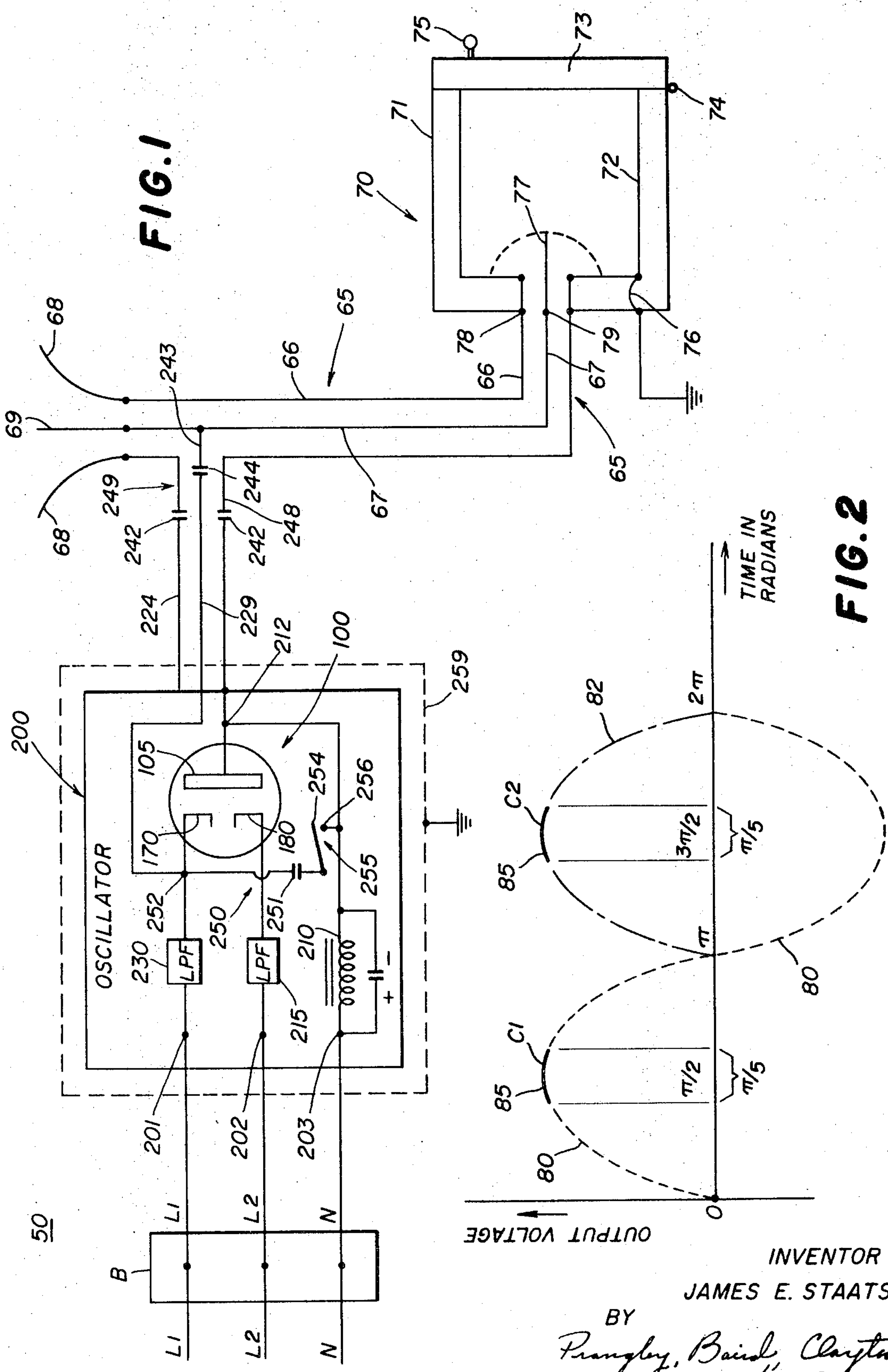
LOW VOLTAGE A.C. MAGNETRON

Filed Dec. 30, 1968 9 Sheets-Sheet 1

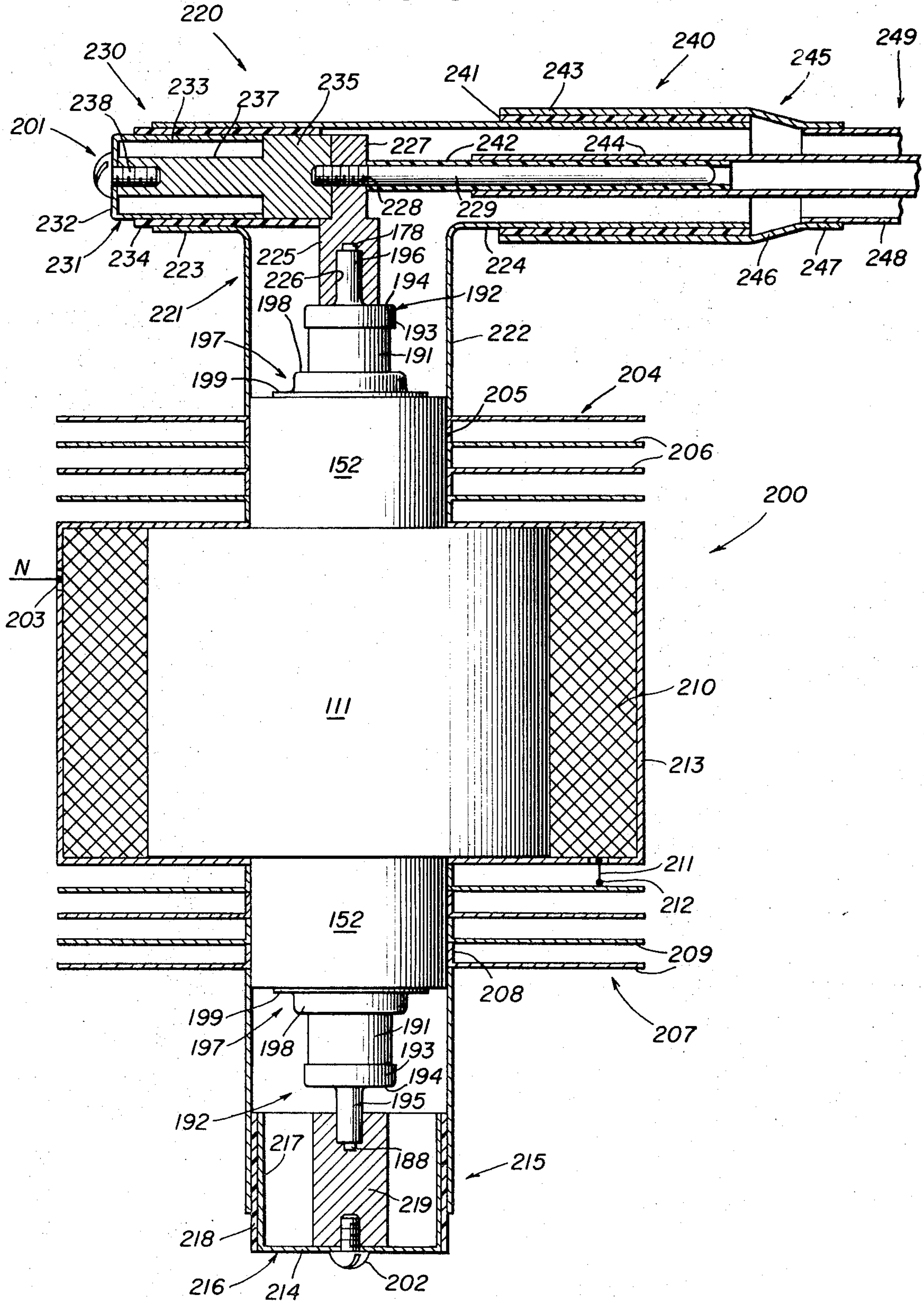
FIG. 1

FIG. 2



INVENTOR
JAMES E. STAATS
BY
Prangley, Baird, Clayton, Miller & Vogel
ATTYS.

FIG. 3


220
230
233
237
235
241
243
240
245
249
238
201
227
242
244
228
229
232
231
234
223
225
178
196
224
246
247
248
226
194
192
221
198
193
222
197
191
199
204
205
206
152
200
N
203
111
210
213
211
212
152
209
208
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195
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188
215
219
218
216
214
202

FIG. 4

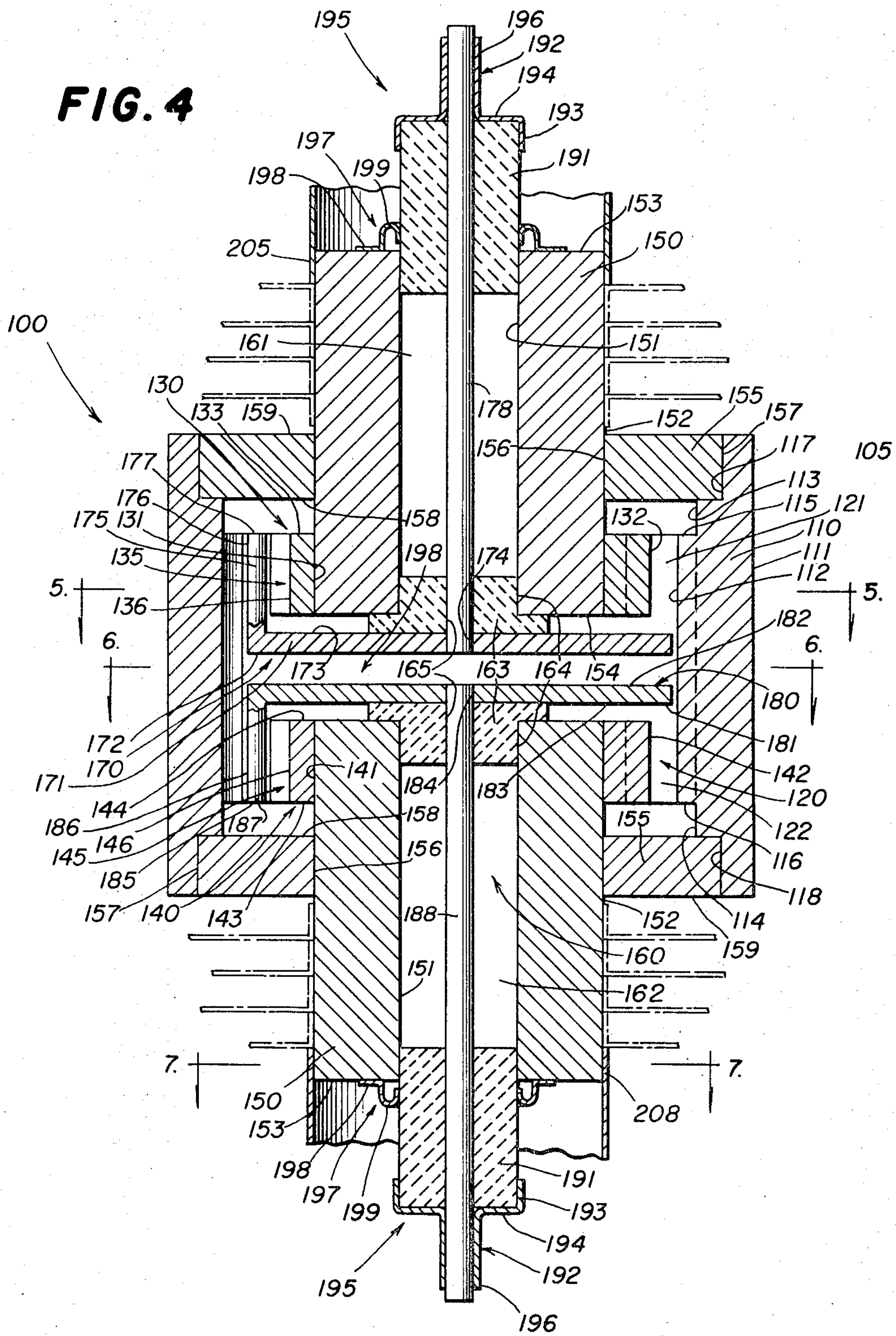

195
196
192
194
193
197
191
198
199
153
205
150
100
161
151
130
178
155
133
159
152
157
177
156
117
105
176
113
175
131
158
132
115
121
135
198
174
110
111
5.
136
112
5.
6.
182
6.
173
165
163
164
154
180
172
181
171
170
141
142
144
184
183
120
186
158
146
187
155
122
145
156
116
185
118
157
140
143
152
114
188
159
160
151
162
7.
7.
150
208
153
198
191
197
193
199
194
195
192
196

FIG. 5

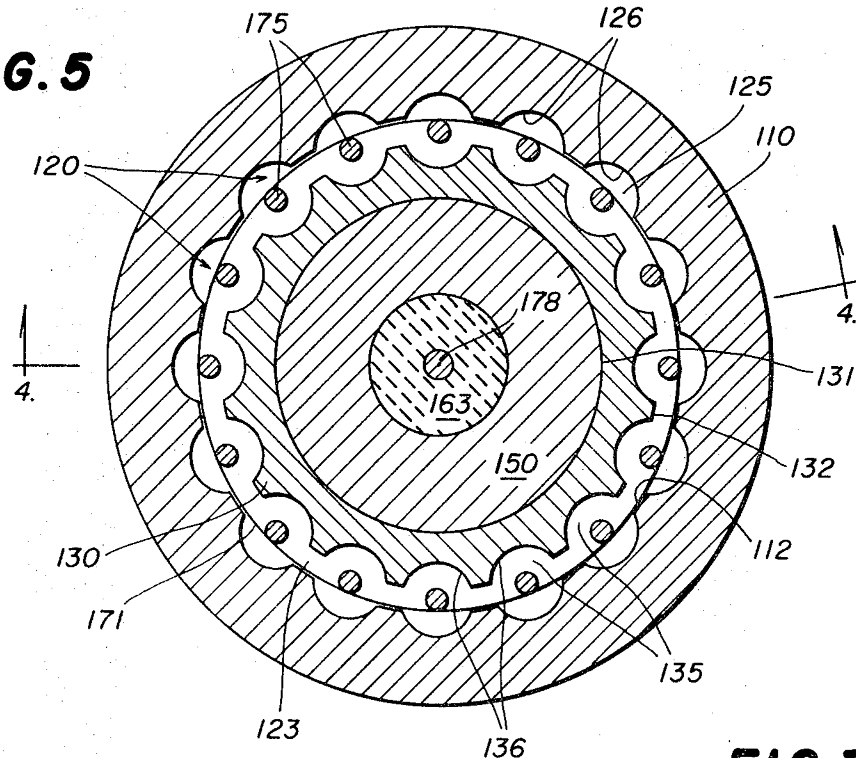


FIG. 7

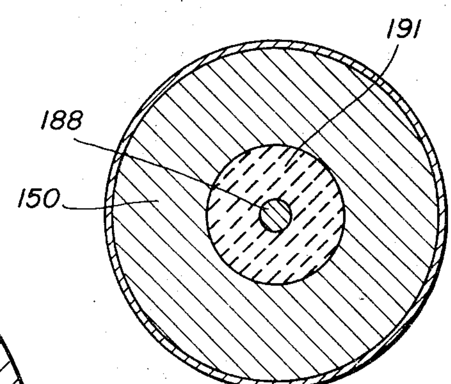


FIG. 6

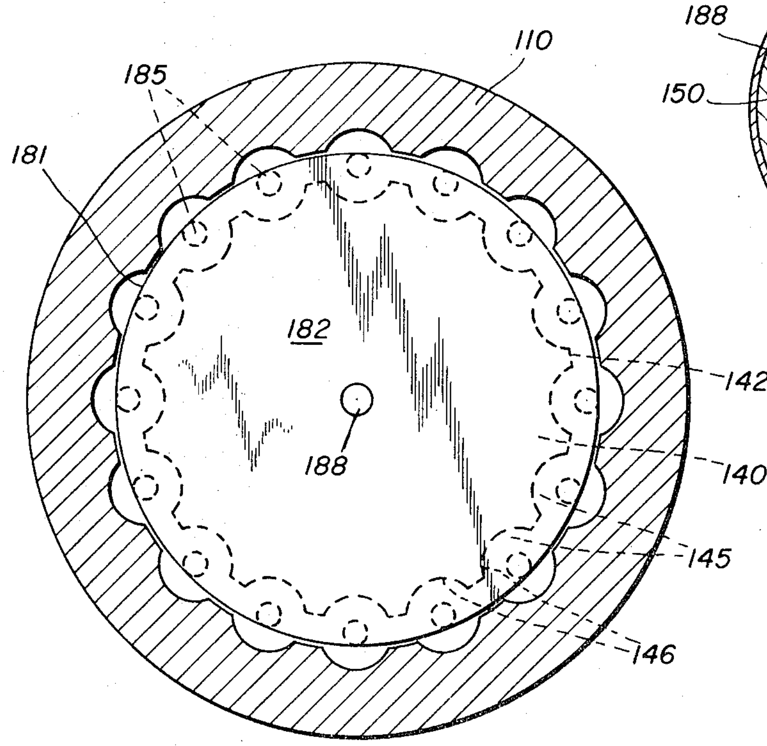


FIG. 8

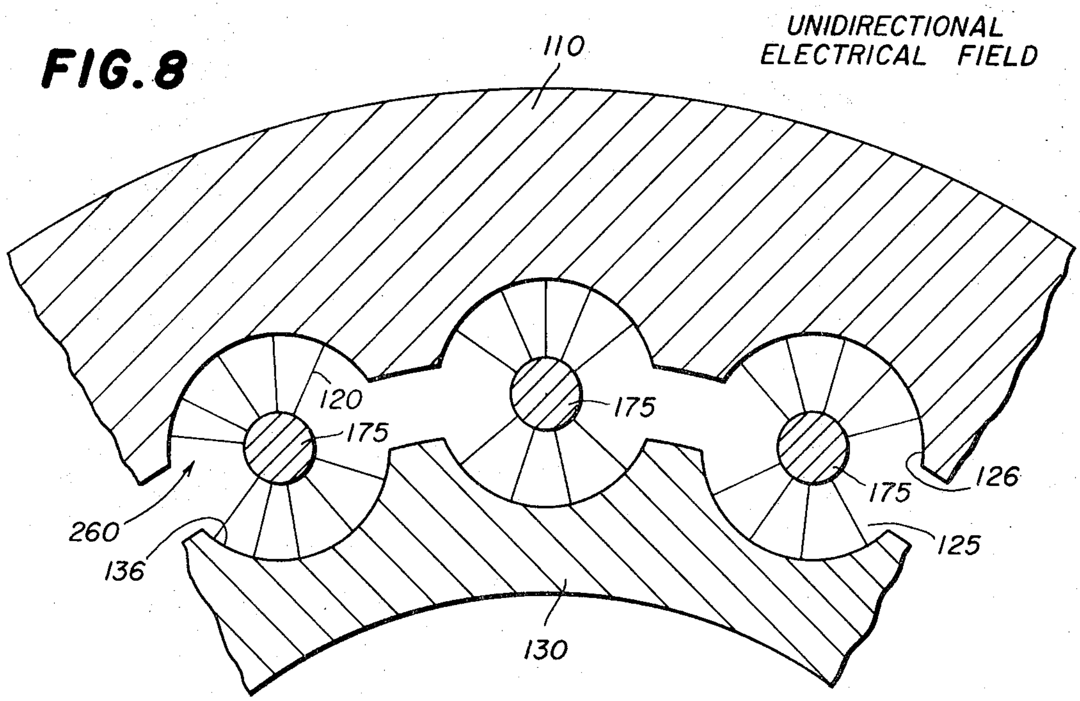

UNIDIRECTIONAL
ELECTRICAL FIELD
110
120
175
175
175
126
260
136
125
130

FIG. 9

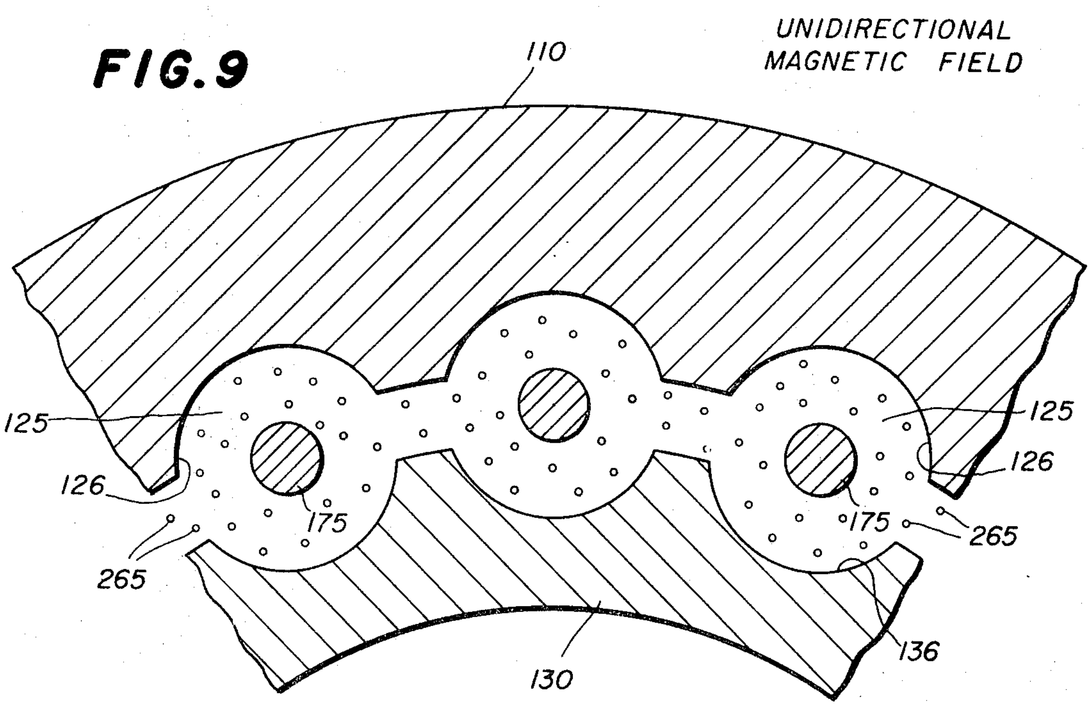

UNIDIRECTIONAL
MAGNETIC FIELD
110
125
125
126
126
175
175
265
265
136
130

FIG. 10

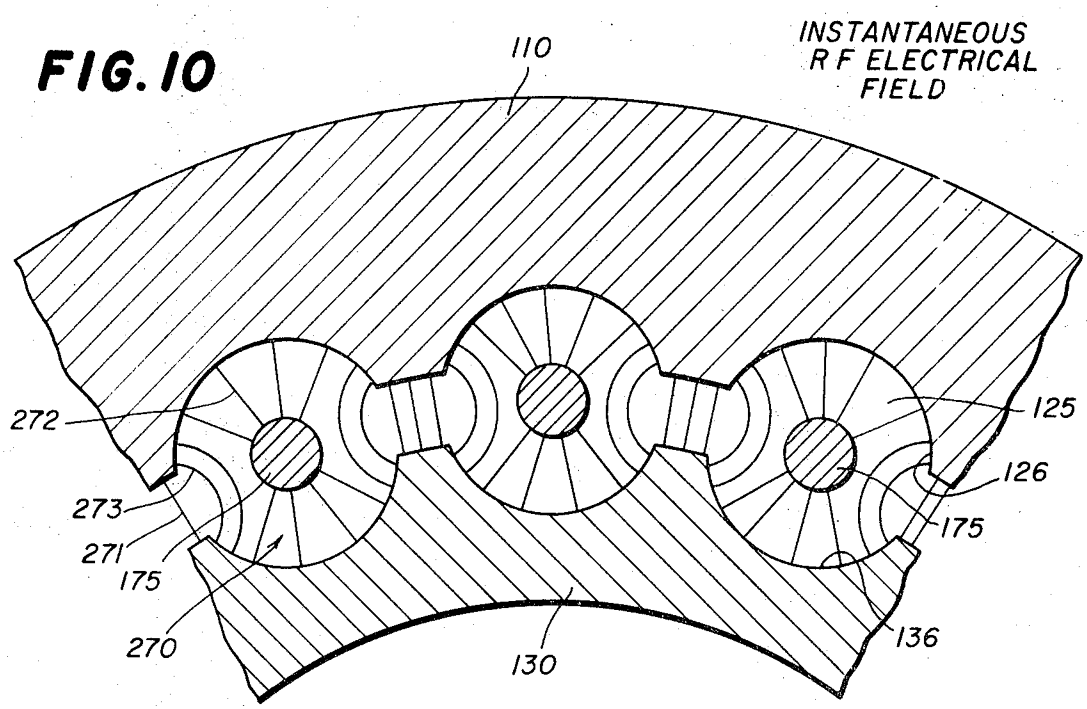

INSTANTANEOUS
R F ELECTRICAL
FIELD
110
272
273
271
175
270
130
125
126
175
136

FIG. 11

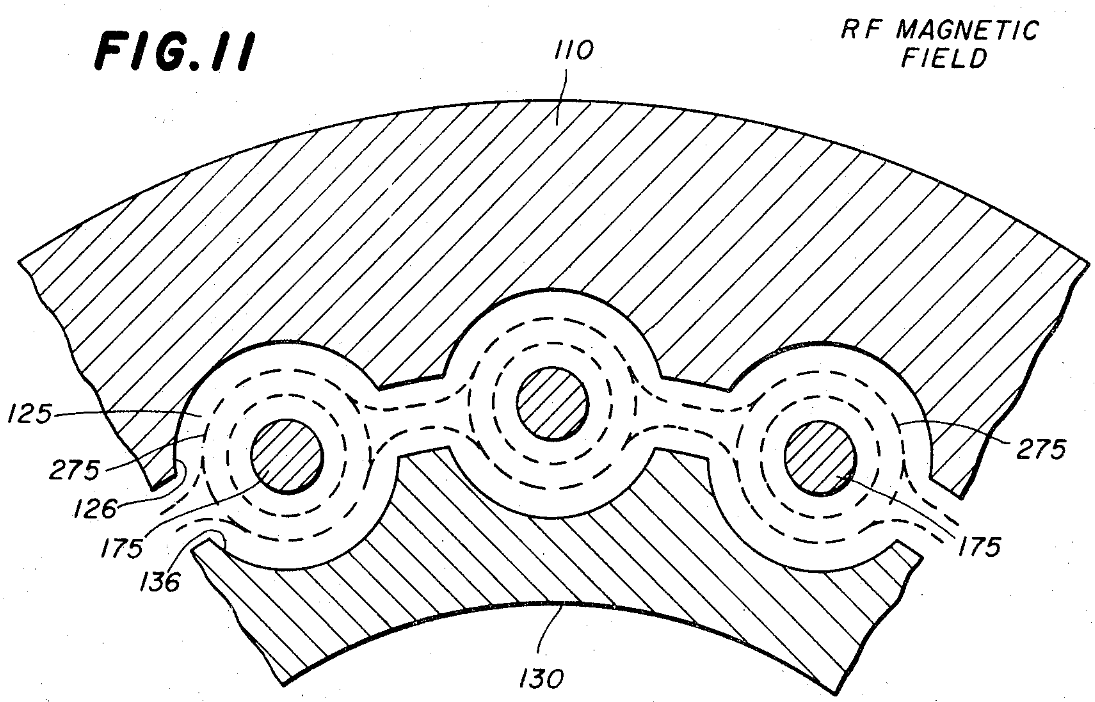

R F MAGNETIC
FIELD
110
125
275
126
175
136
130
275
175

FIG. 12

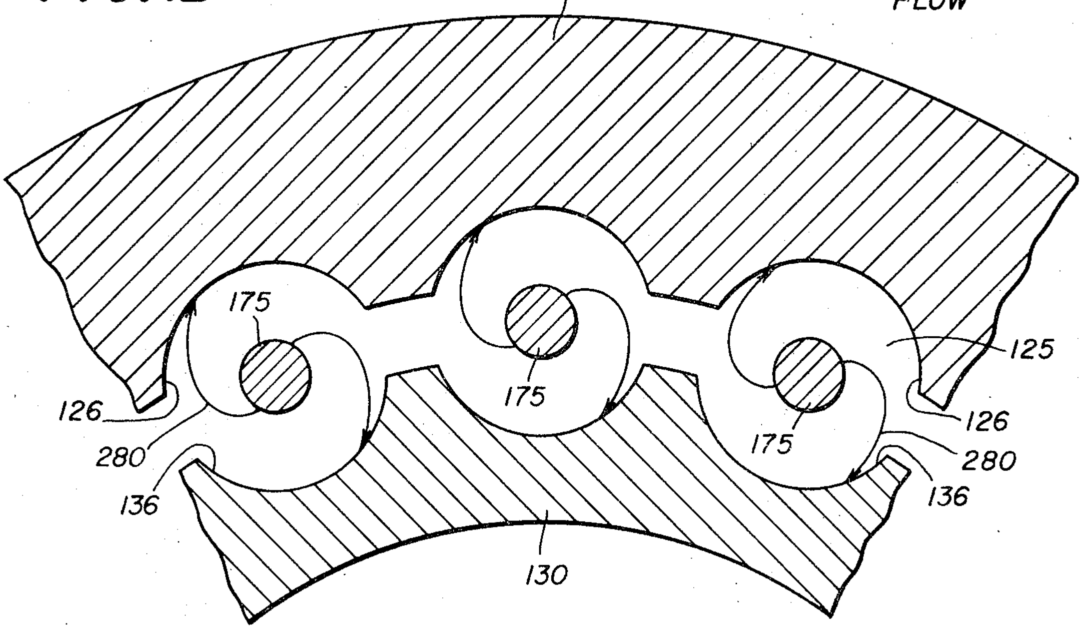
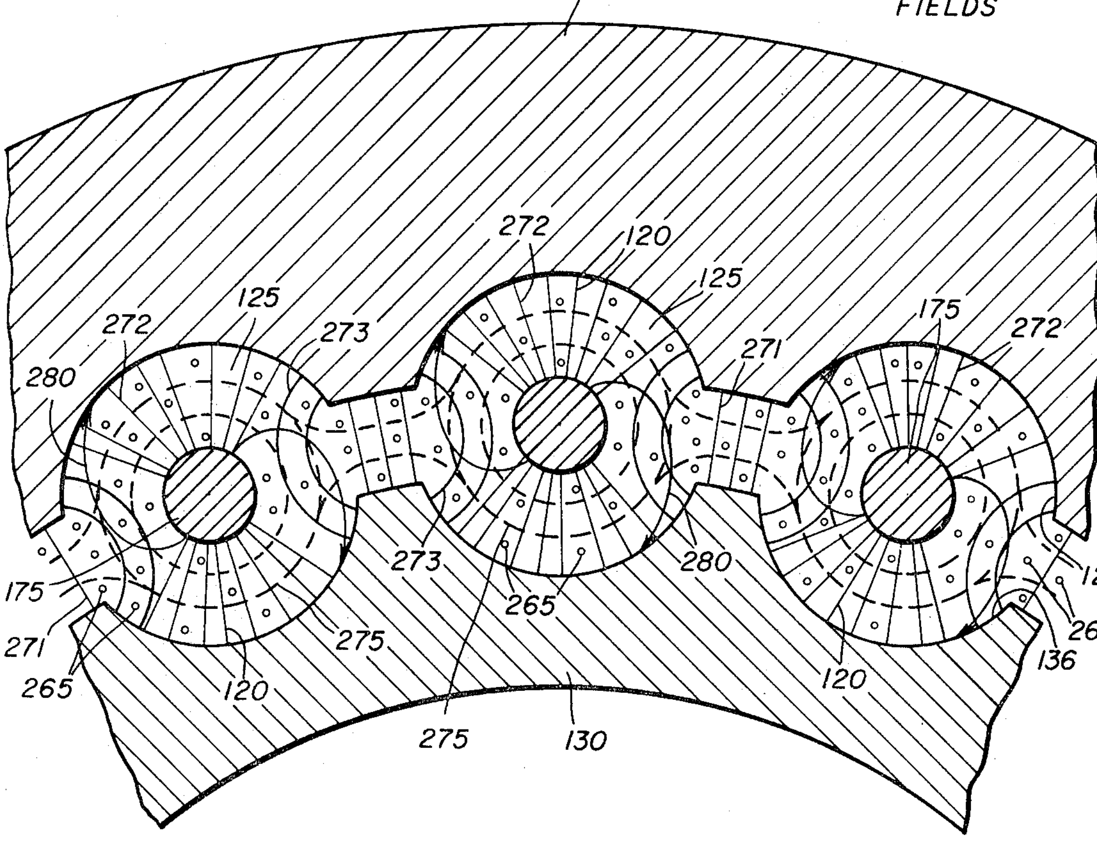
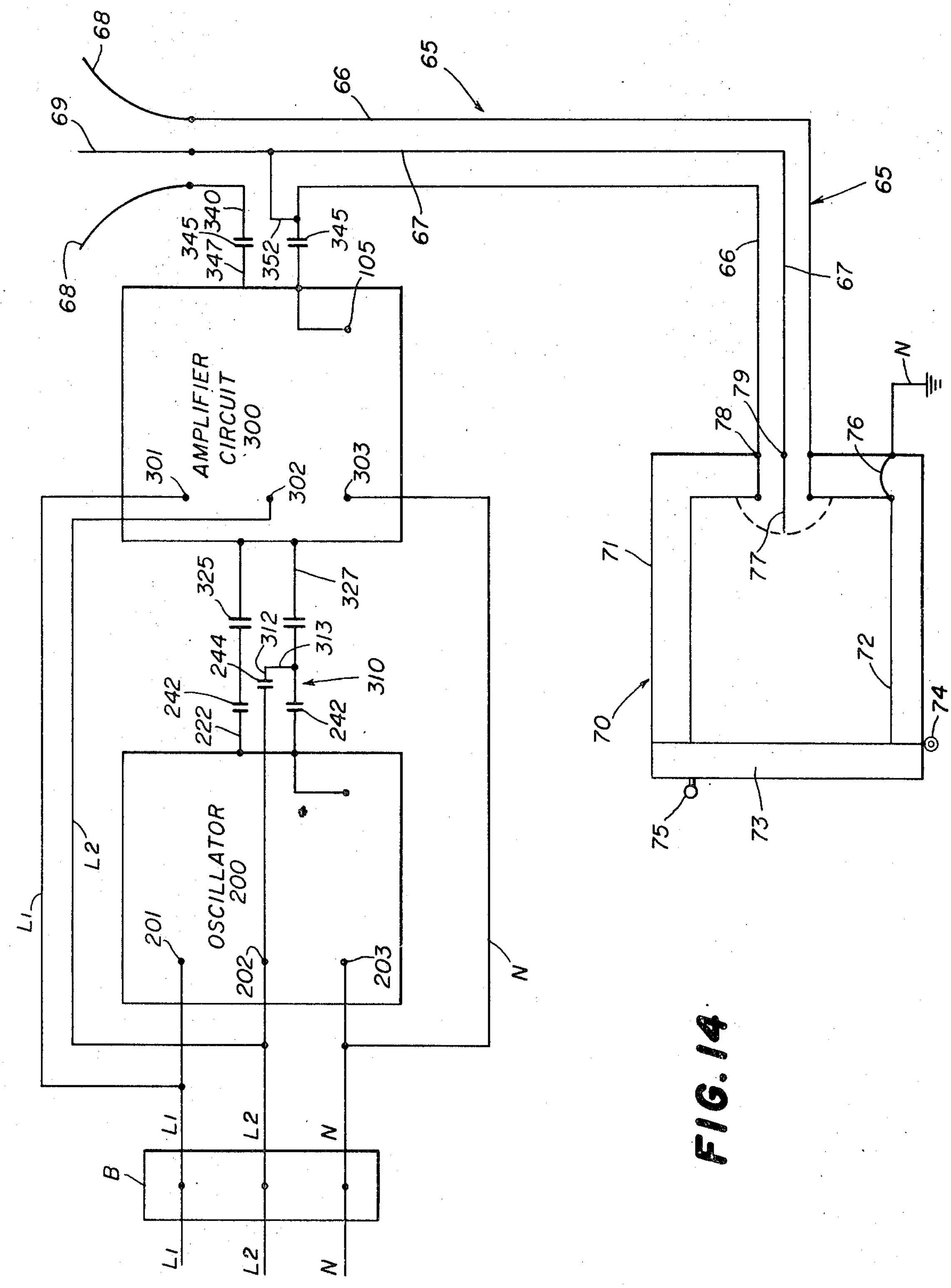

ELECTRON
FLOW
110
175
175
175
125
126
126
280
280
136
136
130

FIG. 13


COMPOSITE
FIELDS
110
272
120
125
125
272
273
175
272
271
280
273
280
175
271
265
275
120
265
275
130
120
126
265
136



AMPLIFIER CIRCUIT 300
OSCILLATOR 200
301
302
303
201
202
203
L1
L2
N
B
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
105
222
242
244
310
312
313
325
327
340
345
347
352

FIG. 14

Jan. 26, 1971 J. E. STAATS 3,559,094

LOW VOLTAGE A.C. MAGNETRON

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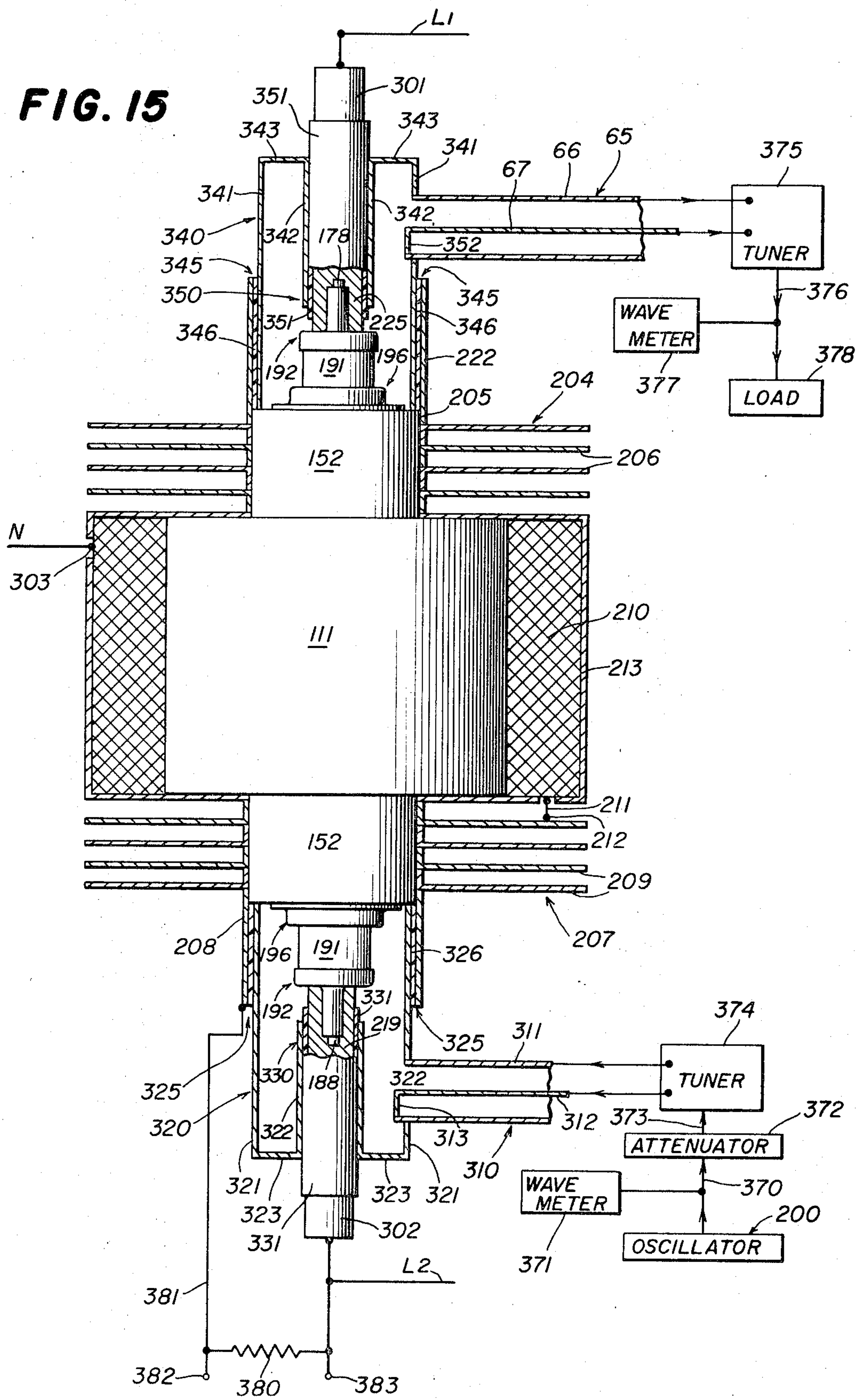
FIG. 15



United States Patent Office 3,559,094
Patented Jan. 26, 1971

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3,559,094

LOW VOLTAGE A.C. MAGNETRON

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Filed Dec. 30, 1968, Ser. No. 787,660
Int. Cl. H03b *9/10*
U.S. Cl. 331—86 65 Claims

ABSTRACT OF THE DISCLOSURE

There is disclosed a crossed-field discharge device including an annular first anode member having arcuate first recesses on the inner surface thereof and two annular second anode members, each having on the outer surface thereof arcuate second recesses equal in number to the first recesses and disposed respectively opposite the first recesses cooperating therewith to form interaction spaces, two axially spaced-apart cathode members each carrying secondary-emitting electron discharge members respectively disposed in the interaction spaces, means for applying low frequency low voltage A.C. operating potentials to the device and starting means for the device; oscillator, amplifier and modulator circuits incorporating the devices are also disclosed.

The present invention relates to improved crossed-field electron discharge device and to microwave circuits incorporating the same including microwave oscillator circuits and microwave amplifier circuits.

It is the general object of the invention to provide a new improved crossed-field electron discharge device for use at microwave frequencies, which device is of exceedingly simple and economical construction and arrangement and which device is particularly adapted for operation upon the application of relatively low-voltage A.C. operating potentials thereto.

It is a further object of this invention to provide an improved crossed-field electron discharge device of the type set forth which upon application of low-frequency, low-voltage operating potentials thereto produces high voltage microwave energy.

Another object of this invention is to provide a crossed-field electron discharge device of the type set forth comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial transmission line sections each including a hollow outer conductor and an inner conductor, the peripheral inner conductors each including electron emissive portions, means coupling the peripheral transmission line sections to the inner transmission line of equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through the peripheral outer conductors parallel to the axes thereof, and means for establishing unidirectional electrical fields between the inner and outer conductors of each of the peripheral transmission line sections for causing electron emission from the associated peripheral inner conductors, whereby the electrons emitted from the peripheral inner conductors interact with the magnetic fields and the electrical fields to generate microwave energy within the peripheral transmission line sections.

In connection with the foregoing object, it is another object of this invention to provide an improved crossed-field electron discharge device wherein the means for establishing unidirectional electrical fields comprises means for applying a 60-cycle, single-phase alternating voltage between the inner and outer conductors of the peripheral transmission line sections, the alternating voltage having an R.M.S. value in the range from about 220 volts to about 250 volts, and each of the peripheral transmission line sections rectifies the alternating voltage for establishing a unidirectional electrical field therein normal to the axis thereof and for causing electron emission from the associated peripheral inner conductors.

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A still further object of this invention is to provide an improved crossed-field electron discharge device of the type set forth comprising an annular anode structure defining therein an inner axially extending storage space extending therethrough and a plurality of outer interaction spaces disposed around the storage space and a radially extending passage interconnecting the interaction space and the storage space at equiangularly spaced points around the periphery thereof, cathode structure disposed within the anode structure and including a plurality of electron discharge members equal in number to the interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through the interaction spaces, and end structures enclosing both the ends of the anode structure and the axially extending spaces.

In connection with the foregoing object, it is another object of this invention to provide an improved crossed-field electron discharge device wherein the outer interaction spaces extend axially of the anode structure and are disposed equiangularly around the storage space.

In connection with the foregoing object, still another object of this invention is to provide an improved crossed-field electron discharge device wherein the anode structure includes an annular first anode member and two annular second anode members disposed within the first anode member, the second anode members cooperating to define the inner axially extending storage space, the first and second anode members cooperating to define therebetween the plurality of outer axially extending interaction spaces and the second anode members being axially spaced apart to provide therebetween the radially extending passage interconnecting the inner axially extending storage space and the interaction spaces.

It is another object of this invention to provide an improved crossed-field electron discharge device of the type set forth wherein the anode structure includes an annular first anode member defining therein an axially extending space extending therethrough, the first anode member having a plurality of arcuate first recesses on the inner surface thereof disposed equiangularly therearound and extending axially thereof, and a cylindrical second anode member having a plurality of arcuate second recesses on the outer surface thereof disposed equiangularly therearound and extending axially thereof, the number of the second recesses being equal to the number of the first recesses, and wherein the cathode structure is disposed within the axially extending space and includes a plurality of axially extending electron discharge members, the discharge members being respectively disposed in the interaction spaces, and further including end structure enclosing the ends of the anode members and the electron discharge members.

In connection with the foregoing object, it is another object of this invention to provide an improved crossed-field electron discharge device wherein the anode structure includes two cylindrical second anode members, each of the second anode members having a plurality of arcuate recesses on the outer surface thereof disposed equiangularly therearound and extending axially thereof, the number of the second recesses on each of the second anode members being equal to the number of the first recesses on the first anode member, the second anode members being respectively disposed in the axially extending space and axially spaced apart with respect to each other, and wherein the cathode structure includes two cathode members, each of the cathode members including a plurality of axially extending electron discharge members, the cathode members being respectively disposed in the axially extending space and being axially spaced apart with respect to each other, the electron discharge members being respectively disposed in the interaction spaces along the axes thereof.

In connection with the foregoing objects, it is another object of this invention to provide an improved crossed-field electron discharge device wherein the anode members and the cathode members are disposed symmetrically with respect to a plane normal to the longitudinal axis of the anode structure midway between the ends thereof.

It is another object of this invention to provide a crossed-field electron discharge device of the type set forth comprising an enclosing anode structure and a cathode structure therein defining therewith an interaction space, the cathode structure including an electron discharge member disposed in the interaction space, means for establishing a unidirectional magnetic field through the interaction space, means for applying a low voltage alternating potential between the anode structure and the cathode structure, wherein the alternating potential has an R.M.S. value no greater than about 250 volts, the cathode structure cooperating with the anode structure upon the application of the alternating potential thereto to rectify the alternating potential and thus to provide a unidirectional electrostatic field in the interaction space, the electron discharge member discharging electrons into the interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within the device, and structure for withdrawing the microwave energy from the device.

Yet another object of this invention is to provide a crossed-field electron discharge device of the type set forth comprising an enclosing anode structure and two spaced-apart cathode structures in the anode structure and cooperating therewith to define an interaction space, each of the cathode structures including an electron discharge member disposed in the interaction space, means for establishing a unidirectional magnetic field through the interaction space, energizing means for applying an alternating voltage between the anode structure and the cathode structures, the cathode structures cooperating with the anode structure upon the application of the alternating voltage therebetween to provide full-wave rectification of the alternating voltage and to provide a unidirectional electrostatic field in the interaction space, the electron discharge members discharging electrons into the interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within the device, and output structure for withdrawing the microwave energy from the device.

In connection with the foregoing object, it is another object of the invention to provide an improved crossed-field electron discharge device wherein the means for applying an alternating voltage comprises a source of alternating voltage operating potentials including two line conductors respectively coupled to the cathode structures and a neutral conductor coupled to the anode structure, and wherein the cathode structures cooperate with the anode structure upon the application of the alternating voltage therebetween to provide a unidirectional electrostatic field in the interaction space, the electron discharge members discharging electrons into the interaction space for interaction with both the magnetic field and the electrostatic field to generate microwave energy within the device, whereby upon application of the alternating voltage operating potentials to the device, a microwave energy can be extracted therefrom via the output structure utilizing the one cathode structure as a probe.

In connection with the foregoing object, it is another object of this invention to provide an improved crossed-field electron discharge device wherein the source of operating potentials is a three-wire Edison network including two line conductors and a neutral conductor, each of the conductors being provided with a corresponding terminal, and means galvanically connecting the terminals of the two line conductors respectively to the two cathode structures and galvanically connecting the terminal of the neutral conductor to the anode structure, the Edison network providing between the terminals of the two line conductors a 60-cycle, single-phase alternating voltage having an R.M.S. value in the range from about 220 volts to about 250 volts.

In connection with the foregoing object, it is yet another object of this invention to provide an improved crossed-field electron discharge device wherein the cathode structure includes electron discharge member disposed in the interaction space, and further including starting means coupled to the energizing means for providing a high starting voltage pulse between the anode structure and the cathode structure.

A further object of the invention is to provide an improved microwave oscillator incorporating therein the crossed-field electron discharged device of the present invention, the resonant circuit for the oscillator being in the form of a resonant cavity within the device.

A still further object of the invention is to provide an improved microwave amplifier incorporating therein a crossed-field electron discharge device of the present invention.

A still further object of the invention is to provide an improved microwave circuit incorporating therein a crossed-field electron discharge device of the present invention together with means for modulating the output of the device, whereby to provide a microwave oscillator having a modulated output and to provide a microwave amplifier having a modulated output.

Further features of the invention pertain to the particular arrangement of parts of the crossed-field electron discharge device and to connection thereof in the various microwave circuits, whereby the above outlined and additional operating features thereof are attained.

The invention, both as to its arrangements and method of operation, together with further objects and advantages thereof will best be understood by reference to the following specification and appended claims when 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 electron discharge device of the present invention;

FIG. 2 is a graph plotting the wave forms of the input and output voltages of the crossed-field electron discharge device of the present invention;

FIG. 3 is a view in vertical section through the oscillator of FIG. 1 and illustrating the circuit connections for the crossed-field electron discharge device including the magnetic field coil therefor and the coupler and filter structure used therewith;

FIG. 4 is an enlarged view in vertical section through the crossed-field electron discharge device illustrated in the oscillator of FIG. 3;

FIG. 5 is a view in horizontal section through the device of FIG. 4 along the line **5—5** thereof;

FIG. 6 is a view in horizontal section through the device of FIG. 4 along the line **6—6** thereof;

FIG. 7 is a view in horizontal section through the device of FIG. 4 along the line **7—7** thereof;

FIGS. 8 to 13, inclusive, are still further enlarged fragmentary views in horizontal section through the device of FIG. 4 along the line **8—8** thereof and illustrating the various electrical and magnetic fields therein;

FIG. 14 is a schematic and diagrammatic illustration of an amplifier circuit for amplifying the output from the microwave oscillator of FIG. 3, the amplifier circuit utilizing therein a crossed-field electron discharge device made in accordance with and embodying the principles of the present invention; and

FIG. 15 is a view in vertical section through the amplifier circuit of FIG. 14 and illustrating the crossed-field electron discharge device and the circuit connections therefor including the magnetic field coil and the amplifier input circuits and output circuits.

Referring now to FIG. 1 of the drawings, there is diagrammatically illustrated an oscillator circuit **50** embodying 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 A.C., and including two line conductors L1 and L2 and a neutral conductor N, the three conductors mentioned being terminated at an associated electrical insulating block B.

The oscillator circuit **50** comprises an oscillator **200** incorporating therein a crossed-field electron discharge device **100** made in accordance with and embodying the principles of the present invention, the oscillator **200** having three input terminals **201**, **202** and **203** that are connected respectively to the lines L1, L2 and N of the Edison supply network.

The crossed-field discharge device **100** is shown schematically in FIG. 1 and includes an anode structure **105**, two cathode structures **170** and **180** and an electromagnetic field coil **210**. The input terminal **201** is connected to the cathode structure **170** through a low-pass filter **215** and the input terminal **202** is connected to the cathode structure **180** through a low-pass filter **230**. The field coil **210** has one terminal thereof connected to the input terminal **203** of the oscillator and the other terminal thereof connected to the anode structure **105** as at **212**. A bypass capacitor **228** is connected in parallel with the field coil **210**. The oscillator **200** further includes a starting circuit **250** which includes in series combination a capacitor **251** and a switching means **255**, the starting circuit **250** being connected between the cathode structure **170** and the anode structure **105**. As illustrated, all of the parts of the oscillator **200** are surrounded by a grounded metallic casing **259**.

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 **242** between the outer conductor **222** and the outer conductor **66**, and a second capacitive coupling being provided by the coupler **244** between the inner conductor **178** and the inner conductor **67**.

The microwave energy supplied from the oscillator **200** to the transmission line **65** may be used for any desired purposes, two typical uses of the microwave energy being illustrated in FIG. 1, the first use being illustrated in the upper right-hand portion of FIG. 1 and the second use being illustrated in the lower right-hand portion of FIG. 1. Referring to the upper right-hand portion of FIG. 1, in the first use of the microwave energy illustrated therein the transmission line **65** is coupled to an antenna of the type commonly used in search radar, the outer conductor **66** being connected to outer radiating or antenna elements **68** and the inner conductor **67** being connected to an inner radiating or antenna element **69**, the antenna elements **68** and **69** serving to match the impedance of the transmission line **65** to the impedance of the atmosphere. Referring to the lower right-hand portion of FIG. 1, in the second use of the microwave energy illustrated therein 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. More particularly, the range **70** comprises an upstanding substantially box-like 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 box-like 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 hinge 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 lines **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** 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. 3 to 7 of the drawings. The device **100** comprises an anode structure **105** including an outer anode member **110** and two inner anode members **130** and **140**, two annular anode storage members **150**, two annular pole pieces **155**, two cathode structures **170** and **180** and two end structures **190**.

The anode structure **105** is essentially annular in shape and comprises an outer annular member **110** surrounding two inner annular members **130** and **140**, which in turn respectively surround annular storage members **150** and **155**. The outer member **110** is generally tubular in shape and symmetrical with respect to a plane normal to the longitudinal axis thereof midway between the ends thereof, which plane will hereinafter be referred to as the "midplane of the anode member **110**." The anode member **110** has concentric cylindrical outer and inner surfaces **111** and **112**, the inner surface **112** having adjacent each end thereof a recess defining upper and lower annular side wall surfaces **113** and **114** as viewed in FIG. 4 having diameters equal to each other and slightly less than the diameter of the inner surface **112** and being concentric with the outer surface **111** of the anode member **110**. The side wall surfaces **113** and **114** are respectively connected to the inner surface **112** by upper and lower end walls **115** and **116** which are generally annular in shape and parallel to each other and disposed substantially normal to the longitudinal axis of the anode member **110**. Each of the annular side wall surfaces **113** and **114** is further recessed at the outer end thereof to respectively form steps or notches **117** and **118** at the upper and lower ends of the anode member **110** as viewed in FIG. 4. The inner surface **112** of the anode member **110** between the end walls **115** and **116** has a plurality of arcuate recesses **125** therein, each of the recesses **125** extending axially of the anode member **110** from the end wall **115** to the end wall **116**, the recesses **125** being equiangularly spaced around the inner surface **112** of the anode member **110** as shown in FIGS. 5 and 6. Each of the recesses **125** has an arcuate wall **126**, the outermost portion of which is coplanar with the annular side walls **113** and **114**, each of the walls **126** being preferably part circular in shape normal to the longitudinal axis of the anode member **110**. Adjacent ones of the recesses

125 are separated by unrecessed portions 127 of the inner surface 112, all of the portions 127 having the same circumferential extent which varies with the number and radius of curvature of the recesses 125.

Disposed within the outer anode member 110 and also forming a part of the anode structure 105 are the two identical anode members 130 and 140 symmetrical with respect to the midplane of the anode member 110 and each having an outer diameter less than the inner diameter of the member 110 so as to be radially spaced inwardly therefrom. The anode member 130 is generally annular in shape and is disposed within the anode member 110 concentric therewith and adjacent to the upper end thereof as viewed in FIG. 4. The anode memebr 130 has a cylindrical inner surface 131 and a substantially cylindrical outer surface 132, the inner and outer surfaces 131 and 132 being connected at the upper and lower ends thereof as viewed in FIG. 4 respectively by an annular outer end surface 133 and an annular inner end surface 134, the end surfaces 133 and 134 being substantially parallel to each other and disposed substantially normal to the longitudinal axis of the anode member 110. The axial extent of the inner and outer surfaces 131 and 132 is preferably substantially less than the axial extent of the inner surface 112 of the anode member 110 between the end walls 115 and 116 thereof. In particular, the outer end surface 133 of the anode member 130 is coplanar with the end wall 115 of the anode member 110 and the inner surface 134 of the anode member 130 is disposed a predetermined distance above the midplane of the anode member 110 as viewed in FIG. 4. The outer surface 132 of the anode member 130 has a plurality of arcuate recesses 135 therein, each of the recesses 135 extending axially between the end surfaces 133 and 134 and being equiangularly spaced around the outer periphery of the anode member 130. Each of the arcuate recesses 135 has an arcuate wall 136, each of the walls 136 being part circular in shape normal to the longitudinal axis if the device 100. As can be seen from FIGS. 5 and 6 the number of recesses 135 in the anode member 130 is equal to the number of recesses 125 in the anode member 110. Further, the recesses 135 are respectively disposed opposite the recesses 125, the angular spacing between the recesses 135 being the same as the angular spacing between the recesses 125. Each of the recesses 135 preferably has the same radius and the same center of curvature as its corresponding recess 125. Adjacent ones of the recesses 135 are separated by unrecessed portions 137 of the outer surface 132, all of the portions 137 having the same circumferential extent which varies with the number and radius of curvature of the recesses 135.

Disposed within the anode member 110 adjacent to the lower end thereof as viewed in FIG. 4 and concentric therewith is the anode member 140. The anode member 140 has a cylindrical inner surface 141 and a substantially cylindrical outer surface 142, the inner and outer surfaces 141 and 142 being connected at the lower and upper ends thereof as viewed in FIG. 4 respectively by an outer end surface 143 and an inner end surface 144, the end surfaces 143 and 144 being substantially parallel to each other and being disposed substantially normal to the longitudinal axis of the device 100. The axial extent of the anode member 140 is preferably substantially less than the axial extent of the inner surface 112 of the anode member 110 between the end walls 115 and 116 thereof. More particularly, the outer end surface 143 of the anode member 140 is coplanar with the end wall 115 of the anode member 110 and the inner end surface 144 of the anode member 140 is disposed a predetermined distance below the midplane of the anode member 110 as viewed in FIG. 4. The outer surface 142 of the anode member 140 has a plurality of arcuate recesses 145 therein, each of the recesses 145 extending axially between the end surfaces 143 and 144 and having an arcuate wall 146 which is part circular in shape normal to the longitudinal axis of the anode member 140. The recesses 145 are equiangularly spaced around the outer periphery of the anode member 140 and are equal in number to the recesses 125 of the anode member 110 and are respectively disposed opposite thereto, the angular spacing between the recesses 145 being the same as the angular spacing between the recesses 125. Furthermore, each of the recesses 145 in the anode member 140 has the same radius and the same center of curvature as its corresponding recess 125 on the anode member 110. Adjacent ones of the recesses 145 are separated by unrecessed portions 147 of the outer surface 142, all of the unrecessed portions 147 having the same circumferential extent which varies with the number and radius of curvature of the recesses 145.

The recesses 135 and 145 in the anode members 130 and 140 respectively cooperate with the corresponding recesses 125 in the anode member 110 to form a plurality of axially extending interaction spaces 120 therebetween, each of the interaction spaces 120 having an upper portion 121 and a lower portion 122. More particularly, the recesses 135 in the anode member 130 respectively cooperate with their corresponding recesses 125 in the anode member 110 to form the upper portions 121 of the interaction spaces 120 and the recesses 145 in the anode member 140 respectively cooperate with their corresponding recesses 125 in the anode member 110 to form the lower portions 122 of the interaction spaces 120. Each of the interaction spaces 120 is circumferentially connected to the adjacent ones of the interaction spaces 120 by circumferentially extending connecting passages 123 as can be seen in FIGS. 5 and 6, the passages 123 being respectively defined by the unrecessed portions 137 and 147 of the outer surfaces 132 and 142 of the anode members 130 and 140 and the oppositely arrayed unrecessed portions 127 of the inner surfaces 112 of the anode member 110. More particularly, the unrecessed portions 137 and 147 of the outer surfaces 132 and 142 cooperate to respectively define the inner walls of the passages 123 and the unrecessed portions 127 of surface 112 respectively define the outer walls of the passages 123.

Respectively disposed within the inner anode members 130 and 140 are the two annular anode storage members 150 symmetrical with respect to the midplane of the anode member 110. The members 150 are identical in construction and, therefore, like reference numerals will be used for like parts of the two members 150. The upper member 150 as viewed in FIG. 4 will be described in detail, the construction and disposition of the lower member 115 being identical to that of the upper member 150. The upper anode member 150 is tubular in shape, being circular in transverse cross section at all points therealong and being disposed concentrically with the inner anode member 130. The anode member 150 has a cylindrical inner side wall surface 151 and a cylindrical outer side wall surface 152, the outer surface 152 having a diameter only slightly less than the diameter of the inner surface 131 of the inner anode member 130, whereby the anode member 150 can fit within the anode member 130 and ultimately is connected thereto as by brazing. The inner and outer surfaces 151 and 152 of the anode member 150 are connected at the upper and lower ends thereof as viewed in FIG. 4 respectively by an outer annular end surface 153 and an inner annular end surface 154, the end surfaces 153 and 154 being parallel to each other and disposed substantially normal to the longitudinal axis of the device 100. The axial extent of the anode member 150 is substantially greater than the axial extent of the anode member 130. More particularly, the inner end surface 154 of the anode member 150 is coterminous with the inner end surface 134 of the anode member 130, while the upper end of the anode member 150 as viewed in FIG. 4 extends outwardly a substantial distance beyond the upper end of the outer anode member 110. The disposition of the lower anode member 150 as viewed in FIG. 4 with respect to the anode member 140 is the same as the disposition of the upper anode member **150** with respect to the anode member **130**.

There is provided adjacent to the ends of the outer anode member **110** two anular pole pieces **155**. The pole pieces **155** being identical in construction and symmetrically disposed with respect to the longitudinal midplane of the device **100** and, therefore, like reference numerals will be used for like parts of the pole pieces **155**. Referring to the upper pole piece **155** as viewed in FIG. 4, the pole piece **155** has a cylindrical inner surface **156** and a cylindrical outer surface **157**, the surfaces **156** and **157** being coaxial with each other and with the inner and outer surfaces **151** and **152** of the anode member **150**. The inner surface **156** of the pole piece **155** has a diameter only slightly greater than the diameter of the outer side wall surface **152** of the anode member **150**, whereby the pole piece **155** fits snugly around the anode member **150** in surrounding relationship therewith and ultimately is connected thereto as by brazing. The inner and outer surfaces **156** and **157** of the pole piece **155** are connected at the upper and lower ends thereof as viewed in FIG. 4 respectively by an annular outer surface **158** and an annular inner surface **159**, the surfaces **158** and **159** being parallel to each other and disposed substantially normal to the longitudinal axis of the device **100**. The outer surface **157** of the pole piece **155** has a diameter only slightly less than the diameter of the recessed or notched portion **117** of the outer anode member **110**, whereby the pole piece **155** fits snugly into the notch **117** and is ultimately connected to the anode member **110** as by brazing. Similarly, the lower one of the pole pieces **155** fits into the notch **118** at the opposite end of the anode member **110**.

Disposed within the anode structure **105** adjacent to the inner ends of the anode storage members **150** are two annular insulating spacers **163** symmetrical with respect to the midplane of the anode member **110**. The insulating spacers **163** are identical in construction and, therefore, like reference numerals will be used for like parts thereof. The upper one of the insulating spacers **163** as viewed in FIG. 4 is annular in shape having a recessed portion **164** in the outer side wall thereof, the spacer **163** fitting within the lower end of its corresponding anode member **150** so that the recessed portion **174** fits snugly against the inner ends of the side wall **151** and the inner end wall **154**. The insulating spacer **163** has a circular opening **165** extending therethrough along the longitudinal axis thereof. The lower one of the insulating spacers **163** as viewed in FIG. 4 is similarly disposed with respect to the lower one of the anode members **150**.

The cathode structures **170** and **180** are disposed within the anode structure **105** and are symmetrical with respect to the midplane of the anode member **110**. The cathode structure **170** is disposed adjacent to the upper end of the anode structure **105** as viewed in FIG. 4 and the cathode structure **180** is disposed adjacent to the lower end of the anode structure **105**. The cathode structure **170** includes an annular plate member **171** being essentially disc-like in shape and having a flat inner surface **172** and a flat outer surface **173**, the surfaces **172** and **173** being parallel to each other and disposed substantially normal to the longitudinal axis of the device **100**. The plate member **171** is disposed within the outer anode member **110** and has a diameter slightly less than the diameter of the inner surface **112** thereof so as to be spaced radially inwardly a small distance therefrom. The inner surface **172** of the plate member **171** is disposed above the midplane of the anode member **110** as viewed in FIG. 4 and is spaced a predetermined small distance therefrom. Disposed centrally of the plate member **171** is a relatively small circular opening **174** extending axially therethrough. Disposed around the periphery of the plate member **171**, integral therewith and extending axially outwardly therefrom is a plurality of electron discharge members **175**, each of the discharge members **175** being cylindrical in shape and having a cylindrical external surface **176** and an end surface **177** at the outer end thereof. The electron discharge members **175** are equal in number to the interaction spaces **120** and are respectively disposed in the upper portions **121** thereof. More particularly, each of the electron discharge members **175** has its longitudinal axis disposed along the longitudinal axis of its corresponding interaction space **120**, the axial extent of the electron discharge members **175** being such that their outer ends **177** are coterminous with the outer end surface **133** of the anode member **130** and with the upper end wall **115** of the anode member **110**. Disposed in the central opening **174** of the plate member **171** and attached thereto is an input-output lead **178** being cylindrical in shape and extending outwardly from the plate member **171** along the longitudinal axis of the device **100** to a point beyond the outer end of the anode structure **105**, the lead **178** serving to convey electrical energy to and from the device **100**.

The cathode structure **180** includes an annular plate member **181** being essentially disc-like in shape and having a flat inner surface **182** and a flat outer surface **183**, the surfaces **182** and **183** being parallel to each other and disposed substantially normal to the longitudinal axis of the device **100**. The plate member **181** is disposed within the outer anode member **110** and has a diameter slightly less than the diameter of the inner surface **112** thereof so as to be spaced radially inwardly a small ditsance therefrom. The inner surface **182** of the plate member **181** is disposed below the midplane of the anode member **110** as viewed in FIG. 4 and is spaced a predetermined small distance therefrom. Disposed centrally of the plate member **181** is a relatively small circular opening **184** extending axially therethrough. Disposed around the periphery of the plate member **181**, integral therewith and extending axially outwardly therefrom is a plurality of electron discharge members **185**, each of the discharge members **185** being cylindrical in shape and having a cylindrical external surface **186** and an end surface **187** at the outer end thereof. The electron discharge members **185** are equal in number to the interaction spaces **120** and are respectively disposed in the lower portions **122** thereof. More particularly, each of the electron discharge members **185** has its longitudinal axis disposed along the longitudinal axis of its corresponding interaction space **120**, the axial extent of the electron discharge members **185** being such that their outer ends **187** are coterminous with the outer end surface **143** of the anode member **140** and with the lower end wall **116** of the anode member **110**. Disposed in the center opening **184** of the plate member **181** and attached thereto is an input-output lead **188** being cylindrical in shape and extending outwardly from the plate member **181** along the longitudinal axis of the device **100** to a point beyond the outer end of the anode structure **105**, the lead **188** serving to convey electrical energy to and from the device **100**.

Each of the electron discharge members **175** and **185** is provided on the external surface **176** thereof with a coating of a suitable electron emissive oxide material, whereby upon application of a high starting voltage pulse between the anode structure **105** and the cathode structures **170** and **180** the resulting electrical field will cause the electron emissive coating to begin to emit electrons from the outer surface thereof, which emission, once started, will be self-sustaining in the presence of the A.C. operating potentials applied to the device **100**.

The anode members **110, 130, 140** and **150** are formed of a metal having good thermal conductivity, the preferred material being copper. These anode members must also have good electrical conductivity as well as the good thermal conductivity. The pole pieces **155** are formed of a material having high magnetic permeability, the preferred material being a low carbon steel. The pole pieces

155 are preferably copper plated to render the outer surfaces thereof high conductive to R.F. energy and to provide a good electrical connection between the anode member 110 and the anode members 150. The cathode structures 170 and 180 are formed of a metal having a good electrical conductivity, the preferred metal being copper. The insulating spacers 164 are formed from an electrically insulating dielectric material, the preferred material being a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon."

The anode structure 105 and the pole pieces 155 and the cathode structures 170 and 180 are all symmetrical with respect to the midplane of the anode member 110 and they cooperate to define a group of interconnected spaces which are also symmetrical with respect to the same midplane. In particular, the tubular anode storage members 150 cooperate to define an inner axially extending storage space 160 extending through the device 100, the storage space 160 having an upper portion 161 defined by the upper one of the anode members 150 and a lower portion 162 defined by the lower one of the anode members 150 as viewed in FIG. 4. Furthermore, as has been described above, the inner anode members 130 and 140 cooperate with the outer anode member 110 to define therebetween a plurality of outer axially extending interaction spaces 120. The inner surfaces 158 of the pole pieces 155 are respectively spaced outwardly from the outer end surfaces 133 and 143 of the anode members 130 and 140 and from the end walls 115 and 116 of the anode member 110, thereby defining upper and lower end spaces 166 and 167 as viewed in FIG. 4, the end spaces 166 and 167 being closed respectively by the outer side wall surfaces 156 of the anode storage members 155 and communicating with and forming extensions of the interaction spaces 120 at the upper and lower ends thereof. The facing inner surfaces 172 and 182 of the cathode members 170 and 180 are spaced apart a predetermined distance and define therebetween a radially extending gap or passage 190 which communicates the interaction spaces 120 at the mid-regions thereof with the inner axially extending storage space 160 at the midregion thereof.

Upper and lower end structures 195 are provided respectively at the upper and lower ends of the device 100, the end structures 195 serving ot provide a hermetic seal between the associated anode storage members 150 and the associated cathode leads 178 and 188. The end structures 195 are identical in construction and symmetrical with respect the midplane of the anode member 110 and, therefore, like reference numerals will be used for like parts thereof. Referring now to the upper one of the end structures 195 as viewed in FIG. 4, there is provided an annular insulator 191, the lower end of which is received within the upper end of the anode storage member 150, the insulator 191 being formed, for example, of a good electrically insulating ceramic. The annular insulator 191 has an axially extending opening therein receiving therethrough the cathode lead 178. Surrounding the upper end of the insulator 191 and the adjacent portion of the cathode lead 178 is an end cap 192, the cap 192 being generally annular in shape and including an annular flange 193 surrounding an outer periphery of the upper end of the insulator 191 and being hermetically sealed thereto. Integral with the upper edge of the outer flange 193 is an inwardly directed flange 194 carrying on the inner edge thereof an outwardly directed annular inner flange 193 surrounding the adjacent portion of the lead 178 and hermetically sealed thereto as by brazing. At the upper end of the anode member 150 there is provided in surrounding relationship with the insulator 191 an annular seal member 197. The seal member 197 includes a mounting flange 198 fixedly secured as by brazing to the outer end surface 153 of the anode member 150, the mounting flange 198 having integral there-

with an annular flange 199 folded inwardly upon itself so as to define an attachment flange which is substantially U-shaped in vertical cross section, the inner fold of the flange 199 surrounding and being secured to the outer wall of the insulator 191. It is pointed out that the cap 192 and the seal member 197 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% iron, 28% nickel and 18% cobalt. It will be seen that the end structure 195 forms a good hermetic seal that also provides electrical insulation between the anode member 150 and the cathode lead 178, the end structure 195 likewise providing the necessary mechanical support of the cathode structure 120 to position it within the anode structure 105. The lower one of the end structures 195 is similarly disposed with respect to the lower one of the anode members 150 and the cathode lead 188 of the cathode structure 180 to provide a hermetic seal at the lower end of the device 100 and to mechanically support the cathode structure 180 within the anode structure 105, the end structures 195 being the only seals necessary for the device 100.

Disposed around the upper end of the upper anode member 150 in surrounding relationship therewith is a cooling fin package 204, the package 204 comprising a cylindrical heat conductive sleeve 205 attached to the anode member 150 at the outer surface 152 thereof, the sleeve 205 carrying thereon a plurality of axially spaced-apart cooling fins disposed substantially normal to the sleeve 205 and extending outwardly therefrom. The sleeve 205 extends axially outwardly beyond the outer end of the anode member 150 thereby forming a cylindrical conductor to be described more fully hereinafter. Similarly, there is disposed about the outer end of the lower anode member 150 in surrounding relationship therewith a second cooling fin package 207 comprising a cylindrical heat-conductive sleeve 208 attached to the anode member 150 at the outer surface 152 thereof and carrying a plurality of axially spaced-apart cooling fins 209 disposed substantially normal to the sleeve 208 and extending outwardly therefrom. The sleeve 208 extends outwardly beyond the outer end surface 153 of the lower anode member 150 to form a cylindrical conductor the purpose of which will be more fully described hereinafter. The cooling fine packages 204 and 207 are formed of a good heat-conductive material, the preferred material being copper, for dissipating the heat generated within the device 100. There is preferably provided a means such as a fan or blower (not shown) for passing a stream of cooling air over the fins 206 and 209 for cooling the device 100. It is noted that the sleeves 205 and 208 are in good electrical connection as well as thermal connection with the anode members 150 thereby providing a good electrically conductive path from the anode structure 105 to the sleeves 205 and 208.

When the device 100 is incorporated as a crossed-field discharge device in a microwave circuit, the pole pieces 155 arranged adjacent to the opposite ends of the anode member 110 are utilized for establishing a unidirectional magnetic field extending axially through the several interaction spaces 120 within the anode structure 105. To this end a magnet coil 210 has been provided, the magnet coil 210 being disposed about the anode member 110 in surrounding relationship therewith as viewed in FIG. 3. The magnet coil 210 is shaped as a torous and is wound of electrically conductive wire and is supported around the anode member 110 by any annular casing 213. It will be understood that the pole pieces 155 are formed of metals having a high magnetic permeability, such as soft iron or low carbon steel, whereby when the magnet coil 210 is energized a strong and uniform unidirectional magnetic field is established between the pole pieces 155 extending axially through the interaction spaces 120 within the device 100.

The circuit for energizing the coil **210** can be traced with reference to FIGS. 1 and 3 from the Edison supply network, and specifically the neutral conductor N thereof, to the input terminal **203** of the oscillator **200** to which is connected one terminal of the magnet coil **210**. The other terminal of the magnet coil **210** is connected by a conductor **211** to one of the cooling fins **209** as at **212**, whereby the input terminal **203** is connected via magnet coil **210**, the conductor **211**, and the cooling fin **209** to the anode member **150** of the device **100**. The flow of current through the magnet coil **210** serves to produce the unidirectional magnetic field in the interaction spaces **120** of the device **100**.

Referring now to FIG. 3 of the drawings, the manner in which the crossed-field electron discharge device **100** is incorporated in the oscillator **200** will be described in further detail. At the lower end of the device **100** as viewed in FIG. 3 there is provided an R.F. rejection filter **215**, the filter **215** comprising an annular cup-like electrically conductive member **216** having a flat annular end wall **214** disposed in a plane substantially normal to the longitudinal axis of the device **100** and a cylindrical side wall **217** integral with the end wall **214** at the outer periphery thereof and extending axially inwardly therefrom. The cup-like member **216** is telescopically received within the outer end of the sleeve **208** and is separated therefrom by an annular insulator **218** disposed therebetween, the insulator **218** preferably being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon." There is also provided a cylindrical inner conductor **219** electrically connecting the outer end of the cathode lead **188** to the end wall **214** of the cup member **216**, the inner end of the conductor **219** having a centrally disposed opening therein in which is received the outer end of the cathode lead **188** and the outer end of the flange **195** of the end cap **192**, the outer end of the conductor **219** having an internally threaded opening therein in which is received a terminal screw **202** which is passed through an opening in the end wall **214** and which forms the input terminal **202** of the oscillator **200** and which secures the cup **216** to the coupler **219**. The terminal **202** is one of the A.C. input terminals for the oscillator **200**, the rejection filter **215** serving to prevent the microwave energy generated within the device **100** from being introduced into the Edison supply network through the terminal **202**.

At the opposite end of the device **100** there is provided a coupler and filter structure **220** to accommodate the application of the A.C. operating potentials to the device **100** and the withdrawal of microwave energy therefrom while preventing the introduction of R.F. energy into the Edison supply network over the line conductor L1 thereof. The coupler and filter structure **220** includes an electrically conductive T-member **221** comprising an axially extending lower arm **222** and two radially outwardly extending arms **223** and **224**. The T-member **221** is hollow, the lower arm **222** being annular in shape and extending outwardly from and being integral with the outer edge of the sleeve **205**. The radial arm **223** is integral with the lower arm **222** and forms a hollow annular conductor extending to the left of the lower arm **222** and substantially normal thereto as viewed in FIG. 3. The radial arm **224** is also integral with the lower arm **222** and forms a hollow annular conductor extending to the right of the lower arm **222** substantially normal thereto and coaxial with the arm **223** as viewed in FIG. 3. Coupled to the outer end of the cathode lead **178** is an axially extending cylindrical bullet coupler **225** having in the lower end thereof an opening **226** for receiving therein the outer end of the cathode lead **178** and the surrounding flange **196** of the end cap **192**. The upper end of the coupler **225** has a reduced diameter portion **227** having a threaded eye **228** therethrough along the longitudinal axis of the arms **223** and **224**. An electrically conductive probe member **229** is disposed in the radial arm **224** of the T-member **221** along the longitudinal axis thereof the left-hand end of the probe **229** as viewed in FIG. 3 being disposed through the eye **228** in the bullet coupler **225** and threadedly engaged therewith and extending slightly beyond the bullet coupler **225** at the left-hand side thereof.

Coupled to the T-member **221**, and in particular to the radial arm **223** thereof, is an R.F. rejection filter **230**. The filter **230** includes an annular cup-like conductor **231** having a flat annular end wall **232** disposed normal to the longitudinal axis of the radial arm **223**, the end wall **232** carrying at the periphery thereof and integral therewith an annular side wall **233** extending axially of the arm **223** and telescopically received therein. Surrounding the side wall **233** and separating the side wall **233** from the arm **223** is an annular insulating sleeve **234**, the sleeve **234** preferably being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon." Electrically coupling the bullet coupler **225** to the end wall **232** of the cup **231** is an inner conductor **235**, the conductor **235** being cylindrical in shape with the right-hand end thereof abutting the recessed portion **227** of the bullet coupler **225** and having an internally threaded opening therein in which the left-hand end of the probe member **229** is threadedly engaged. The conductor **235** has a reduced diameter portion **237** at the left-hand end thereof, the portion **237** abutting the end wall **232** of the conductor **231** and having an internally threaded opening therein in which is threadedly engaged a terminal screw **201** which is passed through an opening in the end wall **232** and which forms the input terminal **201** of the oscillator **200** and secures the cup **231** to the coupler **235**. The right-hand end of the side wall **233** of the cup **231** abuts the unrecessed portion of the coupler **235** while the left-hand end extends outwardly beyond the end of the arm **223**, and the right-hand end of the insulating sleeve **234** abuts the unrecessed portion of the bullet coupler **225** while the left-hand end extends outwardly beyond the end of the arm **223** but not as far as the end **232** of the cup **231**.

The arm **224** of the T-member **221** cooperates with the probe member **229** to form a coaxial output transmission line for withdrawing microwave energy from the device **100**. There is provided for this output transmission line, a capacitive coupler **240**, the coupler comprising an insulating sleeve **241** surrounding and firmly embracing the right-hand end of the arm **224** and an insulating sleeve **242** surround and firmly embracing the probe member **229** and extending to the right a short distance beyond the end thereof. The sleeves **241** and **242** are formed of an electrically insulating dielectric material, the preferred material being a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon." Overlapping the sleeve **241** is an annular outer conductor **243** and overlapping the right-hand end of the sleeve **242** is an annular inner conductor **244**, the sleeves **241** and **242** serving respectively to provide a capacitive coupling between the outer conductors **224** and **243** and between the inner conductors **229** and **244**. The outer conductor **243** has at the right-hand end thereof and integral therewith a short inwardly tapered section **245** integral at the inner end thereof with a short reduced diameter portion **247**. Telescopically received within the reduced diameter portion **247** and connected thereto is an annular outer conductor **248**. The inner annular conductor **244** extends outwardly beyond the right-hand end of the sleeve **242** and into the outer conductor **248**, the outer conductor **248** and the inner conductor **244** cooperating to form a coaxial output transmission line **249** for the device **100**.

In operation, the line conductors L1 and L2 are respectively connected to the cathode structures **170** and

180 to apply an A.C. operating potential thereto. More particularly, the line conductor L1 is connected to the cathode structure 170 via the input terminal screw 201, the inner conductor 235, the bullet coupler 225 and the cathode lead 178 while the line conductor L2 is connected to the cathode structure 180 via the input terminal 202, the inner conductor 219 and the cathode lead 188. The microwave energy generated within the device 100 is coupled to the load via a series of interconnected coaxial transmission lines. The first of these transmission lines has an outer conductor defined by the arm 222 and an inner conductor defined by the cathode lead 178 and the bullet coupler 225. This transmission line is coupled to a second transmission line the outer conductor of which is defined by the arm 224 and the inner conductor of which is defined by the probe member 229, which second transmission line is capacitively coupled via the coupling structure 240 to a third transmission line having an outer conductor defined by the outer conductors 243 and 248 and an inner conductor 244. Introduction of the microwave energy into the Edison supply network is prevented by the R.F. rejection filters 215 and 230. The length of each of the cup-like members 216 and 231 is substantially one-fourth of the wavelength of the operating frequency of the device 100 whereby the cup-like members define quarter-wave cavities which operate as rejection filters at the microwave frequency of the device 100.

Since the electron discharge members 175 and 185 of the cathode structures 170 and 180 are of the cold cathode type, to initiate the emission of electrons therefrom it is necessary to provide a starting circuit. The starting circuit 240 is shown schematically in FIG. 1 and includes a capacitor 251 and a two-terminal switching device 255. One terminal of the capacitor 251 is connected to the cathode structure 170 as at 252, the other terminal of the capacitor 251 being connected to a movable contact 254 of the switch 255. The switch means 255 has a fixed contact 256 which is connected to the anode structure 105. Suitable actuating means (not shown) are provided to momentarily close the switch means 255 when the capacitor 251 has become charged thereby discharging the capacitor 281 through the anode structure 105 and the magnet coil 210 thereby providing an initial magnetic field and a transient pulse of high voltage for establishing an initial electrical field for starting electron emission in the device 100. Once started, the electron emission from the discharge members 175 and 185 is sustained by the A.C. operating potentials applied between the anode structure 105 and the cathode structures 170 and 180.

During the operation of the crossed-field discharge device 100 in the oscillator 200, the anode members 110, 130 and 140 and the cathode structures 170 and 180 cooperate to provide a plurality of coaxial transmission lines within the device 100, the coaxial transmission lines thus formed accommodating axially extending R.F. waves therein and providing a frequency determining resonant cavity for the device 100 and for the oscillator 200. The coaxial transmission lines more specifically include an inner coaxial transmission line defined by the inner annular surfaces 151 on the anode members 150 and the cathode leads 178 and 188 of the cathode structures 170 and 180; the surfaces 151 cooperate to provide a hollow outer conductor for the inner transmission line and the cathode leads 178 and 188 cooperate to form an inner conductor for the inner transmission line. The anode members 110, 130 and 140 and the electron discharge members 135 and 145 cooperate to define a plurality of outer axially extending transmission line sections, in particular, the arcuate recess walls 126, 136 and 146 cooperating to define a plurality of outer conductors for the outer transmission line sections and each of the electron discharge members 135 cooperating with its corresponding electron discharge member 145 to form an inner conductor for the associated one of the outer transmission line sections. The radial passage 190 serves to couple the outer transmission line sections to the inner transmission line thereby coupling microwave energy generated in the outer transmission line sections from these sections to the inner transmission line.

In the operation of the device 100, the outer transmission line sections provide a resonant cavity which can be excited to cause oscillations therein at a frequency equal substantially to twice the length thereof, i.e., twice the axial distance between the inner surfaces 158 of the pole pieces 155, whereby to provide an axially extending wave in the interaction spaces which is reflected by the inner surfaces 158 at the ends of the transmission line sections to produce a standing R.F. wave. The standing R.F. waves of microwave energy are communicated to the inner transmission line by the radial passage 190 which acts as a wave guide for this purpose, the cathode lead 178 or 188 being utilized as a probe for extracting the microwave energy from the inner transmission line.

In the operation of the oscillator 200, it is necessary to produce within the crossed-field discharge device 100 a pattern of electrical and magnetic fields. More particularly, there must be established in the interaction spaces 120 an axially extending unidirectional magnetic field and a unidirectional electrical field normal to the axes of the interaction spaces. It is noted that the operating potentials applied to the input terminals 201–203 of the oscillator 200 are alternating, having a frequency of 60 cycles per second. In order to establish unidirectional magnetic and electrical fields within the device 100, it is necessary that the alternating component of the operating potentials be substantially eliminated. This function is accomplished in the device 100 by the two cathode structures 170 and 180 which cooperate with the anode structure 105 to provide a full-wave rectification of the alternating potentials within the device 100. Referring to FIG. 2 there is shown a waveform diagram illustrating the operating potentials applied to the device 100 and their rectification thereby. The 60-cycle, single-phase alternating voltage which is applied to the input terminals of the oscillator 200 from the Edison supply network is represented by the sine wave 80 shown in broken lines, only one cycle of the sine wave being shown for purposes of convenience. The cathode structures 170 and 180 serve to full-wave rectify the input voltage wave 80, thereby producing the rectified voltage waveform 82. The device 100 conducts for only a portion of each half cycle of the input voltage waveform, the conducting portion of each one-half cycle preferably being about 20% thereof, this conductive portion being indicated by the solid line 85 at the peak of each half cycle of rectified input voltage. Thus, the device 100 has a somewhat intermittent, but unidirectional operation.

The 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 now be given. The operating potentials for device 100 are derived directly from the Edison supply network, as is indicated above, the conductors L1, L2 and N being respectively galvanically connected to the input terminals 201, 202 and 203 of the oscillator 200. The input terminal 201 is connected through the filter 230 and the coupler 225 to the cathode structure 170 which is in turn connected to the output of the device 100 via the coupler 225, the probe 219 and the coupler 240; the input terminal 202 is connected through the filter 215 to the cathode structure 180; the input terminal 203 is connected to one terminal of the magnet coil 210, the other terminal of the magnet coil 210 being connected to the anode structure 105 and thence to the output conductor 222 at the output of the device 100. Upon the application of the operating potentials to the device 200 the capacitor 251 of the starting circuit 250 becomes charged to a predetermined potential. Upon operation of the switch means 255 of the starting circuit 250, the capacitor 251 becomes discharged, thereby providing a high voltage starting pulse between the cathode structure 180 and the anode structure 105 for initiating electron emission in the device 100. The capacitor 251 also cooperates with the field coil 210 to provide an initial magnetic field within the device 100.

The application of the above-described alternating potentials to the device 100 and their rectification thereby serves to establish a unidirectional electrical field 260 (see FIG. 8), that extends between the electron discharge members 175 (for example) and the anode members 110 and 130 (for example). In particular, the electrical field extends between the electron discharge members 175 and the walls 126 and 136 of the arcuate recesses 125 and and 135. The electrical field 250 extends substantially normal to the longitudinal axes of the interaction spaces 120, the field lines entering walls 126 and 136 normal thereto and entering the surfaces 176 of the discharge members 175 normal thereto, whereby the field 250 takes the shape illustrated in FIG. 8. It will be understood that a like-shaped unidirectional electrical field is provided between the electron discharge members 185 and the anode segments 110 and 140 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 260, a current is established in the magnet coil 210. More particularly, electrons flow from the anode structure 105 through the cooling fins 209, the conductor 211, the magnet coil 210 and the conductor N to the Edison supply network output terminal. With such a flow of electrons through the magnet coil 210, a strong unidirectional magnetic flux is established through a path including the upper magnetic pole piece 155, the interaction spaces 120 and the lower magnetic pole piece 155. Referring to FIG. 9 of the drawings, the unidirectional magnetic flux lines extending through the interaction spaces 120 are designated by the numeral 265, the flux lines 265 extending axially through the spaces 120 and, therefore, normal to the plane of the sheet of drawing in FIG. 9. Due to the provision of the pole pieces 155 having a high magnetic permeability there is a unidirectional distribution of the unidirectional flux lines 265 throughout the spaces 120. It is further pointed out that the unidirectional magnetic flux lines 265 are disposed normal to the unidirectional electrical field 260 illustrated in FIG. 8, whereby the unidirectional electrical field 260 and the unidirectional magnetic field 265 provide the necessary "crossed" fields for the operation of the crossed-field discharge device 100.

As has been pointed out above, the axially extending interaction spaces 120 provide coaxial transmission line sections extending axially of the device 100, each having a length equal to one-half the wave length of the operating frequency of the device. The transmission line thus provided forms a tuned cavity for the oscillator 200, the tuned cavity being readily excited at a frequency having a wave length corresponding to twice the axial distance between the inner surfaces 158 of the pole pieces 155. When the tuned resonant cavity thus formed is excited by the establishment therein of the unidirectional electrical field 260 of FIG. 8 and the unidirectional magnetic field 265 of FIG. 9, the tuned cavity resonates at a frequency having the wave length mentioned, i.e., a standing R.F. wave is established within the tuned cavity and extends axially thereof and axially of the device 100.

There is believed to be associated with the standing R.F. wave thus established an R.F. electrical field disposed normal to the axis of the device 100, a diagrammatic representation of the field being illustrated in FIG. 10. In FIG. 10 the instantaneous R.F. electrical field has been designated by the numeral 270, the field 270 having a first portion 271 disposed between the unrecessed portions 127 of the inner surface 112 of the anode member 110 and the corresponding unrecessed portions 137 of the outer surface 132 of the anode member 130 (for example). The field 270 also includes a second portion 272 disposed between the electron discharge members 175 and their associated recess walls 126 and 136 (for example). The field 270 also includes a third portion 273 extending between the recess walls 126 and their corresponding recess walls 136 (for example). Each of the flux lines 270 is so disposed that it enters the anode and cathode surfaces normal thereto. It will be understood that a like R.F. electrical field 270 is disposed in the lower end of the device 100 between the unrecessed surfaces 127 and 147 and between the electron discharge members 185 and their corresponding recess walls 126 and 146 and between the recess walls 126 and their corresponding recess walls 146.

Associated with the R.F. electrical field 270 of the standing R.F. wave is a R.F. magnetic field 275 shown is believed to have the form illustrated in FIG. 11. The R.F. magnetic field 275 is also disposed normal to the axis of the device 100 and is concentric about and surrounds the electron discharge members 175 (and 185). The major portion of the R.F. magnetic field 275 is disposed within the interaction spaces 120 and is designated by the numeral 276, but a portion of the magnetic field 275 extends into the spaces 123 interconnecting adjacent ones of the interaction spaces 120, this portion of the magnetic field 275 being designated by the numeral 277. It will be understood that the R.F. magnetic field 275 is symmetrically disposed in both the upper and lower portions of the device 100.

After the application of the operating potentials to the device 100 and after the starting circuit 250 has been actuated to establish a high voltage pulse between the anode structure 105 and the cathode structure 180 for starting the device 100, electrons are emitted from the emissive coating of the electron discharge members 175 and 185, the electrons being emitted into the interaction spaces 120 where they are subjected to the action of the unidirectional fields and the R.F. fields described hereinabove. There is illustrated in FIG. 12 of the drawings a diagrammatic representation of what are believed to be typical paths of electrons emitted from the electron discharge members 175 and 185, the electron paths being designated by the numeral 280. As illustrated, the electrons follow an arcuate path, the initial direction of flow being in a clockwise direction, this being due to the influence of the unidirectional magnetic field 265 described above. The arcuate paths 280 of the electrons carry them into contact with the anode members 110 or 130 (for example), whereby to complete an electrical circuit through the device 100. During the time that the electrons are in the arcuate paths 280, they impart a portion of the energy contained therein to the R.F. standing wave within the device 100 to add power thereto and to reinforce the standing wave. It will be understood that like electron paths 280 are found between the electron discharge members 185 and the anode members 110 and 140 in the lower portion of the device 100.

There is illustrated in FIG. 13 a composite representation of all of the fields that are believed to be present in the device 100 and in the interaction spaces 120 thereof when the device 100 is operating as part of the oscillator 200. From FIG. 13 it is apparent that the electrons in the paths 280 clearly interact with the unidirectional fields and the R.F. fields within the interaction spaces 120, whereby to give up a portion of the energy of the electrons to the R.F. fields within the interaction spaces 120. More specifically, when the R.F. electrical field 270 is established in the interaction spaces 120 it tends to bunch electrons that rotate around the electron discharge members 175 and 185 in the presence of the D.C. electrical field 260 and the D.C. magnetic field 265. These electrons tend to rotate in synchronization with a slow wave component of the axial fast wave and to extract energy from the D.C. fields while giving up energy to the R.F. fields. In this manner the R.F. standing wave within the device **100** is maintained and the energy contained thereof increased and replenished due to the operation of the oscillator **200**.

As is best seen from FIGS. 3 and 13, the cathode **170** is coupled to the R.F. standing wave within the interaction spaces **120** and, therefore, serves a probe for the removal of a portion of the R.F. energy from the tuned cavity for the supplying thereof to the coupler and filter structure **220** and thence to the output transmission line **65**. In the structure illustrated, the cathode lead **178** is directly connected to the bullet coupler **225** and the anode member **150** is directly connected to the sleeve **205** which is integral with and forms a part of arm **222** of the T-structure **221**, whereby an output R.F. potential appears between the conductor **222** and the coupler **225**. The coupler and filter structure **220**, including the capacitive coupling **240**, serves to connect the R.F. energy between the coupler **225** and the conductor **222** to the output transmission line **65**, and also to apply to the cathode **170** via the couplers **235** and **225** an A.C. operating potential, all without the introduction of R.F. energy into the Edison supply network via the terminal **201**. As has been explained above, the R.F. wave within the oscillator **200** extends axially with respect to the device **100**, there being no radial R.F. waves within the device **100**, i.e., no R.F. waves extending normal to the axis of the device **100**. Furthermore, the radial distance between the axis of the device **100** and the outer wall **126** of the arcuate recesses **125** is less than that required to accommodate a radial standing wave at the operating frequency of the oscillator **200**. Likewise, the radial distance between the outermost point of the recess wall **126** and the innermost point of the corresponding recess wall **136** is less than that required to accommodate a radial standing wave at the operating frequency of the device **100** as defined above.

In a constructional example of the crossed-field discharge device **100** the various parts thereof preferably have the following dimensions. The electron discharge members **175** and **185** each has a diameter of 10 mils; each of the interaction spaces **120** has a diameter of 32 mils; the axial extent of the interaction spaces **120**, i.e., the axial distance between the inner surfaces **158** of the pole pieces **155** is effectively one half wave length at 915 mHz.

From the above description it will be seen that the physical dimensions of the device **100** are relatively small compared to the wave length of the microwave energy to be generated thereby and the power output therefrom. The thermal characteristics of the device **100** are excellent, the effects of thermal expansion of the parts being minimized resulting in improved thermal suitability. It will be understood that cooling may be provided by means of clamp-on radiators or cooling coils in lieu of the stacked array of cooling fins **206** and **209** illustrated. The anode members **110, 130, 140** and **150** are all constructed from a good heat conducting material and the thick radial extending portions thereof offer a very low thermal resistance thus permitting high power operation.

In a test version of the device **100**, with the dimensions indicated above, and with a peak value of 150 volts applied between the anode and either one of the cathode structures **170** or **180**, the associated electron discharge members operated at a current density of 1.35 amperes per square centimeter, the magnetic field for this operating condition being about 2,000 gauss. Each of the electron discharge members **175** and **185** cooperates with its corresponding arcuate recess walls **126, 136** and **146** to operate as a dipole, each dipole producing a peak pulse power output of 14 watts at 915 mHz., the duty cycle being 20% and the average output power per dipole being 2.8 watts at 50% efficiency. For the 16 sections or dipoles illustrated, the power output would be 45 watts total. The duty cycle may be increased by reducing the magnetic field slightly to obtain a higher power output at a lower efficiency. A power output of 55 watts may be obtained in this manner. Higher power output may be obtained by adding more sections, the mode characteristics of the anode being such that a very large number of sections can be used. Operation at higher power output may also be obtained with smaller interaction spaces and cathode diameters with resulting higher magnetic field and current density.

Referring to FIG. 14 of the drawings, there is diagrammatically illustrated the manner in which the output from the oscillator circuit **50** can be connected to the input of an amplifier circuit **300** which embodies therein certain additional features of the present invention. Inasmuch as the construction and operation of the oscillator **200** in the circuit of FIG. 14 is identical to those described above, like reference numerals have been applied to like parts throughout and the description thereof will not here be repeated. It will be understood that the output of the oscillator **200** is applied to a coaxial transmission line **310** which has the outer conductor **311** thereof connected to the capacitive coupler **242**, and the outer conductor **311** is in turn connected by capacitive couplers **325** to a cavity connected to one end of a crossed-field discharge device **100** of the type set forth above. The transmission line **310** also comprises an inner conductor **312** which terminates in a radiating probe **313** that radiates into a cavity formed by a coaxial transmission line **320** connected to the lower end of the device **100** (see FIG. 15 also). The amplifying circuit **300** also includes three input terminals **301, 302** and **303** that are connected respectively to the conductors L1, L2 and N of the Edison supply network.

The output of the amplifier circuit **300** is applied to a cavity including an outer conductor **347** that is capacitively coupled by the coupler **345** to an output transmission line **340** which connects with the transmission line **65**. More specifically, the outer conductor of the transmission line **340** is directly connected to the outer conductor **66** of the transmission line **65** and a coupling probe **352** is provided within the transmission line **340** and is connected to the inner conductor **67** of the output transmission line **65**. The capacitive coupling provided by the coupler **345** is desirable and necessary since the output terminal **347** is at a relatively high D.C. potential, whereby it is necessary electrically to isolate the output terminals **347** from the outer conductor **66** so that the outer conductor **66** can be grounded.

The microwave energy supplied from the amplifier circuit **300** to the transmission line **65** can be used for any desired purpose, two typical uses of the microwave energy being illustrated in FIG. 14, the first use being illustrated in the upper right-hand portion of FIG. 14, and the second use being illustrated in the lower right-hand portion of FIG. 14. Referring to the first use illustrated in the upper right-hand portion of FIG. 14, the transmission line **65** is shown coupled to an antenna of the type commonly used in search radar, the outer conductor **66** being connected to outer radiating or antenna elements **68**, and the inner conductor **67** being connected to an inner radiating or antenna element **69**, the antenna elements **68** and **69** serving to match the impedance of the transmission line **65** to the impedance of the atmosphere. Referring to the second use of the microwave energy illustrated in the lower right-hand portion of FIG. 14, the transmission line **65** is shown coupled to an electronic heating apparatus, such as the electronic range **70** illustrated that is especially designed for home use. The electronic range **70** in FIG. 14, is identical to the electronic range **70** described above with respect to FIG. 1 of the drawings, and accordingly, like reference numerals have been applied to like parts throughout. The microwave energy within the transmission line **65** is radiated into the internal cavity of the electronic range **70** to provide the power for heating materials disposed therein. It further will be understood that in a preferred embodiment of the range **70**, the oscillator **200** and the amplifier circuit **300** together with the transmission line **65** are all preferably disposed within a common housing that also includes the casing **71**, the common housing preferably being formed of an electrically conductive metal of high magnetic permeability and grounded for safety purposes.

Further details of the construction of the amplifier circuit **300** and the connections thereof to the crossed-field discharge device **100** incorporated therein will now be described with reference to FIG. 15 of the drawings. The construction of the crossed-field discharge device **100** incorporated in the amplifier circuit **300** of FIG. 15 is identical to the construction of the crossed-field discharge device **100** described above with reference to the oscillator **200** and illustrated in detail in FIGS. 3–7 of the drawings, whereby like reference numerals have been applied to like parts throughout including the magnet coil **210** and the associated mechanical and electrical connections. As illustrated, the input coaxial transmission line **310** includes the annular outer conductor **311** within which is disposed the inner conductor **312**, the left-hand end of the outer conductor **311** communicating with the outer coaxial transmission line **320** that is connected to the lower end of the device **100**. More specifically, the coaxial transmission line **320** includes an outer annular conductor **321** within which is disposed an annular inner conductor **322**, the lower and outer ends thereof being interconnected and the space therebetween closed by an end wall **323**. An opening is formed adjacent to the lower end of the outer conductor **321** and the outer conductor **311** is mechanically and electrically connected thereto in surrounding relationship with the opening therein. Connected between the input transmission line conductors **311** and **312** is the radiating probe **313** that serves to radiate the microwave energy within the input transmission line **310** into the coaxial transmission line **320**. The outer conductor **321** extends upwardly toward the sleeve **208** of the lower cooling fin package **207** and is capacitively coupled thereto by the coupler **325**; more particularly, the sleeve **208** surrounds the adjacent portion of the outer conductor **321**, an insulating dielectric sleeve **326** being disposed in and substantially filling the annular space between the concentric conductors **321** and **208**, the sleeve **326** being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon." The inner conductor **322** extends upwardly toward the lower end of the cathode lead **188** and is capacitively coupled thereto by a coupler **330**; more particularly, an outer terminal **302** is connected at the upper end thereof to the conductor **219** that is in turn connected to the cathode lead **208** and is capacitively coupled thereto at the lower end thereof, the terminal **303** extending downwardly beyond the end wall **323** and being disposed within and surrounded by the inner conductor **322**, an insulating and dielectric sleeve **331** being disposed in and substantially filling the annular space between the terminal **303** and the conductor **322**, the sleeve **331** being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon."

The output from the amplifier circuit **300** is taken from the upper end of the crossed-field discharge device **100**, the output being taken from the coaxial transmission line **340** connected to the upper end of the device **100**. More specifically, the coaxial transmission line **340** includes an outer annular conductor **341** within which is disposed an annular inner conductor **342**, the upper ends thereof being interconnected and the space threbetween closed by an end wall **343**. An opening is formed adjacent to the upper end of the outer conductor **341** and the outer conductor **66** of the output transmission line **65** is mechanically and electrically connected thereto in surrounding relationship with the opening therein. Connected between the output transmission line conductors **66** and **67** is the probe **352** that serves to pick up the microwave energy within the output transmission line **340** and to apply the microwave energy to the output transmission line **65**. The outer conductor **341** extends downwardly toward the sleeve **205** of the upper cooling fin package **204** and is capacitively coupled thereto by the coupler **345**. More particularly, the sleeve **205** surrounds the adjacent portion of the outer conductor **341**, an insulating dielectric sleeve **346** being disposed in and substantially filling the annular space between the concentric conductors **341** and **205**, the sleeve **346** being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon." The inner conductor **342** extends downwardly toward the upper end of the cathode lead **178** and is capacitively coupled thereto by a coupler **350**. More particularly, the output terminal **301** is provided having the lower end thereof attached to the bullet coupler **225** that is in direct electrical connection with the upper end of the cathode lead **178** and extends upwardly therefrom and outwardly beyond the end wall **343**, the inner annular conductor **342** surrounding the adjacent portion of the terminal **302**, and an insulating dielectric sleeve **351** being disposed in and substantially filling the annular space between the terminal **302** and the conductor **342**, the sleeve **351** being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon."

The conductor N of the Edison supply network is connected as at **303** to one terminal of the magnet coil **210**, whereby to apply the operating potential to the anode structure **105** of the device **100** through the upper magnet coil **210**, the conductor **211** and the cooling fin **209** that is electrically connected to the anode member **150**. The conductor L2 of the Edison supply network is attached to the terminal **302** that is in turn directly connected to the cathode **180** through the cathode lead **188**. Finally, the other terminal L1 of the Edison supply network is connected to the terminal **301** that is in turn connected to the other cathode **170** through the cathode lead **178**.

The microwave energy to be amplified in the amplifier circuit **300** is applied thereto through the input transmission line **310**, and more particularly, the probe **313** radiates into the coaxial transmission line **320** that is capacitively coupled both to the anode structure **105** and the cathode **180**, thereby to apply the input energy between the anode structure **105** and the cathode **180**. In order to provide a suitable match between the impedance of the transmission line **310** and the impedance of the amplifier circuit **300**, the transmission line **320** preferably has a length equivalent to 5/4 of the wave-length of the energy to be amplified, i.e., the distance between the inner surface of the end wall **323** and a plane normal to the axis of the device **100** and disposed midway between the ends of the anode structure **105** is equivalent to 5/4 of the wavelength of the microwave energy to be amplified. It would also be permissible to connect the transmission line **310** to the transmission line **320** at points spaced 1/4 or 3/4 of the wavelength of the microwave energy to be amplified from the midplane of the device **100**, but for most frequencies to be amplified it is not possible to make the necessary electrical connections at this point as illustrated in FIG. 15.

In order to provide a suitable match between the impedance of the amplifier circuit **300** and the impedance of the output transmission line **65**, the transmission line **340** preferably has a length equivalent to 5/4 of the wavelength of the microwave energy to be amplified, i.e., the distance between the inner surface of the end wall **343** and a plane normal to the axis of the device **100** and disposed midway between the ends of the anode structure **105** is equivalent to 5/4 of the wavelength of the microwave energy to be amplified. It would also be permissible to connect the transmission line **65** at points spaced 1/4 or 3/4 of the wavelength of the microwave energy being amplified from the midplane of the device **100**, but for most frequencies it is not possible to make the necessary electrical connections at this point as illustrated in FIG. 15.

The microwave energy thus injected into the lower end of the amplifier circuit **300** passes into the crossed-field discharge device 100 and specifically along the coaxial transmission line provided by the cooperation between the cathode lead 188 forming one conductor and the anode members 150 thereof forming the other conductor therein, then along the radial passage 190 into the peripheral transmission line sections provided by the cooperation between discharge members 135 and 145 forming one members 110, 130 and 140 forming the other conductor. As the microwave energy passes through the device 100, the R.F. fields associated therewith are reinforced and augmented by interaction with the electrons that pass from the electron discharge members 134 and 145 to the anode members 110, 130 and 140. It is believed that the amplifier circuit 300 operates in accordance with the M-type fast wave interaction principle, whereby the input microwave energy in passing through the interaction spaces 120 interacts with the fields disposed therein, and the power content of the microwave energy is augmented and amplified so that a microwave energy output is obtained between the anode structure 105 and the cathode 170 at the other end of the device 100 that has the same frequency as the microwave energy supplied through the input transmission line 310, but has a power content substantially greater than the power content of the microwave energy supplied via the transmission line 310.

The output microwave energy appears between the conductors 341 and 342, the conductor 341 being capacitively coupled by the coupler 345 to the sleeve 205 and the conductor 342 being capacitively coupled by the coupler 340 to the cathode lead 178. The microwave energy in the transmission line 340 formed by the concentric conductors 341 and 342 is coupled by the probe 352 to the output transmission line 65, and specifically between the outer conductor 66 and the inner conductor 67 thereof.

It is pointed out that there is no cutoff frequency for the amplifier circuit 300 since the device 100 essentially comprises an open ended transmission line formed by the cooperation of the cathode leads 178 and 188 serving as one conductor and the anode members 150 serving as the other conductor, whereby a wide spectrum of microwave energy can be amplified utilizing the amplifier circuit 300. The power gain, however, is a function of the bandwidth of the system which is determined by the Q of the cavity that is formed by the cooperation of the input transmission line 320 and the device 100; a large bandwidth requiring a lower Q results in a lower power gain, and conversely, a small bandwidth requiring a higher Q results in a higher power gain. The power gain is also a function of the width of the interaction spaces 120 in the device 100, i.e., the radial distance between the surface 176 of the electron discharge member 175 (for example) and the wall 126 or 136 (for example) of the interaction space 120, a greater width of the interaction space 160 providing a greater power gain, and conversely, a smaller width of the interaction space 160 providing a smaller power gain.

To further illustrate the characteristics of the amplifier circuit 300, there are illustrated in FIG. 15 test connections to the input transmission line 310 and the output transmission line 65 by means of which other characteristics of the amplifier circuit 300 may be illustrated. The oscillator 200 as illustrated in FIG. 15 has the output thereof connected by a transmission line 370 to the input of an attenuator 372, a wave meter 371 also being connected to the transmission line 370 so that the frequency of the microwave energy supplied to the transmission line 370 can be monitored. The output from the attenuator 372 is applied by a transmission line 373 to the input of a tuner 374 which in turn has the output thereof connected to the input transmission line 310. The output transmission line 65 is conencted to the input of an output tuner 375 that in turn is connected by a transmission line 376 to a load 378 by which the power provided from the amplifier circuit 300 can be measured; also connected to the transmission line 376 is a wave meter 377 by which the frequency of the microwave energy within the transmission line 376 can be monitored.

In a first test of the amplifier circuit 300, the operating potentials were removed therefrom, i.e., the operating potentials applied via the conductors L1, L2 and N were removed; the input and output tuners 374 and 375, respectively, were adjusted to give maximum power transfer from the oscillator 200 into the load 378. When the operating potentials were then applied to the amplifier circuit 300 via the conductors L1, L2 and N, the amount of microwave energy delivered to the load 378 was found to increase in proportion to the input power. The efficiency of amplification obtained was of the same order as that found when the device 100 was operated as a power oscillator as described above with reference to FIG. 3.

The frequency of the output energy delivered to the load 378 was then measured by means of the wave meter 377, and it was found that a single frequency of microwave energy was present in the transmission line 376, that frequency being the frequency of operation of the oscillator 200 as determined by the wave meter 371. The frequency of operation of the oscillator 200 was then varied to determine whether the frequency of the output was due to the tuning of the circuits in the amplifier circuit 300, and it was found that the output frequency of the amplified microwave energy as measured by the wave meter 377 varied directly in accordance with the variations in the frequency of operation of the oscillator 200 as determined by the wave meter 371, whereby it was concluded that there was no electronic tuning effect in the amplifier circuit 300. Further to verify that there was no operation of the amplifier circuit 300 as an oscillator, the operating potentials were removed from the oscillator 200 so that no output was obtained therefrom as measured by the wave meter 371. The output from the amplifier circuit 300 immediately dropped to zero indicating that there were no oscillations in the amplifier circuit 300, whereby to verify that the operation of the circuit 300 was truly as an amplifier and not as an oscillator.

Finally, the microwave energy to the amplifier circuit 300 was varied by means of the attenuator 372 over the range from 1 watt to 100 watts. It was determined that there was stable operation of the amplifier circuit 300 over the entire range of power input, the output from the amplifier circuit 300 as measured by the load 378 being directly proportional to the power supplied as an input to the amplifier circuit 300 via the input transmission line 310.

There further are illustrated in FIG. 15 additional connections to the amplifier circuit 300 to accommodate the application of modulating signals thereto. More specifically, there is provided a resistor 380 having one terminal thereof connected by a conductor 381 to the tubular conductor 208 that is connected to the lower anode member 150 of the device 100, the conductor 381 also being connected to a terminal 382; and the other terminal of the resistor 380 is connected by the conductor L2 to the terminal 302 that is directly connected to the cathode 180, the conductor L2 also being connected to a terminal 383. Accordingly, it will be seen that the input terminal 382 is directly connected to the anode structure 105 and the input terminal 383 is connected to the cathode 180 of the device 100. A modulating signal can be applied between the input terminals 382 and 383, whereby to modulate the amplitude of the microwave energy supplied by the output of the amplifier circuit 300 to the output transmission line 65.

From the above it will be seen that there have been provided an improved crossed-field discharge device, an improved microwave oscillator circuit incorporating the crossed-field discharge device therein, an improved amplifier circuit incorporating the crossed-field discharge device therein and an improved modulating circuit incorporating the crossed-field discharge device therein which fulfill all of the objects and advantages set forth above. 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 having an anode structure and two cathode structures. The device is particularly adapted for operation with low voltage alternating applied potentials between the anode and the cathode thereof, the device providing full-wave rectification of the applied alternating potentials.

While there have been described what are at present considered to be the preferred embodiments of the invntion, 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 is claimed is:

1. A crossed-field electron discharge device comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial transmission line sections each including a hollow outer conductor and an inner conductor, said peripheral inner conductors each including electron emissive portions, means coupling said peripheral transmission line sections to said inner transmission line at equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through said peripheral outer conductors parallel to the axes thereof, and means for establishing unidirectional electrical fields between the inner and outer conductors of said peripheral transmission line sections extending normal to the axes thereof for causing electron emission from the associated peripheral inner conductors, whereby the electrons emitted from said peripheral inner conductors interact with said magnetic fields and said electrical fields to generate microwave energy within said peripheral transmission line sections, said coupling means coupling microwave energy from said peripheral transmission line sections to said inner transmission line for propagation to a load.

2. The crossed-field electron discharge device set forth in claim **1**, wherein said inner coaxial transmission line and said peripheral coaxial transmission line sections are all circular in transverse cross section.

3. The crossed-field electron discharge device set forth in claim **1**, wherein the longitudinal axes of said peripheral coaxial transmission line sections are parallel to the longitudinal axis of said inner coaxial transmission line.

4. The crossed-field electron discharge device set forth in claim **1**, wherein said coupling means are disposed substantially normal to the longitudinal axis of said inner coaxial transmission line.

5. The crossed-field electron discharge device set forth in claim **1**, wherein each of said peripheral coaxial transmission line sections has an axial extent equal to one-half of the wavelength of the operating frequency of said device.

6. The crossed-field electron discharge device set forth in claim **1**, wherein the ends of each of said peripheral coaxial transmission line sections are closed.

7. The crossed-field electron discharge device set forth in claim **1**, wherein the longitudinal axes of said peripheral coaxial transmission line sections are parallel to the longitudinal axis of said inner coaxial transmission line and are equiangularly arranged around the periphery thereof.

8. The crossed-field electron discharge device set forth in claim **1**, and further comprising means coupling adjacent ones of said peripheral transmission line sections circumferentially around said inner coaxial transmission line.

9. A crossed-field electron discharge device comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial transmission line sections each including a hollow outer conductor and an inner conductor, said peripheral inner conductors each including electron emissive portions, means coupling said peripheral transmission line sections to said inner transmission line at equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through said peripheral outer conductors parallel to the axes thereof, and means for applying an alternating voltage between the inner and outer conductors of said peripheral transmission line sections, each of said peripheral transmission line sections rectifying the alternating voltage for establishing a unidirectional electrical field therein normal to the axis thereof and for causing electron emission from the associated peripheral inner conductor, whereby the electrons emitted from said peripheral inner conductors interact with said magnetic fields and said electrical fields to generate microwave energy within said peripheral transmission line sections, said coupling means coupling microwave energy from said peripheral transmission line sections to said inner transmission line for propagation to a load.

10. A crossed-field electron discharge device comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial trasmission line sections each including a hollow outer conductor and an inner conductor, said peripheral inner conductors each including electron emissive portions, means coupling said peripheral transmission line sections to said inner transmission line at equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through said peripheral outer conductors parallel to the axes thereof, and means for applying an alternating voltage between the inner and outer conductors of said peripheral transmission line sections wherein the alternating voltage has an R.M.S. value no greater than about 250 volts, each of said peripheral transmission line sections rectifying the alternating voltage for establishing a unidirectional electrical field therein normal to the axis thereof and for causing electron emission from the associated peripheral inner conductor, whereby the electrons emitted from said peripheral inner conductors interact with said magnetic fields and said electrical fields to generate microwave energy within said peripheral transmission line sections, said coupling means coupling microwave energy from said peripheral transmission line sections to said inner transmission line for propagation to a load.

11. A crossed-field electron discharge device comprising an annular anode structure defining therein an inner axially extending storage space extending therethrough and a plurality of outer interaction spaces disposed around said storage space and a radially extending passage interconnecting said interaction spaces and said storage space at equiangularly spaced points around the periphery thereof, cathode structure disposed within said anode structure and including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, said anode structure including said storage space and said interaction spaces and said radially extending passage therein defining a frequency determining resonant cavity for said device, and end structures enclosing both the ends of said anode structure and said axially extending spaces.

12. The crossed-field electron discharge device set forth in claim **11**, wherein the ends of said storage space are open and the ends of said interaction spaces are closed.

13. The crossed-field electron discharge device set forth in claim **11**, wherein the length of said radially extending passage is substantially less than the wavelength of the operating frequency of said device.

14. The crossed-field electron discharge device set forth in claim 11, wherein said annular anode structure further defines a plurality of circumferentially extending passages interconnecting adjacent interaction spaces.

15. A crossed-field electron discharge device comprising an annular anode structure defining therein an inner axially extending storage space extending therethrough and a plurality of outer axially extending interaction spaces disposed equiangularly around said storage space and a radially extending passage interconnecting said interaction spaces and said storage space, cathode structure disposed within said anode structure and including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, said anode structure including said storage space and said interaction spaces and said radially extending passage therein defining a frequency determining resonant cavity for said device, and end structures enclosing both the ends of said said anode structure and said axially extending spaces.

16. The crossed-field electron discharge device set forth in claim 15, wherein said interaction spaces are symmetrical with respect to a plane normal to the longitudinal axis of said storage space.

17. The crossed-field electron discharge device set forth in claim 15, wherein said radially extending passage communicates with each of said interaction spaces at the longitudinal midpoint thereof and communicates with said storage space at the longitudinal midpoint thereof.

18. A crossed-field electron discharge device comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, cathode structure disposed between said first anode member and said second anode members and including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, and ends structures enclosing the ends of said anode structures and said interaction spaces, said anode members defining a frequency determining resonant cavity for said device.

19. The crossed-field electron discharge device set forth in claim 18, wherein the inner axially extending space and the interaction spaces are circular in shape normal to the longitudinal axes thereof.

20. The crossed-field electron discharge device set forth in claim 19, wherein each of said electron discharge members has a diameter approximately one-third the diameter of its corresponding interaction space.

21. The crossed-field electron discharge device set forth in claim 18, wherein said cathode structure cooperates with those portions of said second anode members which define said inner axially extending space to define a first coaxial transmission line and said electron discharge members cooperate with those portions of said first and second anode members which define said interaction spaces to define a plurality of second transmission lines, said lateral passage connecting said first transmission line to each of said second transmission lines.

22. A crossed-field electron discharge device comprising, an annular first anode member defining therein an axially extending space extending therethrough, said first anode member having a plurality of arcuate first recesses in the inner surface thereof disposed equiangularly therearound and extending axially thereof, two cylindrical second anode members, each of said second anode members having a plurality of arcuate second recesses in the outer surface thereof disposed equiangularly therearound and extending axially thereof, said second recesses in each of said second anode members being respectively disposed opposite said first recesses in said first anode member and cooperating therewith to define a plurality of axially extending interaction spaces, two cathode members, each of said cathode members including a plurality of axially extending electron discharge members, said cathode members being respectively disposed in said axially extending space and being axially spaced apart with respect to each other, said electron discharge members being respectively disposed in said interaction spaces along the axes thereof, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, and end structures enclosing the ends of said anode members and said electron discharge members and said interaction spaces.

23. The crossed-field electron discharge device set forth in claim 22, wherein each of said arcuate first recesses is part-circular in shape normal to the longitudinal axis thereof and each of said arcuate second recesses is part-circular in shape normal to the longitudinal axis thereof, cooperating first and second recesses having the same radius and center of curvature.

24. The crossed-field electron discharge device set forth in claim 22, and further including two annular pole pieces respectively disposed adjacent to the ends of said first anode member, said pole pieces respectively closing the ends of said interaction spaces.

25. The crossed-field electron discharge device set forth in claim 22, wherein said first and second anode members further define therebetween a plurality of circumferentially extending passages interconnecting adjacent ones of said interaction spaces.

26. A crossed-field electron discharge device comprising an annular first anode member defining therein an axially extending space extending therethrough, said first anode member having a plurality of arcuate first recesses in the inner surface thereof disposed equiangularly therearound and extending axially thereof, two cylindrical second anode members, each of siad second anode members having a plurality of arcuate second recesses in the outer surface thereof disposed equiangularly therearound and extending axially thereof, the number of said second recesses in each of said second anode members being equal to the number of said first recesses in said first anode member, said second anode members being respectively disposed in said axially extending space and axially spaced apart with respect to each other, said second recesses in each of said second anode members being respectively disposed opposite said first recesses in said first anode member and cooperating therewith to define a plurality of axially extending interaction spaces, two cathode members, each of said cathode members including a circular plate having a lead extending outwardly therefrom, each of said circular plates carrying a plurality of axially extending electron discharge members, said cathode members being respectively disposed in said axially extending space with said circular plates axially spaced apart a predetermined distance with respect to each other, said electron discharge members being carried by the associated circular plate adjacent to the periphery thereof and being respectively disposed in said interaction spaces along the axes thereof, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, and end structures enclosing the ends of said anode members and said electron discharge members and said interaction spaces.

27. The crossed-field electron discharge device set forth in claim 26, wherein the circular plates of said cathode members are disposed substantially normal to the longitudinal axis of said device with the facing surfaces thereof spaced apart said predetermined distance.

28. The crossed-field electron discharge device set forth in claim 26, wherein each of said electron discharge members is cylindrical in shape, the inner ends of said electron discharge members being integral with their coresopnding circular plate, and the outer ends of said electron discharge members being substantially coterminous with the adjacent ends of said interaction spaces.

29. The crossed-field electron discharge device set forth in claim 26, wherein each of said interaction spaces has an axial extent substantially equal to one-half of the wavelength of the operating frequency of said device.

30. A crossed-field electron discharge device comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, two cathode structures disposed between said second anode members, each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, said anode members and said cathode structures being symmetrical with respect to a plane normal to the longitudinal axis of said anode structure midway between the ends thereof, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, and end structures enclosing the ends of said anode structures and said interaction spaces.

31. The cross-field electron discharge device set forth in claim 30, wherein said end structures comprise two end seals respectively disposed adjacent to the opposite ends of said device and hermetically sealing said inner axially extending space.

32. A crossed-field electron discharge device for generating microwave energy comprising an enclosing anode structure and a cathode structure therein defining therewith an interaction space, said cathode structure including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, means for applying a low voltage alternating potential between said anode structure and said cathode structure, wherein the alternating potential has an R.M.S. value no greater than about 250 volts, said cathode structure cooperating with said anode structure upon the application of the alternating potential thereto to rectify said alternating potential and thus to provide a unidirectional electrostatic field in said interaction space, said electron discharge member discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within said device, and structure for withdrawing the microwave energy from said device.

33. A crossed-field electron discharge device for generating microwave energy comprising an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, said electron discharge members discharg- netic field through said interaction space, means for applying an alternating voltage between said anode structure and said cathode structures, said cathode structures cooperating with said anode structure upon the application of the alternating voltage therebetween to provide full-wave rectification of said alternating voltage and to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within said device, and structure for withdrawing the microwave energy from said device.

34. The crossed-field electron discharge device set forth in claim 33, wherein said alternating voltage has a frequency of 60 cycles per second.

35. A crossed-field electron discharge device for generating high voltage microwave energy comprising an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, means for applying a low frequency low voltage A.C. operating potential to said cathode structures and a neutral potential to said anode structure, wherein said operating potential has an R.M.S. value no greater than said anode structure upon the application of the operating potential thereto to provide full-wave rectification of about 250 volts, said cathode structures cooperating with the A.C. operating potential and thus to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field to generate microwave energy within said device, and output structure for withdrawing high voltage microwave energy from said device.

36. A crossed-field electron discharge device comprising an annular anode structure defining therein an inner axially extending storage space extending therethrough and a plurality of outer interaction spaces disposed around said storage space and a radially extending passage interconnecting said interaction spaces and said storage space at equiangularly spaced points around the periphery thereof, cathode structure disposed within said anode structure and including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, means for applying an alternating voltage between said anode structure and said cathode structure, said anode structure cooperating with said cathode structure upon the application of the alternating voltage therebetween to rectify said alternating voltage and to provide a unidirectional electrostatic field in said interaction spaces, said anode structure including said storage space and said interaction spaces and said radially extending passage therein defining a frequency determining resonant cavity for said device, and end structures enclosing both the ends of said anode structure and said axially extending space.

37. A crossed-field electron discharge device comprising an annular anode structure defining therein an inner axially extending storage space extending therethrough and a plurality of outer interaction spaces disposed around said storage space and a radially extending passage interconnecting said interaction spaces and said storage space at equiangularly spaced points around the periphery thereof, cathode structure disposed within said anode structure and including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, means for applying a low voltage alternating potential between said anode structure and said cathode structure wherein the alternating potential has an R.M.S. value no greater than about 250 volts, said cathode structure cooperating with said anode structure upon the application of the alternating potential thereto to rectify said alternating potential and thus to provide a unidirectional electrostatic field in said in interaction space, said anode structure including said axially ex-

tending interaction spaces and said radially extending passage therein defining a frequency determining resonant cavity for said device, and end structures enclosing both the ends of said anode structure and said axially extending space.

38. A system for generating high voltage microwave energy comprising a device including an enclosing anode structure and a cathode structure therein defining therewith an interaction space, said cathode structure including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, a source of low-frequency low-voltage A.C. operating potential including two conductors each provided with a terminal, means galvanically connecting said terminals to said anode structure and said cathode structure respectively, said cathode structure cooperating with said anode structure upon the application of the operating potential thereto to rectify said operating potential and to provide a unidirectional electronic field in said interaction space, said electron discharge member discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within said device, and structure for withdrawing the microwave energy from said device.

39. A system for generating high voltage microwave energy comprising a device including an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, a source of low frequency low voltage A.C. operating potentials including two line conductors and a neutral conductor each provided with a corresponding terminal, means galvanically connecting the terminals of said two line conductors, respectively to said cathode structures and galvanically connecting the terminal of said neutral conductor to said anode structure, said cathode structures cooperating with said anode structure upon the application of said operating potentials therebetween to provide full-wave rectification of said operating potentials and thus to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within said device, and output structure for withdrawing high voltage microwave energy from said device.

40. A system for generating microwave energy comprising a device including an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, a source of alternating voltage operating potentials including two line conductors respectively coupled to said cathode structures and a neutral conductor coupled to said anode structure, said cathode structures cooperating with said anode structure upon the application of the alternating voltage therebetween to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field to generate microwave energy within said device, and output structure coupled to said anode structure and one of said cathode structures for withdrawing microwave energy from said device, whereby upon application of the alternating voltage operating potentials to said device, microwave energy can be extracted therefrom via said output structure utilizing said one cathode structure as a probe.

41. The system set forth in claim **40**, wherein said means for establishing a unidirectional magnetic field comprises an electromagnetic field coil coupled between said anode structure and said neutral conductor.

42. The system set forth in claim **41**, and further including a first low-pass filter means coupled between one of said cathode structures and one of said line conductors, a second low-pass filter means coupled between the other of said cathode structures and the other of said line conductors, and a by-pass capacitor connected in parallel with said field coil, whereby microwave energy from said device is prevented from entering said source of alternating voltage.

43. The system set forth in claim **40**, wherein said output structure includes capacitive coupling means to provide a D.C. block in the output of said device.

44. A system for generating high voltage microwave energy comprising a device including an enclosing anode structure and a cathode structure therein defining therewith an interaction space, said cathode structure including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, means for applying an alternating voltage between said anode structure and said cathode structure, said cathode structure cooperating with said anode structure upon the application of said alternating voltage therebetween to provide a unidirectional electrostatic field in said interaction space, said electron discharge member discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field to generate microwave energy within said device, starting means coupled to said anode structure and said cathode structures for providing a high starting voltage pulse between said anode structure and said cathode structure, and structure for withdrawing microwave energy from said device.

45. A system for generating high voltage microwave energy comprising a device including an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, means for applying an alternating voltage between said anode structure and said cathode structures, said cathode structures cooperating with said anode structure upon application of said alternating voltage therebetween to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field to generate microwave energy within said device, starting means coupled to said anode structure and one of said cathode structures for providing a high starting voltage pulse between said anode structure and said cathode structure, and structure for withdrawing microwave energy from said device.

46. A system for generating high voltage microwave energy comprising a device including an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, energizing means for applying an alternating voltage between said anode structure and said cathode structures, said cathode structures cooperating with said anode structure upon the application of said alternating voltage therebetween to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field to generate microwave energy within said device, starting means coupled to said anode structure and one of said cathode structures for providing a high starting voltage pulse between said anode structure and said cathode structure, said starting means including a capacitor having two terminals and a switching means having two normally open contacts, one terminal of said capacitor being coupled to one of said cathode structures and the other terminal thereof being connected to one contact of said switching means, the other contact of said switching means being coupled to said anode structure, whereby upon closing of said switch contacts a high starting voltage pulse is applied between said anode structure and said cathode structure.

47. The system set forth in claim **46**, wherein said means for establishing a unidirectional magnetic field comprises an electromagnetic field coil coupled between said energizing means and said anode structure, the common connection between said field coil and said anode structure being coupled to said other contact of said switching means, whereby upon closing of said switch contacts said starting means cooperates with said field coil to supply an initial magnetic field for said device.

48. A microwave oscillator comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial transmission line sections each including a hollow outer conductor and an inner conductor, said peripheral inner conductors each including electron emissive portions, means coupling said peripheral transmission line sections to said inner transmission line at equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through said peripheral outer conductors parallel to the axes thereof, and means for establishing unidirectional electrical fields between the inner and outer conductors of said peripheral transmission line sections extending normal to the axes thereof for causing electron emission from the associated peripheral inner conductors, whereby the electrons emitted from said peripheral inner conductors interact with said magnetic fields and said electrical fields to generate microwave energy within said peripheral transmission line sections, said inner coaxial transmission line and said peripheral coaxial transmission line sections and said coupling means defining a frequency determining resonant cavity for said oscillator.

49. A microwave oscillator comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, cathode structure disposed between said first anode member and said second anode members and including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, means for establishing a unidirectional electrical field in said interaction spaces normal to the axes thereof, and end structures enclosing the ends of said anode members and said electron discharge members and said interaction spaces; said first anode member and said second anode members and said cathode structure defining a frequency determining resonant cavity for said oscillator.

50. The microwave oscillator set forth in claim **49**, and further including output connections respectively coupled to said anode structure and said cathode structure, said unidirectional electrical field and said unidirectional magnetic field and said resonant cavity cooperating to establish an axially extending R.F. wave in said interaction spaces and having associated therewith R.F. electrical fields and R.F. magnetic fields normal to the longitudinal axis of said device and disposed in said interaction spaces, said output connections removing R.F. energy from said interaction spaces utilizing said cathode structure as a probe interacting with said R.F. fields.

51. A microwave oscillator comprising an annular first anode member defining therein an axially extending space extending therethrough, said first anode member having a plurality of arcuate first recesses in the inner surface thereof disposed equiangularly therearound and extending axially thereof, two cylindical second anode members, each of said second anode members having a plurality of arcuate second recesses in the outer surfaces thereof disposed equiangularly therearound and extending axially thereof, the number of said second recesses in each of said second anode members being equal to the number of said first recesses in said first anode member, said second anode members being respectively disposed in said axially extending space and axially spaced apart with respect to each other, said second recesses in each of said second anode members being respectively disposed opposite said first recesses in said first anode member and cooperating therewith to define a plurality of axially extending interaction spaces, two cathode members, each of said cathode members including a plurality of axially extending electron discharge members, said cathode members being respectively disposed in said axially extending space and being axially spaced apart with respect to each other, said electron discharge members being respectively disposed in said interaction spaces along the axes thereof, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, and means for establishing a unidirectional electrostatic field in said interaction spaces normal to the axes thereof, and structures enclosing the ends of said anode members and said electron discharge members and said interaction spaces, said anode members and said cathode members cooperating to define a frequency determining resonant cavity for said oscillator.

52. A microwave oscillator comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, two cathode structures disposed between said second anode members, each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, said anode members and said cathode structures being symmetrical with respect to a plane normal to the longitudinal axis of said anode structure midway between the ends thereof, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, means for establishing a unidirectional electrostatic field in said interaction spaces normal to the axes thereof, and end structures enclosing the ends of said anode structures and said interaction spaces, said anode structure and said cathode structures cooperating to define a frequency determining resonant cavity for said oscillator.

53. A microwave oscillator comprising an enclosing anode structure and two spaced-apart cathode structures in said anode structure and cooperating therewith to define an interaction space, each of said cathode structures including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, means for applying an alternating voltage between said anode structure and said cathode structures, said cathode structures cooperating with said anode structure upon the application of the alternating voltage therebetween to provide full-wave rectification of said alternating voltage and to provide a unidirectional electrostatic field in said interaction space, said electron discharge members discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within said device, and structure for withdrawing the microwave energy from said device, said anode structure and said cathode structures cooperating to define a frequency determining resonant cavity for said oscillator.

54. A microwave oscillator comprising an enclosing anode structure and a cathode structure therein defining therewith an interaction space, said cathode structure including an electron discharge member disposed in said interaction space, means for establishing a unidirectional magnetic field through said interaction space, means for applying a low voltage alternating potential between said anode structure and said cathode structure, wherein the alternating potential has an R.M.S. value no greater than about 250 volts, said cathode structure cooperating with said anode structure upon the application of the alternating potential thereto to rectify said alternating potential and thus to provide a unidirectional electrostatic field in said interaction space, said electron discharge member discharging electrons into said interaction space for interaction with both the magnetic field and the electrostatic field therein to generate microwave energy within said device, and structure for withdrawing the microwave energy from said device, said anode structure and said cathode structure cooperating to define a frequency determining resonant cavity for said oscillator.

55. A microwave oscillator comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, two axially spaced-apart cathode structures disposed between said first anode member and said second anode members, each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, a source of low frequency low voltage A.C. operating potentials including two line conductors and a neutral conductor, each of said conductors being provided with a corresponding terminal, and means galvanically connecting the terminals of said two line conductors respectively to said cathode structures and galvanically connecting the terminal of said neutral conductor to said anode structure, and end structures enclosing the ends of said anode members and said electron discharge members and said interaction spaces; said first anode member and said second anode members and said cathode structures defining a frequency determining resonant cavity for said oscillator.

56. A microwave amplifier comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial transmission line sections each including a hollow outer conductor and an inner conductor, said peripheral inner conductors each including electron emissive portions, means coupling said peripheral transmission line sections to said inner transmission line at equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through said peripheral outer conductors parallel to the axes thereof, and means for establishing unidirectional electrical fields between the inner and outer conductors of said peripheral transmission line sections extending normal to the axes thereof for causing electron emission from the associated peripheral inner conductors, whereby the electrons emitted from said peripheral inner conductors interact with said magnetic fields and said electrical fields to generate microwave energy within said peripheral transmission line sections, a microwave input coupled to said inner coaxial transmission line at one end thereof; a microwave output coupled to said inner coaxial transmission line at the other end thereof; said coupling means coupling microwave energy from said peripheral transmission line sections to said inner transmission line, whereby a microwave signal fed to the microwave input of said amplifier is amplified thereby and the amplified microwave signal appears at the output of said amplifier.

57. A microwave amplifier comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending storage space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said storage space and said interaction spaces, two cathode structures disposed between said first and second anode members each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, said anode members and said cathode structures being symmetrical with respect to a plane normal to the longitudinal axis of said anode structure midway between the ends thereof, means for establishing a unidirectional magnetic field extending axially through said interaction spaces, and means for applying an alternating voltage between said anode structure and said cathode structures, a microwave input coupled between said anode structure and one of said cathode structures at one end of said device; a microwave output coupled between said anode structure and the other of said cathode structures at the other end of said device; said anode structure cooperating with said cathode structures upon the application of the alternating voltage therebetween to produce a unidirectional electrostatic field in said interaction space; whereby a microwave signal fed to the input of said amplifier is amplified thereby and the amplified microwave signal appears at the output of said amplifier.

58. The microwave amplifier set forth in claim **57**, wherein said microwave output includes a pair of output connections respectively coupled to said anode structure and one of said cathode structures, said unidirectional magnetic field and said unidirectional electrical field and said microwave input cooperating to establish an axially extending R.F. wave in said interaction spaces and having associated therewith R.F. electrical fields and R.F. magnetic fields normal to the longitudinal axis of said device disposed in said interaction spaces, said output connections removing energy from said interaction spaces utilizing said one cathode structure as a probe interacting with said R.F. fields.

59. The microwave amplifier set forth in claim **57**, wherein each of said cathode members has a lead, said leads being respectively disposed in said inner axially extending storage space and extending outwardly toward the opposite ends of said device, said microwave input being coupled between said anode structure and one of said leads, said microwave input being coupled between said anode structure and the other of said leads, whereby microwave energy is fed into and withdrawn from said inner axially extending storage space.

60. A microwave amplifier comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending storage space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said storage space and said interaction spaces, two cathode structures disposed between said first and second anode members each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, said anode members and said cathode structures being symmetrical with respect to a plane normal to the longitudinal axis of said anode structure midway between the ends thereof, a source of low frequency low voltage A.C. operating potentials including two line conductors and a neutral conductor, each of said conductors being provided with a corresponding terminal, and means galvanically connecting the terminals of said two line conductors respectively to said cathode structures and galvanically connecting the terminal of said neutral conductor to said anode structure, said anode structure of said cathode structures cooperating upon the application of said operating potentials therebetween to produce a unidirectional electrostatic field in said interaction space; a microwave input coupled between said anode structure and one of said cathode structures at one end of said device; a microwave output coupled between said anode structure and the other of said cathode structures at the other end of said device; means for producing a unidirectional magnetic field extending axially through said interaction spaces; whereby a microwave signal fed to the input of said amplifier is amplified thereby and the amplified microwave signal appears at the output of said amplifier.

61. A microwave circuit comprising an inner coaxial transmission line including a hollow outer conductor and an inner conductor, a plurality of peripheral coaxial transmission line sections each including a hollow outer conductor and an inner conductor, said peripheral inner conductors each including electron emissive portions, means coupling said peripheral transmission line sections to said inner transmission line at equiangularly spaced points around the periphery thereof, means for establishing unidirectional magnetic fields extending through said peripheral outer conductors parallel to the axes thereof, and means for establishing unidirectional electrical fields between the inner and outer conductors of said peripheral transmission line sections extending normal to the axes thereof for causing electron emission from the associated peripheral inner conductors, whereby the electrons emitted from said peripheral inner conductors interact with said magnetic fields and said electrical fields to generate microwave energy within said peripheral transmission line sections, said coupling means coupling microwave energy from said peripheral transmission line sections to said inner transmission line for propagation to a load, and means for applying a modulating signal between the inner and outer conductors of said inner coaxial transmission line for modulating the output of said microwave circuit.

62. A microwave circuit comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, two cathode structures disposed between said second anode members, each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, said anode members and said cathode structures being symmetrical with respect to a plane normal to the longitudinal axis of said anode structure midway between the ends thereof, means for establishing a unidirectional magnetic field through said interaction spaces, means for applying an alternating voltage between said anode structure and said cathode structure, said anode structure cooperating with said cathode structures upon the application of the alternating voltage therebetween to provide a unidirectional electrostatic field in said interaction spaces, and means for applying a modulating signal between said anode structure and one of said cathode structures for modulating the output of said microwave circuit.

63. The microwave circuit set forth in claim **62**, wherein said anode structure and said cathode structures define a frequency determining resonant cavity for said device, whereby said microwave circuit is an oscillator having the output thereof modulated in accordance with the modulating signal applied to said modulating means.

64. The microwave circuit set forth in claim **62**, and further comprising a microwave input coupled between said anode structure and one of said cathode structures; and a microwave output coupled between said anode structure and the other of said cathode structures; whereby said microwave circuit is an amplifier in which the output thereof is modulated in accordance with the modulating signal applied to said modulating means.

65. A microwave circuit comprising an anode structure including an annular first anode member and two annular second anode members disposed within said first anode member, said second anode members cooperating to define an inner axially extending space extending therethrough, said first and second anode members cooperating to define therebetween a plurality of outer axially extending interaction spaces, said second anode members being axially spaced apart to provide a lateral passage therebetween interconnecting said inner axially extending space and said interaction spaces, two cathode structures disposed between said second anode members, each of said cathode structures including a plurality of electron discharge members equal in number to said interaction spaces and respectively disposed therein, said anode members and said cathode structures being symmetrical with respect to a plane normal to the longitudinal axis of said anode structure midway between the ends thereof, means for establishing a unidirectional magnetic field extending axially through said interaction space, a source of low frequency low voltage A.C. operating potentials including two line conductors and a neutral conductor, each of said conductors being provided with a corresponding terminal, means galvanically connecting the terminals of said two line conductors respectively to said cathode structures and galvanically connecting the terminal of said neutral conductor to said anode structure, means for applying an alternating voltage between said anode structure and said cathode structures, and means for applying a modulating signal between said anode structure and one of said cathode structures for modulating the output of said microwave circuit.

No references cited.

JOHN KOMINSKI, Primary Examiner

U.S. Cl. X.R.

315—39.51, 39.63, 39.71, 39.73; 330—47; 332—5

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,559,094 Dated January 26, 1971

Inventor(s) J. 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 28, Claim 26, Line 44, "siad" should be -- said --.

Column 29, Claim 28, Line 5, "corresopnding" should be -- corresponding --.

Column 29, Claim 33, Line 65, after "interaction space," change "said electron discharge member discharge-netic" to -- means for establishing a unidirectional magnetic

Column 30, Claim 35, Line 20, after "the" delete "said anode structure upon the application of the operating potential thereto to provide full-wave rectification of"

Column 30, Claim 35, Line 22, after "with" insert -- said anode structure upon the application of the operating potential thereto to provide full-wave rectification of --.

Signed and sealed this 18th day of May 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents