Dec. 16, 1941. C. W. HANSELL 2,266,197

WIDE FREQUENCY BAND AMPLIFIER SYSTEM

Filed Nov. 26, 1938

Fig. 1

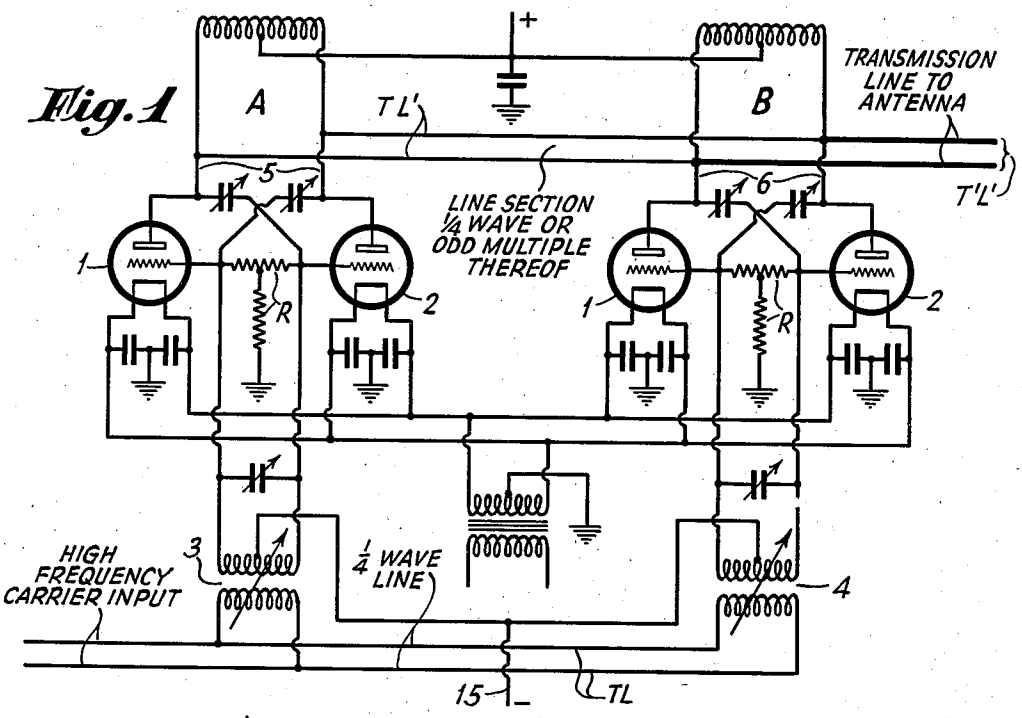


Fig. 2

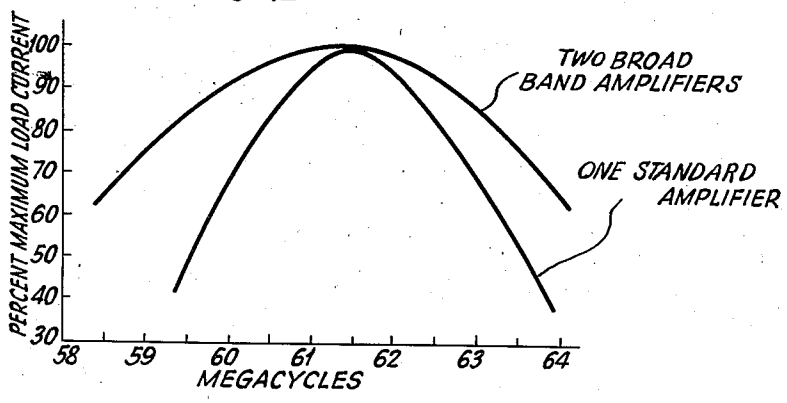
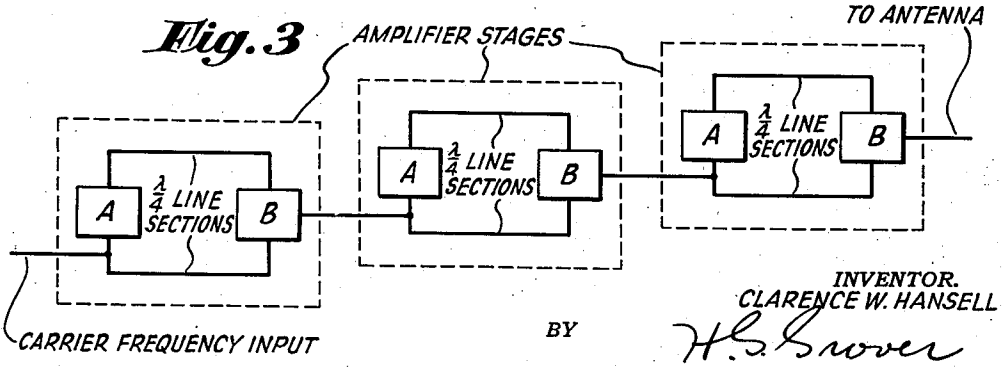


Fig. 3



INVENTOR.
CLARENCE W. HANSELL

BY H. A. Snover

ATTORNEY.

Patented Dec. 16, 1941 2,266,197

UNITED STATES PATENT OFFICE

2,266,197

WIDE FREQUENCY BAND AMPLIFIER SYSTEM

Clarence W. Hansell, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application November 26, 1938, Serial No. 242,442

17 Claims. (Cl. 179—171)

The present invention relates to electron discharge device amplifiers of high frequency currents, and particularly to vacuum tube amplifiers for amplifying a wide band of frequencies.

The invention is particularly applicable to radio transmitters and receivers, especially for the transmission and reception of television signals, and will be described with regard thereto, although it is to be distinctly understood that the invention is not limited in this respect, but may be used wherever there is need for a wide frequency band amplifier.

In some kinds of radio transmitters, particularly those used for television transmission, it is extremely difficult to obtain sufficient broad band frequency response in the modulated high frequency circuits. A similarly difficult problem has existed in the receivers.

The lack of sufficient band width in the high frequency amplifier circuits has been a result of the dielectric capacity of electron tubes and circuits. This capacity is balanced out, by tuning with inductance, for some frequency in the transmitted band, which is usually the carrier frequency. For any other frequency, above or below the resonant frequency, the capacity and inductance no longer have equal reactance and do not balance out. At resonance the amplifier vacuum tubes deliver power to an output circuit which is substantially an effective resistance but, for higher or lower frequencies the output circuit becomes reactive, as well as resistive, and the vacuum tubes must deliver output current to supply a reactive component as well as a resistive component. This requires an increase in electron current through the tube to supply the reactive component of output current at frequencies different from the resonant frequency. In practice it has been, so far, impossible to build vacuum tubes with enough useful electron emission and peak electron current to supply the unbalanced component of reactive current to the output circuit, in addition to the resistive component, over a frequency band wide enough for really satisfactory television. Amplifier tubes are needed with a much greater ratio of peak available electron current to interelectrode dielectric capacity, but in spite of the great effort and huge expenditures for development of better tubes, only very slow progress has been made and the best of the existing tubes, although they are not good enough, seem to have been pushed very close to the ultimate limits for this kind of device.

The present invention recognizes this fundamental limit in the obtainable ratio of useful peak electron current to dielectric capacity between electrodes and provides a means for widening the frequency band of amplifiers without further improvement in the vacuum tubes. Briefly, the manner of bringing about this improvement in band width and frequency response is to employ two amplifiers which cooperate not only to deliver a useful output of modulated high frequency energy but which also cooperate to reduce the reactive component of current required from each amplifier. To obtain this result the output circuits of the two amplifiers of the invention are joined together through a section of real or artificial transmission line of suitable characteristic impedance, which is electrically a quarter wave at the center of the frequency band to be transmitted, or in some cases an odd number of quarter waves long. Where double side band transmission is employed, the length of the line will be electrically and effectively a quarter wave, or an odd multiple of a quarter wave, at the carrier frequency. The two amplifiers are then provided with high frequency inputs which are 90° different in phase. The output from the two amplifiers is taken from that end of the quarter wave line section which has lagging phase. Putting it another way, in as brief and general a statement as possible, the invention provides an impedance inverter in the form of a quarter-wavelength line, or odd multiple thereof, placed between a pair of amplifiers to achieve an effective broadening of the frequency response characteristic.

A better understanding of the invention may be had by referring to the following description, which is accompanied by a drawing, wherein:

Fig. 1 shows, by way of example only, the principles of the invention applied to a pair of amplifiers in the last stage of a television transmitter;

Fig. 2 shows, graphically, the improvement obtained in using a pair of amplifiers in accordance with the invention over a single amplifier, in one embodiment successfully used in practice; and

Fig. 3 shows diagrammatically, in box form, how the system of Fig. 1 can be used in a cascaded amplifier system.

Referring to Fig. 1 in more detail, there are shown two amplifiers A and B, each comprising a pair of push-pull connected, cross-neutralized, evacuated electron discharge devices 1 and 2. The input circuits 3 and 4, as well as the output circuits 5 and 6 of the two amplifiers A and B are, respectively, interconnected by quarter wave-

length lines TL and TL', so as to provide a 90° phase relation therebetween.

Both input circuits 3 and 4 are supplied with an equal amount of high frequency carrier current by means of transformers, and it is assumed that the input circuit 3 of amplifier A is 90° leading in phase with respect to input circuit 4 of amplifier B. This 90° phase relation is shown obtained by joining both input circuits with a quarter wave transmission line TL which has its characteristic impedance matched at amplifier B. If desired, of course, the transformers can be omitted, and the carrier frequency current applied directly to the grids of the amplifiers A and B, in association with suitable tuning and loading means to obtain impedances equal to the characteristic impedance of the line section TL. The line TL is made to be a quarter wavelength long, electrically, at the mid frequency of the band to be amplified. To obtain this condition, the physical length will usually be slightly less than a quarter wave. It will be understood, of course, that other methods of obtaining the 90° phase relation between input circuits 3 and 4 can be used. For example, the two inputs 3 and 4 can be coupled to a common source of carrier frequency without a quarter wave line between them, and the phase relations of their currents controlled by detuning the two input circuits in opposite directions so as to obtain the desired 90° phase relation. Also, when the line section is used, variable tuning may be used for obtaining more exact desired phase relations.

The two tubes 1 and 2 of each amplifier are shown provided with neutralizing condensers coupled in known manner between the anode of one tube and the grid of the associated tube. In order to reduce the possible effects of imperfect amplifier neutralizing or balancing and also to reduce the effects of modulation upon the phase and amplitude of the excitation power, the input circuits are preferably made to have considerable resistive loading at the grids, as shown by resistances R. Also, when wide band modulation is to be applied to the anodes or grids of the amplifier tubes, it is desirable to employ rather large capacity and low inductance for tuning the grids so as to produce considerable circulating current in the input circuits. The grids of the tubes, it should be noted, are maintained at a negative potential with respect to their cathodes by means of grid bias lead 15 extending to the negative terminal of a source of bias potential, not shown.

The outputs from the two amplifiers are shown joined together through a quarter wave transmission line TL' which is preferably connected as nearly as possible between the two vacuum tube anodes in each amplifier at each end of the line. Line TL' is made to be a quarter wavelength long or an odd multiple of a quarter wavelength at the center of the band of frequencies to be transmitted. Another transmission line T'L' connected to the antenna and having half the characteristic impedance of the first quarter wave line section is connected to the end of the quarter wave line TL' at the point of attachment to the anodes of the tubes of the amplifier B with the lagging phase.

The whole system is so designed and adjusted that the two amplifiers A and B are tuned to resonance at a mid output frequency, which is preferably the input carrier frequency, where double side band transmission is employed. The two amplifiers A and B should deliver equal amounts of output power to the main transmission line T'L' extending to the antenna. The output circuit of each amplifier A and B preferably consists of a parallel tuned circuit of inductance and capacitance, although a tuned lecher wire circuit can be employed instead.

In order to effect grid modulation of the amplifiers A and B, the low frequency grid potentials of the tubes may be controlled by suitable circuits coupled to lead 15, and these grid potentials varied together by means of direct current and alternating current video frequency modulation potentials so as to vary the outputs from both amplifiers in accordance with the television signals to be transmitted. Instead of grid modulation, the high frequency carrier input may be modulated by introducing modulation ahead of the last stage.

In many cases it may be preferable to introduce the modulation into the anode supply lead for the amplifiers A and B. The choice of the location for introducing the modulation depends upon many factors including difficulties encountered by the designer in providing high power modulation equipment.

If now, assuming grid modulation, the grid bias on the amplifiers is varied by video frequency input, the two amplifiers will have their outputs changed or modulated accordingly and both outputs will remain substantially equal for any value of output, that is, both amplifiers are in parallel relation for the modulation although differing in phase by 90° for radio frequency output.

If the modulation produces a current component of frequency above or below the frequency to which each circuit is tuned, then each of the output circuits for the two ampliers will show a component of reactive impedance and the reactive component of current will be greater and greater the farther we go from the carrier frequency to which each of the circuits is tuned. In amplifiers of the prior art, this reactive component of current flowing to each of the amplifier output circuits would have to be supplied by the tube, or the modulation response characteristic would suffer. That is, the output at the off resonance frequency would be reduced and shifted in phase with respect to the carrier with corresponding changes in the modulation of the carrier represented by these off resonance frequencies. In the system of the invention, however, the amplifiers react upon one another through the quarter wave line section TL' in such a way as to eliminate or greatly reduce the reactive component of current required from the tubes.

If we assume that a high frequency component of current exists in the amplifier outputs which is at a higher frequency than the resonant frequency, then each individual output circuit taken alone would present an equivalent capacitive reactance and a resistance to the tubes. In the system of the invention, however, the capacitive reactance of each amplifier circuit appears at the other amplifier circuit as an equivalent inductive reactance by virtue of the quarter wave line TL' between them. Consequently, the reactive component of current required from the tubes is very greatly reduced because the reactive component for each circuit is balanced by reactive current exchanged through the quarter wave line TL'.

The balancing of reactance in the two output circuits of the amplifiers A and B of the invention is not quite perfect and becomes less and less perfect as we depart far from resonance

because the quarter wave line is no longer a quarter wave for frequencies far from the resonant frequency and because, if too much reflection along the quarter wave line exists, a reactive component of current at one end of the line does not represent an equal reactive current component of opposite sign at the other end of the line. However, the balancing of reactive components of current obtainable by the invention represents a very great improvement, even if not quite perfect.

In the design and operation of the system of the invention, it is desirable not only that the quarter wave line section TL' between the amplifiers A and B have a characteristic impedance twice as great as that of the transmission line T'L' to the antenna, but also that the quarter wave line section have a characteristic impedance equal to the desired load resistance to be presented to the vacuum tubes of each of the amplifiers A and B. If possible, it is preferred that the impedance presented to each of the amplifiers match the effective resistance, or plate impedance, of the tubes to give maximum power output, but it may be necessary to present lower impedances than this in order to obtain a broader flat frequency response band at the expense of lower power conversion efficiency. In other cases we may wish to operate the amplifiers with smaller power output and higher efficiency by presenting a higher impedance load to the tubes. In any case, my invention makes it possible to use a higher load resistance and to obtain higher efficiency than can be obtained in ordinary amplifiers of the prior art when these amplifiers are required to operate over an arbitrary wide band of frequencies.

It should be noted that the balancing out of reactive components occurs both in the input and output circuits of the amplifiers A and B. This condition is especially desirable when the amplifier is used for amplifying currents extending over a wide range of frequencies.

Fig. 2 shows graphically the improvement obtained in one particular embodiment constructed in accordance with the invention, over a single amplifier. The curve labeled "One standard amplifier" shows the rate of change of current in a resistance load with variation of frequency when a single amplifier was used. The curve labeled "Two broad band amplifiers" shows the variation in current in the load when two amplifiers, each having two tubes, were used in accordance with the present invention, one of said amplifiers being coupled to the load directly and the other of said amplifiers being coupled through a quarter wave line, in the manner described and illustrated in connection with Fig. 1. Of course, the two amplifiers were excited with inputs differing by 90° in phase, as nearly as possible, by means of the quarter wave line section between the input circuits, in the same manner described above in connection with Fig. 1. If we call the output to the load 100% when the input frequency is adjusted to give maximum output, then we might set the limits of the frequency band at the frequencies on either side of the frequency giving maximum output at which the current in the load has dropped down to 70% of maximum. With this assumption, tests made on an arrangement like Fig. 1 indicate that the band width of my amplifier was increased from 2.9 megacycles to 5.03 megacycles by means of the invention. This increase is equivalent to an improvement of about 1.73 to 1 in band width of the amplifier. If, on the other hand, we set a more rigid standard for frequency response, than the ratio of improvement in band width will be greater. For example, if the allowable drop in load current is arbitrarily allowed to reduce the load current to other percentages between 70% and 100%, then according to tests made in the laboratory, the ratio of increase in band width due to the application of the principles of the invention is given in the following table.

Minimum allowable percentage load current	Ratio of increase in band width
70	1.73
75	1.77
80	1.82
85	1.9
90	1.95
95	2

It should be noted that the ratio of improvement is greater when we set a more rigid band width requirement. This condition, found in practice, follows the theory which indicates that the more severe the frequency response requirement is made the greater will be the ratio of improvement brought about by the invention. The reason for this greater improvement is that the quarter wavelength line impedance inverter gives more nearly perfect compensation as the band width is reduced by setting a more severe requirement in establishing the allowable drop in load current at the limits of the frequency band.

At this time it may be advisable to set forth very briefly the manner in which the tests were made upon which the curves of Fig. 2 are based. The method of making the tests involved applying a certain amount of load to one of the amplifiers operating independently of the other. Then the two amplifiers were joined together through the quarter wavelength line section and adjusted until the load on each amplifier was substantially the same as had been the load on the one amplifier alone. Of course, the excitation to each of the two amplifiers was made substantially the same as that for one amplifier alone, which condition automatically assured substantially 90° phase relation between the high frequency inputs. For both the single amplifier and for the system using the two amplifiers joined through the quarter wave line, the frequency of the input excitation was varied over a wide band. The excitation source was one of the wide band testing transmitters used at the laboratories for broad band antenna developments and tests. It should be noted that the load on the amplifier tubes was not adjusted to obtain maximum possible band width from each amplifier, but was adjusted simply to obtain a fairly heavy load in each case. The load resistance used consisted of two carbon lamps which were applied with the shortest possible connections to one of the amplifier circuits.

Fig. 3 illustrates how a chain of amplifier stages having quarter wave, quarter phase input and output circuits can be cascaded. Each stage includes two amplifiers A and B, as in Fig. 1, and is shown enclosed in a box or electromagnetic shield with the output of one stage feeding the input of the succeeding stage. An arrangement as illustrated in Fig. 3 is useful in broad frequency band amplifier systems and increases

the band width and efficiency of the whole system.

In the system of Fig. 3, it is preferable, though not essential, that the inductive input coupling shown in Fig. 1 be replaced by direct connections similar to those shown in the output circuit in order that there may be no loss of band width due to leakage reactance in the inductive coupling.

In constructing the transmitter systems of Figs. 1 and 3, it may happen that there are required quarter wave line sections having characteristic impedances of rather high values which are not easily reached with ordinary types of transmission lines. Consequently, in these cases the line sections may be made out of coiled wire or coiled conductors so dimensioned as to give the desired impedances. I have found that a line constructed with coiled conductors may be given almost any desired value of characteristic impedance over a wide range lying above the value obtained with straight conductors of the same size. There may also be used artificial lines constructed with lumped coils and condensers.

In cases where it is desired to employ transmission lines of ordinary impedances obtainable without coiling, it is possible to lower the amplifier tube impedances as well as the load impedance by employing a number of tubes in parallel for each tube of the amplifier stage.

In some cases the impedance of the line T'L' required to give correct loading on the amplifiers may be too high or too low to be suitable for a long line to the antenna. In such cases we may transfer the impedance to any other value, over a wide range, by means of a section of transmission line of continuously changing characteristic impedance as described in my United States Patent No. 1,926,807, granted September 12, 1933. We may accomplish a similar result not quite so well but more easily by employing two quarter wave line sections of different impedances in series.

What is claimed is:

1. The method of operating a pair of electron discharge device amplifiers having substantially equal loading conditions at all input and output amplitudes which includes the step of exciting said amplifiers with alternating current power at substantially a 90° phase relation, and establishing substantially zero phase relation between the two components of power derived from said amplifiers.

2. In an amplifier system having a pair of amplifier units, the method of broadening the frequency response characteristic of said system which comprises adjusting said units to receive and deliver equal values of power at all amplitudes, and causing the reactive components in the input and output circuits of one unit to react respectively upon the reactive components in the input and output circuits of the other unit to greatly reduce the reactive component of current required from said amplifier units.

3. The method of operating a pair of electron discharge device amplifiers having substantially equal input and output power at all amplitudes which includes the step of exciting said amplifiers with alternating current power at substantially a 90° phase relation, establishing substantially zero phase relation between the two components of power derived from said amplifiers, and deriving useful power from the amplifier with lagging phase.

4. The method of operating a single stage of amplification comprising a pair of similar and similarly adjusted amplifiers, which comprises exciting said amplifiers from a single source of carrier frequency current at a 90° phase relation, whereby the reactive components in the input circuits appearing on both sides of the carrier frequency are balanced out, producing a compensating phase shift of the amplified waves, whereby they combine in additive phase, and deriving useful power from a point on that amplifier which has lagging phase.

5. An amplifier stage comprising a pair of similar and similarly adjusted amplifiers each having an input and an output circuit, a utilization circuit coupled to said output circuits, and means for balancing out the reactances appearing in said input and output circuits, said means comprising a section of transmission line whose length is substantially one-quarter of a wavelength at the center of the frequency band to be amplified connected between said input circuits, and a section of line having similar characteristics to said first section of line connected between said output circuits.

6. A broad frequency band amplifier stage comprising a pair of similar and similarly adjusted amplifiers, a section of transmission line whose length is an odd multiple including unity of a quarter wave at the center of the frequency band to be amplified coupling together the input circuits of said amplifiers, and another section of line whose length is an odd multiple including unity of a quarter wave at the center of the frequency band to be amplified coupling together the output circuits of said amplifiers.

7. The method of operating a pair of electron discharge device amplifiers having substantially equal input and output power at all amplitudes which includes the step of exciting said amplifiers with alternating current power at substantially a 90° phase relation, establishing substantially zero phase relation between the two components of power derived from said amplifiers, and combining said two components into a single output circuit.

8. A broad frequency band amplifier stage comprising two sets of push-pull connected amplifier tubes, each set comprising a pair of electron discharge devices having input and output electrodes, means for similarly biasing the input electrodes of said amplifier tubes whereby said two sets are substantially equally responsive for all values of excitation voltage, a tuned circuit coupled to the input electrodes of each set for supplying out of phase potentials thereto, means for exciting said tuned circuits with equal values of alternating current power at all power values but at 90° phase relation, a path whose electrical length is an odd multiple including unity of a quarter wave at the center of the frequency band connecting the output electrodes of one set to the output electrodes of the other set, and a utilization circuit coupled to the output electrodes of that set which has lagging phase.

9. A broad frequency band amplifier stage comprising two sets of push-pull connected amplifier tubes, each set comprising a pair of electron discharge devices having input and output electrodes, means for similarly biasing the input electrodes of said amplifier tubes whereby said two sets are substantially equally responsive for all values of excitation voltage, a tuned circuit coupled to the input electrodes of each set for supplying out of phase potentials thereto,

means for exciting said tuned circuits with equal values of alternating current power at all power values but at 90° phase relation, a section of transmission line whose electrical length is an odd multiple including unity of a quarter wave at the center of the frequency band to be amplified connecting the output electrodes of one set to the output electrodes of the other set, and another section of transmission line coupled to the output electrodes of that set which has lagging phase, said last section of line having a characteristic impedance which is half that of said first section of line.

10. A cascaded amplifier system comprising a first stage having two sets of push-pull connected amplifier tubes, each set comprising a pair of electron discharge devices having input and output electrodes, means for similarly biasing the input electrodes of said amplifier tubes whereby said two sets are substantially equally responsive for all values of excitation voltage, a tuned circuit coupled to the input electrodes of each set for supplying out of phase potentials thereto, means for exciting said tuned circuits with equal values of alternating current power at all power values but at 90° phase relation, a path whose electrical length is an odd multiple including unity of a quarter wave at the center of the frequency band connecting the output electrodes of one set to the output electrodes of the other set, and a second similar amplifier stage coupled to the output electrodes of that set which has lagging phase.

11. Means for obtaining a broad band radio frequency amplifier system comprising two similar and similarly adjusted amplifiers supplied with radio frequency input through connections differing in electrical length and delivering power to a load through connections differing in electrical length by an odd multiple including unity of a quarter of a wave at the center of the frequency band to be amplified.

12. Means for obtaining a broad band radio frequency amplifier system comprising two similar and similarly adjusted amplifiers joined together at their inputs and outputs by sections of transmission line which are each electrically one-quarter or an odd multiple of one-quarter wave long.

13. Means for obtaining a broad band radio frequency amplifier system comprising two similar and similarly adjusted amplifiers joined together at their inputs and outputs by impedance inverting networks or lines.

14. The method of operating a pair of electron discharge device amplifiers which includes the step of exciting said amplifiers with equal values of alternating current power at all amplitudes and at substantially a 90° phase relation, and establishing substantially zero phase relation between the two components of power derived from said amplifiers.

15. In an amplifier stage having two similar and similarly adjusted amplifier units interconnected with impedance inverting circuits, the method of broadening the frequency response characteristic of said amplifier stage which comprises balancing out the reactive components in the input and output circuits of said amplifier stage.

16. A broad frequency band amplifier stage comprising two sets of push-pull connected amplifier tubes, each set comprising a pair of electron discharge devices having input and output electrodes, means for similarly biasing the input electrodes of said amplifier tubes whereby said two sets are substantially equally responsive for all values of excitation voltage, a tuned circuit coupled to the input electrodes of each set for supplying out of phase potentials thereto, means for exciting said tuned circuits with equal values of alternating current power at all power values but at 90° phase relation, said last means including a line whose electrical length is an odd multiple including unity of a quarter wave at the center of the frequency band, a path whose electrical length is an odd multiple including unity of a quarter wave at the center of the frequency band connecting the output electrodes of one set to the output electrodes of the other set, and a utilization circuit coupled to the output electrodes of that set which has lagging phase.

17. In an amplifier system having a pair of amplifier units, the method of operation which comprises adjusting said units to receive equal values of power at all amplitudes at a desired phase relation and to amplify equal values of power at all amplitudes at the same desired phase relation, and producing a compensating phase shift of the amplified waves, whereby they combine in additive phase.

CLARENCE W. HANSELL.