March 29, 1932. R. S. HAYES 1,851,905

VACUUM TUBE AMPLIFYING CIRCUITS

Filed Nov. 30, 1927 2 Sheets-Sheet 1

Fig. 1.

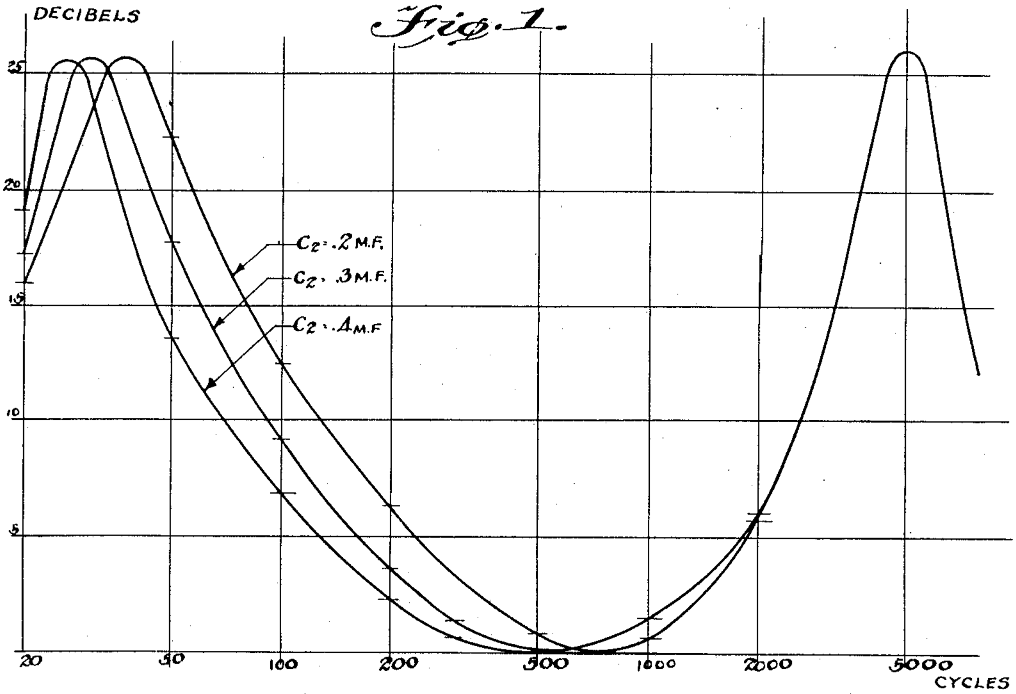
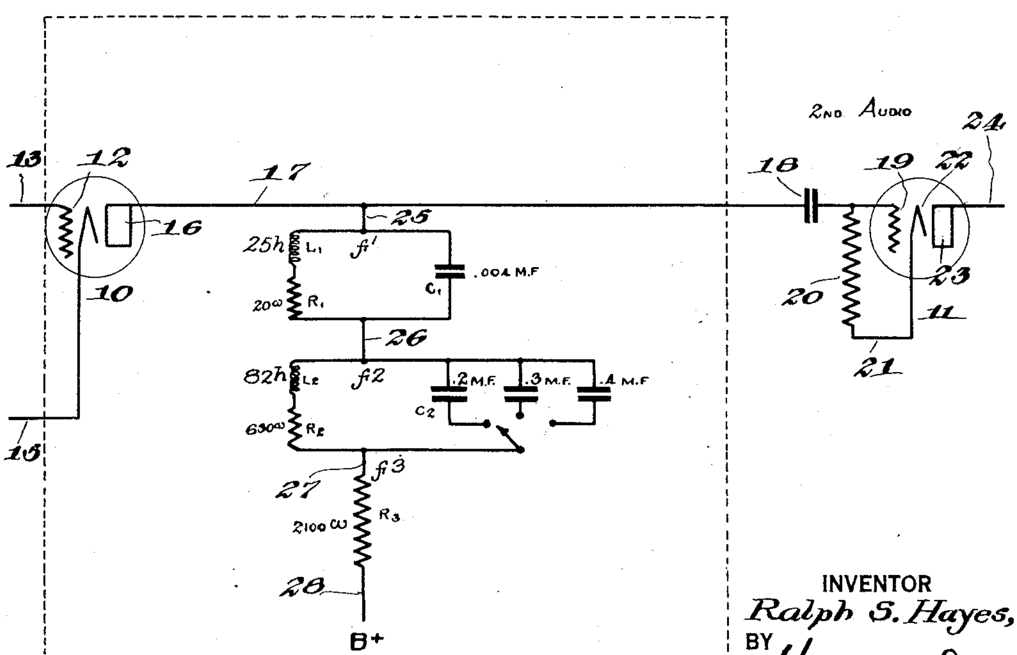


Fig. 2.



INVENTOR
Ralph S. Hayes,
BY
Munn & Co.
ATTORNEY

March 29, 1932. R. S. HAYES 1,851,905

VACUUM TUBE AMPLIFYING CIRCUITS

Filed Nov. 30, 1927 2 Sheets-Sheet 2

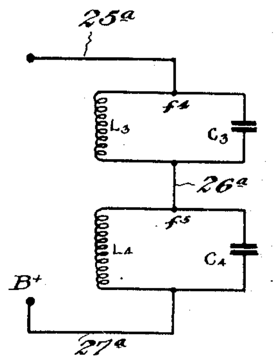


Fig. 3.

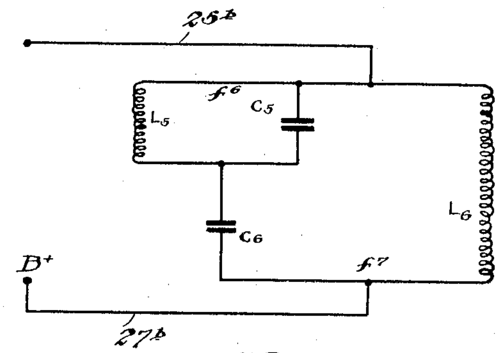


Fig. 4.

Fig. 5.

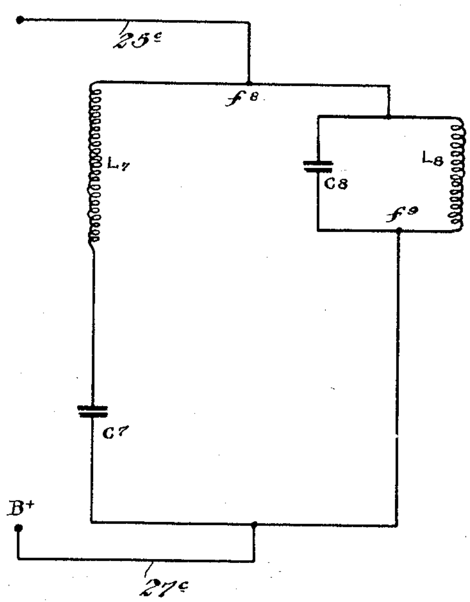
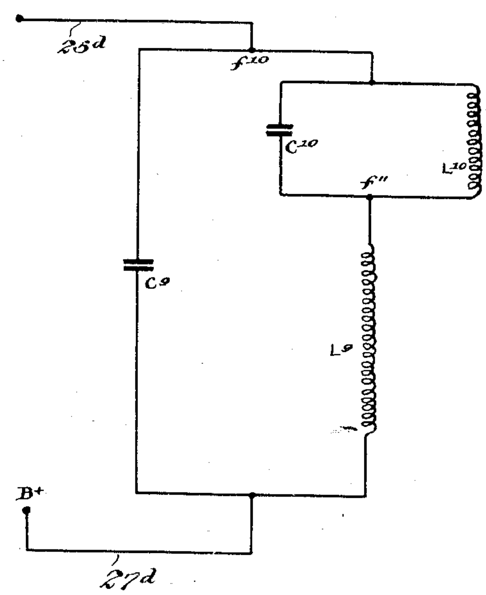


Fig. 6.



INVENTOR
Ralph S. Hayes,
BY
Munn & Co.
ATTORNEY

Patented Mar. 29, 1932 **1,851,905**

UNITED STATES PATENT OFFICE

RALPH S. HAYES, OF ARDMORE, PENNSYLVANIA

VACUUM TUBE AMPLIFYING CIRCUITS

Application filed November 30, 1927. Serial No. 236,804.

This invention relates to improvements in vacuum tube amplifying circuits generally, and more particularly to a new and improved method of obtaining a desired non-linear gain-frequency characteristic in vacuum tube amplifiers employed in certain radio receiving and phonograph pick-up circuits.

In the present and known types of radio receiving sets, it is a well recognized fact that the very high tones and the very low tones from broadcasting stations are reproduced poorly, and this has been found to be due to the usual flat audio amplifier characteristics of such sets disclosing a marked deficiency from perfect tone production or reproduction, which is caused by certain inherent forms of frequency distortions, wherein the higher tones are lost by reason of radio frequency tuning, which is called side-band cutting, and of the relatively poor efficiencies of loud speakers at the higher tones; and the lower tones by reason of the intentional softening down of the bass instruments at the broadcasting stations or studios, of the comparatively attenuated transmission of such tones through the amplifiers of many stations, and of the relatively poor efficiencies of loud speakers or the pick-up attachments for phonographs for the bass tones. Although these facts have been known in the practice, no attempt has heretofore been made commercially to correct or cure both these deficencies, principally on account of the complex apparatus thought to be necessary or required for the purpose, not only in the audio but also in the radio frequency part of the system.

It is, therefore, the principal object of the invention to provide for a simple and comparatively inexpensive method and means for effectively overcoming the serious disadvantages occasioned by the present intentional softening down of the low tones of the bass instruments in broadcasting stations or studios as aforesaid, and the unnecessary deficiencies in receiving sets to properly and perfectly reproduce both the high and low tones from such stations or studios.

Another object of the invention is to provide for a method and means as hereinbefore generally characterized, wherein the usual flat audio frequency characteristics of radio receiving sets will be modified into "dished" gain-frequency characteristics, such as will greatly improve the quality of tone reproduction and otherwise correct or compensate for the deficiencies aforementioned throughout the range of the higher and the lower frequencies, providing, in other words, a tone control circuit.

A further object of the invention is to provide for an equalizing stage of audio frequency amplification to be used in connection with radio receiving circuits as and for the purposes aforesaid and also in connection with electrical pick-ups for phonographs.

In carying out the present invention, the equalizing stage of audio amplification under contemplation is constituted in a stage of doubly tuned audio frequency amplification, having two frequencies of maximum gain, which are obtained by the parallel resonance of two tuned parallel or tandem circuits, and one frequency of minimum gain obtained by the resonance of the smaller inductance with the larger capacity. This double parallel resonance circuit has the unique and appropriate qualities to accomplish the desired results, in that it gives two peaks in the amplification curve, dependent upon the parallel resonant frequencies selected therefor and a minimum point between the two peaks dependent on the series resonant frequency. The invention includes a higher tuned circuit and a lower tuned circuit, and at one particular frequency there is a series resonant effect of minimum gain created by the inductance of the higher tuned circuit, and the capacity of the lower tuned circuit. In the practical application of the invention, a wide range of selective constants are available to give the proper parallel resonant and series resonant frequencies.

With the foregoing and other equally important objects, purposes and advantages in view, the invention resides in the certain new and useful combinations and arrangements of instrumentalities and circuits as will be hereinafter more fully described, set forth in the appended claims, and illustrated in the accompanying drawings in which:

Figure 1 is a plot of the gain frequency characteristic of the equalizing amplifier stage in accordance with the exemplified application of the invention,

Figure 2 is a preferred circuit arrangement, and

Figures 3, 4, 5 and 6 are slightly modified but equivalent net works or circuit arrangements.

Referring to the drawings, wherein similar characters of reference designate corresponding elements or parts throughout the several views thereof, and more particularly to Figure 2, 10 and 11 indicate two three-electrode vacuum tubes constituting preferably the first and second stages of audio frequency amplification of a conventional form of radio receiving circuit. In this particular circuit the grid 12, of the tube 10, is connected by a conductor 13, and the filament 14 thereof by a conductor 15 for the application thereto of a band of audio frequencies from a suitable source (not shown). The plate 16, of the tube 10, is, in turn, connected by a conductor 17 through an interposed condenser 18 to the grid 19 of the tube 11. Connected to the conductor 17 at a point between the condenser 18 and the grid 19 is one end of a resistance 20, from the opposite end of which a conductor 21 leads to and connects with the filament 22 of the tube 11. The resultant amplified frequencies from the tubes 10 and 11 are available from the plate 23, of the tube 11, through the conductor 24 leading from the plate 23.

To create the two peaks in the impedance or audio amplification curve, as aforesaid, the invention contemplates the provision of two parallel resonant circuits, designated f^1 and f^2, coupled in tandem or in series parallel, as shown in Figure 2. One side of the circuit f^1 is coupled by a conductor 25 to the conductor 17, between the plate 16, of the tube 10 and the condenser 18, and this circuit includes an inductance L_1, a resistance R_1 and a condenser C_1, all connected in series in a local circuit. The conductor 25 connects the circuit f^1 at a point between the condenser C_1 and the inductance L_1. The opposite side of the circuit f^1, between the resistance R_1 and the condenser C_1 is connected by a conductor 26 to one side of the second circuit f^2, which consists of the inductance L_2, the resistance R_2 and a variable condenser C_2. The conductor 26 connects the circuit f^2 between the inductance L_2, and the condenser C_2, while a conductor 27 leads from this circuit from a point between the resistance R_2 and the condenser C_2. R_1 and R_2 represent the necessary coil resistance in the coupled circuits f^1 and f^2. The conductor 27 is lead to and is connected with one terminal of a resistance R_3, which has its other terminal connected by a conductor 28 to be connected to the positive side of a "B" battery (not shown). The circuit f^1 is preferably designed to tune to approximately 5000 cycles, and the circuit f^2 to approximately 40 cycles.

To obtain the desired "dished" gain-frequency characteristic necessary to improve the quality of tone reproduction in accordance with the present invention, which characteristic should, preferably, be flat from about 200 cycles to 1000 cycles, and rise at each end of this band 25 or more decibels to a maximum at about 40 cycles, and at 5000 cycles, two peaks are desired or necessary in the impedance frequency curve, and these are produced by the two circuits f^1 and f^2 coupled in tandem or series parallel substantially as shown. Further, the 5000 cycle tuned circuit f^1 should have a ratio of

$$\frac{L}{C}$$

not too large nor too small, since the sharpness of resonance varies at this ratio, also, the minimum impedance of the two circuits f^1 and f^2 should be between 200 and 700 cycles, since the frequency of this minimum impedance is determined by the resonant point of the impedance L_1 of the 5000 cycle parallel circuit f^1 with the capacity C_2 of the 40 cycle circuit, which capacity C_2 should preferably be between .2 mf. and .4 mf. Having determined the value of C_2, the value of L_2 can be determined from the fact that L_2 and C_2 must be resonant at approximately 40 cycles. Finally, this resistance R_3, in the circuit f^3, which is connected in series with the two resonant circuits f^1 and f^2, serves to flatten out the resonant minimum gain of the stage. The resistance in the inductances R_1 and R_2 of the two parallel circuits f^1 and f^2, as would be used for such an equalizing stage, as herein contemplated, have been found to have a negligible effect, and taking into account rather large resistances as compared to computations neglecting such resistances, the following tendencies have been noted (*a*) that there is a slight reduction in the maximum gain, and (*b*) a comparatively slight increase in minimum gain.

As an example of the practical application of the invention, after having determined the gain of an amplifier stage to be approximately:

$$\text{Voltage amplification} = \frac{\mu Z}{Z + r_p}$$

where μ= tube amplification constant; Z= impedance of the output circuit; and r_p=plate resistance of the tube. It was evident that the gain of a stage could be designed to vary with frequency by suitably choosing the output impedance Z, since μ and r_p are constants of the tube, and in a high mu type of tube, as an instance, these constants are approximately 20 and 40000, respectively. Now, by trial computations, it was found that L_1 should be from .25 to .50 henry for proper results, but, for present purposes, L_1, in the circuit f^1 (Figure 2) is indicated at a value of .25 henry, and C_1 at .00404 mf., tuning to 5000 cycles, while in the circuit f^2, L_2 has been taken at a value of 82 henries, for convenience, and C_2 in three steps having values of .2; .3 and .4 mf. The resistance R_3, in series with the two circuits f^1 and f^2, and serving to flatten out the resonant minimum gain of the stage, has been indicated at a value of 2100 ohms in order to show a minimum gain of zero.

The values of the several condensers C, impedances Z and the resistance R; the frequencies, both resonant and anti-resonant, obtaining in the circuits f^1 and f^2, and of the gains with the condensers of different rating in circuits f^2 are to be computed as follows, by way of example:—

1. Coupling resistance (R_3) for zero gain

$$\text{Gain} = \frac{\mu Z}{Z + r_p}$$

$$I = \frac{20\,R_3}{R_3 + 40000}$$

$$R_3 = 2100\omega \text{ ohms}$$

2. Resonant frequencies for 40 cycle circuit

(a) Assuming $C_2 = .2$

$$f^2 = \frac{1000}{6.28\sqrt{82\,x\,.2}} = 38 \text{ cycles}$$

(b) Assuming $C_2 = .3$

$$f^2 = \frac{1000}{6.28\sqrt{82\,x\,.3}} = 32 \text{ cycles}$$

(c) Assuming $C_2 = .4$

$$f^2 = \frac{1000}{6.28\sqrt{82x\,.4}} = 28 \text{ cycles}$$

3. Resonant frequencies of L_1 with C_2

(a) Assuming $C_2 = .2$

$$f^3 = \frac{1000}{6.28\sqrt{.25x.2}} = 710 \text{ cycles}$$

(b) Assuming $C_2 = .3$

$$f^3 = \frac{1000}{6.28\sqrt{.25x.3}} = 580 \text{ cycles}$$

(c) Assuming $C_2 = .4$

$$f^3 = \frac{1000}{6.28\sqrt{.25x.4}} = 500 \text{ cycles}$$

4. The impedance Z_1 of a parallel resonant circuit is computed by the usual formula for the impedance of an inductance in parallel with a capacity (neglecting coil resistance), i. e.—

$$Z = \frac{j(2\pi f L)}{(1-(2\pi f)^2 LC}$$

Such calculations result in the following impedance values for the various tuned circuits at various frequencies, where—

Z_1 = impedance of 5000 cycle tuned circuit,

Z_{2a} = impedance of 40 cycle tuned circuit with $C_2 = .2$ mf.,

Z_{2b} = impedance of 40 cycle tuned circuit with $C_2 = .3$ mf.,

Z_{2c} = impedance of 40 cycle tuned circuit with $C = .4$ mf.

f	Z_1	Z_{2a}	Z_{2b}	Z_{2c}
20	$31.4/\underline{90}$	$13900/\underline{90}$	$16900/\underline{90}$	$21700/\underline{90}$
50	$78.5/\underline{90}$	$41700/\overline{90}$	$18200/\overline{90}$	$10500/\overline{90}$
100	$157/\underline{90}$	$9340/\overline{90}$	$5950/\overline{90}$	$4290/\overline{90}$
200	$314/\underline{90}$	$4130/\overline{90}$	$2720/\overline{90}$	$2020/\overline{90}$
300	$472/\underline{90}$	$2710/\overline{90}$	$1790/\overline{90}$	$1340/\overline{90}$
500	$793/\underline{90}$	$1600/\overline{90}$	$1070/\overline{90}$	$794/\overline{90}$
1000	$1630/\underline{90}$	$793/\overline{90}$	$535/\overline{90}$	$397/\overline{90}$
2000	$3750/\underline{90}$	$396/\overline{90}$	$265/\overline{90}$	$198/\overline{90}$
5000	$00/\underline{90}$	$159/\overline{90}$	$106/\overline{90}$	$79/\overline{90}$
8000	$8130/\overline{90}$	$99/\overline{90}$	$66/\overline{90}$	$50/\overline{90}$

5. The voltage amplification and the equivalent gain in decibels are computed from the relations:—

$$\text{Voltage amplification} = \frac{\mu Z}{Z r_p},$$

$$\text{Decibels} = 20 \log \frac{\mu Z}{Z r_p}.$$

Using the previously mentioned value of R_3, 2100 ohms, and mu equals 20, there results the following decibels gain for the entire amplifying stage for the three values of C_2:—

f	C_2=.2 mf.	C_2=.3 mf.	C_2=.4 mf.
20	16.1	17.5	19.3
50	23.0	18.0	13.8
100	12.8	9.3	6.9
200	6.3	3.6	2.2
300	3.2	1.4	.7
500	.7	0	0
1000	.7	1.0	1.3
2000	5.5	5.7	5.9
5000	26.1	26.1	26.1
8000	12.0	11.9	12.0

In the use of this equalizing stage, the following agreeable impressions obtain, (a) an effective sharpening of the radio frequency tuning at the cut-off frequencies, which gives the effect of band-pass radio frequency tuning in a simpler manner; (b) the bass fundamentals are reproduced with an appreciable increase of the naturalness in reception; (c) a natural sparkle and brilliancy to the program due to the improved reproduction of the higher harmonics; (d) in speech reception, the sounds Z, S, F, TH and V are reproduced with clearness and better understanding; (e) a feeling is experienced of volume without loudness, and (f) an apparent increase in the broadcasting station or studio reverberation, which gives somewhat of a binaural effect to the reproduction.

It is to be noted that the equalizing stage, as designed, assumes a flat characteristic from the broadcasting station, which, however, is not always the case, but, if the low tones are only partially transmitted, the using of the lower values of C_2 is of considerable benefit. Again, if there is an over emphasis of the higher tones from the broadcasting station, as sometimes may be the case, then the 5000 cycle circuit f^1 of the equalizing stage should be partially shunted by a resistance.

In fact, by a proper selection of the constants of the circuits, by partially shunting the circuits with resistances to dampen their effect, any desired variation of the "dished" gain frequency characteristic may be obtained.

It is to be further noted that full benefit from this equalizer stage cannot be obtained without sufficient power handling capacity in the final power amplifier and in the loud speaker.

In Figures 4, 5 and 6, are shown net works or circuits coupled in series parallel or in tandem, each of which net works have been found to be substantially equivalent to the two parallel resonant circuits f^1 and f^2, as illustrated in Figures 2 and 3.

In Figure 4, the lead 25*b* connects a conductor extending between one terminal of an impedance coil L_5, of a by-pass condenser C_5, in the circuit f^6, and an impedance coil L_6, in the circuit f^7, with its point of connection being preferably between the terminal of the condenser C_5 and that of the impedance coil L_6. The other terminals of the impedance coil L_5 and the condenser C_5 being connected one to the other by a conductor, which, in turn, is, at an intermediate point, connected to one terminal of a condenser C_6, in the circuit f^7. The remaining terminal of the latter condenser C_6 being, in turn, connected by a conductor to the other terminal of the impedance coil L_6. A conductor 27*b* from plus "B" battery is connected to the last-mentioned conductor of the circuit f^7 at an intermediate point on the same conductor between the condenser C_6 and the impedance coil L_6.

In Figure 5, the lead 25*c* connects a conductor extending between a terminal of an impedance coil L_7, in the circuit f^8, and an intermediate point of connection with a conductor forming one side of the circuit f^9, the latter conductor being extended between and connected to one terminal of a condenser C_8 and of an impedance coil L_8. The other terminal of the impedance coil L_7 is connected to one terminal of a condenser C_7, in the circuit f^8, while the remaining terminal of the latter condenser C_7 is, in turn, connected to an intermediate point on a conduction extending between the remaining terminals of the condenser C_8 and the impedance coil L_8 of the circuit f^9. The conductor 27*c* leads from plus "B" battery to and connects the last-named conductor of the circuit f^9.

In Figure 6, the conductor 25*d* leads to and connects a conductor extending from one terminal of a by-pass condenser C_9, of the circuit f^{10}, to and connecting an intermediate point on a conductor extending between one terminal of a condenser C_{10} and of an impedance coil L_{10}, of the circuit f^{11}. The other terminal of the condenser C_9, of the circuit f^{10}, is connected by a conductor to one terminal of an impedance coil L_9, which has its other terminal connected to an intermediate point on a conductor extending between the remaining terminals of the condenser C_{10} and the impedance coil L_{10}, of the circuit f^{11}. The conductor 27*d* leads from plus "B" battery, and connects an intermediate point on the conductor extending between the condenser C_9 and the impedance coil L_9 of the circuit f^{10}.

In employing any one of these modified equalizing circuits with a receiving circuit hook-up, as described in conjunction with the first or preferred form of equalizing stage or circuit, the conductors 25*a*, 25*b*, 25*c* or 25*d* will be connected to the bus-wire or conductor 17 after the manner of the conductor 25, and the conductors 27*a*, 27*b*, 27*c* and 27*d* to the plus "B" battery connections of the said hook-up aforesaid, after the manner of the conductor or lead 27.

It is to be noted of these modified circuits that, after determining the proper values of the several capacities, impedances and resistances comprising the same, in accordance with the usual computations of such values and in the manner of the examples given in connection with the first instance of the invention, the same are capable of being substituted, with equal efficiency in use, one for the other or for the first of the similar circuits described herein.

Without further description, it is thought that the features and advantages of the invention will be readily apparent to those skilled in the art, and it will of course be understood that changes in the form, proportion and minor details of construction may be resorted to, without departing from the spirit of the invention or its scope as claimed.

Having thus fully described the invention, what is claimed is:

1. In a radio receiving system, means for equalizing the audio amplification of the system, comprising an auxiliary stage of audio frequency amplification formed of circuits electrically connected together and coupled in on the output side of the usual audio frequency amplifying means of the said system, said circuits being tuned in such a manner that peaks spaced relatively far apart and

corresponding in number to that of said circuits are produced in the impedance curve of the system, which act to modify the usual flat audio frequency characteristic of the system into a "dished" gain-frequency characteristic.

2. In a radio receiving system, means for equalizing the audio amplification of the system, comprising an auxiliary stage of audio frequency amplification formed of two resonant circuits electrically connected together and coupled in on the output side of the usual audio frequency amplifying means of the said system, said circuits being tuned in such a manner that two peaks spaced relatively far apart are produced in the impedance curve of the system, which act to modify the usual flat audio frequency characteristic of the system into a "dished" gain-frequency characteristic.

3. In a radio receiving system, means for equalizing the audio amplification of the system, comprising an auxiliary stage of audio frequency amplification formed of two resonant circuits electrically connected together in series-parallel and coupled in on the output side of the usual audio frequency amplifying means of the system, said circuits being tuned in such a manner that two peaks spaced relatively far apart are produced in the impedance curve of the system, which act to modify the usual flat audio frequency characteristic of the system into a "dished" gain-frequency characteristic.

4. In a radio receiving system, means for equalizing the audio frequency amplification of the system, comprising an auxiliary stage of audio frequency amplification formed of a plurality of resonant circuits electrically connected together in series-parallel and coupled in on the output side of the usual audio frequency amplifying means of the said system, said circuits being tuned in such a manner that the interaction thereof will produce peaks at different ends of the resonance band in the impedance curve of the system, which modify the usual flat audio frequency characteristic of the system into a "dished" gain-frequency characteristic.

5. In a radio receiving system, means for equalizing the audio frequency amplification of the system, comprising an auxiliary stage of audio frequency amplification formed of a resonant circuit tuned to a high frequency and a second resonant circuit tuned to a comparatively low frequency, said circuits being electrically connected together in series-parallel and coupled in on the output side of the usual audio frequency amplifying circuit of the said system, whereby two peaks are produced in the impedance curve of the system, which act to modify the usual flat audio frequency characteristic of the system into a "dished" gain-frequency characteristic.

6. In a radio receiving system, means for equalizing the audio frequency amplification of the system, comprising an auxiliary stage of audio frequency amplification formed of resonant circuits having different impedance and capacity values, said circuits being electrically connected together in series-parallel and coupled in on the output side of the usual audio frequency amplifying circuit of the said system, and tuned in such a manner that two peaks spaced relatively far apart are produced in the impedance curve of the system which act to modify the usual flat audio frequency characteristic of the system into a "dished" gain-frequency characteristic.

Signed at Philadelphia in the county of Philadelphia and State of Pennsylvania this 21st day of November, A. D. 1927.

RALPH S. HAYES.