

July 19, 1949.

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2,476,875

HIGH-EFFICIENCY AMPLITUDE MODULATION

Filed Feb. 19, 1948

2 Sheets-Sheet 1

FIG. 2

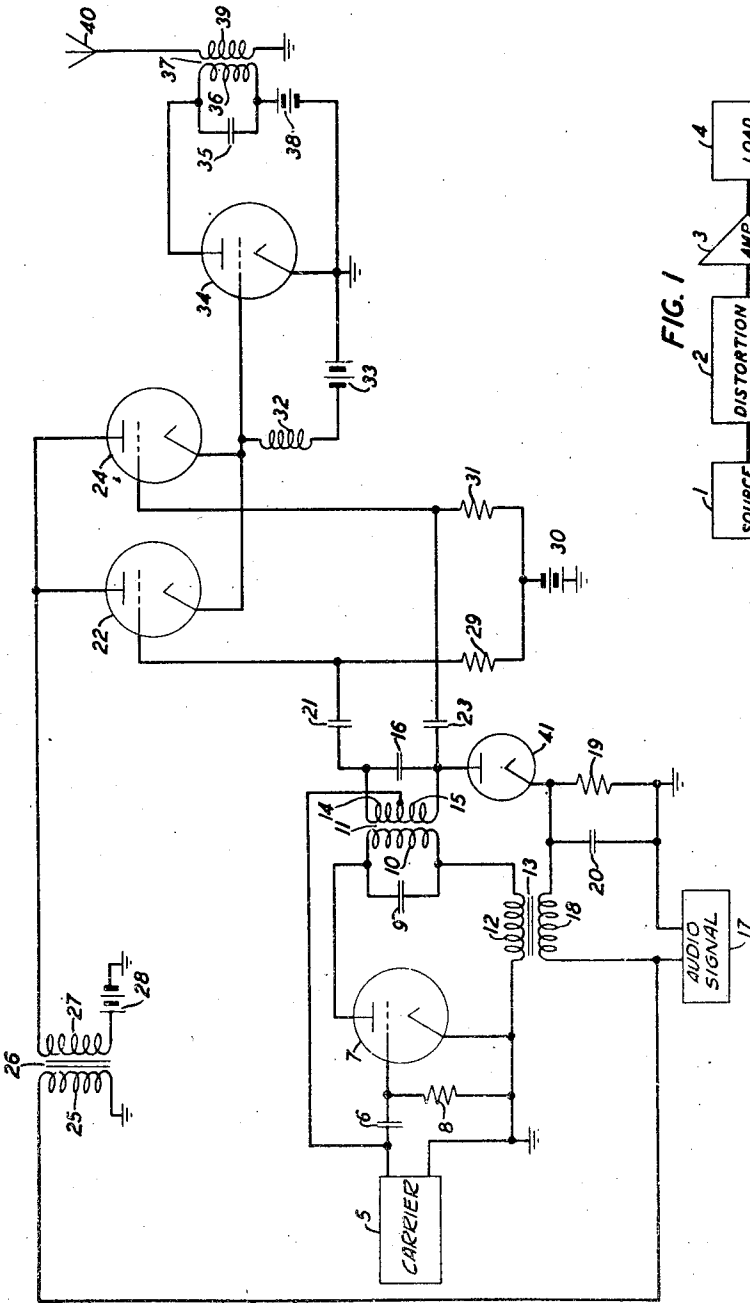
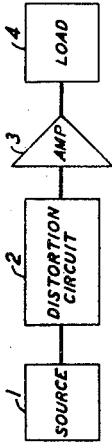


FIG. 1



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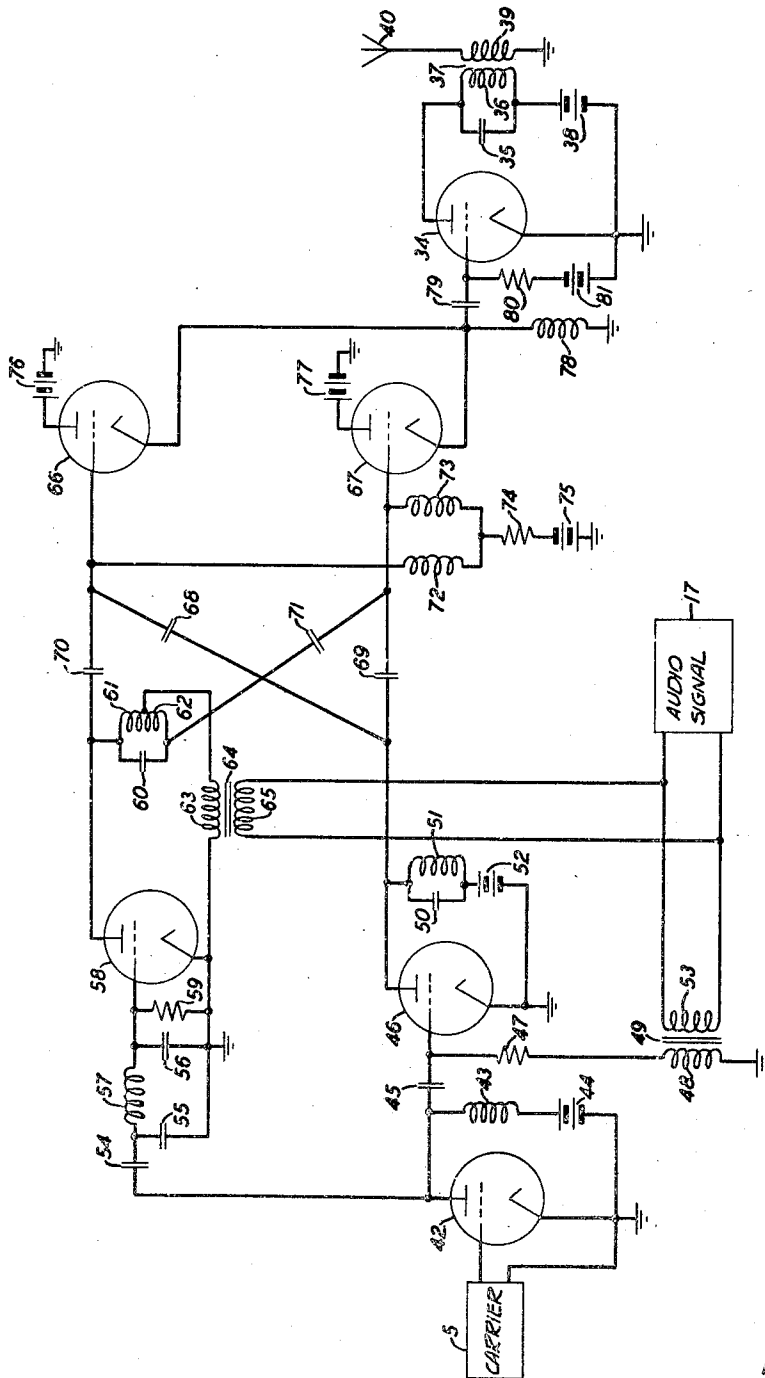


FIG. 3

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HIGH EFFICIENCY AMPLITUDE
MODULATION

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Application February 19, 1948, Serial No. 9,602

44 Claims. (Cl. 332-49)

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This invention relates primarily to class C amplifiers having tuned output circuits and more particularly to class C amplifiers which are employed as power output stages in amplitude modulation systems.

One object of the invention is to obtain an output voltage from a class C amplifier which is greater than the plate supply voltage.

Another and more particular object is to obtain a large output from an amplitude modulation system while drawing only small audio frequency powers and retaining high average efficiency.

An ordinary class C amplifier is operated so that plate current flows in the form of pulses which tend to excite oscillations in the tuned output circuit. These plate current pulses last for less than half the period of each output circuit oscillation. The oscillations are essentially sinusoidal because of the resonant character of the output circuit and, with proper adjustment, have a peak amplitude almost, but not quite, equal to the plate supply voltage. The minimum instantaneous plate potential reached during each oscillation is hence small but not zero. The phase relations are such that, if the input signal to such an amplifier is sinusoidal in nature and of the same frequency as that to which the output circuit is tuned, the minimum instantaneous plate voltage occurs at the same instant as the maximum grid potential, or, in other words, at the same instant as the maximum value of a pulse of plate current. The power lost at the plate at any instant is equal to the product of the instantaneous plate voltage and the instantaneous plate current. The efficiency is high because current is permitted to flow only when most of the plate supply voltage appears as voltage drop across the tuned output circuit, and only a small fraction is wasted as voltage drop at the plate electrode of the tube. The peak amplitude of the voltage oscillations in the tuned output circuit is limited, however, by the magnitude of the plate supply voltage, since the tube will not conduct when the plate is negative.

In the past, a number of methods of amplitude modulation have been used. A widely used method is that of simple plate modulation of a class C amplifier. Such a system gives high efficiency but has the disadvantage of requiring large audio frequency signal powers. Grid modulated systems, on the other hand, draw only small audio powers but operate at efficiencies less than half those of plate modulated systems. A number of high efficiency, low audio power, amplitude

2

modulation systems are known, many of which depend upon the impedance variation properties of a quarter-wave line. However, they tend to be relatively complex and difficult to adjust.

5 In accordance with the present invention, an output voltage can be obtained from a class C amplifier which is greater than the plate supply voltage. The output limitations upon conventional class C amplifiers are avoided by distorting the input signal in a predetermined manner so as to force two plate current pulses to flow during each oscillation of the tuned output circuit. One pulse flows before and the other pulse flows after each plate voltage minimum. As a result, the plate is allowed to become highly negative for appreciable fractions of a plate voltage cycle and the peak amplitude of each oscillation in the output circuit is allowed to increase accordingly. The plate current pulses occur while the plate is just slightly positive and high efficiency is re-
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In amplitude modulation systems employing embodiments of this invention, means are used to transform the input signal to the class C power output stage into a series of carrier frequency pulses. The amplitudes of these signal pulses vary in accordance with the instantaneous amplitude of the audio frequency signal. Each signal pulse divides to form a pair of pulses per carrier cycle during positive excursions of the audio signal, i. e., upward modulation, and is transmitted to the class C output stage unaltered in the absence of audio signal and during negative excursions of the audio signal, i. e., zero and downward modulation.

The peak amplitude of each of the separate pulses in the above-mentioned systems is made to be greater than that of a single unseparated pulse would have been under the same conditions. It can be shown by mathematical analysis that a succession of pairs of separated pulses of increased amplitude and of shorter duration have the same fundamental frequency component as a corresponding succession of single pulses. The transmitted intelligence, then, is in no way affected, and the output from the final stage is a conventional amplitude modulated wave.

50 Modern pulse type tubes enable relatively large pulses of current to flow for short time intervals and may be used to advantage in many embodiments of the present invention.

A more thorough understanding of the invention may be obtained by a study of the following

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detailed description of several specific embodiments. In the drawings:

Fig. 1 is a block diagram showing the general relationship of the various components of an embodiment of the invention as applied to a class C amplifier;

Fig. 2 illustrates a specific embodiment of the invention as applied to an amplitude modulation system; and

Fig. 3 illustrates another specific embodiment of the invention as applied to an amplitude modulation system.

Referring particularly to Fig. 1, an input signal from a source 1 is applied to a distortion circuit 2. The distorted signal is then applied to a tuned class C amplifier 3 and the output from the amplifier 3 is received by a load 4. The input signal tends to excite oscillations in the tuned output circuit of the class C amplifier 3 at the frequency to which the output circuit is tuned. The distortion circuit 2 distorts the incoming signal in the manner heretofore described and produces a greater output than would have been attainable in the absence of the distortion circuit 2.

Fig. 2 shows an amplitude modulation system with incorporated means for distorting the input voltage to the final class C output stage. One side of a carrier source 5 is grounded and the other side is connected through a coupling condenser 6, having negligible resistance at the carrier frequency, to the control grid of a tube 7. The cathode of the tube 7 is grounded and a grid leak resistance 8 is connected between the control grid and ground. The plate of the tube 7 is connected to one side of a tank circuit, made up of a condenser 9 in parallel with the primary winding 10 of an air core transformer 11. The secondary winding 12 of a transformer 13 is connected between the other side of the tank circuit and ground. The secondary winding of the air core transformer 11 is divided into two portions 14 and 15 by a center-tap and the mid-point is connected to the ungrounded side of the carrier source 1. A condenser 16 is connected in parallel with the divided secondary winding 14-15 of the air core transformer 11. A source 17 of audio frequency signals is connected between ground and one side of the primary winding 18 of the transformer 13 and a parallel combination of a resistance 19 and a condenser 20 is connected between the other side of the primary winding 18 and ground.

The grid leak resistor 8 is so chosen that the grid bias of the tube 7 is substantially equal to the carrier amplitude. The audio signal, distorted somewhat by a feedback arrangement which will be described later, is introduced into the plate circuit by the transformer 13 and the tank circuit 9-10 is tuned to the carrier frequency. The tube 7 is thus operated substantially as a plate modulated class C amplifier. However, there is no constant plate supply voltage and, therefore, the tube 7 conducts only on positive excursions of the audio signal. The center-tapped secondary winding 14-15 of the air core transformer 11 is magnetically coupled to the primary winding 10 and is tuned to the carrier frequency by means of the condenser 16. As a result, the voltage appearing across the condenser 16 resulting from the output of the tube 7 is 90 degrees out of phase from the voltage from the carrier source 5.

A coupling condenser 21 is connected between the end of the secondary winding portion 14 and

the control grid of a second tube 22. Similarly, another coupling condenser 23 is connected between the end of the other secondary winding portion 15 and the control grid of a third tube 24. The voltage from either side of the condenser 21 to ground consists of the sum of the voltage induced in the secondary winding portion 14 and the voltage derived from the carrier source 5. These two voltages are 90 degrees out of phase, so that the phase of the resultant combination depends upon the relative magnitudes of the components.

The voltage from either side of the other coupling condenser 23 to ground is derived in a similar manner, except that the other secondary winding portion 15, being a continuation of the first secondary winding portion 14, causes the combination to be, in effect, the difference between the voltage derived from the tube 7 and that derived from the carrier source 5. Since these two voltages are also at 90 degrees with respect to each other, the magnitude of the combination will be the same as that formed at the first coupling condenser 21. However, the phases of these two combined voltages will differ except when the output of the tube 7 is zero due to a negative or zero audio signal. The process here is to add separately to the reference voltage from the carrier source 5 two voltages, each having a 90-degree phase difference from the reference voltage, derived from the output of the tube 7, in such a way as to obtain two new voltages whose magnitude will always be equal but whose phases will be modulated in opposite senses by the output from the tube 7. The resultant voltage waves, then, are both phase and amplitude modulated.

As an example, if the output of the tube 7 is zero the voltages at the coupling condensers 21 and 23 will each consist solely of the voltage derived from the carrier source 5 and will, therefore, have the same phase and magnitude. On the other hand, if the tube 7 is delivering output, the voltages added to the carrier source voltage by the secondary winding portions 14 and 15 will produce resultant voltages at the coupling condensers 21 and 23 which, while still equal to each other in magnitude and having greater magnitude than the carrier source voltage alone, will differ in phase from the carrier source voltage by equal and opposite amounts. Thus the voltages at the coupling condensers 21 and 23 are, on upward modulation, modulated upward in amplitude and shifted apart in phase, while on zero or downward modulation these two voltages are of constant amplitude and the same phase.

The primary winding 25 of a transformer 26 is connected in parallel with the audio signal source 17. One end of the secondary winding 27 of the transformer 26 is connected to the positive terminal of a battery 28, the negative terminal of which is grounded. The other end of the secondary winding 27 is connected to the plates of tubes 22 and 24. A grid leak resistor 29 is connected between the control grid of tube 22 and the negative terminal of a battery 30, the positive terminal of which is grounded. Another grid leak resistor 31 is connected between the control grid of tube 24 and the negative side of the battery 30. The cathodes of tubes 22 and 24 are connected to a choke coil 32, which is, in turn, connected to the negative side of a battery 33. The positive side of the battery 33 is grounded.

The grid leak resistors 29 and 31, in combination with the battery 30, furnish bias to tubes 22

and 24, which are excited by the voltages passed by the coupling condensers 21 and 23, respectively. Plate voltage for tubes 22 and 24 is furnished by the battery 28. The primary winding 25 of transformer 26 is poled so that on upward modulation, when tube 7 is causing the excitation of tubes 22 and 24 to be increased, the audio signal passed by the transformer 26 causes the plate voltage on tubes 22 and 24 to be increased. On downward modulation the audio voltage induced in the secondary winding 27 of the transformer 26 opposes the battery 28 voltage and thereby reduces the plate voltage of tubes 22 and 24. Thus the outputs of tubes 22 and 24 are amplitude modulated by the audio signal to increase their output on upward modulation and to decrease their output on downward modulation. The outputs of tubes 22 and 24 are combined across the choke coil 32, which is preferably high in impedance in comparison with the output impedances of tubes 22 and 24. The tubes 22 and 24 operate as class C cathode followers and deliver outputs which comprise short pulses at the carrier frequency. Combining the outputs at the cathode terminals allows either tube to deliver an output voltage to the following stage, regardless of whether the other tube is conducting. Thus the voltage delivered consists of a series of pulses formed by the superposition of the pulses delivered by tubes 22 and 24, respectively.

The cathodes of the tubes 22 and 24 are connected to the control grid of a fourth tube 34. The cathode of the fourth tube 34 is grounded and the plate is connected to one side of a tank circuit, made up of a condenser 35 in parallel with the primary winding 36 of a second air core transformer 37. The other side of the tank circuit 35—36 is connected to the positive terminal of a battery 38 and the negative terminal of the battery 38 is grounded. One side of the secondary winding 39 of the second air core transformer 37 is grounded and the other side is connected to an antenna 40.

The battery 33, which supplies a bias to tube 34, is of sufficient voltage to cause tube 34 to conduct only on the crests of the exciting pulses of tubes 22 and 24, thereby causing the angle of current flow in tube 34 to be relatively short even for class C operation. Class C amplifiers generally operate with an angle of current flow of approximately 90 to 150 degrees, out of a complete cycle of 360 degrees. In this embodiment of the present invention the angle of flow of tube 34 is made materially shorter, e. g., of the order of 10 to 30 degrees. The tube 34 delivers these pulses to the tank circuit 35—36, which is tuned to the carrier frequency. The battery 38 supplies plate voltage to the tube 34. Other antenna coupling arrangements than that described are well known and are equally useful. In any event, the pulse output of tube 34 is passed through a resonant tank circuit before being coupled to the antenna.

The pulse output of tube 34 differs from that of conventional class C amplifiers in that conventional amplifiers deliver a single pulse per cycle of carrier frequency, while tube 34 may deliver two pulses per cycle of carrier frequency, thereby enabling tube 34 to deliver a peak output voltage of carrier frequency greater than the voltage of the battery 38. On zero or downward modulation the tubes 22 and 24 are excited solely by the carrier source 5 and, therefore, are effectively in parallel to deliver a single pulse per cycle to the output tube 34, the amplitude of which varies

in accordance with the audio voltage induced in the secondary winding 27 of the transformer 26. Thus, on zero modulation the single carrier frequency pulse per cycle delivered by the tubes 22 and 24 to the grid of the output tube 34 is constant in amplitude and tube 34 delivers its average output to the antenna 40. On downward modulation the amplitude of each output pulse from the tubes 22 and 24 is decreased by means of the voltage induced in the secondary winding 27, which reduces the plate voltage of the tubes 22 and 24. This reduction in the pulse amplitude delivered to tube 34 reduces its output by reducing the intensity of its plate current pulses.

On upward modulation the tube 7 delivers an output, causing the phases of the exciting voltages on the grids of tubes 22 and 24 to be shifted apart. Therefore, tubes 22 and 24 no longer conduct simultaneously but one conducts somewhat earlier in the cycle than before and the other conducts somewhat later. Consequently, the pulse across the choke coil 32 which is delivered to the control grid of the output tube 34 divides into two pulses per carrier cycle. At the same time the amplitude of the pulses is increased by the action of the voltage induced in the secondary winding 27 of the transformer 26, increasing the plate voltage on tubes 22 and 24 and thereby causing them to deliver greater outputs.

The voltage across the tank circuit 35—36 continues to oscillate at the carrier frequency and in phase with the carrier. However, the splitting of the grid pulse on the output tube 34 into two pulses, one occurring somewhat earlier and one somewhat later than the single pulse previously present, causes the instantaneous plate voltage of the tube 34 to be highly positive at the times of conduction. With the single pulse present, the amplitude of the carrier frequency voltage across the tank circuit 35—36 increases until the plate voltage on tube 34 is only moderately positive at the time of conduction. The splitting apart of the grid pulse and the early and late occurrence of the new grid pulses cause two pulses of plate current to flow per cycle in tube 34. These pulses flow at a time when the instantaneous plate voltage of tube 34 is highly positive. This causes tube 34 to conduct intense pulses of plate current until the amplitude of the voltage across the tank circuit 35—36 has increased to a point where the instantaneous plate voltage at the time of conduction is again only moderately positive. The increase in the grid pulse amplitude upon the upward modulation caused by the pulse splitting also assists in increasing the plate current pulses and in retaining high efficiency in the output tube 34.

The foregoing explanation has shown how the output of a class C amplifier, with particular reference to an amplitude modulation system employing a class C power output stage, may be increased by appropriately distorting the incoming grid signal. To obtain highly linear modulation or to keep distortion to a small minimum, various well-known negative feedback circuits may be used. Alternatively or in addition one may use the distortion correction circuit which is shown incorporated into the system of Fig. 1.

The plate of a diode 41 is connected to one side of the condenser 16 and the cathode is connected to the ungrounded side of the parallel combination of the resistance 19 and the condenser 20. It should be noted that parallel combination 19—20 is used in connection with this distortion 75 correction circuit and, in the absence of such a

correction device, the primary winding 18 of the transformer 13 would be connected directly across the audio signal source 17.

On zero or downward modulation the output of the first tube 7 is zero and the distortion correction circuit is not operative. Downward modulation is accomplished by modulation of the outputs of the tubes 22 and 24 and may be made highly linear by well-known means. On upward modulation it is desirable to have the separation between the two pulses applied to the control grid of the tube 34 to conform approximately to the relationship

$$\cos d = \frac{1}{1+m}$$

where d is the separation between the split pulses on the grid of the tube 34 and m is the modulation index.

Such a relationship may be obtained, by adding a modulated voltage to a constant voltage at 90 degrees in such a manner that their vector sum is modulated linearly. The diode 41 rectifies a portion of the combined outputs of the tube 7 and the carrier source 5 and applies it to the resistance 19, which acts as a load resistance. The condenser 20 by-passes carrier frequency components so that the voltage across the load resistor 19 consists almost solely of the envelope of the combined voltages. The audio voltage across the primary winding 18 of the transformer 13 therefore consists of the combination of the audio signal derived from the source 17 and the audio signal derived from the modulated carrier frequency output at the coupling condenser 23. By negative feed-back action the modulation of the carrier frequency voltage at the coupling condenser 23 is constrained to be linearly modulated by the audio signal from the source 2 on upward modulation. This causes the output of tube 7 to vary in such a manner as to produce the desired phase variation in the carrier frequency voltage at the coupling condenser 23. Because the voltage at the other coupling condenser 21 is derived in a similar manner, its modulation is also linear and its phase shift is the desired equal and opposite shift to that of the voltage at the coupling condenser 23.

The system shown in Fig. 3 accomplishes somewhat the same purpose as does that shown in Fig. 2, but in a different manner. One side of the carrier source 5 is grounded and the other side is connected to the control grid of a tube 42. The cathode of the tube 42 is grounded and the plate is connected to one side of an inductance 43. The other side of the inductance 43 is connected to the positive terminal of a battery 44, the negative terminal of which is grounded.

The battery 44 furnishes a plate supply voltage for tube 42 and the inductance 43 acts as a radio frequency choke. The tube 42 amplifies the carrier and the amplified wave appears between the plate of the tube 42 and ground.

The plate of tube 42 is connected through a coupling condenser 45 to the control grid of a tube 46. A grid leak resistance 47 is connected between one side of the secondary winding 48 of a transformer 49 and the grid of tube 46. The other side of the secondary winding 48 is grounded. The cathode of tube 46 is grounded and the plate is connected to one side of a tank circuit which comprises a condenser 50 in parallel with an inductance 51. A battery 52 with its negative terminal grounded has its positive terminal connected to the other side of the tank

circuit. The primary winding 53 of the transformer 49 is connected across the audio signal source 17.

The tank circuit 50—51 is tuned to the carrier frequency and the battery 52 acts as plate voltage supply. The grid leak resistor 47 biases the tube 46. The operating voltages of tube 46 are adjusted so that the output of the tube may be grid bias modulated downward by an audio signal from the source 17 but with limited capabilities of upward modulation. This is accomplished by operating tube 46 substantially as a conventional class C amplifier so that decreases in bias can produce no greater output but sufficient increases in bias voltage can reduce the output gradually to zero. Thus the output of tube 46 developed across the tank circuit 50—51 decreases on downward modulation but remains constant in amplitude on zero or upward modulation.

The plate of the first tube 42 is also connected through a coupling condenser 54 to a phase shifting network which comprises two condensers 55 and 56 and an inductance 57. The coupling condenser 54 is connected to one end of the inductance 57 and one condenser 55 is connected between that end of the inductance 57 and ground. The other condenser 56 is connected between the other end of the inductance 57 and ground. The other end of the inductance 57 is also connected to the control grid of a tube 58. The cathode of the tube 58 is grounded and a grid leak resistor 59 is connected between the control grid and ground. The plate is connected to one side of a tank circuit which comprises a condenser 60 in parallel with two series inductances 61 and 62. The secondary winding 63 of a transformer 64 is connected from a point between the two inductance coils 61 and 62 to ground. The primary winding 65 of the transformer 64 is also connected across the audio signal source 17.

The tank circuit 60—61—62 is tuned to the carrier frequency by the condenser 60 and the audio frequency voltage induced in the secondary winding 63 of the transformer 64 is the sole source of plate voltage for tube 58. The poling of the windings 63 and 65 is so arranged that tube 58 delivers no output on zero or downward modulation. On upward modulation the tube 58, the output of which is, essentially, plate modulated, develops a modulated carrier frequency voltage across the tank circuit 60—61—62. The arrangements of the coils 61 and 62 is such that equal and opposite voltages of carrier frequency appear at the respective ends of the coils 61 and 62.

The outputs of tubes 46 and 58 are delivered to the control grids of two additional tubes 66 and 67 through a number of coupling condensers 68, 69, 70 and 71. The coupling condensers 68 and 69 are connected from the plate of the tube 46 to the control grids of the tubes 66 and 67, respectively. The coupling condenser 70 is connected from the plate of tube 58 to the control grid of tube 66 and the other coupling condenser 71 is connected from a point between the tank condenser 60 and coil 62 to the control grid of tube 67. Due to the presence of the phase shifting network in the grid circuit of tube 58 the voltages at the condensers 70 and 71 are 90 degrees out of phase from the voltages at the condensers 68 and 69.

The process thus far has been to obtain a voltage of carrier frequency from the tube 46 which

is constant in amplitude on zero or upward modulation but which decreases on downward modulation and to obtain two voltages from tube 58 which are zero on zero or downward modulation but which increase with upward modulation, these voltages being 180 degrees out of phase with each other and each 90 degrees out of phase with voltage from tube 46.

The coupling condensers 68, 69, 70 and 71 have, at carrier frequency, high impedances in comparison with the output impedances of tubes 46 and 58 but not so high as to prevent the delivery of useful signals to tubes 66 and 67. The condensers 68 and 70 deliver to tube 66 a combination of the output of tube 46 and the direct output of tube 58, while the condensers 69 and 71 deliver to tube 67 a combination of the output of tube 46 and the reversed output of tube 58.

By means of the combination of the two modulated carrier frequency voltages whose phases differ by 90 degrees there is formed at the grid of tube 66 a resultant voltage which is constant in phase on zero or downward modulation and increases or decreases in amplitude with upward or downward modulation, respectively, while the phase is varied in the desired sense only on upward modulation. Likewise, at the grid of tube 67 there is formed a resultant voltage of the same amplitude as that formed at the grid of tube 66. The phase of the voltage at the grid of tube 67 is also constant on zero or downward modulation, while on upward modulation the phase is shifted in accordance with the modulating signal by an equal but opposite amount to that shift produced at the grid of tube 66.

An inductance 72 is connected to the grid of tube 66 and another inductance 73 is connected to the grid of tube 67. The inductances 72 and 73 are both connected to one side of a grid leak resistance 74. The other side of the grid leak resistance 74 is connected to the negative terminal of a battery 75, the positive terminal of which is grounded. The positive terminals of the batteries 76 and 77 are connected to the plates of tubes 66 and 67, respectively. The negative terminals of both batteries 76 and 77 are grounded. The cathodes of tubes 66 and 67 are connected together and an inductance coil 78 is connected between them and ground.

The grid leak resistor 74, in conjunction with the battery 75, furnishes bias to tubes 66 and 67. The batteries 76 and 77 furnish plate voltage to these tubes. The inductance coils 72 and 73 offer direct current paths for the grid currents of tubes 66 and 67 but offer high impedances to carrier frequency voltages. The cathode outputs of tubes 66 and 67 are combined across the inductance coil 78, which is, at the carrier frequency, of high impedance in comparison with the output impedances of tubes 66 and 67. The voltage applied across coil 78 consists of pulses of carrier frequency from either or both of tubes 66 and 67.

A coupling condenser 79 is connected from the cathodes of tubes 66 and 67 to the control grid of the output tube 34, the cathode of which is grounded. A grid leak resistor 80 is connected between the grid and the negative side of a battery 81, the positive side of which is grounded. The plate of the output tube 34 is connected to one side of a tank circuit which comprises a condenser 35 in parallel with the primary winding 36 of an air core transformer 37. The positive terminal of a battery 38 is connected to the other side of the tank circuit 35-36. The negative terminal of the battery 38 is grounded. The

secondary winding 39 of the air core transformer 37 is connected between an antenna 40 and ground.

The grid leak resistor 80, in conjunction with the bias battery 81, causes tube 34 to conduct only at the crests of the exciting pulses from tubes 66 and 67, so that the angle of current flow is relatively short compared to that of conventional class C amplifiers. Plate voltage for the output tube 34 is obtained from the battery 38 and the tank circuit 35-36 is tuned to the carrier frequency. The output of the tube 34 is coupled to the antenna 40 by means of the air core transformer 37.

The operation of tube 34 is much the same as was explained for Fig. 1 in that the control grid of the output tube 34 is excited by carrier frequency pulses from tubes 66 and 67 which coincide on zero or downward modulation but shift apart in phase on upward modulation to permit the tube 34 to deliver a peak output voltage across the tank circuit 35-36 which exceeds the voltage of the battery 38. Downward modulation is obtained by decreasing the amplitude of the pulses at the control grid of the output tube 34.

The present invention has been described largely with reference to the specific field of amplitude modulation. However, it is also applicable to certain other fields, including the general field of class C amplification. Various other embodiments and modifications, within the spirit and scope of the appended claims, may be used to advantage.

What is claimed is:

1. In a class C amplifier having an output circuit tuned to a predetermined frequency, the method of increasing the output of said amplifier without increasing the plate supply voltage which comprises distorting the input signal to allow the plate to become highly negative for appreciable fractions of each cycle of plate voltage at said predetermined frequency.

2. In a class C amplifier having an output circuit tuned to a predetermined frequency such that the intermittent pulses of plate current that an input signal tends to produce tend to excite plate voltage oscillations at said predetermined frequency in said output circuit, the method of obtaining an output from said amplifier greater than the plate supply voltage which comprises distorting the input signal so that plate current pulses flow twice during each of said oscillations, once before and once after each plate voltage minimum, thus allowing the plate to become negative for appreciable fractions of each of said oscillations.

3. In a class C amplifier having an output circuit tuned to a predetermined frequency such that the intermittent pulses of plate current that an input signal tends to produce tend to excite plate voltage oscillations at said predetermined frequency in said output circuit, the method of varying the output of said class C amplifier without varying the plate supply voltage and yet retaining high average efficiency which comprises distorting the input signal so that a pair of plate current pulses flow during each of said oscillations while the plate is only slightly positive, one of said pulses before and one after each plate voltage minimum, thus allowing the plate to become negative for appreciable fractions of each of said oscillations and keeping power losses in the plate circuit low.

4. In a class C amplifier having an output cir-

cuit tuned to a predetermined frequency such that the intermittent pulses of plate current that an input signal tends to produce tend to excite plate voltage oscillations at said predetermined frequency in said output circuit, the method of obtaining an output from said amplifier greater than the plate supply voltage which comprises translating the input signal into a succession of paired pulses, the time separation of which varies in correlation with the variations in instantaneous amplitude of said input signal, forcing plate current pulses to flow twice during each of said oscillations, before and after each plate voltage minimum, the time separation between one of said plate current pulses and one of said plate voltage minimums depending on the said time separation of said paired input signal pulses, thus allowing the plate to become negative for appreciable fractions of each of said oscillations, the extent of said fraction being dependent on the said time separation between each of said plate current pulses and the corresponding plate voltage minimum.

5. In an amplifier having an output circuit tuned to a predetermined frequency, the method which comprises translating an input signal into a succession of pairs of pulses that vary in intra-pair separation in correlation with the characteristic variations of said signal and that follow each other at a rate corresponding to said predetermined frequency, applying said pulses to said amplifier, and deriving the resultant signal-bearing oscillations from said tuned output circuit.

6. In an amplifier having an output circuit tuned to a predetermined frequency, the method which comprises translating an input signal into a succession of pairs of pulses that vary in intra-pair separation in correlation with the characteristic variations of said signal and that follow each other at a frequency systematically related to the frequency of said tuned output circuit, applying said pulses to said amplifier, and deriving the resultant signal-bearing oscillations from said tuned output circuit.

7. In an amplitude modulation system which includes a class C output stage having its plate circuit tuned to the carrier frequency, the method of increasing the output of said amplitude modulation system without increasing the plate supply voltage of said output stage which comprises translating the modulating signal and the carrier wave into a succession of phase and amplitude modulated pulses and applying said pulses to the control grid of said class C output stage, each of said pulses coinciding with a minimum output stage plate voltage point in the absence of modulating signal and on downward modulation, and each of said pulses dividing into a pair of pulses, one before and one after each minimum output stage plate voltage point, on upward modulation, thereby causing a similar succession of plate current pulses to flow in said output stage and allowing the plate voltage to become negative for appreciable fractions of a carrier cycle during upward modulation.

8. In a system including an amplifier having an output circuit tuned to a predetermined frequency, the method of amplitude-modulating a carrier wave of said frequency with a signal which comprises deriving from the carrier a periodic succession of pairs of pulses, varying the time separation of the individual pulses comprising said pairs in correlation with signal varia-

tions, and applying said succession of pulses to said amplifier.

9. In a system including an amplifier having an output circuit tuned to a predetermined frequency, the method of amplitude-modulating a carrier wave of said frequency with a signal which comprises deriving from the carrier a periodic succession of pulses, causing at least some of said pulses to divide and form a pair of successive pulses when the instantaneous amplitude of said signal exceeds a predetermined value, varying the time separation of the pulses comprising the pairs thus formed under the control of variations of the instantaneous amplitude of said signal, and applying said succession of pulses to said amplifier.

10. In a system including an amplifier having an output circuit tuned to a predetermined frequency, the method of amplitude-modulating a carrier wave of said frequency with a signal which comprises deriving from the carrier a periodic succession of pulses, causing at least some of said pulses to divide and form a pair of successive pulses when the instantaneous amplitude of said signal exceeds a predetermined value, varying both the time separation and the amplitude of the pulses comprising the pairs thus formed under the control of variations of the instantaneous amplitude of said signal, and applying said succession of pulses to said amplifier.

11. In a system including an amplifier having an output circuit tuned to a predetermined frequency, the method of amplitude-modulating a carrier wave of said frequency with a signal which comprises deriving from the carrier a periodic succession of pulses, causing the individual pulses to divide and form a pair of successive pulses when the instantaneous amplitude of said signal exceeds a predetermined value, varying both the time separation and the amplitude of the pulses comprising the pairs thus formed under the control of variations of the instantaneous amplitude of said signal, varying the amplitude of the undivided pulses in correlation with the instantaneous amplitude of said signal when said instantaneous amplitude goes below said predetermined value, and applying said succession of pulses to said amplifier.

12. In combination, a signal source, a class C amplifier having an output circuit tuned to a predetermined frequency such that the intermittent pulses of plate current that an input signal from said source tends to produce tend to excite plate voltage oscillations at said predetermined frequency in said output circuit, means for distorting the signal from said source so that when the distorted signal is applied to said class C amplifier plate current pulses tend to flow twice during each of said plate voltage oscillations, once before and once after each plate voltage minimum, and connections from said source to said distortion means and from said distortion means to said class C amplifier.

13. In combination, a signal source, an amplifier having an output circuit tuned to a predetermined frequency such that the intermittent pulses of plate current that an input signal from said source tends to produce tend to excite plate voltage oscillations at said predetermined frequency in said output circuit, means for applying the signal from said source to said amplifier, said amplifier being biased so that plate current flows only when the instantaneous amplitude of said signal exceeds some predetermined positive value, and means for distorting said signal so

that plate current tends to flow in pulses twice during each of said plate voltage oscillations, once before and once after each plate voltage minimum.

14. In combination, an amplifier having an output circuit tuned to a predetermined frequency, means for translating an input signal into a series of pulses occurring at a rate corresponding to said predetermined frequency, means for dividing said pulses into individual pairs of pulses when the instantaneous amplitude of said signal exceeds a predetermined value, and means for applying said pulses to said amplifier.

15. In combination, an amplifier having an output circuit tuned to a predetermined frequency, an input signal source, means for translating the input signal into a series of pulses occurring at a rate corresponding to said predetermined frequency, means for dividing said pulses into individual spaced pairs of pulses when the instantaneous amplitude of said signal exceeds a predetermined value, means for varying the spacing of said individual pairs of pulses under the control of said instantaneous signal amplitude, and means for applying said pulses to said amplifier.

16. In combination, in accordance with claim 15, including means for varying the amplitude of said individual pairs of pulses under the control of said instantaneous signal amplitude.

17. In combination, an amplifier, means for translating an input signal into a series of paired pulses of direct current, means for varying the time separation of the pulses comprising at least some of said pairs of pulses under the control of input signal variations, and means for applying said series of pulses to said amplifier.

18. In combination, an amplifier, means for translating an input signal into a succession of pulses, means for advancing said pulses in phase under the control of said signal, means for retarding said pulses in phase under the control of said signal, means for combining said advanced pulses and said retarded pulses, and means for applying the combined succession of pulses to said amplifier.

19. In combination, an amplifier, at least two separate devices for converting an input signal into a succession of pulses, means for applying an input signal directly to one of said devices, means for applying said signal through a phase-shifting circuit to the other of said devices, means for combining the outputs of said devices, and means for applying said combined output to said amplifier.

20. In combination, a carrier wave source, a source of modulating potential, means for translating the carrier wave into a succession of pulses having a repetition rate corresponding to the carrier frequency, means for dividing said pulses into individual pairs of pulses when the instantaneous amplitude of the modulating potential exceeds a predetermined value, an output amplifier stage, and means for applying said pulses to said amplifier stage.

21. In combination, a carrier wave source, a modulating signal source, means for translating the carrier wave into a periodic succession of paired pulses, means for varying the time separation of the pulses comprising the individual pairs in correlation with variations of the modulating signal, an amplifier having an output circuit tuned to the carrier frequency, and means for applying said pulses to said amplifier.

22. In combination, a carrier wave source, a

modulating signal source, means for translating the carrier wave into a succession of carrier frequency pulses, means for dividing said pulses into individual pairs of pulses when the instantaneous amplitude of the modulating signal exceeds a predetermined value, means for varying both the time separation and the amplitude of the pulses comprising said individual pairs in correlation with the instantaneous amplitude of said signal, a class C amplifier having an output circuit tuned to the carrier frequency, and means for applying said pulses to said amplifier.

23. A combination, in accordance with claim 22, including means for varying the amplitude of said carrier frequency pulses in correlation with the instantaneous amplitude of said signal when said instantaneous amplitude goes below said predetermined value.

24. In combination, a carrier wave source, an input signal source, an amplifier having an output circuit tuned to the carrier frequency, means for translating the carrier wave into a series of carrier frequency pulses, means for dividing said pulses into individual spaced pairs of pulses when the input signal becomes positive with respect to a predetermined reference potential, means for increasing the time separation of the pulses comprising said individual spaced pairs under control of positive increases of instantaneous amplitude of said signal, and means for applying said pulses to said amplifier.

25. A combination, in accordance with claim 24, including means for increasing the amplitude of the pulses comprising said individual spaced pairs in correlation with positive increases of instantaneous amplitude of said signal.

26. A combination, in accordance with claim 24, including means for increasing the amplitude of the pulses comprising said individual spaced pairs in correlation with positive increases of instantaneous amplitude of said signal and means for decreasing the amplitude of said carrier frequency pulses in correlation with negative increases of instantaneous amplitude of said signal when said signal becomes negative with respect to said predetermined reference potential.

27. In combination, a carrier wave source, an input signal source, a class C amplifier having an output circuit tuned to the carrier frequency, at least two pulse-forming devices, means for advancing the phase of the carrier wave under the control of variations in the input signal and applying it to one of said devices, means for retarding the phase of the carrier wave under the control of variations in said input signal and applying it to the other of said devices, means for combining the outputs of said devices, and means for applying the combined output to said class C amplifier.

28. In combination, a carrier wave source, an input signal source, a class C amplifier having an output circuit tuned to the carrier frequency, at least two pulse-forming devices, means for advancing the phase of the carrier wave in correlation with the instantaneous amplitude of the input signal when said instantaneous amplitude exceeds a predetermined value, means for retarding the phase of said carrier wave in correlation with the instantaneous amplitude of said signal when said instantaneous amplitude exceeds said predetermined value, means for applying the advanced and retarded carrier waves each to a respective one of said pulse-forming devices, means for combining the outputs of said

devices, and means for applying the combined output to said class C amplifier.

29. In combination, a carrier wave source, an input signal source, a class C amplifier having an output circuit tuned to the carrier frequency, at least two pulse-forming devices, means for advancing the phase and increasing the amplitude of the carrier wave in correlation with the instantaneous amplitude of the input signal when said instantaneous amplitude exceeds a predetermined value, means for retarding the phase and increasing the amplitude of said carrier wave in correlation with the instantaneous amplitude of said signal when said instantaneous amplitude exceeds said predetermined value, means for applying the advanced and retarded carrier waves each to a respective one of said pulse-forming devices, means for combining the outputs of said devices, and means for applying the combined output to said class C amplifier.

30. A combination, in accordance with claim 29, including means for reducing the amplitude of the carrier wave in correlation with the instantaneous amplitude of said signal when said instantaneous amplitude goes below said predetermined value and means for applying the reduced carrier wave to both of said pulse-forming devices.

31. A combination, in accordance with claim 29, including means for reducing the outputs of said pulse-forming devices in correlation with the instantaneous amplitude of said signal when said instantaneous amplitude goes below said predetermined value.

32. In combination, a carrier wave source, an input signal source, an output circuit, means for translating the carrier wave into a succession of pulses having a repetition rate corresponding to the carrier frequency, means under the control of said signal source for dividing said pulses into individual pairs of pulses whenever the instantaneous amplitude of the input signal is positive with respect to a predetermined reference potential, and means for applying said pulses to said output circuit.

33. In combination, a carrier wave source, an input signal source, an output circuit which is resonant at a frequency integrally related to the carrier frequency, means for translating the carrier wave into a succession of pulses which occur at a rate corresponding to the carrier frequency, means under the control of said signal source for dividing said pulses into individual pairs of pulses whenever the instantaneous amplitude of the input signal is positive with respect to a predetermined reference potential, and means for applying said pulses to said output circuit.

34. In combination, an audio signal source, a carrier source, a class C amplifier having an output circuit tuned to the carrier frequency, means for amplitude modulating said carrier with said audio signal, means for phase modulating said carrier on positive excursions of said audio signal, means for combining the outputs of the two said modulating means into a succession of carrier frequency pulses, and means for applying said succession of carrier frequency pulses to the input of said class C amplifier.

35. In combination, a carrier source, an audio signal source, a class C amplifier having an output circuit tuned to the carrier frequency, means for amplitude modulating said carrier with said signal on only positive excursions of said signal, with no output in the absence of signal or on

negative excursions, means for achieving a 90-degree phase shift in the output of said modulating means, means for dividing said shifted output into two portions, opposite in phase, means for combining said portions with said original carrier wave, thereby giving resultant waves both amplitude and phase modulated for positive excursions of said signal but with the phase modulation in one of said resultant waves opposite in sense from that of the other, means for amplitude modulating both of said resultant waves with said audio signal, means for combining the outputs of both of the second said amplitude modulating means into a series of carrier frequency pulses, and means for applying said succession of carrier frequency pulses to the input of said class C amplifier.

36. A combination, in accordance with claim 35, including a distortion correction circuit which comprises means for rectifying a portion of at least one of said resultant waves formed by combining said shifted modulated output with said carrier, means for by-passing the carrier frequency components of the rectified wave, and means for distorting said audio signal with the resulting voltage envelope of said rectified wave so that the modulation of said resultant wave becomes more nearly linear.

37. In combination, a carrier wave source, a source of modulating potential, a class C amplifier having an output circuit tuned to the carrier frequency, means for advancing the phase of the carrier wave under the control of the instantaneous amplitude of the modulating potential when said instantaneous amplitude exceeds a predetermined value, means for retarding the phase of the carrier wave under the control of said instantaneous amplitude of said modulating potential when said instantaneous amplitude exceeds said predetermined value, means for amplitude-modulating the advanced carrier wave with said modulating potential comprising a first space discharge device containing at least an anode, a cathode, and a control electrode, said advanced carrier wave being applied between the control electrode and the cathode and said modulating potential being applied between the anode and the cathode of said first device, means for amplitude-modulating the retarded carrier wave with said modulating potential comprising a second space discharge device containing at least an anode, a cathode, and a control electrode, said retarded carrier wave being applied between the control electrode and the cathode and said modulating potential being applied between the anode and the cathode of said second device, and means for coupling the cathodes of both of said devices to said class C amplifier.

38. A combination, in accordance with claim 37, in which the cathodes of said first and second space discharge devices are connected together.

39. A combination, in accordance with claim 37, in which said carrier wave advancing means and said carrier wave retarding means comprise a space discharge device containing at least an anode, a cathode, and a control electrode, said carrier wave being applied between the control electrode and the cathode of said device, a first parallel resonant circuit connected to the anode of said first device, said first circuit being resonant at the carrier frequency, means for applying said modulating potential between said first circuit and the cathode of said device, said modulating potential comprising the only source of

plate supply voltage for said device, a second parallel resonant circuit coupled magnetically to said first circuit, said second device being also resonant at the carrier frequency and comprising a substantially center-tapped inductance shunted by a capacitance, and a feedback path connected between the center tap of said inductance and the control electrode of said device.

40. In combination, a carrier source, an audio signal source, a class C amplifier having an output circuit tuned to the carrier frequency, means for amplitude modulating said carrier with said audio signal on only negative excursions of said signal, with constant output in the absence of signal or on positive excursions, means for shifting the phase of said carrier through 90 degrees, means for amplitude modulating the shifted carrier with said signal on only positive excursions of said signal, with no output in the absence of signal or on negative excursions, means for combining the outputs of both of the said modulating means to form the vector sum of the modulated waves, means for translating said vector sum into a succession of carrier frequency pulses, means for combining the outputs of both of the said modulating means to form the vector difference of the modulated waves, means for translating said vector difference into a succession of carrier frequency pulses, means for combining both of said successions of carrier frequency pulses into a single succession of carrier frequency pulses, and means for applying said single succession of pulses to the input of said class C amplifier.

41. In combination, a carrier wave source, a source of modulating potential, a class C amplifier having an output circuit tuned to the carrier frequency, means for advancing the phase and increasing the amplitude of the carrier wave under the control of the instantaneous amplitude of the modulating potential when said instantaneous amplitude exceeds a predetermined value, means for retarding the phase and increasing the amplitude of said carrier wave under the control of the instantaneous amplitude of said modulating potential when said instantaneous amplitude exceeds said predetermined value, means for decreasing the amplitude of said carrier wave under the control of the instantaneous amplitude of said modulating potential when said instantaneous amplitude goes below said predetermined value, a pair of space discharge devices each containing at least an anode, a cathode, and a control electrode, both of said devices being biased for class C operation, means for coupling the advanced carrier wave between the control

electrode and the cathode of one of said devices, means for coupling the retarded carrier wave between the control electrode and the cathode of the other of said devices, means for coupling the reduced carrier wave between the control electrodes and the cathodes of both of said devices, means for supplying space current between the anodes and cathodes of both of said devices, and means for coupling the cathodes of both of said devices to said class C amplifier.

42. A combination, in accordance with claim 41, in which the cathodes of both of said space discharge devices are connected together.

43. A combination, in accordance with claim 41, in which said carrier wave advancing means and said carrier wave retarding means comprise a space discharge device which contains at least an anode, a cathode, and a control electrode, said carrier wave being applied between the control electrode and the cathode of said device, a parallel resonant circuit connected to the anode of said device, said circuit being resonant at the carrier frequency and comprising a substantially center-tapped inductance shunted by a capacitance, and means for applying said modulating potential between the center tap of said inductance and the cathode of said device, said modulating potential comprising the only source of plate supply voltage for said device.

44. A combination, in accordance with claim 41, in which said means for decreasing the amplitude of said carrier wave comprises a space discharge device which contains at least an anode, a cathode, and a control electrode, said carrier wave being applied between the control electrode and the cathode of said device, a parallel resonant circuit connected to the anode of said device, said circuit being resonant at the carrier frequency, means for supplying space current to said device connected between said resonant circuit and the cathode of said device, and means for supplying a variable biasing potential between the control electrode and the cathode of said device, said biasing potential being under the control of said modulating potential.

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