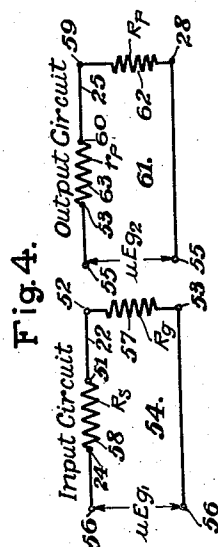
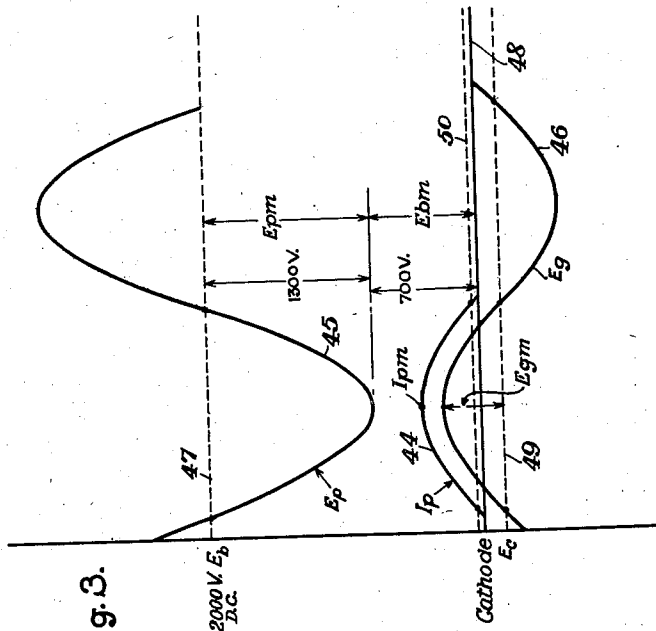
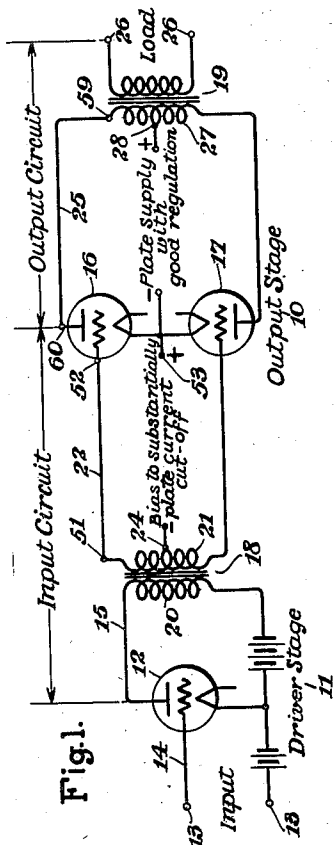
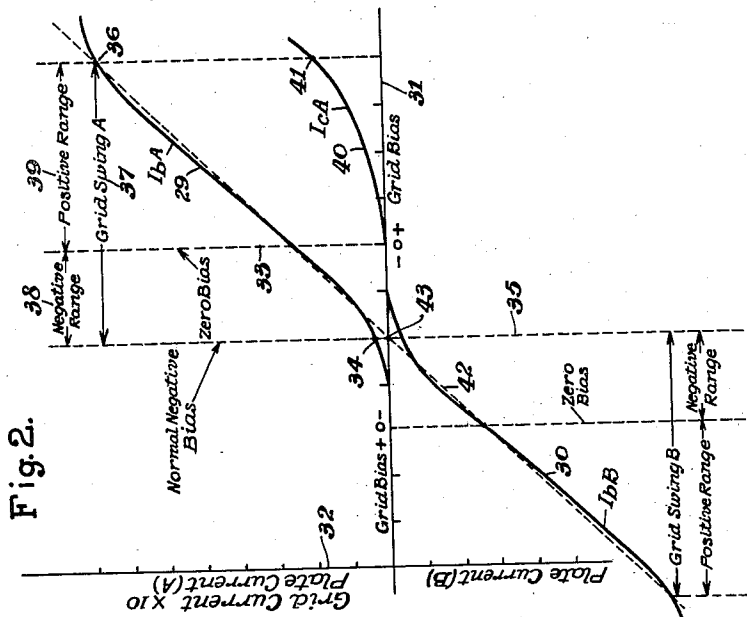


June 15, 1937.

L. E. BARTON
RADIO SIGNALING SYSTEM
Filed Jan. 15, 1932

2,084,180

3 Sheets-Sheet 1



INVENTOR.
Loy E. Barton.
BY *J. R. Goldsborough*
ATTORNEY.

June 15, 1937.

L. E. BARTON

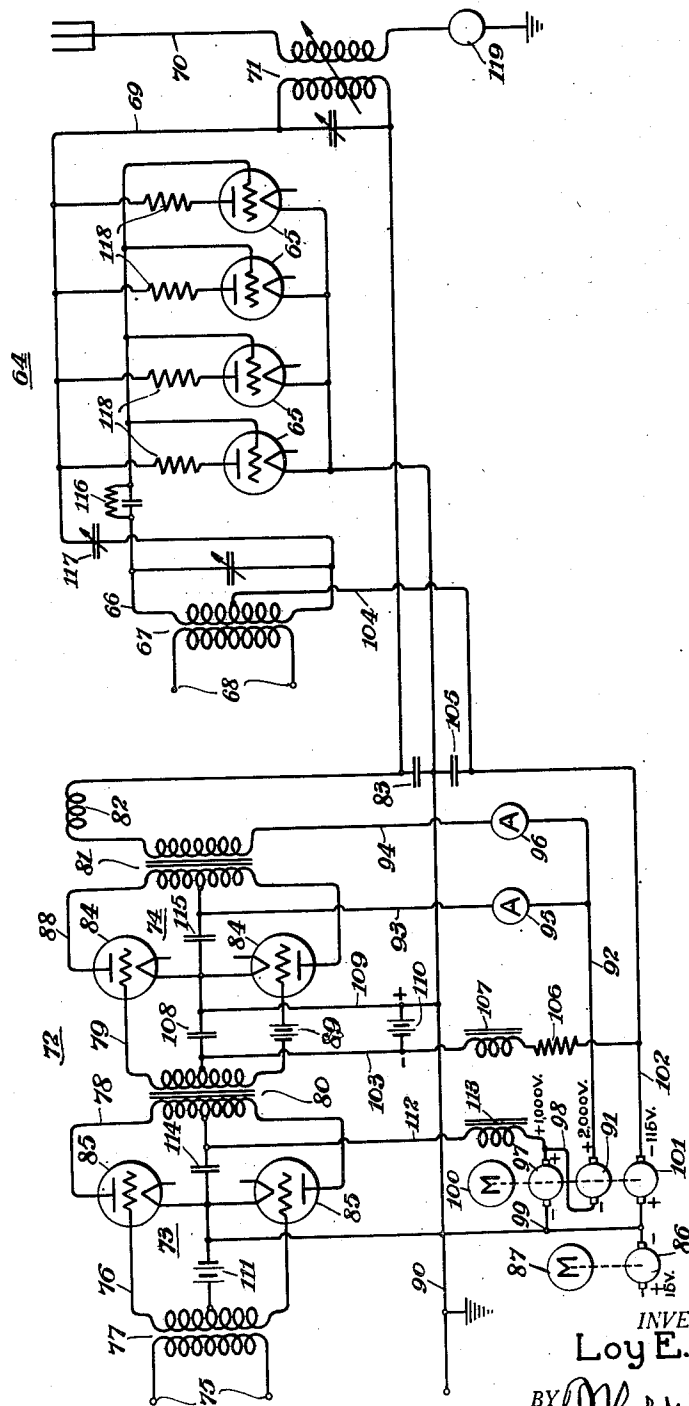
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3 Sheets-Sheet 2

Fig. 5.



INVENTOR.
Loy E. Barton.
BY *M. Goldsborough*
HIS ATTORNEY.

June 15, 1937.

L. E. BARTON
RADIO SIGNALING SYSTEM

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3 Sheets-Sheet 3

Fig. 8.

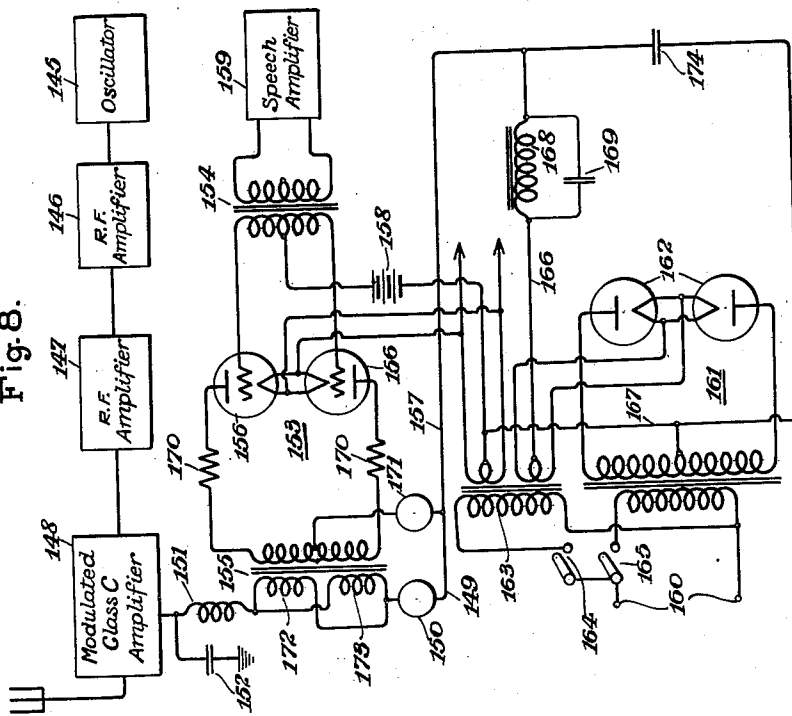


Fig. 6.

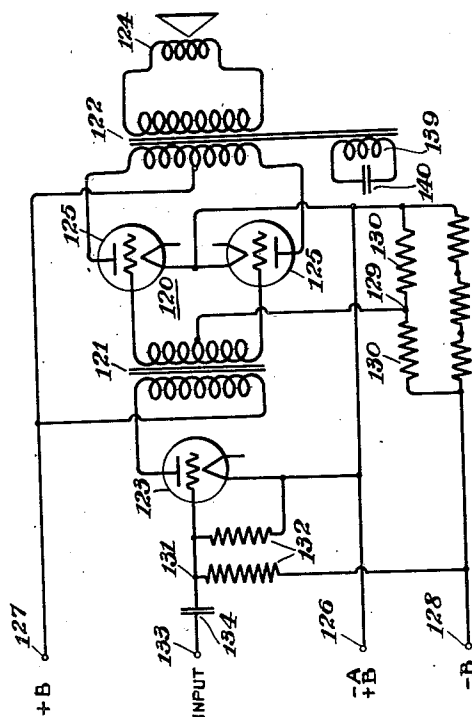
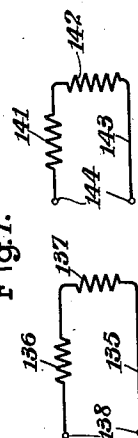


Fig. 7.



INVENTOR.
Loy E. Barton.
BY *M. Holdsworth*
HIS ATTORNEY.

UNITED STATES PATENT OFFICE

2,084,180

RADIO SIGNALING SYSTEM

Loy E. Barton, Collingswood, N. J., assignor to
Radio Corporation of America, a corporation
of Delaware

Application January 15, 1932, Serial No. 586,874

14 Claims. (Cl. 179-171)

The present invention relates to radio signaling systems and more particularly to systems of that character embodying electric discharge devices as audio frequency amplifiers and modulators.

Since the early use of electric discharge devices or vacuum tubes in the broadcasting art, the demand for higher output power from audio frequency amplifier systems has steadily increased, in both radio receiving and transmitting apparatus.

In radio receiving apparatus, as is well known, the demand for higher power output occurs chiefly in connection with the output stage of the audio frequency amplifier, while in transmitting apparatus it occurs both in connection with the power amplifier and in connection with the modulator, used in conjunction with the power amplifier, to apply the modulating or audio frequency signal to the carrier wave.

This demand for higher audio frequency power has heretofore been met chiefly by the development of tubes having a higher plate or anode dissipation and a lower plate or anode resistance, and the use of these or available standard tubes in balanced or push-pull relation and in multiple, both in radio receiving and amplifying apparatus and in transmitting apparatus. This expedient has the disadvantage that it involves a multiplicity of tubes and associated apparatus, with corresponding complication and cost. This is particularly true in connection with transmitters arranged for substantially 100 percent modulation and having appreciable power output, for the reason that the power requirements for a suitable modulator therefor is of a corresponding magnitude and cost.

When the antenna or output current of a transmitter is caused to fluctuate according to a modulating wave of any shape, the average antenna current may remain the same, but the effective value of the current increases, therefore, increasing the average power input to the antenna. This increase in antenna power must be supplied (a) by the modulators employed, (b) by an equivalent increase in power, (c) by an increase in the plate current to the power amplifier tubes, or (d) by an increase in the average efficiency of the power amplifier tubes.

It is generally conceded that the increased power may best be obtained by method (a) above, in supplying the increased power in the form of audio frequency power to the anode or plate circuit of the radio frequency power amplifier. However, this has heretofore involved the use of

tubes of higher rating, adapted to carry the larger modulator power output. Therefore, in meeting such increased power requirements, modulators heretofore and at present may often include a plurality of high power tubes connected in balanced and in multiple relation, with attendant high cost of operation as well as initial cost.

It is, therefore, an object of the present invention to provide an improved modulator adapted to economically supply relatively large amounts of audio frequency power with electric discharge devices of normal power rating and without employing an excessively large number of such devices as has heretofore been necessary.

The following table, by way of example, indicates the necessary modulator power output to modulate a 1000 watt transmitter from zero to 100 percent modulation, if, in the rating of the transmitter a plate circuit to antenna efficiency is assumed as 50 percent.

Table A

Percent modulation	Modulator output required in watts	
0	0	
10	10	
20	40	
30	90	
40	160	30
50	250	
60	360	
70	490	
80	640	35
90	810	
100	1000	

It is well recognized that 100 percent modulation is the most economical degree of modulation. This is for one reason, among others, that the higher percentage modulation permits the use of a transmitter of lower power for the production of the same signal strength at a given distance from the transmitter. Furthermore, the higher modulated signal is subject to much less interference.

It will be seen from the preceding table that for 50 percent modulation, the power required is only one fourth of the power required to modulate to 100 percent. It will thus be seen that to cause an antenna current to vary at a signal frequency such as an audio frequency or to modulate the carrier wave of a transmitter, requires a relatively high power with respect to the output of the transmitter.

A further consideration of amplifiers and modulators, and the power requirements thereof, involves a careful consideration and understanding of three existing types of vacuum tube or electric discharge amplifiers. The classification is based upon the operating characteristics depending upon values of grid bias, excitation, allowable distortion, and other features.

A type of amplifier known as a class "A" amplifier is the type most used in receiving apparatus in the usual audio and radio frequency amplifiers, and in which the average value of plate or anode current for the electric discharge devices or tubes employed therein, does not vary appreciably when a signal is impressed on the tube grids, and the grids are usually not driven positive. The distinguishing characteristic is that the output alternating current voltage bears a linear relation to the input alternating current voltage.

A type of amplifier, known as a class "B" amplifier, is one which is usually employed as a radio frequency output amplifier in a transmitter, and its distinguishing characteristic is that the power output is proportional to the square of the excitation grid voltage. The electric discharge devices or tubes employed therein are biased to essentially plate current cut off or slightly above, and the average value of direct plate current varies with the input alternating current voltage. The plate current flows only during the positive swings of the input voltage. The grids may be driven positive until the output voltage begins to deviate from a linear relation with respect to the input voltage.

Since plate current flows only during one-half of the cycle, the plate circuit must be tuned to preserve the input wave form or if an audio or an aperiodic amplifier is desired, two tubes must be used in a typical push pull or balanced arrangement in order that plate current to one or the other of the tubes may flow at all times.

The excitation may be strong enough to swing the grid or grids positive and thus produce an appreciable rectified grid current. Rather heavy loads are therefore placed on the preceding amplifier by the large amount of grid excitation required to overcome the grid losses in the tube. The output efficiency is very good because of the fact that the peak plate or anode current may be comparatively high for peak positive voltage swings on the grid and the instantaneous direct current resistance of the tube is low during the half cycle the plate current flows.

A third type of amplifier, known as a class "C" amplifier, is a special type of radio frequency amplifier or oscillator and is one in which the output varies as the square of the plate voltage within certain limits. The tubes are biased to about double the value for plate current cut off and the grid is driven to a degree such that small changes in input voltage does not appreciably change the output voltage.

The excitation peak voltages must be sufficient to drive the grid considerably positive in order to secure large amplitudes of plate current. This results in a very high efficiency of tube operation due to the fact that the internal direct current resistance of the tube is very low during the time of plate or anode current flow. However, the grid excitation losses are relatively high and the preceding stage must deliver enough energy to supply these losses. In fact, the grid excitation may go so far positive that saturation

may be reached for a relatively large portion of the cycle.

The class "C" amplifier is, therefore, capable of providing large amounts of power if properly supplied by a driver amplifier, and in a broadcast transmitter is capable of supplying high power output if sufficient audio power is available to modulate its plate circuit. Heretofore this has been difficult to do economically.

The class "C" type of amplifier is considered to be the most efficient type for transmitters, but the plate circuit must be tuned if sinusoidal voltage output is desired. For constant input voltage, the output voltage or antenna current is proportional to the plate voltage. Therefore, this type of amplifier is well adapted to plate modulation. If enough energy is taken from the output of a class "C" amplifier to drive its grid, the amplifier becomes the usual radio frequency oscillator.

For 100 percent modulation it will be seen that in a high power transmitter employing a class "C" amplifier, a relatively large amount of audio frequency power is required from the modulator. It is a common practice at present to supply the modulating power to such amplifiers by a modulator having a plurality of electric discharge amplifiers connected in multiple or balanced relation, the number of such devices being in any case relatively large and depending upon the amount of power required from the modulator. As has been shown heretofore, the amount of power required for modulation purposes may be in the order of the power output of the output amplifier.

In the field of radio receiving apparatus and the like, employing audio frequency power amplifiers, the output requirements may also reach relatively high values as the demand for higher output power increases. This demand is in part, a result of designs directed at greater fidelity of tone and larger sound coverage from the output of an amplifier. The present power output requirements from the amplifier of a radio receiver may be in the order of several watts, while for operating a plurality of loud speakers or other devices for wide sound coverage, the audio frequency power requirements may often be in the order of several hundred watts.

Because of operating characteristics, whereby it is adapted economically to meet demands for high power output, the present invention relates more particularly to the class "B" type of amplifier as the output stage of an audio frequency amplifier unit for signaling systems, and has for a further object to provide an audio frequency electric discharge amplifier or modulator of that type from which a higher undistorted output power may be obtained at audio frequencies than has heretofore been obtainable by known means or arrangement of electric discharge devices in an amplifier, while taking advantage of the desirable operating characteristics of a normal class "B" amplifier.

It has been found that an amplifier of the above character capable of delivering a high undistorted audio frequency power output may be adapted to use as a modulator of high power transmitters, as an output amplifier in radio receiving apparatus and the like, and that it may permit the use of ordinary electric discharge devices or tubes of the so called battery type to deliver relatively high audio frequency power in battery and portable receiving apparatus, with economical current consumption.

Furthermore, an amplifier, in accordance with the invention, is adapted to supply large amounts of audio frequency power sufficient to modulate a class "C" or a class "B" output amplifier for a transmitter of relatively high power, to any desired degree of modulation, and to supply large amounts of audio frequency power in an output amplifier for radio receiving apparatus and the like, without requiring the use of electric discharge devices of a corresponding higher power rating or in a multiple arrangement heretofore required.

In providing an amplifier for high audio frequency power output from electric discharge devices or vacuum tubes simply and economically as is desirable, several principal governing factors in design must carefully be taken into account. Such factors are:

1. The plate or anode dissipation must be kept within rated or normal values.
 2. It is desirable to use as low plate or anode potentials as is possible.
 3. It is also desirable that the power required for operation be kept to a low value. This is particularly true in the case of portable and battery operated amplifier apparatus.
 4. The power output, relative to the normal power rating of the electric discharge devices employed, must be kept high.
- The class "A" type of audio frequency amplifier or modulator which is extensively used at the present time, does not satisfy all of the above conditions. The maximum plate or anode dissipation occurs while the amplifier is receiving no signal current and the maximum anode efficiency is relatively low, being normally not over 25 percent at maximum output. The result of the high anode dissipation is that the output or power tubes must be large, and in general a relatively high anode voltage is required. Furthermore, a plurality of such tubes, and at least two in balanced or push pull relation, are required in the usual amplifier. In the last case, the tubes must be of a higher power rating to obtain a higher power output. This type of amplifier is therefore usually uneconomical in the power required for the anode supply.

In the class "B" type of amplifier, the output or power tubes are biased to essentially anode current cut off and when the input electrodes or grids are properly biased and driven by signal currents to substantially zero bias swing, the first three of the above conditions are satisfied to a fair degree. However, like the class "A" amplifier, this type requires relatively low audio frequency power from the signal source to operate it, and the input system thereto may be the usual relatively high resistance type. An amplifier of the class "B" type, however, does not in itself satisfy the fourth requirement above mentioned.

It is, therefore, a further object of this invention to provide an improved audio frequency amplifier arranged to operate the electric discharge devices or tubes therein in such a manner and to such limits that they may supply an audio frequency output relatively higher than the normal output of the same electric discharge devices or tubes with the same anode voltage, with a lower average anode dissipation, and with no serious effects upon their life. Thus, in accordance with the invention, the usual requirements for higher plate or anode dissipation and higher anode voltages, both of which are costly in tube

construction and in the matter of the supply of operating potentials, are entirely obviated.

In accordance with the invention there may be provided an audio frequency amplifier by which a relatively high audio frequency output, for example of five to ten times the usual or normal output, may be obtained without increasing the size, rating, or number of electric discharge devices employed therein, and without increasing the anode potential or anode dissipation.

An amplifier of this type may be used as a source of high audio frequency power for plate modulation of a transmitter as hereinbefore described, and may be applied to any signaling system requiring a relatively high audio frequency output, with a minimum of equipment.

Because of the class "B" type of operation, a varying load is placed upon the anode power supply for an improved amplifier and modulator embodying the invention; and accordingly it is a further object of the invention to provide means in connection with the source of anode or plate current supply, whereby fluctuations in load are prevented from appreciably affecting the voltage regulation of the source.

The invention will be better understood from the following description when taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings, Figure 1 is a circuit diagram of an audio frequency amplifier embodying the invention;

Figs. 2 and 3 are curve diagrams illustrating operating characteristics of the amplifier shown in Fig. 1;

Fig. 4 is a circuit diagram of equivalent circuits representative of the input and output circuits shown in Fig. 1;

Fig. 5 is a circuit diagram of a modulator embodying the invention as applied to a broadcast transmitter having a high power output amplifier of the class "C" type;

Fig. 6 is a wiring diagram of an audio frequency amplifier embodying the invention and adapted for battery operation;

Fig. 7 is a circuit diagram of equivalent circuits to those shown in Fig. 6; and

Fig. 8 is a circuit diagram of an alternating current amplifier or modulator embodying the invention and applied to a short wave transmitter system.

Referring to Fig. 1, an improved class "B" audio frequency amplifier embodying the invention is shown. This amplifier includes an output stage 10 and a driver stage 11 therefor, which are so coupled and controlled, that by means of an electric discharge amplifier or vacuum tube 12 of relatively low power output in the driver stage, which may be of the class "A" type for example, the output stage may be driven substantially to the limit of the emission or space charge of the electric discharge devices or tubes therein for maximum audio frequency power output. For a given power output, the latter tubes also may be of normal power rating as will be seen hereinafter.

The amplifier 12 receives audio frequency signal voltage from any suitable source such as input terminals 13 which are connected with it through a suitable input or grid circuit 14, whereby audio frequency signal potentials applied to said terminals or to the input of the amplifier, are amplified by the device 12 and through its output or anode circuit indicated at 15, are applied to the output stage 10.

The output amplifier stage consists essentially 75

of two tubes 16 and 17 connected in push pull or balanced relation between push pull input and output coupling devices 18 and 19 respectively, and biased for class "B" operation, as indicated.

5 The grid bias supply indicated is preferably of relatively low direct current resistance. The output stage is provided with a suitable anode voltage or plate supply source as indicated in the drawings. The anode voltage supply source

10 should have good voltage regulation under wide load variations, as it should be understood that the load current increases with an increase in the amplitude of applied signal voltages in this type of amplifier.

15 The output stage is provided with an input circuit or system, including the coupling device 18 and the output circuit 15 of the driver stage, having a relatively low impedance in itself, whereby the signal voltage is permitted to carry the grids

20 of the tubes 16 and 17 therein, far into the positive range of operation, without a reduction of the available signal voltage and hence distortion, because of the impedance drop in such input circuit or system, and without excessively loading

25 the driver stage.

The driver or first stage of the amplifier is preferably but not necessarily, transformer coupled to the output stage. In the present example, device 18 is a transformer having a step down

30 ratio from a primary winding 20 in the anode circuit 15, to each side of the secondary winding 21, which is included in an input or grid circuit 22 for each of the output tubes. It should again be noted that two tubes in balanced or push pull

35 relation is preferred for substantially distortionless class "B" operation in an audio frequency amplifier, for reasons pointed out in the preceding description of the class "B" type of amplifier.

The step down ratio of the coupling device or

40 input transformer 18 for the output stage is arranged to permit a relatively low reflected impedance, over from the anode or output circuit 15 of the driver stage, in each half of the input or grid circuit 22 of the amplifier 10, in series

45 therewith. Therefore, when the grids of the tubes 16 and 17 are driven into the positive range, the low effective input resistance permits grid current to flow without seriously affecting the shape of the signal or input voltage wave as applied at

50 the input terminals 13 of the amplifier.

The impedance ratio of the input coupling means, furthermore, is such that the current requirements of the grid circuit 22 are met without overloading the driver stage 11 and introducing distortion, and, is further of an order such

55 that the anode circuit impedance of the driver stage reflected over into each half of the grid circuit 22 of the output stage 10 in series therewith, is substantially less than the grid to cathode

60 impedance of the electric discharge device 16 or 17 in the output stage connected with that half of said grid circuit, when drawing maximum grid current through said circuit.

The output or power amplifier devices 16 and

65 17 are preferably of the type having a higher, rather than a lower, amplification factor, and a higher, rather than a lower, internal impedance. Like the device 12 shown in the driver stage, they are illustrated in the present example as

70 being of the usual three-element type of vacuum tube, although other types of electric discharge devices may be used. In general, these tubes are of the ordinary audio frequency amplifier type.

In any case, the output tubes 16 and 17 are

75 ranged to be operated in accordance with class

"B" operation, that is, the control electrodes or grids are biased to substantially anode or space-current cut off as indicated by the legend in the drawings, Fig. 1.

The bias source is located in the grid circuit 22, and is common to both devices 16 and 17. In the present example, the input or grid circuit 22 for devices 16 and 17 is provided by a winding or impedance 21, this being the secondary of the coupling device or transformer 18, and is mid-tapped as indicated at 24 for application of the biasing potential, in the usual manner for push pull circuits.

The load connected with the output stage is also arranged to have a relatively low impedance with respect to the internal impedance of the output stage. To this end, the output circuit of the power stage is arranged to have a low impedance with respect to the internal or plate impedance of the electric discharge devices therein.

The output circuit of the power or output stage 10 includes a balanced output or anode circuit 25 for devices 16 and 17, a source of load therefor indicated by output terminals 26, and the output coupling device or transformer 19 which is interposed between the circuit 25 and the load, as an impedance transforming means.

The anode or operating potentials for the devices 16 and 17 are applied through a mid-tap connection 28 on the primary winding 27 of the output transformer or coupling device, and the anode circuit 25, in the usual manner for push pull amplifiers. The plate or anode supply source which may be connected between the cathodes and the tap 28 should, as indicated,

35 have good regulation for the reason that in operation the devices or tubes 16 and 17 draw a varying load current in response to changes in the impressed signal voltage.

In accordance with the invention, therefore, the grid or input circuit per se as distinguished from the entire input circuit or system, of the power amplifier or output stage, must be of low resistance and the input circuit as a whole must be of low impedance, so that the power or current requirements of the tubes through the grid circuit may be met without seriously distorting the wave shape of the signal applied to the driver stage, and the reflected load back into the output circuit, or the output circuit impedance, must be

50 kept low with respect to the internal impedance of the output tubes in order that the tubes may be driven to the limit of their emission or space charge, without distortion in the plate circuit.

The output power is limited by the plate dissipation, the maximum direct current to the plate, or the maximum allowable grid voltage swing within the distortion limits. If the grid voltage swing limits the output because of distortion, it does so by swinging in a positive direction until it approaches the minimum instantaneous plate voltage. When the two voltages approach each other, the direct current of the grid rises very rapidly with any increase in grid voltage swing. The plate or anode current swing for a given excitation depends upon the load resistance in the plate circuit. The load resistance, then, bears a very important relation to the tube loss, the maximum power output and the power required to drive the grid, as will be seen herein-after.

Referring now to Fig. 2, 29 and 30 are plate or anode-current, grid-bias curves for tubes 16 and 17 respectively, of Fig. 1. The curves are plotted with respect to a grid bias scale or zero

75

plate current line 31, and an ordinate 32 representing plate current and grid current scales. The curve 29 is plotted from data obtained by varying the applied grid potential and reading the corresponding anode current for one tube such as tube 16, in the circuit 25 of Fig. 1. The plate current curves are taken with load, that is with a load at 26 reflected over in series with one tube in the plate circuit 25.

The zero bias line for curve 29 is indicated at 33 and it will be noted that the normal anode current for class "B" operation is indicated at 34 through which is drawn the normal negative bias line 35. It will also be noted that the negative bias is such that the point 34 on the curve 29 is substantially at zero or cut off for the anode current. In response to applied signal potentials, the anode current increases along the line 29 to a maximum point such as the point 36 for example. The total grid swing for such operation is indicated at 37, which includes the negative range 38 and a considerably larger positive range 39. This is the grid or input signal voltage swing, A, for the tube 16.

It will be noted that the operation of each tube is carried far into the positive range and that after the zero bias at line 33 is passed, the grid begins to draw an increasing amount of grid current indicated by the curve 40, a point of maximum slope on which is indicated at 41.

The lower curve 30 for the tube 17, is the same as the upper curve 29 except that it is reversed and shifted along the bias line 31 until the curves 29 and 30 coincide as nearly as possible to a line 42 drawn through the straight portion of the upper curve 29. The bias potential indicated at the point 43 through which the straight line 42 passes in crossing the zero plate current line or the grid bias line 31, is the proper normal negative bias potential to use for the two tubes 16 and 17 having characteristics substantially as shown.

If the tubes or electric discharge devices are not similar, or if the anode supply voltage is slightly different from the values indicated by the curves shown, the bias may be adjusted until the anode current is obtained as indicated by the curves.

The relation of the plate or anode current curves 29 and 30 of Fig. 2 is an indication of the operation of devices 16 and 17 respectively in the circuit shown in Fig. 1. When the grid of one tube is driven in a positive direction from its normal negative bias value, the plate or anode current of that tube increases with the swing, and flows through one half of the primary winding of the output device 19. The output voltage for this half cycle bears a linear relation to the input voltage to the amplifier. At the beginning of the next half cycle the above tube becomes idle because its grid becomes more negative and the other tube functions in a manner similar to the first except that the anode current flows in the other half of the output winding of the device 19, and the output voltage is therefore 180 degrees out of phase with the first half wave.

These two output waves will thus unite to form a wave similar to the input signal wave, with no distortion, if the plate current and grid voltage have a linear relation substantially as shown in Fig. 2. This relation is substantially linear as will be seen by the similarity between the curves 29 and 30 and the straight line 42 drawn through them.

It should be noted that the input coupling device or transformer 18 delivers current to the

grids of the output tubes from only one side of the secondary at any particular instant, which must be considered in the design of this device.

If the signal swings to the right, as indicated, in Fig. 2, from the zero center line or bias line 35 common for both tubes, the plate current 29 of the tube 16 which may be designated as I_{bA} , increases, and as the grid becomes positive, grid current designated as I_{cA} , flows according to curve 40. As the signal reverses, I_{bA} decreases and as it passes the common bias line, I_{bA} becomes zero and plate current I_{bB} of the other tube 17 increases according to the curve 30. Therefore, each tube functions over one-half cycle, while the other is practically idle.

It should also be noted that the entire output power must be transferred from only one side of the output transformer primary during each half cycle. Therefore, the load impedance applied at 26, which either the tube 16 or the tube 17 is working into, is calculated as if only one tube is supplying the total power from one side of transformer primary 27, but in calculating plate dissipation, each tube functions for one-half the time so that the total plate loss is divided between the two tubes.

The plate current input to the output tubes resembles a true full-wave rectified current, the frequency of which is double the frequency of the signal. Therefore, the power input to the plate of the output tube is:

$$0.637 I_{pm} E_b = \text{power input} \quad (1)$$

in which I_{pm} = peak plate current (alternating current)
 E_b = plate or anode supply voltage (direct current)

$$0.637 I_{pm} = I_b \text{ or average plate current}$$

The power output may be represented as:

$$0.707 E_{pm} \times 0.707 I_{pm} = \text{power output} \quad (2)$$

in which E_{pm} = maximum voltage (alternating current) delivered to the load.

The efficiency of this amplifier is given by:

$$\frac{0.707 E_{pm} \times 0.707 I_{pm}}{0.637 I_{pm} E_b} = \text{efficiency} \quad (3)$$

If E_{pm} approaches E_b as a limit, then the efficiency becomes 78.5 percent for half-sine-wave outputs.

The output power from (2) is:

$$\frac{I_{pm}^2 R_p}{2} = \text{power output for two tubes} \quad (4)$$

And

$$\frac{I_{pm}^2 R_p}{1.274 I_{pm} E_b} = \text{efficiency} \quad (5)$$

in which R_p = load resistance

As was noted above, the plate current is not limited as in the class "A" amplifier, so that a load resistance for maximum power output is such a value that the limit of emission is approached. The minimum instantaneous plate voltage E_{bm} and the allowable plate dissipation are also factors which determine the load resistance.

The load resistance for this amplifier is calculated as with a class "A" amplifier which is:

$$\frac{E_{pm}}{I_{pm}} = R_p \text{ load resistance} \quad (6)$$

The peak plate current at a point on the desired load curve, which is within the permissible distortion limit, is used to calculate the output power of two tubes operating as a class "B" audio

amplifier. This value of peak plate current and the corresponding load resistance are used in Equation (4) to obtain the power output of two tubes operating as a class "B" audio amplifier. The input plate power is calculated by using Equation (1) and the plate circuit efficiency by using Equation (5).

The input resistance of the amplifier is indefinite, as with a class "A" amplifier with the grids driven positive, but a minimum value can be obtained from the grid current curve 40 of Fig. 2, being in the present example, point 41 for a maximum positive signal voltage swing. This may be used to indicate the input series resistance that may be permitted for a given degree of distortion. The minimum input resistance is calculated from the maximum grid current and also the voltage swing required for this current. However, the slope of the grid current curve must also be considered because if this resistance represented by the slope of the curve is low compared with the effective grid series resistance, considerable distortion will result. This is especially true if the operating bias is considerably negative as indicated.

Referring now to Fig. 3, the alternating current component of the anode or plate current I_p , the alternating current plate voltage E_p , and the alternating signal voltage E_s , applied to the grids of the output tubes are plotted as ordinates against time, in curves 44, 45 and 46 respectively. The curve 45 for the plate voltage is shown with respect to the normal applied anode or plate potential E_b indicated by a line 47, while the cathode potential or zero axis is indicated by a line 48. The normal negative grid bias potential with respect to the cathode line 48 is indicated by a line 49, about which as an axis, the curve 46 is drawn. One half cycle of the alternating current component of the alternating current anode or plate current I_p is shown and is drawn with respect to a line 50 corresponding to the normal anode or plate current indicated in Fig. 2 at point 34 on curve 29.

These curves show the relation between the various instantaneous values of the alternating current components of the anode current, anode voltage, and grid voltage.

The operating characteristics indicated by the curves of Figs. 2 and 3 will now be considered in the design of the amplifier shown in Fig. 1 as follows:

1. The determination of the maximum anode current I_{pm} , the peak positive grid potential or signal swing E_{gm} , to obtain such plate current, and the minimum instantaneous plate voltage E_{bm} , required to cause the plate current to flow. The grid current and grid voltage may be estimated for the above conditions. Incidentally the above condition for minimum plate voltage is a condition where the space charge limitation and emission limitations are practically equal.

2. With the above data, which may be estimated from standard data sheets of characteristic curves of available tubes, the minimum input resistance R_g is estimated between the grid and the cathode at the point of maximum positive grid swing. The peak grid voltage swing is also estimated.

3. Knowing the voltage and current requirements of the input circuit, the next step is to provide a means in the input circuit for supplying the required grid current without appreciably affecting the voltage input wave, even though at times the grid current in the output stage may

be zero or the input resistance may be very high.

By way of example, and as a preferred value which has been found to be desirable, the permissible input regulation may be chosen at approximately 10 percent, from which the effective resistance in series with the grid of each output stage tube approximately may be one tenth of the value of the minimum grid to cathode resistance, for maximum positive grid voltage swing in response to a signal wave.

4. Knowing this allowable grid series resistance and the voltage required, the transformer or input device 18 is designed with a proper ratio for this purpose, and to permit the use of a tube in the driver stage that, without overloading, will supply the necessary input signal voltage at the known impedance of the tube, to the primary 20 of the input transformer 18 for the output stage.

The above procedure permits a grid swing of the output tubes to a point where the plate current becomes limited by the space charge or by the emission. This is a feature of importance in permitting maximum power output from the amplifier. It is obvious that, if this grid voltage variation or swing and plate current swing are obtained, plate dissipation must be considered to prevent overheating of the plates. The latter may be controlled by the load resistance.

The above features may be used successfully to the limit or the output of the tubes, if a load resistance is used, such that when maximum plate current flows, the voltage drop in the load resistance causes the plate voltage to drop from the value E_b (Fig. 3) of the plate voltage supply to the minimum value E_{bm} (Fig. 3) as determined by emission and space charge. It has been found that such desirable loading of the output tubes requires that the load resistance be made lower than the plate resistance of the output tubes. This is a feature of the improved class "B" audio amplifier, which is highly desirable and effective in providing a maximum power output economically.

The following will explain the method of calculating the minimum input resistance of each of the tubes in the output stage.

The slope of the curve 40 in Fig. 2 at the maximum swing point 41 is the minimum resistance of grid to cathode or the internal input impedance of one of the output tubes, which may be called R_g .

The total input or grid voltage change or swing on each output tube is the swing indicated at 38 plus that indicated at 39, with a minimum resistance R_g . R_s , or the resistance of the input circuit in series with the grid of one output tube, must be appreciably lower than the resistance R_g , and is preferably of the order of one-tenth of R_g , as hereinbefore pointed out, although it is not limited thereto. However, no shunt resistance must be permitted except to improve the frequency characteristic and the coupling device in the input circuit is designed to provide, in itself, this desired effective input resistance in series with the grids of the output tubes when coupled with the output circuit of the driver stage.

Assuming the transformer or coupling device 18 to have a turn ratio of N_1 to N_2 for primary and secondary, respectively; if the tube 12 in the driver stage has a plate impedance, r_p , of 3000 to 3500 ohms, then R_L , the load resistance in the driver stage output circuit 15, which in Fig. 1 is the primary 20 of device 18, should be 30,000 to 35,000 and if in push pull, twice this amount

depending upon the nature of R_g or the minimum grid resistance in the grid circuit of the output stage which, as pointed out before, depends upon the internal impedance or grid impedance of each output tube when drawing maximum grid current. This may be expressed as follows:

$$R_1 \left(\frac{N_2}{N_1} \right)^2 = R_g = \frac{R_o}{10} \quad (7)$$

and the signal voltage across R_L (primary 20 in Fig. 1) =

$$\frac{N_1}{\frac{N_2}{2}}$$

× maximum grid swing (38 and 39 in Fig. 2).

The following will explain the method used to determine the optimum load resistance R_p for the output stage.

Referring to Figs. 2 and 3, the maximum alternating plate voltage E_{pm} delivered to the load across the primary 27 of the output device 19, or the maximum voltage decrease from the plate supply E_b (Fig. 3), is determined by the minimum allowable plate voltage E_{bm} which will cause the peak plate current to flow. This is dependent upon the space charge of the tube and is limited thereby. E_{bm} is then, the minimum plate voltage necessary to obtain peak emission or as nearly peak emission as safe operation permits, the peak plate current being I_{pm} .

The peak grid swing is such that I_{pm} flows with E_{bm} on the plate and the plate current must be proportionate to grid voltage E_g to the point I_{pm} , Fig. 3, as indicated at point 36 in Fig. 2, for example.

The load resistance R_p for each of the tubes 16 and 17 for the time it operates is:

$$\frac{E_{pm}}{I_{pm}} = R_p \quad (8)$$

If the available potential is such that the value of E_b is low compared to a certain selected value of E_{bm} , then it is desirable to use a lower value of E_{bm} so that I_p will be limited by the space charge rather than the emission.

The underlying thought in the above design is that of providing a class "B" output amplifier, with input and output circuits including suitable coupling means, whereby a maximum power output is provided without appreciable distortion of the signal wave applied to the driver stage in the input circuit.

In providing this amplifier arrangement, in the input circuit there is interposed between the grid circuit of the output stage and the output circuit of the driver stage, a coupling means such as a step-down transformer so designed that a reflected series impedance R_s , over from the preceding driver stage, is of a lower value than the impedance of the grid circuit between the grid and cathode of each tube in the output stage, when said grid is at a maximum positive potential and drawing a maximum grid current.

At the same time, in the output circuit, a coupling means such as a transformer, is provided whereby the reflected load R_p back into the plate circuit of the output stage is of a lower value than the internal impedance r_p of each of the output tubes, in series with the plate circuit.

Furthermore, the direct current resistance of the grid or input circuit of the output stage must be relatively low, together with the source of bias potential, to prevent distortion, because of volt-

age drop in the elements of the circuit. Also, in the output circuit of the output stage, the anode potential supply must have good regulation.

It will be noted that a low impedance grid circuit, as a part of the input circuit for the output stage, is provided without resorting to artificial loading means such as a shunt resistance, in connection with the grid circuit. The loading effect of such resistance upon the grid circuit and upon the driver stage, would seriously introduce distortion or introduce practical limits into the design, whereby the desired operating characteristics would not be obtained. Chief among the disadvantages of such a circuit would be the lowering of the applied signal voltage to the output stage and additional load upon the driver stage.

Stated in other words, an audio frequency amplifier is provided, in which a class "B" type of output stage, and a driver stage therefor, are connected in cascade between a source of signal potentials and a source of load for maximum power output, limited only by the space charge or emission of the output devices. The output stage includes electric discharge devices in balanced or push pull relation, and a coupling device, preferably a transformer, is arranged to couple the anode circuit of the driver stage with the grid circuit of the output stage.

The impedance ratio of the transformer is such that the current requirements of the grid circuit are met without over-loading the driver stage and introducing distortion, and furthermore, is of such an order that the anode circuit impedance of the driver stage, or operating impedance, reflected over into each half of the grid circuit of the output stage in series therewith, is substantially less than the grid impedance of the electric discharge device connected with that half when drawing maximum grid current through the grid circuit.

Between the output stage and a load impedance there is provided an impedance changing or transformer means having an impedance ratio such that the load impedance, or operating impedance, reflected back into each half of the anode circuit of the output stage may be substantially less than the anode impedance of the electric discharge device connected with that half, and in series therewith, whereby the electric discharge devices in the output stage may be driven to the limit of their emission or space charge.

Viewed in still another way, the grid or input circuit, including the secondary of the coupling device or transformer, must be of low impedance so that the power or current requirements of the tubes through the grid circuit may be met without seriously distorting the wave shape of the signal applied to the driver stage, and the reflected load back into the output circuit, or the output circuit impedance, must be kept low with respect to the internal impedance of the output tubes, whereby the tubes may be driven to the limit of their emission or space charge without distortion in the plate circuit.

The desired relation between the internal impedance of the electric discharge devices or tubes in a class "B" amplifier of the type embodying the invention, and the impedance of the input and output circuits therefor, may further be understood by referring to Fig. 4 along with the preceding figures, particularly Fig. 1.

In an amplifier embodying the invention, the impedance between certain points such as the mid-tap 24 and a point 51 of Fig. 1 representing the input impedance R_s , must be substantially

less than the impedance between certain other points 52 and 53, representing the grid impedance R_g . The impedance R_a is the reflected impedance of the plate circuit 15 of the driver stage over into and in series with the grid circuit 22 as hereinbefore pointed out. The impedance R_a is the internal impedance of the output tube connected with that portion of the input circuit, as pointed out hereinbefore, when it is drawing a maximum grid current.

The entire input circuit may be reduced to the circuit 54 of Fig. 4, in which terminals 56 represent the signal voltage applied to the output stage. This signal voltage as indicated, will be the μ or amplification factor of the tube 12 multiplied by the value of the applied signal voltage at terminals 13, and by the turn ratio of transformer 18, Fig. 1.

The internal grid to cathode impedance of the output tube 16 for example, or the impedance between points 52 and 53, is indicated at 57 and is the value R_g above mentioned.

The reflected impedance of the driver stage output circuit, over in series with the circuit 22, is indicated at 58 and is the impedance between the points 51 and 24, as indicated. The circuit 54 of Fig. 4 is thus the equivalent of and serves to illustrate the fundamental values of the input circuit shown in Fig. 1.

Coupled to the output stage is the load impedance as provided between the terminals 26, and which when reflected back into the output circuit of the amplifier, appear in each half of the output circuit, such as between points 28 and 59, for example. This reflected load impedance over into the output circuit is preferably relatively low with respect to the internal impedance of the corresponding output tube, such as the tube 16 for example, between a point 60 and the point 53, being the plate to cathode or internal anode impedance of the tube. This output circuit is represented in Fig. 4 by the circuit 61 in which the impedance 62 is the reflected load impedance between points 59 and 28, for example, in the output circuit 25, and the impedance 63 is the internal impedance of the tube between the points 60 and 53 as above pointed out.

The signal voltage delivered by the output tube is applied as indicated by the terminals 55 and is, as indicated, the μ or amplification factor of the output tube multiplied by the signal potential E_g applied from the driver stage to the output stage.

By way of example, if the tubes 16 and 17 in the output stage each have a μ or amplification factor of 20, and the signal potential applied by the driver stage is 160 volts, then the potential available in the output circuit will be 20×160 or 3200 volts, of which, 1300 volts may exist between points 28 and 59 across the load, and the remainder of which, 1900 volts, may exist between points 60 and 53 or across the tube in the output circuit.

Assuming now that an applied potential of 2000 volts or E_b is provided as indicated in Fig. 3, the 1300 volts or E_{pm} will leave an instantaneous minimum potential E_{bm} on the plate of 700 volts. As hereinbefore explained, this last named voltage may be and preferably is, the minimum anode potential necessary to maintain a maximum flow of plate current as determined by the space charge of the particular tube. At the same time, the impedance of the output circuit should be and preferably is such that a maximum plate current I_{pm} may flow with minimum in-

stantaneous applied potential. It will thus be seen, as hereinbefore pointed out, that the power output is affected by the load impedance and by the space charge of the tubes employed. It is also affected by the emission limits of the tubes, and the load impedance must be such that the plate dissipation of the tube is not exceeded.

The values of the circuit elements of the input and output circuits of Figs. 1 and 4 may vary in different installations, depending upon the character of work to be performed and the amounts of power to be transmitted, but in any case impedance R_a must always be less than impedance R_g , and the impedance R_p must always be less than the impedance r_p for maximum power output.

The load impedance on each tube of the balanced tube arrangement, during the time it works, must be relatively low in order to obtain a desired power output, while at the same time it must be high enough to prevent a plate dissipation beyond the rating of the tube employed. The load resistance is thus chosen that for a maximum grid excitation the normal plate dissipation may be reached and the minimum instantaneous plate voltage E_{bm} , Fig. 3, is sufficiently high to prevent anode or space current limitation, that is, to permit I_{pm} to flow against the space charge and also to permit the plate current to reach values near the limit of the emission of the tubes.

Through the medium of an amplifier of the type shown and described, an audio frequency power output may be obtained, which is many times larger than the output available from the same number of tubes in an ordinary class "A" or class "B" amplifier. This is chiefly for the reason that because of the amplifier design having the features hereinbefore pointed out, the output is limited only by the space charge or emission of the electric discharge devices without introducing appreciable distortion of the applied signal wave. An amplifier of this character is therefore particularly well adapted for use as a modulator in a broadcast transmitter.

By way of example, it has been found that it is possible to use a one K. W. output tube with class "C" operation for a one K. W. broadcast transmitter, and modulate the plate circuit to 100 percent by two 350 watt tubes as a class "B" audio frequency amplifier of this type, whereas otherwise with existing systems it is necessary to use a 4 K. W. tube operating as a class "B" high frequency amplifier for a one K. W. station with 100 percent modulation, with its associated input system. A broadcast transmitter having a modulator system of this character embodying the invention, is shown in Fig. 5, to which attention is now directed.

Referring to Fig. 5, a radio frequency power amplifier of the class "C" type is indicated at 64 and includes a plurality of electric discharge amplifying devices 65 connected in parallel with a tuned radio frequency input circuit 66, through a coupling device 67 and radio frequency input terminals 68. The output or anode circuit indicated at 69 is also parallel connected with the devices 65 and is coupled with a radiating system 70 through a suitable output coupling device 71.

Audio frequency modulating signals are applied to the anode circuit 69 to modulate it, through a modulator 72, which includes a driver stage 73 and an output stage 74 cascade connected, between audio frequency input terminals 75 and the anode circuit 69.

The audio frequency input terminals 75 are suitably coupled to an input circuit 76 for the driver stage 73 by an audio frequency coupling device or transformer 77. Between the output circuit of the driver stage indicated at 78 and the input or grid circuit of the output stage indicated at 79, a second audio frequency coupling device 80 is interposed and is designed to provide an impedance relation between circuits 78 and 79 substantially like that provided by device 18 in Fig. 1, and for the same purpose.

Likewise between the output circuit of output stage 74, as indicated at 88, and the anode circuit 69, an output coupling device 81 is connected to provide a load impedance arrangement in the output circuit 88 substantially like that provided by device 19 in Fig. 1 and for the same purpose. A radio frequency choke coil 82 and a suitable by-pass condenser 83 serves as a filter to isolate the anode circuit 69 from the modulator 72.

It will be noted that in the output stage 74, the electric discharge devices indicated at 84 are arranged in a balanced relation between the input coupling device 80 and the output coupling device 81 in substantially the same manner as in the basic circuit shown in Fig. 1 in connection with devices 16 and 17. The driver stage, however, includes two devices 85 arranged also in balanced relation as distinguished from the single driver tube utilized in Fig. 1.

For greater power output, this arrangement in the driver stage has the advantage that the generated voltage from plate to plate in the output circuit thereof is doubled for a given input voltage between grid and cathode on the output stage, and the step-down ratio of the input coupling device 80 may then be increased by two, or an impedance ratio of four. At the same time the plate resistance of the driver stage in series with the primary or coupling device 80 is only increased by two. Therefore, the net gain may be one half of the effective resistance in series with the grid, such for example as resistance R_s of Fig. 4.

In a modulator and a class "C" output amplifier embodying the circuit shown in Fig. 5, tubes known as radiotrons type UV-211 have been successfully been employed in the driver stage at 85 with tubes of the type UV-851 used at 84 in the class "B" modulator stage 74, while in the RF power amplifier 64, tubes of the UV-204-A type have been used at 65. These tubes are designated only by way of example, since their characteristics are well known and thereby the values employed in the design of the modulator may more readily be appreciated and understood.

With electric discharge devices of the types named, the coupling device 80 is preferably a step-down transformer having a turn ratio of substantially 5 to 1, or 10 to 1, to each side of the secondary. This provides an impedance ratio of substantially 100 to 1 and with an internal plate impedance R_p in the driver stage of substantially 7000 ohms, thus providing a reflected impedance over through the coupling device 80, in series with the grid circuit 79, of substantially 70 ohms. As compared with the internal impedance R_g of the devices 84 in the output stage, of 800 to 1200 ohms, this impedance is relatively low, as will be seen. The impedance of 800 to 1200 ohms, of course, is measured at a maximum positive potential on the grid which in the present example was substantially 80 volts.

Since the driver stage is a class "A" amplifier, and anode current is flowing at all times in both halves of the coupling device 80, in calculating the

reflected impedance over, the entire primary is considered in connection with one half of the secondary of the device 80. Thus, in the circuit of Fig. 4 applied to the circuit of Fig. 5, R_s or 58 is equal to substantially 70 ohms, while R_g is equal to 800 to 1200 ohms.

In the output circuit 88 of the class "B" stage 74, the calculated load over from the load circuit 69 is provided by the power amplifier 64 and is substantially 2200 ohms. With an internal impedance of each of devices 84 or r_p of substantially 1400 ohms the coupling or output device 81 is so designed that a turn ratio of one to 1.4 from each side of primary to secondary is provided, and an impedance ratio of one to two. The reflected impedance, R_p , of the load, over into each half of the output circuit 80 is then approximately 1100 ohms, which, as will be seen, is lower than the internal impedance of the output tube associated therewith.

With a modulator of the character described, connected as shown, an output of approximately 1500 watts is obtainable from the two tubes, which is more than sufficient to modulate to 100 percent the 1000 watt station, provided by the remainder of the equipment including the RF amplifier indicated at 64. It may be noted that in the modulator shown, the grids of the devices 84 have in practice been driven into the positive range to such an extent that relatively high values of grid current were obtained. For the tubes indicated, this grid current at substantially 80 volts positive, on a positive signal swing reaches as high a value as 140 milliamperes. As this current has to be supplied without an appreciable drop in the signal voltage delivered by the driver stage, it will be appreciated that the direct current resistance of the grid or input circuit 79 must be maintained at a relatively low value, otherwise serious distortion may take place. Likewise, the direct current resistance of the bias potential source must be kept low. It may further be interesting to note that the corresponding power output of the same tubes 84 in a class "A" type of amplifier and at a maximum output rating, is approximately 200 watts. Therefore, the greater power output from the modulator above described is more readily apparent.

As a practical consideration in the design of the modulator shown and described, the cost of tube equipment was found to be prohibitive when utilizing the usual modulator or class "A" amplifier. For example, to provide the same modulator power output as the two UV-851 tubes in the amplifier described, it was found that between 8 and 10 one K. W. tubes would be required in a usual class "A" amplifier, each tube being valued at several hundred dollars. It will, therefore, be appreciated that in the use of an improved class "B" amplifier in a modulator such as that shown and described, a material saving in cost may be effected.

In order to simplify the diagram, the filament or cathode supply circuits have been omitted. The source of cathode current supply, however, is indicated at 86 and is a generator driven by a suitable motor 87. The positive terminal of the generator 86 should be understood as being connected to all of the cathodes, although as above mentioned, the connection lead is omitted. The opposite or negative terminal of the generator is connected thru a common grounded supply lead 90 to all of the cathodes as indicated, and serves as a grounded cathode return

lead for all circuits. In practice this connection is provided by making all connections to ground.

Anode or plate potentials for the amplifier tubes 65 and the class "B" modulator tubes 84 are supplied by a suitable high voltage direct current generator 91 thru a positive supply lead 92 having branches 93 and 94, in each of which branches is located a suitable ammeter 95 and 96 respectively. It will be seen from the diagram that the branch 94 supplies the anode circuit 69 in series with the output device 81, while the branch circuit 93 supplies the class "B" modulator tubes 84 thru the usual push-pull circuit arrangement.

A generator 97 in series with generator 91 serves to raise the voltage supplied by the generator 91 to an initial value from which the required potential for operating the above named modulator and amplifier is raised by the generator 91. Generators 91 and 97 are connected in series by a lead 98 and generator 97 is in turn connected with the common ground lead 90 as indicated at 99, whereby the operating anode potentials are applied between the cathode and anodes of the tubes supplied by said generators.

A direct current generator, or generators, are employed in the system of the present example for the reason that they provide good regulation under a varying load condition imposed by the operation of the class "B" amplifier 74. An anode supply source of this character also has a large power capacity.

In the supply of anode potentials to amplifiers of the above character, it will be appreciated that rectified alternating current may be employed. However, certain precautions must be observed to provide good regulation. An alternating current supply means of this character will be described hereinafter.

The generators 91 and 97 are also driven by a suitable motor 100, and on the same shaft therewith is indicated a third generator 101 which at its positive terminal is connected with the common grounded cathode return lead 90 and which at its negative terminal is connected thru a circuit lead 102 to branch supply leads 103 and 104 to supply a negative biasing potential to the class "B" modulator stage 74 and to the radio frequency amplifier 64. The branch lead 104 is suitably by-passed to the ground lead 90 by a by-pass condenser 105, while in the branch lead 103 for the class "B" modulator, a filter and voltage reducing means is interposed, comprising a series connected resistor 106, a filter choke coil 107 and a by-pass capacitor 108.

The arrangement is such that the grid circuit 79 of the class "B" modulator 74 is isolated from the bias supply 101 by the filter means and the biasing potential is reduced to a desired value. It will be noted that one side of the filter means is connected with the cathode return lead 90 thru a return lead 109 and that between the leads 103 and 109, adjacent to the filter, there is connected a bias voltage supply battery 110. This last is preferably a storage battery or other suitable means for the purpose of providing a stabilizing reservoir of extremely low resistance in the grid circuit return, or in the grid circuit of the class "B" modulator 74. To exactly balance the anode currents of tubes 84, an additional bias adjusting battery or bias means is provided in connection with one tube. In the present example this is a battery 89 in the grid circuit of one tube.

As hereinbefore pointed out, it is essential that the grid circuit be of relatively low resistance and this also includes the source of bias potential, whereby variations in the amount of grid current drawn by the tubes 84 may have no appreciable effect upon the applied signal potentials to cause distortion. This precaution in the other portions of the transmitter is not as essential, hence in the present example a battery reservoir is utilized only in the position shown.

In the driver stage 73 any suitable bias supply means may be employed, and in the present example this may be a simple battery indicated at 111. Likewise it should be noted that the source of bias potentials 101 and 110 for the class "B" modulator stage is not limited thereto, but may be provided by any suitable means having a low resistance relative to the resistance of the grid circuit to which it is connected and which is carrying the current drawn by the grid circuit 79.

It is of interest to note that in the circuit shown, the direction of grid current flow, as will be well understood, is in such a direction that it charges the battery 110, tending to maintain it in a charged condition.

The anode or plate potential supply for the driver stage 73 is supplied by the generator 97 thru a tap connection lead 112 between it and the generator 91. A suitable choke coil 113 is interposed in the connection lead 112 which, together with a by-pass condenser 114, provides a filter for the supply of anode potential to the driver stage 73. The anode potential or current supply lead 93 in the modulator stage 74 is also suitably by-passed by a condenser 115. In each case the by-pass connection is to the common grounded cathode supply lead 90.

It will be noted that ammeters 96 and 95 are respectively included in the plate circuit of the class "C" output amplifier 64 and in the output plate circuit of the class "B" modulator 72. In the present example, with no signal being transmitted through the modulator, the plate current may be adjusted to substantially 40 milliamperes, while the plate current through meter 96 is substantially one ampere, with tubes of the UV-851 type at 84 and tubes of the UV-204-A type at 65. A variation in the current through the meter 95, in response to signals may be taken approximately as an indication of the modulation being applied to the amplifier 64, since the plate current increases proportionately with an increase in the value of the applied signals.

The plate potential applied to the class "B" amplifier 74 and to the output amplifier 64 through the supply lead 92 is approximately 2000 volts as delivered by the generators 91 and 97 in series. The potential applied to the plate circuit of the driver stage 73 through the lead 112 is approximately 1000 volts.

The filament potential supplied by the generator 86 is approximately 15 volts. The biasing potential applied to the class "C" output amplifier 64 by the generator 101 is approximately 115 volts. The grid bias employed in connection with the class "B" amplifier stage 74, as provided by the battery 110 and the generator 101 is substantially 80 volts negative, the voltage being reduced from that provided by the generator by the series resistor 106. The biasing potential supplied by the source 111 is that required to operate the devices 85 as normal class "A" amplifiers.

The class "C" amplifier 64 is provided with the usual oscillator circuit in connection with the tuned circuit 66, having a grid leak and condenser

combination, 116, in the grid lead and a suitable neutralizing condenser, 117, connected with the plate circuit 69. It will be noted that in each of the individual plate leads there is connected a resistor 118. These are for the purpose of damping out parasitic oscillations in connection with the multiple connected tubes.

The operation is as follows: With the electric discharge devices energized by operation of the supply generators, radio frequency signals from a suitable source are supplied to the terminal 68 of the class "C" radio frequency amplifier 64 and are transmitted through the radiating system 70 as a carrier wave. The value of the signal strength may be measured by a suitable meter 119 in the radiating system.

Audio frequency signals for modulation are applied to the terminals 75 of the modulator 72 and are amplified in the successive stages 73 and 74. The amplified output is supplied to modulate the plate circuit 69 of the amplifier 64 through the coupling means provided by the output device 81. Because of the operation of the devices 84 in the manner hereinbefore described, and because of the result of such operation as described in connection with Fig. 1, a large audio frequency power output is obtained.

While the anode current taken by the devices 84 is maintained at relatively low normal and average values and while the applied anode potentials are within the normal rating of the devices 84, the power output is several times that obtainable from the same devices when used in an ordinary class "A" amplifier. This is for the reason that the impedance of the input circuit in circuit 79 is relatively low, whereby the devices 84 may be driven far into their positive grid bias range without distorting the input wave. At the same time, in the output circuit a load impedance reflected into the circuit 80 is such that the output of the devices 84 is limited only by the space charge or the emission. At the same time the impedance of the load is such that the emission limits of the devices 84 are not exceeded.

A transmitter of this character has the advantage that the radio frequency amplifier and the modulator may be substantially separate units as shown, and may be coupled for plate circuit modulation by an isolating coupling device such as a transformer. Furthermore, by the proper design of the input and output coupling devices of the output stage of the modulator, the amplifier devices employed therein may be driven far beyond their normal useful range of operation to produce a power output many times in excess of that ordinarily provided, thereby materially reducing the cost of manufacture and operation of a transmitter for a given power output. As class "C" radio frequency amplifiers are primarily plate circuit modulated and the class "B" amplifier of the present invention is adapted to operate in connection with various loads by the choice of a suitable impedance matching means, such as a transformer, the class "B" amplifier of the present invention is particularly well adapted for use in combination with the class "C" type of amplifier employed in transmitters.

Referring now to Fig. 6, a class "B" amplifier embodying the invention in its adaptation for battery operation is indicated at 120. This amplifier is similar to that shown in Fig. 1 and includes an input device 121 and an output device 122 between which are connected a pair of balanced or push-pull amplifier devices or tubes 125 similar to devices 16 and 17 of Fig. 1. The input

device 121 is connected with a driver stage including an amplifier device 123.

Anode potentials for the two stages are provided by suitable sources indicated by terminals 126 and 127. Terminal 126 is a common cathode return terminal and grid biasing potentials are supplied between it and a third terminal 128. The grid biasing potential for the output stage 120 is obtained from a tap 129 on a series of resistors 130 connected between terminals 126 and 128.

Likewise, a biasing potential is applied to the driver stage or to the tube 123 from a tap 131 between series connected resistors 132 between the terminals 126 and 128. In this case the resistors 132 are of such values that they serve to operate as coupling resistors in connection with the device 123. The biasing potential applied to either of the stages connected with the source 126—128 are dependent upon the values of the resistors 130 and 132 and the position of the tap points 129 and 131.

Audio frequency signals are applied to this amplifier thru the terminal 126 and a suitable grid input terminal 133 and a suitable coupling device such as a condenser 134. In actual practice, in a battery operated amplifier the terminal 128 is the B minus terminal, terminal 126 is the negative A and the positive 22½ volt terminal of the "B" battery, and terminal 127 is the positive 180 volt terminal of the "B" battery. It will be seen that this provides a "B" battery voltage upon the anode circuits of the devices 123 and 125 of substantially 157 volts. With a battery type of tube or electric discharge device of the Radiotron UX 230 type, substantially 15 volts negative bias is provided at tap point 129 and with a normal plate current to each of the devices 125 of approximately .7 milliamperes.

The conservation of power in a battery receiving set has always been sought for a successful and practical receiver. At the same time sufficient power output for a reasonable volume of sound has also been a desired feature. This is particularly true at present because of the almost universal use of alternating current operated power amplifiers in even the most modest receivers. Heretofore, both features have not been capable of combination in a single receiver.

However, with ordinary tubes of the so-called battery type rated at very low output in an amplifier embodying the invention and connected substantially as shown in Fig. 6, a relatively high audio frequency power output may be obtained with relatively low battery drain. The characteristics of such an amplifier are substantially as follows: The amplifier employs tubes of the Radiotron UX 230 type, having a filament consumption of 120 milliamperes as against 260 milliamperes for a standard battery operated amplifier. The maximum power output is approximately 1.2 60 watts with approximately 7 milliamperes average "B" battery drain with a signal being transmitted. The above standard battery amplifier has a normal output of about .35 watts and a "B" battery drain of approximately 16 milliamperes.

In response to an applied signal, the plate current of each tube increases as the signal potential increased in a positive direction upon its grid. Grid current begins to flow at about one volt positive and increases to approximately 1.5 70 milliamperes at 20 volts positive. The maximum plate current for this grid voltage is approximately 25 milliamperes. Each tube alternately functions to take the load as its grid becomes positive, the operation in this respect being the 75

same as that described in connection with Fig. 1.

The anode impedance r_p of the devices 123 and 125 of the type above mentioned, is approximately 9000 to 10,000 ohms, while the input or grid impedance is approximately 12,000 to 14,000 ohms for a maximum positive grid swing. With these impedance values, the turn ratio of the coupling device 121 is one to .75 for each side of the secondary, or an impedance ratio to each grid of one to .45 step-down. This provides an input or grid circuit for the stage 120 which may be diagrammatically indicated as shown in Fig. 7 to which, along with Fig. 6, attention is now directed.

The input or grid circuit for the amplifier 120 is indicated at 135 and includes the impedance of the driver stage reflected over in series therewith by the coupling device 121 and represented at 136, having in the present example a value of substantially 5,000 ohms. Across the circuit is the grid impedance R_g of each one of the devices 125 as indicated at 137 and has a value of substantially 12,000 to 14,000 ohms. The signal potentials delivered by the driver stage to its output circuit for transfer to the output stage may be indicated by potentials which may exist between input terminals 138 for the circuit 135.

The load impedance necessary for connection with the output circuit of the amplifier 120 for maximum power output is substantially 3750 ohms on each side, although it may be lowered in the present example to 2500 ohms for a maximum power output. However, substantially 4000 ohms, as shown, is believed to be more generally satisfactory and safer from an operating standpoint, as approximately this value insures against excessive plate current on peak signals. In other words, the load impedance becomes a limiting factor in the control of the plate current.

The ratio of the coupling device 122 is such that a 2.7 ohm output device may be employed at 124, and for this purpose a step-down ratio of 70.8 to 1, is provided. A loading device, including a winding and a condenser in series therewith, as indicated, respectively, at 139 and 140 is provided in the coupling device 122 to lower the impedance in the output circuit at high frequencies because the output device 124 produces a high impedance at high frequencies.

The values of the load and plate impedance in the output circuit are indicated at 141 and 142, respectively, in a circuit 143, Fig. 7, representing one half of the output circuit of Fig. 6. In the present example, the value of the plate impedance 141 is substantially 9000 ohms, while that of the load indicated at 142 is approximately 3750 ohms as above mentioned. The output potentials provided by the output stage 120 may be considered as being applied at the terminals 144 and are dependent upon the μ of the tubes in the output stage. Hence, it will be seen that it is desirable to employ higher μ tubes in the power amplifier.

It has been found that with devices of the character described in the present example, a peak swing of 20 volts positive in the grid of one of the devices 125, the peak plate current is approximately 25 milliamperes. This current drawn thru a load of 3750 ohms reduces the plate voltage to about 63 volts. A lower plate resistance serves to raise the minimum plate voltage and permits a greater plate current. It will be seen that, as hereinbefore pointed out in connection with the amplifier of Fig. 1, the relatively low load impedance above indicated is desirable in

order that the power output may not be reduced by a limitation of the plate current by the space charge.

The maximum grid current depends upon the power available to drive the grids positive. The grid current for a 2500 ohm load at a positive bias potential of 20 volts is approximately one milliamper, which represents a resistance for the instant of about 35,000 ohms. Therefore, the voltage from the driver stage must not drop appreciably when such load resistances are encountered. The minimum resistance as calculated from the slope of the current grid voltage curve is about 14,000 ohms as indicated above.

Since the output tubes are biased to nearly 15 plate current cut off, the plate current must increase with power output. This requires that the plate current supply source be adapted to provide a constant voltage, with good regulation. The power requirements for a battery operated amplifier of this character may best be understood from the fact that with an output of 1.2 watts the input power to the plate circuit is approximately 18.7 milliamperes at 158 volts or 2.96 watt for continuous sine wave output. The plate efficiency for the average load at full output is about 40% for sine wave inputs.

It is possible and practical to use tubes as class "B" output tubes in a battery receiver or amplifier, because the plate and grid voltages are constant and regulation is a factor that need not be considered. The sensitivity of a receiver using two class "B" operative output tubes is equal to that of the sensitivity of a receiver using a normal battery operated amplifier. The power capabilities of the class "B" amplifier using relatively small amplifier tubes is about three times that available from the normal larger and ordinarily much more powerful tubes of the Radiotron UX-231 type, for example. Furthermore, the average "B" battery drain is approximately 12 to 15 milliamperes for a receiver using the class "B" amplifier described, as compared with a drain of from 25 to 30 milliamperes for the usual battery operated receiver. In each case, the "B" battery load is about 100% greater. The filament current drain is also substantially less than that of standard amplifier tubes employed for battery operation.

As a general comparison of the capabilities of a class "B" battery operated amplifier, it has been found that power output of tubes of the UX-230 type, connected in accordance with the invention as class "B" amplifiers, could be equalled only by resorting to the use of two tubes of a character such as the Radiotron UX-171—A type, connected in push pull as class "A" amplifiers. Such tubes, of course, would have excessive and prohibitive "B" battery drain and would require a storage type of battery for filament excitation.

Referring now to Fig. 8, a transmitter having a modulation system provided by a class "B" modulator embodying the invention, is shown in connection with an alternating current source of operating potentials.

In the transmitter shown in Fig. 8, the radio frequency system includes a crystal oscillator 145 followed by two cascade connected radio frequency amplifiers 146 and 147 which drive a 70 class "C" radio frequency output amplifier 148. The class "C" amplifier, like that shown in Fig. 5, is plate circuit modulated and for this purpose is provided with a plate current connection 149 in which is located an indicating am-

meter 150 and a radio frequency filter means including a choke coil 151 and a suitable by-pass condenser 152 adjacent to the amplifier.

Audio frequency modulation is applied to the circuit 149 from a class "B" amplifier 153 constructed after the manner of that shown in Fig. 1 and connected to the circuit 149 after the manner of that shown in Fig. 5. For this purpose, the amplifier is provided with an input coupling device 154 providing a low impedance input circuit and an output coupling device 155 providing a low impedance output circuit, between which are connected in balanced relation, the class "B" amplifier devices 156.

In common with lead 149 the anode circuit of devices 156 receives its operating current or potential from a supply lead 157, and biasing potentials are supplied by a suitable source 158. Audio frequency signals are supplied to the input coupling device 154 from a suitable source indicated at 159. This may be a speech amplifier as indicated. Direct current anode potentials are delivered to supply lead 157 from an alternating current source indicated by terminals 160, thru a suitable full wave rectifier 161 which includes a pair of cathode rectifier devices 162.

The cathodes of the device 156 and the devices 162 are heated from the source 160 thru a separate transformer 163 which permits the cathodes to be separately heated before the anode potential supply is excited. For this purpose, a separate switch 164 is provided for the cathode heating transformer 163 and another switch 165 is provided for energizing the rectifier 161.

The positive and negative supply leads 166 and 167, respectively, from the rectifier are connected with the cathodes of devices 156 and with the positive supply lead 157. In one of the leads, preferably in the positive supply lead 166, is connected a choke coil 168 in association with a suitable by-pass condenser 169, whereby the desired regulation is obtained under load conditions imposed by the devices 156. The operation of the filter means provided by the choke coil 168 and by-pass condenser 169 will hereafter be considered.

The coupling device 155 should preferably be designed to couple the devices 156, which may be of the Radiotron UV-203-A type, as class "B" audio amplifiers for a maximum anode current of approximately 400 milliamperes for the type of tubes above mentioned, and operated at approximately 1000 volts. Such a loading permits approximately maximum output of the class "B" amplifier. Higher currents to the class "C" amplifier will result in an overloading of the class "B" tubes 156. It should be noted that during a peak modulation of 100% the input power to the plates of the class "C" amplifier 148 increases 50% so that the plate dissipation increases by the same percentage. However, the plate current to the class "C" tubes as indicated by the meter 150, will remain steady so that care must be taken not to exceed the tube rating.

If a maximum output is desired from the modulator 153, medium power tubes should be used in the output stage of the speech amplifier 159 to excite the class "B" tubes 156 thru the coupling device 154.

It will be noted that a resistor 170 is employed in the anode circuit of each of the devices 156. These may be of a value of approximately 40 ohms, for example, and serve to prevent any high voltages because of high oscillations, or

surges in the plate circuits of the class "B" tubes. The radio frequency choke coil 151 and the condenser 152 prevent radio frequency currents from entering the transformer 155. The "C" battery 158 for the class "B" tubes, is adjusted to such a value that each tube draws a normal plate current of approximately 20 to 30 milliamperes for the type of tubes above mentioned, this being substantially plate current cut off for such tubes. The battery 158 represents any suitable source of "C" bias having a low resistance as described in connection with the preceding embodiment of the invention, and is preferably a heavy duty type of "B" battery.

A meter 171 is placed in circuit with the anodes of the devices 156. As the maximum plate current to a class "B" audio frequency modulator or amplifier depends upon the power output, the variations of the meter 171 may be taken as a fair indication of the percentage modulation.

It will be noted that the secondary of the output coupling device 151 is arranged in two sections 172 and 173, whereby the sections may be connected in series, or in parallel as shown. The type of connection depends upon the type of tubes used in the class "C" radio frequency amplifier 148. For lower plate currents at higher voltages the series connection may be used, while for higher plate currents and lower voltages the parallel connection may be used.

Any change in plate voltage and current to the amplifier 148, or change in plate voltage on the class "B" amplifier 153, should be carefully studied to make sure that the modulator and class "C" amplifier tubes are not being overloaded.

The above described system of modulation in connection with a class "C" amplifier is of relatively low cost and of simple construction and has a relatively high radio frequency power output with 100% modulation. Furthermore, the use of the meters in circuit, as indicated, particularly the meter 171, provides a visible indication of the operation of the modulator and an indication of the percentage modulation.

It will be noted that the rectifier 161 or anode supply circuit of which it forms a part, is the usual type of full wave rectifier. However, the filter reactor 168 is a special design to improve regulation, and the filament transformer 163 is separate from that of the rectifier 161 so that hot cathode mercury vapor tubes may be employed at 162 and heated before the plate supply switch 165 is closed. During silent periods of operation of the transmitter, the filaments of all of the tubes may be left on while the plate supply is turned off, thereby requiring a minimum time to start when placed again in operation.

With reference to the filter 168 and 169, the inductance 168 is preferably of the iron core type in series, as shown, with the rectifier source, and is tuned as by the condenser 169 to a frequency such as the second harmonic, being 120 cycles for a 60 cycle supply circuit. As indicated in the drawings, there should be no filtering between the rectifier and the resonant filtering element because it is arranged to operate upon an appreciable alternating current component. Any additional filter means, such as a shunt condenser 174, may be added in the anode supply circuit following the filter shown, altho none is necessary in the supply circuit of the present example.

The circuit arrangement is such that in connection with the filter, an increase in the current taken by the load or by the class "B" amplifier 153 in the present example, de-tunes the tuned

filter element and results in a tendency to raise the voltage across the output of the supply source because of a drop in the impedance to the unfiltered alternating current component. The 120 cycle component is selected as the strongest of the available harmonics of the supply source.

It is preferable also that the choke coil 168 should be so designed that normally sufficient current may flow thru the choke coil to bring it near to its saturating point, since a change of reactance for regulation purposes must be proportional to an increase in the load current. The tuning condenser 169 may be omitted if the reactor is so designed that its impedance decreases rapidly with an increase in direct current.

In operation, the regulation is aided somewhat by providing for a normal load current, or from 10 to 20% of the output current derived from the plate supply source. With this normal load current, the filter is tuned until the inductance offers a maximum impedance at the chosen frequency which reduces the output voltage to a minimum.

The choke coil is also designed so that it tends to saturate as the load current is increased so that it tends to introduce a lower reactance in the circuit for greater load currents, while at the same time the change in reactance detunes the circuit, which also tends to sharply reduce the impedance of the circuit to maintain the tube voltage more nearly constant regardless of the tube current within the power range of the plate supply means. The condenser 174 functions as a normal filter condenser and should be relatively large to effectively by-pass the A. C. components to currents to the class "B" modulator.

While the invention has been illustrated and described for purposes of convenience in its present preferred application to audio frequency amplifiers generally, to battery operated amplifiers, and for the modulation of high power transmitters, it is obvious that it is not limited thereto, but may be applied to any electrical apparatus requiring large quantities of fluctuating electric power, without involving costly and complicated equipment including a large number of amplifier devices and associated potential supply apparatus.

I claim as my invention:

1. An audio frequency amplifier including, in combination, a pair of electric discharge devices each having an anode, a cathode, and a control grid, said devices being connected in balanced relation to each other and being connected to be biased to substantially anode current cut off, an input circuit of low alternating current impedance with respect to the grid impedance of each of said devices when drawing a maximum grid current, and an output circuit of low alternating current impedance with respect to the anode impedance of each of said devices.

2. An audio frequency amplifier including in combination, a pair of balanced electric discharge devices, an input circuit therefor and an output circuit therefor, said input circuit having a lower alternating current impedance in series with the input electrodes of said devices than the lowest input operating impedance of said devices effected by high signal amplitudes causing current flow to said electrodes, and said output circuit having a lower series alternating current impedance than the output impedance of said devices, by an amount sufficient to permit said devices to be driven in response to signals to the limit of their emission or space charge.

3. An audio frequency amplifier system including in combination, an input circuit therefor and

an output circuit therefor, and means arranged for connecting between said circuits a pair of electric discharge devices in balanced relation as an amplifier biased to substantially anode current cut off, said means providing in said input circuit a lower series alternating current impedance than the lowest operating impedance of said devices, and in said output circuit a lower series alternating current impedance than the output impedance of said devices, whereby said devices may be driven in response to signals to the limit of their emission or space charge.

4. An audio frequency power amplifier including in combination, an output stage having a balanced input circuit and a balanced output circuit for a pair of electric discharge devices when connected therebetween, the normal no load anode current for said devices being biased substantially to zero, an input coupling device in the input circuit adapted when connected with a driving source of signal potentials to provide an alternating current impedance in series with each half of the input circuit of a value substantially lower than, and having a direct current resistance of a value one-tenth of the value or less of the internal impedance of each of said electric discharge devices when drawing a maximum grid current, and an output coupling device connected with said output circuit having a coupling ratio such that when connected with a load source the series alternating current impedance provided thereby in each half of the output anode circuit may be substantially less than the internal or anode impedance of the device connected therewith.

5. In an audio frequency amplifier, means for connecting a pair of electric discharge devices in balanced relation and for biasing the same to essentially space current cut off, said means providing series input and output alternating current impedance in connection with the input and output electrodes of said devices of values lower than the lowest internal operating input and output impedances respectively of said devices, whereby signal potentials may be applied to each of said devices, having maximum positive values and the anode current of each of said devices is limited only by the space charge or by the emission characteristics of said devices.

6. An audio frequency amplifier including, in combination, a pair of electric discharge devices each having an anode, a cathode, and a control grid, said devices being connected in balanced relation to each other and provided with means for biasing the same to substantially anode current cut off, an input circuit of low alternating current impedance with respect to the grid impedance of each of said devices when drawing maximum grid current, and an output circuit of low alternating current impedance with respect to the anode impedance of each of said devices, said input circuit further being of relatively low direct current resistance, said output circuit alternating current impedance being of such low value, that the output anode current of each of said devices is limited by the space charge or emission characteristics thereof, and said anode circuit including a source of anode potential supply having a predetermined relatively high regulation.

7. An electric discharge amplifier having a balanced grid circuit and a balanced anode circuit, means for biasing said amplifier substantially to anode current cut off, an input coupling means connected with said grid circuit providing

an alternating current impedance in series therewith of a value lower than the internal input impedance of said amplifier when drawing maximum grid current, and an output coupling device for an alternating current load circuit adapted to provide a load impedance, lower than the output impedance of output anode, whereby the output anode current of the amplifier is limited by the space charge or by the emission of the electric discharge devices therein and whereby a grid potential variation is permitted to a value whereat the anode current becomes so limited.

8. In an audio frequency amplifier, a balanced electric discharge amplifier device, an input transformer and an output transformer pertaining thereto, providing input and output circuit alternating current impedance values therefor substantially lower than operating values of the internal input and output operating impedances of said device when drawing grid current.

9. An audio frequency amplifier including in combination, a step-down input transformer and a step-down output transformer adapted to be connected with a pair of electric discharge devices of the vacuum tube amplifier type in balanced relation thereto, the first named transformer providing a lower series input circuit alternating current impedance than the lowest input operating impedance of either of said devices, and the second named transformer providing a lower series output alternating current impedance than the output impedance of either of said devices.

10. In an audio frequency amplifier, a balanced input and a balanced output transformer arranged to be connected with a pair of electric discharge amplifier devices having input and output electrodes, each half of the secondary of the balanced input transformer having an operating alternating current impedance lower than the lowest alternating current impedance of said amplifier devices to be connected therewith between their respective input electrodes when drawing current in response to signals of high amplitude, and the balanced output transformer having a lower alternating current impedance in each half of its primary than the internal impedance of the amplifier device to be connected therewith between its output electrodes and lower than is permissible for class A operation thereof.

11. An audio frequency amplifier including, in combination, a pair of electric discharge devices each having an anode, a cathode, and a control grid, means providing a balanced signal input circuit connected between said control grids and the cathodes of said devices, the alternating current impedance of said input circuit being substantially less than the input impedance of said devices when the grids are driven into the extreme positive range of grid potentials by the peak of the signal wave to be amplified, a balanced output circuit connected between the

anodes and the cathodes of said devices, a load circuit, and coupling means linking said output circuit and said load circuit for determining the alternating current load circuit impedance reflected over into the output circuit, said reflected load impedance having a value lower than the output impedance of said devices, when said grids are driven into said extreme positive range of grid potentials.

12. An audio frequency amplifier including, in combination, a pair of electric discharge devices each having an anode, a cathode, and a control grid, said devices being connected in balanced relation to each other, an input circuit for said devices of low alternating current impedance with respect to the grid impedance of each of said devices when the grids thereof are made positive with respect to the cathodes by the magnitude of the applied alternating current energy, a balanced output circuit connected between the anodes and the cathodes of said devices, a loud speaker, and coupling means linking said output circuit and said loud speaker for determining the alternating current load impedance of the loud speaker reflected over into the output circuit, said reflected load impedance having a value lower than the output impedance of said devices, when said grids are made positive by the magnitude of the applied alternating current energy.

13. A balanced electric discharge amplifier system of the type in which the signal grids are biased to a point such that signal energy causes the said grids to operate in a positive region that causes grid current to flow, having an input circuit and an output circuit characterized by the fact that both the input and the output circuits have low alternating current impedance and direct current resistance of such values that the potential drop through said circuits resulting from flow of signal current is substantially negligible in its effect upon the signal wave characteristics.

14. In an electron tube circuit, a pair of power output electron tubes, an electron tube driver for said power output tubes, an impedance adjusting transformer connected to couple said driver tube to said output tubes, said transformer having an impedance ratio whereby the driver tube output impedance reflected into the input circuit of said output tubes is substantially lower than the grid impedance of the output tubes when driven into a positive bias range by a strong signal, means providing an output load for said power output tubes, and an impedance adjusting transformer connected to couple said output tubes, with said last named load means, said transformer having an impedance ratio whereby the load impedance reflected back into the anode circuit of said power output tubes is substantially lower than the anode impedance of said power output tubes when said grids are driven into said positive bias range by a strong signal.

LOY E. BARTON.