

Dec. 22, 1942.

F. H. SHEPARD, JR

2,305,905

AMPLIFIER

Filed May 10, 1940

3 Sheets-Sheet 1

Fig. 1.

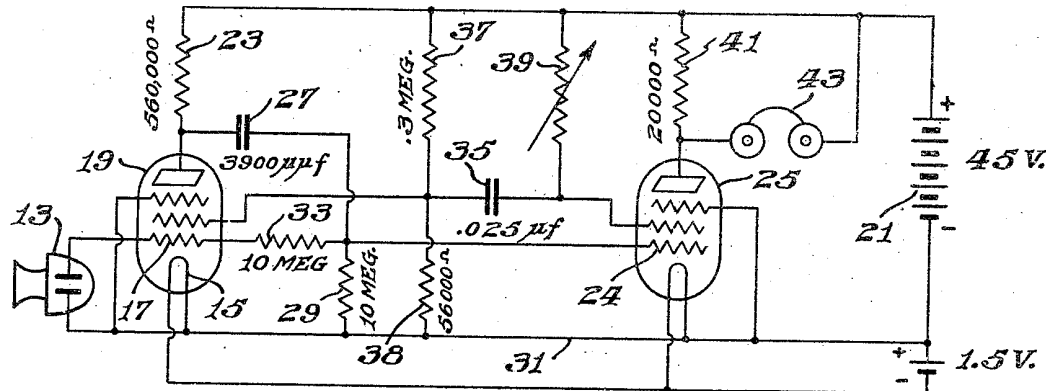


Fig. 2.

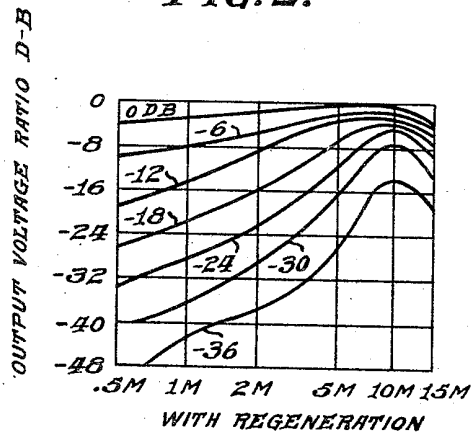


Fig. 3.

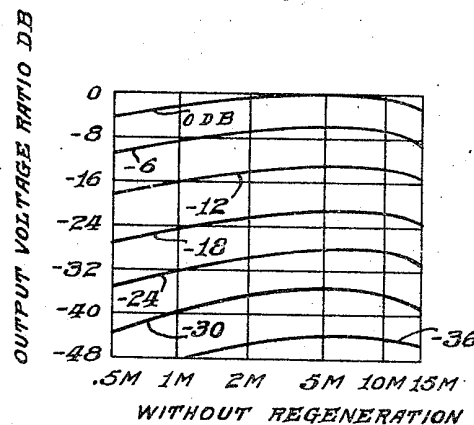


Fig. 4.

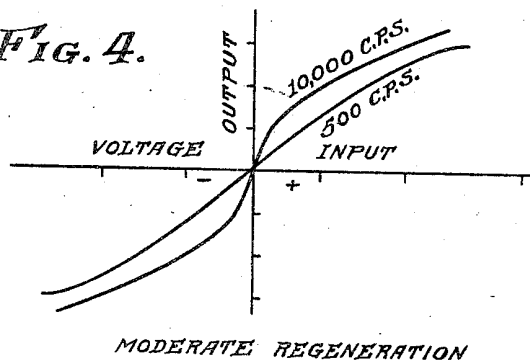
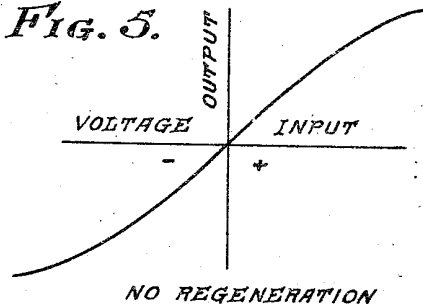


Fig. 5.



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38

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Filed May 10, 1940.

3 Sheets-Sheet 2

FIG. 6.

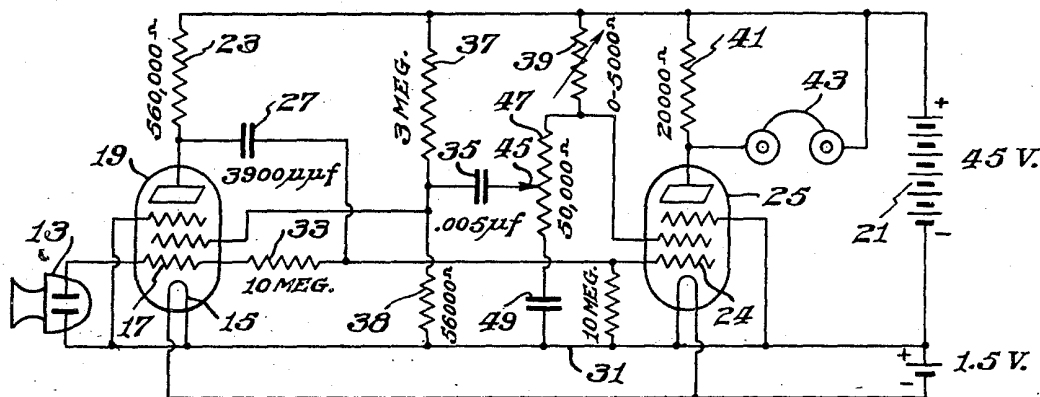


FIG. 7.

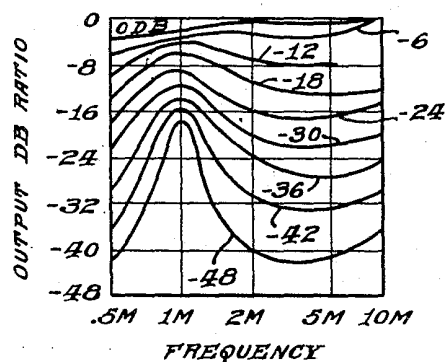


FIG. 8.

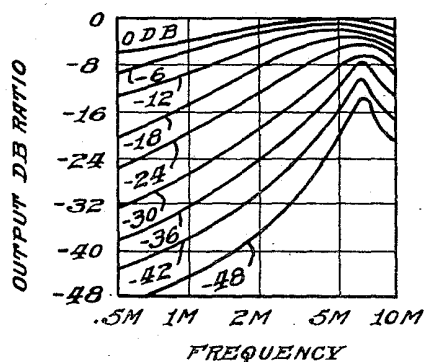
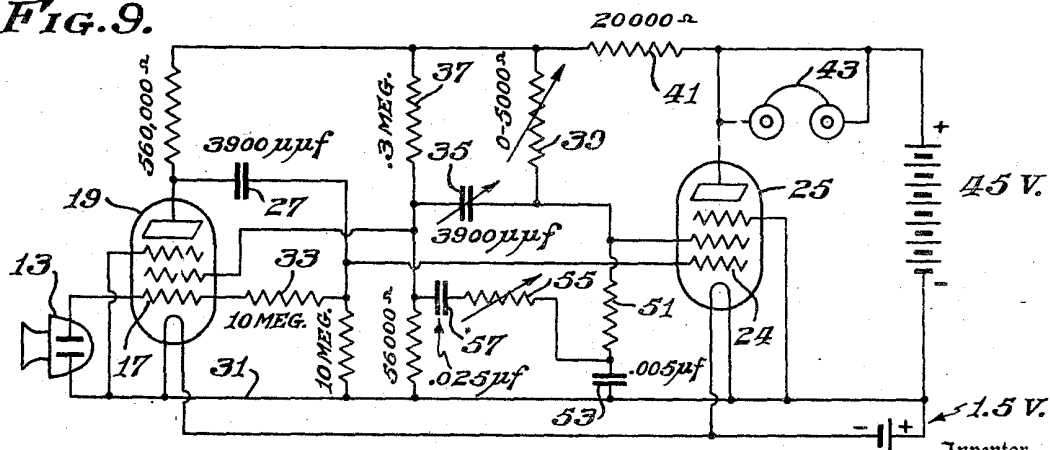


FIG. 9.

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2,305,905

AMPLIFIER

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3 Sheets-Sheet 3

FIG. 10.

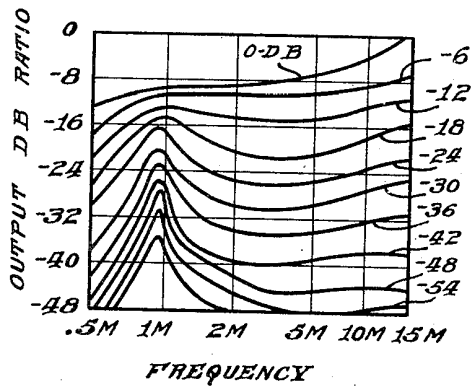
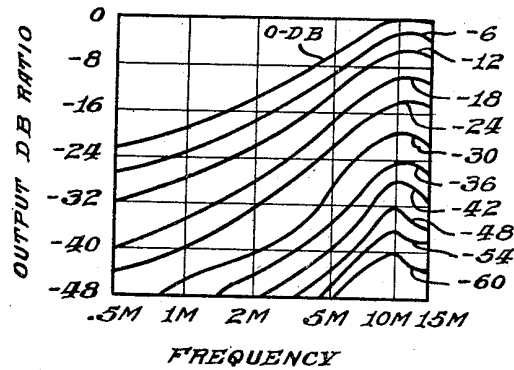


FIG. 11.



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UNITED STATES PATENT OFFICE

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Application May 10, 1940, Serial No. 334,312

1 Claim. (Cl. 179—171)

This invention relates to amplifiers, and more particularly to an improved amplifier which provides a high degree of amplification at selectable frequencies. One important use for such an amplifier is in connection with devices which are used to aid the hearing of the deaf.

One important requirement for a hearing aid is that the device must be sensitive and yet have a minimum of background noise. Background noise is due largely to a phenomenon known as tube hiss, although a considerable portion of the undesirable noise may originate in the use of a carbon button microphone or the like. It is therefore the principal object of this invention to provide a thermionic amplifier which is characterized by a minimum of background noise.

Another requirement that must be met in the design of a satisfactory hearing aid is that the device must have sufficient sensitivity to pick up sounds above a given minimum without overloading or blasting when the device is subjected to sounds of a considerably greater amplitude. Otherwise stated, an amplifier suitable for the indicated purpose must have an automatic volume control system which is rapidly responsive to extremely wide variations of sound intensity. The variations of sound intensity likely to be encountered vary from the amplitude of normal conversation at a distance of 30 feet or more, for example, to sounds of shouting or clapping of the hands directly in front of the microphone. It is, therefore, a further object of this invention to provide a thermionic amplifier having an efficient automatic volume control or compression system to protect the ears of the user from sudden near-by noises of excessive amplitude.

It is well known that the frequency response characteristic of the normal human ear is not linear and that in certain forms of deafness one portion of the response characteristic of the ear is affected more seriously than other portions, that is, certain types of deafness result from a failure of the ear mechanism to respond to sounds of certain definite frequencies. Consequently, a device which is designed to compensate for the deficiency of the affected ear should provide sound vibrations adjusted to the particular deficiency of the individual user's ear. Another object of this invention is to provide a hearing aid which includes a peaked amplifier having a frequency response characteristic which may be adjusted by a simple control device to compensate for the particular deficiencies of each individual user. For example, an amplifier is provided in which it is possible to shift the range of maximum

sensitivity to any point between, say, 500 and 10,000 cycles per second.

It is well known that the response characteristic of the human ear is different at different levels of sound intensity. In order to provide automatic compensation for this variation, it is a further object of this invention to provide a hearing aid in which the response characteristic is also a function of the input intensity of the received sound impulses, that is, the increase in sensitivity at the selected frequency should be greater at low sound levels than at higher sound levels.

In accordance with the present invention, the foregoing objects are accomplished by providing an amplifier having a nonlinear dynamic response characteristic. The slope of the instantaneous response characteristic at its center approaches infinity, giving high gain for low level signals while the slope of the characteristic at both extremities approaches zero, enabling the device to handle high level sounds without running into any abrupt discontinuity. In this respect, the device operates much as the human ear, and hence it will handle without apparent distortion to the listener sounds varying over the extremely wide intensity ranges and durations, especially when this characteristic is combined with a frequency compensating arrangement which is also provided.

The nonlinear dynamic characteristic is obtained by controlled regeneration. The regeneration control varies the slope of the characteristic near its center, thus boosting the sensitivity to the stronger sounds. Regeneration thus reduces the apparent perspective of the sound. The threshold of audibility can be set at will by adjusting the regeneration control which is provided. In addition, a unique A. V. C. circuit is provided in which the second amplifier produces a negative D. C. potential proportional to the amplitude of the input signal, which potential is applied directly to the control grid of the first amplifier tube.

It is to be understood that while the present invention will be described in a particular application as a hearing aid, the principles of amplifier compensation are applicable, as well, to various other types of amplifiers, such as those used in connection with public address systems, sound recording systems, radio receivers and the like.

The invention will be better understood from the following description when considered in connection with the accompanying drawings. Similar reference numerals refer to similar parts

throughout the several figures of the drawings.

Referring to the drawings, Figure 1 is the schematic diagram of an embodiment of this invention; Figures 2, 3, 4 and 5 are curves illustrating the operation of the device illustrated in Fig. 1; Figure 6 is the schematic diagram of a modification of this invention in which an adjustable peaking circuit is provided; Figures 7 and 8 are curves illustrating the operation of the device shown in Fig. 6; Figure 9 is the schematic diagram of an embodiment of this invention in which separate means are provided for producing low and high frequency peaks in the operating characteristic; and Figures 10 and 11 are curves illustrating the operation and adjustment of the device illustrated in Fig. 9.

Referring to Fig. 1, reference numeral 13 indicates a microphone which is preferably of the quartz crystal or Rochelle salt type. The use of such a microphone provides a substantial reduction over the minimum noise level which would be achieved by the use of a carbon button microphone. This microphone is connected between the cathode 15 and control grid 17 of a pentode amplifier tube 19. Being a high impedance device, it requires no coupling transformer. The microphone impedance varies with frequency, and, by way of example, is ordinarily of the order of 800,000 ohms at 100 cycles. The microphone being the equivalent of a 2,000 mmf. capacitor. The anode electrode is energized by a battery 21, or the like, to which it is connected through a plate load resistor 23.

The plate electrode of the first amplifier tube 19 is coupled to the control grid 24 of a second pentode amplifier 25 through a coupling capacitor 27. A high resistance grid leak 29 is connected between the control grid 24 and the common cathode connection 31.

A high impedance resistor 33 connected between control grids 17 and 24 of the two amplifier tubes provides the automatic volume control bias for the first amplifier tube. The impedance of the resistor 33 is high compared to the A. C. impedance of the crystal microphone 13. Consequently, only a small portion of the A. C. output voltage which is applied to the grid 24 of the second amplifier tube 25 is impressed on the grid 17 of the first amplifier tube as a degenerative feedback voltage. However, the negative D. C. potential developed by grid rectification in the second amplifier provides the first amplifier with a negative D. C. control bias whose amplitude is proportional to the input signal level.

The screen grid of the first amplifier tube is coupled to the screen grid of the second amplifier tube by coupling capacitor 35. D. C. bias for the two screen grids is provided by voltage divider 37, 38 and resistor 39, respectively, the latter being variable. The output circuit of the second amplifier tube includes a plate resistor 41 and an output device 43 such as a pair of headphones, or the like.

It is to be noted that the screen grid circuits are not maintained at ground potential, as is the usual case. The screen grid circuits, therefore, constitute a regenerative feedback coupling which operates in the following manner. Assuming that grid 24, at any particular instant, becomes slightly more positive, due to a signal voltage, for example, the resulting increase in the screen grid current flowing through resistor 39 will cause the potential of the screen grid to become less positive. This negative impulse is impressed on the screen grid of the first ampli-

fier tube through capacitor 35. In the first amplifier tube, when the screen becomes less positive, the anode current through resistor 23 decreases causing an increase in the anode potential. This increase is then impressed on the grid of the second amplifier tube through capacitor 27. Since the voltage induced on grid 24 through the feedback circuit is in phase with the original voltage, it will be appreciated that a regenerative action is present. The circuit is prevented from breaking into sustained oscillations by suitably adjusting the value of resistor 39. For example, this resistor should be of the order of 5,000 ohms maximum.

The particular frequency at which maximum feedback occurs is determined by the circuit constants chosen. When capacitor 35 has a value of .025 microfarad, for example, resistor 37 is of the order of 0.3 megohm, and resistor 38 approximately 56,000 ohms, the operating characteristics of the amplifier will be similar to those illustrated in Fig. 2, to which reference is now made.

Fig. 2 represents a family of output curves taken for various values of input voltage throughout a range of frequency extending from 500 cycles to 15,000 cycles. The ordinate of the curve as plotted is the output voltage ratio in decibels. The various curves are taken for various input voltages between zero and minus 36 db. It will be noted that the minus 36 db. curve has a substantial peak at 10,000 cycles, while the output at 500 cycles is a minimum. The mid-range curve corresponding to minus 18 db., for example, is also peaked at 10,000 cycles, but does not fall off as rapidly as the frequency is decreased, and at 500 cycles has considerably greater amplitude than the curves corresponding to the lower levels of input voltage. The falling off, at the high frequency end, is due to the effect of shunt tube and circuit capacities. These curves are to be compared with the curves illustrated in Fig. 3 which represent similar operating characteristics for the amplifier without regenerative feedback. It will be noted that in the latter case, that is in the case without regeneration, the amplifier output is substantially constant over the illustrated frequency range and is also directly proportional to the input voltage.

Figs. 4 and 5 are dynamic characteristic curves corresponding to the operation of the amplifier with and without regeneration, respectively. Thus, it may be seen that for the case where the amplifier is peaked at 10,000 cycles, the slope of the input versus output voltage curve is a maximum in the vicinity of the zero input point and decreases as the input increases, the curve being substantially exponential. That is to say, the amplifier gain is a maximum for low values of input voltage, as has been pointed out above, since at that point the regenerative action is most effective. At the lower frequency, however, the curve is a substantially straight line, since the output voltage is then nearly proportional to the input voltage. The curve at the low frequency end of the range is similar to the dynamic characteristics of the amplifier without regeneration, which is illustrated in Fig. 5.

Fig. 6 illustrates an embodiment of the invention in which means are provided for adjusting the frequency at which the peak response occurs to any point within the desired range. The circuit is essentially identical to that illustrated in Fig. 1 and need not be described again in detail. As before, the degree of feedback is con-

trolled by the screen resistor 39. The frequency at which feedback occurs in the present instance, however, is determined by the position of the movable arm 45 of a potentiometer 47, one end of which is connected to the screen grid of the second amplifier tube 25, the other end of which is connected through a capacitor 49 to the common cathode return 31. The capacitor 35 couples the movable arm 45 of the potentiometer to the screen grid of the first amplifier tube.

The function of the potentiometer 47 and capacitor 49 is to permit the desired frequency characteristic to be selected. Thus, when the potentiometer arm is placed at the low end of the potentiometer, the maximum regeneration occurs in the low frequency range as illustrated in Fig. 7. The reason for this is that high frequency voltages are bypassed to the common cathode connection through the capacitor 49. When the contact arm 45 is placed at the high or grid end of the potentiometer, the bypassing effect of this capacitor is removed and maximum feedback occurs at the high frequency voltage which has been determined by the circuit constants as in the case illustrated in Figs. 1 and 2. By suitably adjusting the potentiometer it is, therefore, possible to obtain maximum gain at any frequency within the operating range of the amplifier as indicated by Figs. 7 and 8.

A still further modification of this invention is illustrated in Fig. 9, to which reference is now made. The circuit is essentially the same as that illustrated in Fig. 1. However, the features of Fig. 6 have been combined with the arrangement of Fig. 1 to produce an amplifier which may be peaked at two separate frequencies to produce either separate response peaks or to provide substantially constant amplification throughout a desired range.

As in the case of Fig. 1, the screen grid of the second amplifier 25 is directly coupled to the screen grid of the first amplifier 19 by means of a coupling capacitor 35, the value of which, in the present instance is approximately 3900 micro-microfarads. In addition, a second coupling circuit is provided which includes a resistor 51 serially connected with a capacitor 53 between the grid of the second amplifier tube 25 and the common cathode connection 31. The point intermediate resistor 51 and capacitor 53 is connected to the screen grid electrode of the first amplifier tube through a variable resistor 55 and a coupling capacitor 57. The value of capacitor 53 may be, for example, of the order of .005 microfarad, while the value of capacitor 57 may be of the order of .025 microfarad.

Capacitor 35 provides a regenerative feedback voltage which produces a peak around 10,000 cycles similar to that provided by the corresponding capacitor of Fig. 1. In addition, a

second feedback path is provided which provides more or less feedback voltage in the low frequency range only. That is, by decreasing the resistance of the variable resistor 55, the maximum low frequency feedback is produced, by increasing its resistance the low frequency feedback may be substantially eliminated. In each case, the automatic volume control circuit functions in the manner described in connection with Fig. 1.

Various operating curves which may be achieved are illustrated in Figs. 10 and 11. These curves are similar to those described in greater detail in connection with Figs. 1 and 2, and are believed to be self-explanatory. Briefly, Fig. 10 illustrates the response characteristics of the amplifier for various input voltages when adjusted for compensation at low frequencies. Fig. 11 represents similar resonance characteristics for the amplifier when the low frequency feedback circuit has been adjusted for minimum response. Thus, the amplifier can be peaked broadly at both ends of the frequency response characteristic, and can have a substantially flat characteristic between the peaks. By adjusting the positions and relative heights of the two peaks, almost any type of frequency characteristic can be obtained. The amplifier can thus be made complementary to the deficiencies in the hearing of most deaf people. This type of frequency compensation avoids the unpleasant blasting or overloading common to prior methods of boosting any desired frequency range. When the amplifier characteristic is thus adjusted to complement the normal hearing characteristic (Fletcher's curves) for frequency and volume and to compensate for the well-known greater attenuation of the high frequencies, all sounds appear to occur right next to the listener.

I claim as my invention:

An amplifier comprising a pair of thermionic discharge devices having cathode, grid, screen grid and anode electrodes, means for applying input voltages between the cathode and grid electrodes of the first of said tubes, means coupling the anode of the first amplifier tube to the grid electrode of the second amplifier tube, a resistor interconnecting the grid electrodes of said tubes directly from grid to grid for applying the negative direct current potential developed by grid rectification in the second amplifier tube to the grid of said first amplifier tube, a variable resistance-capacity network coupled between said screen grid electrodes providing regenerative feedback between said tubes in response to signals at a predetermined frequency, said network providing operation of said screen grid electrodes above ground audio frequency potential, and output means coupled to the anode electrode of said second tube.

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