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NEGATIVE FEEDBACK AMPLIFIER

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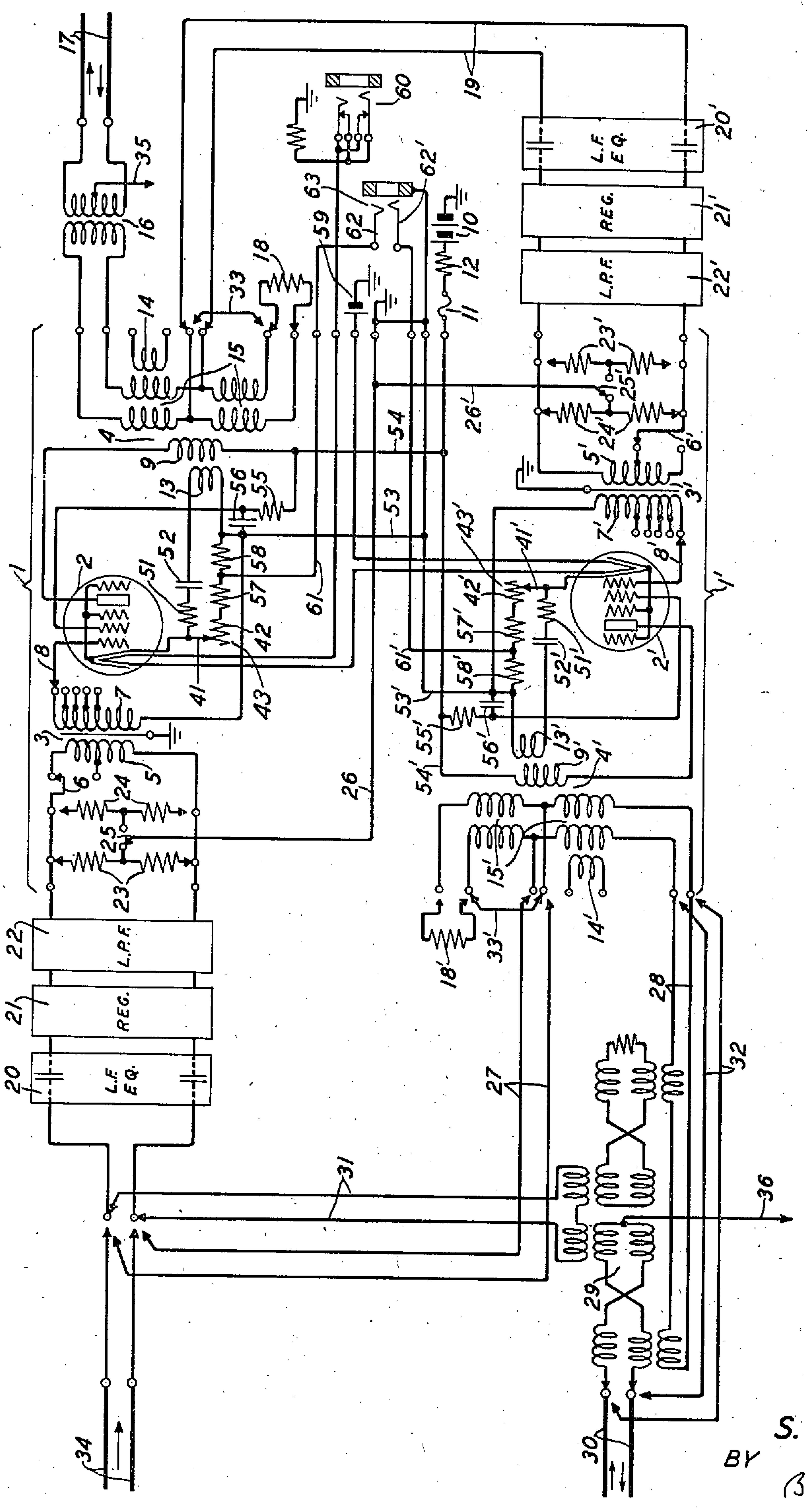

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NEGATIVE FEEDBACK AMPLIFIER

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5 Claims. (Cl. 179—171)

This invention relates to negative feedback amplifiers.

Objects of the invention are to control transmission properties of such an amplifier, as to vary its gain by varying the loss in its feedback path without unduly changing its output impedance or the variation of its gain with frequency or producing objectionable noise in its output.

The invention may be applied, for example, to an amplifier of the general type disclosed in my Patent 2,167,367, July 25, 1939, wherein a suppressor grid pentode with indirectly heated cathode has a series-series negative feedback obtained by a feedback resistor in series with the secondary winding of the input transformer and also in series with the primary winding of the output transformer and a series-shunt negative feedback obtained 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 in accordance with the present invention the resistance and the coil may be in series between the cathode and the negative pole of the space current supply source (which may have some point grounded), so the secondary winding of the input transformer can have its end that is remote from the grid connected to the negative pole of the space current source, a point which may be substantially at ground potential for alternating current. This prevents distributed capacities (of the secondary winding of the input transformer to either the shield or the line winding which may be grounded), from producing such large phase shift in the feedback as to materially lower the singing margin of the amplifier.

Further, in accordance with the invention a stopping condenser may be connected in series with the feedback resistor and the feedback coil between the cathode and the space current source, a gain control resistor may be connected across the feedback resistor, the condenser and the feedback coil, and the loss in the feedback path and consequently the gain of the amplifier may be varied by varying the resistance value of this gain control resistor, for instance by adjustment of a contact movable on the resistance element of the gain control resistor and carrying the unidirectional space current of the tube (for example, the unidirectional plate and screen grid currents). The condenser, by blocking unidirectional current in the condenser path, increases the unidirectional current flow through the contact, and this increase is important in maintaining good contact and in reducing variations in gain in the amplifier due to poor contact on the gain control resistor.

Another important function of the condenser effected by the additional unidirectional current flow through the gain control resistor is reduction of the amplification in the tube when the loss in the feedback path is decreased by adjustment of the contact in such direction as to decrease the amplifier (over-all) gain. This reduction of tube amplification is accomplished by increase of the negative bias on the control grid. This bias increase results from increase of the resistance of the gain adjusting resistor. In accordance with the invention this tube amplification reduction may be made sufficient to substantially compensate for the increased transmission in the feedback path across the gain control resistor and thus reduce variation of loop gain or maintain the loop gain substantially constant throughout the range of adjustment of the contact, so as to stabilize the amplifier output impedance against changes in setting of the contact, or in other words against changes made in the loss of the feedback path by adjustment of the contact to adjust the amplifier gain. This stabilization may be used, for example, when the tube is a suppressor grid pentode with the feedback substantially reducing the amplifier output impedance to match it to the line impedance in the cases where the feedback loop gains for the various settings of the contact are too small to prevent the amplifier output impedance from being materially changed by the changes of loop gain that would result from the changes of contact setting if the tube amplification were constant.

The condenser, in functioning to substantially reduce variation of loop gain, or maintain the loop gain substantially constant throughout the range of adjustment of the contact, can also, as explained hereinafter, reduce the effect of adjustments of the gain control on the form of the gain-frequency characteristic of the amplifier, or in other words, reduce the variation with frequency of the amplifier gain change produced by any change of the contact setting.

The condenser can have such capacity value that its impedance increases materially with frequency decrease at low frequencies, to consequently increase the amount of series-series negative feedback and so compensate for decrease of the series-shunt negative feedback with frequency decrease at low frequencies resulting from decrease of the mutual impedance of the primary winding of the output transformer and the feedback coil with frequency decrease at the low frequencies. This increase of the amount of series-series feedback counteracts decrease of loop gain resulting from the decrease of the series-shunt feedback and thereby tends to prevent decrease in the amount of feedback with decrease of frequency at low frequencies; and the increase of the amount of series-series negative feedback relative to the amount of series-shunt negative feedback tends to increase the amplifier output impedance and thereby compensate for decrease of amplifier output impedance with frequency decrease at low frequencies resulting from decrease of mutual impedance of the primary and secondary windings of the output transformer.

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

The single figure of the drawing shows a repeater system employing amplifiers in accordance with the invention.

The repeater system shown may be, for example, a voice frequency telephone repeater system. It comprises a repeater adapted for either two-wire or four-wire operation at the west side (regardless of whether its connection at the east side is a two-wire connection or a four-wire connection) and adapted for either two-wire or four-wire operation at the east side (regardless of whether its connection at the west side is a two-wire or a four-wire connection).

The repeater comprises a west-east amplifier **1** and an east-west amplifier **1'**.

Amplifier **1** comprises a vacuum tube **2**, an input transformer **3**, and an output transformer **4**. The tube may be, for example, a Western Electric Company type 310A suppressor grid pentode. The input transformer has a primary winding **5** with a variable tap **6**, and has a secondary winding **7** with a variable tap **8**. The tap **8** is connected to the control grid of the tube **2**.

The output transformer has a primary winding **9** connected between the plate of the tube and the positive pole of a 13-volt B-battery **10** whose negative pole may be grounded as shown. In series with the primary winding and the battery **10** are shown a fuse **11** and a 5-ohm protective resistance **12** for limiting the battery current when the fuse blows, so that the arc at the fuse will not destroy adjacent fuses (not shown) which may be associated with similar repeaters. The output transformer has also a feedback winding or coil **13**, a monitoring winding **14**, and a secondary or output winding **15**.

The secondary winding **15** is a divided balanced winding having four sections which are shown connected as the line and network windings of a bridge transformer or so-called hybrid coil. The other winding of the hybrid coil is the primary winding **9**. The upper sections of winding **15** form the line windings of the hybrid coil. They are shown connected through a repeating coil **16** to a two-wire line **17** for two-way or west-east and east-west transmission. The lower sections of winding **15** form the net windings of the hybrid coil. They are shown connected to a balancing network **18** for balancing the impedance of coil **16** and line **17**. Conductors **19** are shown connecting the bridge points of the hybrid coil to the input terminals of the east-west amplifier **1'** through low frequency equalizer **20'**, transmission regulator **21'** and low-pass filter **22'**, corresponding respectively to low frequency equalizer **20**, transmission regulator **21** and low-pass filter **22** shown connected to the input terminals of the west-east repeater **1**.

The equalizer **20** introduces in west-east transmission a loss that, at frequencies below approximately 1,000 cycles per second, increases with frequency decrease in a manner complementary to the decrease of the line attenuation with frequency, thus equalizing or compensating for the variation of the line attenuation with frequency.

The regulator **21** may be for example a pilot wire regulator for compensating for changes in line attenuation of west-east transmission due to temperature changes.

The low-pass filter **22** may have a cut-off frequency of 3,500 cycles, for example, and prevents transmission of frequencies above its cut-off frequency to the input of amplifier **1**, thus reducing the frequency range over which hybrid coil balance is required to insure proper margin against repeater singing.

Elements **20'**, **21'** and **22'** function in connection with amplifier **1'** for east-west transmission in the same manner that elements **20**, **21** and **22**, respectively, function in connection with amplifier **1** for west-east transmission.

Amplifier **1** comprises two 300-ohm resistors **23** shown connected in series across its input terminals to form a 600-ohm terminating resistance for the input of the amplifier. This termination is used when the repeater is to be connected for four-wire operation at its west side, and then tap **6** is connected, as shown, to its upper contact on the primary winding **5** of input transformer **3**. When the repeater is to be connected for two-wire operation at its west side, the tap **6** is connected to its lower contact on winding **5**, and the resistors **23** are disconnected from the amplifier input terminals and two 150-ohm resistors **24** in series are connected across the amplifier input terminals as a 300-ohm terminating resistance for the input of the amplifier. When the 600-ohm termination is used, contact **25** connects the junction of resistors **23** to ground, as shown, through conductor **26**. When the 300-ohm termination is used, the contact **25** is connected to the junction of resistors **24**, instead of to the junction of resistors **23**. The impedance of the transformer **3** is made sufficiently great to adapt it for satisfactory working with either the 600-ohm or the 300-ohm termination. Preferably, when the 600-ohm termination is employed, the regulator **21** and filter **22** are designed to have their input and output impedances 600 ohms; and a 300-ohm regulator and 300-ohm filter are used, instead, when the 300-ohm termination made up of resistors **24** is employed.

The amplifier **1'** for amplifying east-west transmission is structurally and functionally similar to the amplifier **1** for amplifying west-east transmission, and its parts corresponding to those of amplifier **1** are designated by the same reference characters primed.

The west or output side of amplifier **1'** is shown connected for four-wire operation of the west side of the repeater. That is, the bridge points of hybrid coil **4'** are shown disconnected from conductors **27** which are adapted for connecting those points to the input terminals of amplifier **1** through equalizer **20**, regulator **21** and filter **22** when the west side of the repeater is to be connected for two-wire operation; the line windings of the hybrid coil are shown connected through conductors **28** and four-wire terminating set **29** to two-wire line **30** for east-west transmission over the line, the four-wire terminating set being shown as also connecting the line **30** for west-east transmission over the line **30** through conductor **31** to the input terminals of amplifier **1** through equalizer **20**, regulator **21** and filter **22**, for west-east transmission from line **30** through amplifier **1** to line **17**; the network terminals of the hybrid coil are shown disconnected from balancing network **18'**, which is adapted for connection to those terminals to balance the impedance of line **30** when line **30** is to be connected to the line terminals of the hybrid coil through conductors **32** for two-wire operation of the west side of the repeater instead of through four-wire terminating set **29** and conductors **28** for four-wire operation of the west side of the repeater; and a conductor **33'** is shown connecting one of the two sections of the net windings of the hybrid coil in series with the two sections of the line windings of the hybrid coil so that the hybrid coil then operates not as a bridge transformer but as a transformer having a primary winding **9'** and having a secondary winding consisting of two sections of the line windings and one section of the net windings in series aiding connection. The impedance of the transformer as viewed from the four-wire terminating set **29** through conductors **28** is then about 675 ohms or approximately the same value as the impedance (600 ohms) of the hybrid coil viewed from the line **30** through conductors **32** when the hybrid coil is connected as a bridge transformer for two-wire operation of the west side of the repeater.

When the west side of the repeater system is to be connected for four-wire operation of that side of the repeater system, the west side of the repeater is connected for four-wire operation of that side of the repeater by connecting the west side (or input) of amplifier **1** and also the west side (or output) of amplifier **1'** for four-wire operation of the west side of the repeater, as described above, but with line **30** connected through conductors **32** to the line terminals of the hybrid coil **4'** and with line **34** connected to the input of amplifier through equalizer **20**, regulator **21** and filter **22**, and with conductors **27** and **31** and four-wire terminating set **29** all out of circuit i. e., all disconnected from the transmission circuit). Then line **34** serves as one line and line **30** serves as the other line of a four-wire transmission system, line **34** for west-east transmission to amplifier **1** and line **30** for east-west transmission from amplifier **1'**.

The four-wire terminating set **29** may be of any suitable type, as for example, of the type disclosed in the copending application of N. Botsford, Serial No. 239,005, filed November 5, 1938, now Patent No. 2,207,531, July 9, 1940, for Four-wire signaling circuits.

Phantom taps **35** and **36** on repeating coil **16** and four-wire terminating set **29**, respectively, may be provided where the repeater is to serve as a side circuit repeater of a phantom group of repeaters.

If desired, a four-wire terminating set similar to the set **29** shown connecting the west side of the repeater for two-way transmission over two-wire line **30** can similarly be provided for connecting the east side of the repeater for two-way transmission over line **17**. Then, in place of repeater coil **16** connecting line **17** to the line windings of hybrid coil **4**, the four-wire terminating set so provided would connect line **17** to those windings (as set **29** is shown connecting line **30** to the line windings of hybrid coil **4'**); conductors **19** (instead of connecting equalizer **20'** to the bridge points of hybrid coil **4**) would connect the equalizer **20'** to the four-wire terminating set as conductors **31** are shown connecting equalizer **20** to the four-wire terminating set **29**; conductor **33** would connect one of the bridge points of hybrid coil **4** to one of the net terminals of the coil, as conductor **33'** is shown connecting the corresponding terminals of hybrid coil **4'**; network **18** would be disconnected from the net terminals of hybrid coil **4**, as network **18'** is shown disconnected from the net terminals of hybrid coil **4'**; resistances **23'** would be connected in circuit, as resistances **23** are shown connected; resistances **24'** would be disconnected from circuit; contact **25'** would be connected to the junction of resistances **23'**; and contact **6'** would be connected to the lower end of winding **5'**.

If desired, a line corresponding to line **34** can be provided at the east side of the repeater to serve for one-way (east-west) transmission, as line **34** shown at the west side of the repeater has been described as serving for one-way (west-east) transmission, and the line so provided and line **17** can be connected to the east side of the repeater as the two one-way lines of a four-wire line, in the manner in which lines **34** and **30** have been described as connected to the west side of the repeater to form the two one-way lines of a four-wire line. Then the line terminals of hybrid coil **4** may be connected to line **17** directly (repeating coil **16** being omitted from circuit); conductors **19** connect to the other two-wire line of the four-wire line instead of, as shown, to the bridge points of hybrid coil **4**; network **18** is disconnected from the hybrid coil **4** as network **18'** is shown disconnected from hybrid coil **4'**, and conductor **33** connects one of the bridge points of the hybrid coil **4** to one of the net terminals of the coil as conductor **33'** is shown connecting the corresponding terminals of hybrid coil **4'**; resistances **23'** are connected in circuit and resistances **24'** disconnected from circuit; contact **25'** is connected to the junction of resistances **23'**; and contact **6'** is connected to the lower end of winding **5'**.

While the repeater can be arranged for either two-wire or four-wire operation at either side, it is contemplated that in most cases the equipment arrangement will be such that the repeater will be connected as a four-wire repeater and the equalizers, regulators, filters, balancing networks, etc., will not be associated directly with the repeater but will be associated with the two-wire line equipment and placed in any arrangement in the office that is most economical from an installation and maintenance standpoint. The repeaters can be used as four-wire units on the terminal side where four-wire patching is used. At points where the repeater must connect to a two-wire circuit, four-wire terminating sets such as **29** may be used if desired, and by their use considerable saving in maintenance may be effected because of the flexibility they give in office layout.

The repeater, itself, consists of two amplifiers **1** and **1'** whose input and output impedances are approximately 600 ohms, and the amplifiers have taps on the primary windings of the input transformers and the secondary windings of the output transformers so that by suitable changes of connections and the addition of balancing networks the amplifiers may be connected as described above to form a two-wire repeater system whose input and output impedances are approximately 600 ohms. Each amplifier may have, for example, approximately flat gain over a frequency range from 135 to 3400 cycles, with a maximum gain of 34 decibels in a four-wire connection and 28 decibels in a two-wire connection, and with the gain variable over a range of 25 decibels from maximum gain.

Referring to amplifier 1, for instance, 20 decibels of this range may be obtained by tap 8 adjustable on the secondary winding of the input transformer to provide, for example, four gain steps of 5 decibels each; and a smooth or continuous adjustment over a range of approximately 5 decibels may be obtained by adjustment of a contact 41 on a section 42 of a gain control resistor 43 in a negative feedback circuit for the amplifier, this adjustment varying the loop gain or amount of feedback over the range between its maximum and minimum values, which may be, for example, approximately 9 decibels and 6 decibels.

Series-series negative feedback is obtained by a feedback resistor 51 and stopping condenser 52, which are in series with the secondary winding 7 of the input transformer and also in series with the primary winding 9 of the output transformer; and series-shunt negative feedback is obtained by the feedback coil 13, which is in series with the winding 7 and is inductively related to the winding 9 on the output transformer. The feedback resistor 51, stopping condenser 52 and feedback coil 13 are connected in series between the cathode of tube 2 and the negative pole of the space current source 10 which is shown grounded, conductor 53 connecting coil 13 to ground. The gain control resistor 43 is connected across the feedback resistor 51, stopping condenser 52 and feedback coil 13.

The path of the alternating plate current of the tube 2 extends from the cathode through the branched circuit comprising resistor 43 in parallel with series connected resistor 51, condenser 52 and coil 13; thence through conductor 53 to ground; and thence through space current supply source 10, conductor 54 and winding 9 to the plate. In a simple view of the feedback action in the amplifier, resistance 51 can be considered the impedance element that produces, or in other words is primarily responsible for, the series-series feedback of alternating voltage, this element 51 acting as a source of voltage that is in series with (coil 13 and) the secondary winding 7 of the input transformer with respect to the grid-cathode path in tube 2 and that has the magnitude of its voltage (the voltage across 51) dependent on or proportional to the load current flowing from the cathode through 51, 52, coil 13, conductor 53, ground, battery 10, and winding 9. Coil 13 can be viewed as the element that produces the series-shunt feedback, this coil acting as a source of voltage that is in series with (resistance 51 and) the secondary winding 7 of the input transformer with respect to the grid-cathode path in tube 2 and that has the magnitude of its voltage (the voltage across coil 13 due to induction from winding 9) dependent on or proportional to the load voltage or voltage across 9. Resistance 51 and coil 9 then act as two generators of feedback voltage components in series with each other and the secondary winding 7 of the input transformer with respect to the grid-cathode path in tube 2. Resistance 43, constituted by resistances 42, 57 and 58 in series, is an adjustable shunt across the two feedback voltage sources 51 and 13 in series. Adjustment of this shunt 43 varies the attenuation that this shunt produces in the voltage applied from these sources (through the secondary winding 7 of the input transformer) across the grid-cathode path in tube 2. In other words, adjustment of shunt 43 adjusts the amount of loss in the feedback path.

Unidirectional plate current for the tube flows from the source 10 through conductor 54, winding 9, the plate-cathode space path in the tube, resistor 43, and conductor 53 to ground.

Unidirectional screen grid current for the tube flows from the source 10 through conductor 54, resistor 55 which may have, for example, a value of 5,000 ohms, the screen grid-cathode space path in the tube, resistor 43, and conductor 53 to ground. Condenser 56 is a by-pass condenser of, for example, 2 microfarad capacity connected from the screen grid to ground.

The alternating current and direct current voltages across the resistor 43 are fed back to the control grid through the secondary winding 7 of the input transformer, and the amount of loss in the feedback path and the value of the amplifier gain can be adjusted by adjustment of contact 41 to adjust the amount of resistance 43 included in circuit. When the amount of the resistance included is maximum the loss in the feedback path is minimum, the negative grid bias is maximum, the transconductance of the tube is minimum, and the amplifier gain is minimum. The minimum amount of the resistance 43 to be employed is the amount of the resistance 43 in circuit when all of section 42 has been cut out of circuit by contact 41. Sections 57 and 58 of resistor 43 are always in circuit. By way of example, the value of resistance 42, with contact 41 at the extreme left-hand position, may be 2,000 ohms, with the resistor 57 of 400 ohms, the resistor 58 of 100 ohms, the resistor 51 of 1,000 ohms, and the capacity 52 of 1 microfarad value.

Current for heating the filament of tube 2, in series with the filament of tube 1, may be supplied from a source shown as battery 59. A filament jack 60 is shown, into which may be plugged a meter for measuring the filament current. A conductor 61 connects the junction of resistors 57 and 58 to spring 62 of a jack 63 into which may be plugged a direct current meter to measure the direct current voltage drop across resistor 58, for ascertaining the unidirectional space current (plate and screen grid current) of tube 2. This may be desirable, for instance, for testing the filament activity by noting the change in space current for a prescribed change in filament current.

As indicated above, condenser 52, by blocking unidirectional current in the condenser path and allowing it to flow through the gain control resistor 43, reduces variation of loop gain of amplifier 1 with change of adjustment of contact 41; and this can reduce variation with frequency of the amplifier gain change produced by change of the contact setting. This reduction in the frequency variation of the amplifier gain change with change of contact setting results from the reduction of variation of the loop gain with change of contact setting, because the effect of feedback on the transmission through the amplifier is inversely proportional to $(1+X)$ where X is the loop propagation in the feedback path expressed vectorily. If X is small so that it is comparable to 1, then any change in X in either phase or magnitude or both will result in a change in $(1+X)$ and hence a change in the over-all transmission of the amplifier. When variations in X, due to any change in the gain control resistor, are kept small, variations in $(1+X)$ will be small, and hence changes in the over-all transmission of the amplifier will be small. The over-all amplification of the amplifier is expressed by

$$\frac{A}{1+X}$$

where A is the amplification before feedback or the amplification when $X=0$. Then gain adjustments due to the gain control resistor, when variations in X are small, are achieved by causing A to vary with adjustments of this control resistor. In a circuit of this type A is proportional to the transconductance of the tube. Variations in transconductance have little effect on the frequency characteristic of the amplifier.

What is claimed is:

1. An electric space discharge device having an anode, a cathode, a grid and input and output circuits, a wave source for association with said input circuit, an output transformer having primary and secondary windings for association with said output circuit to receive waves from said output circuit, means producing negative feedback in said device, said means comprising a feedback coil inductively related to said primary winding and a feedback impedance serially related to said input circuit and said feedback coil with respect to said wave source and serially related to said feedback coil and said primary winding with respect to said output circuit, a space current supply source for supplying space current for said amplifier, a path between said cathode and the negative pole of said space current supply source, including said feedback impedance and said feedback coil serially connected therein, and means connecting the terminal of said wave source electrically farthest from said grid to that end of said path electrically nearest said pole.

2. An electron amplifier with a space current path, a space current source for supplying space current to said path and input and output transformers, each having a primary winding and a secondary winding, and means for producing negative feedback in said amplifier comprising a feedback impedance, a feedback coil inductively related to said primary winding of said output transformer, means connecting said impedance in serial relation to said secondary winding of said input transformer and also in serial relation to said coil and said primary winding of said output transformer, a resistance, a contact movable on said resistance, and means for causing said contact to carry unidirectional space current of said amplifier comprising conductors connecting said contact and a variable portion of said resistance across said impedance and said feedback coil and in serial relation with said space current supply source and said space current path.

3. A vacuum tube amplifier comprising an anode, a cathode, a grid, a grid circuit, an anode circuit, a transformer having a winding in said anode circuit, a space current supply source, and a feedback circuit connected between said cathode and the negative pole of said source and common to said grid and anode circuits, said feedback circuit having two parallel branches, one of said branches comprising in series a resistance for producing negative feedback in said amplifier, a condenser and a coil inductively related to said winding for producing negative feedback in said amplifier, and the second of said branches comprising a resistance and a contact for carrying unidirectional space current of said amplifier movable on the latter resistance to vary the value of that resistance.

4. An amplifier comprising a forward amplifying path and a feedback path connected around said forward path for producing negative feedback in said amplifier, an electric space discharge device in said forward path having a discharge control grid, a resistance in said feedback path, means for changing the value of said resistance sufficiently to produce substantial change in the transmission efficiency of said feedback path and the gain of said amplifier, and means responsive to said change of said resistance for changing the unidirectional biasing voltage on said grid in such amount and sense that the transmission efficiency of said forward path is so varied as to substantially compensate for the loop gain change produced by said change in the transmission efficiency of said feedback path and thus maintain the loop gain substantially constant notwithstanding said change of transmission efficiency of said feedback path.

5. An amplifier comprising an electric space discharge device having an anode, a cathode and a grid, a grid circuit, an anode circuit, a space current supply source, and an impedance connected between said cathode and the negative pole of said source and common to said grid and anode circuits for producing negative feedback of alternating current in said amplifier and unidirectional biasing voltage for said grid, said impedance comprising, in series with each other with respect to said space current supply source, a resistance and a contact for carrying unidirectional space current of said amplifier movable on said resistance to vary said resistance between such values that the amount of the negative feedback and at the same time said unidirectional biasing voltage and consequently the transconductance of said device change between such values that substantial change is produced in the amplifier gain yet the gain around the feedback loop is maintained substantially constant.

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