

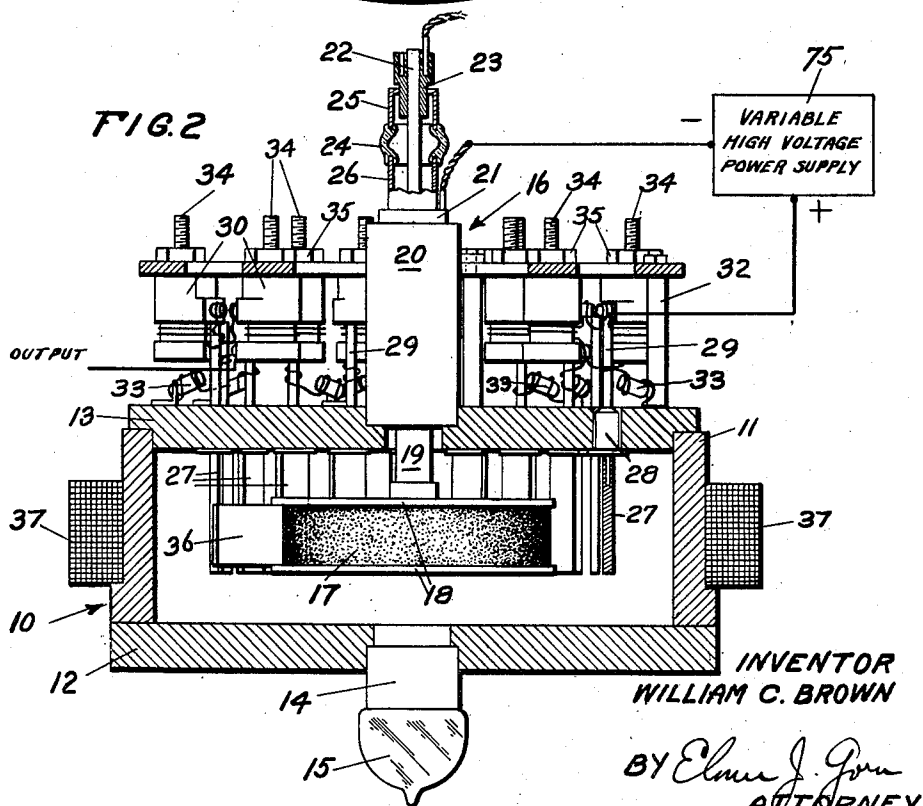
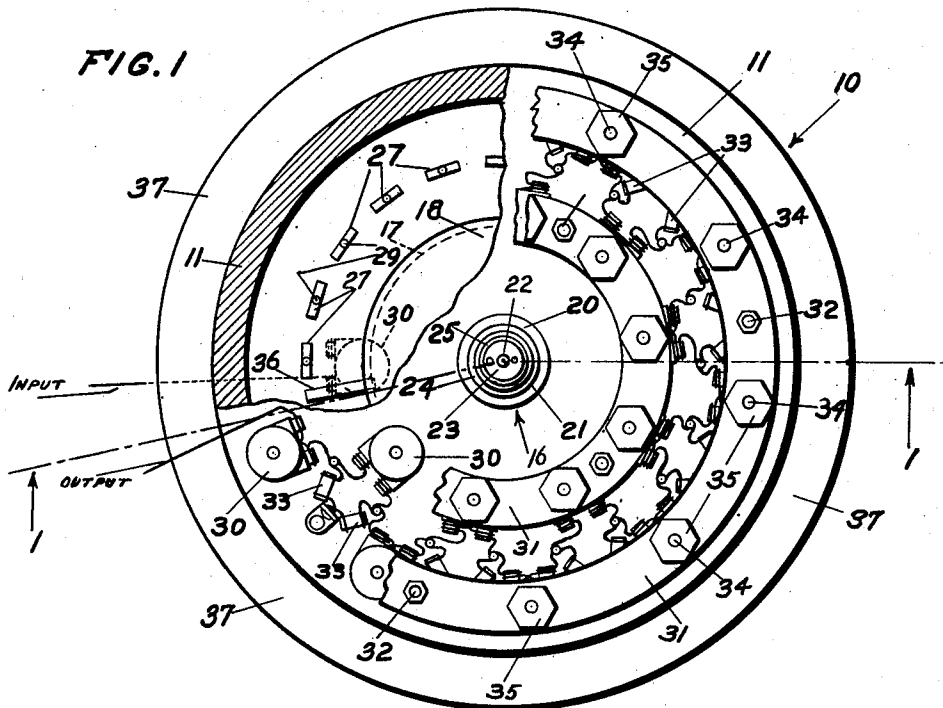
March 23, 1954

W. C. BROWN
MAGNETRON AMPLIFIER

2,673,306

Filed March 16, 1949

3 Sheets-Sheet 1



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MAGNETRON AMPLIFIER

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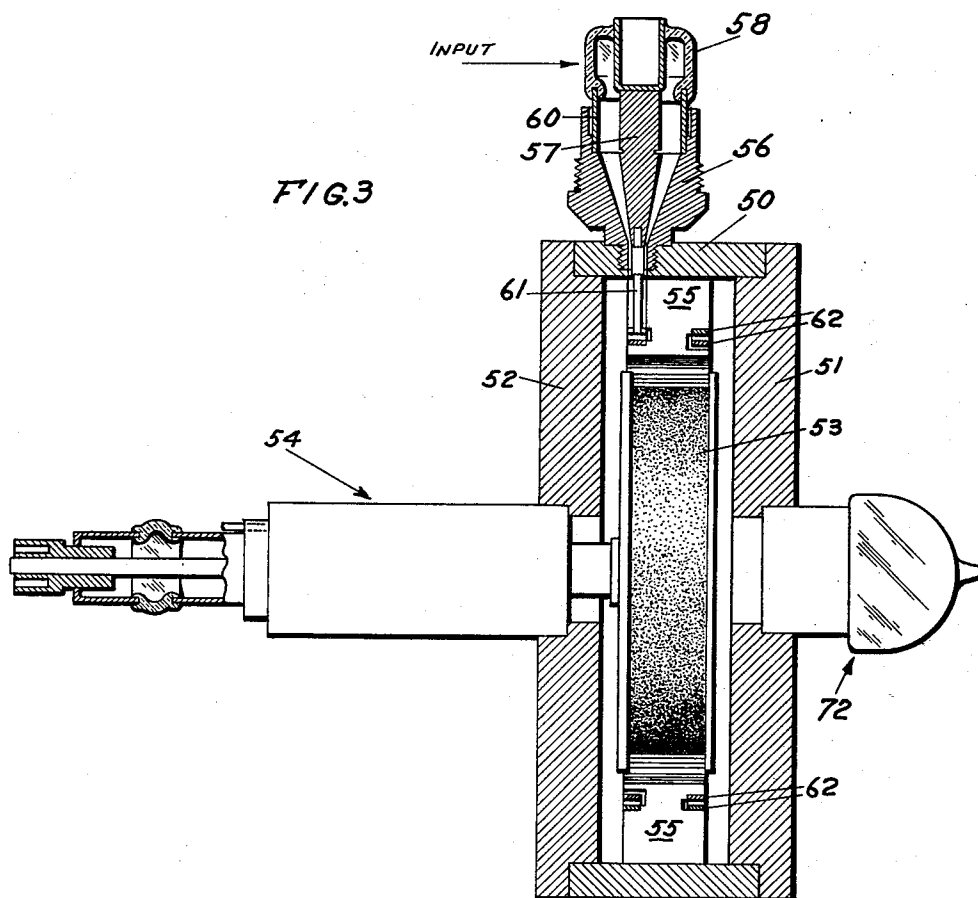


FIG. 5

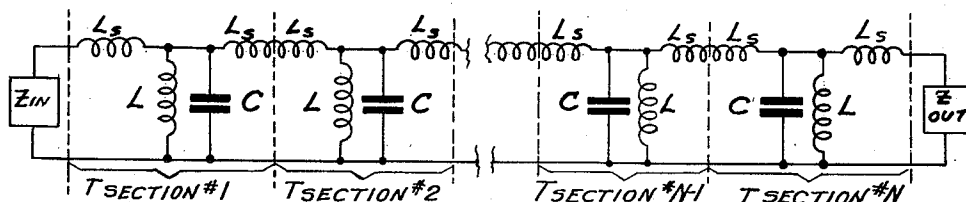
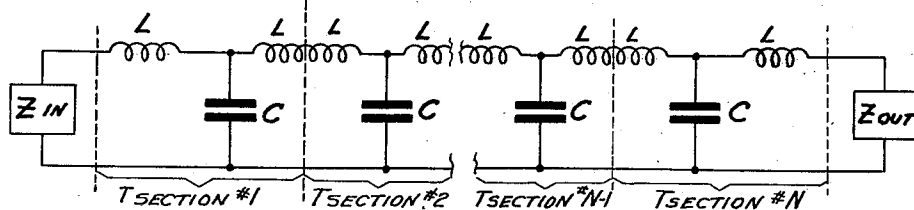


FIG. 6

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March 23, 1954

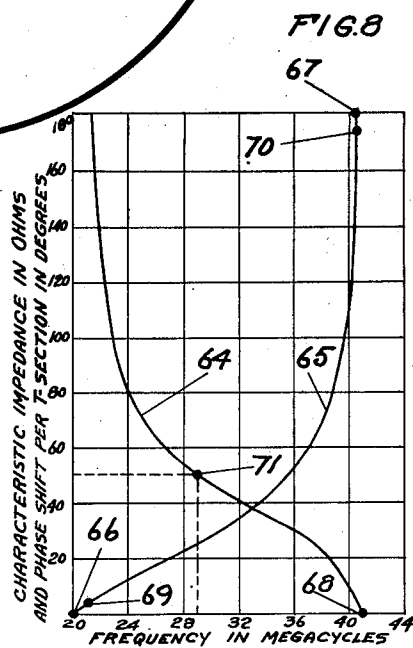
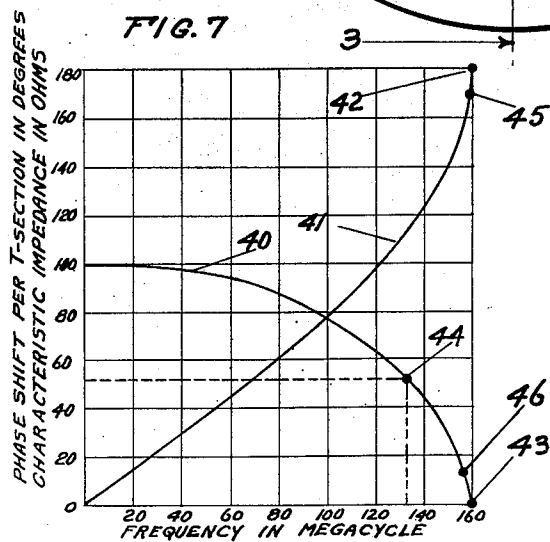
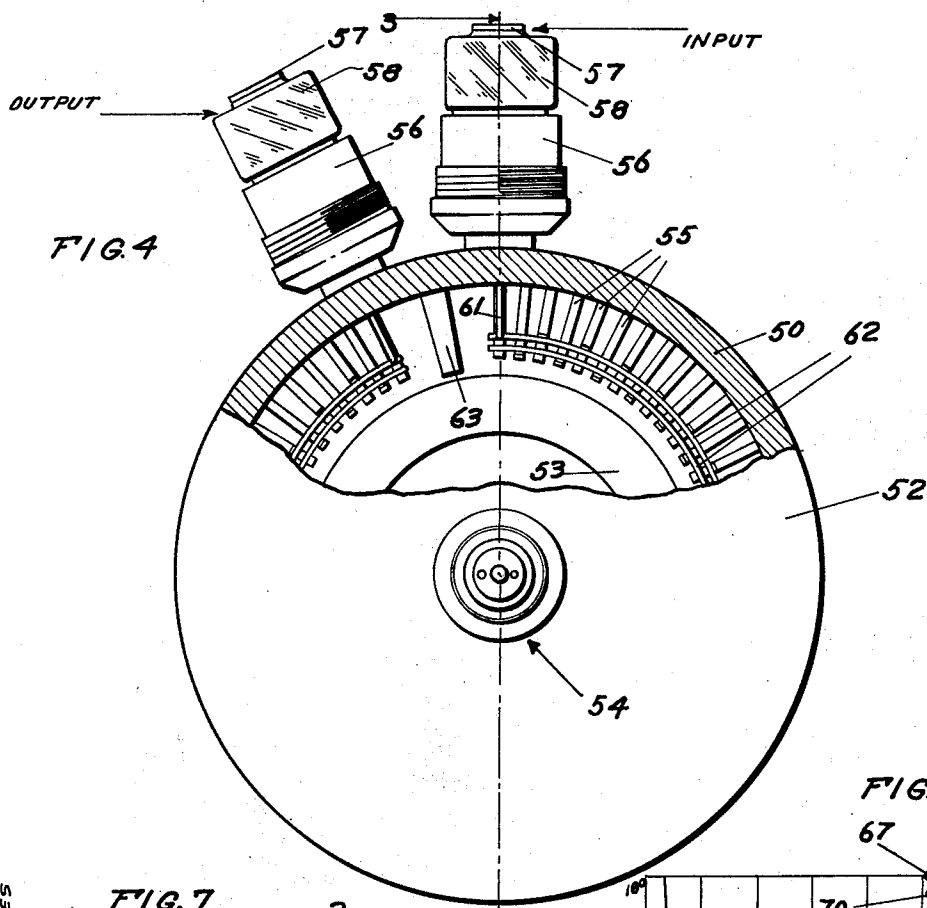
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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,673,306

MAGNETRON AMPLIFIER

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Application March 16, 1949, Serial No. 81,804

6 Claims. (Cl. 315-40)

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This application relates to electron discharge devices, and more particularly to power amplifiers of the traveling wave type.

In traveling wave amplifiers of the type generally known today, an electron beam is accelerated to a relatively high velocity on the order of one-tenth the velocity of light and then passed through a structure containing an electric wave moving parallel to the direction of motion of said electron beam. Since the overall direction of motion of the electrons is linear, and since energy can no longer be effectively transferred to the electric wave when the velocity of the electrons decreases below a certain value, the residual velocity of the electrons after passing through the structure containing the traveling electric wave is lost, thereby resulting in a low efficiency tube.

This invention discloses means to direct the electrons in a circular path by means of a magnetic field similar to the method used in magnetron oscillators. By so doing, the high operating efficiencies inherent in magnetrons may be utilized in the traveling wave amplifier.

Since this structure has a tendency to oscillate it is necessary that feedback from the output terminals to the input terminals be minimized. This is accomplished by minimizing reflection of the traveling wave at the output terminals so that the wave traveling back along the structure is, when again reflected by the input terminals, of a value less than the original input signal. This is accomplished by careful matching of the input and output impedances, and by attenuation of the signal by insertion of lossy material in the structure.

Therefore, it is an object of this invention to produce a traveling wave amplifier having a substantially circular electron path.

It is a further object of this invention to produce a traveling wave amplifier wherein the input and output impedances are substantially matched to the characteristic impedance of the traveling wave network at the frequency of operation of said amplifier.

Yet another object of this invention is to attenuate the reflected wave sufficiently to prevent oscillation of the amplifier.

Still another object of this invention is to increase the frequency range of operation by strapping the anode members of the traveling wave structure.

Other and further objects of this invention will become apparent as the description thereof progresses, reference being had to the accompanying drawings wherein:

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Fig. 1 is a longitudinal cross-sectional view of an embodiment of this invention taken along line 1-1 of Fig. 2;

Fig. 2 is a partially cutaway view of the embodiment of the invention shown in Fig. 1 looking down from the top of Fig. 1;

Fig. 3 is another embodiment of the invention showing a cross-sectional view thereof taken along line 3-3 of Fig. 4;

Fig. 4 is a partially cutaway view of the embodiment of the invention shown in Fig. 3 looking down from the top of Fig. 3;

Fig. 5 represents the equivalent electrical network of the anode structure of Figs. 1 and 2;

Fig. 6 represents the equivalent electrical network of the anode structure shown in Figs. 3 and 4;

Fig. 7 represents curves of operation of the structures shown in Figs. 1 and 2; and

Fig. 8 represents curves of operation of the structures shown in Figs. 3 and 4.

Referring now to Figs. 1 and 2, there is shown an amplifier of the magnetron type which comprises an anode structure 10 which consists of an annular ring 11 whose ends are closed by two plates 12 and 13, thereby forming a closed cylindrical container. This container structure may be made of any good electrical and heat conducting material, for example, copper. One of the end plates 12 has connected thereto a structure for evacuating and sealing the container which comprises a metallic cylinder 14, one end of which is attached to a hole in the end of plate 12 and the other end of which is sealed by a mass of glass 15.

The other end plate 13 contains a circular opening in the center thereof, through which extend the supporting means 16 of a cathode 17. The cathode is of the indirectly-heated type wherein a coil is wound inside a cylinder, the outside of said cylinder being coated with electron emissive material. The ends of the cathode cylinder 17 are covered by disks 18 which are slightly larger in diameter than the cylinder, and which act as heat shields and as electron space charge shields.

The cathode support means 16 comprises a metallic sleeve 19, one end of which is attached to one of the shields 18 and the other end of which extends out through the opening in end plate 13 and through a supporting cylinder 20 of the supporting means 16. The metallic sleeve 19 is rigidly attached to a second sleeve 21, which in turn is attached to the supporting cylinder 20 which is of insulating material.

Inside sleeve 19 is a rod 22 which extends into

the cathode cylinder 17 and attaches to one end of the heater coil (not shown), the other end of said heater coil being attached to sleeve 19. The rod 22 extends through the supporting member 20 and sleeve 21 to a contact member 23 which is rigidly supported with respect to the supporting member 20 by an insulated bead 24 and a pair of metallic sleeves 25 and 26 associated therewith. The details of this cathode structure and the supporting and leading means are well known and described in greater particularity in copending application Serial No. 66,249 filed December 20, 1948.

Surrounding said cathode 17 is a plurality of anode members 27 which consist of bars rigidly attached at one end to lead-in members 29. The other end of said anode bars extends into the cavity of the anode structure 10 past the cathode structure 17 to a point adjacent the lower edge of said cathode structure. The lead members 29 extend through, and are rigidly held by insulators 28 set in plate 13, into the region outside of the anode cavity adjacent the plate 13.

The insulators 28 comprise metallic sleeves which are attached to openings in the plate 13. These sleeves contain glass beads therein, which surround the lead-in members 29, thereby insulating said lead-in members from the sleeves and the plate 13. The anode bars are spaced from each other by an amount approximately equal to the width of said bars.

The anode members are positioned in a circle whose center is concentric with the cathode 17 and the inner surfaces of said members are slightly curved to follow the curvature of said circle. At one point in the circle there is a gap in the anodes caused by the omission of two of the anode members 27, thus reducing the configuration of the anode structure to the arc of a circle.

Successive lead-in members 29 are connected together through coils 30 which are mounted on a pair of concentric rings 31 rigidly attached to the plate 13 by a series of supporting bars 32. The lead-in members 29 are each connected to the plate 13 through condensers 33 whose capacitances are substantially equal. The coils 30 are of the variable type having movable cores which are adjusted by threaded screws 34 which are locked in position by nuts 35. By adjusting the value of these coils a symmetrical electrical network may be produced.

The end anode members of the arc are connected through inductances to input and output leads, respectively. The value of the inductances used for these connections is approximately half the value of the inductances used for connection between the anode members. This structure produces a network having the electrical characteristic substantially equivalent to those of an unstrapped magnetron anode structure.

By omitting a portion of the anode members, coupling of electromagnetic energy between the end anode members of the arc is eliminated and the device will not in general oscillate as a magnetron oscillator.

In order to insure that electrons in the interaction space between the cathode structure 17 and the anode members 27 will not derive radio frequency energy from the output end of the arc of anode members and carry it around through the interaction space to the anode members at the input end of the arc of anode members, a shield 36 has been attached to the cathode 17. This shield consists of a plate which extends

radially from the cathode 17 out through the interaction space and substantially into the space in the circular gap which would normally be occupied by anode members 27. Any electrons moving from the output end of the anode structure through the interaction space will impinge upon plate 36 and thereby be prevented from traveling to the input anode area of the device.

In order to produce a magnetic field in the proper direction through the device, a coil 37 is placed around the annular ring 11 of the anode structure. When current is passed through coil 37 magnetic flux lines are generated in the interaction space between the cathode 17 and the anode structure, said lines being substantially parallel to the axis of the annular anode structure. This magnetic field will cause an action on electrons emitted from the cathode 17 which causes them to travel in a circular path about the cathode in a well-known manner.

The operation of this structure may be analyzed as follows.

With a suitable potential between the anode members 27 and the cathode 17 by means of a variable voltage power supply 75 and a suitable flux generated by the magnet 37, electrons are caused to travel in concentric circles about the cathode 17 except in the vicinity of the shield 36. By varying the potential, the outermost of these concentric circles may be varied in diameter. When this diameter is increased until it is equal to the inside diameter of the circular anode structure made up of the members 27 whereupon the electrons in said outer orbit are just grazing the inner edges of the anode members 27, the velocity of these grazing electrons may be computed from the formula:

$$V_0 = 256,000 V^2 \quad (1)$$

where V_0 is the anode voltage and

$$V = \frac{V}{C}$$

where V is the velocity of the electrons and C is the velocity of light.

There is a corresponding magnetic field defined by the formula:

$$B_0 = 3380 V \frac{r_b}{r_b^2 - r_a^2} \quad (2)$$

where B_0 is the magnetic flux required to produce the grazing condition with an anode voltage of V_0 , r_a is the radius of the cathode structure and r_b is the radius of the anode structure.

Under these conditions, there is no radial current flow to the anode members 27. This condition is known as critical cut-off. If the value of B is increased to a value greater than B_0 , the space charge configuration shrinks in from the anode and travels in concentric circles of smaller radii. The tube is now in the cutoff state past critical cut-off.

A radio frequency wave traveling on the anode structure in the same direction as the space charge and having a relative velocity V which is determined by characteristics of the anode structure will cause a reaction on the space charge. The presence of the R. F. wave permits a current flow to the anode if the anode voltage is raised to the value V_h , where

$$V_h = \left[\frac{2B}{B_0} - 1 \right] V_0 \quad (3)$$

However, in the absence of the R. F. wave the tube is still cut off since the voltage required to

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exceed the cutoff condition must exceed the voltage given by the formula:

$$V_{\text{cut-off}} = (B/B_0)^2 V_0 \quad (4)$$

An R. F. wave impressed on the input terminals of the anode structure will produce an R. F. voltage between the anode members. This R. F. voltage is determined by the following relation:

$$V_{rf} = \sqrt{P_i Z_0} \quad (5)$$

where V_{rf} is the R. F. voltage appearing between adjacent anode members. P_i is the input power and Z_0 is the characteristic impedance of the anode structure. Since this R. F. voltage appears between the anode members, the electric field strength between the anode members will follow the relationship

$$E_{rf} = \frac{V_{rf}}{\Delta} \quad (6)$$

where E_{rf} is the electric field strength between adjacent anode members and Δ is the distance between adjacent anode members.

In the presence of the magnetic field the R. F. voltage will cause a radial component of velocity of the electrons which will follow the relationship

$$U_r = \frac{E_{rf}}{B} \quad (7)$$

where U_r is the radial velocity, E_{rf} is the electrostatic field strength between the anode members which is assumed to extend well into the interaction space between the anode members and the cathode, and B is the magnetic flux density in the interaction space. This component of velocity U_r causes the electrons to move either outward from the cathode or inward toward the cathode depending on the polarity of the R. F. potential on the anode members at any particular time.

Since the outer orbits of the electrons are moving at substantially the same speed as the wave on the anode structure, it follows that the electrons in those portions of the outer circular orbits which are in that polarity of the R. F. wave, such that the component of radial velocity of electrons is outward, will draw closer to the anode structure, with the result that some electrons will impinge thereon. On those portions of the outer orbits which are a half wave length difference from the previously discussed portions, the polarity of the R. F. wave on the anode structure will be such as to produce a radial velocity of the electrons inward toward the cathode.

A phase focusing action of the electrons is caused by the R. F. field in a manner well known in conventional magnetron oscillators whereby they come in phase with a portion of the R. F. wave on the anode structure which will cause them to move outward. Therefore, the density of these portions of the outer orbits, wherein movement of the electrons is outward, is considerably increased over portions influenced by R. F. voltages of the opposite polarity.

The result of this action is a bunching of the electron space charge about the cathode into a configuration resembling the spokes on a wheel, said spokes moving about the cathode with the same angular velocity as the R. F. wave applied to the anode members.

One method of computing the power added to the radio frequency signal input to the anode structure is as follows.

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The anode current density is equal to the space charge density surrounding the cathode multiplied by the radial velocity of the electrons. The space charge density is given by the formula

$$\rho = \frac{\epsilon_0 e B^2}{8 \phi m} \quad (8)$$

where ρ is the space charge density, ϵ_0 equals the dielectric constant of free space, e is the charge of an electron and m is the mass of an electron. The anode current is equal to the effective area of the anode structure, which is the area of the cylindrical space defined by the inner edges of the anode members and the space between them, multiplied by the anode current density. Combining Equations 5, 6, 7 and 8, and multiplying by the effective anode area, there may be derived the formula for anode current as follows:

$$I_a = .775 \times 10^{-6} \sqrt{P_i Z_0} B l N \quad (9)$$

where:

I_a is anode current in amperes

P_i is the signal input power in watts

Z_0 is the characteristic impedance of the anode structure in ohms

B is the magnetic field in gauss

l is the length of each anode member in centimeters

N is number of anode or network sections.

Since the space charge is moving in phase with the wave, the kinetic energy of electrons due to their tangential velocity at the anode is determined by the wave velocity V and is equal to V_0 electron volts. The available energy due to application of anode potential is V_h electron volts. The energy contributed by the space charge to the wave is $(V_h - V_0)$. The power transferred to the wave, or added power, is then

$$P_a = I_a (V_h - V_0) \quad (10)$$

where P_a is the power added to the R. F. wave in the anode structure from the electron stream.

Appropriate substitutions in Equation (10) yield

$$P_a = 1.55 \times 10^{-6} \times V_0 \left[\frac{B}{B_0} - 1 \right] B l N \sqrt{P_i Z_0} \quad (11)$$

The electronic gain in db is given by the formula

$$G = 10 \log_{10} \left[\frac{P_0}{P_i} \right] = 10 \log_{10} \left[\frac{P_i + P_a}{P_i} \right] = 10 \log_{10} \left[1 + \frac{P_a}{P_i} \right] \quad (12)$$

Thus the gain parameter is P_a/P_i given by the formula

$$P_a/P_i = 1.55 \times 10^{-6} V_0 \left[\frac{B}{B_0} - 1 \right] B l N \sqrt{\frac{Z_0}{P_i}} \quad (13)$$

The electronic efficiency is given as

$$\eta_e = \frac{P_a}{I_a V_h} = \left[1 - \frac{V_0}{V_h} \right] = 1 - \frac{1}{\left[\frac{2B}{B_0} - 1 \right]} \quad (14)$$

Symbols used in the above equations

r_a = cathode radius, cm.

r_b = anode radius, cm.

l = axial length of anode, cm.

Δ = distance between anode segments, cm.

N = number of anode members or network elements

Z_0 = characteristic impedance of network

V =wave phase velocity referred to velocity of light

P_i =R. F. power fed into network, watts

P_o =R. F. power output from network, watts

P_a =added R. F. power due to electronic interaction $P_a=P_o-P_i$

G =electronic power gain in db

V_o =voltage required to accelerate electrons to velocity V

B_o =magnetic field yielding critical cutoff at anode voltage V_o

E_{rf} =R. F. field strength

V_{rf} =R. F. voltage in one network section

B =applied magnetic field

ρ =space charge density

U_r =radial velocity

ϵ_o =dielectric constant of free space

η_e =electronic efficiency

Thus it may be seen that the gain varies as a function of B , l and N , as well as V_o , B_o , Z_o and P_i . Increasing B will increase the gain and, if sufficient feedback is not encountered to produce oscillations, very large gains may be produced by this type of amplifier. It may be seen that the efficiency varies as a function of

$$\left(1 - \frac{V_o}{V_h}\right)$$

and since the ratio

$$\frac{V_o}{V_h}$$

may be made very small, the efficiency may be made very large.

It may be noted that this represents electronic efficiency and the actual efficiency produced is somewhat lower due to losses in the circuit components. The particular embodiment shown in Fig. 1 operates at approximately 125 megacycles; however, this theory is equally applicable to magnetron structures operating at higher frequencies, for example, 4,000 megacycles. Since this structure behaves as an oscillator when a sufficient signal from the output is fed back into the input, it becomes necessary to minimize feedback. This feedback is principally due to reflection of the traveling wave generated in the anode structure at the output terminals of the equivalent transmission line network, due to a mismatch between the impedance of the output load into which the transmission structure feeds energy. The reflected wave then travels back along the transmission line to the input where it is again reflected by the mismatch between the impedance of the transmission line and the impedance of the input signal source.

Since the impedance of this anode structure transmission line varies with frequency, it is impossible to exactly match the anode structure transmission line with the input and output impedance at all frequencies, and since the phase shift of the transmission line varies with frequency there will be certain frequencies at which the reflected wave will arrive at the input end of the transmission line and be reflected in phase with the incoming wave or the originating wave.

If the inphase reflected wave is larger than the incoming wave, an unstable condition may occur wherein the device will oscillate. Therefore, in order to produce a more stable amplifying device, the reflected waves are attenuated in a manner to be described below.

Referring now to Fig. 5, there is shown the substantially equivalent lumped constant transmis-

sion line for the anode structure described in Figs. 1 and 2. This transmission line comprises a pair of parallel lines, one line of which is a continuous straight wire having no inductance or resistance and representing, in fact, the grounded parts of the anode structure such as the heavy outer ring and face plates. The other line is made up of a plurality of inductances connected in series. These inductances L are grouped in pairs, the connecting point between each pair being connected to the first-mentioned line by a condenser C thus forming a T network section. The horizontal arms of the T's are connected together such that there is an inductance of $2L$ between the junction points which are connected to ground by the condensers. One end of the line is connected to a box labeled Z_{in} which represents the impedance of the signal source which is connected to the input of the anode structure. The other end of the transmission line is connected to a load labeled Z_{out} which represents the impedance of the load into which the anode structure is operating.

In actual construction the inductances L are shunted by condensers (not shown) due to stray capacitances and capacitances in the inductances themselves. However, since these shunt capacitances are sufficiently small they will not resonate with the inductances over the operable range of frequencies of the device.

This network operates as a low-pass filter, the cutoff point being where there is 180° phase shift between the input and output of each of the T sections in the transmission line. This is illustrated by the curves shown in Fig. 7 wherein the curve 40 is a plot of the characteristic impedance versus frequency for the transmission line of the type shown in Fig. 5. Along the ordinate is plotted the frequency in megacycles and along the abscissa is plotted characteristic impedance in ohms and phase shift in degrees for each T section of the transmission line. The curve 41 is a plot of phase shift for each T section versus frequency. As may be seen from the curve 41 the phase shift across each T section is zero at zero frequency and 180° at 160 megacycles, as shown by point 42. It may be noted that the curve of characteristic impedance 40 becomes zero at 160 megacycles, as shown by point 43. This frequency is known as the π mode of operation in a conventional magnetron.

Since this network is the substantial equivalent of an unstrapped magnetron anode structure, frequencies above the π mode will not produce operation of the structure either as an oscillator or an amplifier. It may be seen that the curve 40 approaches 100 ohms when the frequency is zero.

The input and output impedances used are 50 ohms; hence the point where these impedances would be equal to the characteristic impedance of the line will be at approximately 135 megacycles, as shown by point 44 on curve 40. Actually, due to the stray capacitance facts mentioned previously, the frequency of operation where this match occurs is slightly lower at 125 megacycles.

It may be seen that, at other frequencies than point 44, a mismatch will occur between the input and output impedance and the transmission line structure. This impedance mismatch causes a reflection according to the formula

$$A = \left(\frac{Z_{out} - Z_o}{Z_{out} + Z_o} \right)^2$$

where A is the reflection factor,

It may be seen that this reflection factor A will be largest at 160 megacycles at point 43 of the curve and equal to 1. At this point a transmission line will cause a signal reflection back along the line which, when again reflected by the input impedance mismatch, will be in phase with the originating wave, thus producing a condition which will set up oscillations.

Therefore, it is necessary that the product of the reflection factors A^2 at the ends of the transmission line multiplied by the attenuation factor (power transfer with attenuation divided by power transfer without attenuation) going down and coming back in the line be less than the reciprocal of the gain factor computed in the Equation 13 in order to prevent oscillation of the structure in the π mode at a frequency of 160 megacycles.

This attenuation is accomplished by making the inductance L of low Q or lossy material so that at the π mode, when high currents are flowing in the inductance due to the resonance action of the inductances L with the condensers C, the attenuation will be high. However, at frequencies below the π mode the attenuation will be less since the system will not be operating in its resonant condition and high currents will not be flowing in the inductances L. Therefore, the apparatus will operate reasonably efficiently at frequencies below the π mode, for example, the point 44 chosen.

The next lowest frequency below the π mode at which the reflected waves will be in phase with the signal input will depend on the number of T sections in the transmission line. For example, in the structure shown in Figs. 1 and 2 having 18 sections, the next lower frequency will be at a point where the phase shift per section is $1/18$ of the phase shift at the π mode. This occurs at 170° , as shown by point 45 on curve 41, and at a frequency of roughly 158 megacycles. At this frequency the characteristic impedance of the line would be roughly 10 ohms, as shown by point 46 on curve 40. This causes a considerable decrease in the reflection factor, for example,

$$A = \frac{4}{9}$$

and, since the attenuation factor is still fairly high due to its proximity to the resonant condition of the inductance L and the condensers C previously described, the combined products of the attenuation factor multiplied by the reflection factors will be less than the reciprocal of the gain.

Similarly, the overall attenuation for inphase waves of other frequencies may be determined, the frequency having the largest value for the product of its attenuation factor multiplied by the reflection factors being the frequency at which oscillation will occur when the reciprocal of the gain is less than said value. At point 44, where a perfect match is encountered, there will be no reflected wave and hence at this frequency, gain can be very high.

Referring now to Figs. 3 and 4, there is shown an embodiment of the invention designed for operation at high frequencies, for example, 2000 to 4000 megacycles. This device comprises a standard magnetron anode structure having an anode ring 50 which may be made of a good heat conducting material, such as copper. The ends of ring 50 are closed by a pair of flat plates 51 and 52 respectively. Through one of the plates 52, extends cathode structure 53 of the same type

shown in Figs. 1 and 2 and an identical support structure 54. The plate 51 contains an evacuating seal 72 similar to that of Figs. 1 and 2. Extending inwardly from the annular ring 50 is a plurality of anode members 55 which comprise flat rectangular metallic structures whose planes are radial to the axis of the ring 50. These members 55, which may be termed vanes, extend inwardly to a point adjacent the cathode structure 53 with the space therebetween constituting an electron interaction space for operation of the device. The vanes extend around the cathode over substantially its entire circumferential distance.

However, at one portion a few of the vanes, approximately 8 in number, have been omitted. The vanes bordering on this section wherein the vanes are omitted constitute the input and output ends, respectively, of the anode transmission line structure which makes up the traveling wave amplifier.

The vanes are strapped in the conventional manner of oscillating magnetrons by a pair of straps 62 on the top edge of the vanes adjacent the plate 51. A similar pair of straps exist on the bottom edge of the vanes adjacent the plate 52. These straps are set slightly back from the central edge of the vanes adjacent the cathode 53. The straps connect alternate anode members together and extend along the vanes from the input end of the vanes to the output end thereof but not across the space containing no vanes between the input and output ends of the structure.

The input and output ends are coupled to their respective loads by coaxial leads. These leads comprise an outer cylindrical member 56 attached to a hole in the anode ring 50 adjacent the end of the anode vane transmission line structure to be coupled to said lead. This member 56, which is hollow, contains therein a central member 57 which is insulatedly supported therefrom by a glass sleeve 58 attached to said central member 57 and to a cylindrical metallic member 60 which is in turn attached to the member 56. Attached to the member 57 is a lead-in member 61 which extends through the opening in the member 50 concentrically with the member 56 and attaches to one of the straps 62, thus producing a very tight coupling into the anode structure. The other lead is the member 56 which is attached to the anode ring 50 representative of ground R. F. potential. Between the input and output coupling device there is a member 63 comprising a copper block extending inwardly from the anode ring 50 to a position in close proximity with the cathode. This is a modification of the member 36 used in Figs. 1 and 2, and may be substituted therefor.

The magnetic field required to operate the device may be obtained by placing the end plates 12 and 13 between the poles of a magnet in any manner well known and used in conventional magnetron operation.

The electron interaction between the cathode and the anode structure follows the same theory previously explained in connection with Figs. 1 and 2. The anode, however, being of strapped construction, presents different impedance characteristics from those previously described. If the straps 62 were omitted, the operation would be in accordance with that previously explained by the network of Fig. 5 and the curves of Fig. 7.

However, the strapping produces a different network configuration.

Referring now to Fig. 6, there is shown the equivalent electrical network for the strapped anode structure disclosed in Figs. 3 and 4. This becomes a plurality of T sections wherein L_s represents the inductance of the straps, L represents the inductance of the cavity and C represents capacitance of the cavity plus stray capacitances. The analysis of this network is described in more detail in connection with application Serial No. 66,249 filed December 20, 1948. The characteristic curves of a strapped magnetron amplifier, of the type illustrated in Figs. 3 and 4, are shown in Fig. 8. The ordinate represents frequency in megacycles and the abscissa represents impedance in ohms and the phase shift per section in degrees for an anode transmission line structure of the type shown in Figs. 3 and 4. The curve 64 is a curve of the characteristic impedance of the anode structure versus frequency. The curve 65 represents the phase shift versus frequency for one section of the transmission line network which is represented by one cavity of the anode structure. It may be seen that the phase shift is zero at approximately 2000 megacycles, as shown by point 66, this point being known as the π mode of operation. The curve 65 shows that the phase shift becomes 180° at approximately 4100 megacycles, as shown by point 67 on the curve 65. At 2000 megacycles, the π mode of operation, the L and C of each cavity resonate and, therefore, behave as very high impedance placed across the transmission line. Consequently, the characteristic impedance of the line approaches infinity. As frequency is increased from 2000 megacycles the L and C tanks look like equivalent capacitances and, when the inductive reactance of L_s equals the capacitive reactance of these tanks, a resonant condition is produced across the transmission line similar to that previously described in connection with the graphs of Fig. 7 and the characteristic of the characteristic impedance of the line drops to zero, as shown by point 68 on curve 64. This occurs at the same frequency as point 67 wherein the phase shift per section becomes 180° .

In a magnetron anode structure of the type shown in Figs. 3 and 4, having, for example, 60 vanes, the first mode above the π mode where inphase energy may be fed back along the line will be when a 3° phase shift occurs across each section, as shown by point 69 on the curve 65. At this frequency the characteristic impedance is still in the range of 200 ohms or above. Hence for input and output impedances of 50 ohms, the reflection factor will be extremely high. Similarly, at the frequency of point 68 and the next frequency below this frequency at which the magnetron will oscillate, for example, at roughly a phase shift of 177° , as shown by point 70 on the curve 65, the characteristic impedance, as shown by curve 64, will be substantially zero and hence produce a high reflection factor when used in combination with 50 ohm input and output impedances.

Therefore, for the device to operate as an amplifier having gains of more than one, a substantial amount of attenuation must be introduced into the transmission lines in the regions of 2000 to 2400 and 3600 to 4100 megacycles to prevent reflected waves from causing oscillation of the device at frequencies lying within these regions. This attenuation may be introduced

satisfactorily by placing lossy material in the anode structure. A preferable way of accomplishing this is to fabricate the vanes of the anode structure of a lossy substance such as Nichrome, a nickel chromium alloy, cupronickel, a copper-nickel alloy, iron or other lossy materials, or inserting lossy dielectrics in the cavities. Also, the strapping may be made of such lossy materials.

It may be seen that in the regions wherein high reflection factors are produced, there will be high currents in the anode structure due, for example, to high tank currents in the LC tanks, as shown in Fig. 6, and due to the high currents in L_s and the LC tank when operating near its series resonant condition. Therefore, attenuation will be high in these regions while, in other regions where low circulating currents are flowing in the anode members and straps, a smaller amount of attenuation is present. Hence, when the device is operated at a frequency such that the characteristic impedance of the anode transmission line structure is equal to the input and output impedance, for example, 50 ohms, as shown by point 71 on curve 64, which occurs at roughly 2900 megacycles in this particular design, the reflection factor will be zero and the attenuation relatively low, since low circulating currents will be flowing in the anode elements since there is no resonant condition existent therein at this frequency. Therefore, relatively high gains may be efficiently produced at this frequency.

While the strapped anode structure shown here is circular in nature in the form of a conventional magnetron, the advantages of strapping may be applied to linear traveling wave amplifiers, for example, of the type disclosed in copending application Serial No. 745,703, filed May 3, 1947.

By the use of strapping, lower and more uniform values for the quantity V , referred to previously in the equations, may be obtained. This becomes particularly advantageous at higher frequencies.

Furthermore, the anode voltage V_h required to produce oscillations increases slightly with increases in frequency. Therefore, by carefully maintaining the anode voltage V_h at the minimum voltage required for operation of the device at the desired frequency, oscillations at frequencies above the desired operating frequency may be minimized or even eliminated.

This completes the description of the particular embodiments of the invention described herein. However, many variations will be apparent to persons skilled in the art without departing from the spirit and scope of this invention. For example, the modification as shown in Figs. 1 and 2 could have straps applied thereto, and the modification shown in Figs. 3 and 4 could be unstrapped. The magnetic field could be applied by a permanent magnet applied to the end plates of the anode structure if desired, various numbers of anode elements could be used and various configurations other than cylindrical anode structures could be employed.

Therefore, applicant does not wish to be limited to the specific details of the embodiments disclosed herein except as defined in the appended claims.

What is claimed is:

1. An electron discharge device comprising an anode structure comprising a plurality of anode members spaced along a curved path and forming a continuous signal wave transmission net-

work structure between the ends of said path, an electrode structure spaced from said network structure and cooperating with said network structure to define a region adapted to be energized by a unidirectional electrostatic field having a terminating surface substantially at said electrode structure during operation of said device, said electrode structure comprising a cathode spaced from said anode structure and having an electron-emissive surface substantially at said field terminating surface of said electrode structure, a first signal energy transfer means coupled at the operating frequency of said device to said network structure substantially at one end of said curved path, a second signal energy transfer means coupled at the operating frequency of said device to said network structure substantially at the other end of said curved path, signal isolating means positioned between the ends of said path, and means for producing a magnetic flux perpendicular to the plane of said curved path.

2. An electron discharge device comprising an anode structure comprising a plurality of anode members spaced along a curved path and forming a continuous signal wave transmission network between the ends of said path, a cathode concentric with the path of said anode members and having electron-emissive material thereon spaced along the major portion of said path, the ends of said anode members adjacent said cathode being alternately connected by conductive straps, signal energy transfer means coupled at the operating frequency of said device to said device substantially at one end of said group of anode members, signal energy absorbing means coupled at the operating frequency of said device to said device substantially at the other end of said group of anode members, and means producing a magnetic flux perpendicular to the plane of said curved path.

3. An electron discharge device comprising an anode structure comprising a plurality of anode members spaced along a curved path and forming a continuous signal wave transmission network between the ends of said path, a cathode having substantially constant electron-emissive properties extending along the major portion of said path adjacent said network, a plurality of signal energy transfer means coupled at the operating frequency of said device to said network at points spaced along said network, and means for directing electrons along paths adjacent said network whereby interaction between said electrons and signals in said network is produced comprising means for producing a magnetic flux perpendicular to the plane of said curved path.

4. An electron discharge device comprising an anode structure comprising a plurality of anode members spaced along the arc of a circle and forming a continuous signal wave transmission network between the ends of said arc, a cathode having electron-emissive material spaced along the major portion of said network, signal input means coupled at the operating frequency of said

device to said network substantially at one end of said arc, signal output means coupled at the operating frequency of said device to said network substantially at the other end of said arc, means for substantially preventing the movement of electrons between the region adjacent said output means and the region adjacent said input means except along paths adjacent said network, and means for producing a magnetic flux parallel to the axis of said circle.

5. An electron discharge device comprising an anode structure comprising a plurality of anode members spaced along the arc of a circle and forming a continuous signal wave transmission network between the ends of said arc, a cathode having electron-emissive material spaced along the major portion of said network, signal input means coupled at the operating frequency of said device to said network substantially at one end of said arc, signal output means coupled at the operating frequency of said device to said network substantially at the other end of said arc comprising a vane radially extending from said cathode, and means for producing a magnetic flux parallel to the axis of said circle.

6. An electron discharge device comprising an anode structure comprising a plurality of anode members spaced along a curved path and forming a continuous signal wave transmission network structure between the ends of said path, an electrode structure spaced from said network structure and cooperating with said network structure to define a region adapted to be energized by a unidirectional electrostatic field having a terminating surface substantially at said electrode structure during operation of said device, said electrode structure comprising a cathode spaced from said anode structure and having an electron-emissive surface substantially at said field terminating surface of said electrode structure, signal energy transfer means coupled at the operating frequency of said device to said device substantially at one end of said group of anode members, signal energy absorbing means coupled at the operating frequency of said device to said device substantially at the other end of said group of anode members, signal isolating means positioned between the ends of said path, and means producing a magnetic flux perpendicular to the plane of said curved path.

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