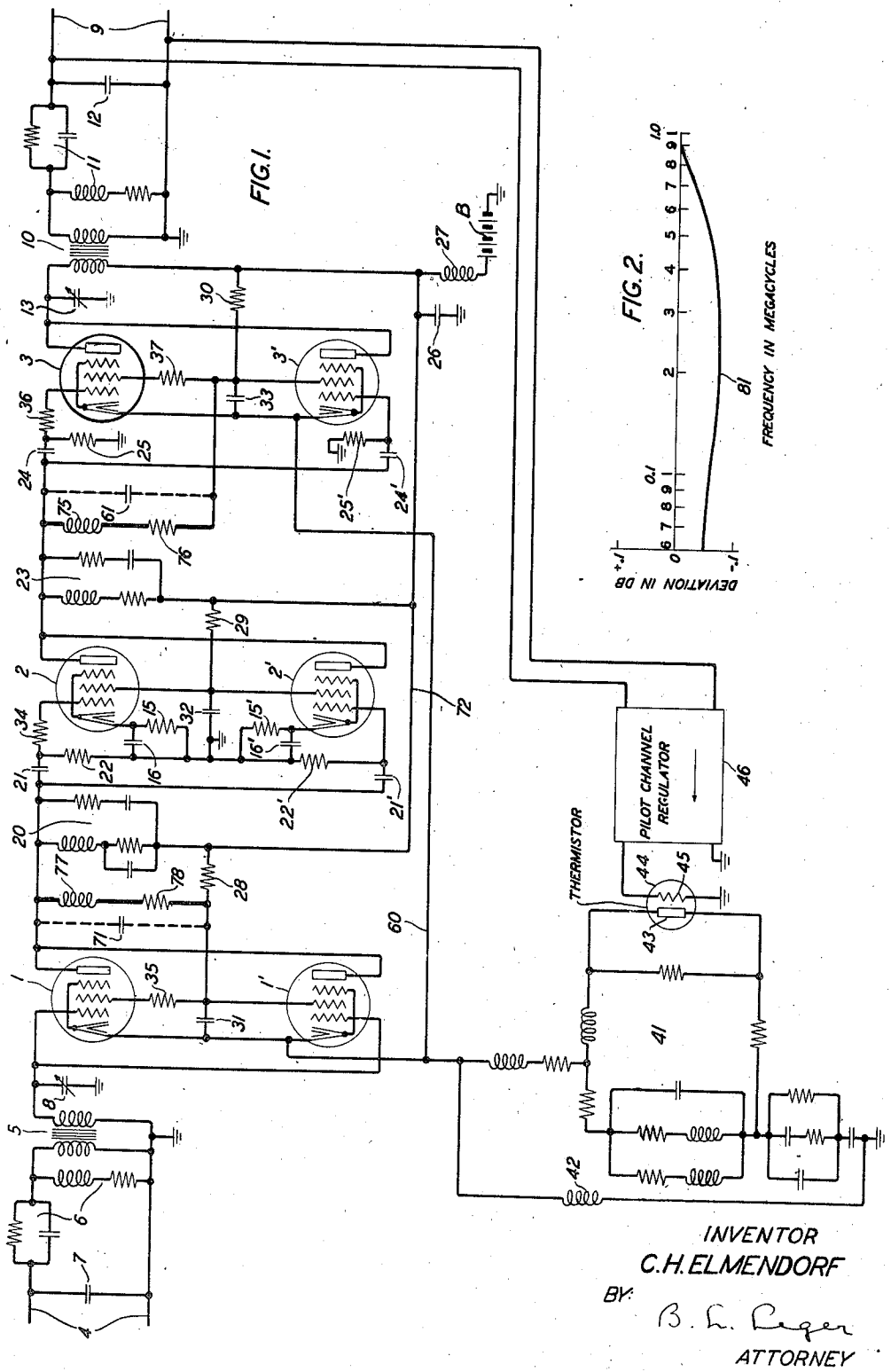
Oct. 7, 1947. C. H. ELMENDORF 2,428,363

NEGATIVE FEEDBACK AMPLIFIER

Filed July 26, 1944



INVENTOR
C. H. ELMENDORF
BY: B. H. Rieger
ATTORNEY

Patented Oct. 7, 1947

2,428,363

UNITED STATES PATENT OFFICE

2,428,363

NEGATIVE FEED-BACK AMPLIFIER

Charles H. Elmendorf, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 26, 1944, Serial No. 546,646

12 Claims. (Cl. 179—171)

1

This invention relates to feedback systems, as for example, vacuum tube amplifiers using negative feedback.

Objects of the invention are to control transmission properties of such systems, for example, feedback in the systems and gain and distortion introduced by the systems.

In one specific aspect the invention is a multistage negative feedback vacuum tube amplifier having fortuitous local feedbacks that deleteriously influence the return ratios of certain stages, with means for controlling the local feedbacks to reduce the deleterious effects. (The return ratio for any tube or stage is the total feedback around it through all paths connecting its output to its input. Thus, the concept of return ratio is a generalization for multiple loop amplifiers of the well-known concept of feedback or loop propagation $\mu\beta$. The feedback in a single loop amplifier is the return ratio for each tube or stage. In a multiple loop amplifier the return ratios may be not the same for each tube or stage; because the total voltage fed back to the input of any given stage is the sum of the voltages fed back to that point through all paths from the output of that stage to the input of that stage, and the paths may be not all the same for each stage.) More specifically, the amplifier is a broad band three-stage amplifier having an over-all negative feedback path and two two-stage local negative feedback loops. One of these two includes the first two stages and includes the grid-cathode capacity of the third stage as a series arm. The other includes the last two stages and includes the plate-cathode capacity of the first stage as a series arm. In the absence of preventive means, local feed-back around the one two-stage loop makes the gain of the return ratio of the third stage decrease with increasing frequency in the vicinity of the upper edge of the transmission band. In this frequency region, this local feedback so lowers the gain and increases the phase of the return ratio of the third stage as to make that return ratio differ widely from the return ratio of the second stage; and local feedback around the other two-stage loop similarly affects the return ratio of the first stage. To prevent these effects, networks between the plate and cathode of the first tube and between the grid and cathode of the third tube are provided, for lessening the local feedbacks and controlling their phase. The return ratios of the first and third stages may thus have their gains increased in the region just mentioned, and if desired may thus be made approximately the same as the return ratio of

2

the second stage. The increase of the return ratios increases the reduction that feedback produces in the modulation introduced by the stages; and it reduces the amplifier aging deviation (i. e., the amplifier gain change due to vacuum tube aging), thereby prolonging the useful life of the vacuum tubes. As indicated hereinafter, having all of the return ratios the same is advantageous in simplifying the shape of the amplifier aging effect characteristic (i. e., the characteristic of aging deviation versus frequency) by reducing the number of deviation shapes from three to one, which shapes have to be equalized for in any long system. An additional advantage is that by controlling the return ratios in a suitable manner it is possible, in addition to reducing the number of shapes, to control such shape in such a manner as to produce deviation shapes which are susceptible of equalization by simple means.

The amplifier may have its gain regulated, for example, to compensate for temperature change of a line section to which it is connected, by pilot channel control of the over-all feedback path or beta-circuit of the amplifier; and with the return ratios of all stages the same, the phase of each return ratio at the pilot frequency may be made to approximate 90 degrees, the value required to give minimum amplifier aging deviation at that frequency (or in other words the value required to make the aging deviation at that frequency as small as practicable). As indicated hereinafter, having minimum amplifier aging deviation at the pilot frequency is desirable so that operation of the regulator to correct for gain change at the pilot frequency due to tube aging will not produce objectionable gain change at other frequencies. Moreover, making the changes in gain zero at the pilot frequency simplifies the second order deviations which must be equalized later in the system.

Objects of the invention are to control gain and phase of return ratios of individual vacuum tube stages of negative feedback multiple loop amplifiers, reduce deleterious effects of vacuum tube interelectrode capacities on such return ratios and reduce local feedbacks deleteriously affecting return ratios of individual stages of multistage negative feedback amplifiers.

It is also an object of the invention to render the return ratios of all of the stages of a negative feedback multiple loop amplifier approximately the same.

A further object of the invention is to reduce deleterious effects of vacuum tube aging on the

gain-frequency characteristics of vacuum tube amplifiers.

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

Fig. 1 shows the specific form of amplifier referred to above; and

Fig. 2 shows its aging effect characteristic.

The amplifier of Fig. 1 may be, for example, a line amplifier (repeater amplifier) for an .3 megacycle coaxial conductor multiplex carrier telephone system transmitting 180 telephone channels in the frequency band between 68 kilocycles and 800 kilocycles.

The amplifier is a three-stage negative feedback amplifier, each stage including two vacuum tubes with their plates in parallel and their grid circuits in parallel. The tubes are 1 and 1' for the first stage, 2 and 2' for the second stage, and 3 and 3' for the third stage. (The two tubes in parallel in each stage are shown only for purposes of a specific example. The invention applies equally well to a single string of tubes. Likewise, the invention applies to any multiple loop amplifier and is not limited to a three-stage cathode feedback connection.)

The incoming line 4 is coupled to the first stage by a transformer circuit including input transformer 5, network 6 and condensers 7 and 8; and the last stage is coupled to the outgoing line 9 by a transformer circuit including output transformer 10, network 11 and condensers 12 and 13. These transformer circuits are designed in accordance with the teaching of H. W. Bode Patent 2,244,878, May 20, 1941, with regard to their external gain characteristics, their volume performance characteristics and their potentiometer terms or contributions to the return ratios of the tubes or stages of the amplifier. Condenser 8 is for adjusting the capacity of the high impedance side of transformer 5 to its design value. Network 6 is for obtaining an approximate impedance match between the line and the repeater in which the amplifier is designed to be connected, at frequencies in the low end of the transmission band of the amplifier, so as to avoid reflections at those frequencies, where the loss in the cable is insufficient to damp out reflections and thus render them unimportant. Condenser 7 is for building out the capacity across the low-impedance side of the transformer circuit to the value required to give the repeater (including a line equalizer, not shown, ahead of the amplifier) the desired gain-frequency characteristic to provide fixed equalization of transmission over a repeater section of the line at normal line temperature.

The cathode of tube 2 is connected to ground through grid bias resistor 15 and by-pass condenser 16; and resistor 15' and by-pass condenser 16' similarly connect the cathode of tube 2' to ground. An interstage network 20 and coupling condensers 21 and 21' and grid leak resistors 22 and 22' couple the first and second stages. An interstage network 23 and coupling condensers 24 and 24' and grid leak resistors 25 and 25' couple the second and third stages. The networks 20 and 23 connect to ground through condenser 26, which by-passes the series circuit comprising choke coil 27 and the plate current supply source B connected between ground and the coil 27 and common to the two oppositely directed amplifiers of a repeater (not shown). The coil 27 is for suppressing cross-talk between the amplifiers.

The plate current supply source supplies screen grid potentials for the three stages of the amplifier through resistors 28, 29 and 30, by-passed by condensers 31, 32 and 33.

A small resistance 34, for example 100 ohms, in the grid lead of tube 2 suppresses tendency of the parallel connected tubes 2 and 2' to sing due to their parallel connection at high frequency above the transmission band of the amplifier. A similar purpose is served for tubes 1 and 1' by a similar resistance 35 in the screen grid lead of tube 1; and a similar purpose is served for tubes 3 and 3' by a similar resistance 36 in the grid lead of tube 3 and a similar resistance 37 in the screen grid lead of tube 3.

The amplifier is of the cathode feedback type disclosed, for example, in J. M. West Patent 2,227,043, December 31, 1940, with a single shunt arm beta-circuit or feedback connection, impedance network 41, the network 41 being connected from the cathodes of the first and third stages to ground. Plate current of the last stage sets up across impedance 41 a voltage which is fed back to the grids of the first stage through the secondary winding of transformer 5 and condenser 8 in parallel, the impedance 41 thus producing over-all negative feedback. The impedance 41 also produces local negative feedback around the first stage and local negative feedback around the third stage.

Coil 42 in network 41 has the proper resistance for supplying grid bias for the first and third stages, and has the proper inductance for anti-resonating the beta-circuit capacity at approximately 50 megacycles in the upper part of the high frequency cut-off region of the return ratios of the amplifier stages.

One element of the beta-circuit 41 is resistor 43 of thermistor 44. Resistor 43 has a high temperature coefficient of resistance, and has its temperature controlled by heater 45, for varying the feedback impedance 41 to vary the amplifier gain. The line and the amplifier transmit, along with the carrier signals, an .84 megacycle pilot current. The pilot current, to the exclusion of currents of other frequencies, is selected by pilot channel regulator circuit 46, which is responsive to the pilot current for controlling the heater 45. The regulator may be of any suitable type, as for example, the type disclosed in R. R. Blair Patent 2,178,333, October 31, 1939, or R. R. Blair Patent 2,323,192, June 29, 1943. Through the beta-network thermistor resistance 43 the regulator compensates for loss variations due to changes in temperature of the line section preceding the amplifier. As the line loss varies, the 840-kilocycle pilot operates through the regulator to maintain the pilot at a fixed level at the amplifier output. Therefore to keep the carrier signals at the correct levels the elements of the beta-circuit network 41 are proportioned to make the amplifier gain change follow the same frequency function as the change in line loss with temperature, over the frequency range including the carrier signals and the 840-kilocycle pilot.

If the screen grids of the input and output tubes of the amplifier were supplied through a common screen grid resistance and by-passed to the common cathode lead of the two stages with a common by-pass condenser, the potential developed across such condenser by the third stage screen grid current would appear between the input control grid and cathode structure via the control grid-screen capacity. Thus there would be effectively a second feedback path partially by-passing the principal regulating feedback

path. This might result in poor external gain regulation. The effect is avoided by providing the first and third stage screen grids with separate dropping resistors and by-pass condensers as shown.

The heater circuits (not shown) for the vacuum tubes of the amplifier may be, for example, of the type disclosed in A. L. Stillwell Patent 2,260,493, including a heater isolating network to prevent the total heater-cathode capacity of the tubes of the first and third stages from appearing across the beta-circuit.

The cathode feedback connection employed in the amplifier results in a multiple loop structure in which the return voltage of each stage is obtained from three interdependent feed-back paths. This implies that design consideration must be given to the return ratios of all three stages. However, such design consideration can often be greatly simplified by making all of the return ratios approximately the same, for example, in the manner described hereinafter. The interdependent feedback paths which determine the return ratios can be considered as somewhat independent parts of the design. Various combinations of the one-stage feedback paths around the first and third stages appear as local feedback terms in the return ratio expressions and they must be accounted for in shaping the return ratio characteristics. The three-stage feedback path is the principal factor in all three of the return ratios. In addition to these one-stage and three-stage paths, which completely determine the second stage return ratio in the region of the transmission band of the amplifier, the first and third stage return ratios are affected to a large extent by two two-stage feedback paths. That is, the third stage return ratio includes a term descriptive of the transmission around the first and second stages through the third stage grid-cathode admittance, and the first stage return ratio includes the effect of the transmission around the second and third stages through the plate-cathode admittance of the first stage, these parasitic grid-cathode and plate-cathode capacities being of such magnitude that unless adequate means are provided for control of the feedback through these two-stage paths the potentials fed back through them become large enough in the upper part of the transmission band to seriously impair the first and third stage return ratios.

The feedback including the first two stages and the grid-cathode admittance of the third stage as a series arm is a negative feedback, the feedback from the output of tubes 2 and 2' to the input of tubes 1 and 1' occuring as follows: A portion of the plate current of tubes 2 and 2' flows from the cathodes of tubes 2 and 2' to ground, thence through the secondary winding of transformer 5 and condenser 8 in parallel, thence through the grid-cathode impedance of tubes 1 and 1', thence through conductor 60, thence through the cathode-grid impedance of tubes 3 and 3' including inherent or parasitic grid-cathode capacity 61, and thence to the plates of tubes 2 and 2'. (The path from ground through the secondary winding of transformer 5 and condenser 8 in parallel, and thence through the grid-cathode impedance of tubes 1 and 1' in parallel, is shunted by impedance 41 which is thus included in the two-stage feedback loop that includes the first two stages. The cathode current of the second stage flowing from ground through impedance 41 and capacitance 61 produces across 41 a voltage which is fed back to the grids of the first stage through the secondary winding of transformer 5 and condenser 8 in parallel.) The feedback around the two-stage loop including the first and second stages makes the gain of the return ratio of the third stage decrease with increasing frequency in the upper part of the transmission band of the amplifier and, in the region of the upper edge of the transmission band, lowers the gain and increases the phase of the return ratio of the third stage, making that return ratio differ widely from the return ratio of the second stage.

The feedback including the last two stages and the plate-cathode admittance of the first stage as a series arm is a negative feedback, the feedback from the output of tubes 3 and 3' to the input of tubes 2 and 2' occuring as follows: A portion of the plate current of tubes 3 and 3' flows from the cathodes of tubes 3 and 3' through conductor 60 to the cathodes of tubes 1 and 1', thence through the plate-cathode impedance of tubes 1 and 1' including the inherent or parasitic plate-cathode capacity 71, thence through interstage network 20 to conductor 72, and thence to the plates of tubes 3 and 3' through the branched circuit comprising the primary winding of transformer 10 in parallel with condensers 26 and 13 in series. The feedback around the two-stage loop including the second and third stages affects the return ratio of the first stage of the amplifier in the same way that the two-stage feedback around the first two stages affects the return ratio of the third stage, as described above.

To prevent or alleviate these deleterious effects of the two two-stage feedback paths and obtain the desired return ratios for the first and third stages, the third stage grid-cathode admittance and the first stage plate-cathode admittance may be modified by the addition of suitable elements. As a simple example, a series combination of a coil 75 and a resistance 76 may be added across capacity 61 and a series combination of a coil 77 and a resistance 78 may be added across capacity 71. The inductance of coil 75 may be chosen to be parallel-resonant with the parasitic grid-cathode capacity of the third stage in the vicinity of the upper edge of the transmission band of the amplifier and the value of the resistance 76 may be set to approximately equal the coil impedance at 1 megacycle. Similarly, the inductance of coil 77 may be chosen to be parallel-resonant with the parasitic capacity of the first stage in the vicinity of the upper edge of the transmission band of the amplifier and the value of the resistance 78 may be set to approximately equal the coil impedance at 1 megacycle.

Without elements 75 and 76, i. e., with only the parasitic capacity in the grid-cathode arm of the third stage, the return ratio of the third stage has its gain curve falling with frequency increase in the upper part of the transmission band of the amplifier, and this diminution of the gain of the third stage return ratio is associated with a block of unfavorable phase shift in the third stage return ratio in the frequency region of the upper edge of the transmission band of the amplifier, this increased phase shift rendering virtually impossible the task of designing the .84 megacycle phase of both the second and third stage return ratios to the desired 90-degree value, which is the value required to give minimum amplifier aging deviation (or, in other words, to make the aging deviation as small as practicable) at the 840-kilocycle pilot frequency, as indicated hereinafter. These objectionable effects are

greatly reduced and the return ratio of the third stage made approximately the same as that of the second stage by the addition of the elements 75 and 76. By introducing additional complexity into the grid-cathode branch of the second interstage circuit the objectionable effects of the two-stage local feedback could be still further diminished and the second stage return ratio more closely simulated. A discussion similar to that above applies to the first stage return ratio with the first stage plate-cathode admittance used as the design parameter.

Design consideration of the return ratios of the stages of the amplifier can be greatly simplified by making the return ratios of all stages approximately the same; for with return ratios different functions of the same design and parasitic parameters it would be necessary to investigate each return ratio and satisfy simultaneously specified requirements on the individual return ratios. Moreover, with different return ratios, if the maximum return ratio for each stage were needed, it would be necessary to design the return ratio of each stage to conform to a characteristic whose asymptote is that associated with the particular stage; for it can be seen from the loss-phase relations developed in H. W. Bode Patent 2,123,178, July 12, 1938, that if a broad band feedback amplifier is to be absolutely stable there is an upper limit on the amount of return ratio that can be achieved on any tube, and this limit is dependent upon the asymptotic characteristic of the return ratio at frequencies remote from the transmission band and upon the unfavorable transit time phase introduced below the gain cut-off by the vacuum tubes. However, when the available feedback is not a limiting factor in the amplifier design and the return ratios of all stages are made approximately the same, rigorous treatment of the return ratio asymptotes may be dispensed with. Instead of carrying out such treatment the return ratio of each stage can be made to approximate the desired ideal or nominal three-stage loop return ratio characteristic which is to characterize the internal amplifier design. This characteristic can be derived from the asymptotic structure of the amplifier in accordance with the teaching of the patent just mentioned, as an ideal return ratio characteristic that provides constant feedback over the transmission band and a constant phase margin between the edge of the band and gain cut-off, for decreasing the return ratio from its value in the transmission band to its ultimate asymptote with the required margins against instability. Such ideal or nominal return ratio characteristic that the return ratios of the stages of the amplifier of Fig. 1 were each designed to approximate, had a 40-decibel gain over a band extending up to a frequency of 970 kilocycles. The 970-kilocycle band for the return ratio was chosen to facilitate obtaining a return ratio phase of 90 degrees at the 840-kilocycle frequency, the condition which the return ratio phases of the amplifier stages must satisfy if the amplifier aging deviation is to be a minimum at the pilot frequency. Aging deviation occurs because the external gain of the usual feedback amplifier with the gain of its return ratios finite is not completely independent of small changes in gain of the vacuum tubes, or in other words, because of the effect described in J. M. West Patent 2,196,844, April 9, 1940, as the $\mu\beta$ finitude effect and sometimes referred to as the $\mu\beta$ effect or the $\mu\beta$ error. Thus, as the vacuum tubes age there is a progressive change in the external gain of the amplifier of Fig. 1, except at the pilot frequency. Since the amplifier gain change produced by the action of the pilot channel regulator upon the beta-circuit is not the proper function of frequency to compensate for the $\mu\beta$ deviation, i. e., the aging deviation, it is desirable to have the aging deviation a minimum (or, in other words, as small as practicable) at the pilot frequency, so operation of the regulator to compensate for the effect at the pilot frequency will not produce objectionable gain change at other frequencies. Return ratio phase may be designated Φ, as in H. S. Black Patent 2,102,671, December 21, 1937. The condition $\Phi=90°$ is the condition represented as boundary E in Figs. 2 and 4 of that patent. In other words, 90 degrees is the value of return ratio phase for which gain stability (against small variations is $|\mu|$) is improved by an amount corresponding to twice the reduction in gain due to feedback; and, as indicated in that patent, for large values of negative feedback, boundaries C and J shown in that patent approach boundary E asymptotically. Boundary C, given by

$$|\mu\beta|=\frac{1}{\cos\Phi}$$

is the condition for perfect gain stability against small variations in $|\mu|$; and boundary J, given by

$$|\mu\beta|=\frac{1}{2\cos\Phi}$$

is the condition for zero $\beta\mu$ effect. Therefore, if Φ is made 90 degrees at the pilot frequency the aging deviation will be very small at that frequency.

In general, increasing the return ratio of a stage reduces the amplifier aging deviation, thereby prolonging the useful life of the vacuum tubes, and also increases the reduction that feedback produces in the modulation introduced by the stage.

The aging effect characteristic or deviation characteristic for a sample amplifier of the type represented in Fig. 1 is shown in Fig. 2, as curve 81. This curve shows a measurement of the aging deviation corresponding to a reduction of approximately 3 decibels in the transconductance of each stage. The 3 decibel-reduction in the vacuum tube transconductance represents the difference between average new tubes and average old tubes (aged to the rejection point). Having the return ratios of the amplifier stages approximately the same greatly simplies the shape of the aging effect characteristic; for if the return ratios are not approximately the same, each stage will contribute in a different manner to the over-all gain deviation, for example, a change in the gain of the output stage producing, say, a much larger external gain deviation than the same change in a stage gain would produce if it appeared in a stage having a return ratio materially different (in gain or phase or both) from that of the output stage.

It is desirable to keep the return ratio phase of each stage of the amplifier as near as practicable to 180 degrees in the lower part of the signal band, in order that the aging effect characteristic will have a simple shape. (The relation $\Phi=180°$ represents boundary G shown in the above-mentioned Black Patent 2,102,671, and is the condition for improvement of gain stability, against small variations in $|\mu|$, by an amount equal to the reduction in gain due to feedback.)

In designing a low frequency cut-off charac-

teristic with satisfactory margins against instability, to keep the return ratio phases as near as practicable to 180 degrees in the lower part of the signal band, and also to insure that the loop transmissions of the stages are cut off (i. e., reduced below zero) at a frequency high enough so that power supply filtering elements (not shown) are not a factor needing consideration in the design of the return ratios, and further, to prevent a grid-cathode short circuit on any one stage from causing low frequency singing, the second stage grid leak and blocking condenser combination was made effective in the upper part of the cut-off and the first stage grid leak and blocking condenser combination was made effective approximately a decade and a half lower in frequency.

What is claimed is:

1. An amplifier comprising cascaded vacuum tubes each having interelectrode cathode-anode and cathode-grid impedances, a feedback impedance between the cathodes of two of the tubes, means producing negative feedback from the output of a tube to the input of another through said feedback impedance, means connecting in series said feedback impedance, one of said interelectrode impedances of one tube and one of said interelectrode impedances of an adjoining tube, and means parallel resonant with the last-mentioned impedance at a prescribed frequency.

2. A vacuum tube amplifier comprising cascaded vacuum tubes, an impedance common to the output circuit of the last stage and the input circuit of the first stage of the amplifier for producing over-all negative feedback around all of the stages, a local feedback loop around less than the whole number of the amplifier stages comprising means connecting said impedance in the plate-cathode circuit of a tube of the amplifier and in the grid-cathode circuit of a tube of the amplifier, one of the two last-mentioned circuits comprising an impedance having its terminals at the cathode and another electrode of a tube next to a tube to which one of said two last-mentioned circuits is attached, and means for reducing the feedback around said local feedback loop comprising means parallel-resonant with said last-mentioned impedance at a prescribed frequency.

3. A multistage vacuum tube amplifier comprising an impedance in the output circuit of the last tube, means connecting the plate-cathode path in the next-preceding tube in series with said impedance and the grid-cathode path in said last tube, means producing negative feedback of voltage from said impedance to the input of said preceding tube, and means in parallel with said grid-cathode path for increasing the grid-cathode impedance at a frequency in the neighborhood of the transmission band of the amplifier.

4. A multistage vacuum tube amplifier comprising an impedance in the input circuit of the first tube, means connecting said impedance in series with the plate-cathode path in said first tube and the grid-cathode path in the second tube, means producing negative feedback of voltage from the output of said second tube to the input of said first tube, and means in parallel with said plate-cathode path for increasing the plate-cathode impedance at a frequency in the neighborhood of the transmission band of the amplifier.

5. An amplifier comprising cascaded vacuum tubes, an impedance common to the plate-cathode circuits of two of the cascaded tubes and the grid-cathode circuit of one of the cascaded tubes, one of said plate-cathode circuits including an impedance having its terminals at the grid and the cathode of one of said two tubes, and means parallel-resonant with said last-mentioned impedance at a prescribed frequency.

6. An amplifier comprising cascaded vacuum tubes, an impedance common to the plate-cathode circuit of one of the cascaded tubes and the grid-cathode circuits of two of the cascaded tubes, one of said grid-cathode circuits including an impedance having its terminals at the plate and the cathode of one of said two tubes, and means parallel-resonant with said last-mentioned impedance at a prescribed frequency.

7. An amplifier comprising three cascaded vacuum tube stages, an impedance between the cathode of the second stage and the cathodes of the other stages, means comprising said impedance for producing over-all negative feedback from the output of the amplifier to the input of the amplifier, a local feedback loop including said impedance and the first two of said stages producing local feedback that causes substantial change in the return ratio of the third stage, capacity across the grid and cathode electrodes of said third stage being included in said local feed-back loop and substantially affecting said local feedback at a given frequency, and means for controlling said local feedback comprising means for reducing the effective capacity across said electrodes at said given frequency.

8. A broad band multistage vacuum tube amplifier having an over-all negative feedback path and having vacuum tube interelectrode capacity that renders the return ratio for one of the stages widely different from that for another in the frequency region of the upper edge of the transmission band of the amplifier, and means for compensating for said effect of said capacity and rendering said return ratios approximately the same in said region, comprising means parallel-resonant with said capacity at a frequency in said region.

9. The combination with a broad band three-stage vacuum tube amplifier, of an over-all negative feedback path, a two-stage negative feedback loop included in said amplifier and path, said two-stage loop including an interelectrode capacity of one of said three stages, said capacity causing the two-stage feedback to render the return ratio for said one stage widely different from the return ratio for another of said three stages in the frequency region of the upper edge of the transmission band of the amplifier, and means for compensating for said effect of said capacity upon said two-stage feedback and rendering said return ratios approximately the same in said region, comprising means parallel-resonant with said capacity at a frequency in said region.

10. A broad band three-stage vacuum tube amplifier having a negative feedback path around the three stages and having a negative feedback loop that comprises two only of said stages but includes in series an interelectrode capacity of the remaining stage and an impedance common to the output of the second of said two stages and the input of the first of said two stages, said capacity causing the feedback around said two-stage loop to render the return ratio for said remaining stage widely different from that for one of said two stages in the frequency region of the upper edge of the transmission band of the amplifier, and means for counteracting the effect of said capacity in causing said difference and rendering said two return ratios approxi-

mately the same in said region, comprising means parallel-resonant with said capacity at a frequency in said region.

11. A broad band three-stage vacuum tube amplifier having a negative feedback path around the three stages and having a second negative feedback path around the first two stages only, said second path including in series the grid-cathode capacity of the third stage and an impedance common to the output of the second stage and the input of the first stage, and means parallel-resonant with said capacity at a frequency in the neighborhood of the upper edge of the transmission band of the amplifier.

12. A multistage broad band amplifier having an over-all negative feedback path, means in said path variable for controlling the attenuation of the path, means responsive to output of said amplifier of a given frequency in the transmission band of the amplifier for controlling said variable means, said amplifier having a plurality of

local feedback loops that render the return ratios of certain of the amplifier stages widely different in the region of said given frequency, and means reducing the effect of said local feedback loops in producing said difference and rendering said return ratios approximately the same in said region comprising means in said local feedback loops for rendering the phase of the return ratios of all of the amplifier stages approximately ninety degrees at said given frequency.

CHARLES H. ELMENDORF.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,269,408	Kinsburg	Jan. 6, 1942
2,231,374	Stillwell	Feb. 11, 1941
2,350,951	Zinn	June 6, 1944