

Dec. 3, 1940.

H. S. BLACK

2,223,506

WAVE AMPLIFICATION

Original Filed April 22, 1932

3 Sheets-Sheet 2

FIG. 3

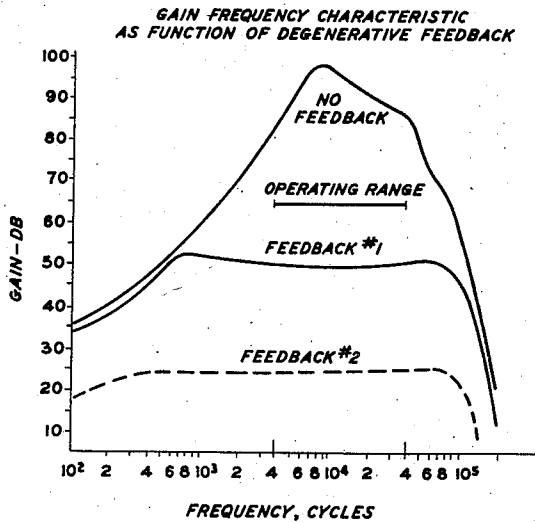


FIG. 4

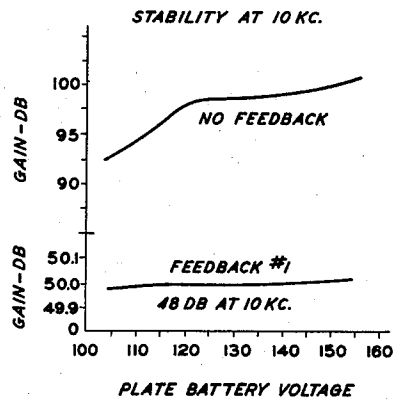


FIG. 5

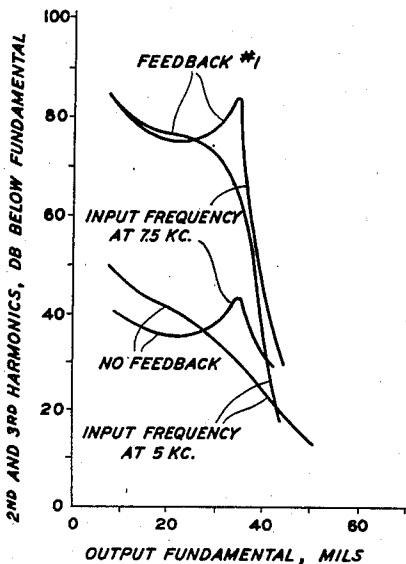
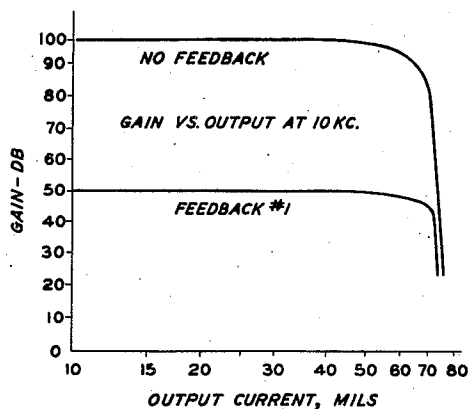


FIG. 6



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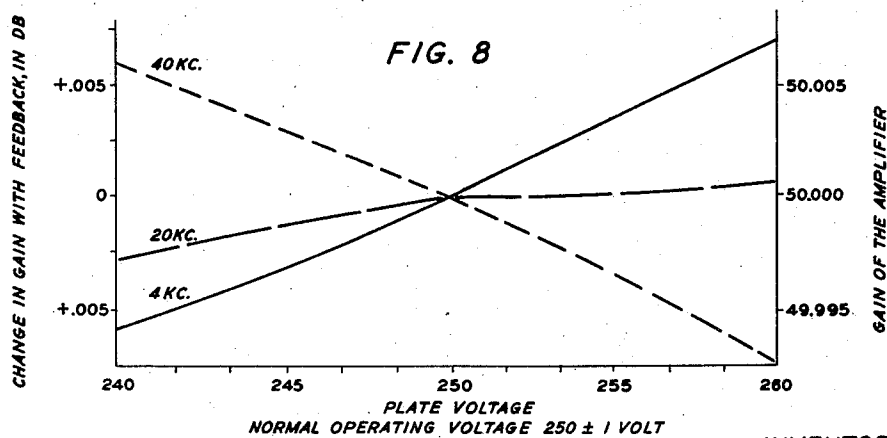
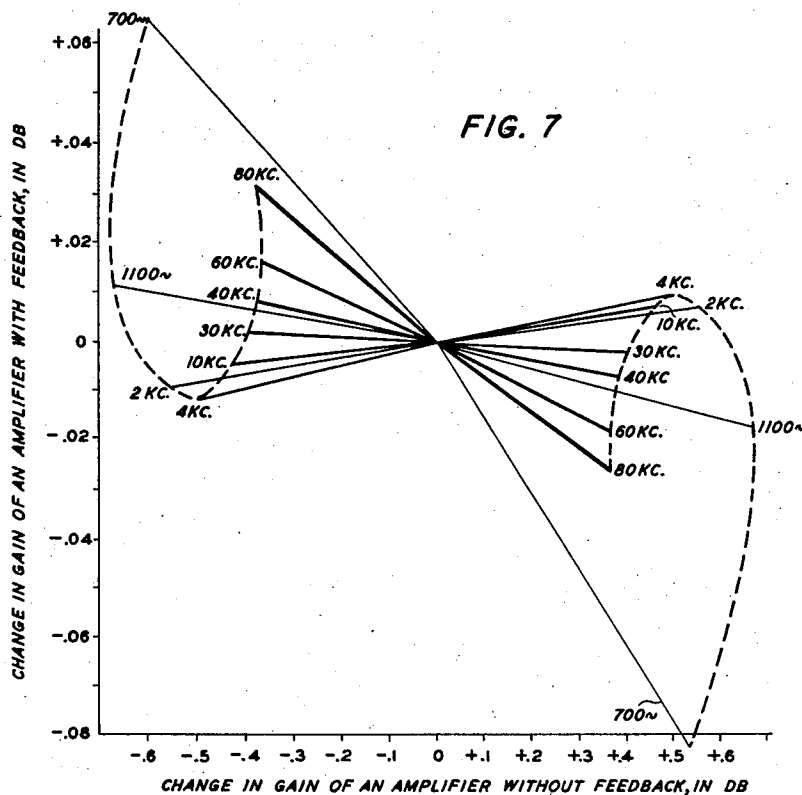
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2,223,506

WAVE AMPLIFICATION

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Original application April 22, 1932, Serial No. 606,871. Divided and this application November 10, 1937, Serial No. 173,749

7 Claims. (Cl. 179—171)

The present invention relates to wave amplifying systems employing negative feedback for improving the operation of the system; for example, for increasing linearity or improving stability.

This is a division of my prior application Serial No. 606,871, filed April 22, 1932, Patent No. 2,102,671, issued December 21, 1937.

The general object of the invention is to provide, in novel manner, negative feedback in requisite amount to secure the desired degree of improvement in transmission characteristic; and more especially in a broad band amplifier employing a number of stages in tandem.

The basic theory of operation of amplifiers provided with negative feedback and the design procedure therefor are quite fully set forth in the parent patent to which reference may be made. It is there pointed out that the use of a large amount of negative feedback is capable of reducing the modulation or distortion in an amplifier substantially decibel for decibel and likewise improves the stability of gain and other properties substantially in proportion to the gain reduction resulting from the negative feedback. In the same way that the distortion is improved and in like degree noise and all other variations that arise in the amplifier itself are reduced by the negative feedback.

The invention is capable of broad application in the field of wave amplification generally and the basic principle of the invention is not confined to the amplification of electrical waves.

The nature and objects of the invention will be more fully understood from the consideration of a specific example which will be described in detail in the following specification and illustrated in the accompanying drawings.

Fig. 1 is a circuit diagram of a negative feedback amplifier suitable, for example, for amplifying waves of a frequency range extending from 4 kilocycles to 40 kilocycles in a non-loaded cable used for multiplex carrier telephony; and

Figs. 2 to 8 show characteristics of the amplifier of Fig. 1.

Fig. 1 shows the circuit of a negative feedback amplifier 240 comprising vacuum tubes 241, 242 and 243 in cascade connection, for amplifying waves of a frequency range extending from 4 kilocycles to 40 kilocycles received over incoming line or circuit 238 and transmitting the amplified waves to outgoing line or circuit 239. The circuits 238 and 239 may be, for example, sections of a non-loaded multiplex carrier telephone cable circuit, the amplifier amplifying simultaneously

a number of carrier telephone and/or carrier telegraph messages of channels extending over the 4 kilocycles to 40 kilocycles range.

The incoming circuit comprises an input transformer 244 and is connected to the input side of the amplifier through a bridge circuit 245. The four ratio arms of the bridge comprise the four resistances 246, 247, 248 and 249, respectively, and in the arm containing resistance 246 is also an adjustable phase correcting condenser 246' which balances the effective input capacity of tube 241 and reduces the phase shifts around the feedback loop to values favorable for avoiding danger of the amplifier tending to be self-oscillatory at high frequencies. The circuit 238 is connected across two of the bridge arms in series and forms one diagonal of the bridge. The input circuit of the amplifier is connected across the arm 249.

The output circuit of the amplifier is connected to the outgoing or load circuit 239 through a bridge circuit 250 and a stopping condenser 251, the stopping condenser having negligibly low reactance for the waves to be amplified. An output transformer 252 is included in the outgoing circuit. The ratio arms of the bridge are resistances R_0 , KR_0 , KR and R , K being a constant and R_0 being the space path resistance of tube 243. A stopping condenser 259 is included in the arm that contains resistance R . The circuit 239 is the output diagonal of the bridge.

Across the resistances KR and KR_0 in series is connected the input end of a feedback path for the amplifier, comprising conductor or feedback lead 253 and ground, the output end of this path being connected across the arms 247 and 248 of bridge 245. Thus, the feedback path is a diagonal (the feedback diagonal) of output bridge 250, and is also a diagonal of the input bridge 245, as in the case of Fig. 5 of the parent patent.

Tubes 241 and 242 are heater type screen grid tubes of high amplification factor (Western Electric Company type 245-A tubes). Tube 243 is a coplanar grid tube of the general type disclosed by H. A. Pidgeon and J. O. McNally in their copending application Serial No. 368,647, filed June 5, 1929, or in their copending application Serial No. 542,252, filed June 5, 1931, (which have now patented as No. 1,923,686, August 22, 1933, and No. 1,920,274, August 1, 1933, respectively), or in their paper published in the Proceedings of the Institute of Radio Engineers, vol. 18, pages 226 to 293, February, 1930. Such a tube has two grids, each active elementary area on either grid being close to a corresponding active area on the other grid and being at substantially the same

location as that corresponding area with respect to the cathode and the anode or plate. For example, each grid may have its active area in the same surface, for instance the same plane or cylindrical surface, as the active surface of the other grid. As brought out in the above-mentioned disclosures of Pidgeon and McNally, a vacuum tube having a space charge grid in coplanar relation with a control grid is especially adapted for operation as a power tube by employing a high value of control grid negative biasing potential and a control grid input voltage wave of large amplitude (i. e., a large grid swing) and a high positive biasing voltage on the space charge grid. Tube 243 is a Western Electric Company type 281-A tube operated in that way, with grid 254 serving as a control grid receiving the signal voltage transmitted from tube 242, and with grid 255 serving as a space charge grid. Grid 254 is maintained at negative potential by a negative biasing voltage applied from a 70-volt battery or source 256 through resistance 257. Grid 255 is maintained positive by a positive biasing voltage applied from a 70-volt battery or source 258 across which is shunted a by-pass condenser 259.

Tubes 241, 242 and 243 have a common 130-volt plate battery or source 260 and a 24-volt filament heating battery or source 261 sending heating currents through the filaments of the three tubes in series, the positive pole of the filament heating battery being shown connected to the negative pole of the plate battery.

Plate current for tube 243 passes from battery 260 through choke coil 262 and the primary winding of output transformer 252 to the plate of the tube. This direct current is prevented from reaching resistance R by the stopping condenser 259 and is prevented from reaching resistance KR_0 by condenser 251 which is a by-pass condenser for waves of the frequency to be amplified and which cooperates with the choke coil 262 and a condenser 270 to prevent voltage fluctuations in the battery circuit from reaching the plate and to prevent the alternating current plate voltage from causing feedback in the amplifier through the common battery circuit.

Plate current for tube 241 passes from battery 260 to the plate through a resistance 263 and an interstage coupling impedance or choke coil 264. The resistance 263 and a condenser 265, in conjunction with the condenser 270, form a frequency selective circuit for preventing voltage fluctuations in the battery circuit from reaching the plate and for preventing the waves in the alternating current output circuit of the tube from passing to portions of the plate battery circuit common to a plurality of tubes of the amplifier. The condenser 265 is a by-pass condenser for waves of the frequency to be amplified.

Plate current for tube 242 passes from battery 260 through a resistance 266 and a choke coil 267 to the plate of the tube. Elements 266 to 268 function in connection with tube 242 in the manner in which elements 263 to 265 function in connection with tube 241.

Battery 260 supplies steady positive biasing potential for the screen grid of tube 241 through a frequency selective network comprising a series resistance arm 271 and shunt capacity arms 272 and 270, and supplies steady positive biasing potential for the screen grid of tube 242 through a frequency selective network comprising a series resistance arm 273 and shunt capacity arms 274 and 270. These networks prevent voltage variations in the plate battery circuit from

reaching the screen grids, and prevent waves in the screen grid circuits from passing to portions of the plate battery circuit common to a plurality of tubes of the amplifier. The resistances 271 and 273 adjust the voltages applied from battery 260 to the screen grids of tubes 241 and 242, respectively, to the proper operating values, and assist in maintaining the amplification at proper values at frequencies in the lower portion of the utilized frequency range.

Negative biasing potentials for the control grids of tubes 241 and 242 are obtained from the voltages across resistors 275 and 276, respectively, that result from flow of the space currents of the respective tubes through those resistors. The voltage across resistor 275 reaches the control grid of tube 241 through the bridge 245 and conductor 227 and the secondary winding of transformer 244. The voltage across resistor 276 reaches the control grid of tube 242 through grid 20 leak resistor 278. Condensers 279 and 280 in the interstage coupling circuits are stopping condensers, of negligibly low reactance for the frequencies of the waves to be transmitted.

Resistances 275 and 276 are not by-passed for alternating currents and hence form a common impedance between the plate circuit and grid circuit of their respective tubes and produce negative feedback stabilizing the gain introduced by these two tubes 241 and 242.

From Fig. 2, which is a polar plot of $\mu\beta$ for the amplifier of Fig. 1, the values of $|\mu\beta|$ for various frequencies can be seen. For example, for frequencies in the neighborhood of 10 kilocycles $|\mu\beta|$ is approximately 100.

Fig. 3 shows the gain-frequency characteristic of this amplifier of Fig. 1 without feedback, and with two different adjustments of the circuit as regards amounts of negative feedback, the curve labeled Feedback 1 corresponding to one of these two adjustments and the curve labeled Feedback 2 corresponding to the other of these two adjustments. The three curves show how the gain varies with frequency as the amount of feedback is changed, and make it readily apparent that the gain variation with frequency is far less in the feedback condition. The gain includes that due to the input and output transformers. The line labeled "Operating range" in Fig. 3 extends from 4 kilocycles to 40 kilocycles to indicate that the amplifier is designed for operation over that frequency range.

Fig. 4 shows how negative feedback affects variations of the gain of this amplifier of Fig. 1 caused by variation of plate battery voltage. The curves of this figure were taken at 10 kilocycles, the upper curve with no feedback and the lower one with negative feedback. They show that the gain variations are reduced by the negative feedback—by an amount corresponding to the gain reduction at the frequency of measurement. This is 48 db. at 10 kilocycles as shown in the curve labeled Feedback 1 in Fig. 3.

Fig. 5 gives curves obtained with this amplifier of Fig. 1, showing the effect of negative feedback upon second harmonic and third harmonic, for the same outputs of fundamental (in milliamperes or watts) with feedback as without feedback. The curves taken without feedback are labeled "No feedback." The curves labeled Feedback 1 are taken with the same adjustment of the circuit as was used for the curve labeled Feedback 1 in Fig. 3. The frequency of the fundamental wave used in taking the curves of the second harmonics was 7.5 kilocycles; and the 75

fundamental frequency used in taking the third harmonic curves was 5 kilocycles. It can be seen that up to about 35 milliamperes output of fundamental, the negative feedback reduces the ratio of harmonics to fundamental by approximately the amount of the gain reduction. (The gain reductions at 7.5 kilocycles and at 5 kilocycles can be read from the curves labeled "No feedback" and Feedback I in Fig. 3.)

Fig. 6 gives the gain-load characteristics of the amplifier of Fig. 1 with and without feedback. The curve labeled Feedback I was taken at 10 kilocycles and with the same circuit adjustment as the curves labeled Feedback I in Fig. 5. The curves of Fig. 6 show that the negative feedback greatly reduces the change of gain with level. The output current is given in milliamperes into a fixed resistance as usual in such curves.

Fig. 7 shows curves representative of the gain stability of a single amplifier such as that of Fig. 1 as determined by an average of the variations in 69 such amplifiers connected in tandem (in a non-loaded carrier telephone cable circuit approximately 1700 miles long). In comparison of this figure with Fig. 2, which gives a plot of $\mu\beta$ for a large range of frequencies (for the amplifier of Fig. 1 which is representative of each of the 69 amplifiers in tandem) and the stability boundaries in Figs. 2, 3 and 4 of the parent patent, it will be noted that there are four frequencies for which $|\mu\beta|$ and Φ satisfy boundary "C" and result in perfect stability. Frequencies between approximately 200 cycles and 1300 cycles should all decrease in gain as the μ of the amplifier is increased; while frequencies between approximately 1300 cycles and 30,000 cycles should increase in gain with an increase in μ , and likewise frequencies between approximately 30,000 cycles and 200,000 cycles should decrease with any increase in μ . Fig. 7 demonstrates that the experimental evidence supports the theoretical deductions.

To illustrate how the amplifier of Fig. 1 operates on each of the other boundaries, D, E, G and I, these boundary lines have been drawn in or indicated on the polar plot of Fig. 2. From reference to that figure it is seen that the amplifier operates on boundary D at a frequency of approximately 200 cycles; on boundary E at two frequencies, respectively; just below 2 kilocycles and just above 30 kilocycles; on boundary G at approximately 12 kilocycles; and on boundary I at four frequencies, respectively, about 280 cycles, approximately 1900 cycles, approximately 31 kilocycles and approximately 180 kilocycles. Boundaries B and H are also indicated on this same figure but the measurements were not carried far enough to determine the relationship of the operating characteristic to either of these boundaries. It will be apparent from the curve, however, that with the proper circuit constants the amplifier could be made to operate at some one or more frequencies desired on either of these latter boundaries.

Fig. 8 shows curves of stability of gain with respect to varying plate voltage plotted as abscissae. Within the limits indicated on this figure, it is found that the decibel change in gain without feedback is substantially proportional to change in anode voltage, so that the curves on this plot should have substantially the same shape as those in Fig. 7. It will be seen that this is the case, considering that a more open scale is used for ordinates in Fig. 8. The plots

in Fig. 8 are also from data measured on 69 amplifiers in tandem, as in the case of Fig. 7, and show how much the gain varies with feedback for a given change in plate voltage which as stated is approximately proportional to the change in gain without feedback. A comparison of this Fig. 8 with the polar plot of Fig. 2 and the conditions for boundary "C" in Figs. 2, 3 and 4 of the parent patent shows the variations in stability with various values of $\mu\beta$. From Fig. 2 it can be seen that there are four frequencies for which the stability is perfect. Fig. 7 shows two of the cross-over points approximately 1300 cycles and 25,000 cycles.

What is claimed is:

1. A three stage amplifier comprising two voltage amplifier stages followed by a power stage, a negative feedback path from the output of the last to the input of the first stage feeding back a portion of the output waves in sufficient amount to improve the linearity of said amplifier substantially in proportion to the extent of the gain reduction due to the feedback, and a local negative feedback path for each of said voltage amplifier stages for stabilizing the gain introduced by these two stages.

2. An amplifier according to claim 1 for amplifying waves of a broad band of frequencies in which said local feedback path in each instance comprises an impedance from cathode to ground common to the input and output circuits of the respective stage and effective to reduce the gain of the respective stage substantially at all of the frequencies in said band.

3. In an amplifier subject to variations in gain from variations in circuit parameters and tending to distort the wave form of the waves being amplified, one gain reducing negative feedback path for stabilizing the gain substantially in proportion to the amount of reduction in gain produced by said feedback and another negative feedback path for reducing the distortion in said amplifier.

4. In an amplifier circuit, a space discharge device having a cathode, a grid and an anode, an output circuit therefor, a source of anode voltage having its negative terminal connected to ground, a signal input circuit connected between the grid and ground, means making the cathode potential above ground for both direct current and signal voltages, whereby the grid is supplied with degenerative signal and negative biasing voltages, and a negative feedback connection from the output side to the input side of said amplifier feeding back a portion of the output waves in sufficient amount to improve the linearity of said amplifier substantially in proportion to the extent of the gain reduction due to the feedback.

5. In an amplifier circuit comprising a plurality of stages, a feedback loop embracing a plurality of said stages for producing gain reduction in said stages and an individual gain reducing negative feedback path for one of the plurality of stages embraced by said loop for stabilizing the gain of said one stage substantially in proportion to the amount of reduction in gain produced by said individual feedback.

6. An amplifier comprising a voltage amplifying portion followed by a high current portion, said high current portion having a tendency to produce distortion in the amplified output current, both portions being subject to unstable operation, one gain reducing feedback around

both portions of said amplifier for improving linearity and stability and another gain reducing feedback around the voltage amplifying portion for improving the stability of said last-mentioned portion.

5 7. In a tandem stage amplifier comprising a voltage amplifying portion followed by a power stage, a gain reducing feedback connection from

the output of the power stage to the input of the voltage amplifying portion for improving the linearity and stabilizing the gain of said amplifier, and a separate gain-reducing feedback path around the voltage amplifying portion for further stabilizing the gain of that portion of the 5 amplifier.

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