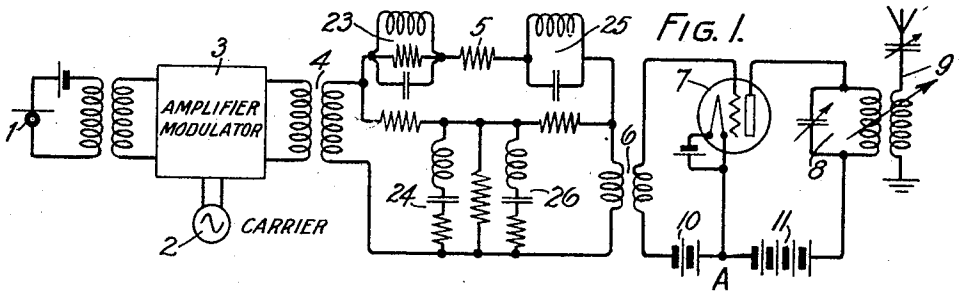
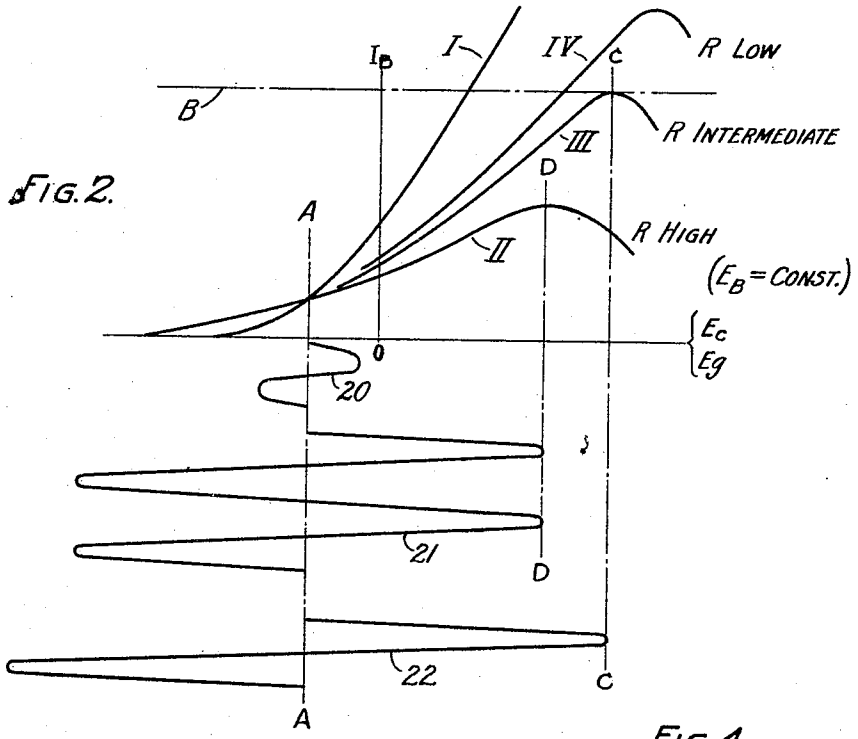
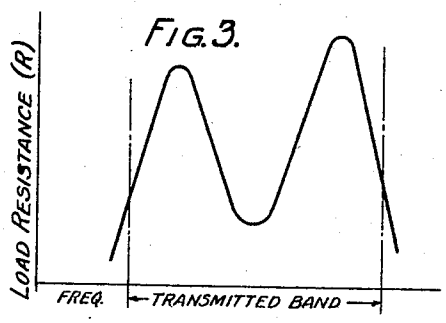
June 10, 1930. E. PETERSON 1,762,737

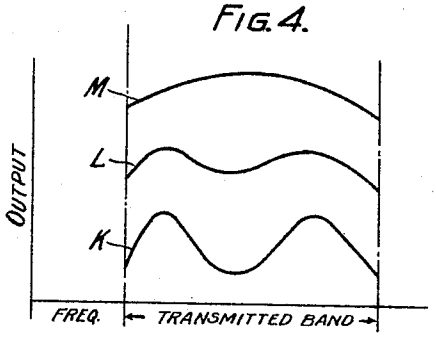
SYSTEM EMPLOYING SPACE DISCHARGE DEVICE

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SYSTEM EMPLOYING SPACE-DISCHARGE DEVICE

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The present invention relates to circuits employing space discharge devices for amplifying signal waves or for other purposes, in which the space current is made to flow in impulses. The invention is particularly applicable to a radio transmitter and will be described in connection with such use but it is also applicable to other uses particularly where the discharge tubes develop considerable amounts of power.

An object of the invention is to improve the operating characteristics of a circuit or system of the type referred to from the standpoints particularly of quality of signal transmission and power output obtainable.

A related object is to equalize the distortion arising from a non-linear impedance-frequency relation in the load circuit.

In the case of a space discharge tube circuit for developing oscillating current power in the load circuit it is known in the prior art that the efficiency of the discharge tubes and the available power output are dependent upon the character of the space current flow through the tubes, and upon the relation of the load impedance to the internal plate impedance of the tube. In particular it has been known that maximum power output and maximum efficiency can not both be secured by one and the same adjustment but that the adjustments are quite different for these two conditions. Higher load impedance and shorter space current impulses raise the efficiency but result in lower power output. In any given situation a practical compromise must generally be made between maximum efficiency and maximum power.

In the case involving transmission of a band of frequencies such as in speech transmission, the foregoing principles are applicable to an extent but a very important limiting factor comes in, namely the preservation of the true character of the signal wave throughout the steps in the process of transmission, or in other words, quality. If the quality is maintained throughout so that the signal may eventually be received as a faithful reproduction of the original, neither power considerations on the one hand nor efficiency on the other can be carried to the extreme, since large amounts of distortion and a sacrifice of quality would result.

In accordance with the present invention, the factors which determine the operating characteristics of the system are proportioned from the standpoints of quality, tube efficiency and power output so as to insure maintenance of the required quality while securing the largest power output consistent with this quality and with a safe energy dissipation within the tubes. The invention enables this result to be obtained whether the load impedance is the same or different at the different frequencies within the transmitted frequency band.

The nature and objects of the invention will appear more fully from the detailed specification to follow, in which reference will be made to the accompanying drawings.

In the drawings, Fig. 1 represents a transmission circuit embodying the invention and Figs. 2, 3 and 4 show curves which will be used in describing the principle of operation of the invention.

Referring first to Fig. 1, a source of waves such as speech waves is diagrammatically indicated at 1, together with means for modulating a carrier wave from source 2 by the speech or other signal waves. For this purpose the amplifier-modulator 3 is provided, this being of any suitable type such as those well known in the art. The carrier wave from the source 2 is a radio frequency wave, although if desired a system of modulation may be employed in which the speech does not in the first instance modulate the final radio frequency wave but first modulates an intermediate frequency wave. The modulated side band

or the modulated side band and the unmodulated carrier wave together pass from the output of the modulator amplifier 3 through the transformer 4, corrective network 5 and transformer 6 to the input circuit of the power amplifier 7 by which they are stepped up in power to the requisite extent for transmission. The amplifier 7 has in its output circuit preferably a resonant circuit 8 coupled to antenna circuit 9. The purpose of the corrective network 5 will be described more fully hereinafter.

The amplifier 7 is shown as comprising a single space discharge device but it will be understood that this is intended to represent any suitable number of vacuum tubes or space discharge devices which act in common to amplify the input waves and impress them upon the antenna.

The amplifier 7 is shown as containing cathode, grid and anode elements. The grid is provided with a negative bias illustrated in the form of a battery 10, and a source of plate potential 11 is also indicated in the form of a battery. It will, of course, be apparent that any other suitable sources of voltage may be used in place of the batteries 10 and 11. The amplifier 7 has its applied voltages and impedances adjusted as will more fully appear hereinafter so that the space current does not flow continuously but flows in pulses with intervals of no current flow between the pulses, except that for small amplitudes of the input wave the space current is not actually interrupted, as described later on. This type of amplifier is of itself known in the prior art and one of its characteristics is that the vacuum tube or space discharge device may be operated at a relatively high power level without exceeding the limit of safe dissipation of power within the tube. If a large current were permitted to flow at all times through the tube, excessive heating of the tube would result, causing a breakdown or other injury to the tube or at least limiting the amount of useful output from the tube. It is found that by causing the space current to flow in pulses the tube may be made to develop in the antenna circuit a much larger amount of power without undue heating of the tube. This fact has been appreciated in the prior art.

When attempt has been made to employ an amplifier of the type above described for transmitting signal waves such as speech frequencies, it has been found difficult to maintain a high standard of quality in the transmitted signal waves, particularly where it has been desired to obtain large power output from the amplifier. Applicant has in accordance with the present invention determined the fundamental conditions of operation of an amplifier of the type described such as to determine the highest permissible power output and at the same time maintain high quality in the transmitted signal.

In order better to understand the principles upon which the invention is based, reference will now be made to the various graphs shown in Figs. 2 to 4.

In Fig. 2 the full line axes are the usual plate current grid voltage axes commonly employed for indicating the characteristics of vacuum tubes. It will be assumed that the curve I is the static characteristic curve of a tube such as amplifier tube 7 of Fig. 1. This curve toward the left end approaches and finally reaches the axis of zero space current, the point where it coincides with the zero axis being the cut-off point, meaning that when a grid bias (cut-off voltage) corresponding to this point is employed the space current is reduced to zero. The curves II, III and IV are dynamic characteristics of the same tube under typical operating conditions. For simplicity it is assumed that the voltage of the plate supply 11 is the same in the case of these curves, (E_B is constant). The curves II, III and IV correspond to three different values of load resistance, that is the resistance of the antenna 9 or other suitable load as viewed from the output terminals of the amplifier 7. Curve II corresponds to a relatively high value of load resistance, curve III to an intermediate value and curve IV to a relatively low value of load resistance. Assuming unlimited filament emission it would be possible with given plate voltage and a lower load impedance to have a long succession of curves like II, III and IV extending to higher and higher values. Each of these curves, however, bends downward after a certain point is reached in the direction of positive grid swing, the point of downward flexure occurring at about where the instantaneous grid voltage begins to exceed the instantaneous plate voltage. The amount of power output can be increased by lowering the load resistance, that is, operating on a higher and higher characteristic and at the same time extending the amplitude of the grid swing accordingly.

For the purpose of transmitting a side band representing speech or similar signal waves, if the grid swing is increased beyond the peak value of the dynamic characteristic, large amounts of distortion are produced and quality is sacrificed without materially increasing the power output. The positive grid swing should therefore be limited to about the peak value of any given curve such as II, III and IV from the standpoint of quality considerations.

The negative bias is also fixed by quality considerations at some point such as A, the criterion being that at small amplitudes of the signal wave the distortion due to the curvature of the characteristic is not pro-

hibitive. Quality considerations, therefore, place the operating limits for the grid swing between some point such as A and the peak value of the dynamic curve on which the tube is being operated. By choosing a lower and lower load resistance and increasing the grid swing to correspond, as stated above, larger and larger outputs might be obtained but a point is reached indicated by the line B, beyond which it is unsafe to raise the level because of increasing dissipation within the tube itself, endangering the tube from excessive heating or other causes.

Assuming for the moment, therefore, a constant load resistance at all frequencies, this resistance should be made sufficiently low in the interest of large output to bring the point of maximum space current near to the maximum safe dissipation limits for the tube, such as curve III of Fig. 2. Quality considerations require, then, that the maximum positive grid swing shall not exceed the peak value C of space current corresponding to this impedance and that the normal negative bias on the grid shall be at some point A such that for low signal inputs the distortion is not prohibitive. In Fig. 2 curve 20 represents a low amplitude side band wave, while curve 22 with a positive swing from A to C indicates the maximum side band permissible from quality considerations when operating on the curve III, this curve in turn being determined by the maximum safe dissipation limit B.

It was assumed above that the resistance was constant throughout the transmitted range. This is rarely the case when working into a coupled resonant circuit system such as the system 8, 9 of Fig. 1, which is typical of radio transmitters. An actual measured characteristic of such a system is given, for example, in Fig. 24 of a paper by Oswald and Schelleng published in the Proceedings of the Institute of Radio Engineers for June, 1925, Vol. 13, No. 3. The load resistance frequency characteristic of such a system may be assumed for illustration to be that shown in Fig. 3. This curve exhibits a resistance at certain frequencies in the band several times as great as the magnitude of the resistance at other frequencies in the band, which is frequently the case. When the load resistance possesses a characteristic which varies markedly with frequency it is obvious, referring to Fig. 2, that the tube will be operating on some such characteristic as II at certain frequencies and on an entirely different characteristic such as III or IV at other frequencies in the band. The resultant power output varies widely with frequency in such a case and the signal wave is considerably distorted.

Such distortion is, in accordance with the present invention, eliminated or minimized by the use of a corrective network shown at 5 in Fig. 1 for varying the amplitude of the signal wave impressed on the amplifier 7 in such a way as to enable the amplifier 7 to operate at high and substantially constant output level for all frequencies within the band. This network is of the type disclosed in U. S. Patent 1,606,817, granted to G. H. Stevenson November 16, 1926. The network in any instance is designed in accordance with the principles laid down in the patent to possess a characteristic which is preferably complemental to the resistance characteristic of the resonant load circuit into which the amplifier works, although, as will be described, the network may have a characteristic matching that of the load. Assuming a double-peaked curve of the general type indicated in Fig. 3, the network is made to have two pairs of resonant circuits 23—24 and 25—26, respectively, on account of the two peaks in the load characteristic.

For the sake of illustration two different adjustments requiring two different designs of corrective network will be described. First, let it be assumed that the load has its minimum resistance corresponding to curve III and that the peak resistance corresponds to some lower curve such as II. In this case curve III representing the minimum impedance is chosen within the safe dissipation limits for the tube 7. If a constant grid swing were to be employed quality considerations would require that this should not exceed the value A—D since the curve II representing the maximum impedance condition begins to bend downward at about the point D so that if this point were exceeded serious distortion would be introduced. However, for a constant grid swing as assumed, the output at the instants of minimum resistance, corresponding to curve III, will be less than at the instants of maximum resistance represented by curve II. In order to make the output the same at the two impedance values, it is necessary to increase the grid swing to the value A—C when the load resistance corresponds to III.

This is done by a proper design of the corrective network 5, it being noted that the amplitude of grid swing is made greater at those frequencies at which the load resistance is smaller and vice versa. With an adjustment of this kind the power output level may be made substantially the same at all frequencies.

In the second type of adjustment referred to the peak resistance of the load would be made to correspond to curve III and the grid swing at this resistance would be placed at the value A—C. If no equalizer were used it is apparent that at the lower load resistance values such as indicated by curve IV and with the same grid swing A—C the

space current would exceed the maximum safe level indicated at B. In order to avoid this it is necessary to design the corrective network 5 so as to decrease the grid swing at those frequencies at which the impedance falls below the peak value. In Fig. 2 the grid swing at the minimum impedance would have a value slightly in excess of A—D so as always to keep the instantaneous space current below the safe maximum B. In this case it will be noted that the corrective network 5 is so designed that the amplitude of grid swing is made largest at those frequencies at which the load impedance is highest and vice versa, which represents the opposite of the case mentioned above.

Fig. 4 is introduced to show graphically the importance not only of equalizing for the effects of resistance irregularities in the load at any given input level, but to show also the importance from a quality standpoint of choosing the proper absolute value of load resistance. In this figure the curve K represents the output frequency characteristic which may be obtained at a fairly low input level with a load resistance of the type shown in Fig. 3, where no attempt is made to equalize for the impedance irregularities, that is, where the grid swing is constant at all frequencies. If now, the input level is raised, a frequency output characteristic L is obtained which is more nearly flat than the characteristic K. The reason for this may be seen from consulting Fig. 2. At the high resistance points it is assumed that the grid swing exceeds the peak on the tube characteristic so that the instantaneous output current does not increase correspondingly beyond this point but may actually fall off. At the points of lower resistance, however, increasing grid swing produces increasing output and so raises the central portion of the curve. At a still higher input level a frequency output curve M is obtained by accentuation of the same effects. While the curve L or M might at first be thought to represent what is desired, it is clear that both of these curves contain a large amount of distortion components on account of overloading at the impedance peaks of the load, so that while these curves represent a more nearly steady output power level at all frequencies, in reality they represent a distortion which would not be permissible. These curves represent the effects that have been obtained in prior art practice when attempts have been made to increase the output level. With the aid of a corrective network 5, however, in accordance with the invention as has been described above the output level may be maintained at a high and substantially constant value for all frequencies within the band, while at the same time maintaining a high degree of quality because no overloading occurs at any impedance value within the transmitted range.

Various modifications of the circuit and circuit adjustments or proportions that have been specifically set forth may, of course, be made within the spirit of the invention, the scope of which is defined in the attached claims.

What is claimed is:

1. The method of operating a three-element space discharge tube in which the space current flows in impulses the envelope of which varies in accordance with a signal wave, comprising operating the grid about a normal negative potential less than the static cut-off potential, proportioning the load impedance to a low value within the limit of safe power dissipation in the tube, and proportioning the maximum grid voltage swing to correspond substantially to the maximum instantaneous space current for the given anode voltage.

2. In a system for transmitting modulated waves embracing a range of frequencies, employing a space discharge device in which the space current is interrupted in each cycle of the carrier wave, a load circuit having a non-linear resistance frequency characteristic, and an equalizer connected to the input side of the device having a loss characteristic which is non-linear with respect to frequency and is proportioned to the load resistance characteristic to maintain the power output substantially the same at all frequencies and substantially equal to that at the point of maximum load resistance.

3. In combination, a space discharge amplifier tube having cathode, grid and anode, a source of input waves embracing a range of frequencies, a negative bias applied to the grid such that the space current is interrupted during a considerable portion of the negative grid swing produced by the waves from said source, a load into which said amplifier works, having a non-linear resistance-frequency characteristic, and means comprising a variable loss element in the input circuit for accommodating the grid swing at all input frequencies to substantially the value corresponding to the maximum permissible output at the peak resistance of the load.

4. In combination, a space discharge amplifier having cathode, anode and grid, a source of input waves embracing a range of frequencies, means to polarize the grid negative to an extent such that the space current is interrupted for a considerable part of the negative grid swing for all amplitudes of the impressed waves except substantially the smallest, and a load having a resistance varying with frequency within the range of the transmitted waves, said load resistance being proportioned relative to the amplifier

output impedance such that at the peak load resistance the amplifier operates near but below the safe dissipation limit of the amplifier for the given plate supply voltage, the input amplitude being proportioned to confine the maximum positive grid swing at all frequencies to a value corresponding substantially to the maximum space current for the aforementioned plate supply and peak resistance.

In witness whereof, I hereunto subscribe my name this 27th day of March, 1929.

EUGENE PETERSON.