July 25, 1939. S. T. MEYERS 2,167,367

ELECTRIC WAVE AMPLIFYING SYSTEM

Filed Dec. 5, 1936 2 Sheets-Sheet 1

FIG. 2

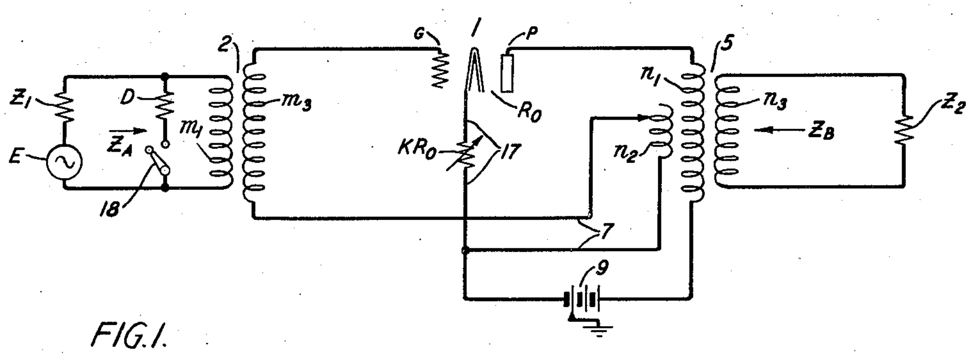


FIG. 1.

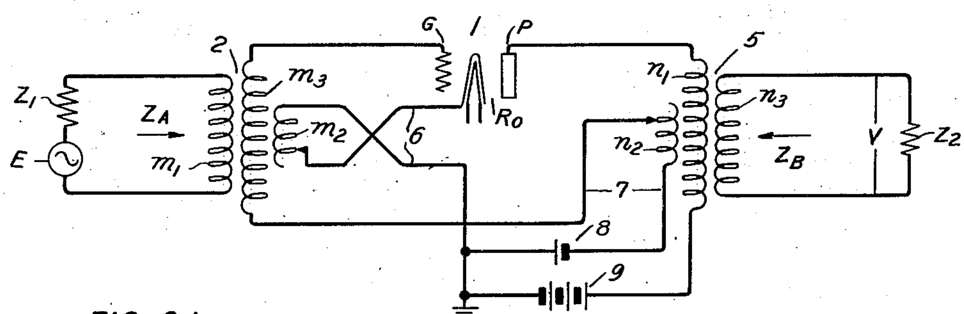
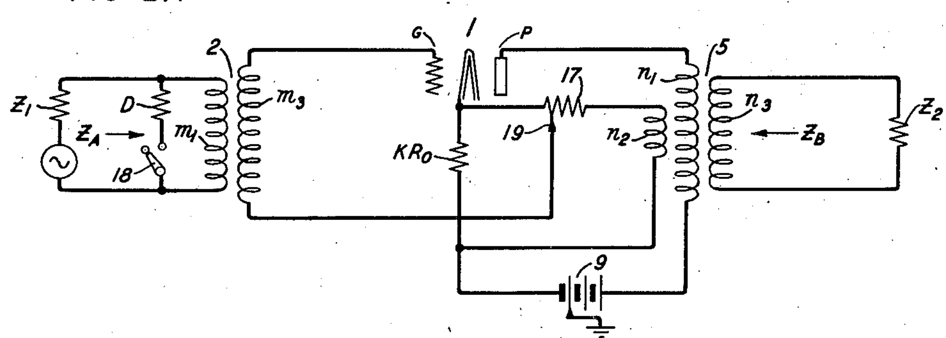


FIG. 2A



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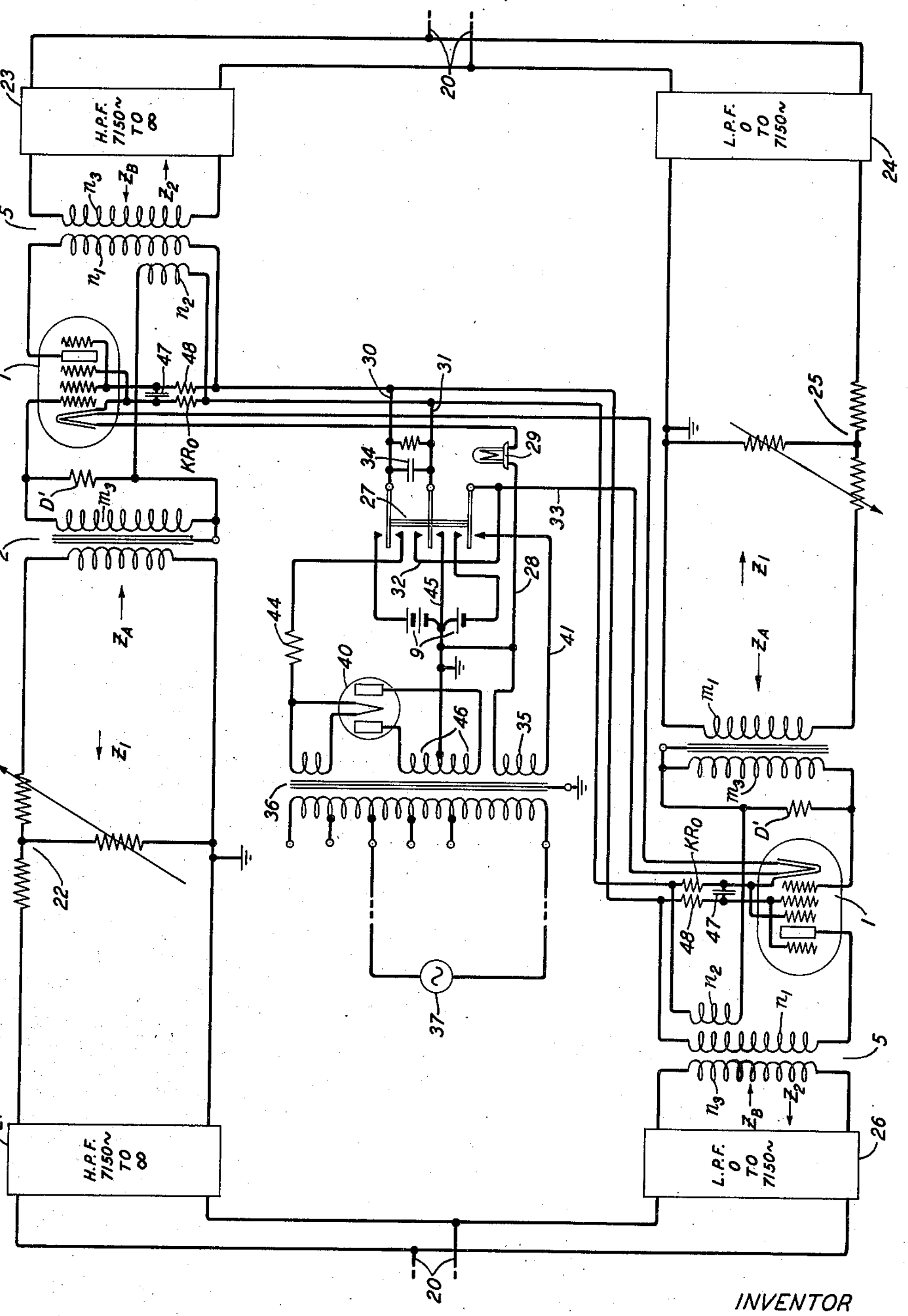

FIG. 2B

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ELECTRIC WAVE AMPLIFYING SYSTEM

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Application December 5, 1936, Serial No. 114,400

4 Claims. (Cl. 179—171)

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 series-series negative feedback and a series-shunt negative feedback. (A series-shunt feedback refers to a feedback that is series feedback at the amplifier input and shunt feedback at the amplifier output; and a series-series feedback refers to a feedback that is series feedback at the amplifier input and series feedback at the amplifier output.)

The series-series feedback may be obtained, for example, by a feedback resistor or impedance in series with the secondary winding of an input transformer for the amplifier and also in series with the primary winding of an output transformer for the amplifier; and the series-shunt feedback may be obtained, for example, by a feedback coil in series with the secondary winding of the input transformer and inductively related to the windings of the output transformer.

Then the feedback path, including the feedback resistor and the feedback coil in series with each other, is in series with the secondary winding of the amplifier input transformer, and therefore the impedance of the feedback path as viewed from its terminals at the input side of the amplifier (i. e., as viewed from the cathode and the low voltage end of the secondary winding of the input transformer) can be low without introducing undue loss in transmission from the incoming line to the amplifier. Having this impedance low minimizes deleterious effects of distributed shunt capacity in the feedback circuit upon phase shift in the feedback path and singing tendency in the amplifier. Also, due to this low impedance the tendency for longitudinal voltages from the primary winding of the input transformer to appear across the feedback path and thus be amplified and transmitted to the output is reduced.

When the amplifier is, for example, of the vacuum tube type, the feedback coil causes little loss in transmission from the plate-cathode path in the last tube to the outgoing line, because the coil need have but few turns compared to the primary winding of the amplifier output transformer and moreover is in series with the grid-cathode impedance of the first tube, which ordinarily is high.

The feedback resistor may serve also as a grid biasing resistor, the steady biasing voltage being created for example by space current of the last tube flowing through the resistor.

If desired, the amplifier input and output impedances Z_A and Z_B can be resistance impedances, with Z_A and Z_B each independent of variations in the attached impedances Z_1 and Z_2; and moreover, if desired, Z_A can be a match for Z_1.

With large values of negative feedback of both types (i. e., series-series and series-shunt), the insertion gain of the amplifier can be made independent of frequency and Z_B is practically independent of variations in μ and R_0 or of variations in the amount of feedback, and by adjustment of the amplifier circuit, as described hereinafter, the gain of the amplifier can be changed without causing variation of Z_B. The quantity μ referred to here is the amplification of the amplifying element or path of the amplifier; and the quantity R_0 is the output resistance or impedance of that path, as for example, the plate-cathode resistance in the last tube in the case of a vacuum tube amplifier.

Regardless of the amount of feedback in the amplifier, the feedback is practically independent of variations in Z_1. This constancy of the feedback not only tends to give constancy of the distortion reduction and gain stability produced by feedback, but is of especial value for avoiding singing around the feedback loop, i. e., for stabilizing the amplifier against singing or for reducing singing tendency.

Also regardless of the amount of feedback in the amplifier, the amplifier circuit can be proportioned as described hereinafter to render the feedback independent of Z_2 to any desired degree, and this can be done without necessitating connection of loss-producing resistance across the path from R_0 to Z_2; but if complete independence is to be obtained and at the same time the insertion gain of the amplifier is to be made independent of frequency as referred to above, then Z_1 and Z_2 must be resistance impedances.

For given values of Z_1 and Z_2 and with considerable amounts of (series-series and series-shunt) negative feedback, by proportioning the amplifier as described hereinafter, Z_A can be made equal to Z_2 with Z_B equal to Z_1; but then the insertion gain of the amplifier, in general will not be independent of frequency, though the independence can be obtained if Z_1 and Z_2 be made resistance impedances.

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

Fig. 1 is a circuit diagram for facilitating explanation of the invention, showing a wave amplifying system claimed in divisional application Serial No. 169,116, allowed January 14, 1939, employing shunt-series and series-shunt feedbacks;

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

Figs. 2—A and 2—B show modifications 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 m_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 Black patent and article mentioned above. The feedback through path **6** may be, for example, negative feedback with $\mu\beta_1>>1$ and the feedback through path **7** may be, for example, negative feedback with $\mu\beta_2>>1$. 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.)

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

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

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:

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

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

$$Z_A=Z_2 \quad (1\text{—B})$$

It can also be shown that the output impedance is:

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

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

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

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

$$Z_B=Z_1. \quad (2\text{—B})$$

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

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

If the feedback is large (3) simplifies to

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

Here again under the conditions of the turns ratios above,

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

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.

Fig. 2 shows a modification of the circuit of Fig. 1 in which an impedance KR_0, giving series-series-negative feedback through a feedback path 17, replaces the feedback coil m_2 that gave shunt-series feedback through feedback path 6 of Fig. 1. The factor K may have any desired value, constant or variable, and if desired may be a complex quantity. Thus, the impedance KR_0 may be given any value desired.

The amplifier output impedance in Fig. 2 can be obtained directly from Equation 2 by substituting KR_0 for Z_1

$$\left(\frac{m_2}{m_1}\right)^2$$

and (since the coupling between m_2 and m_3 has been eliminated) dropping out the term

$$\frac{m_3}{m_2}$$

It is

$$Z_B=\frac{R_0+KR_0(1+\mu)}{\left(\frac{n_1}{n_3}\right)^2\left(1+\mu\frac{n_2}{n_1}\right)} \quad (7)$$

From similar treatment of Equation 3, i. e., by substituting KR_0 for Z_1

$$\left(\frac{m_2}{m_1}\right)^2$$

and eliminating all components of propagation due to any coupling between m_2 and m_1 or m_3, the voltage amplification is found to be:

$$\frac{V}{E}=\frac{Z_2\left(\mu\frac{n_1m_3}{n_3m_1}\right)}{R_0(1+K+K\mu)+Z_2\left(\frac{n_1}{n_3}\right)^2\left(1+\mu\frac{n_2}{n_1}\right)} \quad (8)$$

If the feedback is made large (i. e., if terms involving μ are large compared to all others), Equation 7 becomes

$$Z_B=\frac{(n_3)^2}{n_1n_2}KR_0 \quad (7\text{—A})$$

and Equation 8 becomes

$$\frac{V}{E}=\frac{Z^2\left(\frac{n_1m_3}{n_3m_1}\right)}{KR_0+Z_2\frac{n_1n_2}{(n_3)^2}}=\frac{Z_2\left(\frac{n_3m_3}{n_2m_1}\right)}{Z_2+\frac{(n_3)^2}{n_1n_2}KR_0}=\frac{Z_2\left(\frac{n_3m_3}{n_2m_1}\right)}{Z_2+Z_B} \quad (9)$$

Equation 9 shows that the voltage amplification is a constant times the impedance ratio

$$\frac{Z_2}{Z_2+Z_B}$$

Equation 7—A shows that Z_B can be made equal to Z_1 by making KR_0 equal to

$$\frac{n_1n_2}{(n_3)^2}Z_1$$

If this be done, Equation 9 shows that the voltage amplification will become

$$\frac{V}{E}=\frac{Z_2}{Z_2+Z_1}\left(\frac{n_3m_3}{n_2m_1}\right) \quad (9')$$

or in other words that the voltage amplification will be a constant

$$\left(\frac{n_3m_3}{n_2m_1}\right)$$

times the voltage across Z_2 working out of Z_1 before the amplifier was inserted. Thus the insertion gain of the amplifier is then constant or independent of frequency.

However, though the insertion gain is then constant, a large reflection may occur at the amplifier input since the self impedance of the input transformer and consequently the value of Z_A ordinarily is high compared to the value of Z_1. Where this reflection is not desired, it can be avoided by connecting across the winding m_1 or m_3 a terminating impedance of proper value to make Z_A match Z_1. For example, generalized impedance D of value D may be connected across winding m_1 by switch 18, and D may be equal to Z_1 where the impedance presented by winding m_1 is so high in comparison to D that the value of Z_A is substantially D. The connection of D modifies by a factor

$$\frac{D}{D+Z_1}$$

the value of amplification given by equation 9′, but the insertion gain of the amplifier will still be constant or independent of frequency if the factor

$$\frac{D}{D+Z_1}$$

is constant or independent of frequency, and the value of this factor is 1/2 when D is equal to Z_1.

When desired, the amplifier input and output impedances Z_A and Z_B can be made resistance impedances. With the self impedance of the input transformer high, Z_A is equal to D, and so can be made a resistance impedance of any chosen value by making D a resistance impedance of the chosen value. As shown by Equation 7, Z_B can be made a resistance impedance by making KR_0 a resistance impedance; and, with either μ or the feedback made large, equation 7—A shows Z_B is equal to KR_0 times the turns ratio.

$$\frac{(n_3)^2}{n_1n_2}$$

When KR_0 has a resistance component, the steady voltage drop created across the resistance by the flow of space current from source 9 can be used as a grid biasing voltage.

As indicated above, the impedance of the feedback circuit to which the input connection is made, i. e., the impedance of the feedback circuit through paths 17 and 7 in series as viewed from the cathode and the lower end of winding m_3, can readily be made low, minimizing deleterious effects of distributed capacity of the feedback circuit. The loss in transmission from R_0 to Z_2 can readily be made low.

Z_A is substantially independent of variations in Z_2 and feedback.

Z_B and $\mu\beta$ are each practically independent of variations in both Z_1 and D. This independence is obtained by having the feedbacks series feedbacks at the amplifier input, inasmuch as the grid-cathode impedance in tube 1 is high compared to the impedance presented by winding

m_3. This constancy of Z_B is of value, for example, in facilitating maintaining Z_B matched to Z_2; and this constancy of $\mu\beta$ is of value for example in stabilizing against singing. The variations in Z_1 might be due for example to variations of the impedance of the incoming line with frequency, temperature, humidity or type of line. The variations in D might be due for example to changes made in D in order to match different values of Z_1.

With the negative feedback large, Equation 7—A shows that Z_B is practically independent of variations in μ or of variations in the amount of feedback due to changes in μ.

Regardless of the amount of feedback in the amplifier, the feedback is practically independent of variations in Z_1.

Also regardless of the amount of feedback, by making

$$\frac{K}{1+K}=\frac{n_2}{n_1}$$

i. e., by making

$$K=\frac{n_2}{n_1-n_2}$$

$\mu\beta$ can be made independent of Z_2 or any desired approximation or closeness of approach to the independence can be obtained by sufficiently closely approximating the relation

$$K=\frac{n_2}{n_1-n_2}$$

However, if complete independence is to be obtained and at the same time the insertion gain of the amplifier is to be made independent of frequency as described above, then Z_1 and Z_2 must be resistance impedances.

For given values of Z_1 and Z_2 and with considerable amounts of negative feedback, Z_A can be made equal to Z_2 with Z_B equal to Z_1, by making D equal to Z_1 and making KR_0 equal to

$$\frac{n_1 n_2}{(n_3)^2}Z_1$$

but then the insertion gain of the amplifier in general will not be independent of frequency, though the independence can be obtained if Z_1 and Z_2 be made resistance impedances.

As shown by Equation 7, Z_B is independent of Z_2.

As shown by Equation 7—A, with considerable amounts of negative feedback, Z_B is constant when KR_0 times the turns ratio

$$\frac{(n_3)^2}{n_1 n_2}$$

is maintained constant. By varying these two factors (i. e. KR_0 and this turns ratio) inversely, so their product will not vary, the amplifier gain can be changed without causing variation of Z_B. For example, with a given proportion of series-series and series-shunt feedbacks, n_2 can be increased by a given percentage and KR_0 increased by the same percentage, to change the amount of feedback without varying Z_B. This increases the negative feedback in the amplifier (and decreases the amplifier gain).

Fig. 2A shows a modification of Fig. 2 in which a single adjustment, instead of the two adjustments provided at KR_0 and n_2 in Fig. 2, serves to change the gain without causing change of Z_B. In Fig. 2A a potentiometer resistance **17** is connected across KR_0 and n_2 in series, and winding m_3 is connected to a contact **19** movable along this resistance, (instead of to a contact movable along n_2), so that by adjusting the contact **19** the amplifier gain can be varied without causing variation of Z_B.

Fig. 2B shows a two-way repeater for a circuit **20** which may be, for example, a carrier telephone circuit. The repeater comprises an east amplifier for amplifying waves transmitted from west to east and a west amplifier for amplifying waves transmitted from east to west. Each amplifier is similar to the amplifier of Fig. 2. The terminating resistance D', across winding m_3, corresponds to resistance D across winding m_1 of Fig. 2.

Transmission from west to east may be, for example, in the frequency range above 7,150 cycles per second and transmission from east to west may be, for example, in the frequency range below 7,150 cycles per second. The waves to be amplified by the east amplifier are selected by directional high-pass filter **21** and transmitted through variable attenuator **22** to the amplifier. The attenuator may be used to adjust the gain of the amplifier circuit. The amplified waves pass through directional high-pass filter **23** to line **20** for transmission to the east.

Waves to be amplified by the west amplifier are selected by directional low-pass filter **24** and transmitted through attenuator **25**, the west amplifier and directional low-pass filter **26**.

When switch **27** is raised, filament heating current for the tubes **1** is supplied from the lower section of battery **9** and space current for the tubes is supplied from the whole of the battery. The filament heating current passes from the battery through conductor **28**, ballast lamp **29**, the filament of the east amplifier, the filament of the west amplifier, conductor **33**, and the lower spring of the switch. The space current passes from the battery through the top spring of the switch, conductor **30**, windings n_1, tubes **1** and resistances KR_0, conductor **31**, the middle spring of the switch, conductor **32** and the lower spring of the switch. A filtering network **34** for the space current supply circuit comprises a capacity and a resistance which are shunted across conductors **30** and **31** and whose values may be, for example, 4 microfarads and one-tenth megohm.

When switch **27** is lowered, filament heating current for the tubes **1** is supplied from a secondary winding **35** of transformer **36**, whose primary winding is supplied with current from a 60-cycle source of power **37**, and space current for the tubes **1** is supplied from a rectifier **40** operated from transformer **36**. The filament heating current passes from winding **35** through the ballast lamp **29**, the filaments of tubes **1** in series, conductor **33**, the lower spring of switch **27**, and conductor **41**. The space current for tubes **1** passes from the filament of the rectifier **40** through a resistance **44**, the top spring of switch **27**, windings n_1, tubes **1** and resistances KR_0, conductor **31**, the middle spring of switch **27**, conductor **45** and winding **46** of transformer **36**. The resistance **44** may have a value of 4500 ohms, for example. This resistance controls the value of the direct current supplied to the tubes **1**, and also cooperates with the filtering network **34** to form a resistance-capacity filter for the plate current supply circuit.

The feedback resistors KR_0 supply the grid biasing potentials for the control grids of the tubes **1**.

Steady potentials for the screen grids of the tubes **1** are supplied from the place current supply conductors **30** and **31** through resistors **48**, condensers 47 being the usual by-pass condensers.

What is claimed is:

1. 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 to receive waves from said output circuit, and means producing negative feedback in said device, said means comprising an impedance serially related to said input circuit with respect to said wave source and serially related to said load circuit with respect to said output circuit, and means effectively connecting a portion of said load circuit in serial relation to said input circuit with respect to said wave source and thereby supplying to said input circuit a voltage in series with that of said source and dependent upon that across said load circuit.

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

3. An amplifier with input and output transformers each having a primary winding and a secondary winding, means for producing negative feedback in said amplifier, comprising a resistance in serial relation to said secondary winding of said input transformer and also in serial relation to said primary winding of said output transformer, and a coil for producing negative feedback in said amplifier, said coil being in serial relation to said secondary winding of said input transformer and forming a third winding of said output transformer.

4. A system comprising an amplifier including a vacuum tube with an input transformer and an output transformer, a sending impedance from which said input transformer works including a source of speech modulated carrier waves, a receiving impedance into which said output transformer works, a source of direct current for supplying space current to said tube, a feedback resistance in serial relation to said secondary winding of said input transformer and also in serial relation to said primary winding of said output transformer, a feedback coil for producing negative feedback in said amplifier, said coil being in serial relation to said secondary winding of said input transformer and forming a third winding of said output transformer and a terminating resistance in shunt relation to one of said windings of said input transformer, said terminating resistance having its magnitude such as to make the impedance facing said sending impedance substantially match said sending impedance, said feedback resistance having its magnitude such as substantially to match the magnitude of the amplifier output impedance to the magnitude of said receiving impedance, and said feedback resistance being connected between the cathode of said tube and the negative terminal of said space current supply source, and said source being connected between one terminal of said coil and the anode of said tube.

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