Fig. 1.

High Frequency Input

Low Frequency Input

Fig. 2.

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His Attorney.
My invention relates to amplifier and modulator devices for radio and analogous systems, particularly to amplifiers and modulators of the class A type, and its object is to provide means for and methods of changing the operating point on the characteristic of amplifiers and modulators of this type in such manner as to increase the output and overall efficiency of systems employing such amplifier or modulator devices.

In class A operation of an amplifier or modulator the linear, or substantially linear, portion of the characteristic is utilized, the bias voltage applied to the thermionic tube being such that a definite anode or plate current flows even when no signal voltage is impressed on the input circuit of the tube, whereas in class B operation the tube is so biased that when no signal is impressed on the input circuit, the plate current is reduced substantially to zero.

Class B operation of amplifier and modulator devices has come into use as a means of obtaining higher efficiency and more audio signal from a given tube. It has been found, however, that in many cases difficulties have been encountered in the use of the class B method of operation due to distortion of the output under certain conditions and other causes. With class A operation of amplifier and modulator tubes the above-mentioned distortion and other difficulties encountered in class B operation are largely avoided. But the dissipation rating of tubes operating class A is limited in practice by the possibility of the formation of hot spots in the tubes when operated in this manner.

However, this latter difficulty is not insurmountable since, in class A operation, it is not necessary when no signal voltage is impressed on the input circuit of the tube, that the full maximum anode voltage be applied to the tube, or that the plate current be the same as under maximum signal voltage conditions. The circuit arrangements may in fact be such, in class A operation, that under the condition of minimum or zero signal, the tube operates on a limited characteristic, the operating point being changed from the operating point for maximum signal voltage to a point for minimum or zero signal voltage such that the plate current when the tube is operating at this latter point is relatively small.

For signal voltages between maximum and minimum or zero, the operating point is caused to lie between the point for maximum signal and the point for zero or minimum signal. Since, in practice, the average input signal in the system is substantially less than maximum, therefore, by the above-mentioned changing of the operating point, the plate current is held to a relatively small average value and an increase in overall efficiency is thereby effected.

The operating point of the amplifier or modulator tube may be varied in several ways to obtain the above described result. For example, the change in operating point may be made at a substantially constant plate voltage by a change only in the bias voltage. Preferably, however, in accordance with my invention, the change in operating point of the tube is made by varying both the bias voltage and the plate voltage. This variation of the bias voltage and plate voltage is arranged to occur in accordance with the variations in the amplitude of the envelope of the modulating or signal potentials impressed on the audio or low frequency input circuit of the system. The variations in amplitude of the audio signal envelope occur in a range of frequencies including syllabic frequencies (so called because their frequency is substantially that of the occurrence of syllables in speech) which are below substantially the minimum range of frequencies of the modulating potentials corresponding to voice and music frequencies, this minimum being substantially the order of 35 to 30 cycles per second. In a modification of my invention the change in operating point of the tube is made at constant bias voltage by varying only the plate voltage in accordance with the variations in the amplitude of the envelope of the impressed audio signal.

My invention will be better understood from the following description when considered in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

Referring to the drawing, Fig. 1 illustrates curves showing ways in which the operating point of a class A or similar amplifier or modulator, may be changed as the tube is operated between maximum signal condition and minimum or zero signal condition, and Fig. 2 is a circuit diagram illustrating a radio transmitter system in which my invention has been embodied.

In Fig. 1, the point A represents the operating point for maximum signal of a class A amplifier or modulator tube or device and the points B1, B2, B3, and B4 indicate operating points for zero signal. The change of the operating point from A to B1 is made by a change in the grid bias voltage impressed on the tube, the plate voltage being maintained substantially constant. In this method of changing the operating point,
the external plate impedance of the tube must be low for direct current, the resistance of the audio frequency choke coil in the plate circuit being necessarily low for this purpose. The
change from A to B is made by varying the plate voltage, the grid bias voltage being maintained substantially constant, and the change from A to B is made by varying both the grid bias and the plate voltage. The changes from A to B and to B are made by a change in grid bias alone when the external direct current impedance of the tube is approximately the same as the alternating current impedance.

In the radio transmitter apparatus illustrated

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In the radio transmitter apparatus illustrated

In Fig. 2 a radio frequency carrier supplied from any suitable source (not shown) is impressed on the input circuit 10 of a radio frequency power amplifier 11 the output circuit 12 of which is connected to an antenna. Modulating potentials impressed on the input circuit 10 of an amplifier 14. Since the intensity of the sound, in the audio or speech and music range of frequencies, impressed on the microphone is not ordinarily constant but varies at a relatively slow rate, therefore the amplitude of the envelope of the audio signal potentials impressed on the input circuit 12 correspondingly varies, this variation occurring at relatively low frequencies, including the above-mentioned so-called syllable frequencies, below the minimum of the audio frequencies. The output of amplifier 14 is impressed, as through leads 15 and input transformer 16, on the input circuit 17 of a class A modulator 18, the plate circuit 19 of which is connected to the plate circuit 12 of radio frequency power amplifier 11. In order to provide a self-biasing means for the modulator 18, the grid-cathode or input circuit 17 comprises a resistance-capacity network which will pass these relatively low frequencies, this network having a resistor 20 in series in the circuit and a capacity 21 in parallel with the resistor.

Plate voltage for the power amplifier 11 and the modulator 18 is supplied preferably from a suitable A. C. power source (not shown) through a main rectifier, indicated generally by the number 22, comprising the rectifier elements or tubes 23 and 24 having anodes 25 and cathodes 26, the latter tubes 24 further including grids or control electrodes 27. To prevent disturbing pulsations from the rectifier 22 from being impressed on the plate circuits of modulator 18 and power amplifier 11, a filter means 28, including a choke coil 29 and a condenser 30 is connected between the rectifier 22 and the tube 18 and 11. The cutoff frequency of this filter being in the neighborhood of 20 to 25 cycles. As the power source supplying rectifier 22 is preferably of a usual commercial frequency, for example 60 cycles, the filter 28 is adapted to remove the ripple due to the 60 cycle supply. This filter however, having the cutoff frequency above stated, offers negligible impedance to frequencies below this minimum. The rectifier 22 is connected to the plate circuit 19 of modulator 18 through the audio choke 31.

In order to vary the plate voltage of modulator tube 18 and amplifier tube 11 in accordance with the variations in the amplitude of the envelope of the signal voltage supplied to the audio input circuit 13 from the microphone or other signal source, a control means is provided for varying the output of the current source which supplies plate current for the tubes 18 and 11, this current source in the present embodiment of the invention being the main rectifier 22. The above-mentioned control means comprises a rectifier-filter circuit including a rectifier 32 and a low-pass filter 33 having a cutoff frequency sufficiently low to offer a high impedance to frequencies in the audio signal or speech and music range but offering negligible impedance to the relatively low frequencies which characterize the variations in amplitude of the audio signal envelope. The input of the rectifier and filter circuit is connected to the audio amplifier 14 through a transformer 34. The control means further includes a resistor 35 connected across the output terminals of the rectifier-filter circuit. One extremity of resistor 35 is connected to the positive end of a constant grid bias voltage means, as battery 36, the negative end of which is connected to the grids 27 of rectifier tubes 24. The other extremity of resistor 35 is connected to the cathodes 26 of tubes 24 through lead 37. The total bias voltage impressed on grids 27 is, therefore, the voltage determined by the fixed voltage of battery 36 and the varying voltage drop across resistor 35, the larger the drop across resistor 35 the less negative the grid bias impressed on grids 27. A voltage limit means is connected across resistor 35 comprising a rectifier 38 and a fixed voltage means, as a battery 39, in series with the rectifier 38.

In operation of the radio transmitter system shown in Fig. 2, the carrier frequency impressed on power amplifier 11 is modulated in the usual manner by audio frequencies from modulator 18 transmitted thereto from the microphone or other signal source through audio amplifier 14, A. C. power, three-phase in the present instance, which is impressed on the rectifier 22, is rectified in the rectifier 22 and filtered in filter 28, and the resulting direct current is supplied to the plate circuits 12 and 19 of the tubes 14 and 18. As a result of impressing the audio signal voltage from transformer 34 on the rectifier 32 a pulsating direct current tends to pass the latter rectifier, or, in other terms, a current tends to pass the rectifier 32 having a direct component and alternating components. One set of alternating components corresponds to the audio frequencies in the voice and music range, for example the range above substantially 25 to 30 cycles. Another set of alternating components corresponds to the recurring variations in amplitude of the envelope of the audio frequencies. Since, however, 33 is a low pass filter offering a high impedance to the frequencies in the usual audio range, above 25 to 30 cycles, but offering negligible impedance to the relatively slow variations in amplitude of the audio signal envelope, therefore the alternating components in the range above 20 to 25 cycles are suppressed and only the components corresponding to the variations in the amplitude of the audio signal envelope are allowed to pass. Consequently a direct current is caused to flow through the resistor 35, this direct current varying from a maximum to a minimum in accordance with the envelope amplitude variations. During a period of maximum amplitude of the envelope the direct current flowing in resistor 35 is a maximum and the drop 75.
across this resistor is also a maximum. The resistor 35 is so poled with reference to bias battery 36 that the drop through the resistor 35 opposes the voltage of the latter bias battery. Therefore, at the assumed period of maximum amplitude of the envelope of the audio signal potentials, the resultant negative bias voltage on grids 27 is decreased to its minimum value, and the grid bias voltage in tube 18, being at its minimum, the increase in grid bias in the rectifier 22 having the effect of increasing the output of the rectifier 22 which supplies the plate circuits of tubes 11 and 18. The filter 28 permits the increase of output since 28 is a low-pass filter offering negligible impedance to frequencies corresponding to the relatively slow variations in the amplitude of the audio signal envelope. Since, in modulator tube 18, the plate current which flows through resistor 20 in series in the plate-cathode circuit is at its maximum, the voltage drop through this resistor 20 is high and the negative grid voltage in tube 18, due to the drop in resistor 20, is at its maximum.

At the above-assumed period of maximum amplitude of the audio signal envelope, with the amplifier and modulator plate voltage at its maximum and the negative grid bias on modulator tube 18 at its maximum as above described, the operating point for class A modulator tube 18 is designated in Fig. 1 by the point A representing the operating point for maximum signal.

If now the amplitude of the envelope of the audio signal potentials impressed in input circuit 43 is decreased to its minimum, or to its zero value, the direct current in the resistor 35 correspondingly decreases, the value of the negative bias voltage on the grids 27 of tubes 24 there by increasing to the value determined by grid bias battery 36 alone. Therefore at the period of minimum amplitude of the envelope of the audio signal potentials, the negative bias voltage on grids 27 is increased to its maximum value.

Since the negative bias on grids 27 is now at its maximum, the plate voltage supplied by main rectifier 22 to the plate circuits of tubes 11 and 18 is at its maximum, the increase in grid bias in the rectifier 22 having the effect of decreasing the output of this plate supply source. The plate current in modulator tube 18 now being at its minimum, the voltage drop through resistor 20 is low and the negative grid bias voltage in tube 18 is at its minimum.

At the assumed period of minimum amplitude of the envelope of the audio signal potentials, the plate voltage of amplifier 11 and modulator 18 being at a minimum and the negative grid bias of modulator 18 also at a minimum, the operating point of class A modulator tube 18 is shown in Fig. 1 by the point B which represents the point for minimum or zero amplitude of the envelope of the audio signal potentials.

From the foregoing description of the operation of the radio apparatus illustrated in Fig. 2, it will be understood that with variation in amplitude of the envelope of the audio signal potentials, the operating point of class A modulator tube 18 changes automatically along the line 40 connecting the point A of Fig. 1, representing maximum amplitude of the envelope of the audio signal potentials; and point B, representing minimum or zero amplitude of the envelope.

Thus if the average modulation during operation of the system is 25%, the total plate input power is 634 kw. for the modulator and modulated power amplifier. The reduction of the radio frequency carrier to 50% of its maximum or normal value will not cause noticeable distortion in a receiver which picks up the signal radiated from the transmitter. With automatic volume control the apparatus illustrated herein provides a substantially distortionless system for reducing peaks of modulation, thereby preventing to a certain extent overloading distortion in receivers.

A transmitter powered similarly to the above-assumed system but having class B modulator apparatus takes the following power, assuming the same power amplifier efficiency as in the first case, 84% modulator efficiency at 100% modulation:

<table>
<thead>
<tr>
<th>Percent modulation</th>
<th>Power amplifier kw input</th>
<th>Modulator kw input</th>
<th>Total kw input</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>700</td>
<td>60</td>
<td>760</td>
</tr>
<tr>
<td>25</td>
<td>720</td>
<td>108</td>
<td>828</td>
</tr>
<tr>
<td>50</td>
<td>720</td>
<td>233</td>
<td>953</td>
</tr>
<tr>
<td>75</td>
<td>720</td>
<td>478</td>
<td>1198</td>
</tr>
<tr>
<td>100</td>
<td>720</td>
<td>801</td>
<td>1521</td>
</tr>
</tbody>
</table>

Thus from a comparison of the above two tabulations, it will be seen that the transmitter having the class B modulator power amplifier system takes, under the 25% average modulation conditions, 46% more power than the transmitter having the class A modulator power amplifier system in accordance with my invention. The apparent efficiencies for the similar class B and the class A...
amplifier and modulator systems are 54.5% and 79% respectively.

With power at a cost of 1e per kw. hour, and considering 18 hour daily programs, the yearly power saving is $18,600 for the herein described system in accordance with my invention, over the transmitter having the class B modulator system.

It will be understood that the transmitter apparatus illustrated in Fig. 2 may be operated as herebefore described to vary the plate voltage of the power amplifier and modulator tubes in accordance with the amplitude of the envelope of the audio signal potentials in the audio input, but without variation of the grid bias voltage of the modulator 15. In this case, with variation in amplitude of the envelope of the impressed audio signal, the operating point of class A modulator tube 18 and power amplifier tube 11 changes automatically along the line 41 connecting the maximum operating point A of Fig. 1 and the point B, the latter point representing minimum or zero amplitude of the envelope of the audio signal potentials.

In a transmitter operating as above set forth on the AB characteristic of Fig. 1, with no change in modulator grid bias, the following power values are calculated, assuming a 20% reduction in plate voltage and 20% of maximum plate current for 0% modulation:

<table>
<thead>
<tr>
<th>Percent modulation</th>
<th>Power amplifier kw. input</th>
<th>Modulator kw. input</th>
<th>Total kw. input</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>690</td>
<td>21</td>
<td>641</td>
</tr>
<tr>
<td>5</td>
<td>730</td>
<td>20</td>
<td>650</td>
</tr>
<tr>
<td>10</td>
<td>753</td>
<td>18</td>
<td>671</td>
</tr>
<tr>
<td>15</td>
<td>784</td>
<td>17</td>
<td>691</td>
</tr>
<tr>
<td>20</td>
<td>816</td>
<td>15</td>
<td>731</td>
</tr>
</tbody>
</table>

From a comparison of the latter table with the table herebefore given showing power requirements for the transmitter having class B modulator apparatus, it will be noted that the latter system draws 10% more power under average modulation conditions than the system in accordance with my invention operating on the AB characteristic of Fig. 1. It will be seen from the foregoing description of radio transmitter apparatus and methods of operation thereof in accordance with my invention, that as compared particularly with apparatus including class B modulator systems, less audio harmonic distortion and at the same time better overall efficiency results from the use of class A modulation devices with varying operating points.

My invention has been described herein in particular embodiments for purposes of illustration. It is to be understood, however, that the invention is susceptible of various changes and modifications, and that by the appended claims I intend to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent in the United States is:

1. The combination with a signaling system comprising a thermionic device, means to impress on said system modulating potentials in the audio frequency range, said potentials having an envelope varying in amplitude, and plate voltage supply means for said thermionic device including a rectifier having a control electrode, of a second rectifier and means to supply current thereto from said first-named means, a filter connected to said second rectifier arranged to pass only the direct current component and current representing the envelope amplitude variations of said current supplied from said first-named means, means to impress bias voltages on said control electrode varying in accordance with the current variations passed by said filter thereby to vary the plate voltage of said thermionic device in accordance with said variations in amplitude of said envelope, and means responsive to the plate current of said thermionic device to vary the grid bias thereof.

2. The combination with a modulated carrier wave system comprising a carrier frequency amplifier, a modulator connected to said amplifier, means to impress on said system modulating potentials of audio frequency, said potentials having an envelope varying in amplitude, and voltage supply means for said amplifier and modulator including a rectifier having a control electrode, of a second rectifier and means to impress voltages thereon from said first-named means, a filter connected to said second rectifier arranged to pass those frequency variations only which correspond to said envelope amplitude variations, means to impress bias voltages on said control electrode varying in accordance with the frequency variations passed by said filter, and means responsive to the plate voltage of said modulator to vary the grid bias thereof.

3. The combination with a modulated carrier wave system comprising an audio input circuit means to impress on said system modulating potentials of audio frequency, said potentials having an envelope varying in amplitude, a modulator, and means including a rectifier having a control electrode to supply plate voltage to said modulator, of means to shift the operating point of said modulator from a point corresponding to the maximum value of said modulator potentials to a point corresponding to substantially zero value thereof, said last-named means including a second rectifier and means to impress voltages thereon from said first-named means, a low-pass filter connected to said second rectifier having its cut-off point below the voice frequencies of said modulating potentials, means to impress bias voltages on said control electrode varying in accordance with the frequency variations passed by said filter, and means responsive to the plate voltage of said modulator to vary the grid bias thereof.

4. The combination with a modulated carrier wave system comprising a carrier frequency amplifier and means to impress a carrier frequency thereon, an audio input circuit and means to impress modulating potentials of audio frequency thereon, said potentials having an envelope varying in amplitude, a modulator, voltage supply means for said amplifier and modulator including a rectifier having a control electrode, means to impress on said modulator said modulating potentials from said input circuit, and means comprising said modulator to modulate said carrier frequency in said amplifier with said modulating potentials, of means to shift the operating point of said modulator corresponding to maximum audio signal impressed on said input circuit to a point corresponding to substantially zero audio signal, said last-named means including a second rectifier and means to impress voltages thereon from said audio input circuit, a control electrode of said second rectifier having its cut-off point below the voice frequencies of said modulating potentials,
means to impress bias voltages on said control electrode varying in accordance with the frequency variations passed by said filter, and means responsive to the plate voltage of said modulator to vary the grid bias thereof.

5. In a signalling system comprising a thermionic tube, a source of modulating potentials of audio frequency, said potentials having an envelope varying in amplitude, a source of plate voltage for said thermionic tube comprising a rectifier device including a control electrode, a rectifier-filter circuit and means to supply voltage thereto from said modulating potential source, said circuit being arranged to pass those frequency variations only which correspond to said amplitude variations of said envelope, and means to impress bias voltages on said control electrode varying in accordance with the frequency variations passed by said rectifier-filter circuit, thereby to control the plate voltage impressed on said thermionic tube in accordance with said variations in amplitude of said envelope.

6. In combination in a radio system, a thermionic tube having a plate circuit, an alternating current source, a source of modulating potentials of audio frequency, said potentials having an envelope varying in amplitude, a rectifier connected to said alternating current source and comprising a plurality of tubes including control grids, a filter connected to said rectifier adapted to pass only a direct current having superposed thereon alternating components of low frequencies of the order of the frequency of the variations in amplitude of said envelope, means to connect said filter to said plate circuit, bias voltage means for said grids comprising a constant voltage source and a resistor in series therewith, a rectifier-filter circuit, means to connect the input of said rectifier-filter circuit to said modulating potential source, and means to connect the output of said rectifier-filter circuit to said resistor, said rectifier-filter circuit being adapted to supply to said resistor a direct current having an alternating component superposed thereon corresponding to said envelope amplitude variations, whereby the voltage impressed on said plate circuit varies in accordance with said envelope amplitude variations.

GEORGE W. FYLER.