that is not transparent is inserted, the insertion must be effected at particular points in the loading section or the loading section adjusted to take care of the position of the repeater.

If desired, the feedback coil in series in the output circuit of the amplifier may be connected in the secondary circuit of the output transformer; and if desired, the feedback coil in series in the input circuit may be connected in the primary circuit of the input transformer. The feedbacks then more effectively reduce distortion in the transformers, as, for example, distortion caused by modulation in the transformers or by variation of the transmission efficiency of the transformers with frequency; yet the primary winding of the input transformer and the secondary winding of the output transformer need not be connected otherwise than electromagnetically, and if desired, the incoming and outgoing lines may be balanced with respect to ground.

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

Fig. 1 is a circuit diagram of a wave amplifying system embodying a form of the invention employing shunt-series and series-shunt feedbacks;

Figs. 1A and 1B show modifications of the system of Fig. 1;

Fig. 2 is a circuit diagram of another wave amplifying system embodying a form of the invention employing shunt-series and series-shunt feedbacks; and

Fig. 2A shows a modification of the system of Fig. 2.

The system of Fig. 1 comprises 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 outgoing line or circuit Z_2 of impedance value Z_2 .

The amplifier comprises two feedback paths or circuits 6 and 7. Path 6 comprises a feedback coil m_2 of m_2 active turns on transformer 2. This coil m_2 is in series with winding n_1 , and provides shunt-series negative feedback. Any parasitic series-series feedback which it produces does not materially affect the operation of the circuit provided such feedback is small compared to the shunt-series and series-shunt feedbacks. Path 7 comprises a feedback coil n_2 of n_2 active turns on transformer 5. This coil n_2 is in series with winding m_3 , and provides series-shunt negative feedback. A C-battery 8 for providing negative grid bias is shown in the lead from the lower end of coil n_2 . A B-battery 9 is shown for supplying space current. If desired, any series-series feedback produced by the impedance of coil m_2 can be avoided by shifting the connection of the positive terminal of battery 8 to the cathode.

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 6 and the β_2 -circuit 7, the significance of μ and β being as indicated in the patent and article mentioned above. The feedback through path 6 may be, for example, negative feedback with $\mu\beta_1 \gg 1$ and the feedback through path 7 may be, for example, negative feedback with $\mu\beta_2 \gg 1$. Preferably the coupling between m_2 and m_1 , and also the coupling between n_2 and n_3 , is as close as practicable. The closer this coupling, the more nearly complete will be the correction that the feedback produces in the transformer distortion (e. g., the modulation produced in the transformers and the distortion due to variation of the transmission efficiency of the transformers with frequency).

$$\frac{V}{E} = \frac{\left(\frac{n_1}{n_3}\right) \frac{m_2}{m_1} Z_2^2 \left[1 + \mu \left(1 + \frac{m_3}{m_2}\right)\right]}{R_0 + Z_2 \left(\frac{n_1}{n_3}\right)^2 + Z_1 \left(\frac{m_2}{m_1}\right)^2 + \mu \left[\left(\frac{n_2}{n_1}\right) \left(\frac{n_1}{n_3}\right)^2 Z_2 + \left(\frac{m_2}{m_1}\right)^2 Z_1 \left(1 + \frac{m_3}{m_2}\right) \right]} \quad (3) \quad 50$$

The amplifier has the desirable features of stabilized negative feedback amplifiers in general, such as the features of amplifier distortion reduction and gain stabilization by the feedback. Moreover, by proper adjustment of the circuit the amplifier input and output impedances Z_A and Z_B may be made to look like the output and input terminating impedance Z_2 and Z_1 respectively. That is, the circuit can be adjusted so that if the amplifier output is terminated in Z_2 the value Z_A of the amplifier input impedance becomes Z_2 , and if the amplifier input is terminated in Z_1 the value Z_B of the amplifier output impedance becomes Z_1 . As indicated above, this transparency as to impedance is a very useful property.

With an amplifier of any number of stages and input and output transformers with three windings as shown, the gain and input and output impedances may be made to have the values indicated by the following formulae.

It can be shown that the input impedance with feedback is

$$Z_A = \frac{R_0 + Z_2 \left(\frac{n_1}{n_3}\right)^2 \left(1 + \mu \frac{n_2}{n_1}\right)}{\left(\frac{m_2}{m_1}\right)^2 \left[1 + \mu \left(1 + \frac{m_3}{m_2}\right)\right]} \quad (1) \quad 5$$

where R_0 is the plate impedance in the last tube.

With considerable amounts of feedback, or in other words if μ be made large, so that all terms involving μ are large compared to all other terms in the equation, the equation may be simplified and the input impedance becomes:

$$Z_A = Z_2 \frac{\left(\frac{n_1}{n_3}\right)^2 \frac{n_2}{n_1}}{\left(\frac{m_2}{m_1}\right)^2 \left(1 + \frac{m_3}{m_2}\right)} \quad (1-A) \quad 15$$

Then if the expression involving the turns ratios be made equal to unity,

$$Z_A = Z_2 \quad (1-B) \quad 20$$

It can also be shown that the output impedance is:

$$Z_B = \frac{R_0 + Z_1 \left(\frac{m_2}{m_1}\right)^2 \left[1 + \mu \left(1 + \frac{m_3}{m_2}\right)\right]}{\left(\frac{n_1}{n_3}\right)^2 \left(1 + \mu \frac{n_2}{n_1}\right)} \quad (2) \quad 25$$

Then, as before, with considerable amounts of feedback, or when μ is large so that terms in which it is involved are large compared to all other terms in the equation, Z_B becomes

$$Z_B = Z_1 \frac{\left(\frac{m_2}{m_1}\right)^2 \left(1 + \frac{m_3}{m_2}\right)}{\left(\frac{n_1}{n_3}\right)^2 \frac{n_2}{n_1}} \quad (2-A) \quad 35$$

The factor involving the turns ratios is the inverse of that in (1-A) and is unity when that in (1-A) is unity, making

$$Z_B = Z_1 \quad (2-B) \quad 40$$

The voltage amplification, which is the ratio of the voltage V across Z_2 to the voltage E can be shown to be

$$\frac{V}{E} = \frac{\left(\frac{n_1}{n_3}\right) \frac{m_2}{m_1} Z_2^2 \left[1 + \mu \left(1 + \frac{m_3}{m_2}\right)\right]}{R_0 + Z_2 \left(\frac{n_1}{n_3}\right)^2 + Z_1 \left(\frac{m_2}{m_1}\right)^2 + \mu \left[\left(\frac{n_2}{n_1}\right) \left(\frac{n_1}{n_3}\right)^2 Z_2 + \left(\frac{m_2}{m_1}\right)^2 Z_1 \left(1 + \frac{m_3}{m_2}\right) \right]} \quad (3) \quad 50$$

If the feedback is large (3) simplifies to

$$\frac{V}{E} = \frac{Z_2 \frac{m_2}{m_1} \left(1 + \frac{m_3}{m_2}\right) \left(\frac{n_1}{n_3}\right)}{Z_2 \left(\frac{n_2}{n_1}\right) \frac{n_1}{n_3} + Z_1 \left(\frac{m_2}{m_1}\right)^2 \left(1 + \frac{m_3}{m_2}\right)} \quad (3-A) \quad 55$$

Here again under the conditions of the turns ratios above,

$$\frac{V}{E} = \frac{Z_2 \left(\frac{n_1}{n_3}\right) \left(\frac{m_1}{m_2}\right)}{Z_2 + Z_1} \quad (3-B) \quad 60$$

The transmission is then

$$\left(\frac{m_1}{m_2}\right) \left(\frac{n_1}{n_3}\right)$$

times the transmission before the amplifier was inserted. Thus, the insertion gain of the amplifier is then constant or independent of frequency.

Similar properties are obtained with the circuit

of Fig. 1A. However, here the transformers are more effectively included in the feedback paths 6' and 7' which correspond to the paths 6 and 7 respectively of Fig. 1; and consequently the transformer distortion (as for example the modulation and the distortion due to variation of the transmission efficiency of the transformers with frequency) as well as the variation of the impedances of the transformers with frequency is more effectively reduced by the feedback, so Z_A , Z_B and

$$\frac{V}{E}$$

are more direct functions of the turns ratios. It can be shown that, with a large amount of feedback,

$$Z_A = Z_2 \left(\frac{m_1}{m_2} \right) \left(\frac{n_3}{n_2} \right) \quad (4-A)$$

$$Z_B = Z_1 \left(\frac{n_3}{n_2} \right) \left(\frac{m_1}{m_2} \right) \quad (5-A)$$

$$\frac{V}{E} = \frac{n_3}{n_2} \frac{Z_2 \left(\frac{m_1}{m_2} \right)}{Z_2 \left(\frac{m_1}{m_2} \right) + Z_1 \left(\frac{n_3}{n_2} \right)} \quad (6-A)$$

If

$$\frac{m_1}{m_2} = \frac{n_3}{n_2}$$

$$Z_A = Z_2 \quad (4-B)$$

$$Z_B = Z_1 \quad (5-B)$$

$$\frac{V}{E} = \left(\frac{n_3}{n_2} \right) \frac{Z_2}{Z_2 + Z_1} \quad (6-B)$$

This circuit is well adapted for use in a resistance loaded cable system, for example. An advantageous feature is that the amplifier may be placed at any point on the cable. Moreover, the system can be modified as indicated in Fig. 1B, so that direct current, for use in heating the filament of amplifier 1, for example, can readily be simplexed over the cable and passed around the amplifier without disturbing the feedback conditions in the transmission path.

In Fig. 1B, with switches 10, 11 and 12 in the condition shown, an A-battery 13 supplies heating current for the amplifier filament. However, instead, current for heating the filament can be supplied from battery 14 over the line or cable L in which the amplifier is connected. This can be done by closing switches 12, closing switches 11 on their upper contacts, and closing switches 10 on their outer contacts. Coils 15 and 16, through which the direct current from battery 14 is simplexed over the line L, are balanced to ground; as are the line windings m_1 and n_3 and feedback windings m_2 and n_2 of the transformers 2' and 5' which correspond to transformers 2 and 5 of Fig. 1A. The centers of the feedback windings m_2 and n_2 can be tied together through switches 11 and 10 and the amplifier filament, for supplying filament heating current from battery 14 as just described, or can be grounded together at switches 11 with switches 12 then open and current for heating the amplifier filament then supplied by battery 13 through switches 10 closed on their inner contacts.

The amplifier is bilaterally transmitting. It can pass waves to be transmitted from Z_2 to Z_1 , for example, where two-way transmission through the amplifier is desired. However, where it has a gain in one direction, it introduces an equal loss in the other direction.

The properties of the circuit of Fig. 1A pointed out above can be obtained without the auxiliary windings on the transformers, by employing resistance connections, for example as shown in Fig. 2. In this figure a resistance 58 is included in series with Z_1 , and a resistance 59 is included in series with Z_2 . Conductors 61 and 62 form a feedback path F_1 providing shunt-series negative feedback; and conductors 62 and 63 form a feedback path F_2 providing series-shunt negative feedback. Resistances 64, 65 and 66 are included in conductors 61, 62 and 63, respectively. These resistances, as well as the resistances 58 and 59, are shown as variable. These resistances may be varied to adjust the gain and input and output impedances of the amplifier. For instance, if the feedback is large and resistances 58 and 59 are small compared to Z_1 and Z_2 respectively and resistances 64, 65 and 66 large compared to both Z_1 and Z_2 , it can be shown that transparency may be realized when resistance 58 equals 59 and resistance 64 equals 66. The insertion gain between Z_1 and Z_2 will then be a constant equal to the sum of resistances 64 and 65 divided by resistance 58.

With large amounts of negative feedback this circuit gives substantially complete correction of transmission variations in the amplifier and transformer 2 and 3.

Fig. 2a shows a modification of Fig. 2 in which a circuit balanced with respect to ground is obtained by placing the feedback connections symmetrical with respect to the line impedances. A resistance r is connected in series with winding m_1 , between the two halves of the winding, and a similar resistance r is connected in series with winding n_3 , between the two halves of the winding. Conductors 71 and 72 form a feedback path F_1 providing shunt-series negative feedback; and conductors 73 and 74 form a feedback path F_2 providing series-shunt negative feedback. Resistances R are included in the respective conductors 71, 72, 73 and 74. These resistances, as well as the resistances r , are shown as variable.

It can be shown that, when r is small compared to Z_1 and Z_2 and R large compared to Z_1 and Z_2 , transparency may be obtained when the feedback is large. Also under the same conditions the insertion gain between Z_1 and Z_2 will be a constant equal to

$$2 \frac{R}{r}$$

The conductors 71, 72, 73 and 74 form, in addition to the feedback paths F_1 and F_2 , four incidental feedback paths each producing negative feedback. One of these four incidental paths is formed by conductors 71 and 73, and produces shunt-shunt negative feedback. A second is formed by conductors 74 and 72, and produces shunt-shunt negative feedback. A third is formed by conductors 71 and 74, and produces (shunt and series)-(shunt and series) negative feedback. The fourth is formed by conductors 73 and 72, and produces (shunt and series)-(shunt and series) negative feedback.

These paths, while they exist, are only parasitic and do not modify the results when the feedback through the path F_1 and F_2 is large.

What is claimed is:

1. A wave amplifying device having input and output circuits, a wave source for association with said input circuit, an input transformer having a primary winding connected to said source and a secondary winding connected to said input circuit, a load circuit for said device, an output transformer having a primary winding connected to said output circuit and a secondary winding connected to said load circuit, means for producing negative feedback in said device through the first-mentioned primary and secondary windings, said means comprising an impedance in serial relation to said first-mentioned primary winding with respect to said wave source and effectively in shunt relation to said load circuit with respect to said output circuit, and means for producing negative feedback in said device of voltage induced in said second-mentioned secondary winding by current from said output circuit flowing in said second-mentioned primary winding, said latter means comprising an impedance in serial relation to said load circuit with respect to said second-men-

tioned secondary winding and effectively in shunt relation to said input circuit with respect to said source.

2. A wave transmission system comprising a wave amplifying device having input and output circuits, a wave source, an input transformer for associating said source with said input circuit, a load circuit, an output transformer for associating said output circuit with said load circuit, and means transmitting waves from said output circuit to said source and producing gain-reducing feedback in said device through each of said transformers, said means comprising an impedance connected effectively in shunt relation to said input circuit with respect to said source and connected in series with said secondary winding of said output transformer and said load circuit, and an impedance connected in series with said primary winding of said input transformer and said source and connected effectively in shunt relation to said load circuit with respect to said output circuit.

STANLEY T. MEYERS.