April 7, 1953 A. M. GUREWITSCH 2,634,383

CAVITY RESONATOR HIGH-FREQUENCY
ELECTRON DISCHARGE DEVICE
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Fig. 3.

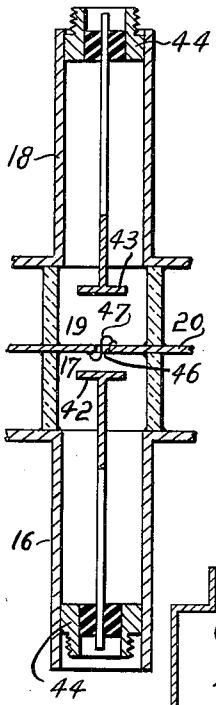


Fig. 1.

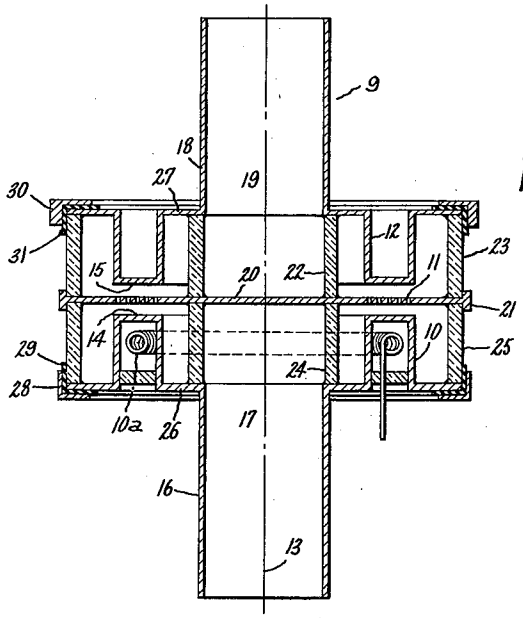
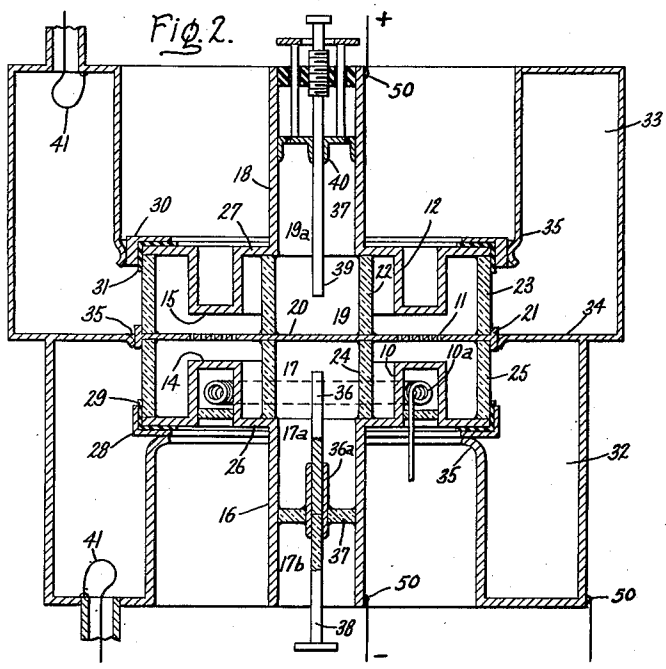


Fig. 2.



Inventor:
Anatole M. Gurewitsch,
by Paul A. Frank
His Attorney.

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CAVITY RESONATOR HIGH-FREQUENCY ELECTRON DISCHARGE DEVICE

Anatole M. Gurewitsch, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

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8 Claims. (Cl. 315—6)

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My invention relates to high frequency electron discharge devices and associated apparatus and, more particularly, to such electron discharge devices and apparatus capable of handling comparatively large amounts of high frequency electric energy.

One object of my invention is to provide an electron discharge device having a comparatively simple and economical construction and yet capable of fulfilling high power requirements in high frequency electromagnetic circuitry.

Another object of my invention is to provide an electron discharge device which may easily be adapted to fulfill a number of different functions in high frequency circuitry such as to function as an amplifier, oscillator or detector.

Another object of my invention is to provide a high frequency electron discharge device which has a self-contained easily accessible electromagnetic field region which may be employed to effect symmetrically the electric characteristics of an external cavity resonator circuit associated with the device.

A further object of my invention is to provide a high frequency electron discharge device which may be constructed to have internal tuning means whereby the resonant frequency of external cavity resonators associated with the discharge device may be controlled with little appreciable distortion of the resonator fields.

A still further object of my invention is to provide a high frequency electron discharge device which produces a self-contained electromagnetic field region through which input high frequency energy may be delivered and output high frequency energy may be taken without the resonator field distortion attendant upon the conventional direct coupling to cavity resonators associated with the device.

A still further object of my invention is to provide an electron discharge device which produces a self-contained electromagnetic field which may be employed to provide a predetermined interaction between input and output high frequency circuits of the device for such purposes as regenerative or degenerative coupling when the device is connected as an amplifier, or to provide feedback sufficient to sustain oscillations when the device is employed as an oscillator.

Yet another object of my invention is to provide a high power high frequency electron discharge device having an electrode structure which facilitates cooling of the electrodes of the device.

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In general, my invention comprises a plurality of annular electrodes supported in spaced planar alignment and formed around an axis of revolution so that the inner cylindrical surfaces of the annular electrodes form a cylindrical wave guide extending along the axis of revolution of the device. This internal wave guide is coupled for high frequency energy to the electron stream region of the device and is preferably divided into two sections by a central transverse disk or "septum" which is connected to the control electrode of the device. The dimensions of the two wave guide sections thus formed are such as to produce a rapid attenuation of any electromagnetic energy coupled thereinto from the variations of the electron stream. In other words, the wave guide sections are dimensioned to operate below "cut-off" at the frequency of operation of the device. By inserting suitable tuning elements into the attenuated electromagnetic field produced within these wave guide sections, a reactive component may be reflected into the device in order to effect a corrresponding variation in the resonant frequency of cavity resonators associated with the device. This self-contained electromagnetic field region may also be used to provide input and output coupling to the device. In addition, suitable coupling elements such as apertures or interconnecting loops may be provided through the disk separating the two wave guide sections in order to obtain any desired regenerative or degenerative coupling between input and output circuits of the device.

It will be appreciated that since this internal field region is located along the axis of the device, the introduction of tuning or coupling elements thereinto has a symmetric loading effect upon cylindrical cavity resonators generated around the axis so that little appreciable distortion of the resonator field results.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 is a cross-sectional view of an electron discharge device embodying my invention; Fig. 2 is a similar cross-sectional view of the discharge device of Fig. 1 associated with suitable cavity resonators and incorporating structures whereby the internal electromagnetic field region may be employed for tuning purposes; Fig. 3 is a cross-sectional view of a cen-

tral portion of the electric discharge device of Fig. 1 showing a structure whereby the internal electromagnetic field region may be used for coupling purposes and also illustrating further modifications of my invention whereby a predetermined internal coupling between input and output circuits of the device may be achieved.

Referring to Fig. 1, I have shown an electron discharge device 9 embodying my invention comprising a plurality of annular electrodes including a thermionic cathode 10, a control electrode 11, and an anode 12 located in spaced alignment and formed around a central axis of revolution indicated by a line 13. Cathode 10 may be heated by any appropriate means such as an internal heating coil 10*a*. An annular electron emitting surface 14 of cathode 10 and a corresponding annular electron receiving surface 15 of anode 12 are located in close planar alignment to provide a short electron path therebetween. Cathode 10 also has a cylindrical portion 16 axially extending from the inner edge of electron emitting surface 14 to define an axially extending tube constituting a cylindrical wave guide 17. Similarly, anode 11 has a cylindrical portion 18 extending from the inner edge of the electron receiving surface 15 to define an axially extending tube constituting a cylindrical wave guide 19. Wave guides 17 and 19 comprise an internal electromagnetic field region of device 9 which communicates with the electron stream passing from cathode 10 to anode 12.

Control electrode 11 is supported in conductive relation with a conductive disk 20 which extends transversely across the center of the device and which serves to divide the device into substantially symmetric input and output circuit portions. Preferably, the control electrode 11 is formed by merely perforating the disk 20, the perforations being in the form of an annular band located in the path of the electron stream. The central portion of the disk 20 serves as a septum dividing the wave guide sections 17 and 19 defined by cathode cylinder 16 and anode cylinder 18 respectively. Disk 20 also preferably extends radially beyond the outer surfaces of the cathode 10 and anode 12 respectively and terminates in a conector ring 21 which may be used to make connection from the control electrode 11 to cavity resonators associated with electron discharge device 9.

A pair of concentric cylindrical insulating members 22 and 23 comprising material, such as glass, completely pervious to high frequency electromagnetic fields, are hermetically sealed between the conductive disk 20 and the annular anode 12 on opposite sides of the electron receiving surface of the anode 12 and function both to enclose the electrodes hermetically and to support the control electrode 11 in proper spaced relation to the anode 12. Similarly, concentric insulating members 24 and 25 are sealed between the conductive disk 20 and the annular cathode 10 on opposite sides of the electron emitting surface 14 in order to complete the enclosure of the electrodes and to maintain the cathode 10 and the control electrode 11 in proper spaced alignment. Preferably, annular ridges or shoulders 26 and 27 are formed in cylinder portions 16 and 18 respectively in order to provide a convenient seat for insulating members 24 and 22.

In order to provide a convenient high frequency by-pass connection between cathode 10 and a cavity resonator structure associated with device 9, whereby different unidirectional potentials may be applied to the cathode and the resonator without interfering with the flow of high frequency currents therebetween, I preferably secure around the outer circumference of the cathode 10 a conductive washer 28 separated from cathode 10 by a thin film 29 of high dielectric material, such as mica. A similar high frequency capacitor comprising a washer 30 and a dielectric film 31 is preferably formed around the outer circumference of anode 12 to enable a high frequency connection between anode 12 and an associated cavity resonator. Although the incorporation of these high frequency capacitors into the structure of the discharge device 9, as described above, is to be preferred, it is not essential that they be so incorporated. Alternatively, suitable high frequency by-pass connections may be incorporated into the structure of cavity resonators associated with device 9 in manners well known to those skilled in the art.

Wave guide sections 17 and 19 are properly dimensioned to cause a rapid attenuation of electromagnetic fields induced therein at the frequency of operation of discharge device 9. Due to the annular configuration of the electrodes of the device, the lowest order electromagnetic wave patterns which may normally be established within cylindrical wave guide sections 17 and 19 are the transverse electric TE_0, or transverse magnetic TM_0, first order modes of propagation in which the designated transverse waves are symmetric about the axis of the guide. The critical dimension for determining the wave length beyond which wave propagation is rapidly attenuated, i. e., the cut-off wave length, for such cylindrical wave guides is the diameter of the guide. For the transverse magnetic mode of operation, this cut-off wave length may be approximately determined by the following relationship

$$(TM_0)\ \lambda = 1.31 d\sqrt{\mu e}$$

and for the transverse electric mode

$$(TE_0)\ \lambda = 0.82 d\sqrt{\mu e}$$

where

d is the diameter of the guide,
μ is the permeability of the medium within the guide,
e is the dielectric constant of the medium within the guide.

For air, $\mu = e = 1$ so that a very simple relationship between the diameter of the guide and the cut-off wave length exists. It is only necessary, therefore, to construct the cylinder portions 16 and 18 to have a diameter small enough that the wave length of the electromagnetic waves produced in device 9 at the desired frequency of operation is longer than the critical cut-off wave length determined by the above formulas for the wave guides defined by these cylinder portions 16 and 18.

As a result, an electromagnetic field is produced in wave guide sections 17 and 19 during operation which is rapidly attenuated as it attempts to propagate away from the dividing disk 20 toward the open ends of the wave guide sections 17 and 19 respectively. The electromagnetic field strength is normally attenuated to a negligible amount within less than one diameter at the frequency of operation of the device, as measured along the axis of the guide. The axial length of wave guide sections 17 and 19 is preferably however, at least one wave-length long at the desired frequency of operation of device 9. If

a more complete attenuation of the internal field regions 17 and 19 is desired, the inner walls of cylinders 16 and 18 may be tapered to a reduced diameter at the ends, or may be completely closed at the ends if the cylinders are of sufficient length to reduce the field intensity to a small enough value to preclude reflection of energy from the end walls.

The electron discharge device of Fig. 1 constitutes a completely operative component of a high frequency circuit. Although in the modifications of Figs. 2 and 3 to be described hereinafter, the internal electromagnetic field region produced during operation of the device is utilized for tuning or energy coupling purposes, the device 9 may be employed in the simple form illustrated in Fig. 1 without such inserted tuning or coupling elements. In fact, for exceptionally high power applications, it is preferable that device 9 be operated without such inserted elements because of the somewhat better cooling of the anode 12 and control electrode 11 which results due to the better heat radiation from cylinder 18 and central disk 20. An even high rate of cooling can be achieved, if desired, by passing a cooling fluid within the wave guide sections 17 and 19. Tuning and coupling to device 9 can then be made within associated cavity resonators in a conventional manner.

Referring to Fig. 2, I have shown the electric discharge device of Fig. 1 in conjunction with a pair of cylindrical cavity resonators 32 and 33 respectively, resonator 32 constituting a grid-cathode resonator for device 9 and resonator 33 constituting a grid-anode resonator. Resonators 32 and 33 may be constructed, as indicated, in an integral unit having a common wall 34 to provide three adjacent end surfaces terminating in suitable contact fingers 35 enabling a plug-in type connection with the discharge device 9 of Fig. 1. The major dimension of resonators 32 and 33 may be along the axis of the device 9, as shown, or may be the radial dimension, depending upon the desired direction of the electric vectors in the generated electromagnetic field of the resonators.

In the electron discharge device of Fig. 2, the wave guide sections 17 and 19 are employed as regions in which tuning of the external cavity resonators 32 and 33 is accomplished. Within wave guide section 17, I have shown one tuning arrangement and within region 19 I have shown an alternative tuning arrangement. It will be appreciated that either of these tuning arrangements may be used in either or both regions 17 and 19.

The tuning arrangement shown in region 17 comprises a conductive rod 36 extending along axis 13 and telescoped within a conductive sleeve 36*a* which is supported by a washer 37 composed of material, such as glass or polystyrene, which is pervious to high frequency electromagnetic fields. A non-conductive rod 38 composed of a field pervious material similar to washer 37 is attached to the end of conductive rod 36 to enable adjustment of the axial depth of conductive rod 36 within region 17.

As will be apparent to those skilled in the art, due to the presence of the axially extending conductive rod 36 and sleeve 36*a*, the portion of electromagnetic field region 17 coextensive with rod 36 and sleeve 36*a*, designated as portion 17*a*, now constitutes a concentric transmission line; while the portion of region 17 lying between the end of sleeve 36*a* and the open end of cylinder 16, designated as portion 17*b*, constitutes a wave guide beyond cut-off. Region 17*b* preferably has an axial length equal to at least one inner diameter of cylinder 16 to provide substantially complete attenuation of electromagnetic energy coupled into line 17*a*. Consequently, portion 17*a* of region 17 appears to the discharge device 9 as an open ended concentric transmission line terminating in almost infinite impedance. By adjusting the combined length of rod 36 and 36*a*, this concentric line can be made to reflect any desired reactive component either capacitive or inductive into the field produced by the electron stream of device 9. Moreover, the axial depth of rod 36 with relation to conductive disk 20 may be adjusted to control the degree of coupling produced by the internal attenuated field region adjacent the electron stream between the resonant circuit represented by the concentric line 17*a* and the resonant circuit represented by cavity resonator 32.

The tuning arrangement shown within region 19 operates upon substantially the same principle as that shown in connection with region 17 with the exception that the concentric line section terminates in a tuning plunger to produce a closed ended line of variable length. A conductive rod 39 axially inserted within region 19 is short circuited along its length for high frequency energy by an annular tuning plunger 40 to define a closed ended concentric line 19*a*. By adjusting the position of plunger 40 relative to rod 39 the line 19*a* can be made to reflect any desired reactive component into the internal attenuated field region produced by the electron stream, and consequently to vary the frequency of resonance of grid-anode resonator 33 accordingly. The degree of mutual coupling between the energy within the concentric line 19*a* and the resonator 33 can be controlled by merely adjusting the axial depth of rod 40 within region 19.

It will be appreciated that the simple and compact tuning elements incorporated in the above-described tuning arrangements are much less expensive to construct and less cumbersome to handle than the tuning plungers conventionally employed within cavity resonators such as resonators 32 and 33 associated with device 9. Moreover, since the tuning elements of my invention, such as rod 36 and sleeve 36*a*, or rod 40 and plunger 41, are located along the axis of device 9, the generated radial fields produced by device 9 are affected symmetrically, and consequently there is little appreciable distortion of the resonator field patterns due to the presence of these central tuning elements.

In the modifications of my invention illustrated in Fig. 2, input and output coupling of the high frequency energy to the resonant circuits, may be accomplished by any suitable means, such as coupling loops 41 associated with cavity resonators 32 and 33. Proper potentials for operating the high frequency apparatus of Fig. 2 as an amplifier, oscillator or detector, may be supplied to the various electrodes of discharge device 9 through suitable connecting terminals such as terminals 50.

Referring now to Fig. 3, I have shown a further modification of my invention wherein the central wave guide sections 17 and 19 are employed for coupling high frequency energy to the input circuit of the device and for extracting high frequency energy from the output circuit of the device. In this modification, high frequency electric coupling elements 42 and 43, terminating in

coupling disks and fed by coaxial cable terminal connectors 44, are inserted along the axis of the device within the wave guide sections 17 and 19 somewhat in the same manner as the tuning elements of Fig. 2. Other well known types of high frequency coupling elements, such as probes, dipoles, or loops may alternatively be used. The electromagnetic field established within wave guide 17 by the input coupling element 42 produces a corresponding variation in the electron stream of discharge device 9 so that high frequency fields are set up within grid-cathode and grid-anode cavity resonators, such as resonators 32 and 33 of Fig. 2, associated with device 9. As the coupling elements 42 and 43 are moved closer to the central septum 20, a tighter coupling is achieved to the electron stream and ultimately to the high frequency energy within the resonators 32 and 33. Here again, as with the tuning elements, it will be appreciated that the coupling is symmetric with relation to the resonator fields with the result that there is little appreciable field distortion and a consequent greater efficiency.

In the modifications of Fig. 3, I have also shown the central septum 20 as including an energy transferring element, such as an aperture 45 through which an intercoupling member 47 is passed, to provide coupling between the wave guide sections 17 and 19. By means of such apertures, with or without additional intercoupling members, any desired degree and phase of direct coupling between input and output circuits, can be achieved. The design and effect of such energy transferring elements between input and output cavity resonators of high frequency devices is well known to those skilled in the art. However, the location of the energy transferring elements between internal auxiliary field regions of an associated electron discharge device, as in the present invention, has the very marked advantage of causing little or no deformation of the field pattern in the resonators.

It will thus be seen that I have provided a high power, high frequency electron discharge device which has a self contained auxiliary electromagnetic field region which can be used to affect symmetrically the electron flow in the discharge device and in the electromagnetic fields produced in cavity resonators associated with the device. The annular electrodes themselves provide a greater current handling capacity for the discharge device than is normally available from the smaller circular electrodes usually found in such high frequency devices. In addition, the central disk 20 which is conductively connected to control electrode 11 facilitates cooling of the control electrode 11; and the central cylinder 12, which defines the wave guide section 17, has the large surface area desirable for radiation cooling of the annular anode 12 of device 9.

It is to be understood that although I have shown particular embodiments of my invention, many other modifications can be made, and I intend, therefore, by the appended claims to cover all such 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. A high frequency electron discharge device comprising a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes substantially in the plane of said control electrode, a pair of conductive cylinders extending axially from said cathode and said anode respectively to define a pair of electromagnetic field regions axially separated by said disk which field regions communicate with an electron discharge from said cathode to said anode, said cylinders each having a wave propagation cut-off characteristic to electromagnetic waves having frequencies equal to the operational frequencies of said device, and a tuning element inserted along the axis of at least one of said field regions for introducing a reactive component into the field of an electron discharge of said device.

2. A high frequency electron discharge device comprising a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes substantially in the plane of said control electrode, a pair of conductive cylinders extending axially from said cathode and said anode respectively to define a pair of electron discharge communicating electromagnetic field regions axially separated by said disk, said cylinders each having a wave propagation cut-off characteristic to high-frequency electromagnetic waves, and a high frequency electromagnetic energy coupling element inserted along the axis of at least one of said electromagnetic field regions to provide electromagnetic energy coupling to an electron discharge from said cathode to said anode.

3. A high frequency electron discharge device comprising a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes substantially in the plane of said control electrode, a pair of conductive cylinders extending axially from said cathode and said anode respectively to define a pair of electron discharge interacting electromagnetic field regions axially separated by said disk, said cylinders having diameters less than the wave propagation cut-off diameter for electromagnetic waves having a frequency equal to a frequency of operation of the device, and said disk having an energy transferring element passing therethrough for providing coupling of electromagnetic waves from one of said electromagnetic field regions to the other.

4. High frequency apparatus comprising an electron discharge device having a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment and all having a common axis of revolution, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes in a plane perpendicular to said axis of revolution, a pair of conductive cylinders extending axially from said cathode and said anode respectively to define together with said disk a pair of axially separated electromagnetic field regions interacting with an electron discharge from said cathode to said anode, a pair of cavity resonators extending around the periphery of said discharge device and connected to said electrodes to form a grid-cathode resonator and a grid-anode resonator respectively,

and a tuning element inserted along the axis of at least one of said field regions for introducing a reactive component into said electron discharge, thereby to tune a corresponding one of said resonators. .

5. High frequency apparatus comprising an electron discharge device having a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes, a conductive cylinder extending axially from said cathode to define together with said disk an electron discharge interacting electromagnetic field region, a grid-cathode cavity resonator extending around the periphery of said discharge device, and a tuning element inserted along the axis of said electromagnetic field region for reflecting a reactive component into said electron discharge, thereby to tune said resonator.

6. High frequency apparatus comprising an electron discharge device having a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes, a conductive cylinder extending axially from said anode to define together with said disk an electron discharge interacting electromagnetic field region, a grid-anode resonator extending around the periphery of said discharge device, and a tuning element inserted along the axis of said electromagnetic field region for reflecting a reactive component into said electron discharge, thereby to tune said resonator.

7. High frequency apparatus comprising an electron discharge device having a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes, a conductive cylinder extending axially from said cathode to define together with said disk an electron discharge interacting cylindrical wave guide, said wave guide having a propagation cut-off characteristic to high frequency electromagnetic waves in the apparatus, a grid-cathode cavity resonator extending around the periphery of said discharge device, and a high frequency coupling element inserted along the axis of said wave guide to effect a transfer of high frequency electromagnetic energy with said resonator.

8. High frequency apparatus comprising an electron discharge device having a plurality of annular electrodes including a cathode, a control electrode and an anode located in consecutive spaced planar alignment, a conductive disk connected to said control electrode and extending across the central region defined by said annular electrodes, a conductive cylinder extending axially from said anode to define together with said disk an electron discharge interacting electromagnetic field region, said cylinder having a diameter less than a wave propagation supporting diameter for high frequency electromagnetic waves in the apparatus, a grid-anode resonator extending around the periphery of said discharge device, and a high frequency coupling element inserted along the axis of said field region to effect a transfer of high frequency electromagnetic energy with said resonator.

ANATOLE M. GUREWITSCH.

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