United States Patent

[11] **3,584,255**

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[54] **CROSSED-FIELD DISCHARGE DEVICE**
19 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **315/39.3,** 315/39.53, 333/33
[51] **Int. Cl.** **H01j 23/20**
[50] **Field of Search** 315/39.51, 39.53, 39.67, 39, 39.3; 333/32, 33

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ABSTRACT: A crossed-field discharge device is disclosed which comprises an annular anode structure having a surface which bounds an axially extending space, a pair of pole pieces respectively arranged adjacent to the opposite ends of the anode structure, an axially extending cathode structure disposed in the axially extending space and cooperating with the adjacent anode surface to define an axially extending annular interaction space, the cathode structure including an electron emissive element having a surface disposed within the anode structure and adjacent to the associated surface of the anode structure, one of the surfaces being a generally concave surface of revolution and cooperating with the other of the surfaces, means for establishing an axially extending RF wave in the axially extending space, and end structures closing the ends of the anode structure and the axially extending space, the anode structure including an anode connection and the cathode structure including a cathode connection which cooperate to provide output connections for the device to an RF load utilizing the cathode structure as a probe.

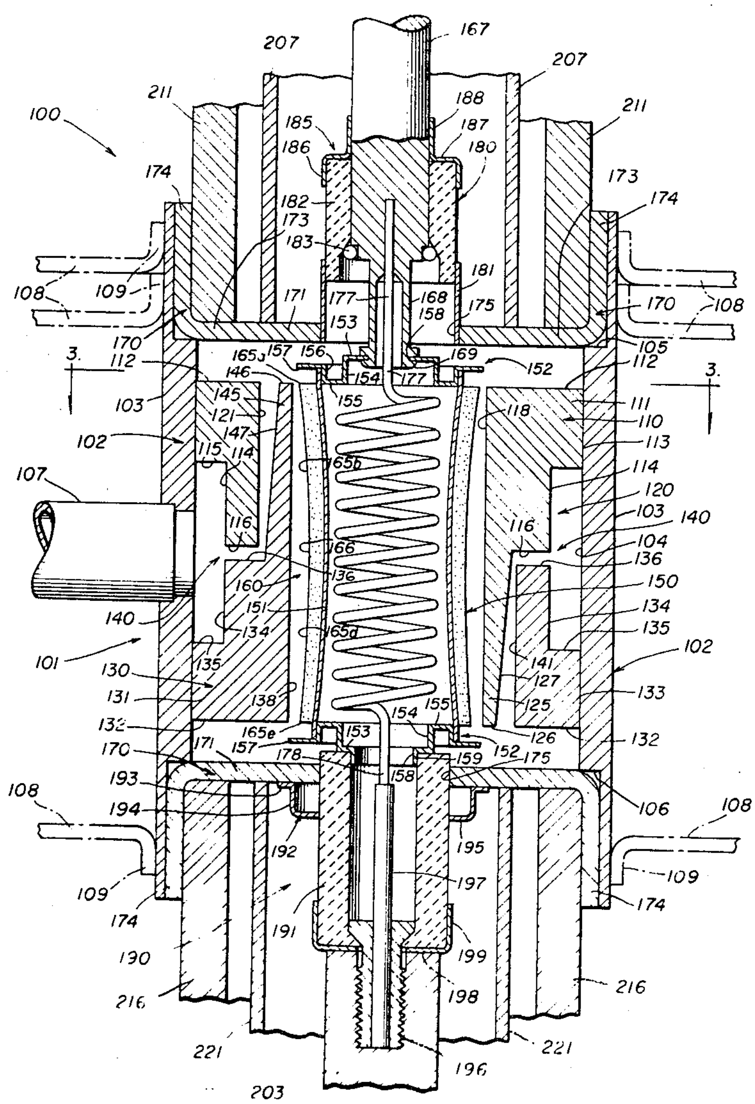

FIG. 1

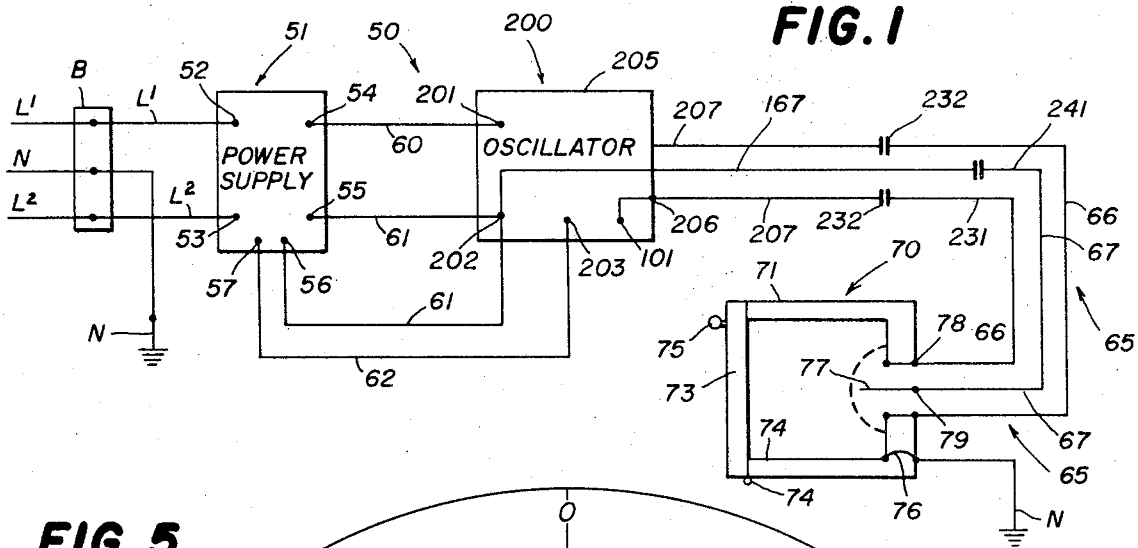

FIG. 5

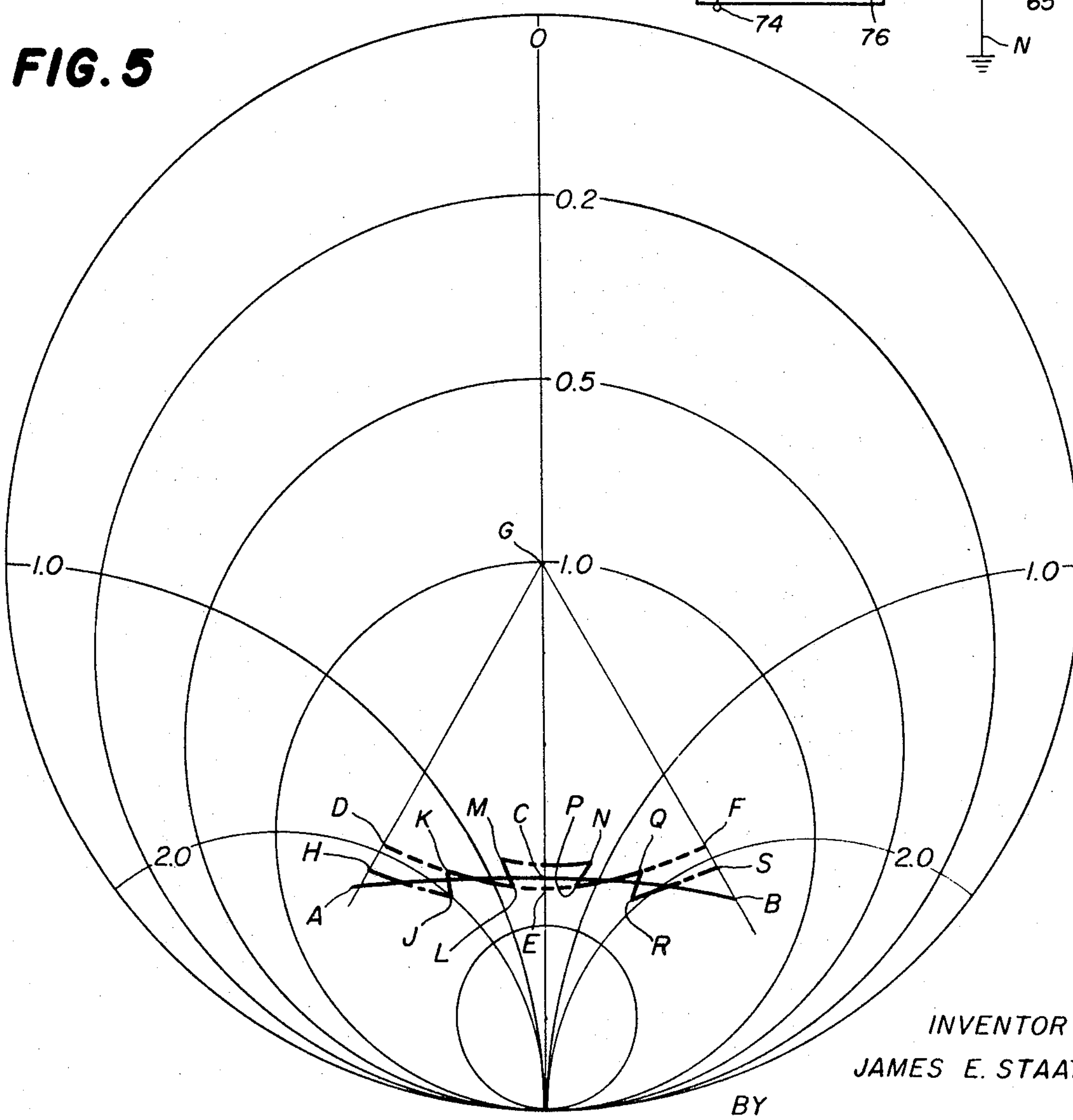

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FIG. 2

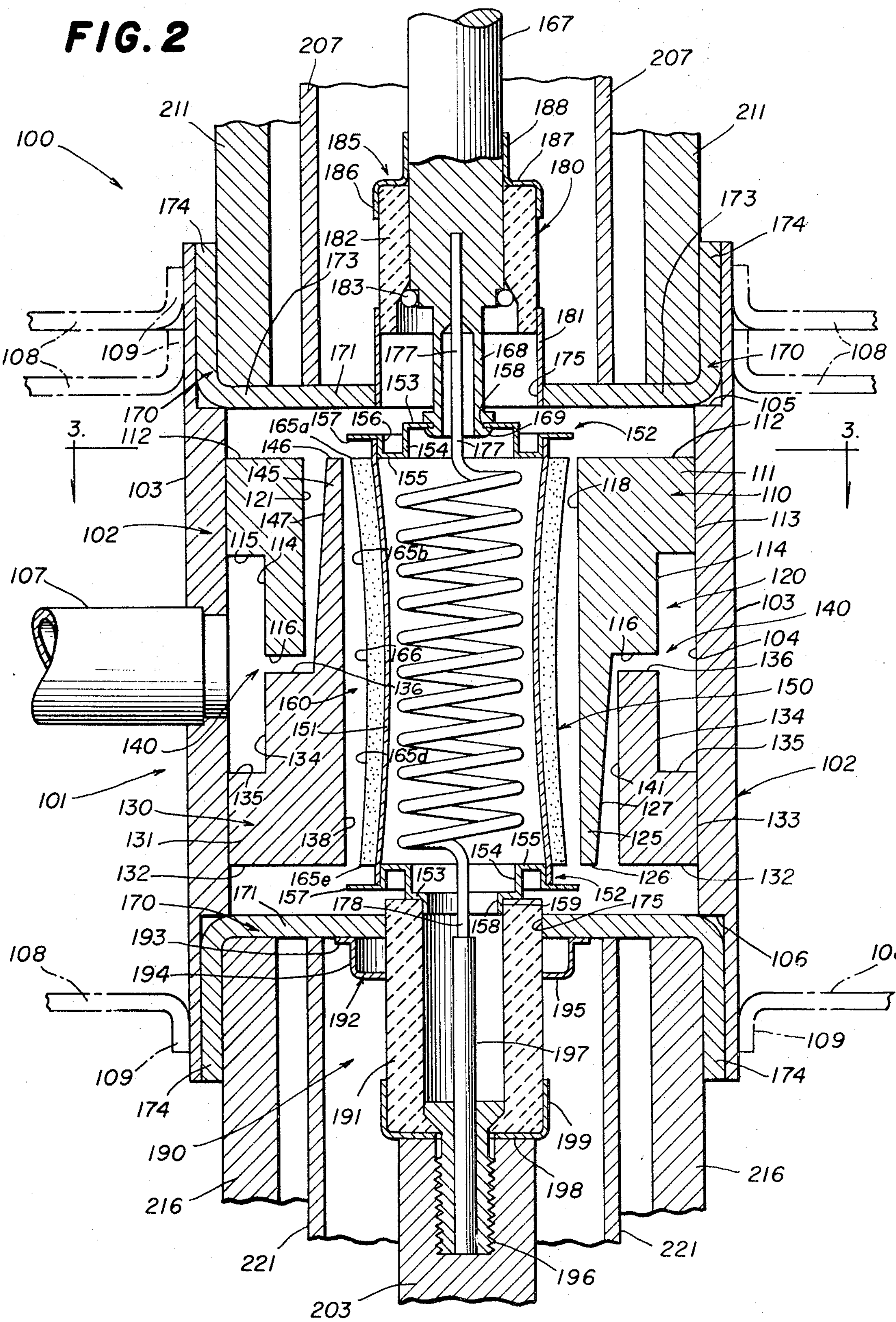
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FIG. 3

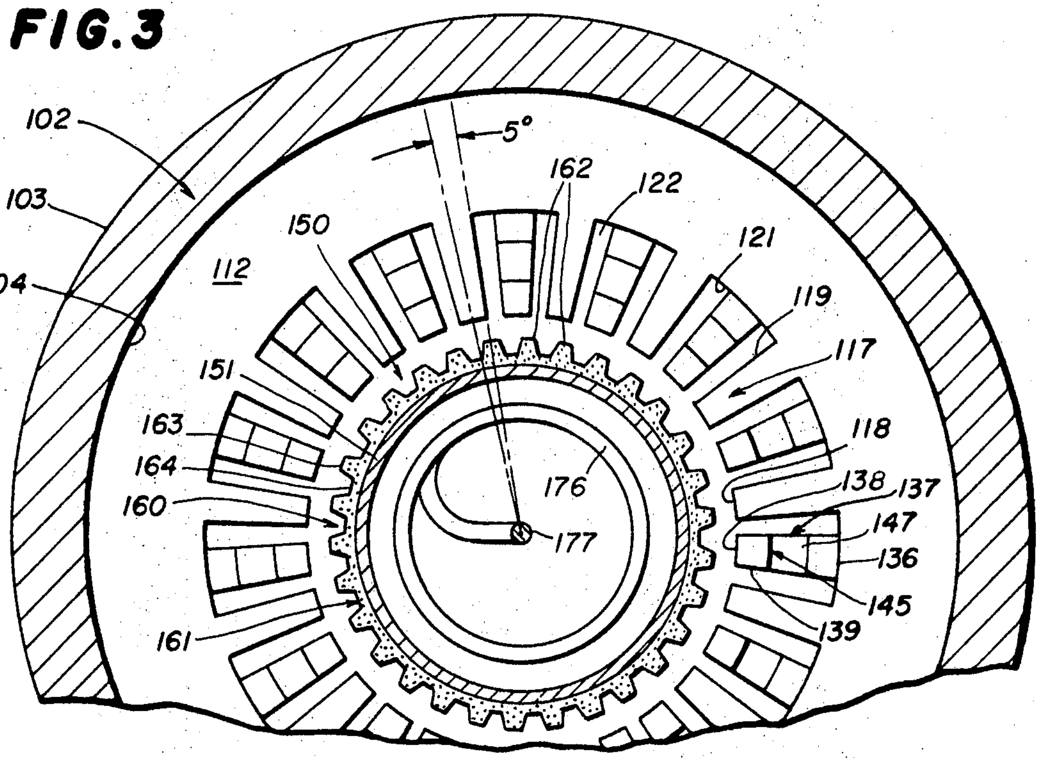
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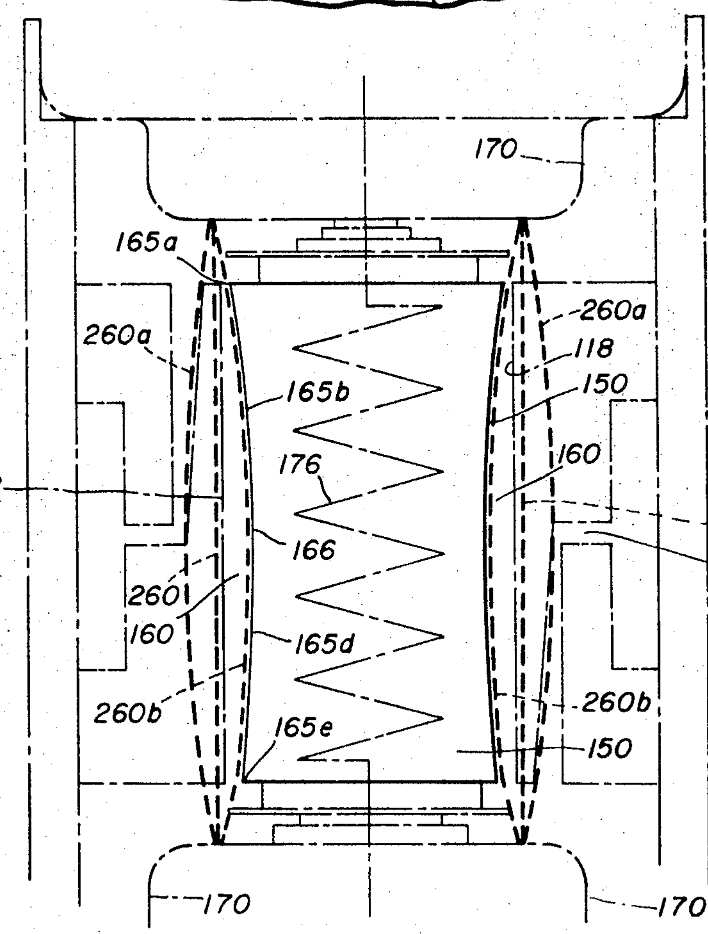
FIG. 4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CROSSED-FIELD DISCHARGE DEVICE

The present invention relates to crossed-field discharge devices, and particularly to such devices incorporating improved load matching characteristics.

It is an object of the invention to provide a crossed-field discharge device comprising an anode structure defining an axially extending space bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of the anode structure, an axially extending cathode structure disposed in the axially extending space and cooperating with the adjacent anode surface to define an axially extending annular interaction space, the cathode structure including an electron emissive element having a surface disposed within the anode structure and adjacent to the associated anode surface, one of the surfaces being a generally concave surface of revolution and cooperating with the other of the surfaces, means for establishing an axially extending RF wave in the axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of the device and extending into the interaction space, and end structures closing the ends of the anode structure including an anode connection extending outwardly beyond one of the end structures and the cathode structure including a cathode connection extending outwardly beyond the one end structure, the anode connection cooperating to provide output connections for the device to an RF load utilizing the cathode structure as a probe interacting with the RF fields.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the surfaces are closest together at the end of the interaction space disposed toward the RF load.

Another object of the invention is to provide an improved crossed-field device of the type set forth comprising a cathode structure which includes an electron emissive element having a surface of revolution of a generally concave smooth curve disposed within the anode structure and adjacent to the anode surface, the surfaces cooperating to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof.

In connection with the foregoing object, it is another object of the invention to provide an improved crossed-field discharge device wherein the concave curve is an arc of a circle with the arc having an included angle of from about 4° to about 5°.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the RF impedance increases from a first value at one end of the interaction space to a maximum value and then decreases to a second value at the other end of the interaction space.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting the outer axially extending space and the inner axially extending space at the longitudinal midsection of the anode structure, the radially extending passage dividing the anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof.

In connection with the foregoing object, it is a further object of the invention to provide an improved crossed-field discharge device wherein the anode and cathode surfaces are spaced farthest apart opposite the radially extending passage.

Further features of the invention pertain to the particular arrangement of the parts of the crossed-field discharge device whereby the above-outlined and additional operating features thereof are attained.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which:

FIG. 1 is a schematic and diagrammatic illustration of an oscillator circuit incorporating therein a crossed-field discharge device of the present invention;

FIG. 2 is an enlarged fragmentary view in vertical section through the crossed-field discharge device;

FIG. 3 is a fragmentary view in horizontal section through the device of FIG. 2 along the line 3–3 thereof;

FIG. 4 is a diagrammatic view in vertical section through the crossed-field discharge device of FIG. 2 showing the magnetic fields therein; and

FIG. 5 is a graph plotting the impedance of the interaction space of the crossed-field discharge device illustrated in FIG. 2.

Referring to FIG. 1 of the drawings, there is diagrammatically illustrated an oscillator circuit 50 embodying the features of the present invention, the oscillator circuit 50 having been illustrated as connected to a three-wire Edison network of 236 volts, single-phase, 60-cycles AC, and including two ungrounded line conductors L1 and L2 and a grounded neutral conductor N, the three conductors mentioned being terminated at an associated electrical insulating block B. The circuit 50 also comprises a power supply 51 having a pair of input terminals 52 and 53 that are respectively connected to the conductors L1 and L2. A first pair of output terminals 54 and 55 is provided for supplying a rectified and filtered DC voltage of low amplitude for the purpose of applying the DC operating potential to the crossed-field discharge device of the oscillator circuit 50; and a second pair of output terminals 56 and 57 is provided for supplying a relatively low voltage AC power for the purpose of energizing the heater of the crossed-field discharge device of the oscillator circuit 50. More specifically, the input terminals 52 and 53 are connected to the output terminals 54 and 55 by a converter, the converter preferably being of the type disclosed in the copending application of James E. Staats, Ser. No. 181,144, filed Mar. 20, 1962, wherein there is disclosed a converter comprising an assembly of capacitors and rectifiers connected between the input terminals and the output terminals thereof, and characterized by the production of a DC output voltage across the output terminals thereof in response to the application of a low frequency AC input thereto across the input terminals thereof, whereby the amplitude of the DC output voltage from the converter is approximately twice the peak value of the AC voltage to the converter. The converter described is in fact a voltage doubler and rectifier circuit wherein the output DC potential therefrom at the terminals 54 and 55 is approximately 666 volts when the AC supply source has an r.m.s. voltage of 236 volts between the conductors L1 and L2, the 666 volts DC being the open circuit or no-load value for the DC output from the power supply 51.

The oscillator circuit 50 further comprises an oscillator 200 incorporating therein a crossed-field discharge device 100 made in accordance with and embodying the principles of the present invention, the oscillator 200 having a pair of input terminals 201 and 202 that are connected respectively to the DC output terminals 54 and 55 of the power supply 51 by means of conductors 60 and 61, respectively; the input terminal 202 is also connected by the conductor 61 to one of the low voltage AC output terminals 56 of the power supply 51. A third input terminal 203 is provided for the oscillator 200, the input terminal 203 being connected by a conductor 62 to the other low voltage AC output terminal 57 of the power supply 51. As illustrated, all of the parts of the oscillator 200 are surrounded by a metallic casing 205 to which is connected as at 206 an outer tubular conductor 207 within which is disposed an inner conductor cathode stud 167 that is also connected to the input terminal 202, the coaxial conductors 167 and 207 providing an output connection for the oscillator 200. Connection is made to an output transmission line 65 including an outer tubular conductor 66 and an inner conductor 67 disposed therein, a first capacitive coupling being provided by a coupler 232 between the outer conductor 207 and the outer conductor 66, and a second capacitive coupling being provided by the coupler 242 between the inner conductor 167 and the inner conductor 67. The capacitive coupling provided by the couplers 232 and 242 is desirable and necessary since for safety purposes the outer conductor 66 of the transmission line 65 must be grounded, which grounding of the outer conductor 66 is not possible if there is a DC connection to the oscillator casing 205, the casing 205 having a potential with respect to ground because of the application of operating potentials thereto from the voltage doubler and rectifier circuit 51, it being inherent in the construction and operation of the circuit 51 that neither the conductor 60 nor the conductor 61 can be grounded. Accordingly, it is also necessary and desirable that the power supply 51 and the oscillator 200 be electrically shielded by a grounded outer housing (not shown) disposed therebetween, all as is fully described in the aforementioned copending application Ser. No. 181,144.

The microwave energy supplied from the oscillator 200 to the transmission line 65 may be used for any desired purpose, a typical use of the microwave energy being illustrated in FIG. 1, wherein the transmission line 65 is coupled to an electronic heating apparatus, such as the electronic range 70 illustrated that is generally designed for home use and provides an RF load for the circuit 50. More particularly, the range 70 comprises an upstanding substantially boxlike casing 71 formed of steel and housing therein a metal liner 72 defining a heating cavity therefor. The metal liner 72 may also be formed of steel, and essentially comprises a boxlike structure provided with a top wall, a bottom wall, a rear wall and a pair of opposed side walls, whereby the liner 72 is provided with an upstanding front opening into the heating cavity defined therein, the casing 71 being provided with a front door 73 arranged in the front opening thus formed and cooperating with the liner 72. More particularly, the front door 73 is mounted adjacent to the lower end thereof upon associated hinged structure 74, and is provided adjacent to the upper end thereof with a handle 75, whereby the front door 73 is movable between a substantially vertical closed position and a substantially horizontal open position with respect to the front opening provided in the liner 72. Also the front door 73 has an inner metal sheet that is formed of steel and cooperates with the liner 72 entirely to close the heating cavity when the front door 73 occupies its closed position. For safety purposes, the inner liner 72 is connected by a conductor 76 to the outer casing 71 which is in turn grounded by the conductor N. The outer conductor 66 of the transmission line 75 is connected as at 78 to the casing 71 and to the liner 72 of the range 70, and there is provided within the range 70 at the rear thereof a radiating element or antenna 77 that is connected as at 79 to the inner conductor 67 of the transmission line 65. Accordingly, the microwave energy within the transmission line 65 is radiated into the cooking cavity of the range 70 to provide the power for cooking materials disposed therein. It further will be understood that in a preferred embodiment of the range 70, the power supply 50 and the oscillator 200 together with the transmission line 65 are all preferably disposed within a common housing that also includes the casing 71, the common housing being preferably formed of metal, such as steel, and grounded for safety purposes.

Further details of the construction of the oscillator 200 and the crossed-field discharge device 100 forming a part thereof will now be described with particular reference to FIGS. 2 and 3 of the drawings. The device 100 comprises an anode structure 101 including a sleeve 102 and a pair of anode members 110 and 130, a cathode structure 150, a pair of opposed pole pieces 170, an upper end structure 180 and a lower end structure 190.

The anode structure 101 is essentially annular in shape and is confined within the interior of the sleeve 102 (see FIGS. 2 and 3), the sleeve 102 being generally tubular and having a circular cross section at all points therealong, the outer surface 103 thereof being cylindrical. The inner surface 104 of the sleeve 102 is also cylindrical in shape and has at each end thereof a recess to define an upper end wall 105 and a lower end wall 106, the end walls 105 and 106 being essentially annular in shape and disposed parallel to each other and normal to the axis of the device 100. Mounted on the sleeve 102 at essentially the midpoint thereof and extending outwardly therefrom is an exhaust tubulation 107 hermetically sealed thereto and communicating with the interior thereof, the exhaust tubulation 107 being useful to evacuate the device 100, the interior of the device 100 being evacuated to a high degree and hermetically sealed, as will be explained more fully hereinafter. Also mounted on the outer surface 103 of the sleeve 102 is a stacked array of cooling fins 108, each of the cooling fins 108 being provided with an annular flange 109 that extends around the sleeve 102 and is fixedly secured thereto as by brazing. It will be understood that the sleeve 102 and the fins 108 are formed of a metal having good thermal conductivity, the preferred material made copper, thereby to accommodate conduction of heat from the device 100 outwardly therefrom and into the fins 108. The shape of the fins 108 is substantially rectangular so that they fit within the casing 205, there preferably being provided means for passing a cooling fluid, such as a stream of air, through the casing 205 and over the fins 108 to effect cooling thereof and a consequent removal of heat from the device 100 during the operation thereof.

Disposed within the sleeve 102 and also forming a part of the anode structure 101 are the two anode members 110 and 130. The anode member 110 is generally annular in shape and includes a body portion 111 disposed at one end thereof (the upper end as viewed in FIG. 2), the body portion 111 having an outer end wall 112 at one end thereof connecting with an annular outer wall 113 having an outer diameter only slightly less than the inner diameter of the sleeve 102, and specifically the inner surface 104 thereof, whereby the anode member 110 can fit within the sleeve 102 and ultimately is connected thereto as by brazing. The end of the body portion 111 opposite the end wall 112 is cut away or recessed to provide an annular inner wall 114 extending therearound and concentric with the annular outer wall 113 but having a substantially smaller diameter, the walls 113 and 114 being joined by an annular end wall 115 disposed parallel to the outer end wall 112 and normal to the walls 113 and 114; the other end of the inner wall 114 connects with an inner end wall 116 that defines the other end of the body portion 111, the end wall 116 being disposed in a plane parallel to the end walls 112 and 115 and normal to the walls 113 and 114.

There is provided interiorly of the anode member 110 and extending the length of the body portion 111 a plurality of axially extending anode segments 117 that project radially inwardly into the axially extending space within the anode member 110 and providing therebetween a corresponding plurality of axially extending anode recesses 122, 15 of the anode segments 117 and 15 of the corresponding recesses 122 being provided in the anode member 110 as illustrated. Each of the anode segments 117 has an axially extending inner surface 118 and a pair of outwardly directed sidewalls 119 on the opposite sides thereof, the circumferential extent of the inner surface 118 being substantially less than the radial extent of the associated sidewalls 119. The outer ends of adjacent pairs of the sidewalls 119 are joined by an outer wall 121, whereby the recesses 122 are defined by the associated sidewalls 119 and the associated outer wall 121, the sidewalls 119 of each recess 122 converging inwardly and being disposed substantially normal to the associated outer wall 121.

The anode member 110 further has thereon and integral therewith 15 rods or vanes 125, each of the rods 125 being integral with and extending longitudinally from one of the anode segments 117. More specifically, the inner surface 118 of each of the anode segments 117 extends forwardly beyond the inner end wall 116 and substantially parallel to the axis of the anode member 110 and forms the inner surface of the associated rod 125. A portion of the sidewalls 119 on the anode segment 117 also extends forwardly beyond the inner end wall 116 to provide the radially extending sides of the associated rod 125, the inner surface 118 and the sidewalls 119 terminating at an end 126 disposed substantially normal to the axis of the anode member 110. An outer surface 127 is provided for each of the rods 125, the outer surface 127 extending from the inner end wall 116 inwardly to the rod end 126; more specifically, the inner end of the outer surface 127 joins the inner end wall 11C at a point spaced radially inwardly away from the adjacent outer walls 121 and tapers inwardly toward the associated inner surface from the end wall 116 to the rod end 126.

The anode member 130 is generally annular in shape and includes a body portion 131 disposed at one end thereof (the lower end as viewed in FIG. 2), the body portion 131 having an outer end wall 132 at one end thereof connecting with an annular outer wall 133 having an outer diameter only slightly less than the inner diameter of the sleeve 102, and specifically the inner surface 104 thereof, whereby the anode member 130 can fit within the sleeve 102 and ultimately is connected thereto as by brazing. The end of the body portion 131 opposite the end wall 132 is cut away or recessed to provide an annular inner wall 134 extending therearound and concentric with the annular outer wall 133 but having a substantially smaller diameter, the walls 133 and 134 being joined by an annular end wall 135 disposed parallel to the outer end wall 132 and normal to the walls 133 and 134; the other end of the inner wall 134 connects with an inner end wall 136 that defines the other end of the body portion 131, the end wall 136 being disposed in a plane parallel to the end walls 132 and 135 and normal to the walls 133 and 134.

There is provided interiorly of the anode member 130 and extending the length of the body portion 131 a plurality of axially extending anode segments 137 that project radially inwardly into the axially extending space within the anode member 130 and providing therebetween a corresponding plurality of axially extending anode recesses (not shown), fifteen of the anode segments 137 and 15 of the corresponding recesses being provided in the anode member 130. Each of the anode segments 137 has an axially extending inner surface 138 and a pair of outwardly directed sidewalls 139 on the opposite sides thereof, the circumferential extent of the inner surface 138 being substantially less than the radial extent of the associated sidewalls 139. The outer ends of the sidewalls 139 are joined by an outer wall 141, whereby the recesses are defined by the associated sidewalls 139 and the associated outer wall 141, the sidewalls 139 of each recess converging inwardly and being disposed substantially normal to the associated outer wall 141.

The anode member 130 further has thereon and integral therewith 15 rods or vanes 145, each of the rods 145 being integral with and extending longitudinally from one of the anode segments 137. More specifically, the inner surface 138 of each of the anode segments 137 extends forwardly beyond the inner end wall 136 and substantially parallel to the axis of the anode member 130 and forms the inner surface of the associated rod 145. A portion of the sidewalls 139 on the anode segment 137 also extends forwardly beyond the inner end wall 136 to provide the radially extending sides of the associated rod 145, the inner surface 138 and the sidewalls 139 terminating at an end 146 disposed substantially normal to the axis of the anode member 130. An outer surface 147 is provided for each of the rods 145, the outer surface 147 extending from the inner end wall 136 inwardly to the rod end 146; more specifically, the inner end of the outer surface 147 joins the inner end wall 136 at a point spaced radially inwardly away from the adjacent outer wall 141 and tapers inwardly toward the associated inner surface from the end wall 136 to the rod end 146.

The anode members 110 and 130 are also formed of a metal having good thermal conductivity, the preferred material being copper. The sleeve 102 and the anode members 110 and 130 also must have good electrical conductivity, the copper providing the necessary good electrical conductivity as well as the good thermal conductivity. The geometry of the anode members 110 and 130 is such that the exterior surfaces 112,

113, 114, 115, 116, 126 and 127 on the anode member 110 and the surfaces 132, 133, 134, 135, 136, 146 and 147 on the anode member 130 can all be formed by machining a block of copper; and all of the interior surfaces of the anode members 110 and 130 including the surfaces 118, 119, 121, 138, 139 and 141 can all be formed by broaching, whereby the anode member 110 and 130 can be formed integral from blocks of copper, thus to provide greater accuracy of the parts than is possible by joining such as by brazing, individual segments of the anode members 110 and 130. As illustrated in FIG. 2, the anode member 110 is disposed in the upper portion of the sleeve 102 with the body portion 111 thereof disposed upwardly and with the rods 125 thereof extending downwardly; the anode member 130 is disposed in the lower portion of the sleeve 102 with the body portion 131 thereof disposed downwardly and with the rods 145 thereof extending upwardly. The anode members 110 and 130 are rotated slightly with respect to each other so that the anode rods 125 on the anode member 130 are disposed in the centers of the recesses of the anode member 130, and conversely the anode rods 145 on the anode member 130 are disposed in the centers of the recesses 122 of the anode member 110. In this arrangement, there is one of the anode rods 125 disposed in each of the anode recesses 142 and equidistantly spaced from the adjacent anode segments 137, and likewise there is one of the anode rods 145 disposed in each of the anode recesses 122 and equidistantly spaced from the adjacent anode segments 117, all as is diagrammatically illustrated in FIG. 3.

The sleeve 102 and the anode members 110 and 130 also cooperate to provide an outer axially extending space 120, the space 120 being annular in shape and bounded on the outer portion by the inner wall 104 of the sleeve 102 and on the inner portion by the inner walls 114 and 134 and at the upper and lower ends by the end walls 115 and 135. The interior of the anode members 110 and 130 form a second or inner axially extending space within which is disposed the cathode structure 150, the space between the outer surface of the cathode structure 150 and the facing surfaces 118 and 138 defining an annular axially extending interaction space 160. Furthermore, the inner end walls 116 and 136 are spaced-apart to provide therebetween a radially extending annular passage 140 interconnecting the outer space 120 at the midportion thereof to the inner axially extending space at the midportion thereof and to the interaction space 160 at the midportion thereof.

The forgoing structure is described in greater detail in the copending application of James E. Staats, Ser. No. 559,267, filed June 21, 1966 and the relevant description contained in that application is incorporated herein by reference.

The cathode structure 150 is provided in the axially extending space defined by the anode members 110 and 130, the cathode structure 150 including a metal wall 151 having a generally concave surface of revolution (see FIGS. 2 and 3) arranged with the axis thereof disposed at the axis of the device 100. The generatrix of the concave surface of revolution comprises a smooth curve and, more particularly, an arc of a circle. The wall 151 is formed of a heat resistant and electrically conducting metal, the preferred material of construction being nickel. Mounted on each end of the wall 151 is a cathode end 152, the cathode ends 152 being substantially identical in construction, whereby the same reference numerals have been applied to like parts of both. Referring to the upper cathode end 152, it includes a substantially flat annular center plate 153 carrying on the outer edge thereof an axially directed annular inner flange 154 carrying on the inner end thereof an outwardly directed flat flange 155; the outer periphery of the flange 155 carries a mounting flange 156 thereon extending outwardly and disposed within the adjacent end of the wall 151 and suitably secured thereto as by welding. The outer edge of the flange 156 carries a radially and outwardly extending shield flange 157 that extends radially outwardly beyond the wall 151 and overlies the adjacent end of the interaction space 160. Each center plate 153 has a central opening 158 therein, the lower cathode end 152 carrying on the inner edge and surrounding the opening 158 therein a center end flange 159. The cathode ends 152 are also preferably formed of nickel. The upper cathode end 152 is mechanically and electrically connected to an inner conductor cathode stud 167, the cathode stud 167 being generally circular in cross section and having at the lower end thereof a reduced diameter portion 168 that extends through the opening 158 in the cathode end 152 and is fixedly secured thereto as by a pair of outwardly directed flanges 169. It will be appreciated that the upper end of the cathode structure 150 is both electrically and mechanically connected to the stud 167.

The cathode wall 151 is provided with a sintered porous coating 161 impregnated with a suitable electron emissive oxide material, whereby upon heating of the cathode structure 150, the coating 161 readily emits electrons from the outer surface thereof. Referring particularly to FIG. 3, it will be seen that the coating 161 is shaped to provide a plurality of outwardly extending projections 162 each having outwardly converging sidewalls joining a generally circumferentially arranged outer surface 163, a space 164 being provided between the adjacent projections 162. As illustrated, the circumferential extent of the outer surface 163 is substantially equal to the space 164 between the adjacent projections 162. The preferred range of the circumferential extent of each of the outer surfaces 163 is approximately 25 percent to approximately 60 percent of the circumferential distance between the centers of adjacent outer surfaces 163. The number of projections 162 provided on the coating 161 is equal to the sum of the number of the anode segments 117 and the number of cooperating rods 145, for example, and is likewise equal to the sum of the number of the anode segments 137 and the number of the cooperating rods 125, whereby there are 30 of the projections 162 provided upon the coating 161. The outer surfaces of the coating 161 together with the inner surfaces 118 and 138 on the anode members 110 and 130, respectively, define the interaction space 160 disposed therebetween in which the emitted electrons from the coating 161 interact with the electrical fields and the magnetic fields disposed between the anode structure 101 and the cathode structure 150. As will be described more fully hereinafter, the projections 162 combine with the anode segments 117 and 137 and with the rods 125 and 145 to provide a preferred distribution of the several fields within the interaction space 160 of the device 100 that results in more desirable operating characteristics thereof. One particularly desirable result of the shape of the coating 161 is the minimized back heating of the cathode structure 150, the desirable emitted electrons emanating from the projections 162, and the undesirable emitted electrons emanating from the space 164 between the projections 162, thereby to facilitate the emission of desirable electrons and to suppress the emission of undesirable electrons.

It further will be noted from FIG. 3 that the center line of each projection 162 is circumferentially displaced relative to the center line of its corresponding anode segment 117 and 137 or its corresponding rods 125 and 145, as the case may be; more specifically, the center line of the projections 162 are displaced in a clockwise direction a circumferential distance equal to approximately 40 percent of the circumferential spacing between the center lines of an adjacent anode segment 117 and an adjacent rod 145 (for example 5° rotation for a 12° spacing or a percentage of 41.8 percent as illustrated). The circumferential displacement of the projections 162 with respect to the corresponding anode segments or rods is preferably in the range between 0 percent and approximately 45 percent of the circumferential spacing between adjacent anode segments and rods, the preferred range being between approximately 25 percent and 45 percent of the spacing between adjacent anode segments and rods, a still more preferred range being between approximately 35 percent and 45 percent of the spacing between adjacent anode segments and rods. Furthermore, the displacement is on the downstream side, i.e., in the direction of normal initial electron flow from the projections 162. It also will be noted that the electron emissive coating 161 is confined between the outer end walls 112 and 132 of the anode members 110 and 130, respectively, the cathode structure 150 being carefully centered with respect to the anode members 110 and 130, whereby each of the cathode projections 162 extends axially of the device 100 parallel to the axis thereof and confined between the outer end walls 112 and 132.

The radial dimension of each of the projections 162 is substantially the same from end to end of the cathode structure. Preferably, the radial dimensions of each of the projections 162 is greater than about 20 percent of the spacing between the anode surfaces 118 and 138 and the coating 161 on the cathode structure 150. Reiterating, the same radial dimension is provided adjacent to the outer ends 165*a* and 165*e* as at portion 166, at the approximately longitudinal midpoint of the emissive coating 161 and opposite the annular passage 140 between the anode members 110 and 130.

As illustrated in FIG. 2, the coating 161 in the area of the spaces 164 has a constant thickness or depth as measured radially from the wall 151 from the end 165*a* to the end 165*e* of the cathode structure. The projections 162 are also of constant thickness or depth as measured radially from the wall 151 from the end 165*a* to the end 165*e* of the cathode structure.

As previously stated, the metal wall 151 has a generally concave surface of revolution, with the generatrix of the concave surface of revolution comprising an arc of a circle. The spaces 163 are tangent to a second surface of revolution disposed radially outwardly with respect to the surface of revolution of the metal wall 151. The outer surfaces 163 of the outwardly extending projections 162 are tangent to a third surface of revolution disposed radially outwardly from the two abovementioned surfaces of revolution. The generatrix of each of the three concave surfaces of revolution comprises a smooth curve and more specifically, an arc of a circle. The circular arc for the outer surface on which lie the surfaces 163 is illustrated in vertical section in FIG. 2 by the longitudinal shape of the projection 162 which includes 165*b*, 166 and 165*d* from the upper outer end 165*a* to the lower outer end 165*e* of the cathode structure 150. The radius of the circles forming the generatrix of the three concave surfaces of revolution are all equal.

The circularly concave cathode surfaces 163 are closest to the anode surface at the end 165*a* disposed toward the RF load. The spacing between the surfaces is greatest at portion 166 opposite the radially extending passage 140. At the end 165*e* the spacing between the surfaces is greater than at the end 165*a*, and at portions 165*b* and 165*d* the spacing is greater than that at 165*e* and less than that at 166.

The impedance at the load is reflected back from the load along the transmission line 65 to provide a reflected load impedance at each point along the transmission line. Maximum power is transferred to the load is there is an impedance match between the actual impedance at each point and the reflected load impedance at that point. In the interaction space 160 the actual impedance at each point is determined by the geometry of the interaction space at that point. Therefore, the actual impedance is dependent upon the spacing between the anode surface and the cathode surface. This invention particularly relates to the matching of the reflected load impedance to the actual impedance at each point in the interaction space.

It has been found that the load impedance transferred to the interaction space 160 varies axially therealong, the reflected load impedance being low adjacent to the outer ends of the interaction space 160 and increasing to a maximum at the longitudinal midpoint thereof. In previous crossfield devices having flat anode and cathode surfaces for a given combination of operating voltage, magnetic field and current through the device 100, there is a single value of RF output voltage and load impedance which produces a maximum efficiency of operation, whereby if the load impedance varies axially of the device 100, there is only one point axially of the interaction space 160 which produces the maximum operating efficiency. In accordance with the present invention, the entire cathode structure has a continuously varying diameter which is arranged such that the anode to cathode spacing varies in a manner so that the RF impedance of each portion of the interaction sp. ~~ 160 matches the RF load impedance at each portion of the interaction space.

In the interaction space described in the aforementioned copending application Ser. No. 559,267, a multiple impedance interaction space was developed by using a plurality of interaction space sections of different dimensions. Thus, each section contained one point that provided an impedance match with the RF load impedance.

Since the reflected wave at the uncoupled end is greater in strength than the reflected wave at the output end, a lower RF impedance at the output end 165*a* of the interaction space is required for an impedance match. This invention specifically provides a cathode having end diameters larger than the center diameter and with the end 165*a* coupled to the RF load being slightly larger in diameter than the uncoupled end 165*e*. With the above cathode configuration the RF impedance of the interaction space increases from a minimum value at the end 165*a* to a maximum value in the portion 166 and then decreases to a value slightly more than the minimum at the end 165*e*. Thus, the electronic impedance of the interaction space 160 is matched to the reflected impedance of the RF load coupled to the output of the device 100 in a manner that improves the efficiency and load range of the device 100.

The crossed-field device of this invention having a cathode with a circular surface of revolution provides a resultant increase in efficiency whereby for the same input power the power output is increased by 10 percent over a device having stepped interaction sections. As a comparison in efficiencies, the efficiency of the device 100 with a cathode of constant cross section from end to end thereof may be, for example 40 percent; by incorporating a stepped cathode in the device 100, the efficiency of operation can be improved to 40 percent and up to 50 percent under optimum conditions; by incorporating the cathode 150 of the present invention having smooth circularly curved protrusions with the ends disposed toward the RF load being closer to the anode than the other ends, the efficiency of operation can be improved by another 5 percent under optimum conditions.

As illustrated, the cathode structure is of the indirectly heated type, and accordingly, there has been provided within the cathode wall 151 a heater 176 in the form of a coiled filament extending substantially the entire length of the cathode wall 151 and spaced inwardly a short distance from the inner surface thereof. The upper end of the heater 176, as viewed in FIG. 2, has an outer end or terminal 177 that extends outwardly into an opening in the lower end of the cathode stud 167, and specifically through an annular opening in the reduced portion 168 thereof and is mechanically and electrically connected to the cathode stud 167 whereby the cathode structure 150 and the heater 176 are both mechanically and electrically connected to the cathode stud 167. The lower end of the heater 176 has an outer end or terminal 178 that extends into an opening in the upper end of a conductor 197 and is mechanically and electrically secured thereto. The conductor 197 is preferably formed of nickel and extends outwardly and into a threaded connector 196. It will be noted that the heater terminal 178 is spaced from and electrically insulated with respect to the lower end of the cathode structure 150.

Mounted within the outer ends of the anode sleeve 102 and forming end walls for the device 100 are the pole pieces 170, the pole pieces 170 being identical in construction, whereby the same reference numerals have been applied to like parts of both of the pole pieces 170. The pole pieces 170 are formed of a material having high magnetic permeability, the preferred material being a low carbon steel, and are copper plated to render the outer surfaces thereof highly conductive to RF energy. As illustrated, each of the pole pieces 170 is generally cylindrical in shape including a first substantially flat inner plate 171 disposed centrally thereof and disposed in a plane substantially normal to the longitudinal axis of the device 100 and in longitudinal alignment with the interaction space 160. Disposed about the periphery of the inner plate 171 and integral therewith is an annular and outwardly extending mounting flange 174. Inner plate 171 carries on the outer edge thereof an outwardly directed outer plate 173 that is substantially flat and lying in a plane normal to the axis of the device 100. The outer edge of the outer plate 173 carries an annular and outwardly extending mounting flange 174 that has an outer diameter slightly less than the inner diameter of the associated recessed end of the anode sleeve 102 to be received therein and hermetically sealed thereto. Finally, there is provided centrally of each of the inner plates 171 a circular opening 175 in general longitudinal alignment with the adjacent end of the cathode structure 150, and specifically the adjacent end of the cathode wall 151, the opening 175 receiving the terminals of the cathode structure and heater therethrough. Preferably the pole pieces 170 are each formed of a single sheet of low carbon steel shaped as described by a stamping operation, thereby to provide accurate dimensions therefor together with an inexpensive manufacture thereof.

An upper end structure 180 is provided at the upper end of the device 100 as viewed in FIG. 2 and a lower end structure 190 is provided at the lower end of the device 100, the end structures 180 and 190 serving to provide a hermetic seal between the associated pole pieces 170 and the associated connections to the cathode structure 150 and/or the heater 176, as the case may be. The upper end structure 180 includes a short tube 181 having the lower end thereof disposed within the opening 175 in the upper pole pieces 170 and suitably hermetically secured thereto as by brazing and extending upwardly therefrom substantially concentric with the longitudinal axis of the device 100 and the axis of the cathode stud 167. The upper end of the tube 181 receives therein the lower end of an annular insulator 182 which is formed, for example, of a good electrically insulating ceramic, the tube 181 being hermetically sealed to the insulator 182. There is provided about the cathode stud 167 at the portion thereof adjacent to the reduced portion 168 a ring 183 that fits within a recess in the lower end of the insulator 182. Surrounding the upper end of the insulator 182 and the adjacent portion of the cathode stud 167 is a cap 185, the cap 185 being generally annular in shape and including an annular flange 186 surrounding an outer periphery of the upper end of the insulator 182 and being hermetically sealed thereto. Integral with the upper edge of the outer flange 186 is an inwardly directed flange 187 carrying on the inner edge thereof an outwardly directed annular inner flange 188 surrounding the adjacent portion of the stud 167 and hermetically sealed thereto as by brazing. It is pointed out that the sleeve 181 and the cap 185 are both formed of a material that can be readily secured both to a metal surface and to a ceramic surface, the preferred material being "Fernico" alloy, a typical composition being 54 percent iron, 28 percent nickel and 18 percent cobalt. It will be seen that the upper end structure 180 forms a good hermetic seal that also provides electrical insulation between the upper pole piece 170 and the output conductor in the form of the cathode stud 167, the end structure 180 likewise providing the necessary mechanical support of the cathode structure 150 to position it within the anode structure 101.

In the lower end structure 190, a ceramic insulator 191 is provided that is annular in shape and has an outer diameter just slightly less than the diameter of the opening 175 in the lower pole piece 170 and an inner diameter just slightly greater than the external diameter of the centering flange 159 on the lower cathode end 152, whereby the insulator 191 serves to center the lower end of the cathode structure 150 with respect to the lower pole piece 170. The insulator 191 extends outwardly well beyond the lower pole piece 170 and there is provided a seal member 192 annular in shape and surrounding the insulator 191, the seal member 192 including a mounting flange 193 fixedly secured as by brazing to the outer surface of the inner plate 171 on the lower pole piece 170, the mounting flange 193 having integral therewith an annular wall 194 carrying an outer flange 195 that is inwardly directed and surrounds and is secured to the outer wall of the insulator 191. The seal member 192 is made of the same material as the sleeve 181 and the cap 185 and is hermetically sealed both to the lower pole piece 170 and the insulator 191. The outer end of the insulator 191 carries thereon a second seal member 198 that overlies the outer end thereof and is suitable secured as by brazing to the connector 196, the seal member 198 including an annular flange 199 surrounding the outer end of the insulator 191 and sealed thereto. The seal member 198 is formed of the same material as the seal member 192 and is hermetically sealed both to the insulator 191 and the connector 196. The lower end structure 190 therefore serves hermetically to seal the lower end of the device 100 and also provides electrical insulation between the lower end of the cathode structure 150 and the associated pole piece 170 and the heater 176, all while providing for the mechanical support of the lower end of the cathode structure 150 and the lower end of the heater 176.

When the device 100 is incorporated as a crossed-field discharge device in a microwave circuit, the pole pieces 170 arranged adjacent to the opposite ends of the anode structure 101 are utilized for establishing a unidirectional magnetic field extending axially through the several spaces within the anode structure 101, and specifically through the axially extending space 120 and through the interaction space 160, as well as the annular passage 140 and the various spaces between the anode members 110 and 130. To this end a pair of magnet coils (not shown) has been provided, one magnet coil being disposed about the upper end of the device and the other magnet coil being disposed about the lower end of the device 100. The magnet coils are both shaped as a torous, and wound of electrically conductive wire, and are disposed respectively about magnet yokes 211 and 216, respectively, that are each in the form of a cylinder disposed within the opening in the associated magnet coil. It will be understood that the pole pieces 170 and the magnet yokes 211 and 216 are all formed of metals having a high magnetic permeability, such as soft iron and low carbon steel, whereby when the magnet coils are energized, a strong and uniform unidirectional magnetic field is established between the pole pieces 170 within the devices 100 and extending axially through the spaces within the device 100 and specifically extending axially through the outer axially extending space 120 and the interaction space 160 therein.

The circuit for energizing the coils (not shown) can be traced with reference to FIG. 1 from the power supply 51, and specifically the DC output terminal 54 thereof, through the conductor 60 to the input terminal 201 of the oscillator 200 to which is connected one terminal of the magnet coil. The flow of current through the magnet coils serves to produce the unidirectional magnetic field in the various spaces of the device 100 and specifically in the outer space 120 and the interaction space 160 thereof.

As is illustrated in FIGS. 1 and 2, the cathode stud 167 at the upper end of the crossed-field discharge device 110 has the outer end thereof disposed below the outer end of the associated magnet yoke 211. The cathode stud 167 and the conductor 207 form a coaxial transmission line that provides output RF terminals for the oscillator 200, the terminals being connected to an RF load 300 and having applied therebetween the output RF energy from the oscillator 200. In addition, the outer conductor 207 has applied thereto the B+ potential from the conductor 60 which is connected thereto via the input terminal 201, the upper magnet coil, a conductor (not shown), the lower magnet coil, a second conductor (not shown), the anode sleeve 102 and the upper pole piece 170, the upper pole piece 170 being directly connected to the lower end of the outer conductor 207 as illustrated. Accordingly, the outer conductor 207 not only serves as one of the RF terminals for the device 100 but also is in direct electrical connection with the B+ potential on the anode sleeve 102. Likewise, the cathode stud 167 not only has the RF output energy thereon but has applied thereto both the B− potential for the cathode 150 of the device 100 and the low voltage AC potential for energizing the heater 176.

In the operation B+ is applied to the outer sleeve 102 and the terminal 202 serves as the B− input terminal and is connected to the cathode 150. The terminal 202 also serves as an input terminal for the low voltage AC filament supply and is connected to one end of the heater 176 via the cathode stud 167, whereby to apply low voltage AC potential to the upper end of the heater 176.

The connector 196 at the lower end of the device 110 (see FIG. 2) is connected to a filter capacitor of the feed through type, and more specifically is connected to the output terminal 203 that has the adjacent end thereof internally threaded and receives the threaded outer end of the terminal 196 therein. A tubular conductor 221 is provided formed of a metal that is electrically conductive, the conductor 221 having the upper end thereof received within the lower pole piece coupling flange 172 in telescoping relation therewith and being electrically connected thereto, the conductor 221 being disposed within the lower magnet yoke 216 and extending downwardly and beyond the lower end thereof. There is provided on the lower end of the conductor 221 and electrical connection to a filter capacitor (not shown) which serves to bypass RF energy, thereby to prevent the introduction of RF energy into the power supply 51 via the conductor 62.

During the operation of the crossed-field discharge device 100 in the oscillator 200, the anode sleeve 102 and the anode members 110 and 130 cooperate to provide a folded coaxial transmission line within the device 100, the coaxial transmission line thus formed accommodating axially extending RF waves therein and providing a frequency determining folded resonant cavity for the device 100 and for the oscillator 200. The coaxial transmission line more specifically includes an outer coaxial transmission line defined by the inner annular surface 104 on the sleeve 102 disposed between the annular end walls 115 and 135 on the anode members 110 and 130, respectively, and the annular inner walls 114 and 134 on the anode members 110 and 130, respectively, the portion of the outer surface 104 provides an outer conductor and the inner walls 114 and 134 provide inner conductors for the outer coaxial transmission line being coterminous with the axially extending space 120 and being shorted at the upper end by the wall 115 and at the lower end by the wall 135. The anode segments 117 on the first anode member 110 and the rods 145 on the second anode member 130 cooperate to provide a first portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, the upper end of this inner coaxial transmission line being open and the lower end connecting through the passage 140 with the midpoint of the outer transmission line 120. In a like manner, the anode segments 137 on the second anode member 130 and the rods 125 on the first anode member 110 cooperate to provide a second portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, the lower end of the second portion of the inner coaxial transmission line being open and the upper end being connected by the passage 140 to the midpoint of the outer coaxial transmission line 120.

In the operation of the device 100, the upper portion of the outer transmission line 120, i.e., the portion between the end wall 115 and the passage 140 cooperates with the first or upper section of the inner transmission line to provide a resonant cavity which can be excited to cause oscillations therein at a frequency equal substantially to four times the length thereof, i.e., four times the distance from the end wall 115 down and through the passage 140 and upwardly along the rods 145 to the upper ends thereof, whereby to provide an axially extending wave therein which is reflected by the end wall 115 at one end and by the open end of the transmission line at the other end to produce a standing RF wave. The lower portion of the outer transmission line 120, i.e., the portion between the end wall 135 and the passage 140 cooperates with the second or lower section of the inner transmission line to provide a resonant cavity which can be excited to cause oscillations therein at a frequency equal substantially to four times the length thereof, i.e., four times the distance from the end wall 135 up and through the passage 140 and down and along the rods 125 to the lower ends thereof, whereby to provide an axially extending wave therein which is reflected by the end wall 135 at one end and by the open end of the transmission line at the other end to produce a standing RF wave. The two transmission lines thus described actually cooperate in the operation of the device 100, and more specifically, when an axial RF wave is excited on the inner transmission line, this RF wave is transmitted to the outer transmission line 120 through the passage 140 and becomes reflected by the end walls 115 and 135. The reflected wave travels down toward the passage 140 and therethrough and then flows oppositely toward each end of the inner transmission line. When the RF wave reaches the open circuited ends of the inner transmission line, reflections again occur and a standing wave is established providing RF electric fields and RF magnetic fields extending into the interaction space 160. It will be seen therefore that the device 100 includes a folded resonant cavity equivalent to a one-half wave resonator disposed in generally a one-fourth wave space, whereby to provide a device having small physical dimensions relative to the wavelength of the microwave energy to be generated thereby.

In the operation of the oscillator 200, it is necessary to produce within the crossed-field discharge device 100 a predetermined pattern of electrical fields and magnetic fields. A description of the electrical fields and magnetic fields within the device 100 during the operation thereof as an oscillator and the method of creating those fields will be given. The operating potentials for the device 100 are derived from the power supply 51 described above. The DC potential from the power supply 51 is derived specifically from the output terminals 54 and 55, and applied to the outer anode sleeve 102 to supply B+ potential thereto, and the output terminal 55 of the power supply 51 is connected to the cathode 150 to supply B– potential thereto.

The application of the above-described B+ and B– potentials to the outer anode sleeve 102 and the cathode 150, respectively, establishes a unidirectional electrical field 250 that extends between the anode segments 117 and the cathode projections 162 and between the rods 145 and the cathode projections 162; it will be noted that each of the projections 162 provides a unidirectional electrical field in cooperation with both an adjacent anode segment 117 and an adjacent rod 145. The electrical field extends substantially normal to the longitudinal axis of the anode members 110 and 130, the field lines entering the surfaces 118 normal thereto the field lines entering the surfaces 138 of the rods 145 normal thereto and the field lines entering the cathode surfaces 163 normal thereto. It will be understood that a like shaped DC electrical field is provided between the cathode 150 and the anode segments 137 and the rods 125 in the lower portion of the device 100.

In order to provide the necessary unidirectional magnetic field normal to or "crossed" with respect to the electrical field 250, a DC current is established in the magnet coils. More particularly, electrons flow from the anode structure 101 to the power supply output terminal 54. When such a flow of electrons is established through the magnet coils, a strong unidirectional magnetic flux is established through the space 120 and the interaction space 160. Due to the provision of the pole pieces 170, and the other portions of the magnetic path having a high magnetic permeability, there is a uniform distribution of the unidirectional magnetic flux lines throughout the space 120 and throughout the recesses 122 about the rods 145 and inwardly to the outer surface of the electron emissive coating 161. It further is pointed out that the unidirectional magnetic flux lines are disposed normal to the unidirectional electrical field whereby the unidirectional electrical field and the unidirectional magnetic field provide the necessary "crossed" fields for the operation of the crossed-field discharge device 100. It will be understood that a like unidirectional magnetic field is disposed between the sleeve 102 and the anode member 130 and the rods 125 and the cathode 150 in the lower end of the device 100.

As has been pointed out above, the axially extending space 120 and the passage 140 and the rods and anode segments cooperate to provide a folded coaxial transmission line, the outer and inner sections of which extend axially with respect to the device 100, the outer section being shorted or terminated at the upper and lower ends thereof by the end walls 115 and 135. The shorted folded transmission line thus provided forms a tuned cavity for the oscillator 200, the tuned cavity being readily excited at a frequency having a wavelength corresponding to four times the distance between the inner surface of the end wall 115 and down and around through the passage 140 and up to the upper ends of the rods 145. When the tuned resonant cavity thus formed is excited by the establishment of the unidirectional electrical field and the unidirectional magnetic field 260, the tuned cavity resonates at a frequency having the wavelength mention, i.e., a standing RF wave is established within the turned cavity and extends axially thereof and axially of the device 100 and through the outer space 120 and the interaction space 160 thereof. The wavelength of the RF wave thus generated is actually substantially greater than four times the distance between the inner end wall 115 and down through the passage 140 and up to the upper ends of the rods 145 because of the high capacitance between the anode members and the rods, which high capacitance is in the tuned circuit and serves to permit the generation of RF waves in the device 100 having wavelengths substantially greater than four times the distance mentioned.

There is believed to be associated with the standing RF wave thus established an RF electrical field disposed normal to the axis of the device 100. At any moment the anode segments 117 have one RF polarity while the rods 145 have the opposite RF polarity, whereby there is a relatively strong RF electrical field between the anode member 110 and the rods 145 as well as weak RF electrical fields between the anode member 110 and the cathode 150 and between the rods 145 and the cathode 150. The anode sleeve 102 also has an RF polarity opposite to that of the anode member 110, whereby there is an RF electrical field therebetween.

After the application of the operating potentials to the device 100, and after the cathode 150 has been heated to the operating temperature thereof by the heater 176, electrons are emitted from the emissive coating 161, the electrons being emitted into the interaction space 160 where they are subjected to the action of the unidirectional fields and the RF fields described hereinabove.

Eventually, the paths of the electrons carry them into contact with the anode member 110 or the rods 145, whereby to complete an electrical circuit through the device 100. During the time that the electrons are in movement, they impart a portion of the energy content thereof to the RF standing wave within the device 100 to add power thereto and to reinforce the RF standing wave.

Referring to the previously cited copending application, Ser. No. 559,267, for a more complete description, an RF electrical field is established between the anode members 110 and 130 and the rods 145 and 125, respectively. This RF electrical field extends into the interaction space 160 and bunches electrons that rotate around the cathode 150 in the presence of the DC electrical field and the DC magnetic field established by the application of a negative potential to the cathode 150 and a positive potential to the anode structure 101. These electrons tend to rotate in synchronization with a slow wave component of the axial fast wave and to extract energy from the DC fields while giving up energy to the RF fields. In this manner the RF standing wave within the device 100 is maintained and the energy content thereof increased and replenished during the operation of the oscillator 200.

The cathode **150** is coupled to the RF standing wave within the interaction space **160** and therefore serves as a probe for the removal of a portion of the RF energy from the tuned cavity for the supplying thereof to the output transmission line **65**.

The RF wave within the oscillator **200** extends axially with respect to the device **100**, there being no radial RF waves within the device **100**, i.e., no RF waves extending normal to the axis of the device **100**. Furthermore, the radial distance between the outer surface of the cathode **150** and the outer walls **121** and **141** of the anode recesses is less than that required to accommodate a radial standing wave at the operating frequency of the oscillator **200**. Likewise the distance between the facing coaxial surfaces of the sleeve **102** and of the anode members **110** and **130** defining the outer transmission line is less than that required to accommodate a radial standing wave at the operating frequency of the device **100** as defined above.

Referring now to FIG. **4**, a fragmentary view of a vertical section through the crossed-field device is illustrated with certain details eliminated or diagrammatically shown for the purpose of clarity. The flat anode surface is spaced from the circularly concave cathode surface providing an interaction space **160** between the two surfaces. The upper end **165*a*** of the cathode structure **150** is disposed toward the RF load and has a diameter slightly larger than the diameter of the lower end **165*e***. Upper and lower pole pieces **170** are located adjacent the anode outside the interaction space **160**.

Three sets of magnetic flux lines are shown. Those illustrated as **260*a*** are due to the limited finite diameter of pole piece **170**. These lines bow outwardly and exhibit the phenomenon commonly known as the "fringing effect"; this effect is more pronounced at the edges than toward the center of the interaction space. The second group of magnetic flux lines is shown as **260*b***. These lines are inwardly curved and depict the representative path of the flux due to fringing effected by the presence of opening **175** in pole piece **170**. In effect, the flux lines **260*b***, which are drawn toward the surface of the cathode structure, compensate for the outwardly bowed fringing magnetic flux lines **260*a***. The resultant magnetic flux lines which actually exist in the interaction space are illustrated by the numeral **260**. These lines are straight and are mathematically computed by the vector addition of lines **260*a*** and **260*b***.

The equation for the electronic impedance in the interaction space is

$$Z=K(y/B)$$

where, Z is the electronic impedance,

K is a constant,

y is the anode to cathode spacing, and

B is the magnitude of the magnetic flux density.

The electronic impedance is affected by the variation of two parameters, y and B. Since the spacing, y, is greatest and the magnitude of the flux density is smallest opposite the center portion **166**, the electronic impedance has its largest value there. Since the spacing continuously decreases due to the circularly curved cathode surface from opposite the center portion **166** to opposite the end portions **165*a*** and **165*e***, and since the magnetic field, B, is greater in the interaction space **160** at the ends than at the center, the electronic impedance, Z, is smaller in the region opposite the ends than in the center. Furthermore, due to the presence of a space charge and amplification, the reflected wave at the uncoupled end **165*e*** is greater in strength than the reflected wave at the output end **165*a*** causing the impedance in the interaction space to be a minimum at the output end and slightly more than this minimum at the uncoupled end.

There is shown in FIG. **5** an impedance plot on a Smith chart of the interaction space **160** in the crossed-field discharge device **100**. The curve ACB depicts the magnitude and phase of the load impedance reflected back from the load to the interaction space. The load impedance reflected back from the space opposite the end **165*e*** is shown at point A; that reflected back to the space opposite the center portion **166** is shown at point C; and, that reflected back to the space opposite the end **165*a*** disposed towards the load is shown at point B. As illustrated, it can be seen that the magnitude of the reflected load impedance varies axially along the interaction space. Furthermore, since the center portion **166** of the interaction space is axially equidistant from the ends **165*a*** and **165*e***, the angle BGC is equal to the angle AGC. In order to provide a most efficient crossed-field discharge device, the RF impedance of each portion of the interaction space must be matched to the reflected load impedance.

In a crossed-field discharge device having a stepped cathode, such as that shown in the aforementioned copending application, Ser. No. 559,267, an impedance curve such as that shown by HJ KL MN PQ and RS would exist. This is the curve for a five section cathode, having five equal impedance sections. The five equal impedance sections are HJ KL MN PQ and RS. An impedance match exists at five points in the interaction space, i.e., the match occuring where the curve ACB intersects the curve HS. At each interface a discontinuity occurs, shown by the radial change on the impedance plot, thereby signifying a step change in the magnitude of the impedance at that point of the interaction space. For a cathode having a longitudinally constant cross section, a corresponding plot of the impedance within the interaction space is shown by the curve DEF.

The circularly curved surface of the cathode structure of this invention provides an impedance match throughout substantially all of the interaction space. The curve of the impedance of the interaction space **160**, shown by the curve ACB, matches the curve of the reflected load impedance, also illustrated by curve ACB. Thus, upon matching the RF impedance of each portion of the interaction space to the reflected RF load impedance, the maximum power transfer requirement is satisfied, thereby to increase the efficiency of the crossed-field discharge device.

In a constructional example of the crossed-field discharge device **100**, the various parts thereof have the following dimensions. The anode sleeve **102** has an external diameter of 1.69 inches, and an overall length of 2.625 inches. The anode members **110** and **130** at the walls **113** and **133** have an external diameter of 1.57 inches, an overall length from the outer and walls **112** and **132** to the rod ends **126** and **146** of 1.25 inch, a distance from the longitudinal axis to the surfaces **118** and **138** of 0.371 inch, a distance from the longitudinal axis to the surfaces **121** and **141** of 0.562 inch, a radial dimension of the recesses **122** and **142**, of 0.191 inch, a circumferential dimension of the recesses of 0.154 inch, a circumferential dimension of the surfaces **118** and **138** of 0.05 inch; a longitudinal dimension of the annular outer walls **113** and **133** of 0.314 inch, a longitudinal dimension of the annular inner walls **114** and **134** of 0.288 inch, and an external diameter of the inner walls **114** and **134** of 1.312 inches. The rods **125** and **145** have a length of 0.648 inch, a radial dimension at the base thereof of 0.125 inch, and a radial dimension at the outer ends thereof of 0.055 inch. The cathode structure **150** has a length of the emissive coating **161** of 1.22 inches, a radius of the surface of revolution of 18.0 inches and the longitudinal arc is included within an angle of about 40° to about 5°; and the angular displacement between the center line of a cathode projection **162** and the center line of the adjacent anode segment **117** or **137** or the adjacent rod **125** or **145** is 5°. The pole pieces **170** have an overall outer diameter at the mounting flange **174** thereof of 1.688 inches, an inner diameter at the coupling flange **172** of 1.12 inches, a longitudinal extent of the mounting flange **174** of 0.25 inch and a longitudinal extent of the coupling flange **172** of 0.25 inch. The foregoing dimensions are for a crossed-field discharge device **100** operating in the general frequency range 890 to 940 megacycles.

From the above it will be seen that there has been provided an improved crossed-field discharge device with improved load matching characteristics. More particularly, there has been provided an improved crossed-field discharge device for use at microwave frequencies which is of simple and economical construction and arrangement. The improved crossed-field discharge device utilizes a cooperation between electrode surfaces to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, whereby the RF impedance of each portion of the interaction space matches the RF impedance at each of the portions thereby to increase the efficiency of the crossed-field discharge device.

While there have been described what are at present considered to be the preferred embodiments of the invention, it will be understood that various modifications may be made therein, and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What I claim is:

1. A crossed-field discharge device comprising an anode structure defining an axially extending space bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure, an axially extending cathode structure disposed in said axially extending space and cooperating with the adjacent anode surface to define an axially extending annular interaction space, said cathode structure including an electron emissive element having surfaces disposed within said anode structure and adjacent to the associated anode surface, one of said surfaces being a generally concave surface of revolution and cooperating with the other of said surfaces to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, means for establishing an axially extending RF wave in said axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, and end structures closing the ends of said anode structure and said axially extending space, said anode structure including an anode connection extending outwardly beyond one of said end structures and said cathode structure including a cathode connection extending outwardly beyond said one end structure, said anode connection and said cathode connection cooperating to provide output connections for said device to an RF load for removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields, whereby the RF impedance of each portion of the interaction space matches the RF load impedance at each of said portions thereby to increase the efficiency of said crossed-field discharge device.

2. The crossed-field discharge device of claim 1, wherein the surface of said electron emissive element includes sections which are circumferentially spaced apart a distance corresponding generally to the circumferential dimension thereof.

3. The crossed-field discharge device of claim 1, wherein said electron emissive element includes a plurality of circumferentially spaced and longitudinally extending protrusions.

4. The crossed-field discharge device of claim 1, wherein the generatrix of said concave surface of revolution comprises an arc of a circle.

5. The crossed-field discharge device of claim 1, wherein the RF impedance increases from a first value at one end of said interaction space to a maximum value and then decreases to a second value at the other end of said interaction space.

6. A crossed-field discharge device comprising an anode structure defining an axially extending space bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure, an axially extending cathode structure disposed in said axially extending space and cooperating with the adjacent anode surface to define an axially extending annular interaction space, said cathode structure including an electron emissive element having surfaces disposed within said anode structure and adjacent to the associated anode surface, one of said surfaces being a generally concave surface of revolution and cooperating with the other of said surfaces to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, means for establishing an axially extending RF wave in said axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, and end structures closing the ends of said anode structure and said axially extending space, said anode structure including an anode connection extending outwardly beyond one of said end structures and said cathode structure including a cathode connection extending outwardly beyond said one end structure, said anode connection and said cathode connection cooperating to provide output connection for said device to an RF load for removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields, said surfaces being closest together at the end of said interaction space disposed toward the RF fields, said surfaces being closest to load, whereby the RF impedance of each portion of the interaction space matches the RF load impedance at each of said portions thereby to increase the efficiency of said crossed-field discharge device.

7. A crossed-field discharge device comprising an anode structure defining an axially extending space bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure, an axially extending cathode structure disposed in said axially extending space and cooperating with said anode structure to define an axially extending annular interaction space, said cathode structure including an electron emissive element having surfaces of revolution of a generally concave smooth curve disposed within said anode structure and adjacent to said anode surface, said surfaces cooperating to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, means for establishing an axially extending RF wave in said axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, and end structures closing the ends of said anode structure including an anode connection extending outwardly beyond one of said end structures and said cathode structure including a cathode connection extending outwardly beyond said one end structure, said anode connection and said cathode connection cooperating to provide output connections for said device to an RF load for removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields, whereby the RF impedance of each portion of the interaction space matches the RF load impedance at each of said portions thereby to increase the efficiency of said crossed-field discharge device.

8. The crossed-field discharge device of claim 7, wherein said concave curve is an arc of a circle.

9. The crossed-field discharge device of claim 8, wherein said arc has an included angle of from about 4° to about 5°.

10. The crossed-field discharge device of claim 7, wherein the RF impedance increases from a first value at one end of said interaction space to a maximum value and then decreases to a second value at the other end of said interaction space.

11. A crossed-field discharge device comprising an anode structure defining an axially extending space bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure, an axially extending cathode structure disposed in said axially extending space and cooperating with said anode structure to define an axially extending annular interaction space, said cathode structure including an electron emissive element having surfaces of revolution of a generally concave smooth curve disposed within said anode structure and adjacent to said anode surface, said surfaces cooperating to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, means for establishing an axially extending RF wave in said axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, and end structures closing the ends of said anode structure and said axially extending space, said

anode structure including an anode connection extending outwardly beyond one of said end structures and said cathode structure including a cathode connection extending outwardly beyond said one end structure, said anode connection and said cathode connection cooperating to provide output connections for said device to an RF load for removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields, said surfaces being closest together at the end of said interaction space disposed toward the RF load, whereby the RF impedance of each portion of the interaction space matches the RF load impedance at each of said portion thereby to increase the efficiency of said crossed-field discharge device.

12. A crossed-field device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, said inner axially extending space being bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure, an axially extending cathode structure disposed in said axially extending space and cooperating with the adjacent anode surface to define an axially extending annular interaction space, said cathode structure including an electron emissive element having surfaces disposed within said anode structure and adjacent to the associated surface of said anode structure, one of said surfaces being a generally concave surface of revolution and cooperating with the other of said surfaces to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, means for establishing an axially extending RF wave in said axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, and end structures closing the ends of said anode structure and said axially extending space, said anode structure including an anode connection extending outwardly beyond one of said end structures and said cathode structure including a cathode connection extending outwardly beyond said one end structure, said anode connection and said cathode connection cooperating to provide output connections for said device to an RF load for removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields, whereby the RF impedance of each portion of the interaction space matches the RF load impedance at each of said portions thereby to increase the efficiency of said crossed-field discharge device.

13. The crossed-field discharge device of claim **12**, wherein said surfaces are spaced farthest apart opposite said radially extending passage.

14. The crossed-field discharge device of claim **12**, including a plurality of axially extending anode segments on the surfaces of said anode sections, said anode segments projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween.

15. The crossed-field discharge device of claim **12**, wherein the surface of said electron emissive element includes circumferential sections spaced apart a distance corresponding generally to the circumferential dimension thereof.

16. The crossed-field discharge device of claim **12**, wherein the RF impedance increases from a first value at one end of said interaction space to a maximum value opposite said radially extending passage and then decreases to a second value at the other end of said interaction space.

17. The crossed-field discharge device of claim **12**, wherein said surface of revolution is an arc of a circle.

18. The crossed-field discharge device of claim **17**, wherein said arc has an included angle of from about 4° to about 5°.

19. A crossed-field device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, said inner axially extending space being bounded by an anode surface, a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure, an axially extending cathode structure disposed in said axially extending space and cooperating with the adjacent surface of said anode structure to define an axially extending annular interaction space, said cathode structure including an electron emissive element having surfaces disposed within said anode structure and adjacent to the associated surface of said anode structure, one of said surfaces being a generally concave surface of revolution to provide a predetermined distribution of RF impedance of the interaction space along the axis thereof, means for establishing an axially extending RF wave in said axially extending space and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, and end structures closing the ends of said anode structure including an anode connection extending outwardly beyond one of said end structures and said cathode structure including a cathode connection extending outwardly beyond said one end structure, said anode connection and said cathode connection cooperating to provide output connections for said device to an RF load for removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields, said surfaces being closest together at the end of said interaction space disposed toward the RF load, whereby the RF impedance of each portion of the interaction space matches the RF load impedance at each of said portions thereby to increase the efficiency of said crossed-field discharge device.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,584,255 Dated June 8, 1971

Inventor(s) James E. Staats

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 18, Claim 6, line 14, change "fields" to -- load --;

Column 18, Claim 6, line 15, delete "said surfaces being closest to load,";

Column 18, Claim 7, line 37, after "structure" insert -- and said axially extending space, said anode structure --.

Column 20, Claim 19, line 44, after "structure" insert -- and said axially extending space, said anode structure --.

Signed and sealed this 16th day of November 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patents

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