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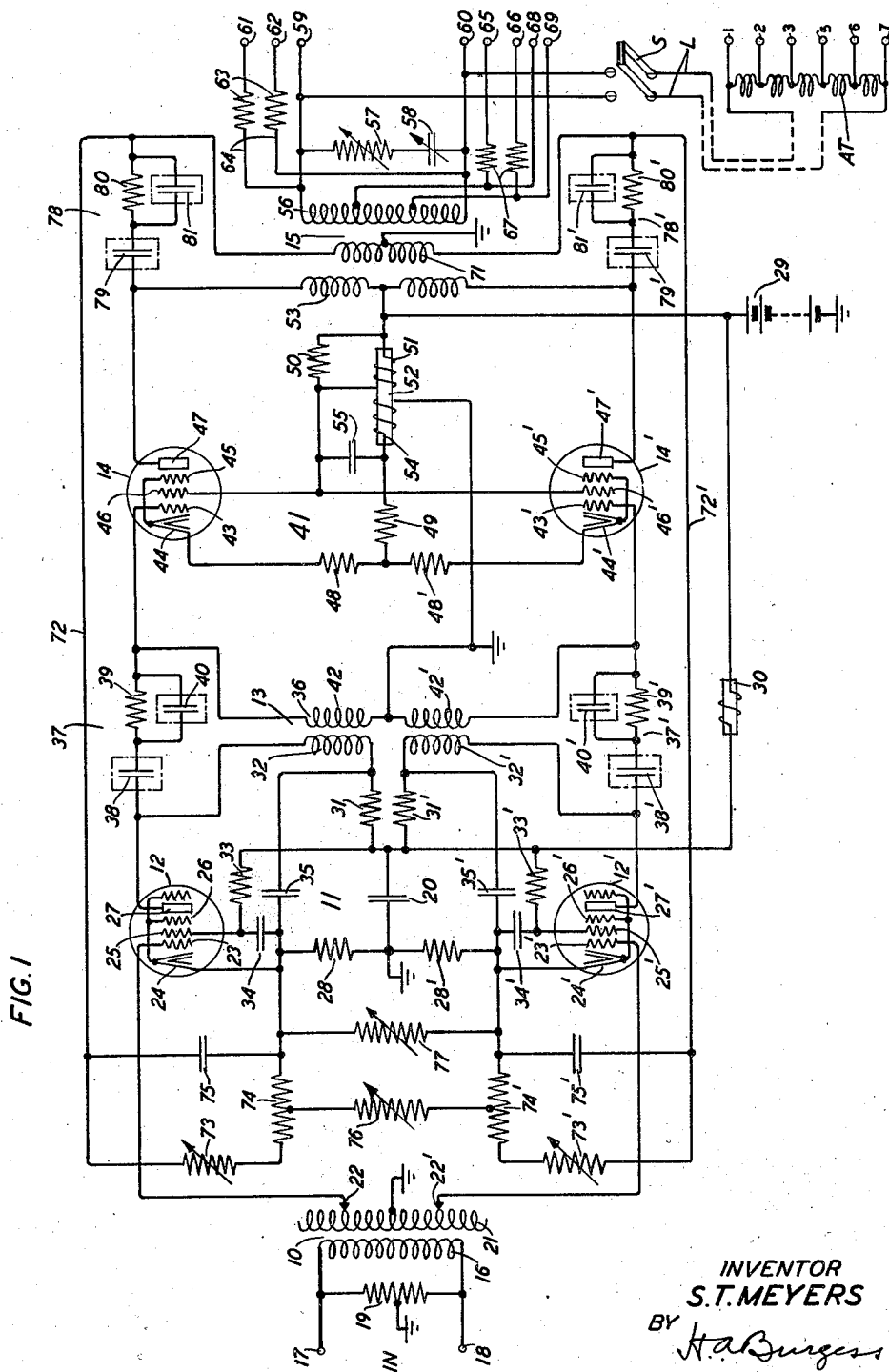
S. T. MEYERS

2,230,256

WAVE AMPLIFYING SYSTEM

Filed June 30, 1938

2 Sheets-Sheet 1



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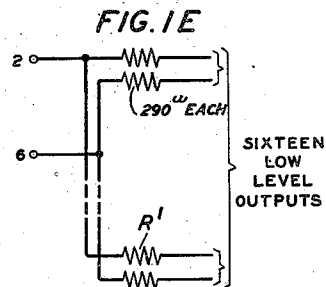
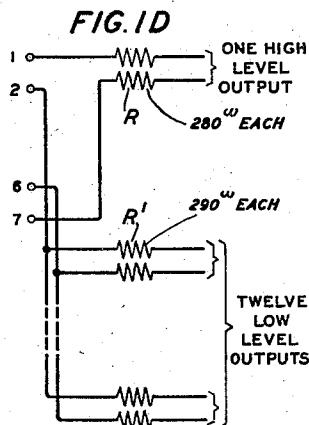
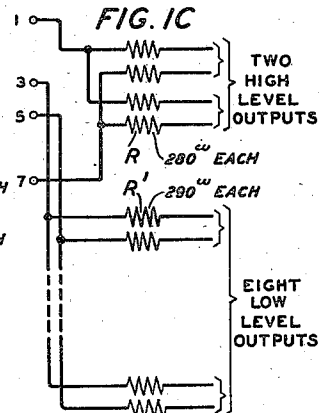
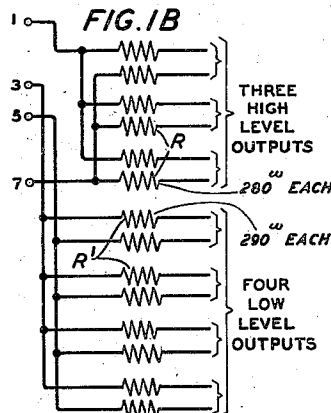
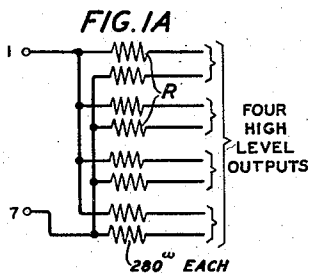
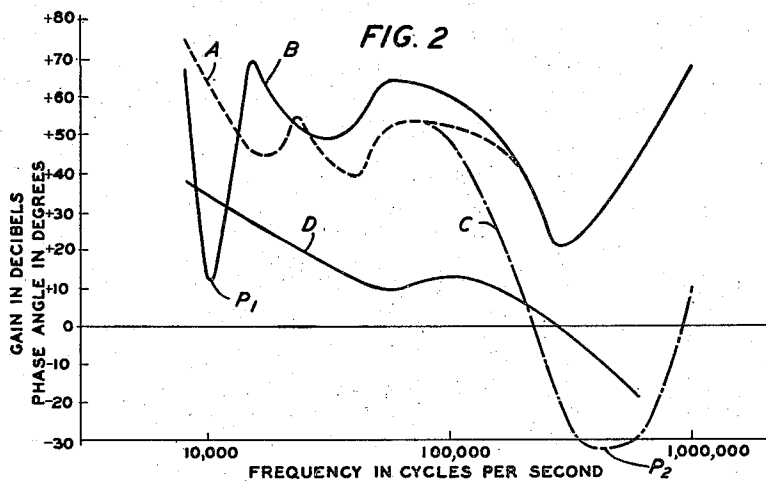
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WAVE AMPLIFYING SYSTEM

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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,230,256

WAVE AMPLIFYING SYSTEM

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Application June 30, 1938, Serial No. 216,679

6 Claims. (Cl. 179—171)

This invention relates to wave amplifying systems, such as, for example, vacuum tube amplifiers.

Objects of the invention are to control transmission properties of the systems, such as, for example, distortion and gain introduced by the systems; to facilitate application of feedback in the systems and to provide adequate margin against singing or tendency to oscillation; to facilitate application of proper biasing and feedback potentials to grids of vacuum tubes in the systems; and, by use of the systems, to enable the distribution of program signals from a single or originating transmission line to one or simultaneously to more than one outgoing program transmission line.

This invention meets the need for a relatively simple circuit, inexpensive, high power wave amplifying system or amplifier for connecting an originating program transmission line with one or more program transmission lines through a multiple outlet, that is, an amplifier for use in a program distribution system.

A feature of the invention is a gain-reducing feedback gain control connection to the cathode end of biasing resistors of vacuum tubes connected in push-pull arrangement, there being a gain-adjusting variable resistors or resistors shunted across the biasing resistors and connected across the feedback connections.

Another feature comprises a gain control for an amplifier that involves adjustability in input to the initial stage of the amplifier, adjustability in a negative feedback connection from the output to the input of the amplifier, and adjustability in degenerative feedback to resistances in a circuit common to the input and output circuits of the initial stage of the amplifier.

Still another feature comprises a network for suppressing singing tendency in a push-pull amplifier, that comprises a condenser in series with a parallel connected resistance and condenser, to be connected across the windings of an interstage transformer, or across a winding and a feedback winding of a circuit coupling transformer.

A further feature comprises a feedback circuit for a push-pull amplifier employing suppressor grid pentodes that includes a retard coil in the cathode-anode circuit, the coil having a plurality of windings one of which is connected to a screen grid and another of which is inductively coupled to the first and connected in the cathode-anode and control grid-cathode circuits.

Another feature comprises arranging the out-

put circuit of the output transformer of an amplifier so that connection may be made to a plurality of lines and the same impedance will be presented to each line.

In accordance with the invention there is provided a two-stage push-pull amplifier employing suppressor grid pentodes, including an overall feedback connection for controlling the gain of the amplifier and correcting for distortion, increasing stability and reducing noise; a feedback connection local to the second stage of the amplifier to provide margin against singing in the parallel path of the power push-pull stage; networks coupled between the windings of the interstage transformer and between the primary and the overall feedback winding of the output transformer for preserving ample singing margin in the series (particularly) and the parallel paths of each push-pull stage; an input circuit including a transformer with tapped secondary for gain control in large steps; and an output circuit including an output transformer having a line winding that may be connected to one or simultaneously to more than one outgoing line: open wire, cable, or a combination of both.

Such an amplifier may be inserted in a program transmission line to supply power to one or simultaneously to more than one outgoing program line. These outgoing lines may be open wire or cable transmission lines or a combination of both; it will pass a band 30-8000 cycles per second wide with a substantially flat gain-frequency characteristic between these limits; and may be used as a line amplifier by simple change in resistance and capacity in the overall feedback connection. A program distribution system in which the amplifier of this invention might be used is described and claimed in A. E. Bachelet U. S. Patent 2,198,326, issued April 23, 1940.

A more complete understanding of the invention may be obtained from the detailed description that follows hereinafter, read with reference to the appended drawings.

Fig. 1 shows a wave amplifying system embodying features of this invention;

Figs. 1A to 1E show five arrangements of output circuits for the system of Fig. 1; and

Fig. 2 shows curves facilitating explanation of the invention.

Specific description

The wave amplifying system of Fig. 1 is a two-stage amplifier that comprises an input transformer 10, an initial or first stage 11 of a pair of

suppressor grid pentodes 12, 12', connected in push-pull, an interstage coupling transformer 13, a second or output stage 41 of suppressor grid power pentodes, 14, 14', and an output transformer 15.

The input transformer comprises a primary winding 16 connected to input terminals 17, 18, the winding having a center-tapped resistance 19 connected thereacross to ensure proper input impedance. The transformer has a secondary winding 21 having a plurality of taps thereon, the center tap being connected to ground. Adjustable contacts 22 and 22' connect the secondary winding and the control grids of the amplifying tubes 12, 12'. A transmission line (not shown) on which a program to be amplified and distributed has been impressed would be connected to the input terminals of the amplifier.

Tube 12 comprises a control grid 23, a cathode 24 which, as indicated, may be of the indirectly heated type, a screen grid 25, a suppressor grid 26, and a plate or anode 27. Tube 12' has corresponding elements 23', 24', 25', 26', 27'. The resistors 28, 28' connected to ground and in the common branch or leg of the control grid-cathode and cathode-anode circuits provide an initial space current biasing potential on the control grids 23, 23'. Space current is derived from positive terminal of battery 29, having its negative terminal connected to ground, through retard coil 30, resistances 31, 31', and the coils 32, 32' of the primary winding of the interstage transformer. Retard coil 30 together with condenser 20 constitutes the usual battery filter. The suppressor grids are connected to the cathodes, and the screen grids are connected through resistances 33, 33', separating the plate and the screen grid, and retard coil 30 is connected to positive terminal of battery 29. Condensers 34, 34' connecting the screen grids to the cathodes, and condensers 35, 35' are audio frequency by-pass condensers.

The interstage transformer has a two-coil secondary winding 36, the center tap of which is connected to ground. Connected across each pair of outer ends of the interstage transformer windings are networks 37, 37' comprising a condenser 38, 38', in series with parallel connected resistance 39, 39' and condenser 40, 40', each condenser being insulated from ground. These networks tend to dampen resonances due to leakage between the transformer windings and distributed capacities across the windings that might cause undesired excessive gain and phase peaks. The outer ends of the coils 42 and 42' are connected to the control grid of the tubes 14, 14'.

Tube 14 comprises a control grid 43, a cathode 44, which, as indicated, may be of the indirectly heated type, a suppressor grid 45, a screen grid 46 and a plate or anode 47. Tube 14' has corresponding elements 43', 44', 45', 46', 47'. The unby-passed resistors 48, 48' connected in the common control grid-cathode and cathode-anode circuits of the tubes 14, 14' provide, together with resistance 49, an initial space current biasing potential on the control grids 43, 43'. The suppressor grids are connected to the cathodes, and the screen grids are connected together and, through the parallel combination of resistance 50 and winding or coil 51 of a retard coil 52, to the mid-point of the primary winding 53 of output transformer 15, and also to the positive side of battery 29. The other winding 54 of the retard coil 52 is coupled to the winding

51 and is connected in series with resistance 49 to ground. A condenser 55 serves as a by-pass between the windings 51 and 54 of the retard coil at high frequencies where the leakage impedance between the windings becomes excessive. A local feedback circuit is provided through the resistors 48, 48', and 49, and winding 54 coupled to winding 51 terminated in resistance 50. Windings 54 and 51 may have the same number of turns and the magnitude of resistance 50 may be 1000 ohms, for example.

The output transformer 15 comprises an output or line winding 56. A variable resistance 57 and a variable condenser 58 connected in series are shunted across this winding and permit adjustment of the gain-frequency characteristic of the amplifier at the upper frequency end so that it is substantially flat up to 8000 cycles per second. This network also may enable obtaining additional phase margin against any tendency for the amplifier to sing.

Terminals 59, 60 are adapted to be connected to a bridging multiple to supply amplifier-output to a plurality of open wire lines, or a plurality of cable pairs, or combinations of both, for example as indicated in Figs. 1A to 1E referred to hereinafter. Terminals 61, 62 are for use where a single line output (open wire or cable) is required, resistances 63 (each of which may have a value of 280 ohms, for example) being connected in series with the conductors 64 for proper impedance matching at the terminals 61 and 62. The impedance viewed in each direction from terminals 61 and 62 may be approximately 600 ohms, for example. Terminals 65, 66 are provided for monitoring purposes, resistances 67 (each of which may be 300 ohms, for example) providing the proper impedance matching at the terminals 65 and 66. The impedance of the amplifier presented to terminals 65 and 66 may be approximately 600 ohms, for example. The impedance of the amplifier viewed from terminals 59 and 60 toward transformer 15 may be approximately 40 ohms, for example. The conductors connected to terminals 68, 69 provide a very low impedance circuit, and might be used for monitoring purposes.

The output transformer has a third and feedback winding 71, the mid-point of which is connected to ground, and the ends of which are connected through conductors 72, 72' in series with variable feedback resistances 73, 73' and through the series feedback resistances 74, 74' to the cathode end of the cathode resistors 28, 28'. Condensers 75, 75' assist in reducing phase shift over a wide band. A variable resistance 76 is connected in shunt to the cathode resistors of the first stage between the mid-points of the resistances 74, 74' and a second variable resistance 77 is also connected in shunt to the cathode resistors and between the feedback connections. The purpose of these resistances will be brought out more fully hereinafter. By selection of appropriate values for resistances 73 and 73' and condensers 75 and 75', the amplifier may readily be converted from a bridging amplifier for working into multiple outlets to a line amplifier for working into a single outlet.

Networks 78, 78', similar to networks 37, 37' and provided for a similar purpose, are connected between each pair of the ends of the primary and the feedback winding of the output transformer. These networks comprise condensers 79, 79' in series with the parallel connected resistances 80, 80' and condenser 81, 81'.

By deriving the overall feedback voltage from a feedback winding on the output transformer separate from winding 53 connected to the power supply battery and separate from the line winding 56, deleterious effects of battery noise are reduced without necessitating conductive connection between the feedback path and the line winding.

In the amplifier described the gain of the amplifier may be controlled in several ways. The tapped arrangement of the input transformer secondary permits gain control in large steps. In an amplifier constructed in accordance with this invention, these were 10 decibel steps. The overall feedback connection from the feedback winding of the output transformer to the cathode ends of the biasing resistors 23, 28' enables degenerative feedback that results in a reduction of the overall gain of the amplifier but that gives great improvement in quality, stability and reduction in noise and distortion. The variable shunt resistances 76 and 77 permit gain control in smaller steps. In an amplifier constructed in accordance with the invention, resistance 76 was proportioned to enable gain changes in .25 decibel steps, and resistance 77, changes in 1 decibel steps.

The amplifier as shown in Fig. 1 has a low impedance high level outlet between terminals 59 and 60 which may be connected by means of switch S, conductors L and autotransformer AT to output multiple combinations as shown in Figs. 1A to 1E. The amplifier as shown is arranged to deliver program to four 600 ohm outlets at +8 decibels above reference volume or sixteen 600 ohm outlets at +2 decibels above reference volume or combinations of 600 ohm outlets at both levels. The impedance of the amplifier output at terminals 59 and 60 being low impedance, sufficient building-out resistance is added in series with it, as indicated at R and R' in Figs. 1A to 1E, to make the output impedance facing each line the proper value for good termination to the line, in this case 600 ohms. At the same time sufficient loss is thus built up between the lines to prevent disturbances on one line from unduly interfering with the transmission of the others. In order to obtain the +2 decibel connection the autotransformer has been used to step the signal voltage down the necessary amount from the whole output winding of the amplifier at terminals 59 and 60. This ordinarily is preferable to using taps on the line winding of the output transformer 15. If low level taps are placed on the line winding of the output transformer the direct current resistance of the winding makes it difficult to add various low level group combinations without changing the loss to these groups due to the bridging of the group impedance across the direct current resistance. Various taps for each group combination may be added to compensate for this bridging effect. But this is expensive and makes the output transformer construction unduly complicated and even impairs its transmission properties (both to the output and to the feedback path). Holding the transmission to the low level outlets constant with various outlet combinations ordinarily is desirable for the proper operation of the amplifier in transmission systems.

With the use of the autotransformer a step down for the low level outlets may be obtained with low direct current resistance in the windings. One property of the autotransformer is the

partial cancellation of the primary and secondary currents in the common portion of the winding, i. e., in this case the low level outlet, which tends to cancel the effect of the direct current resistance in this portion and reduce its effective value. However, there is still a little direct current resistance left and, as shown in Figs. 1A to 1E, an extra set of taps has been added such that when one or two groups of four low level outlets are used, the inner taps (3 and 5) are used and when three or four groups are used, the outer taps (2 and 6) are used. These outer taps include enough extra voltage to compensate for the added bridging of the three and four groups across the residual direct current resistance.

The use of the autotransformer has another advantage in that it need only be associated with the bridging multiple. This is advantageous especially when the multiple is located a substantial distance from the amplifier, as indicated by the broken lines representing conductors L in Fig. 1. Only the two leads L are necessary to connect the amplifier with any outlet combination. If taps were placed on the line winding of the output transformer an extra pair of wires would have to be run over to the multiple for the low level outlets. These leads would have to be very low resistance otherwise an additional resistance component would have to be compensated by the taps of the output transformer. This is an additional complication which would add to the expense of such arrangement.

Regarding the functioning of networks 37 and 37', if these networks be omitted series resonance occurs, at a frequency near or above the upper edge of the signal frequency band of the amplifier, between the leakage inductance of transformer 13 and the capacities effectively on either side of the leakage inductance and distributed across the primary and secondary windings of the transformer. The capacity across the primary includes the effective output capacity of tubes 12 and 12' as well as the distributed capacity of the primary winding, and the capacity across the secondary includes the effective input capacity of tubes 14 and 14' as well as the distributed capacity of the secondary winding. This resonance, if it is not allowed to produce excessive phase shift through the transformer, is of value in maintaining the amplifier gain without feedback high in the neighborhood of the resonance frequency, for example in the neighborhood of 10 kilocycles. However, with the resonance undamped, a high peak gain is produced by the resonance, with an attendant phase shift through the transformer which might become excessive in the neighborhood of the resonance frequency and cause the loop phase shift (that is, the phase shift around the main feedback loop) at this frequency unduly to increase its departure from 180 degrees or in other words, decrease its departure from zero phase angle. The networks 37 and 37' lessen this decrease from zero phase angle and reduce the peak gain due to resonance by damping the resonance (and at the same time lower the resonance frequency somewhat), reducing the singing tendency of the feedback amplifier. In this connection it may be pointed out that, as explained for example in H. S. Black Patent 2,102,671, December 21, 1937, ordinarily it is desirable, for insuring against danger of singing in feedback amplifiers, that the phase shift around the feedback loop be not allowed to pass through (or approach too closely) the zero value, at any

frequency at which the gain around the feedback loop equals or exceeds zero decibels.

The network 37 with half of the leakage inductance of the transformer may be considered in the nature of a resistance terminated high-pass filter with its input terminals connected to the plate of tube 12 and the grid of tube 14. This filter comprises this half of the leakage inductance as the shunt arm, the capacity 38 as the series arm, and the resistance 39 as the terminating resistance. The capacity 40 is so small as to have negligible effect on the terminating impedance or the input impedance below or in the neighborhood of the cut-off frequency, which may be at or somewhat above the upper edge or limit of the signal frequency band. The input impedance of the filter is highly inductive for frequencies up to the cut-off frequency, and then rapidly becomes resistive. The network 37 with the other half of the leakage inductance may be considered a similar high-pass filter. At a frequency somewhat below the cut-off frequency of these high-pass filters the input impedances of the filters react with the network formed by the capacities effectively across the primary and secondary windings of the transformer in the fashion indicated above for the leakage inductance in the absence of networks 37 and 37', and maintain the amplifier gain without feedback high in the upper portion of the operating frequency range of the amplifier. This reaction is held to such an amount as will maintain the amplifier gain without feedback in this region as high as possible without causing the loop phase shift to approach too close to zero. From this region on up in frequency the input impedances of the filters formed by the capacities 38 and 38', resistances 39 and 39' and leakage inductance of the transformer, rapidly become resistive. This increases the circuit damping and reduces the gain without feedback, at the same time preventing the phase shift through the transformer from becoming excessive and causing the loop phase shift to assume values menacing the singing margin of the amplifier. If the condensers 38 and 38' were short-circuited, the damping effect of the resistance would become effective at lower frequencies, and reduce the effectiveness of the reaction of the network with the distributed capacity of the primary and secondary windings of the transformer in holding up the amplifier gain without feedback in the upper portion of the operating frequency range of the amplifier. Thus the capacities 38 and 38' prevent the resistances 39 and 39' from effectively damping the building up of the amplifier gain at frequencies below the resonance frequency, but permit such damping at and above the resonance frequency.

At high frequencies, for example above 100 kilocycles, the leakage of the transformer is so large that the networks 37 and 37' substantially constitute the coupling between the distributed capacity of the primary winding of the transformer and the distributed capacity of the secondary winding. At such frequencies, in the absence of condensers 40 and 40', the plate resistance in tubes 12 and 12' with the first of these distributed capacities would tend to introduce in the loop phase shift a component approaching 90 degrees as the frequency increases, and the resistances 39 and 39' with the second of these distributed capacities would tend to introduce in the loop phase shift a component approaching 90 degrees as the frequency increases. Thus,

these two distributed capacities would tend to introduce 180 degrees phase shift, which would be objectionable as unduly increasing singing tendency of the amplifier. The capacities 40 and 40' are made sufficiently large to prevent the resistances 39 and 39' from effectively separating the distributed capacities of the primary and secondary windings, and thus reduce the component of loop phase shift introduced by these two distributed capacities at these high frequencies, (90 degrees being the maximum possible phase shift contributed by the plate resistance in tubes 12 and 12' working into these two distributed capacities connected substantially in parallel through condensers 40 and 38 and 40' and 38'). However, if capacities 40 and 40' are made too large they will not allow resistances 39 and 39' to produce sufficient damping of the series resonance referred to above as occurring near the upper limit of the operating frequency range of the amplifier.

Networks 78 and 78' are structurally and functionally similar to networks 37 and 37', the feedback winding of transformer 15 being considered the secondary winding corresponding to the secondary winding of transformer 13 as regards transmission around the main feedback loop.

By way of example, for a particular amplifier as shown in Fig. 1, the resistance 39 was 20,000 ohms, resistance 80 was 2000 ohms, condenser 38 was .00025 microfarad, condenser 40 was .00005 microfarad, condenser 79 was .002 microfarad, and condenser 81 was .0005 microfarad, elements 38', 39', 49', 79', 80' and 81' having the same values as elements 38, 39, 40, 79, 80 and 81, respectively.

Fig. 2 may be referred to as indicating the operation of networks 37 and 37' and of networks 78 and 78'. Curve A is the frequency characteristic of the phase shift around the main feedback loop with the circuit in the normal condition, that is, the condition in which it is shown in Fig. 1; and curve D is the frequency characteristic of the gain around the loop in that condition of the circuit. When resistances 39 and 39' and condensers 40 and 40' were short-circuited, the phase shift characteristic changed, becoming curve B; but the gain characteristic remained substantially unchanged, except that it became elevated some 2 or 3 decibels in the region of 10 or 12 kilocycles. When the short circuits just mentioned were removed and condensers 40, 40' and 81 and 81' were removed, the gain characteristic remained substantially curve D; but the phase characteristic, though remaining substantially as shown in curve A up to about 80 or 100 kilocycles, at higher frequencies became curve C.

Thus, with the networks 37, 37', 78 and 78', peaks of phase shift at two points in the frequency spectrum, that is, the downward peaks P₁ and P₂, have been successfully eliminated. These peaks if allowed to exist would be detrimental to successful operation of the amplifier, the peak P₂ causing the amplifier to sing (at a frequency of zero phase shift in the neighborhood of 220,000 cycles per second) and the peak P₁ reducing the phase margin against singing (at the frequency of peak P₁ in the neighborhood of 10,000 cycles per second) to a value of about 12 degrees, a value so low as to be unsatisfactory in view of manufacturing variations in the amplifiers. If the networks 37, 37', 78 and 78' were omitted, the gain characteristic would be substantially unchanged from curve D. However, 75

the phase characteristic would have a downward peak corresponding to peak P_1 of curve B, in the neighborhood of 10 or 12 kilocycles but extending to lower values of phase shift than peak P_1 since the resonance damping effect of resistances 80 and 80' as well as of resistances 39 and 39', would be absent; and the phase characteristic would also have a downward peak similar to peak P_2 of curve C, extending to large values of negative phase shift as in the case of peak P_2 and menacing or eliminating the phase margin of the amplifier against singing at a frequency of loop gain in the neighborhood of 200 kilocycles as in the case of peak P_2 .

To summarize briefly, the amplifier described hereinabove consists of two stages of pentode tubes in push-pull connection with feedback. The first stage is equipped with voltage pentodes transformer coupled to the second stage. The second and output stage consists of power pentodes coupled to the output circuit and the main feedback path through an output transformer. The output transformer has three windings, plate, line and feedback. The feedback winding is connected to the main feedback path comprising series resistances terminating in the cathode resistances of the first stage. The gain control comprises simple adjustable resistance shunts across the cathode resistances and across (from side to side) the feedback path at the center of the series feedback resistances. Stability against singing is helped by the resistance-condenser networks between the primary and secondary windings of the interstage transformer and between the plate and feedback windings of the output transformer. These networks tend to dampen any resonance that may take place between these windings (due to leakage and distributed capacity), the networks thus preventing such resonance from producing excessive gain and phase peaks. The condensers bridged across the series feedback resistances also reduce the phase shift over a wide band. The resistance and condenser combination across the line terminals of the output coil is intended for controlling the shape of the gain-frequency characteristic of the amplifier, as for example, for raising the gain in the upper portion of the operating frequency range to make the gain-frequency characteristic flat over the operating range; but at the same time, with the proper proportioning of the two elements additional phase margin against singing may be obtained especially when all load circuits are removed from the line winding.

Additional factors in connection with the amplifier will now be considered. Additional precaution against singing must be taken in the common path of the push-pull stages. A push-pull amplifier may be considered as having two gain paths which are conjugate, or nearly so, to each other.

The first path is the main or transmission path, the series path, (that is, the currents flow from side to side through the tubes of a given stage in series). This path transmits signals from the input to the output. Feedback is applied to modify the amplification and general amplifier performance from input to output. Precaution is taken by means of the networks described to preserve ample singing margin in this path. However, when this has all been satisfactorily cared for, there is still possibility of the amplifier singing in a conjugate path, the path that exists considering the tubes of each stage in parallel.

The second path, therefore, is termed the par-

allel path, that is, the currents flow through the tubes of a given stage in parallel. This path is purely parasitic and serves no useful function. However, it is as well coupled for feedback as the series path in regions where the leakage impedances are sufficiently high. This takes place mostly at high frequencies. Singing margin, therefore, must also be provided in this path as singing, although it would be conjugate to the output load circuit, would produce undesirable modulation and degrade the performance of the amplifier.

The margin in this path is substantially improved by the resistance-condenser networks of the series path which appear in parallel in the parallel path. In addition, local feedback is purposely added to the output stage, for effecting further improvement.

This local feedback amounted in an amplifier constructed in accordance with the invention to about 15-20 decibels. It reduces the net gain of the parallel path by this amount. Greater reductions in this manner tended to degrade modulation in the series path. This is reasonable as the total voltage amplitude applied to the grid of each tube is increased, thus causing the grids to go positive sooner. At the same time, larger amounts of feedback when a retard coil is used, as shown, tend to produce transients when the plate current of the output tubes changes due to hard driving. This reduces the available plate battery during the time of the transient, limiting the maximum power output in the series path. When steady state measurements are made on such an amplifier, the degradation of modulation and power output is not noticed. However, when speech or program is used for measuring the power output, the degradation is well marked. This is because of the rapidly varying and transient nature of speech and program.

The feedback is limited by the shunt resistance across the retard coil 52. The retard coil is used to make it possible to obtain a high impedance as, for example, 1000 ohms, in the common branch grid-cathode circuit between the resistance 49 and ground, without producing excessive grid bias or losing too much battery voltage, which would be the case with a pure resistance of 1000 ohms. The screen voltage is supplied through one winding of the retard. If too much feedback is allowed to take place between the screen and the control grid, or between the plate and the screen, excessive modulation again takes place in the output of the series path. To prevent this, the windings of the retard coil are connected so that between the screen and the cathode the impedance due to the retard is zero except for the direct current resistance of the retard coil windings. That is, the windings are connected series opposing. Thus, there is no coupling between the screen and the control grid or the plate and the screen except through what direct current resistance there is in the cathode circuit. This is no larger than enough to obtain the proper grid bias.

What is claimed is:

1. A wave amplifying system comprising a plurality of push-pull amplifier stages in tandem, an interstage transformer coupling successive stages, and a network connected between each pair of the ends of an input and an output winding of the transformer, said network comprising a capacitance in series with parallel resistance and capacitance.

2. A wave amplifying system comprising a plu-

ality of push-pull amplifier stages in tandem, an output transformer, the initial push-pull stage having a biasing resistor in each control grid-cathode and anode-cathode circuit, and said output transformer having a feedback winding, the ends of said winding being connected to the cathode ends of said biasing resistors, and variable resistance means shunted across said biasing resistors and between the feedback connections.

3. A wave amplifying system comprising an electron discharge device having a control grid, a cathode, a screen grid and an anode, a degenerative feedback circuit common to the control grid-cathode and cathode-anode circuits, said feedback circuit including resistance in series with a winding of a retard coil, said retard coil having a second winding coupled to the first and connected to the screen grid, said windings being so poled that the impedance between the screen grid and the cathode due to the retard coil is substantially zero, and a resistance shunting said second winding.

4. A wave amplifying system comprising electric space discharge devices having cathode structure and each having an anode, a control grid and a screen grid, means connecting said devices in push-pull relation, and a circuit common to the cathode-control grid and cathode-anode circuits of said devices for producing negative feedback in said system, said feedback circuit including resistance in series with a winding of a retard coil, said retard coil having a second winding coupled to the first and connected to the screen grid of each of said devices, said windings being so poled that the impedance between each screen grid and the cathode structure due to the retard coil is substantially zero.

5. A wave amplifying system comprising a plurality of amplifier stages, an output circuit including a transformer having a primary, a feedback and a line winding, a feedback connection from said feedback winding to one of said am-

plifier stages, and network between said primary and feedback windings for limiting any tendency for the amplifier to sing, in which said network comprises a capacitance in series with a parallel resistance and capacitance.

6. In combination, an amplifier comprising two push-pull stages of vacuum tubes, an output transformer for said amplifier having a primary winding, a secondary winding and a feedback winding, said secondary winding having terminals for connection to a line, an autotransformer, means for connecting said autotransformer to said secondary winding, said autotransformer having taps for supplying waves from said amplifier to groups of lines at different power levels, said amplifier comprising cathode lead impedances connected between the cathodes of said first stage, a feedback path comprising variable series resistors shunted by phase control condensers connecting said feedback winding to the cathode ends of said impedances for producing negative feedback in said amplifier, a variable gain control resistor connecting said series resistors, phase control networks connecting said primary and secondary windings for increasing margin of said amplifier against singing, a gain control and phase control network connected across said secondary winding for shaping the amplifier gain-frequency characteristic and increasing phase margin of the amplifier against singing upon variation of the connections of said groups of lines to said autotransformer, an interstage transformer having primary and secondary windings for coupling said stages, phase control networks connecting said primary and secondary windings of said interstage transformer for increasing the margin of said amplifier against singing, and means for producing negative feedback local to said second stage for reducing parallel-singing tendency of said amplifier.

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