Oct. 18, 1949. E. D. McARTHUR 2,485,400

HIGH-FREQUENCY ELECTRON DISCHARGE APPARATUS

Filed April 19, 1945

Fig. 1.

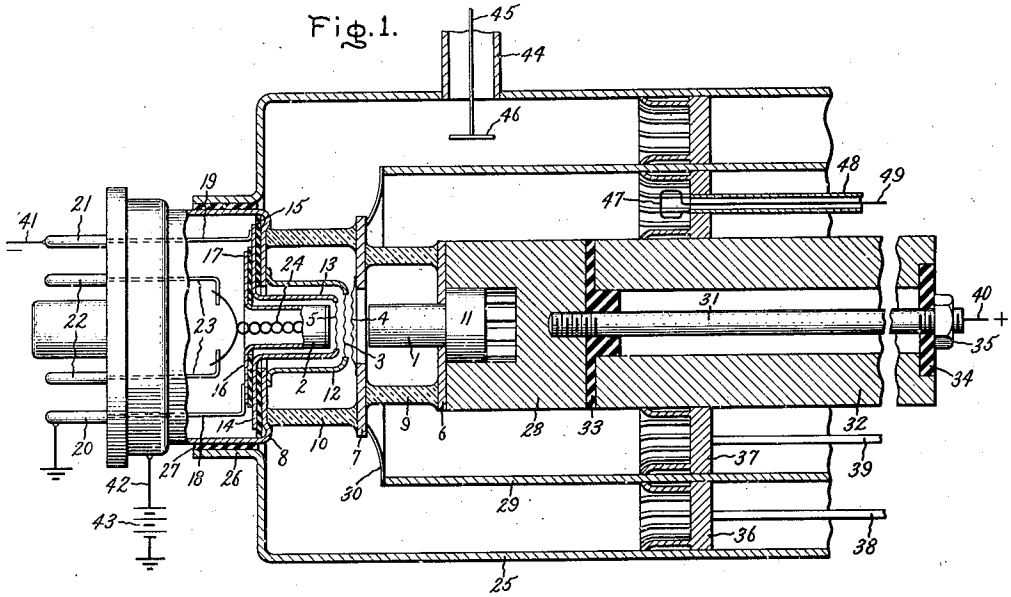


Fig. 2.

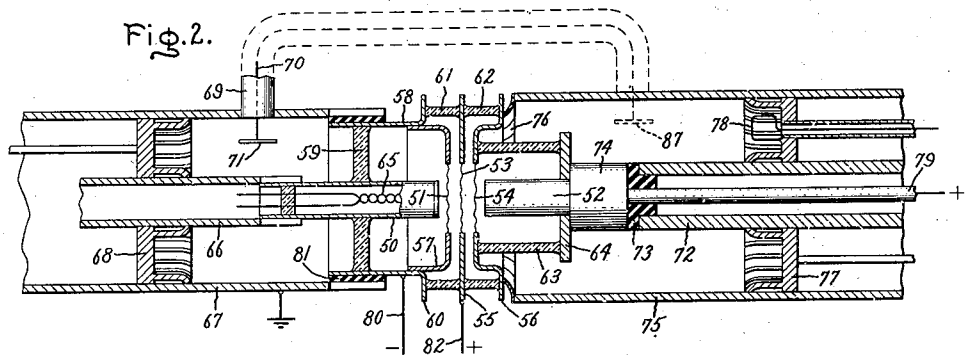


Fig. 3.

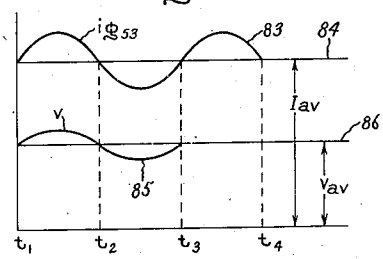
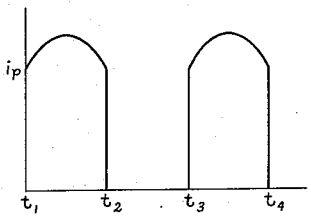


Fig. 4.



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HIGH-FREQUENCY ELECTRON DISCHARGE APPARATUS

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2 Claims. (Cl. 315—39)

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The present invention is directed to electronic tubes and is primarily concerned with the provision of a new and improved space charge control electron tube which employs the principle of sorting electrons in accordance with their velocities for increasing the trans-conductance of the tube.

It is an object of my invention to provide a new and improved electronic tube which is suitable for amplification of both low and very high frequency signals.

It is another object of my invention to provide a new and improved electron discharge device in which the anode current therein is modulated by sorting of electrons in accordance with their velocity.

It is a still further object of my invention to provide new and improved ultra high frequency circuits employing cavity resonators.

One of the features of the invention is the employment in an electronic tube of a pair of control grids spaced between an anode and a cathode, utilizing a first of these control grids to vary the velocity of the electronic stream between the anode and cathode, and utilizing the other of the control grids to sort out electrons in the stream in accordance with their velocity.

The features of the invention desired to be protected herein are pointed out with particularity in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood by referring now to the following description taken in connection with the accompanying drawing in which Fig. 1 diagrammatically illustrates an electron discharge device and amplifying circuits suitably embodying my invention; Fig. 2 diagrammatically illustrates a modification of the electron discharge device of Fig. 1; and Figs. 3 and 4 are graphs illustrating certain operational characteristics of the device of Fig. 2.

Referring particularly to Fig. 1, there is shown an electron discharge device having an anode 1 and a cathode 2 arranged in end-to-end order. The anode and cathode are in the form of cylindrical members substantially coaxially aligned and having closed adjacent ends in opposed spaced relation to form electron emitting and electron receiving surfaces. Disposed between the anode and cathode are a pair of control grids 3, 4, and a focussing grid 5. The envelope within which these electrodes are enclosed comprises a series of three circular metal parts 6, 7, and 8 which are supported in spaced relation by glass cylinders 9 and 10 sealed between them. The

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part 7 provides a terminal for the grid 4 and a terminal for the anode is provided by a cylindrical enlargement 11 which is welded or soldered against the upper surface of the part 6. The grid 3 is supported from the metallic tube 12 which concentrically surrounds the cathode 2 and which is welded or soldered to the part 8. The focussing grid 5 is supported by a metallic tube 13 disposed between tube 12 and cathode 2. The lower end of tube 13 is provided with flange 14 which parallels the under surface of part 8, but which is separated therefrom by an insulating washer 15. Similarly, the cathode 2 extends through a central aperture in the part 8 and is provided, at its lower extremity, with a flange 16 which parallels the under surface of the part 8 but which is separated from that part by an insulating spacer 17 which may be, for example, a mica washer. Preferably, the thickness of the insulating washers 15, 17 is such that the cathode 2 has a high frequency connection with the part 8 through the capacity existing between this part and the flange 16, but is effectively insulated from the part 8 and the part 14 as far as direct currents and low frequency alternating currents are concerned. Separate connections are made to the cathode and grid 5, respectively, for direct currents and low frequency alternating currents by means of lead-in wires 18, 19 secured to the under surface of the part 12 and terminally connected, respectively, to prongs 20, 21 which depend from the base of the discharge tube. Additional prongs 22 and lead-in wires 23 are provided for the purpose of supplying heating current to a coiled filament 24 arranged within the cathode cylinder 2.

For the amplification of high frequency voltages, the electronic tube is incorporated into a cavity resonator forming structure which comprises an outer elongated conductive cylinder 25 having an inwardly flanged portion 26 which surrounds the base portion of the part 8, being insulated therefrom by a cylindrical insulator 27, a centrally disposed conductive member 28 which abuts against the outer surface of disk 6 and is conductively connected to the anode terminal 11, and an intermediate conductive cylinder 29 which is conductively connected to the grid disk 7 through a spring contact arrangement 30. In this cavity resonator, the outer cylinder 25 is insulated from the part 8 by the insulator 27, but is connected to this part for high frequency alternating currents through the capacity existing between the flange 26 and the part 8. The anode cylinder 28 is supplied with unidirectional

currents over a lead-in conductor or rod 31. An extension 32 of the anode cylinder 28 concentrically surrounds the rod 31, being insulated therefrom at one end by an insulating washer 33 disposed between the adjacent ends of parts 28 and 32 and at its opposite end by a washer 34 which, in conjunction with a nut 35, serves as means for clamping the parts 28 and 32 and maintaining them in axial alignment. The structure thus described forms a pair of cavity resonators, one defined by the cylinders 25 and 29 and coupled to the space between the grids 3, 4 and the other defined by the cylinders 28, 32 and intermediate cylinder 29 and coupled to the space between anode 1 and grid 4. The dimensions of these cavity resonators may be adjusted by means of sliding plungers 36, 37 and rods 38, 39 connected to these plungers.

The D. C. connections for the discharge device may be made in various ways and, in the arrangement illustrated, the anode is maintained at a potential above ground being supplied with that potential by a lead-in conductor 40 connected to the rod 31, while the cathode is maintained at essentially ground potential. The focussing grid 5 is maintained slightly negative with respect to the cathode 2 by means of a lead-in conductor 41 connected to prongs 21. For purposes to be explained later, the second control grid 4 is maintained at or near ground potential, while the first control grid 3 is maintained at a positive potential with respect to the cathode, being connected by means of lead 42 to a suitable source of voltage, such as the battery 43.

Signals to be amplified are supplied to the cavity resonator formed by the cylinders 25, 29 over a concentric transmission line comprising a tubular outer conductor 44 and a centrally disposed inner conductor 45 terminating in a capacitive coupling plate 46 disposed within this cavity resonator in spaced relation with the outer surface of intermediate cylinder 29. Amplified signals may be extracted from the cavity resonator coupled with the anode-grid 4 space for utilization in an external circuit by means of a coupling loop 47 which extends into this anode-grid cavity and which is supported from a hollow tubular conductor 48 extending outwardly through the plunger 37. A wire 49, which connects with one extremity of the coupling loop 47 is arranged within the conductor 48 and forms with it a coaxial transmission line.

In the operation of the system of Fig. 1, for the amplification of signals supplied over input transmission line 44, 45, the dimensions of the cavity resonator defined by the members 25, 29 are adjusted by positioning of the plunger 36 to resonate at the frequencies of the input signals. The grids 3, 5 preferably are aligned and the grid 5 is supplied with a focussing potential so that electrons from the cathode 2 do not strike the wires of the grid 3. The grid 3 is maintained at a positive potential to accelerate electrons emitted by the cathode 2. As the focussed electrons from the cathode 2 traverse the region between the wires 3 and 4, they are either further accelerated or decelerated by the electromagnetic fields existing between these wires. The grid 4 is maintained at a potential which is substantially that of the cathode 2 or slightly negative with respect to the potential of this cathode in order to reflect those electrons which are decelerated in traversing the region between the grids 3, 4. As a result, only electrons which are accelerated in this region pass through the grid 4 to excite the output cavity defined by the members 28, 29 and supply energy to the output coupling loop 47.

In the modification of my ultra high frequency system shown in Fig. 2, the electron discharge device there employed differs from that of the device of Fig. 1 in that it is so constructed that inputs signals may be impressed between the cathode 50 and a first grid or control electrode 51. The electron discharge device of this system includes, in addition to the mentioned electrodes, an anode 52 and two additional grids or control electrodes 53, 54 supported between the electrodes 51 and the anode 52. The grids 53, 54 are provided, respectively, with supporting disks 55, 56, while the grid 51 is supported with a cup-shaped metallic disk 57. The disk 57 may be soldered or welded to a metallic sleeve 58 which concentrically surrounds the cathode 50, being spaced therefrom by a disk insulator 59. The sleeve 58 has an outwardly directed flange 60, and insulating cylinders 61, 62, sealed respectively between the members 60, 55 and 55, 56, support the grids 51, 53, 54 in spaced relation. An additional insulating cylinder 63 is sealed between the disk 56 and an enlarged flange portion 64 of the anode 52 to complete the enclosing envelope of the discharge device. The cathode 50 is heated by a filament 65 which is enclosed within the cylinder which forms the cathode.

The input circuit of the system of Fig. 2 comprises a cavity resonator of the concentric conductor type constituted by an inner conductor 66 which slides over the cathode cylinder 50 and a tubular outer conductor 67 which slides over the metallic sleeve 58. In this way, the sleeve 58 and the cathode cylinder 50 form a portion of this cavity resonator. The dimensions of the resonator may be adjusted by means of a plunger 68 and input signals may be supplied over a concentric transmission line comprising a tubular outer conductor 69 and a centrally disposed inner conductor 70 terminating in an input electrode or probe 71 of the capacitive type. The output circuit of the system likewise is in the form of a cavity resonator of the concentric conductor type and comprises an inner conductor 72 and capacitively coupled through an insulator 73 with a cylindrical enlargement 74 attached to the outer surface of the anode. The outer conductor of the output resonator is in the form of a metallic cylinder 75 having resilient fingers 76 engaging the disk 56. The dimensions of this output cavity resonator may likewise be adjusted by means of plunger 77 to adjust the resonance frequency of the resonator. Energy may be extracted from the resonator by means of an output coupling loop 78.

Unidirectional potentials for operating the device 2 are supplied to the anode 52 over a conductor 79. The cathode 50 is preferably maintained at ground potential and a negative potential is supplied to the grid 51 over a conductor 80 connected with the sleeve 58, the sleeve 58 and the outer conductor 67 of the input resonator being insulated by a cylindrical insulator 81 to permit the impression of unidirectional potentials between the cathode 50 and the electrode 51. The control electrode 53 is provided with positive potential by means of a conductor 82 connected to the disk 55. The reflecting electrode 54 preferably is operated at the potential of the cathode or slightly negative with respect thereto, such potentials being supplied directly to the supporting disk 56 for this electrode.

In the operation of the system for amplification of signals supplied to the input circuit over the transmission line **69**, **70**, the grid **53** is maintained at a positive potential to accelerate electrons emitted from the cathode **50** and the grid **54** is maintained substantially at the potential of the cathode or slightly negative with respect to the potential of this cathode in order to repel or reflect the emitted electrons. Thus, between the grids **53**, **54**, there are present electrons flowing in both directions. Both the quantity of electrons and the transit angle in the region between these control electrodes may be controlled by the magnitude of the positive potential applied to the grid **53** so that the system does not oscillate.

The condition which exists when a signal to be amplified is supplied to the input resonator may best be explained by reference to the curves of Figs. 3 and 4. The current flow, $i_{g_{53}}$, in the plane of the grid **53** is shown by the curve **83** of Fig. 3. This current of course varies in magnitude with the potential impressed between the cathode and grid **51**, that is, in accordance with the variations in the electromagnetic field in the input resonator. The average value of the current, I_{av}, is indicated by the line **84** of Fig. 3. The velocity of the electrons, which varies with the accelerating fields existing between the cathode and the grid **51**, is shown by the curve **85** and the average velocity of the electrons in the plane of grid **53** is shown by the straight line **86**. If the voltage on grid **54** is made such that electrons having a velocity v_{av} cannot pass grid **54**, then those electrons arriving at the grid **54** between the times t_1 and t_2 pass through the plane of grid **54** to the anode, while those which arrive at the plane of grid **54** between the time t_2 and the time t_3 are reflected and returned partly to the grid **53** and partly to the cathode **50**.

Those electrons which pass through the grid **54** give a current flow at the anode which is shown by the curves of Fig. 4. The overall effect at the anode of the accelerating potential applied to the grid **53** and the reflecting potential applied to grid **54** is to provide a large flow of current during positive halves of each cycle and zero flow of current during negative half cycles so that, for all purposes, a very large trans-conductance of the electronic tube is obtained.

Since the time of transit of electrons between the planes of the various electrodes is an appreciable part of and frequently more than a cycle, the voltages impressed may be so related with respect to the frequencies of the signals to be amplified that electrons reflected at grid **54** reenter the spacing between grid **51** and the cathode on a subsequent retarding half cycle of the excitation voltage. With this relation between transit time and potentials, the presence of these returning electrons in the cathode-grid **51** space increases the space charge with a resultant decrease in the velocity of forward moving electrons, thus essentially increasing the modulating effect of the excitation signals on the electron stream of the device. The effect, therefore, of introducing signals into the input cavity is to modulate the electron stream passing between the cathode **50** and the control electrode **54**, that is, electrons of this stream are sorted in accordance with their velocities. On positive half cycles, current pulses penetrate the grid **54** and flow to the positively charged anode. The modulated current which flows between the grid **54** and the anode excites the output cavity defined by the cylinders **75**, and

72, **73** and is supplied to utilization circuits by means of the output coupling loop **78**.

The foregoing considerations apply of course only when the electron discharge device is operated as a space charge limited electronic tube. The modulation of electron velocity takes place in the interaction space between the cathode **50** and the control electrode **51**, while the reflection of electrons having a velocity less than the value v_{av} is effective between the grid **53** and the grid **54**. As a result of these effects, there are many more than the normal number electrons or charges between the cathode **50** and the grid **54**. This increase is due to the fact that electrons are both traveling from the grid **54** to the cathode and returning to the cathode from the grid **54**. It is apparent of course that the number of electrons between the cathode and the control grid **53** establishes the magnitude of the current which flows to the anode.

In the foregoing, the system of Fig. 2 has been described as an amplifier. It is apparent, of course, that the systems of both Figs. 1 and 2 may be employed as a source of oscillations. This is indicated in Fig. 2 by the dotted feedback connection, as shown by a coupling probe **87** and the input probe **71**, the feedback being made over a concentric transmission line connecting these two probes. In the operation of the structure as an oscillator, the grid **51**, being maintained at a negative potential, operates to focus the electron beam emitted by the cathode **50**. One of the advantages of the structure is that concentration of the electrons in the interelectrode space into a beam through the action of the negative focussing electrode **51** results in a reduction of current at the positively charged electrode **53**. The overall effect is to increase the space charge density and to provide higher power output for the oscillator.

It is apparent also that the principles which are employed in the systems of Figs. 1 and 2 for the amplification of high frequency signals are applicable also to the generation or amplification of low frequency signals, the result being obtained by sorting of electrons in accordance with their velocities to permit only those having a velocity greater than a threshold level to travel to the anode of the device.

While I have shown and described my invention as applied to particular systems embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention and I aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An ultra high frequency circuit comprising an electron discharge device having an anode cylinder and a cathode cylinder coaxially aligned therewith, said cylinders having adjacent closed ends in opposed spaced relation, three control grids positioned between said ends, three transverse conductive members connected respectively to said anode and two of said control grids, a pair of cylindrical insulating members surrounding said anode and cathode cylinders and sealed respectively between said transverse conductive members, a conductive cylinder surrounding said cathode supporting the third of said grids, means connected to said third grid for maintaining said grid at a negative potential with respect to said

cathode to focus electrons emitted therefrom, means connected to the said two of said control grids for supplying a high frequency signal to be amplified between said two grids, means connected to the one of said two grids adjacent said cathode for maintaining said grid at a positive potential with respect to said cathode to accelerate electrons emitted therefrom, means connected to the other of said two grids for maintaining said grid substantially at the potential of said cathode to sort electrons passing between said cathode and anode in accordance with their velocities.

2. An electron discharge device comprising an anode and a cathode having planar surfaces in opposed spaced relation, a pair of grids interposed between said surfaces, three transverse conductive members conductively supporting said anode and said grids in spaced relation and affording externally accessible terminals therefor, means maintaining said transverse members in spaced relation, a cylinder extending in a direction transverse to said conductive members constituting a

support for and affording an externally accessible terminal for said cathode, a conductive cylinder concentrically surrounding said first mentioned cylinder in insulated relation thereto, and a control grid positioned between said electrodes and said cathode and supported by said conductive cylinder.

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