

April 1, 1941.

I. G. WILSON

2,236,661

CONTROL OF SPACE DISCHARGE APPARATUS

Filed Nov. 16, 1938

2 Sheets-Sheet 1

FIG. 1

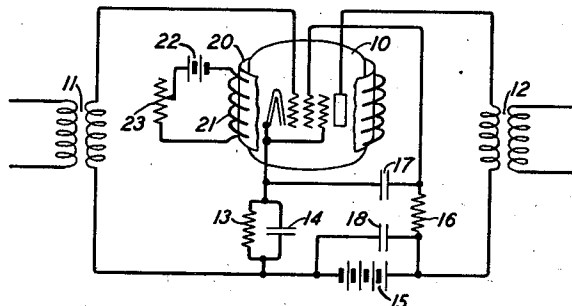


FIG. 2

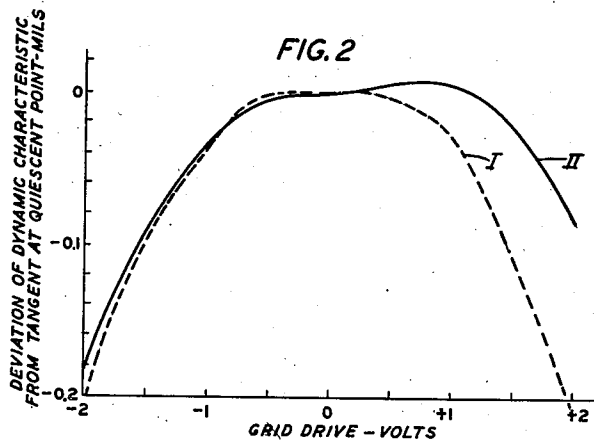


FIG. 3

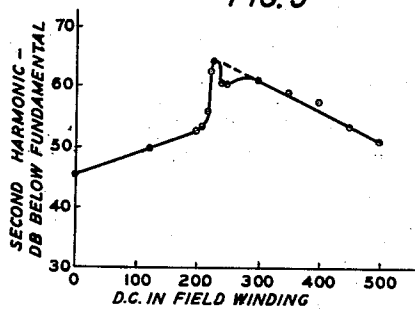
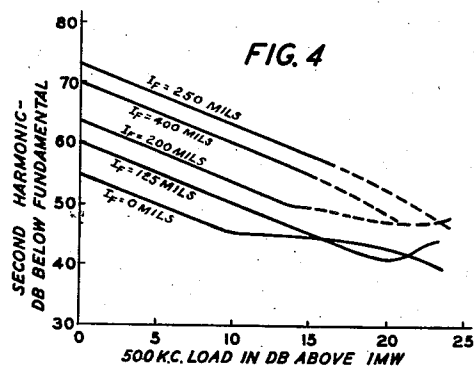


FIG. 4



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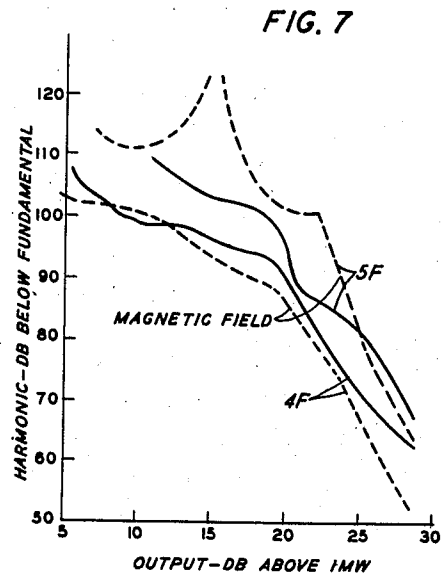
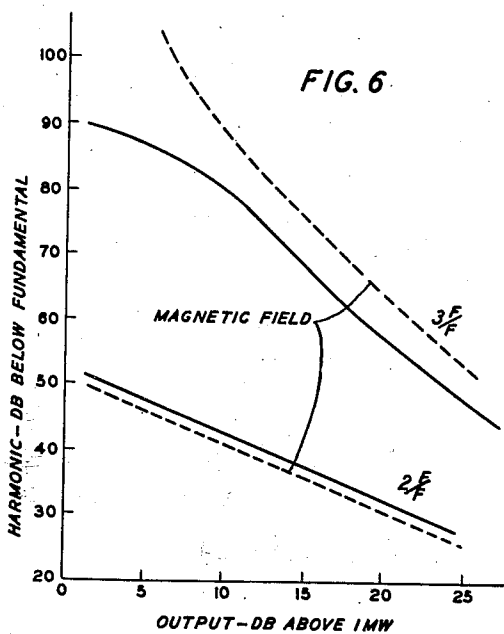
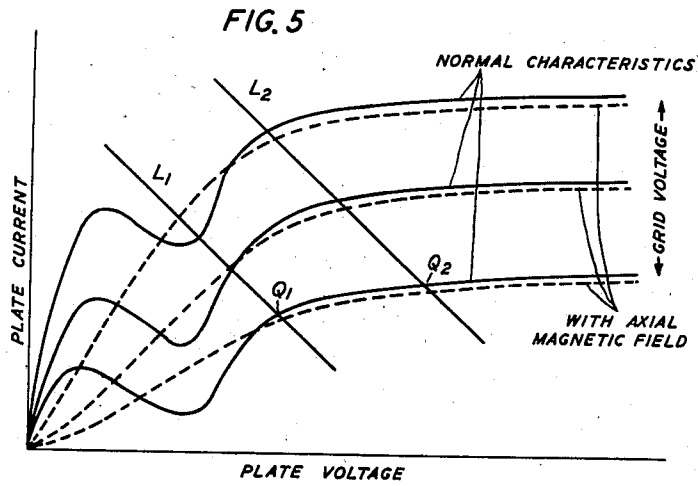
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CONTROL OF SPACE DISCHARGE APPARATUS

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2 Sheets-Sheet 2



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## UNITED STATES PATENT OFFICE

2,236,661

CONTROL OF SPACE DISCHARGE  
APPARATUS

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Application November 16, 1938, Serial No. 240,691

10 Claims. (Cl. 179-171)

The present invention relates to space discharge type apparatus and circuits therefor. More particularly the invention is concerned with the control of the action of space-discharge devices by means of steady magnetic fields, to influence their operating characteristics, and particularly to control the proportion of certain types of modulation to total output.

A general object of the invention is the control of the character of the output wave from a space discharge device by means of an applied steady magnetic field.

A feature of the invention is the use of a field strength which is optimum as regards the production of a chosen type of modulation component.

Applicant has found experimentally that the shape of the static, and also the dynamic, characteristic of a triode, tetrode, pentode or beam power tube can be controlled to a considerable degree by use of a steady magnetic field within the interelectrode space. Best results were obtained with the direction of the field (lines of force) normal to the direction of travel of the electrons from the cathode across to the anode.

In the case of a familiar type of vacuum tube with a generally cylindrical or elliptical anode and grid or grids, and an elongated cathode coaxial therewith, the field was superposed in the axial direction so that the lines of force were parallel to the cathode in its long dimension. It was found that with steady fields of different strength, different percentages of modulation were obtained in the output current. Moreover, for a given type of modulation such as even order or odd order there was found to be a certain field strength which gave a minimum.

The magnetic field can be produced either by a permanent magnet or by an electromagnet. The means to be illustrated comprises the use of solenoid carrying steady direct current as will be described. However, a horseshoe magnet, for example, may have its poles brought up to the side of the tube so that the lines of force travel through the interior of the tube in a direction normal to the electron flow and the strength of the field may be varied by moving the magnet toward or away from the tube.

It is realized that magnetic fields have been used to vary the output current in accordance with variations in field strength, as in the familiar magnetron. The present invention, however, involves quite a different concept, as will be shown.

Broad band transmission systems such as the coaxial line impose very severe requirements upon

amplified design. The coaxial line makes readily available a transmission range extending from any desired lower limit, in practice a limit expressible in kilocycles, up to several megacycles. Terminal facilities can be provided by superposing channels to any desired extent, but the broader the band the more severe are the requirements placed upon the repeaters. Since the repeaters are spaced only 5 or 10 miles apart there are a large number of repeaters in tandem between terminals, and this fact greatly increases the requirements placed upon an individual repeater.

The design of any given system determines the maximum permissible modulation of second order, third order and possibly higher order, for the repeaters. It becomes extremely important, therefore, to be able to exert a control over the amount of modulation of a given type appearing in the output of a repeater. The invention provides such a control in the form of a steady magnetic field of particular intensity applied in proper manner.

The best type of dynamic characteristic for even order distortion is one which is symmetrical about the operating point, sometimes called the quiescent point. By symmetrical is meant that if one half is swung about the operating point by 180 degrees it will exactly overlies the other half. There is no requirement, in this test, as to linearity of the two halves. For minimum third order distortion each half of the dynamic characteristic should be, ideally, linear; the two halves need not be in a straight line. As stated above, it has been found by experiment that the shape of the dynamic characteristic of a tube can be controlled to an extent by a magnetic field, toward its ideal shape for minimum distortion of particular kind. It frequently happens that a tube and circuit meets the requirements for one type of modulation, e. g. third order, with something to spare, but falls short of the requirement for second order distortion. It has been found that when a field strength of proper value was applied, it reduced the second order distortion bringing it within the required limit. At the same time the third order could be kept within the required limit.

As will appear more fully from the detailed description to follow, the control over the shape of the dynamic characteristic can be varied at will to meet different requirements within limits. For example, it is possible under certain conditions either to increase the curvature or to straighten out the dynamic characteristic near the low plate voltage high plate current end without producing

corresponding changes in the portion of the dynamic characteristic lying on the opposite side of the operating point. One effect of this is that if the dynamic characteristic to begin with gave an undesired amount of second harmonic, the curvature of the high plate current end could be changed so as to make the characteristic more symmetrical about the operating point and thus reduce the second order modulation. On the other hand, if the desired effect is to straighten the high plate current end of the dynamic characteristic so as to reduce third order modulation, this may also be done. These various effects are obtained by the use of a magnetic field of the proper intensity in connection with other factors, one of which is the load impedance. Another factor is the effectiveness of the suppressor grid.

In certain types of tube, notably the beam power tube, it was found that by the use of a steady magnetic field it was possible to increase the slope of the dynamic characteristic, that is, to increase the mutual conductance or gain of the tube.

The theory to account for the behavior of the magnetic field in reducing or controlling modulation is not completely known by applicant. It appears, however, that the field deflects slowly moving electrons more than fast moving electrons and that many of the slower electrons are turned back to the emitting surface. This appears to be the tendency in the case of the electrons emitted from the cathode and of the secondarily emitted electrons from the anode or other positively charged surfaces. This effect of the field would appear to weed out from the main space current flow the slower electrons, leaving only or principally the faster moving ones to traverse the total cathode-anode space. Whatever the reason may be for the phenomenon, it has been found possible to reduce the modulation in every one of the several tubes upon which a steady magnetic field has been tried, irrespective of how low the modulation was to begin with.

The nature of the invention and the preferred manner of practicing it will be more fully set forth in the following description with the aid of the accompanying drawings.

Fig. 1 is a simplified schematic diagram showing the manner in which the invention has been applied to an amplifier tube and circuit, and Figs. 2 to 7 inclusive show by means of curves the character of the results obtained by use of magnetic fields according to the invention.

In Fig. 1 a pentode 10 is shown by way of example, having its grid and cathode terminals connected to the secondary winding of input transformer 11, the primary of which is connected to any suitable source of waves to be amplified. The plate and cathode terminals are connected to the primary of output coil 12 forming the coupling to the load. It may be assumed by way of example that the circuit of Fig. 1 is a mid-line repeater in a coaxial line or other broad band system or in any circuit in which amplification is to be effected with low modulation.

Grid bias is provided from cathode resistor 13 which is shunted as usual by by-pass condenser 14. Plate and screen-grid potentials are furnished from battery 15, typical of any suitable or usual source, and voltage controlling resistor 16 is inserted in the screen lead. By-pass condensers 17 and 18 are provided. It will be understood that these circuit details are merely typical and that they can be varied to suit conditions. Also, a plurality of stages in tandem may be provided by duplicating the stage shown.

Surrounding the tube 10 is a Bakelite or other non-magnetic spool or sleeve 20 on which a helix 21 is wound, the terminals of which are connected to a current source 22 through regulating resistance 23. The purpose of this coil is to produce a steady magnetic field within the tube. As stated above, a permanent magnet (not shown) such as a horseshoe magnet, might be used to supply the magnetic field within the tube by including the tube envelope in its vertical direction between the poles of the horseshoe magnet or, in case the tube is too long to go between the poles, the magnet may be brought up to the side of the tube so that the lines of force extend through the tube in the vertical direction, considering Fig. 1.

In a typical example using a tube essentially similar to the Western Electric Company type 350A beam power tube, the coil 21 may consist of 1000 turns in a winding space extending a distance of one inch along the tube 20, the diameter of the Bakelite tube on which the winding is carried being 2 inches. A current of the order of a quarter of an ampere is required, exact values of current being given later. Direction of magnetic field (upward or downward in the figure) appears to have no marked bearing on the results.

This same coil structure was used on different types of tube and is suitable for a tube such as the Western Electric Company 311A pentode or the type R. C. A. 32 tetrode.

That the dynamic characteristic may be made more symmetrical by use of a steady magnetic field of proper value is shown by the curves of Fig. 2 in which the deviations from a tangent drawn at the operating point are given. These curves indicate to one skilled in the art that the modulation produced by the tube would be affected. The data for these curves was taken on a pentode with the magnetic coil specified above and with a current of 0.225 ampere through the coil in the case of curve I and zero current in the coil in the case of curve II.

The effect on second harmonic output caused by varying the magnetic field is shown by the curve of Fig. 3. In this experiment the load remained constant. This curve shows the existence of a definite optimum of field strength as regards reduction of second harmonic. The data for this curve were taken with the same pentode as in the case of Fig. 2, and at a fundamental frequency of 500 kilocycles and harmonic of 1 megacycle. A similar effect was observed using a fundamental frequency of 4 kilocycles from which it was concluded that the effect is independent of frequency within wide limits.

Fig. 4 shows curves taken with the same pentode as in the case of Fig. 3, but with different loads on the tube, and with different field strengths obtained by use of different current values in the coil, as given by  $I_F$  on each curve. In this case it is seen that a current of .200 ampere or of .400 ampere was inferior to a current of .250 ampere in reducing second harmonic output over the load range of +5 to nearly +25 decibels above 1 milliwatt. The current value .250 ampere therefore represents the best value of those tried as regards reduction of second harmonic.

Fig. 5 shows graphically the types of changes that can be made in the shape of tube characteristics by the use of magnetic fields. In this figure the solid line curves are the well-known family of static characteristics for a tetrode showing the familiar valleys due to secondary electron emission from the plate with consequent loss of plate current. The dotted line curves were observed

when a steady magnetic field was applied as herein specified. These curves were taken on an R. C. A. type 32 tube. Two load lines,  $L_1$  and  $L_2$ , at different load resistance values, have been drawn across these tube characteristics. Considering the point of intersection of load curve  $L_1$  with the lowest of the three characteristics shown, it is seen that the dotted line curve lies below the solid line curve, while for the intersections of  $L_1$  with the other characteristics, the dotted line curve lies above the solid line curve in each case. In the dynamic curve which might be plotted for load  $L_1$  in the usual way, the effect of the magnetic field would be to lower the characteristic slightly in the region of the point  $Q_1$ , the operating point, and to raise the characteristic from there on upward in the direction of increasing plate current. In other words, this half of the dynamic characteristic would be raised and straightened.

Considering the intersections on load line  $L_2$ , it is noted that the dotted line lies below the solid line in each instance, with increasing spacing in the direction of greater plate current. The effect of the magnetic field in this case is to lower the upper right-hand portion of the dynamic characteristic and to increase its curvature slightly.

Furthermore, inspection of the curves of Fig. 5 shows that the effect of the magnetic field in removing the folds of the characteristics is somewhat similar to the effect of a suppressor grid, indicating that the secondary electrons from the plate are being turned back. It is noted further that near the origin the effect of the magnetic field is to reduce the slope. This is interpreted to mean that slow-moving electrons leaving the cathode are turned back.

In some cases it was observed that a reduction of second harmonic was accompanied by an increase in third harmonic and vice versa. This was true in the case of experiments performed with a beam power tube essentially similar to the Western Electric Company 350A type. Fig. 6 shows curves obtained with such a tube. The readings for the full line curves were made with no impressed magnetic field, while the readings which gave the broken line curves were taken with a magnetic field applied as in Fig. 1.

Similarly for the fourth and fifth harmonics as shown by the curves of Fig. 7, a field which gave a reduction for the fifth harmonic gave an increase in fourth harmonic. In general, it was concluded that optimum field strength for even order modulation reduction was not optimum for odd order modulation reduction. The data for these curves were taken with the same tube and same field as used for the curves of Fig. 6.

The invention is not to be construed as limited to the specific disclosure, specific types of tubes, circuit or circuit values disclosed, but may assume forms of embodiment differing widely from those that have been set forth by way of example, within the limits and scope of the claims which follows.

What is claimed is:

1. In space discharge apparatus, a device comprising a cathode, an anode and a control element, a source of space current having its positive pole connected to said anode, an input circuit connected to said cathode and control element, an output circuit connected to said cathode and anode, means determining the value of gain from said input circuit to said output circuit, said device tending to produce modulation in the output circuit current, and means to con-

trol the amount of such modulation relative to the unmodulated output current comprising means for producing a steady magnetic field within the space traversed by electrons and in a direction substantially normal to the direction of electron travel, which field, for a given value of tube gain, is proportioned to give a required output of a predetermined type of modulation.

2. In a space discharge apparatus, a device comprising a cathode, an anode and a control element, a source of space current having its positive pole connected to said anode, an input circuit connected to said cathode and control element, an output circuit connected to said cathode and anode, means determining the value of gain from said input circuit to said output circuit, said device tending to produce modulation in the output circuit current, and means to control the amount of such modulation relative to the unmodulated output current comprising means for producing a steady magnetic field within the space traversed by electrons and in a direction substantially normal to the direction of electron travel, which field for a given value of tube gain, is proportioned to optimum value as regards production of a predetermined type of modulation.

3. In an amplifier, a grid-controlled space discharge device, an input and an output circuit therefor, a source of space current for said output circuit, and means to control the shape of the dynamic characteristic of said device comprising a steady magnetic field normal to the direction of electron travel within said device in combination with means to maintain said field at a proper strength to effect the desired shape of a portion of said dynamic characteristic for given slope of the over-all dynamic characteristic.

4. In an amplifier, a grid-controlled space discharge device, an input and an output circuit therefor, a source of space current for said output circuit, means to impress waves of a band of frequencies on said input circuit to be amplified by said device, said device tending to produce distortion in its output circuit current, and means for controlling the relative amount of said distortion comprising means to produce a steady magnetic field within the interelectrode space of said device, having for a given value of tube gain the optimum strength as regards the amount of distortion produced.

5. In an amplifier, a tetrode comprising a cathode, an anode, a control grid and a screen grid, means making the anode and screen grid both positive with respect to the cathode, and means to straighten out the dipped portion of its plate voltage-plate current characteristic comprising a steady magnetic field operative to turn secondary electrons back to the plate.

6. In combination with a grid-controlled space discharge device having an input and an output circuit, a source of space current in said output circuit, said device adapted to amplify waves of a band of frequencies with inherent distortion of both even and odd order, means for selectively controlling the relative amounts of even and odd order distortion while maintaining the tube gain substantially the same, comprising means to apply a steady magnetic field of predetermined intensity to the interelectrode space, normal to the electron travel.

7. In combination with a space discharge device having cylindrical anode and grid electrodes and a cathode coaxial therewith, an input circuit connected to said cathode and grid and an out-

put circuit connected to said cathode and anode, means for controlling the shape of the dynamic characteristic of said device comprising a solenoid surrounding the electrodes of said device and coaxial therewith, and means to send a steady direct current through said solenoid of a value to effect the required change of shape in the characteristic while maintaining the slope of the characteristic as a whole substantially unchanged.

8. In an amplifier, a space discharge device having a cathode and an anode, a source of space current connected between said cathode and anode and a grid for controlling the space current flowing between said cathode and anode, said device having an unsymmetrical dynamic characteristic, and means comprising a magnetic field in the interelectrode space of said device proportioned to the required intensity to make the dynamic characteristic of said device more nearly symmetrical about its operating point.

9. In combination, a space discharge device having a cathode and an anode, a source of space current connected between said cathode and

anode and a grid for controlling the space current flowing between said cathode and anode, said device having a certain mutual conductance when working into a given load resistance, and means to increase the mutual conductance of said device for the same value of load resistance comprising means to set up a magnetic field in the discharge space of said device of such intensity as to spread the static characteristics further apart for the same grid swing.

10. In combination, a pentode tube having inherent distortion characteristic tending to produce unwanted distortion in its output current under given input and output circuit operating conditions and with a given value of gain, and means for modifying said distortion characteristic under the said operating conditions comprising means providing a steady magnetic field in the interelectrode space, said field proportioned in intensity to the value necessary to make the amount of said unwanted distortion substantially a minimum with no substantial change in the value of gain.

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