July 29, 1969 J. E. STAATS 3,458,755

CROSSED-FIELD DISCHARGE DEVICE AND MICROWAVE CIRCUITS INCORPORATING THE SAME

Filed June 21, 1966 12 Sheets-Sheet 1

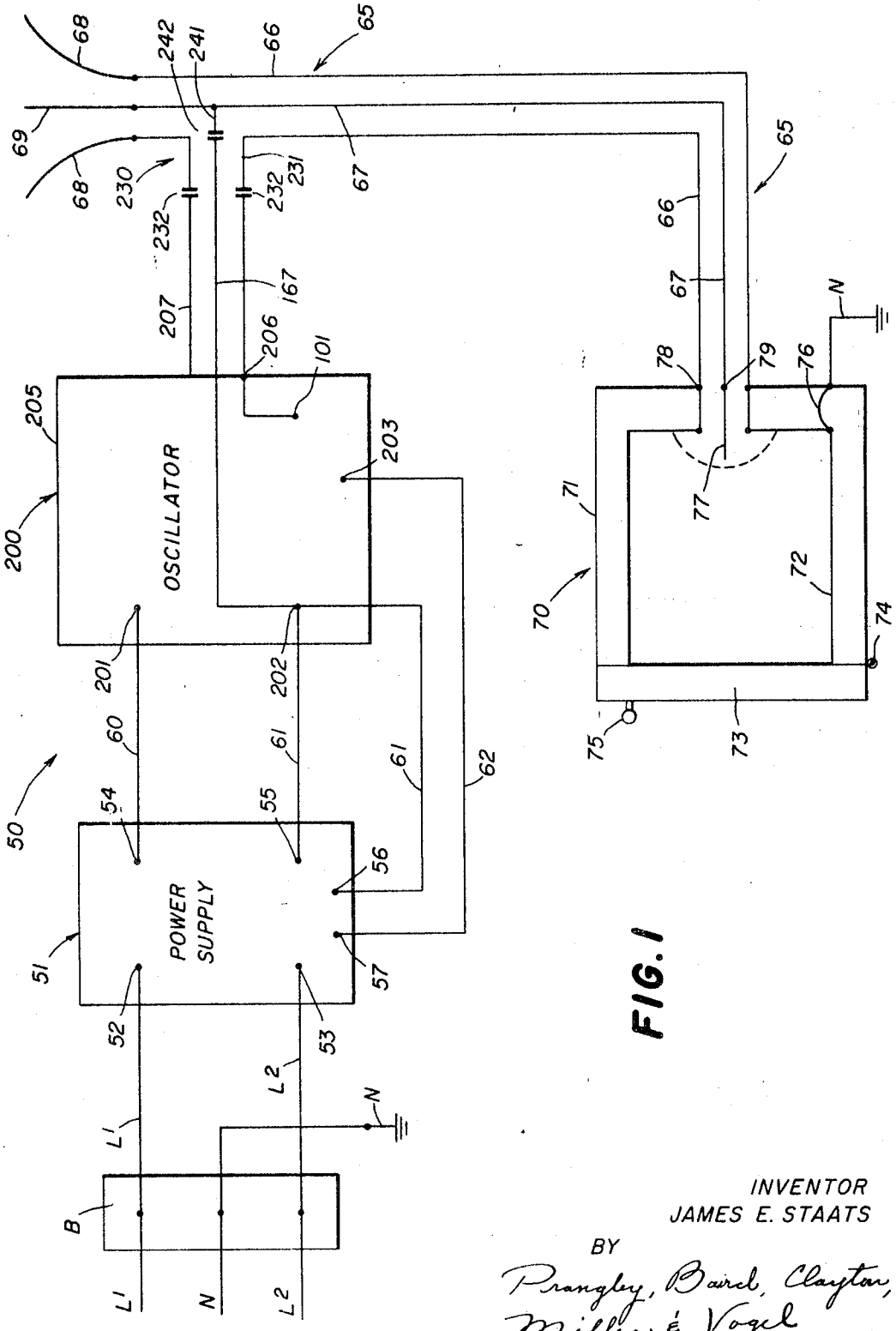
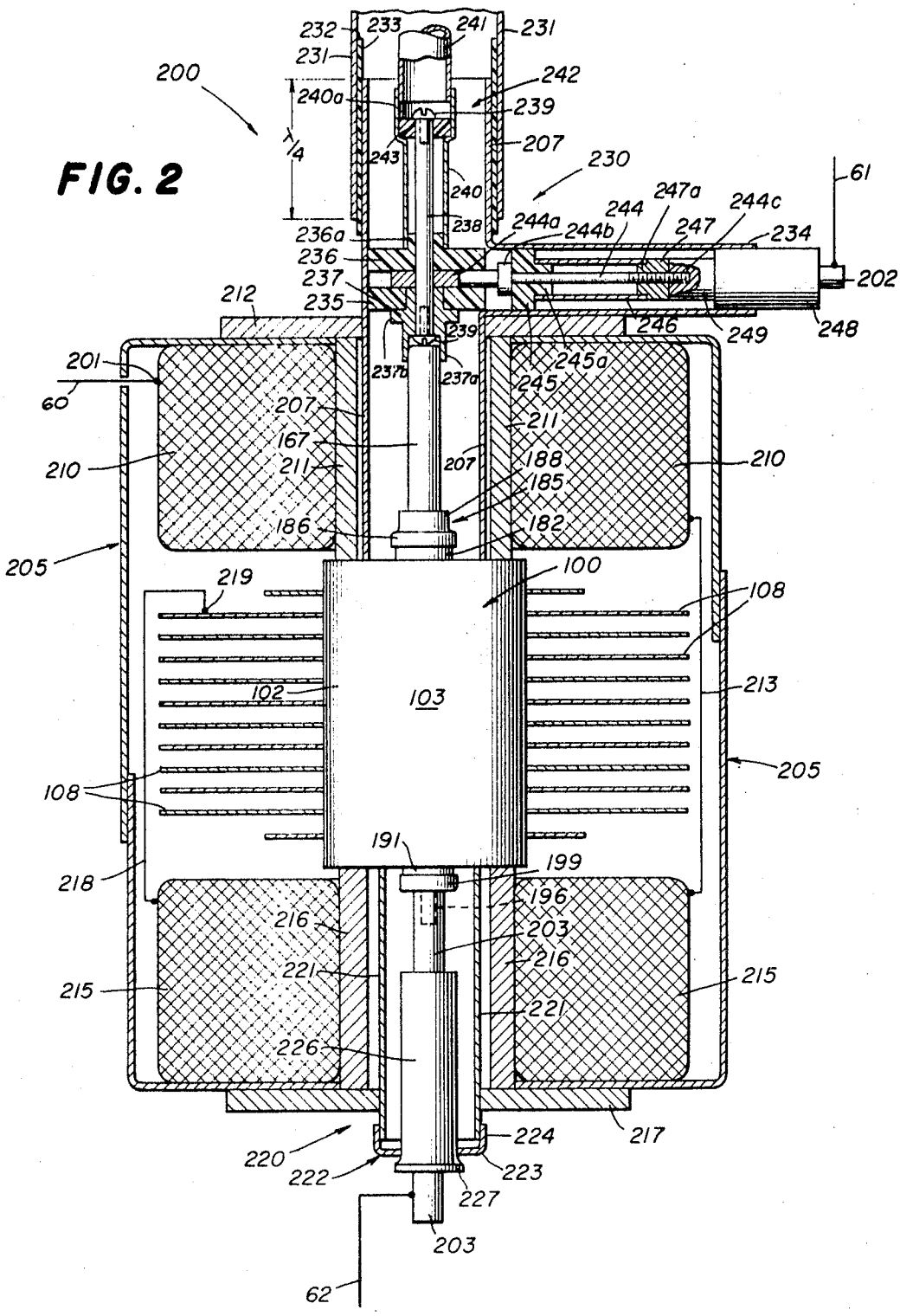


FIG. 1

INVENTOR
JAMES E. STAATS

BY
Prangley, Baird, Clayton, Miller & Vogel ATTYS.

FIG. 2


200
λ/4
232
233
241
231
231
242
240a
239
207
243
230
240
61
247a
244c
244
247
234
244a
244b
238
236a
236
237
235
212
202
246
249
248
239
201
60
245a
245
237b
237a
207
211
167
207
188
210
210
211
185
186
182
205
219
100
108
102
103
213
205
108
191
199
218
196
216
203
216
221
215
215
221
226
224
217
220
222
223
227
203
62

July 29, 1969 J. E. STAATS 3,458,755

CROSSED-FIELD DISCHARGE DEVICE AND MICROWAVE CIRCUITS INCORPORATING THE SAME

Filed June 21, 1966 12 Sheets-Sheet 3

FIG. 3

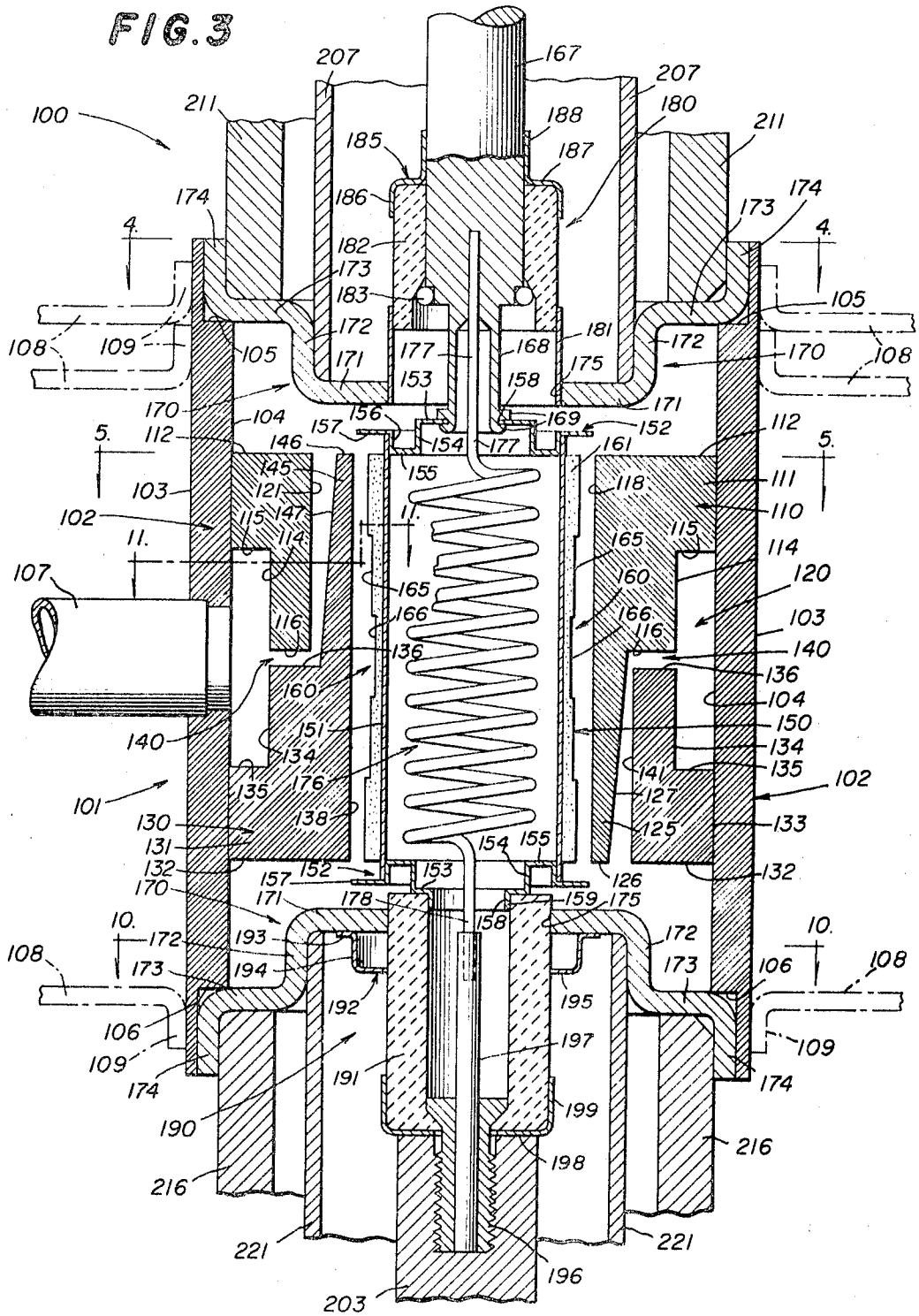


FIG. 4

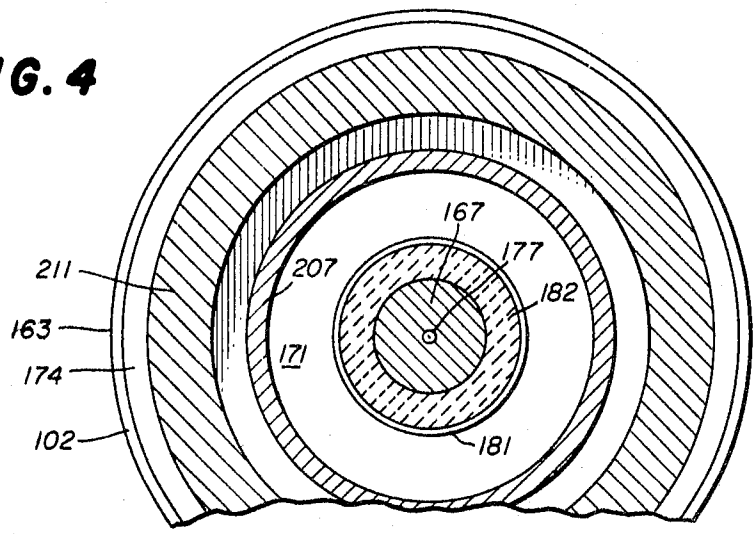

167
177
207
182
211
163
171
174
102
181

FIG. 5

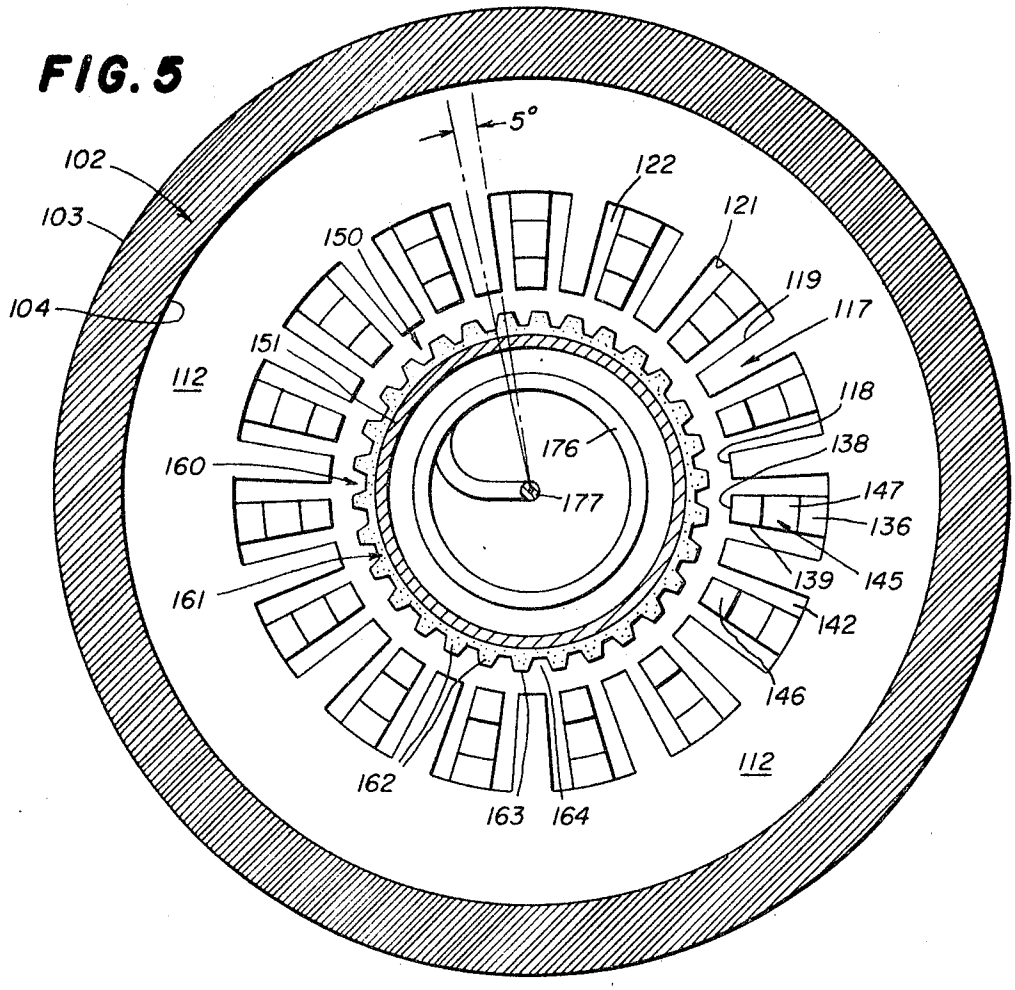

5°
102
122
103
121
150
119
104
117
151
112
118
176
138
160
177
147
136
139
145
161
142
146
162
112
163
164

FIG. 6

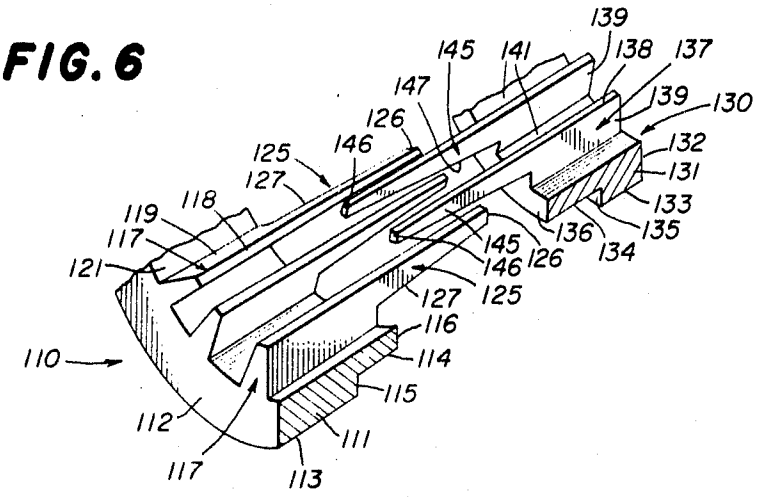


FIG. 7

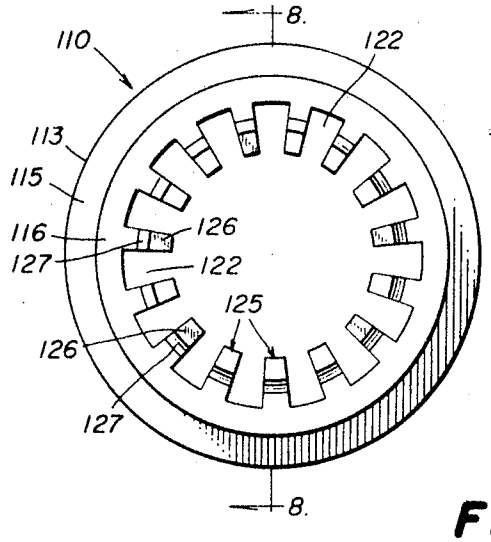


FIG. 8

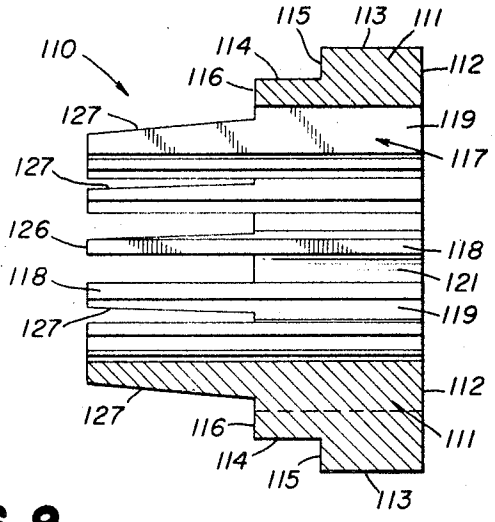


FIG. 9

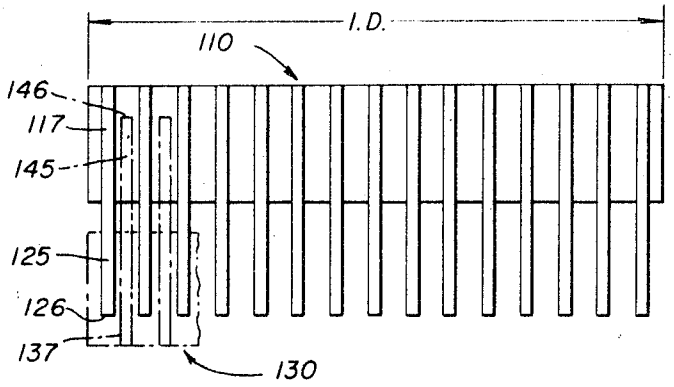


FIG. 10

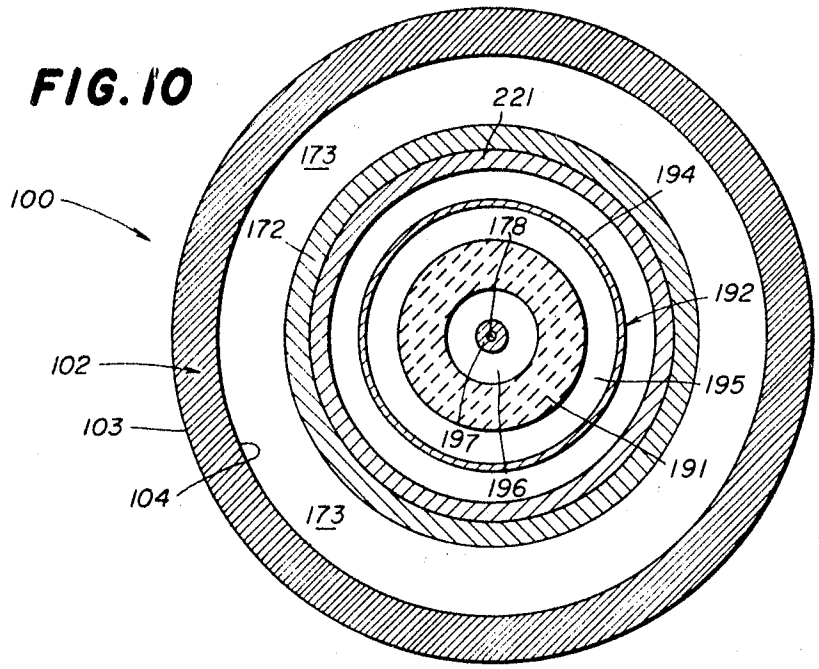

221
173
194
100
172
178
192
102
195
103
197
191
104
196
173

FIG. 11

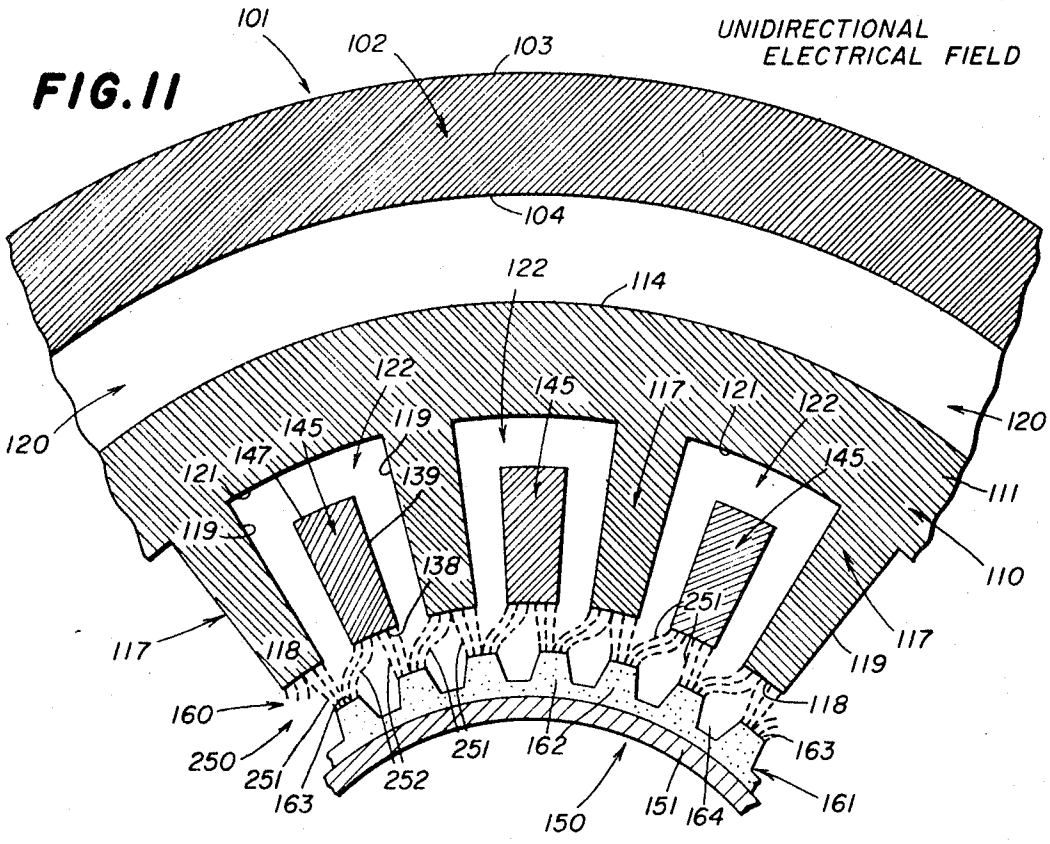

101
102
103
UNIDIRECTIONAL
ELECTRICAL FIELD
104
122
114
122
145
117
121
122
120
120
145
119
147
145
121
139
111
119
110
138
251
117
117
118
119
160
118
250
251
162
163
251
252
163
150
151
164
161

FIG. 12

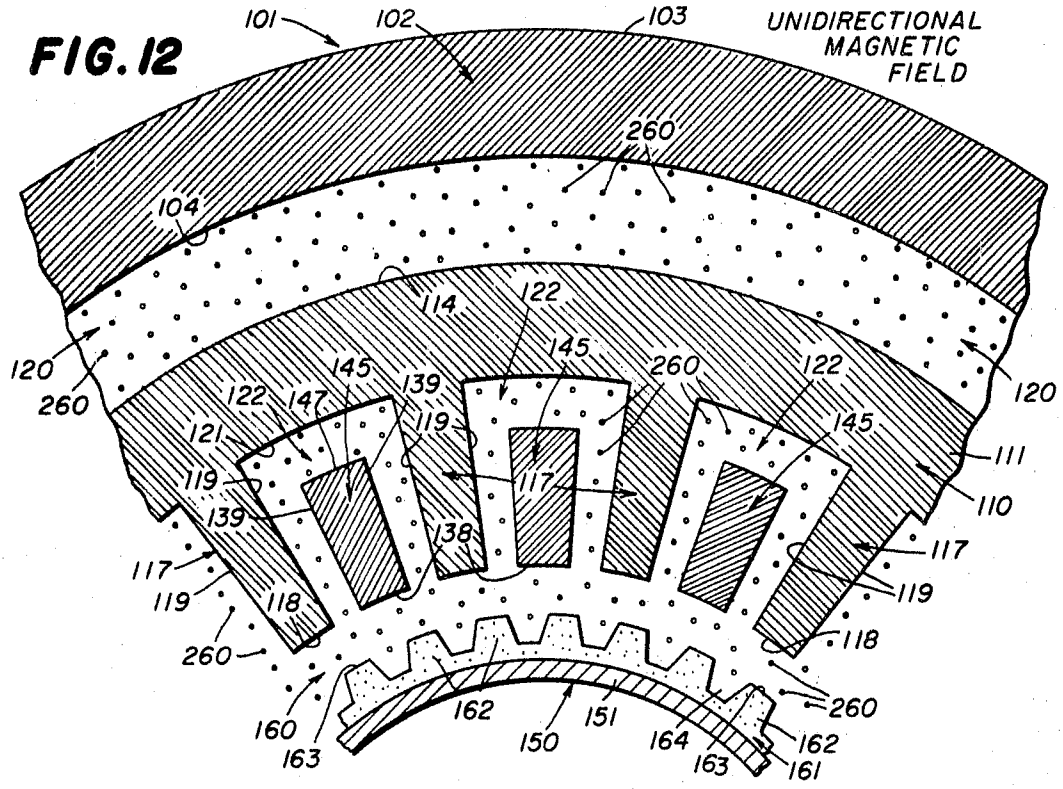

UNIDIRECTIONAL
MAGNETIC
FIELD
101
102
103
104
260
114
122
145
120
147
139
119
121
117
111
110
138
118
162
150
151
164
163
161

FIG. 13

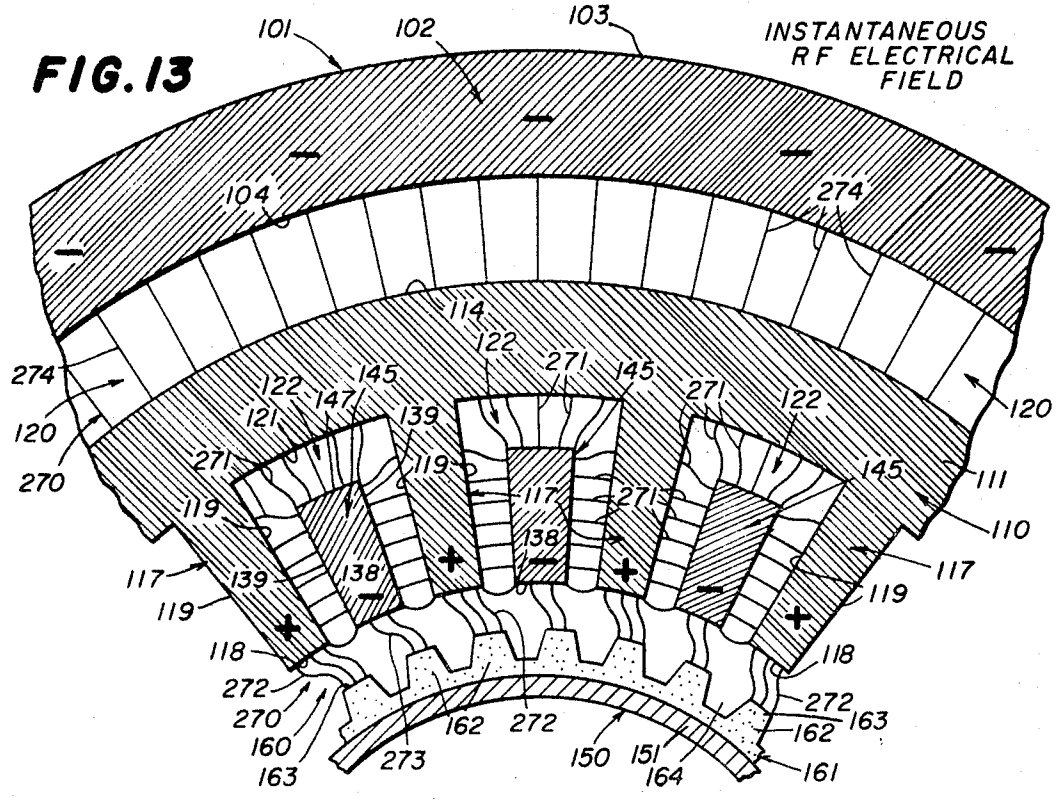

INSTANTANEOUS
RF ELECTRICAL
FIELD
101
102
103
104
274
114
122
271
145
120
147
139
121
270
119
117
111
110
138
118
272
162
150
151
164
163
161

FIG. 15

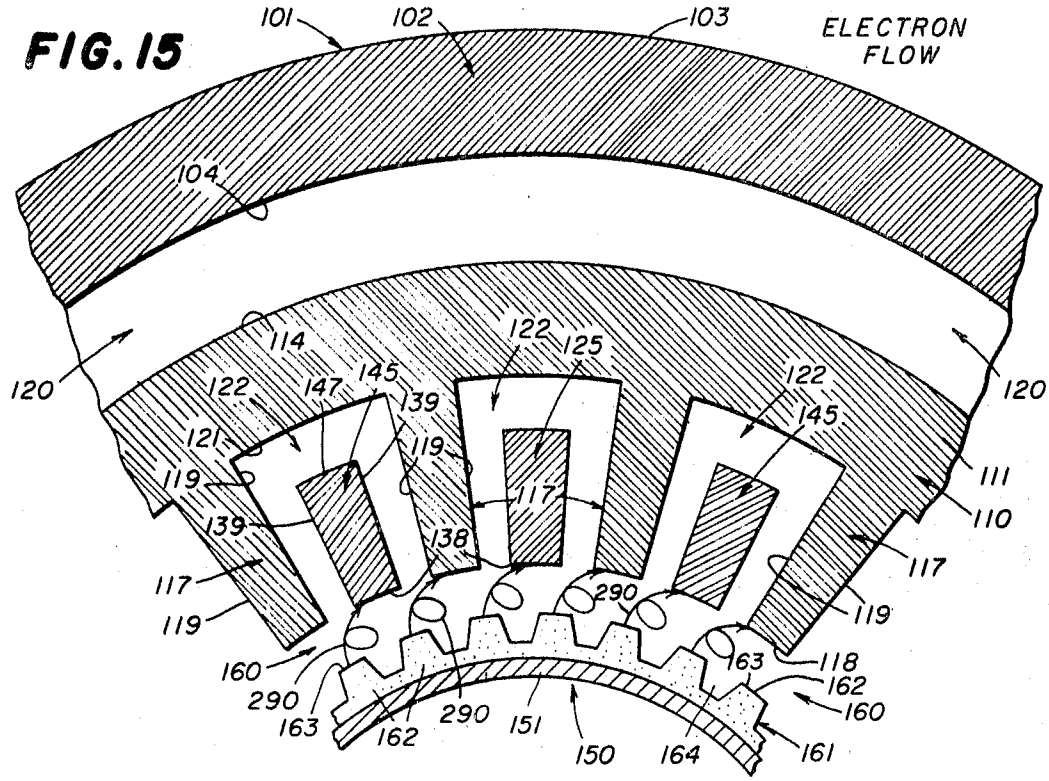
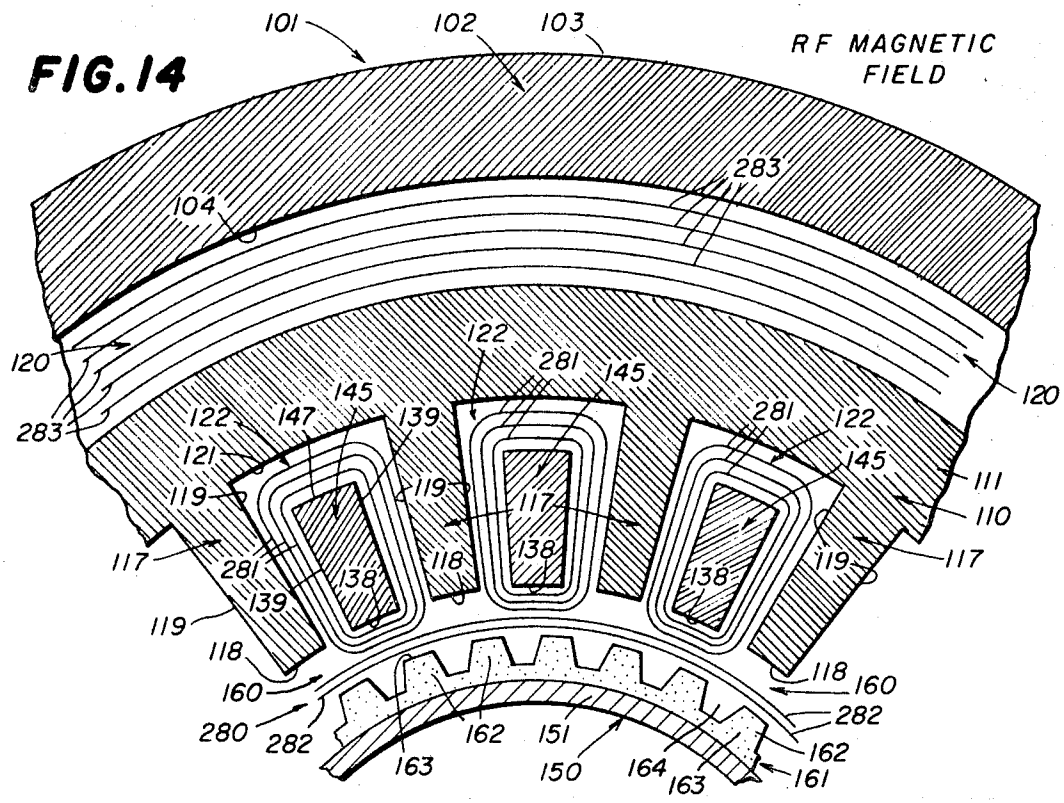

101
102
103
ELECTRON FLOW
104
114
120
122
125
147
145
139
121
119
117
138
290
111
110
160
163
118
162
151
150
164
161

FIG. 14


101
102
103
RF MAGNETIC FIELD
283
104
120
122
281
145
147
139
121
119
117
138
118
111
110
160
280
282
162
151
150
164
163
161

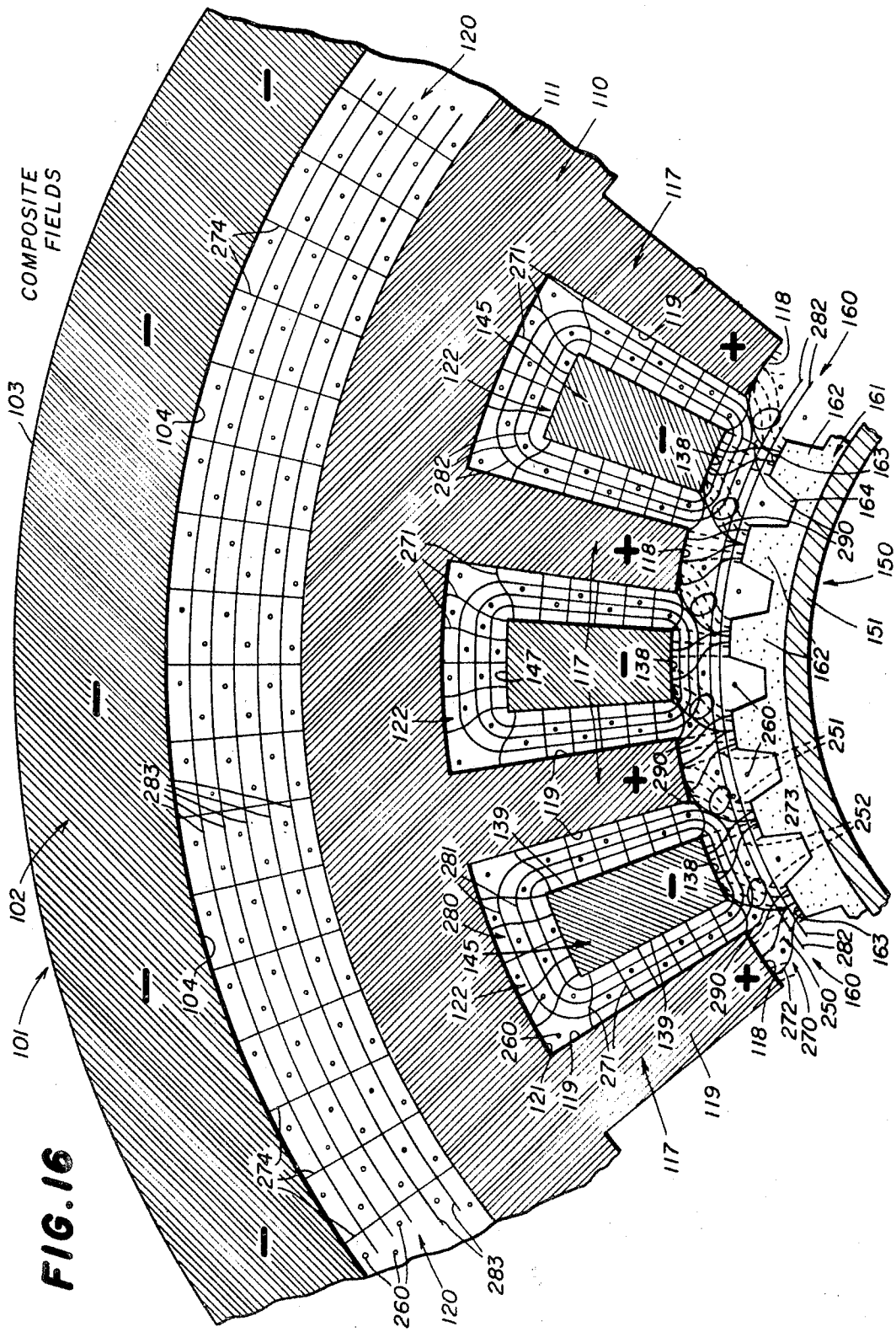
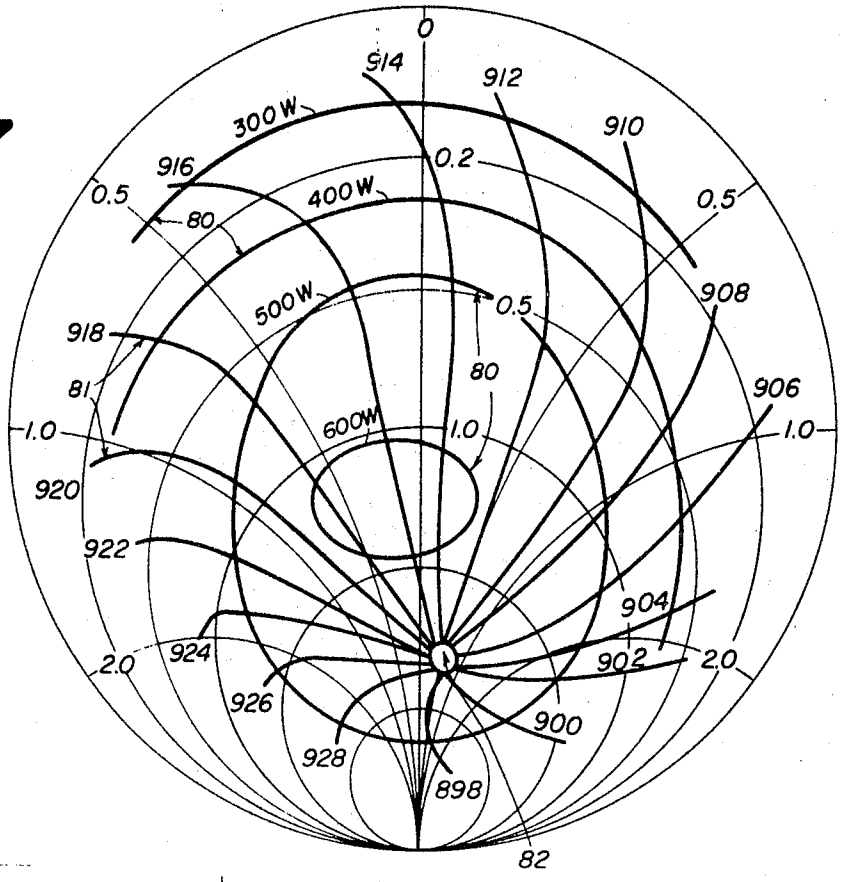

COMPOSITE FIELDS
120
111
110
117
274
271
119
118
282
160
145
122
162
161
104
138
163
164
103
290
150
151
147
260
251
283
273
252
102
139
281
280
101
272
270
250
121
FIG. 16

FIG. 17


0
914
912
910
908
906
904
902
900
898
916
918
920
922
924
926
928
82
300W
400W
500W
600W
0.2
0.5
1.0
2.0
80
81

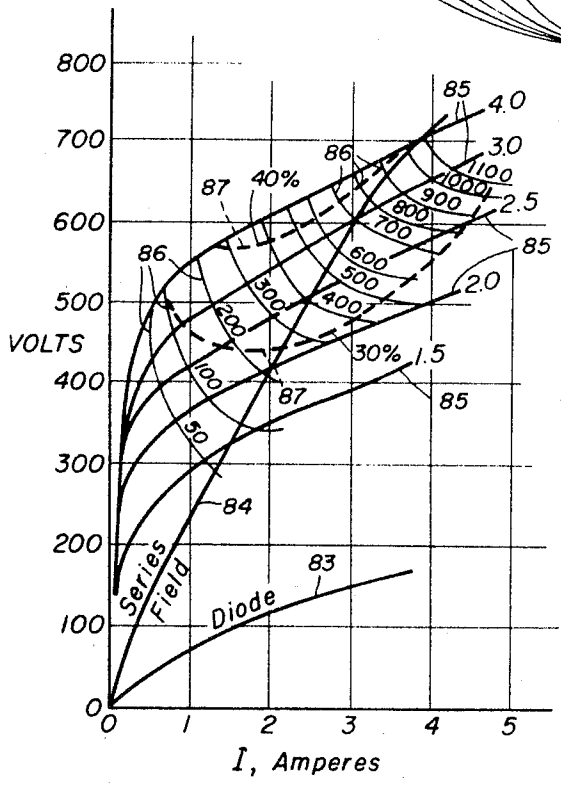

800
700
600
500
400
300
200
100
0
VOLTS
0
1
2
3
4
5
I, Amperes
85
4.0
3.0
2.5
2.0
1.5
86
87
40%
30%
1100
1000
900
800
700
600
500
400
300
200
100
50
84
83
Series Field
Diode

FIG. 18

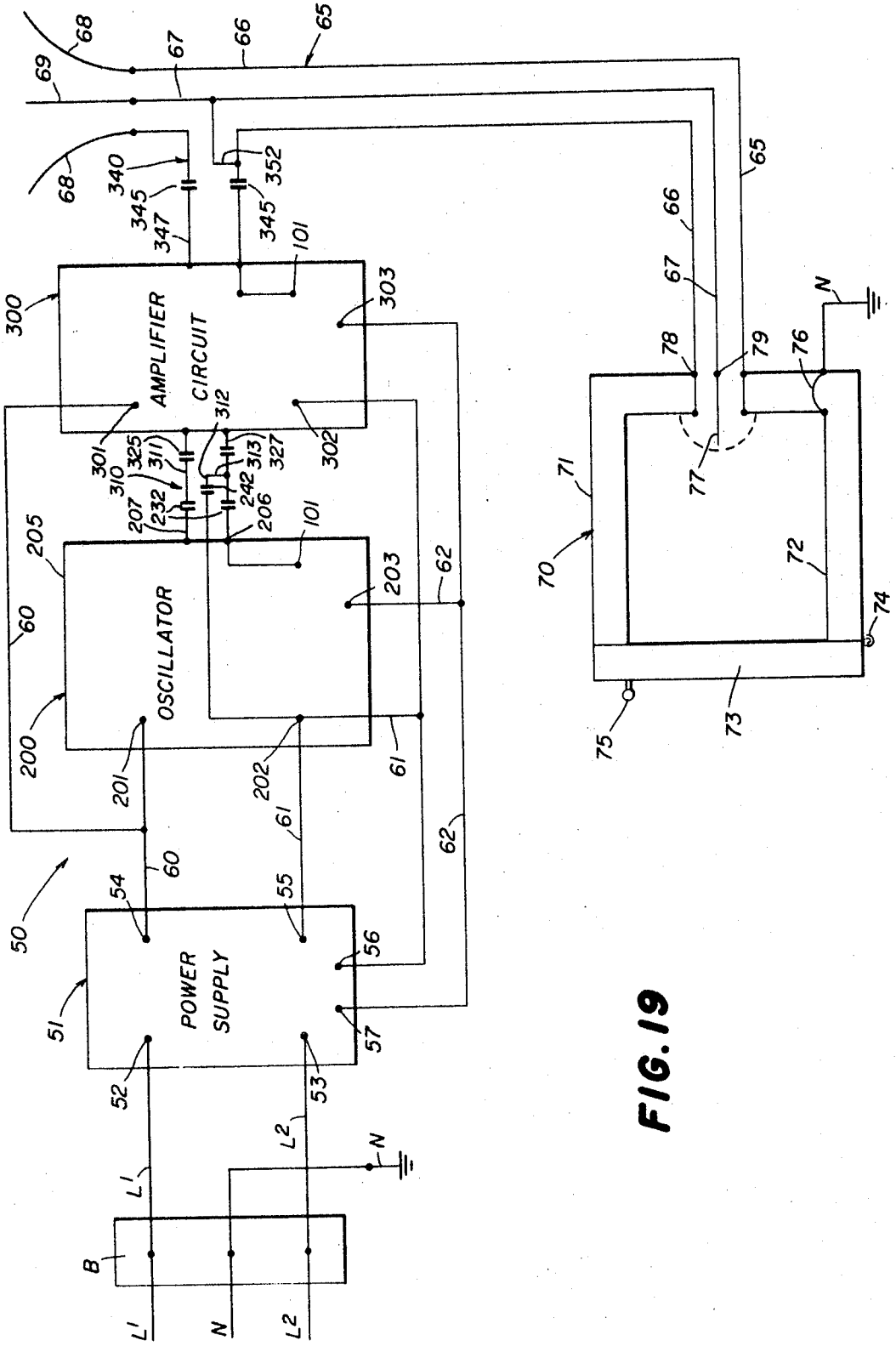
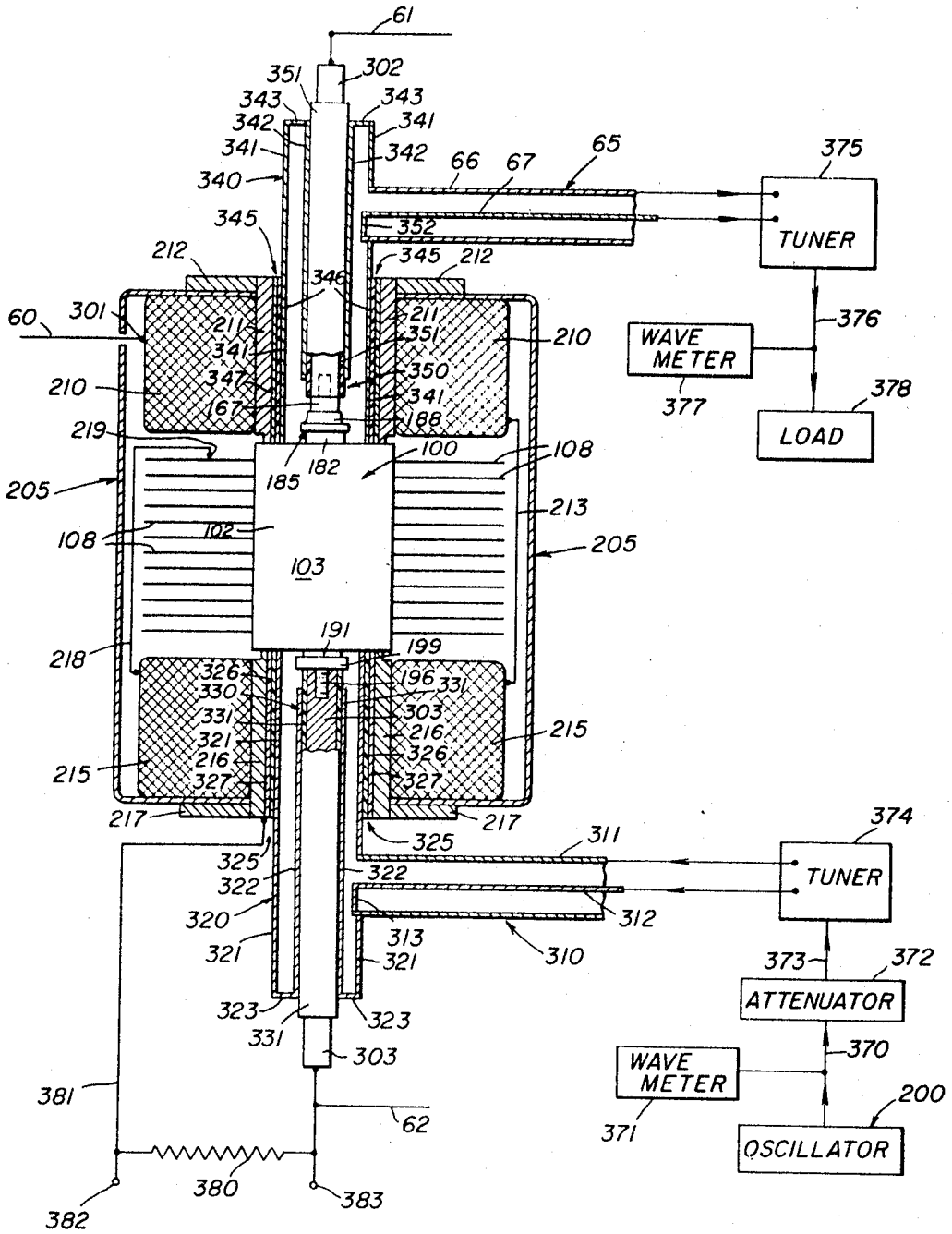


FIG. 19

July 29, 1969 J. E. STAATS 3,458,755
CROSSED-FIELD DISCHARGE DEVICE AND MICROWAVE CIRCUITS INCORPORATING THE SAME
Filed June 21, 1966 12 Sheets-Sheet 12

FIG. 20



United States Patent Office

3,458,755

Patented July 29, 1969

3,458,755

CROSSED-FIELD DISCHARGE DEVICE AND MICROWAVE CIRCUITS INCORPORATING THE SAME

James E. Staats, Louisville, Ky., assignor to General Electric Company, a corporation of New York

Filed June 21, 1966, Ser. No. 559,267

Int. Cl. H01j 25/50

U.S. Cl. 315—39.51 49 Claims

ABSTRACT OF THE DISCLOSURE

There is disclosed a crossed-field discharge device including an annular sleeve surrounding a pair of segmented and axially spaced-apart annular anode members and defining therewith a first annular space, the anode segments defining axially extending recesses therebetween, and each anode member segment including an axially extending rod integral therewith, the rods of each anode member being respectively disposed in the recesses of the other anode member and an axially extending cathode structure having a plurality of electron emissive sections thereon surrounded by the anode members; oscillator, amplifier and modulator circuits incorporating the device are also disclosed.

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

It is a general object of the invention to provide a new and improved crossed-field 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 operating potentials thereto.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth which can provide an unusually high output of microwave energy in proportion to the physical dimensions thereof, whereby to permit the miniaturization of microwave circuits embodying the improved crossed-field discharge device of the present invention.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner annular axially extending space extending therethrough and a radially extending passage interconnecting the outer and inner axially extending spaces at longitudinal midsection of the anode structure, the radially extending passage dividing the anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into the inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on the first anode section disposed respectively in the anode recesses in the second anode section and respectively spaced from the adjacent ones of the anode segments on the second anode section, a plurality of axially extending second rods on the second anode section respectively disposed in the anode recesses in the first anode section and respectively spaced from adjacent ones of the anode segments on the first anode section, an axially extending cathode structure disposed in the inner axially extending space and cooperating with the anode

sections to define an axially extending annular interaction space, the cathode structure including an electron emissive element disposed within the anode sections and adjacent to the inner portion of the interaction space, means for establishing a unidirectional magnetic field extending axially through the outer axially extending space and the interaction space, and end structures enclosing both the ends of the anode structure and the axially extending spaces, the anode structure including the axially extending spaces and the radially extending passage therein defining a frequency determining folded resonant cavity for the device.

In connection with the foregoing object, it is another object of the invention to provide an improved crossed-field discharge device wherein the anode structure includes an annular sleeve and a pair of annular anode members disposed within the sleeve and a plurality of rods disposed adjacent to the inner surface of the anode members, the sleeve and the anode members being electrically connected at the opposite ends of the anode structure and the rods being electrically connected to the anode members at the other ends thereof, the sleeve and the anode members and the rods defining a frequency determining folded resonant cavity for the device of very small longitudinal extent.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the anode structure includes an annular sleeve and first and second annular anode members disposed in the sleeve, the portions of the anode members disposed toward each other having respectively first and second annular recesses on the outer periphery thereof to provide respectively first and second outer surfaces spaced inwardly with respect to the inner surface of the sleeve and to provide first and second annular end surfaces defining an outer axially extending space therebetween, the adjacent portions of the bodies being spaced apart axially to provide a lateral passage therebetween connecting the inner and outer axially extending spaces, the first and second anode members respectively having a plurality of axially extending anode segments on the inner surface thereof and projecting radially into the inner axially extending space and providing a corresponding plurality of axially extending first and second anode recesses respectively therebetween, and a plurality of axially extending first and second rods respectively on the first and second anode bodies disposed respectively in the second and first anode recesses and respectively spaced from the adjacent one of the second and first anode segments, thereby to define a frequency determining folded resonant cavity for the device.

In connection with the foregoing object, it is another object of the invention to provide an improved crossed-field discharge device of the type set forth wherein the inner surface of the sleeve and the first outer surface cooperate to provide an outer section of a first folded transmission line shorted at one end by the first end surface and connected at the other end through the lateral passage to the inner section of the first folded transmission line defined by the first anode segments and the second rods, the inner surface of the sleeve and the second outer surface cooperate to provide an outer section of a second folded transmission line shorted at one end by the second end surface and connected at the other end through the lateral passage to the inner section of the second transmission line defined by the second anode segments and the first rods, the frequency of the resonant cavity being equivalent to twice the combined length of the first and second folded transmission lines.

Another object of the invention is to provide in a crossed-field discharge device of the type set forth an improved rod structure wherein the rods taper toward the outer ends thereof, thereby to provide improved thermal conductance, to provide lower circulating currents and

improved circuit efficiency, to improve mode stability and to reduce the phase shift of RF voltages at the ends of the rods thus to improve electron bunching and consequent improved electronic efficiency.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the anode structure provides short and low impedance paths for rotating waves, thus improving mode separation and stability in the device when utilized as an oscillator.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the anode structure comprises a sleeve and a pair of identical anode members having the anode segments and rods integral therewith, the anode members being producible by broaching operations to provide greater accuracy in the construction thereof, the anode members cooperating with the sleeve in a manner such as to permit complete assembly of the device prior to forming the hermetic seals therebetween.

Another object of the invention is to provide in a crossed-field discharge device of the type set forth an improved cathode structure including a plurality of circumferentially spaced electron emissive sections corresponding in number to the sum of the number of the first anode segments and the first rods, the emissive sections being shaped and located to minimize back heating of the cathode and to encourage emission of useful electrons and to discourage emission of non-useful electrons.

In connection with the foregoing object, another object of the invention is to provide an improved crossed-field discharge device of the type set forth including inner and outer transmission line sections connected by a radially extending annular passage, the electron emissive sections being disposed closer to the anode structure at the outer ends thereof and being spaced farther away from the anode structure adjacent to the radial passage, whereby to minimize losses associated with fringed field distortion in the vicinity of the radial passage.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the cathode is utilized as a probe to extract RF energy from the device, the cathode structure being such that only two ceramic parts and two end seals are required.

Another object of the invention is to provide in an improved crossed-field discharge device of the type set forth, improved pole pieces at each end of the anode structure and hermetically sealed thereto and providing end plates therefor, the pole pieces being shaped to provide the desired distribution of unidirectional magnetic fields through the axially extending spaces in the device, the pole pieces being shaped such that they can be stamped from a substantially flat sheet of material.

In connection with the foregoing object, it is another object of the invention to provide a crossed-field discharge device of the type set forth wherein the output connections are attached to the anode structure and the cathode structure respectively for withdrawing microwave energy from the device, the end spaces between the pole pieces and the anode members defining inductances of predetermined value providing for a predetermined coupling of the RF energy in the device to the output connections.

Another object of the invention is to provide an improved crossed-field discharge device of the type set forth wherein the various parts thereof are constructed and arranged such as to permit assembly of the complete device prior to brazing of the various parts one to another, whereby the cathode is converted during the brazing process permitting fast bake-out and a shorter processing cycle during evacuation of the device, and also resulting in cleaning of the parts by hydrogen in the brazing process and subsequent protection of the parts from exposure to contamination in later processing.

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

A still further object of the invention is to provide an improved microwave amplifier incorporating therein a crossed-field 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 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 discharge device and of the connection thereof in the various microwave circuits, whereby the above-outlined and additional operating features thereof are attained.

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

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

FIG. 2 is a view in vertical section through the oscillator of FIG. 1 and illustrating the circiut connections for the crossed-field discharge device including the magnetic field coils therefor and the coupler and filter construction used therewith;

FIG. 3 is an enlarged view in vertical section through the crossed-field discharge device illustrated in the oscillator of FIG. 2;

FIG. 4 is a partial horizontal section through the device of FIG. 3 along the line **4—4** thereof;

FIG. 5 is a view in horizontal section through the device of FIG. 3 along the line **5—5** thereof;

FIG. 6 is a fragmentary perspective view or portions of the two anode members illustrating them in a spaced apart posiiton;

FIG. 7 is an end view of one of the anode members forming a part of the crossed-field discharge device of FIG. 3;

FIG. 8 is a view in vertical section through the anode member of FIG. 7 along the line **8—8** thereof;

FIG. 9 is a partial diagrammatic lineal view as seen within the anode members;

FIG. 10 is a view in horziontal section through the device of FIG. 3 along the line **10—10** thereof;

FIGS. 11 to 16, inclusive, are still further enlarged fragmentary views in horizontal section through the device of FIG. 3 along the line **11—11** thereof and illustrating the various electrical and magnetic fields therein;

FIGS. 17 and 18 are graphs plotting several operating characteristics of the crossed-field discharge device illustrated in FIGS. 3 to 10;

FIG. 19 is a schematic and diagrammatic illustration of an amplifier circuit for amplifying the output from the microwave oscillator of FIG. 2, the amplifier circuit utilizing therein a crossed-field discharge device made in accordance and embodying the principles of the present invention; and

FIG. 20 is a view in vertical section through the amplifier circuit of FIG. 19 and illustrating the crossed-field discharge device and the circuit connections therefor including the magnetic field coils and the amplifier input circuits and output circuits.

Referring to FIG. 1 of the drawings, there is diagrammatically illustrated an oscillator circuit **50** embodying the features of the present invention, the oscillyator circuit **50** having been illustrated as connected to a three-wire Edison network of 236 volts, single-phase, 60-cycles AC, and including two ungrounded line conductors L1 and L2 and a

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

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

The microwave energy supplied from the oscillator **200** to the transmission line **65** may be used for any desired purposes, two typical uses of the microwave energy being illustrated in FIG. 1, the first use being illustrated in the upper righthand portion of FIG. 1 and the second use being illustrated in the lower portion of FIG. 1. Referring to the upper righthand 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 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 hinged structure **74**, and is provided adjacent to the upper end thereof with a handle **75**, whereby the front door **73** is movable between a substantially vertical closed position and a substantially horizontal open position with respect to the front opening provided in the liner **72**. Also the front door **73** has an inner metal sheet that is formed of steel and cooperates with the liner **72** entirely to close the heating cavity when the front door **73** occupies its closed position. For safety purposes, the inner liner **72** is connected by a conductor **76** to the outer casing **71** which is in turn grounded by the conductor N. The outer conductor **66** of the transmission line **75** is connected as at **78** to the casing **71** and to the liner **72** of the range **70**, and there is provided within the range **70** at the rear thereof a radiating element or antenna **77** that is connected as at **79** to the inner conductor **67** of the transmission line **65**. Accordingly, the microwave energy within the transmission line **65** is radiated into the cooking cavity of the range **70** to provide the power for cooking materials disposed therein. It further will be understood that in a preferred embodiment of the range **70**, the power supply **50** and the oscillator **200** together with the transmission line **65** are all preferably disposed within a common housing that also includes the casing **71**, the common housing being preferably formed of metal, such as steel, and grounded for safety purposes.

Further details of the construction of the oscillator **200** and the crossed-field discharge device **100** forming a part thereof will now be described with particular reference to FIGS. 2 to 10 of the drawings. The device **100** comprises an anode structure **101** including a sleeve **102** and a pair of anode members **110** and **130**, a cathode structure **150**, a pair of opposed pole pieces **170**, an upper end structure **180** and a lower end structure **190**.

The anode structure **101** is essentially annular in shape and is confined within the interior of the sleeve **102** (see FIGS. 3, 4 and 5), the sleeve **102** being generally tubular and having a circular cross section at all points therealong, the outer surface **103** thereof being cylindrical. The inner surface **104** of the sleeve **102** is also cylindrical in shape and has at each end thereof a recess to define an upper end wall **105** and a lower end wall **106**, the end walls **105** and **106** being essentially annular in shape and disposed parallel to each other and normal to the axis of the device **100**. Mounted on the sleeve **102** at

essentially the midpoint thereof and extending outwardly therefrom is an exhaust tubulation **107** hermetically sealed thereto and communicating with the interior thereof, the exhaust tubulation **107** being useful to evacuate the device **100**, the interior of the device **100** being evacuated to a high degree and hermetically sealed as will be explained more fully hereinafter. Also mounted on the outer surface **103** of the sleeve **102** is a stacked array of cooling fins **108**, each of the cooling fins **108** being provided with an annular flange **109** that extends around the sleeve **102** and is fixedly secured thereto as by brazing. It will be understood that the sleeve **102** and the fins **108** are formed of a metal having good thermal conductivity, the preferred material being copper, thereby to accommodate conduction of heat from the device **100** outwardly therefrom and into the fins **108**. The shape of the fins **108** is substantially rectangular so that they fit within the casing **205**, there preferably being provided means for passing a cooling fluid, such as a stream of air, through the casing **205** and over the fins **108** to effect cooling thereof and a consequent removal of heat from the device **100** during the operation thereof.

Disposed within the sleeve **102** and also forming a part of the anode structure **101** are the two anode members **110** and **130**. Referring particularly to FIGS. 3 and 6 to 9, there is illustrated in detail the construction of the anode member **110**. As illustrated, the anode member **110** is generally annular in shape and includes a body portion **111** disposed at one end thereof (the upper end as viewed in FIG. 3), the body portion **111** having an outer end wall **112** at one end thereof connecting with an annular outer wall **113** having an outer diameter only slightly less than the inner diameter of the sleeve **102**, and specifically the inner surface **104** thereof, whereby the anode member **110** can fit within the sleeve **102** and ultimately is connected thereto as by brazing. The end of the body portion **111** opposite the end wall **112** is cut away or recessed to provide an annular inner wall **114** extending therearound and concentric with the annular outer wall **113** but having a substantially smaller diameter, the walls **113** and **114** being joined by an annular end wall **115** disposed parallel to the outer end wall **112** and normal to the walls **113** and **114**; the other end of the inner wall **114** connects with an inner end wall **116** that defines the other end of the body portion **111**, the end wall **116** being disposed in a plane parallel to the end walls **112** and **115** and normal to the walls **113** and **114**.

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

The anode member **110** further has thereon and integral therewith fifteen rods or vanes **125**, each of the rods **125** being integral with and extending longitudinally from one of the anode segments **117**. More specifically, the inner surface **118** of each of the anode segments **117** extends forwardly beyond the inner end wall **116** and substantially parallel to the axis of the anode member **110** and forms the inner surface of the associated rod **125**. A portion of the side walls **119** on the anode segment **117** also extends forwardly beyond the inner end wall **116** to provide the radially extending sides of the associated rod **125**, the inner surface **118** and the side walls **119** terminating at an end **126** disposed substantially normal to the axis of the anode member **110**. An outer surface **127** is provided for each of the rods **125**, the outer surface **127** extending from the inner end wall **116** inwardly to the rod end **126**; more specifically, the inner end of the outer surface **127** joins the inner end wall **116** at a point spaced radially inwardly away from the adjacent outer walls **121** (see FIGS. 7 and 8) and tapers inwardly toward the associated inner surface from the end wall **116** to the rod end **126**.

The anode member **130** is generally annular in shape and includes a body portion **131** disposed at one end thereof (the lower end as viewed in FIG. 3), the body portion **131** having an outer end wall **132** at one end thereof connecting with an annular outer wall **133** having an outer diameter only slightly less than the inner diameter of the sleeve **102**, and specifically the inner surface **104** thereof, whereby the anode member **130** can fit within the sleeve **102** and ultimately is connected thereto as by brazing. The end of the body portion **131** opposite the end wall **132** is cut away or recessed to provide an annular inner wall **134** extending therearound and concentric with the annular outer wall **133** but having a substantially smaller diameter, the walls **133** and **134** being joined by an annular end wall **135** disposed parallel to the outer end wall **132** and normal to the walls **133** and **134**; the other end of the inner wall **134** connects with an inner end wall **136** that defines the other end of the body portion **131**, the end wall **136** being disposed in a plane parallel to the end walls **132** and **135** and normal to the walls **133** and **134**.

There is provided interiorly of the anode member **130** and extending the length of the body portion **131** a plurality of axially extending anode segments **137** that project radially inwardly into the axially extending space within the anode member **130** and providing therebetween a corresponding plurality of axially extending anode recesses **142**, fifteen of the anode segments **137** and fifteen of the corresponding recesses **142** being provided in the anode member **130**. Each of the anode segments **137** has an axially extending inner surface **138** and a pair of outwardly directed side walls **139** on the opposite sides thereof, the circumferential extent of the inner surface **138** being substantially less than the radial extent of the associated side walls **139**. The outer ends of the side walls **139** are joined by an outer wall **141**, whereby the recesses **142** are defined by the associated side walls **139** and the associated outer wall **141**, the side walls **139** of each recess **142** coverging inwardy and being disposed substantially normal to the associated outer wall **141**.

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

141 and tapers inwardly toward the associated inner surface from the end wall 136 to the rod end 146.

The anode members 110 and 130 are also formed of a metal having good thermal conductivity, the preferred material being copper. The sleeve 102 and the anode members 110 and 130 also must have good electrical conductivity, the copper providing the necessary good electrical conductivity as well as the good thermal conductivity. The geometry of the anode members 110 and 130 is such that the exterior surfaces 112, 113, 114, 115, 116, 126 and 127 on the anode member 110 and the surfaces 132, 133, 134, 135, 136, 146 and 147 on the anode member 130 can all be formed by machining a block of copper; and all of the interior surfaces of the anode members 110 and 130 including the surfaces 118, 119, 121, 138, 139 and 141 can all be formed by broaching, whereby the anode member 110 and 130 can be formed integral from blocks of copper, thus to provide greater accuracy of the parts than is possible by joining such as by brazing, individual segments of the anode members 110 and 130. As illustrated in FIG. 3, the anode member 110 is disposed in the upper portion of the sleeve 102 with the body portion 111 thereof disposed upwardly and with the rods 125 thereof extending downwardly; the anode member 130 is disposed in the lower portion of the sleeve 102 with the body portion 131 thereof disposed downwardly and with the rods 145 thereof extending upwardly. As is also illustrated in FIGS. 6 and 9, the anode members 110 and 130 are rotated slightly with respect to each other so that thee anode rods 125 on the anode member 120 are disposed in the centers of the recesses 142 of the anode member 130, and conversely the anode rods 145 on the anode member 130 are disposed in the centers of the recesses 122 of the anode member 110. In this arrangement, there is one of the anode rods 125 disposed in each of the anode recesses 142 and equidistantly spaced from the adjacent anode segments 137, and likewise there is one of the anode rods 145 disposed in each of the anode recesses 122 and equidistantly spaced from the adjacent anode segments 117, all as is diagrammatically illustrated in FIGS. 5, 6 and 9.

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

The cathode structure 150 is provided in the axially extending space defined by the anode members 110 and 130, the cathode structure 150 including a cylindrical metal wall 151 (see FIGS. 3 and 5) arranged with the axis thereof disposed at the axis of the device 100, the wall 151 being formed of a heat resistant and electrically conducting metal, the preferred material of construction being nickel. Mounted on each end of the wall 151 is a cathode end 152, the cathode ends 152 being substantially identical in construction, whereby the same reference numerals have been applied to like parts of both. Referring to the upper cathode end 152, it includes a substantially flat annular center plate 153 carrying on the outer edge thereof an axially directed annular inner flange 154 carrying on the inner end thereof an outwardly directed flat flange 155; the outer periphery of the flange 155 carries a mounting flange 156 thereon extending outwardly and disposed within the adjacent end of the wall 151 and suitably secured thereto as by welding. The outer edge of the flange 156 carries a radially and outwardly extending shield flange 157 that extends radially outwardly beyond the wall 151 and overlies the adjacent end of the interaction space 160. Each center plate 153 has a central opening 158 therein, the lower cathode end 152 carrying on the inner edge and surrounding the opening 158 therein a center end flange 159. The cathode ends 152 are also preferably formed of nickel. The upper cathode end 152 is mechanically and electrically connected to a cathode stud 167, the cathode stud 167 being generally circular in cross section and having at the lower end thereof a reduced diameter portion 168 that extends through the opening 158 in the cathode end 152 and is fixedly secured thereto as by a pair of outwardly directed flanges 169. It will be appreciated that the upper end of the cathode structure 150 is both electrically and mechanically connected to the stud 167.

The cathode wall 151 is provided with a sintered porous coating 161 impregnated with a suitable electron emissive oxide material, whereby upon heating of the cathode structure 150, the coating 161 readily emits electrons from the outer surface thereof. Referring particularly to FIG. 5, it will be seen that the coating 161 is shaped to provide a plurality of outwardly extending projections 162 each having outwardly converging side walls joining a generally circumferentially arranged outer surface 163, a space 164 being provided between the adjacent projections 162. As illustrated, the circumferential extent of the outer surface 163 is substantially equal to the space 164 between the adjacent projections 162. The preferred range of the circumferential extent of each of the outer surface 163 is approximately 25% to approximately 60% of the circumferential distance between the centers of adjacent outer surfaces 163. The number of projections 162 provided on the coating 161 is equal to the sum of the number of the anode segments 117 and the number of cooperating rods 145, for example, and is likewise equal to the sum of the number of the anode segments 137 and the number of the cooperating rods 125, whereby there are thirty of the projections 162 provided upon the coating 161. The outer surfaces of the coating 161 together with the inner surfaces 118 and 138 on the anode members 110 and 130, respectively, define the interaction space 160 disposed therebetween in which the emitted electrons from the coating 161 interact with the electrical fields and the magnetic fields disposed between the anode structure 101 and the cathode structure 150. As will be described more fully hereinafter, the projections 162 combine with the anode segments 117 and 137 and with the rods 125 and 145 to provide a preferred distribution of the several fields within the interaction space 160 of the device 100 that results in more desirable operating characteristics thereof. One particularly desirable result of the shape of the coating 161 is the minimized back heating of the cathode structure 150, the desirable emitted electrons emanating from the projections 162, and the undesirable emitted electrons emanating from the space 164 between the projections 162, thereby to facilitate the emission of desirable electrons and to suppress the emission of undesirable electrons.

It further will be noted from FIG. 5 that the center line of each projection 162 is circumferentially displaced relative to the center line of its corresponding anode segment 117 and 137 or its corresponding rod 125 and 145, as the case may be; more specifically, the center line of the projections 162 are displaced in a clockwise direction a circumferential distance equal to approximately 40% of the circumferential spacing between the center lines of an adjacent anode segment 117 and an adjacent rod 145 (for example 5° rotation for a 12° spacing or a percentage of 41.8% as illustrated). The circumferential displacement of the projections 162 with respect to

the corresponding anode segments or rods is preferably in the range between 0% and approxiamtely 45% of the circumferential spacing between adjacent anode segments and rods, the preferred range being between approximately 25% and 45% of the spacing between adjacent anode segments and rods, a still more preferred range being between approximately 35% and 45% of the spacing between adjacent anode segments and rods. Furthermore, the displacement is on the downstream side, i.e., in the direction of normal initial electron flow from the projections **162**. It also will be noted that the electron emissive coating **161** is confined between the outer end walls **112** and **132** of the anode members **110** and **130**, respectively, the cathode structure **150** being carefully centered with respect to the anode members **110** and **130**, whereby each of the cathode projections **162** extends axially of the device **100** parallel to the axis thereof and confined between the outer end walls **112** and **132**.

The radial dimension of each of the projections **162** varies from end to end of the cathode structure **150**. Adjacent to the outer ends of the cathode structure **150**, the radial dimensions of each of the projections **162** is preferably greater than about 20% of the spacing between the anode surfaces **118** and **138** and the coating **161** on the cathode structure **150**. At the longitudinal midpoint of the emissive coating **161**, an area **166** of reduced radial dimension is provided, the radial extent of the projections **162** being substantially nil and in certain instances the coating **161** being completely removed at the center reduced portion **166**; the portion **166** is opposite the annular passage **140** between the anode members **110** and **130**. There further is provided an intermediate reduced portion **165** between the center reduced portion **166** and each of the outer ends of the cathode structure **150**, the intermediate reduced portions **165** having roughly one-half of the radial extent of the projections **162** that are found at the outer ends of the coating **161**. The longitudinal extent of the outer coating portions are substantially equal to the longitudinal extent of the intermediate reduced portions **165**, which are in turn substantially equal to the longitudinal extent of the center reduced portion **166**. In a typical construction of the coating **161**, the difference in the thickness of the coating is approximately 5 mils from one section to the adjacent section of the coating **161**.

The stepped construction of the coating **161**, i.e., the provision of the reduced portions **165** and **166**, serves to match the electronic impedance of the interaction space **160** to the RF load impedance coupled to the output of the device **100** in a manner that improves the efficiency and load range of the device **100**. More specifically, it has been found that the load impedance transferred to the interaction space **160** varies axially therealong, the load impedance being low adjacent to the outer ends of the interaction space **160** and increasing to a maximum at the longitudinal midpoint thereof. For a given combination of operating voltage, magnetic field and current through the device **100**, there is a single value of RF output voltage and load impedance which produces a maximum efficiency of operation, whereby if the load impedance varies axially of the device **100**, there is only one point axially of the interaction space **160** which produces the maximum operating efficiency. In accordance with the present invention, the plurality of cathode sections of varying diameter are arranged such that the anode to cathode spacing varies in a manner so that the electronic impedance of each section of the interaction space **160** matches the RF load impedance at each section of the interaction space. As a result, the efficiency of the device **100** with a cathode of constant cross section from end to end thereof may be for example 40%; by incorporating the stepped cathode **150** of the present invention in the device **100**, the efficiency of operation can be improved to 45% and up to 50% under optimum conditions.

As illustrated, the cathode structure **150** is of the indirectly heated type, and accordingly, there has been provided within the cathode wall **151** a heater **176** in the form of a coiled filament extending substantially the entire length of the cathode wall **151** and spaced inwardly a short distance from the inner surface thereof. The upper end of the heater **176** as viewed in FIG. 3 has an outer end or terminal **177** that extends outwardly into an opening in the lower end of the cathode stud **167**, and specifically through an annular opening in the reduced portion **168** thereof and is mechanically and electrically connected to the cathode stud **167** whereby the cathode structure **150** and the heater **176** are both mechanically and electrically connected to the cathode stud **167**. The lower end of the heater **176** has an outer end or terminal **178** that extends into an opening in the upper end of a conductor **197** and is mechanically and electrically secured thereto. The conductor **197** is preferably formed of copper and extends outwardly and into a threaded connector **196**. It will be noted that the heater terminal **178** is spaced from and electrically insulated with respect to the lower end of the cathode structure **150**.

Mounted within the outer ends of the anode sleeve **102** and forming end walls for the device **100** are the pole pieces **170**, the pole pieces **170** being identical in construction, whereby the same reference numerals have been applied to like parts of both of the pole pieces **170**. The pole pieces **170** are formed of a material having high magnetic permeability, the perferred material being a low carbon steel, and are copper plated to render the outer surfaces thereof highly conductive to RF energy. As illustrated, each of the pole pieces **170** is generally cylindrical in shape including a first substantially flat inner plate **171** disposed centrally thereof and disposed in a plane substantially normal to the longitudinal axis of the device **100** and in longitudinal alignment with the interaction space **160**. Disposed about the periphery of the inner plate **171** and integral therewith is an annular coupling flange **172** extending outwardly therefrom and carrying on the outer edge thereof an outwardly directed outer plate **173** that is substantially flat and lying in a plane normal to the axis of the device **100** and being in longitudinal alignment with the adjacent end of the outer axially extending space **120**. The outer edge of the outer plate **173** carries an annular and outwardly extending mounting flange **174** that has an outer diameter slightly less than the inner diameter of the associated recessed end of the anode sleeve **102** to be received therein and hermetically sealed thereto. Finally, there is provided centrally of each of the inner plates **171** a circular opening **175** in general longitudinal alignment with the adjacent end of the cathode structure **150**, and specifically the adjacent end of the cathode wall **151**, the opening **175** receiving the terminals of the cathode structure and heater therethrough. Preferably the pole pieces **170** are each formed of a single sheet of low carbon steel shaped as described by a stamping operation, thereby to provide accurate dimensions therefor together with an inexpensive manufacture thereof.

An upper end structure **180** is provided at the upper end of the device **100** as viewed in FIG. 3 and a lower end structure **190** is provided at the lower end of the device **100**, the end structures **180** and **190** serving to provide a hermetic seal between the associated pole pieces **170** and the associated connections to the cathode structure **150** and/or the heater **176**, as the case may be. The upper end structure **180** includes a short tube **181** having the lower end thereof disposed within the opening **175** in the upper pole piece **170** and suitably hermetically secured thereto as by brazing and extending upwardly therefrom substantially concentric with the longitudinal axis of the device **100** and the axis of the cathode stud **167**. The upper end of the tube **181** receives therein the lower end of an annular insulator **182** which is formed, for example, of a good electrically insulating ceramic, the tube **181** being hermetically sealed to the insulator **182**.

There is provided about the cathode stud **167** at the portion thereof adjacent to the reduced portion **168** a ring **183** that fits within a recess in the lower end of the insulator **182**. Surrounding the upper end of the insulator **182** and the adjacent portion of the cathode stud **167** is a cap **185**, the cap **185** being generally annular in shape and including an annular flange **186** surrounding an outer periphery of the upper end of the insulator **182** and being hermetically sealed thereto. Integral with the upper edge of the outer flange **186** is an inwardly directed flange **187** carrying on the inner edge thereof an outwardly directed annular inner flange **188** surrounding the adjacent portion of the stud **167** and hermetically sealed thereto as by brazing. It is pointed out that the sleeve **181** and the cap **185** are both formed of a material that can be readily secured both to a metal surface and to a ceramic surface, the preferred material being "Fernico" alloy, a typical composition being 54% iron, 28% nickel and 18% cobalt. It will be seen that the upper end structure **180** forms a good hermetic seal that also provides electrical insulation between the upper pole piece **170** and the output conductor in the form of the cathode stud **167**, the end structure **180** likewise providing the necessary mechanical support of the cathode structure **150** to position it within the anode structure **101**.

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

When the device **100** is incorporated as a crossed-field discharge device in a microwave circuit, the pole pieces **170** arranged adjacent to the opposite ends of the anode structure **101** are utilized for establishing a unidirectional magnetic field extending axially through the several spaces within the anode structure **101**, and specifically through the axially extending space **120** and through the interaction space **160**, as well as the annular passage **140** and the various spaces between the anode members **110** and **130**. To this end a pair of magnet coils **210** and **215** has been provided, the magnet coil **210** being disposed about the upper end of the device as viewed in FIG. 2 and the magnet coil **215** being disposed about the lower end of the device **100** as viewed in FIG. 2. The magnet coils **210** and **215** are both shaped as a torous, are wound of electrically conductive wire, and as illustrated, are disposed respectively about magnet yokes **211** and **216**, respectively, that are each in the form of a cylinder disposed within the opening in the associated magnet coil. There further are provided outwardly extending flanges **212** and **217**, respectively, about the outer ends of the magnet yokes **211** and **216** and secured respectively thereto, the casing **205** being disposed within the flanges **212** and **217** and forming both a mechanical connection and a good magnetic path therebetween. It will be understood that the pole pieces **170**, the magnet yokes **211** and **216**, the flanges **212** and **217** and the casing **205** are all formed of metals having a high magnetic permeability, such as soft iron and low carbon steel, whereby when the magnet coils **210** and **215** are energized, a strong and uniform unidirectional magnetic field is established between the pole pieces **170** within the device **100** and extending axially through the spaces within the device **100** and specifically extending axially through the outer axially extending space **120** and the interaction space **160** therein.

The circuit for energizing the coils **210** and **215** can be traced with reference to FIGS. 1 and 2 from the power supply **51**, and specifically the DC output terminal **54** thereof, through the conductor **60** to the input terminal **201** of the oscillator **200** to which is connected one terminal of the upper magnet coil **210**. The other terminal of the upper magnet coil **210** is connected by a conductor **213** to one terminal of the lower magnet coil **215**, and the other terminal of the lower magnet coil **215** is connected by a conductor **218** to one of the cooling fins **108** by means of a connection **219**, whereby the input terminal **201** is connected via the upper magnet coil **116**, the conductor **213**, the lower magnet coil **215**, the conductor **218** and the cooling fin **108** to the anode sleeve **102** of the device **100**. The flow of current through the magnet coils **210** and **215** serves to produce the unidirectional magnetic field in the various spaces of the device **100** and specifically in the outer space **120** and the interaction space **160** thereof.

Referring now to FIG. 2 of the drawings, the manner in which the crossed-field discharge device **100** is incorporated in the oscillator **200** will be described in further detail. The tubular conductor **207** is provided formed of a material that is electrically conductive, the conductor **207** having the lower end thereof received within the upper pole piece coupling flange **172** in telescoping relation therewith and is electrically connected thereto, the conductor **207** also being disposed within the upper magnet yoke **211** and extending upwardly and beyond the upper end thereof. As is illustrated in both FIGS. 2 and 3, the cathode stud **167** at the upper end of the crossed-field discharge device **110** has the outer end thereof disposed below the outer end of the associated magnet yoke **211**. The cathode stud **167** and the conductor **207** form a coaxial transmission line that provides output RF terminals for the oscillator **200**, the terminals having applied therebetween the output RF energy from the oscillator **200**. In addition, the outer conductor **207** has applied thereto the B^+ potential from the conductor **60** which is connected thereto via the input terminal **201**, the upper magnet coil **210**, the conductor **213**, the lower magnet coil **215**, the conductor **218**, the cooling fin **108** to which is made the connection **219**, the anode sleeve **102** and the upper pole piece **170**, the upper pole piece **170** being directly connected to the lower end of the outer conductor **207** as illustrated. Accordingly, it will be seen that the outer conductor **207** not only serves as one of the RF terminals for the device **100** but also is in direct electrical connection with the B^+ potential on the anode sleeve **102**. Likewise, the cathode stud **167** not only has the RF output energy thereon but has applied thereto both the B^- potential for the cathode **150** of the device **100** and the low voltage AC potential for energizing the heater **176**.

In order to accommodate the application to and the presence of the various potentials named on the output terminals **167** and **207** while preventing the introduction of RF energy into the power supply **51**, and while preventing the application of the B+ and B− potentials to the output transmission line **65**, there has been provided a coupler and filter structure **230**. Referring to FIG. 2, it will be seen that the coupler and filter structure **230** includes a first RF output terminal in the form of an annular outer conductor **231** which is capacitively coupled to the conductor **207** by a coupler **232**, the coupler **232** including a sleeve **233** of electrically insulating dielectric material, the sleeve **233** preferably being formed of a synthetic organic plastic resin, the preferred resin being a tetrafluoroethylene resin sold under the trademark "Teflon." The insulating sleeve **233** is disposed around and firmly embraces the outermost end of the tubular conductor **207** and extends upwardly therebeyond; the lower end of the outer conductor **231** is in turn placed in telescoping relationship about the sleeve **233**, the lower end of the conductor **231** telescopically overlapping the upper end of the conductor **207** for a distance equal to ¼ of the wavelength of the frequency of operation of the oscillator **200** in order to provide a portion of a second harmonic filter as will be described more fully hereinafter.

An opening is provided in the side wall of the conductor **207** adjacent to the upper end of the oscillator **200**, and joining the conductor **207** and surrounding the opening in the side wall thereof is a second annular conductor **234** that is suitably secured as by welding to the conductor **207** and extends laterally therefrom and to the right as viewed in FIG. 2 with the longitudinal axes of the conductors **207** and **234** disposed substantially normal to each other. Disposed in the conductor **207** adjacent to the junction thereof with the conductor **234** is a pair of annular insulators **235** and **236** substantially filling the conductor **207** and spaced apart a short distance from each other, the insulators **235** and **236** being 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." The lower insulator **235** has an opening centrally therein that receives therethrough a portion of a bullet **237** having on the lower end thereof a plurality of spring fingers **237***a* that resiliently grip the upper end of the cathode stud **167** to form a good electrical contact and mechanical interconnection therewith, a laterally extending flange **237***b* extending around the bullet **237** and being disposed below and in supporting relationship with the insulator **235**.

Extending upwardly through an opening in the center of the bullet **237** is a probe **238** in the form of a solid rod of electrically conductive material, the preferred material being copper. The probe **238** passes through an opening in the center of the insulator **236** and upwardly therebeyond, the insulator **236** having an upstanding flange **236***a* surrounding the probe **238**. A suitable fastener such as a screw **239** is provided at the lower end of the probe **238** and threadedly engages a complementarily threaded opening at the lower end thereof, the head of the screw **239** overlying the lower surface of the bullet **237**. Arranged about and in telescoping relationship with the upper end of the probe **238** is an annular inner conductor **240** that has the lower end resting upon the insulator **236** and surrounding the upstanding flange **236***a* thereon, the upper end of the conductor **240** having an enlarged section **240***a* thereon that extends upwardly well beyond the probe **238** and telescopically receives therein a second tubular inner conductor **241** that serves as an RF output terminal for the coupler and filter structure **230**, whereby the conductors **231** and **241** provide the RF output terminal for the coupler and filter structure **230**, whereby the conductors **231** and **241** provide the RF output terminals for the coupler and filter structure **230**. A capacitive coupling is provided between the probe **238** and the conductors **240** and **241** by a coupler **242** including an annular washer **243** 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." The washer **243** surrounds the upper end of the probe **238** and is seated in the enlarged portion **240***a* at the upper end of the conductor **240** and serves fixedly to position the upper end of the probe **238** with respect to the conductors **240** and **241**. A second fastener in the form of a screw **239** is provided in the upper end of the probe **238** and has a threaded shank threadedly engaged in a complementarily shaped threaded opening in the upper end of the probe **238**, the head of the screw **239** engaging the upper surface of the insulating washer **243**, whereby the two opposed screws **239** serve fixedly to interlock the insulators **235** and **236**, the bullet **237**, the conductor **240** and the insulating washer **243**.

The B− potential and the low voltage AC filament supply for the device **100** are connected to the probe **238** and thus to the device **100** through connections in the conductor **234**, and specifically through a conductor **244** disposed within and concentric with the outer conductor **234**. The conductor **244** carries on the lefthand end thereof as viewed in FIG. 2 a connector **244***a* having an opening therein that receives therethrough the probe **238**, whereby to make good electrical connection therewith. Disposed about the conductor **244** and between the outer conductor **234** and the inner conductor **244** is an annular insulator **245** 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." Disposed to the left of the insulator **245** is an enlargement or flange **244***b* on the conductor **244**, and disposed to the right of the insulator **245** is a cylindrical choke **246** in the form of a tubular conductor that surrounds and receives therethrough the conductor **244** arranged concentrically therewith, the insulator **245** having a laterally extending flange **245***a* surrounding the conductor **244** and extending into the lefthand end of the choke **246** to position the adjacent end of the choke **246** with respect to the conductor **244**. A conductive nut **247** is provided about the conductor **244** adjacent to the righthand end thereof and including a flange **247***a* extending into the righthand end of the choke **246** to position the adjacent ends of the conductor **244** and the choke **246** with respect to each other. The righthand end of the conductor **244** is threaded as at **244***c* and threadedly engages an internally threaded opening in the nut **247** to lock the insulator **245** and the choke **246** against the flange **244***b*; the threaded end **244***c* is connected to the input terminal **202** formed of a conductive metal, the terminal **202** having an enlarged lefthand end **249** having a threaded opening therein to receive the adjacent threaded end **244***c* of the conductor **244**. The terminal **202** extends outwardly to the right beyond the outer conductor **234** and is connected to the conductor **61** from the power supply **51**. Connected between the outer conductor **234** and the inner terminal **202** is a filter capacitor **248** of the feed through type that is in the form of two layers of conductive foil between which are interposed layers of insulating film, the layers of conductive foil and insulating film being wound to form the capacitor **248**, one terminal of the capacitor **248** being connected to the outer conductor **234** and the other terminal of the capacitor **248** being connected to the terminal **202**.

As has been explained above, the inner conductor **207** and the outer conductor **231** telescopically overlap a distance equal to ¼ wavelength of the frequency of operation of the oscillator **200**. In addition, the probe **238**, the inner conductor **240** and the choke **246** are also constructed to have a length equal to ¼ wavelength of the frequency of operation of the oscillator **200**. In the operation of the coupler and filter structure **230**, the

outer conductors 207–234 serve as a B+ input terminal, the conductor 207 being directly connected to the conductor 218 by which a B+ is applied to the outer sleeve 102, and the terminal 202 serves as the B− input terminal and is connected to the cathode 150 via the conductor 244, the probe 238, the bullet 237, and the cathode stud 167 (see FIG. 3 also), whereby to apply B− potential to the cathode 150. The terminal 202 also serves as an input terminal for the low voltage AC filament supply and is connected to one end of the heater 176 via the conductor 244, the probe 238, the bullet 237 and the cathode stud 167, whereby to apply low voltage AC potential to the upper end of the heater 176.

The connector 196 at the lower end of the device 110 (see FIG. 3) is connected to a filter capacitor of the feed through type, and more specifically is connected to the output terminal 203 that has the adjacent end thereof internally threaded and receives the threaded outer end of the terminal 196 therein. A tubular conductor 221 is provided formed of a metal that is electrically conductive, the conductor 221 having the upper end thereof received within the lower pole piece coupling flange 172 in telescoping relation therewith and being electrically connected thereto, the conductor 221 being disposed within the lower magnet yoke 216 and extending downwardly and beyond the lower end thereof. There is provided on the lower end of the conductor 221 a cover 222 formed of conductive metal and including a flange 224 surrounding and in telescoping relationship with the lower end of the conductor 221 and mechanically and electrically secured thereto. Disposed between the terminal 203 and the cover 222 is a filter capacitor 226 of the same type of construction as the filter capacitor 248 described above, one of the terminals of the filter capacitor 226 being connected to the cover 222 and the other terminal of the filter capacitor 226 being connected to the terminal 203, a flange 227 being provided on the exterior of the filter capacitor 226 in overlying relationship with the cover 222. The filter capacitor 226 serves to by-pass RF energy from the terminal 203 to the outer conductor 221 through the cover 222, thereby to prevent the introduction of RF energy into the power supply 51 via the conductor 62.

During the operation of the crossed-field discharge device 100 in the oscillator 200, the anode sleeve 102 and the anode members 110 and 130 cooperate to provide a folded coaxial transmission line within the device 100, the coaxial transmission line thus formed accommodating axially extending RF waves therein and providing a frequency determining folded resonant cavity for the device 100 and for the oscillator 200. The coaxial transmission line more specifically includes an outer coaxial transmission line defined by the inner annular surface 104 on the sleeve 102 disposed between the annular end walls 115 and 135 on the anode members 110 and 130, respectively, and the annular inner walls 114 and 134 on the anode members 110 and 30, respectively; the portion of the outer surface 104 provides an outer conductor and the inner walls 114 and 134 provide inner conductors for the outer coaxial transmission line, the outer coaxial transmission line being coterminous with the axially extending space 120 and being shorted at the upper end by the wall 115 and at the lower end by the wall 135. The anode segments 117 on the first anode member 110 and the rods 145 on the second anode member 130 cooperate to provide a first portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, the upper end of this inner coaxial transmission line being open and the lower end connecting through the passage 140 with the midpoint of the outer transmission line 120. In a like manner, the anode segments 137 on the second anode member 130 and the rods 125 on the first anode member 110 cooperate to provide a second portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, the lower end of the second portion of the inner coaxial transmission line being open and the upper end being connected by the passage 140 to the midpoint of the outer axial transmission line 120.

In the operation of the device 100, the upper portion of the outer transmission line 120, i.e., the portion between the end wall 115 and the passage 140 cooperates with the first or upper section of the inner transmission line to provide a resonant cavity which can be excited to cause oscillations therein at a frequency equal substantially to four times the length thereof, i.e., four times the distance from the end wall 115 down and through the passage 140 and upwardly along the rods 145 to the upper ends thereof, whereby to provide an axially extending wave therein which is reflected by the end wall 115 at one end and by the open end of the transmission line at the other end to produce a standing RF wave. The lower portion of the outer transmission line 120, i.e., the portion between the end wall 135 and the pasage 140 cooperates with the second or lower section of the inner transmission line to provide a resonant cavity which can be excited to cause oscillations therein at a frequency equal substantially to four times the length thereof, i.e., four times the distance from the end wall 135 up and through the passage 140 and down and along the rods 125 to the lower ends thereof, whereby to provide an axially extending wave therein which is reflected by the end wall 135 at one end and by the open end of the transmission line at the other end to produce a standing RF wave. The two transmission lines thus described actually cooperate in the operation of the device 100, and more specifically, when an axial RF wave is excited on the inner transmission line, this RF wave is transmitted to the outer transmission line 120 through the passage 140 and becomes reflected by the end walls 115 and 135. The reflected wave travels down toward the passage 140 and therethrough and then flows oppositely toward each end of the inner transmission line. When the RF wave reaches the open circuited ends of the inner transmission line, reflections again occur and a standing wave is established providing RF electric fields and RF magnetic fields extending into the interaction space 160. It will be seen therefore that the device 100 includes a folded resonant cavity equivalent to a one-half wave resonator disposed in generally a ¼ wave space, whereby to provide a device having small physical dimensions relative to the wavelength of the microwave energy to be generated thereby.

In the operation of the oscillator 200, it is necessary to produce within the cross-field discharge device 100 a predetermined pattern of electrical fields and magnetic fields. A description of the electrical fields and magnetic fields within the device 100 during the operation thereof as an oscillator and the method of creating those fields will be given. The operating potentials for the device 100 are derived from the power supply 51 described above, and more particularly, the heater supply is derived from the power supply output terminals 56 and 57, the terminal 56 being connected by the conductor 61 to the terminal 202 that is in turn connected by the conductor 244, the probe 238, and the cathode stud 167 to one end of the heater 176, and the terminal 57 being connected by the conductor 62 to the terminal 203 that is in turn connected via the connector 196 and the conductor 197 to the other end of the heater 176. The DC potential from the power supply 51 is derived specifically from the output terminals 54 and 55, the conductor 60 interconnecting the output terminal 54 of the power supply 51 to the input terminal 201 (see FIG. 2 also) which is connected via the upper magnet coil 210, the conductor 213, the lower magnet coil 215, the conductor 218 and the fin 108 to the outer anode sleeve 102 to supply B+ potential thereto, and the conductor 61 interconnecting the output terminal 55 of the power supply 51 to the terminal 202 which is connected via the conductor 244, the probe 238, and the cathode stud 167 to the cathode 150 to supply B− potential thereto.

The application of the above described B+ and B− potentials to the outer anode sleeve 102 and the cathode

150, respectively, establishes a unidirectional electrical field 250 (see FIG. 11), that extends between the anode segments 117 (for example) and the cathode projections 162 and between the rods 145 (for example) and the cathode projections 162; it will be noted that each of the projections 162 provides a unidirectional electrical field in cooperation with both an adjacent anode segment 117 and an adjacent rod 145, the field between an anode segment 117 and the associated cathode projections 162 being designated by the numeral 251 and the field between a rod 145 and the associated cathode projections 162 being designated by the numeral 252. The electrical field 250 extends substantially normal to the longitudinal axis of the anode members 110 and 130, the field lines entering the surfaces 118 normal thereto, the field lines entering the surfaces 138 of the rods 145 normal thereto and the field lines entering the cathode surfaces 163 normal thereto, whereby the field 250 takes the shape illustrated in FIG. 8. It will be understood that a like shaped DC electrical field is provided between the cathode 150 and the anode segments 137 and the rods 125 in the lower portion of the device 100.

In order to provide the necessary unidirectional magnetic field normal to or "crossed" with respect to the electrical field 250, a DC current is established in the magnet coils 210 and 215. More particularly, electrons flow from the anode structure 101 through the conductor 218, the lower magnet coil 215, the conductor 213, the upper magnet coil 210 and the conductor 60 to the power supply output terminal 54. When such a flow of electrons is established through the magnet coils 210 and 215, a strong unidirectional magnetic flux is established through a path including the upper flange 212, the upper magnet yoke 211, the upper pole piece 170 (see FIG. 3 also) and through the space 120 and the interaction space 160, and then through the lower pole piece 170, the lower magnet yoke 216 and the lower flange 217. The return path for the unidirectional magnetic field is provided through the casing 205. Referring to FIG. 12 of the drawings, the unidirectional magnetic flux lines extending through the outer space 120 and the interaction space 160 are designated by the numeral 260, the flux lines 260 extending axially through the spaces 120 and 160 and therefore normal to the plane of the sheet of drawing in FIG. 12. Due to the provision of the pole pieces 170, and the other portions of the magnetic path having a high magnetic permeability described above, there is a uniform distribution of the unidirectional flux lines 260 throughout the space 120 and throughout the recesses 122 about the rods 145 and inwardly to the outer surface of the electron emissive coating 161. It further is pointed out that the unidirectional magnetic flux lines 260 are disposed normal to the unidirectional electrical field 250 illustrated in FIG. 11, whereby the unidirectional electrical field 250 and the unidirectional magnetic field 260 provide the necessary "crossed" fields for the operation of the crossed-field discharge device 100. It will be understood that a like unidirectional magnetic field 260 is disposed between the sleeve 102 and the anode member 130 and the rods 125 and the cathode 150 in the lower end of the device 100.

As has been pointed out above, the axially extending space 120 and the passage 140 and the rods and anode segments cooperate to provide a folded coaxial transmission line, the outer and inner sections of which extend axially with respect to the device 100, the outer section being shorted or terminated at the upper and lower ends thereof by the end walls 115 and 135. The shorted folded transmission line thus provided forms a tuned cavity for the oscillator 200, the tuned cavity being readily excited at a frequency having a wavelength corresponding to four times the distance between the inner surface of the end wall 115 and down and around through the passage 140 and up to the upper ends of the rods 145. When the tuned resonant cavity thus formed is excited by the establishment of the unidirectional electrical field 250 of FIG. 11 and the unidirectional magnetic field 260 of FIG. 12, the tuned cavity resonates at a frequency having the wavelength mentioned, i.e., a standing RF wave is established within the tuned cavity and extends axially thereof and axially of the device 100 and through the outer space 120 and the interaction space 160 thereof. The wavelength of the RF wave thus generated is actually substantially greater than four times the distance between the inner end wall 115 and down through the passage 140 and up to the upper ends of the rods 145 because of the high capacitance between the anode members and the rods, which high capacitance is in the tuned circuit and serves to permit the generation of RF waves in the device 100 having wavelengths substantially greater than four times the distance mentioned.

There is believed to be associated with the standing RF wave thus established an RF electrical field disposed normal to the axis of the device 100, a diagrammatic representation of the field being illustrated in FIG. 13. From FIG. 13, it will be seen that at any moment the anode segments 117 have one RF polarity while the rods 145 have the opposite RF polarity, whereby there is a relatively strong RF electrical field between the anode member 110 and the rods 145 as well as weak RF electrical fields between the anode member 110 and the cathode 150 and between the rods 145 and the cathode 150. The anode sleeve 102 also has an RF polarity opposite to that of the anode member 110, whereby there is an RF electrical field therebetween. In FIG. 13, the instantaneous RF electrical field has been designated by the numeral 270, and the stronger portion thereof disposed between the anode member 110 and the rods 145 has been designated 271, the force lines being disposed normal to the surfaces associated therewith, i.e., normal to the side walls 119 and the outer wall 121 of the recesses 122 and the surfaces of the rods 145. There is a weaker portion of the RF electrical field disposed between the anode member 110 and the cathode 150, that portion of the field being designated by the numeral 272, the lines representing the portion 272 of the field being normal to the inner surfaces 118 of the anode segments 117 and normal to the outer surfaces 163 of the cathode projections 162. There is a still weaker portion of the RF electrical field 270 between the rods 145 and the cathode 150, that portion of the field being designated by the numeral 273, the lines representing the portion 273 of the field also being disposed normal to the associated surfaces, and specifically normal to the outer surfaces of the rods 145 and normal to the outer surface 163 of the associated cathode projections 162. Finally, there is a portion of the RF electrical field 270 between the sleeve 102 and the anode member 110 in the space 120, that portion of the field being designated by the numeral 274, the lines representing the portion 274 of the field being disposed normal to the associated surfaces and specifically normal to the inner surface 104 of the sleeve 102 and the surface 114 of the anode member 110. It will be understood that a like RF electrical field 270 is disposed between the sleeve 102 and the anode member 130 and the rods 125 and the cathode 150 in the lower end of the device 100.

Associated with the RF electrical field 270 of the standing RF wave is an RF magnetic field 280 which is believed to have the form illustrated in FIG. 14; the RF magnetic field 280 is also disposed normal to the axis of the device 100 and is concentrated about and surrounds the rods 145 and the cathode 150 and the anode member 110. The major portion of the RF magnetic field 280 is disposed within the anode recesses 122 and is designated by the numeral 281, but a portion of the magnetic field 280 extends about the cathode 150 and is designated by the numeral 282. Another portion of the RF magnetic field 280 is disposed in the outer space 120 between the sleeve 102 and the anode member 110 and is designated by the numeral 283. It will be understood that a like RF magnetic field 280 is disposed between the sleeve 102 and

the anode member 130 and the rods 125 and the cathode 150 in the lower end of the device 100.

After the application of the operating potentials to the device 100, and after the cathode 150 has been heated to the operating temperature thereof by the heater 176, electrons are emitted from the emissive coating 161, the electrons being emitted into the interaction space 160 where they are subjected to the action of the unidirectional fields and the RF fields described hereinabove. There is illustrated in FIG. 15 of the drawings a diagrammatic representation of what are believed to be typical paths of electrons emitted from the cathode projections 162, the electron paths being designated by the numeral 290. As illustrated, the electrons follow a spiral path, the initial direction of flow being in a clockwise direction, this being due to the influence of the unidirectional magnetic field 260 described above. Eventually, the spiral paths 290 of the electrons carry them into contact with the anode member 110 or the rods 145, whereby to complete an electrical circuit through the device 100. During the time that the electrons are in the spiral paths 290, they impart a portion of the energy content thereof to the RF standing wave within the device 100 to add power thereto and to reinforce the RF standing wave. It will be understood that like electron paths 290 are found between the cathode 150 and the anode member 130 and the rods 125 in the lower portion of the device 100.

There is illustrated in FIG. 16 a composite representation of all of the fields that are believed to be present in the device 100 and in the outer space 120 and the interaction space 160 thereof when the device 100 is operating as a part of the oscillator 200. From FIG. 16 it is apparent that the electrons in the paths 290 clearly interact with the unidirectional fields and the RF fields within the interaction space 160, whereby to give up a portion of the energy of the electrons to the RF fields within the interaction space 160. More specifically, when an axial RF wave is excited on the inner portion of the transmission line, i.e., the portion of the transmission line defined by the inner surface of the anode members 110 and 130 and the rods 145 and 125, respectively, the axial wave is transmitted to the outer portion of the transmission line, i.e., to the portion of the transmission line designated 120, and the axial wave is reflected at the inner end surfaces 115 and 135. In this manner an RF electrical field is established between the anode members 110 and 130 and the rods 145 and 125, respectively. This RF electrical field extends into the interaction space 160 and bunches electrons that rotate around the cathode 150 in the presence of the DC electrical field 250 and the DC magnetic field 260 established by the application of a negative potential to the cathode 150 and a positive potential to the anode structure 101. These electrons tend to rotate in synchronization with a slow wave component of the axial fast wave and to extract energy from the DC fields while giving up energy to the RF fields. In this manner the RF standing wave within the device 100 is maintained and the energy content thereof increased and replenished during the operation of the oscillator 200.

As is best seen from FIGS. 3 and 16, the cathode 150 is coupled to the RF standing wave within the interaction space 160 and therefore serves as a probe for the removal of a portion of the RF energy from the tuned cavity for the supplying thereof to the coupler and filter structure 230 and thence to the output transmission line 65. In the structure illustrated, the cathode stud 167 is directly connected to the cathode structure 150 and the outer conductor 207 is directly connected to the upper pole piece 170, whereby an output RF potential appears therebetween. The coupler and filter structure 230 serves to connect the RF energy between the cathode stud 167 and the terminal 207 to the output transmission line 65, and also to apply to the cathode 150 via the probe 238 and the terminal 202 the B− operating potential and the low voltage AC filament supply from the conductor 61 connected to the power supply 51, all without applying DC operating potentials to the conductors 66 and 67 of the transmission line 65 and without the introduction of RF energy into the power supply 51 via the conductor 61.

Referring to FIG. 2, the operation of the coupler and filter structure 230 will be further described. The output terminals including the stud 167 and the conductor 207 connected respectively to the cathode 150 and the upper pole piece 170 of the device 100 also serves as RF input terminals to the coupler and filter structure 230, thereby to connect the oscillator 200 that serves as a source of RF potential to the RF input terminals of the coupler and filter structure 230. The RF input terminals 207 and 167 are capacitively coupled respectively to a pair of output terminals for the coupler and filter structure 230 in the form of the outer conductor 231 and the inner conductor 241, respectively, whereby to insure that the DC B+ and B− potentials on the conductor 207 and the stud 167, respectively, are not coupled to the output RF terminals 231 and 241, respectively. More specifically, the capacitive coupler 232 in the form of the insulating sleeve 233 provides a good RF coupling between the conductor 207 and the conductor 231 while preventing any DC connection therebetween. Likewise, the stud 167 connected to the probe 238 is capacitively coupled by the coupler 242 to the output conductor 241, the insulating washer 243 serving to space the probe 238 and the telescopically arranged conductor 240 therearound.

As has been explained above, the conductors 207 and 231 are preferably telescoped and overlap a distance equivalent to ¼ wavelength of the operating frequency of the oscillator 200, and likewise the probe 238 and the associated conductors 240–241 are telescoped and overlap a distance equal to ¼ wavelength of the operating frequency of the oscillator 200. By so arranging the parts, the capacitive couplers 232 and 242 serve not only to couple the RF energy to the conductors 231 and 241, but also serve as filters for the second and higher harmonics of the operating frequency of the oscillator 200, thereby to attenuate and materially to reduce the amount of second and higher harmonics coupled to the RF output terminals provided by the coaxial conductors 231 and 241.

The DC B− potential on the conductor 61 is directly connected to the cathode 150 via the conductor 244, the probe 238, the bullet 237, and the stud 167 (see FIG. 3 also). The same connection also applies the low voltage AC heater supply to the upper end of the heater 176. In order to prevent the propagation of the RF energy from the oscillator 200 into the conductor 61 via the probe 238 and the conductor 244, the choke 246 has been provided, the choke 246 having a length equal to ¼ wavelength of the operating frequency of the oscillator 200. The choke 246 is shorted at the outer end thereof by the conductive nut 247 and in cooperation with the outer conductor 234 and the capacitive insulator 245 serves to prevent propagation of the RF energy from the oscillator 200 along the conductor 244 and into the terminal 202 and the attached conductor 61. Due to the arrangement and dimensions of the parts, a parallel resonant circuit having a high impedance at the operating frequency of the oscillator 200 is provided, thereby to block the propagation of the RF energy along the conductor 244. In addition, the filter capacitor 248 of high capacitance is connected between the outer conductor 234 (which has applied thereto the B+ potential) and the terminal 202 (which has applied thereto the B− potential) and serves as a short for RF frequencies at and above the operating frequency of the oscillator 200, whereby to by-pass the RF energy and prevent introduction thereof into the power supply 51 via the conductor 61.

Recapitulating, the RF input terminals 207 and 167 for the coupler and filter structure 230 are capacitively coupled to the RF output terminals 231 and 241, respectively, thereby efficiently to transmit the RF energy gen-

erated in the oscillator **200** to the RF output terminals **231** and **241**. A second harmonic and higher harmonic filter is provided between the RF input terminals **167–207** and the RF output terminals **231–241** because of the overlapping telescoping arrangement of the conductors **207–231** and the conductors **238–240**, these conductors respectively overlapping a distance equal to ¼ wavelength of the operating frequency of the oscillator **200**. The fundamental operating frequency of the oscillator **200** cannot propagate over the transmission line comprising the conductors **234** and **244** because of the presence of the high impedance choke **246** disposed therein, the choke **246** acting as a parallel resonant circuit at the fundamental operating frequency of the oscillator **200** and thus presents a high impedance to the propagation of energy along the transmission line **234–244**. In addition, the feed through filter **248** of high capacitance that is connected between the conductors **234** and **244** (thus between the B^+ and B^- input terminals to the coupler and filter structure **230**) provides a low impedance path for RF energy, and particularly the second and higher harmonics of the operating frequency of the oscillator **200**, so that in cooperation with the choke **246**, no RF energy is fed along the conductor **244** to the DC terminal **202** and along the conductor **61** to the power supply **51**, and the lower voltage AC heater supply is nonetheless directly connected from the conductor **61** via the terminal **202**, the conductor **244**, the probe **238**, the bullet **237**, and the stud **167** to the cathode **150** and the upper end of the heater **176**.

Likewise, the capacitive coupler **226** of high capacitance serves to by-pass RF energy between the lower end of the heater **176** and the conductor **221** (also connected to the B^+ supply), whereby to prevent propagation of RF energy from the terminal **203** via the conductor **62** to the power supply **51**. In addition the coiled form of the heater **176** represents a high inductance to the RF energy, thereby to diminish leakage of RF energy therealong, thus to reduce the required size of the filters need to keep RF energy out of the power supply **51**.

As has been explained above, the RF wave within the oscillator **200** extends axially with respect to the device **100**, there being no radial RF waves within the device **100**, i.e., no RF waves extending normal to the axis of the device **100**. Furthermore, the radial distance between the outer surface of the cathode **150** and the outer walls **121** and **141** of the anode recesses **122** and **142**, respectively, is less than that required to accommodate a radial standing wave at the operating frequency of the oscillator **200**. Likewise the distance between the facing coaxial surfaces of the sleeve **102** and of the anode members **110** and **130** defining the outer transmission line is less that that required to accommodate a radial standing wave at the operating frequency of the device **100** as defined above.

There are shown in FIGS. 17 and 18 performance charts for the crossed-field discharge device **100** described above. Referring first to FIG. 17 there is shown a standard Rieke diagram superimposed upon a Smith chart, the data being obtained utilizing a series magnetic field, i.e., the magnet coils **210** and **215** were connected in series with the anode structure **101** with an applied B^+ potential of 580 volts. As illustrated, a family of power curves **80** was attained, the members of the family of curves **80** for 300 watts, 400 watts, 500 watts and 600 watts having been illustrated in FIG. 17. A family of curves **81** showing the frequency of operation and the frequency pulling has also been plotted in FIG. 81, as has also the unstable region indicated by the numeral **82**. It is noted that there is a very large impedance range over which power output is relatively constant. The performance chart for the device **100** has been plotted in FIG. 18, the applied anode voltage being plotted along the vertical axis and the anode current being plotted along the horizontal axis. In the lower portion of FIG. 18 has been ploted a curve **83** wherein no magnetic field was provided for the device **100**, whereby the values represented by the curve **83** are a measure of the emission of the cathode **150**. The curve **84** is a plot with a series field connected to the device **100**, i.e., the magnetic coils **210** and **215** were connected in series with the anode structure **101**. There further is ploted a family of curves **85** showing the anode current for an applied anode potential when a separate magnetic field is applied to the device **100**, the family of curves including performance curves when the separate magnetic field current has a value of 1.5, 2.0, 2.5, 3.0 and 4.0 amperes. There also is provided a family of curves **86** in solid lines plotting lines of constant power output, twelve of the curves in the family of curves **86** being shown plotting values from 50 watts to 1,100 watts of output power from the device **100**. Finally, a family of curves **87** in dashed lines plotting the lines of constant efficiency expressed in percent have been shown in FIG. 18, two of the curves in the family of curves **87** being plotted for values of efficiency of 30% and 40% efficiency.

In a constructional example of the crossed-field discharge device **100**, the various parts thereof have the following dimensions. The anode sleeve **102** has an external diameter of 1.69 inches, and an overall length of 2.625 inches. The anode members **110** and **130** at the walls **113** and **133** have an external diameter of 1.57 inches, an overall length from the outer end walls **112** and **132** to the rod ends **126** and **146** of 1.25 inch, a distance from the longitudinal axis to the surfaces **118** and **138** of 0.371 inch, a distance from the longitudinal axis to the surfaces **121** and **141** of 0.562 inch, a radial dimension of the recesses **122** and **142**, of 0.191 inch, a circumferential dimension of the recesses **122** and **142** of 0.154 inch, a circumferential dimension of the surfaces **118** and **138** of 0.05 inch; a longitudinal dimension of the annular outer walls **113** and **133** of 0.314 inch, a longitudinal dimension of the annular inner walls **114** and **134** of 0.288 inch, and an external diameter of the inner walls **114** and **134** of 1.312 inches. The rods **125** and **145** have a length of 0.648 inch, a radial dimension at the base thereof of 0.125 inch, and a radial dimension at the outer ends thereof of 0.055 inch. The cathode structure **150** has a length of the emissive coating **161** of 1.22 inches, a length of the upper and lower sections of the emissive coating **161** of 0.235 inch, respectively, and a diameter 0.632 inch, a longitudinal length of each of the intermediate reduced portions **165** of 0.25 inch and a diameter thereof 0.622 inch, and a longitudinal extent of the center reduced portion **166** of 0.25 inch and a diameter thereof of 0.612 inch; the projections **162** adjacent to the outer ends of the emissive coating **161** have a radial extent of 0.031 inch, the projections **162** in the intermediate reduced portions **165** have a radial extent of 0.15 inch and the center reduced portion **166** having substantially no projections **162** thereon; the outer surfaces **163** on the projections **162** adjacent to the outer ends of the emissive coating **161** have a circumferential extent of 0.031 inch and the spaces **164** therebetween have a circumferential extent of 0.031 inch; and the angular displacement between the center line of a cathode projection **162** and the center line of the adjacent anode segment **117** or **137** or the adjacent rod **125** or **145** is 5°. The pole pieces **170** have an overall outer diameter at the mounting flange **174** thereof of 1.688 inches, an inner diameter at the coupling flange **172** of 1.12 inches, a longitudinal extent of the mounting flange **174** of 0.25 inch and a longitudinal extent of the coupling flange **172** of 0.25 inch. The foregoing dimensions are for a crossed-field discharge device **100** operating in the general frequency range 900 to 980 megacycles.

From the above description and particularly the dimensions of the illustrative example of the device **100**, it will be seen that the physical dimensions thereof are very small compared to the wavelength 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 an improved thermal stabilitly. It will be understood that external cooling may be provided by means of a clamp-on radiator or cooling coil in lieu of the stacked array of cooling fins **108** illustrated. The anode members **110** and **130** are both constructed from a good heat conducting material and the thick radially extending portions thereof offer a very low thermal resistance thus permitting high power operation. The cantilever mounting of the rods **125** and **145** also contributes to the thermal stability of the device **100** since the major dimension thereof is axially of the tube, whereupon expansion of the rods **125** and **145** does not materially alter the spacing thereof with respect to the inner anode members **110** and **130** and the cathode structure **150**.

The described construction of the device **100** further provides very large mode separation during operation thereof as an oscillator, since a single cavity of the type provided gives principal modes such as ¼, ¾, 5/4, etc. wavelengths having substantial mode separation. Rotating waves present in conventional magnetrons are highly attenuated in the device **100**, the absence of such rotating waves being highly desirable since in conventional magnetrons such rotating waves produce a large number of modes which are not widely separated even with very heavy strapping, thereby to provide problems of mode separation. In the device **100** on the other hand, a ratio of the path for RF waves along inner diameter of the sleeve **102** (i.e., the diameter of the surface **104**) to the path for the RF waves along the inner surface of the anode members **110** and **130** (i.e., along the surfaces **118, 119** and **121** or **138, 139** and **141**, as the case may be) is small, whereby to provide a short and low impedance path for rotating waves; more specifically, the electrical surfaces **104** and **114–134** provide a very low impedance transmission line for rotating RF waves, and by contrast the path of rotating waves along the inner periphery of the anode members **110** and **130** is sinuous and long as is the path for rotating waves along the surface of the cathode **150**; whereby to improve mode separation and stability in the device **100**. Furthermore, the facing surfaces **116** and **136** on the anode members **110** and **130**, respectively, also provide a short and low impedance path for rotating RF waves, thus improving mode separation and stability in the device **100**. Mode stability is also improved due to the tapered structure of the vanes or rods **125** and **145**, this shape of the rods **125** and **145** tending to reduce the capacitance between the rods and the adjacent anode segments **117** and **137**, respectively, thereby to provide a capacitance therebetween that is reduced relative to the capacitance presented by the outer transmission line **120**.

The tapered rods **125** and **145** and the reduced capacitance thereof with respect to the adjacent anode members and anode segments, also results in lower circulating current and the consequent greater circuit efficiency. Such a tapered shape of the rods **125** and **145** also provides for a reduced phase shift of the RF voltages at the outer ends thereof relative to the junction thereof with the attached anode member **110** or **130**, as the case may be, thereby to result in improved electron bunching and consequent improved electronic efficiency during the operation of the device **100**. More specifically, it has been found that the provision of the tapered rods **125** and **145** can increase the power output 20% and the maximum current rating 15% as compared to rods having a uniform cross section from end to end thereof.

It also has been found that the cathode coupling described above is very tight so that the resonant cavity within the device **100** may be heavily loaded for low Q, broad band operation which permits external tuning of at least ten percent. In addition the cathode coupling couples the energy from the device **100** uniformly around the interaction space **160** so that pattern distortion due to loading is avoided with a resultant increase in the efficiency of operation and stability of operation. It further is pointed out that in the region of the annular passage **140**, the RF fields extending into the interaction space **160** can be distorted so as to provide inefficient operation in this region. This condition is avoided by providing the reduced diameter sections **165** and **166** on the emissive coating **161** of the cathode **150** so as to reduce electron emission in this region; more specifically, the DC electrical field is reduced in this region due to the greater spacing between the anode members **110** and **130** on the one hand and the emissive coating **161** on the other hand, and electrons emitted of an undesirable character tend to be cut off by the magnetic field and therefore do not reach the anode members **110** and **130** and have a minimum interaction with the RF fields in the interaction space **160**.

In connection with the coupling of RF energy from the device **100**, it is pointed out that the end space regions betwen the ends of the anode members **110** and **130** and the pole pieces **170** define an inductance of predetermined value, the inductance being directly proportional to the volume of the spaces between the anode members **110–130** and the pole pieces **170**. By adjusting the volume of these end space regions, the desired degree of output coupling can be obtained, a tight coupling being shown in the drawings; an increase in the volume by increasing the spacing between the anode members **110–130** and the pole pieces **170** loosens the coupling, and conversely, a decrease in the volume by decreasing the spacing between the anode members **110–130** and the pole pieces **170** tightens the coupling.

The described construction of the several parts of the device **100** permits complete assembly of the tube prior to brazing of the several parts so that the cathode is converted during the brazing process; this permits a faster bake out of the cathode and a shorter processing cycle for the evacuation of the interior of the device **100**. Another resultant advantage is that the parts are subject to cleaning by hydrogen in the brazing process and are not exposed to subsequent contamination in later processing steps. In this connection it also is pointed out that the inner surfaces of the outer ends of the sleeve **102** that are to be joined to the mounting flanges **174** on the pole pieces **170** are silver plated which permits brazing therebetween without internal fixturing, and thus allows complete assembly of the tube parts prior to brazing thereof.

Referring to FIG. 19 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 power supply **51** and the oscillator **200** in the circuit of FIG. 19 are 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 **232**, 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. 20 also). The amplifying circuit **300** also includes a pair of input terminals **301** and **302** that are connected respectively tot he DC output terminals **54** and **55** of the power supply **51** by means of the conductors **60** and **61**, respectively; the input terminal **302** is also connected by the conductor **61** to the low voltage AC output terminal **56** of the power supply **51**. A third

input terminal **303** is provided for the amplifier circuit **300**, the input terminal **303** being connected by the conductor **62** to the low voltage AC output terminal **57** of the power supply **51**.

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 DC potential, whereby it is necessary electrically to isolate the output terminal **347** from the outer conductor **66** so that the outer conductor **66** can be grounded. As has been pointed out above, it is inherent in the constructon and operation of the power supply **51**, which is of the voltage doubler and rectifier type, that neither the conductor **60** nor the conductor **61** can be grounded, whereby it is also not possible to ground the output terminal **347** of the amplifier circuit **300**. Accordingly, it is also necessary and desirable that the amplifier circuit **300** be electrically shielded by a grounded outer housing (not shown) disposed thereabout in order to prevent a user of the amplifier circuit **300** from being placed in contact with relatively high DC voltages if the user should accidentally come in contact with the amplifier circuit **300**.

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. 19, the first use being illustrated in the upper righthand portion of FIG. 19, and the second use being illustrated in the lower righthand portion of FIG. 19. Referring to the first use illustrated in the upper righthand portion of FIG. 19, 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 a 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 righthand portion of FIG. 19, the transmission line **65** is shown coupled to an electronic heating apparatus, such as the electronic range **70** illustrated that is especially designated for home use. The electronic range **70** in FIG. 19, 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 power supply **51**, 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. 20 of the drawings. The construction of the crossed-field discharge device **100** incorporated in the amplifier circuit **300** of FIG. 20 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 to 10 of the drawings, whereby like reference numerals have been applied to like parts throughout including the magnet coils **210** and **215**, the magnet yokes **211** and **216** 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 lefthand 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 lower pole piece **170** and is capacitively coupled thereto by the coupler **325**; more particularly, an outer annular conductor **327** is mechanically and electrically connected to the lower pole piece **170** and extend downwardly to the lower end of the magnet yoke **216** and 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 **327**, 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 **150** and is capacitively coupled thereto by a coupler **330**; more particularly, an outer terminal **303** is threadedly connected at the upper end thereof to the connector **196** that is in turn connected to the cathode **150** via the heater **176** and is capacitively coupled to the cathode **150** 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 and outer ends thereof being interconnected and the space therebetween 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 upper pole piece **170** and is capacitively coupled thereto by the coupler **345**; more particularly, the outer annular conductor **347** is mechanically and electrically connected to the upper pole piece **170** and extends upwardly to the upper end of the magnet yoke **211** and 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 **347**, 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 **150** and is capacitively coupled thereto by a coupler **350**; more particularly, the output terminal **302** is provided having the lower end thereof threadedly attached to the cathode stud **167** that is in direct electrical connection with the upper end of the cathode **150** 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 **60** that is connected to the B^+ output terminal **54** of the power supply **51** is connected as at **301** to one terminal of the upper magnet coil **210**, whereby to apply the B^+ potential to the anode sleeve **102** of the device **100** through the upper magnet coil **210**, the conductor **213**, the lower magnet coil **215**, the conductor **218** and the cooling fin **108** that is electrically connected to the anode sleeve **102**. The conductor **61** that is connected both to the B^- output terminal **55** of the power supply **51** and one of the terminals **56** carrying the low voltage AC output for the heater **151** is attached to the terminal **302** that is in turn directly connected to the cathode **150** through the cathode stud **167**. Finally, the other terminal **57** of the power supply **51** carrying the low voltage AC output for the heater **176** is connected by the conductor **62** to the terminal **303** that is in turn connected to the other end of the heater **176**.

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 **101** and the cathode **150**, thereby to apply the input energy between the anode structure **101** and the cathode **150**. 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 ¾ of the wavelength of the energy to be amplified, i.e., the distance between the inner surface of the inner wall **323** and a plane normal to the axis of the device **100** and disposed midway between the ends of the anode structure **101** is equivalent to ¾ 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 a point spaced ¼ of the wavelength of the microwave energy to the 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. 20.

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 ¾ 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 is equivalent to ¾ of the wavelength of the microwave energy to be amplified. It would also be permissible to connect the transmission line **65** at a point spaced ¼ 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. 20.

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 **150** forming one conductor and the interconnected anode members **110** and **130** and rods **125** and **145** thereof forming the other conductor therein. As the microwave energy passes through the device **100**, the RF fields associated therewith are reinforced and augmented by interaction with the electrons that pass from the cathode **150** to the anode members **110** and **130** and the rods **125** and **145**. 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 space **160** 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 **101** and the cathode **150** 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 power amplification being for example in the range from about 6 to 10. It has been found that the single interaction space **160** achieves this substantial amplification although the length thereof is on the order of 0.1 times the wavelength of the energy being amplified, whereas prior devices have required lengths of the interaction space that are many times the wavelength of the microwave energy being amplified, for example as many as twenty times the length of the wavelength of the microwave energy being amplified.

The output microwave energy appears between the conductors **341** and **342**, the conductor **341** being capacitively coupled by the coupler **345** to the upper pole piece **170** and the conductor **342** being capacitively coupled by the coupler **350** to the cathode **150**. 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 **150** serving as one conductor and the anode members **100** and **130** and the interconnected rods **125** and **145** 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 length of the interaction space **160** in the device **100**, a greater length of the interaction space **160** providing a greater power gain, and conversely, a smaller length 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. 20 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. 20 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 connected 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 **60**, **61** and **62** 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 **60**, **61** and **62**, 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. 2.

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. 20 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 **327** that is connected to the lower pole piece **170** and thus to the anode 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 **62** to the terminal **303** that is directly connected to the cathode **150**, the conductor **62** also being connected to a terminal **383**. Accordingly, it will be seen that the input terminal **382** is directly connected to the anode structure **101** and the input terminal **383** is connected to the cathode **150** 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, the devices being particularly adapted for operation with low applied potentials between the anode and the cathode thereof. The improved crossed-field discharge device provides a high output of microwave energy in proportion to the physical dimensions thereof, whereby to permit the miniaturization of microwave circuits employing the improved crossed-field discharge device of the present invention.

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

What is claimed is:

1. A crossed-field discharge device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments on said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode sections and adjacent to the inner portion of said interaction space, means for establishing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces, said anode structure including said axially extending spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device.

2. The crossed-field discharge device set forth in claim **1**, wherein said means for establishing a unidirectional magnetic field includes a pair of pole pieces respectively arranged adjacent to the opposite ends of said anode structure and overlying and in axial alignment with said axially extending spaces.

3. The crossed-field discharge device set forth in claim **1**, wherein the portions of said anode structure defining said outer axially extending space cooperate to provide a portion of an outer coaxial transmission line for accommodating an axially extending RF wave therein, the anode segments on said first anode section and said second rods cooperate to provide a first portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, and the anode segments on said second anode section and said first rods cooperate to provide a second portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, said radially extending passage interconnecting said outer coaxial transmission line and the first and second portions

of said inner coaxial transmission line to provide a folded resonant cavity having an operating frequency equivalent to twice the combined length of said coaxial transmission lines.

4. The crossed-field discharge device set forth in claim 3, wherein said outer coaxial transmission line has the ends thereof closed, and said inner coaxial transmission line has the outer ends thereof open.

5. The crossed-field discharge device set forth in claim 1, wherein the radial distance between the outer surface of said cathode structure and the outermost portion of the adjacent one of said anode recesses is less than that required to accommodate a radial standing wave at the operating frequency of the folded resonant cavity for said device, and the radial distance between the outer surface of said cathode structure and the outermost portion of said outer axially extending space is less than that required to accommodate a radial standing wave at an operating frequency of the folded resonant cavity for said device.

6. The crossed-field discharge device set forth in claim 1, wherein said anode structure is symmetrical about a plane normal to the axis of said anode structure midway between the ends thereof.

7. A crossed-field discharge device comprising an anode structure including an annular sleeve and a pair of annular anode members disposed within said sleeve and a plurality of rods disposed adjacent to the inner surface of said anode members, said sleeve and said anode members being electrically connected at the opposite ends of said anode structure and said rods being electrically connected to said anode members at the outer ends thereof, said sleeve and said anode members cooperating to define a first axially extending space therebetween and said anode members cooperating to define a second axially extending space therethrough and said anode members being spaced apart axially to provide a lateral passage therebetween interconnecting said axially extending spaces, each of said anode members having a plurality of radially extending anode segments on the inner surface thereof projecting radially into said second axially extending space and providing a plurality of axially extending anode recesses therebetween, said rods being respectively disposed in said anode recesses and respectively spaced from the ones of said anode segments adjacent to said anode recesses, an axially extending cathode structure disposed in said second axially extending space and cooperating with said anode members to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode members and adjacent to the inner portion of said interaction space, means for establishing a unidirectional magnetic field extending axially through said first axially extending space and said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces, said sleeve and said anode members and said rods defining a frequency determining folded resonant cavity for said device.

8. The crossed-field discharge device set forth in claim 7, wherein said rods are integral with said anode members and extend longitudinally therefrom and into the anode recesses on the other of said anode members.

9. The crossed-field discharge device set forth in claim 7, wherein said rods are integral with said anode members, the rods on each of the anode members being in longitudinal alignment with the anode segments thereon and projecting longitudinally therefrom across said passage and into the anode recesses on the other of said anode members.

10. A crossed-field discharge device comprising an anode structure including an annular sleeve and first and second annular anode members disposed in said sleeve and cooperating to provide an inner axially extending space therethrough, said first anode member including a first annular body having an outer diameter slightly less than the inner diameter of said sleeve and secured thereto adjacent to one end thereof, said second anode member including a second annular body having an outer diameter slightly less than the inner diameter of said sleeve and secured thereto adjacent to the other end thereof, the portions of said bodies disposed toward each other having respectively first and second annular recesses therein to provide respectively first and second outer surfaces spaced inwardly with respect to the inner surface of said sleeve and to provide respectively first and second annular end surfaces on said bodies defining an outer axially extending space therebetween, the adjacent portions of said bodies being spaced apart axially to provide a lateral passage therebetween interconnecting said inner and outer axially extending spaces, a plurality of axially extending first anode segments on the inner surface of said first body and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending first anode recesses therebetween, a plurality of axially extending second anode segments on the inner surface of said second body and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending second anode recesses therebetween, a plurality of axially extending first rods on said first body disposed in said second anode recesses and respectively spaced from the adjacent ones of said second anode segments, a plurality of axially extending second rods on said second body respectively disposed in said first anode recesses and respectively spaced from the adjacent ones of said first anode segments, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode members to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode members and adjacent to the inner portion of said interaction space, means for establishing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces, said anode structure including said axially extending spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device.

11. The crossed-field discharge device set forth in claim 10, wherein said anode members are formed identical one to the other and each is formed from a single block of metal.

12. The crossed-field discharge device set forth in claim 10, wherein said first rods are integral with said first anode segments and extend longitudinally therefrom, and said second rods are integral with said second anode segments and extend longitudinally therefrom.

13. The crossed-field discharge device set forth in claim 12, wherein each of said first anode segments has a first rod thereon, and each of said second anode segments has a second rod thereon.

14. The crossed-field discharge device set forth in claim 12, wherein the outwardly disposed side of each of said rods tapers toward the outer end thereof from the juncture thereof with the associated anode segment.

15. The crossed-field discharge device set forth in claim 12, wherein the radially extending sides of each of said anode segments are disposed in the same plane as the radial extending sides of the rod integral therewith.

16. The crossed-field discharge device set forth in claim 10, wherein the inner surface of said sleeve and said first outer surface cooperate to provide an outer section of a first folded transmission line shorted at one end by said first end surface and connected at the other end through said lateral passage to the inner section of the first folded transmission line defined by said first anode segments and said second rods, and wherein the inner surface of said sleeve and said second outer surface cooperate to provide an outer section of a second folded transmission line

shorted at one end by said second end surface and connected at the other end through said lateral passage to the inner section of the second transmission line defined by said second anode segments being equivalent to twice the combined length of said first and second folded transmission lines.

17. The crossed-field discharge device set forth in claim 10, wherein the ratio of the RF conductive path in said outer axially extending space to the RF conducting path along the inner surface of said anode members is small, whereby said outer axially extending space provides a short low impedance path for rotating RF waves as compared to the path for rotating RF waves provided by the inner surface of said anode members thus to improve mode separation and stability in said device.

18. The crossed-field discharge device set forth in claim 10, wherein the portions of said anode members disposed toward each other and defining said lateral passage provide a short low impedance path for rotating RF waves, thus improving mode separation and stability in said device.

19. A crossed-field discharge device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including a plurality of circumferentially spaced electron emissive sections corresponding in number to the sum of the number of said first anode segments and the number of said first rods and disposed within said anode sections and adjacent to the inner portion of said interaction space, means for establishing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces, said anode structure including said axially extending spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device.

20. The crossed-field discharge device set forth in claim 19, wherein said electron emissive sections are equal in number to the sum of the number of said first anode segments and the number of said second rods and are respectively arranged adjacent to one of said anode segments or one of said rods.

21. The crossed-field discharge device set forth in claim 19, wherein said electron emissive sections are circumferentially spaced apart a distance corresponding generally to the circumferential dimension thereof.

22. A crossed-field discharge device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structuer disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including a plurality of circumferentially spaced and longitudinally extending protrusions corresponding in number to the sum of the number of said first anode sections and the number of said first rods and disposed within said anode sections and adjacent to the inner portion of said interaction space, at least the outermost surface portions of said protrusions being an electron emissive material, means for establishing a unidirectional magnetic field extending exially through said outer axially extending space and said interaction space, and end structures enclosing both the end sof said anode structure and said axially extending spaces, said anode structure including said axially extending spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device.

23. The crossed-field discharge device set forth in claim 22, wherein the radial extent of said protrusions is greatest at the outer ends of said cathode structure and is decreased at the portion thereof disposed opposite said radially extending passage, thereby to decrease the emission of electrons in the area of said radially extending passage.

24. The crossed-field discharge device set forth in claim 22, wherein the radial extent of said protrusions is a first greater predetermined value at the outer ends of said cathode structure and a second minimum predetermined value in the area opposite said radially extending passage and a third intermediate predetermined value in the areas disposed between the outer ends of said cathode structure and the area opposite said radially extending passage.

25. The crossed-field discharge device set forth in claim 22, wherein said electron emissive portions have a circumferential extent of approximately 25% to 60% of the circumferential distance between the centers of adjacent electron emissive portions.

26. The crossed-field discharge device set forth in claim 22, wherein the radial dimensions of each of said protrusions adjacent to the outer ends of said cathode structure is greater than about 20% of the spacing between said anode structure and said cathode structure.

27. A crossed-field discharge device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said

anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including a plurality of circumferentially spaced electron emissive sections equal in number to the sum of the number of said first anode sections and the number of said first rods and disposed within said anode sections and adjacent to the inner portion of said interaction space, said electron emissive sections being symmetrically circumferentially located relative to the associated anode sections and rods, means for establishing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces, said anode structure including said axially extending spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device.

28. The crossed-field discharge device set forth in claim **27**, wherein the center line of each electron emissive section is circumferentially displaced relative to the center line of its corresponding anode segment or rod between 0% and approximately 45% of the circumferential spacing between the center line of an anode segment and the center line of an adjacent rod.

29. The crossed-field discharge device set forth in claim **27**, wherein the center line of each of said emissive sections is circumferentially displaced relative to the center line of its corresponding anode segment or rod between approximately 35% and 45% of the spacing between the center line of an anode segment and the center line of an adjacent rod and on the downstream side of the corresponding anode segment or rod relative to the normal initial electron flow from said electron emissive sections toward said anode segments and said rods in said device.

30. A crossed-field discharge device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode sections and adjacent to the inner portion of said interaction space, means for establishing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space, means for establishing an axially extending RF wave in said axially extending spaces and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, output connections respectively coupled to said anode structure and said cathode structure for removing RF energy from said axially extending spaces utilizing said cathode structure as a probe interacting with said RF fields, and end structures enclosing both the ends of said anode structure and said axially extending spaces.

31. The crossed-field discharge device set forth in claim **30**, wherein the portions of said anode structure defining said outer axially extending space cooperate to provide a portion of an outer coaxial transmission line for accommodating an axially extending RF wave therein, the anode segments on said first anode section and said second rods cooperate to provide a first portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, the anode segments on said second anode section and said first rods cooperate to provide a second portion of an inner coaxial transmission line for accommodating an axially extending RF wave therein, said radially extending passage interconnecting said outer coaxial transmission line and the first and second portions of said inner coaxial transmission line to provide a folded resonant cavity having an operating frequency equivalent to twice the combined length of said coaxial transmission lines.

32. A crossed-field discharge device comprising an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending emissive cathode disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, a heater for said cathode disposed adjacent thereto, a first connector commonly electrically connected both to said cathode and to one terminal of said heater, a second connector electrically connected to the other terminal of said heater, a first end structure joining one end of said anode structure and said first connector for mechanically supporting said cathode and said heater with respect to said anode structure while providing electrical insulation therebetween, and a second end structure joining the other end of said anode structure and said second connector for mechanically supporting said cathode and said heater with respect to said anode structure while providing electrical insulation therebetween, said end structures enclosing and sealing both the ends of said anode structure and said axially extending spaces, said anode structure including said axially extending

spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device.

33. The crossed-field discharge device set forth in claim 32, wherein said end structures are the only electrically insulating seals for said device.

34. A crossed-field discharge device comprising an anode structure including an annular sleeve and an annular anode member disposed within said sleeve and electrically connected thereto and at one end of said anode structure, said sleeve and said anode member cooperating to define a first axially extending space therebetween and said anode member defining a second axially extending space therethrough communicating with said first axially space adjacent to the other end of said anode structure, a plurality of axially extending anode segments on said anode member and projecting radially into said second axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of rods respectively disposed in said anode recesses and respectively spaced from the ones of said anode segments adjacent to said anode recesses, means electrically interconnecting said anode structure and said rods, an axially extending cathode structure disposed in said second axially extending space and cooperating with said anode member to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said inner anode member and adjacent to the inner portion of said interaction space, a first pole piece mounted in one end of said sleeve and spaced from the adjacent end of said anode member and hermetically sealed to said sleeve, a second pole piece mounted in the other end of said sleeve and spaced from the adjacent end of said anode member and hermetically sealed to said sleeve, a first end structure providing a seal between said first pole piece and one end of said cathode structure and providing a mechanical support for said cathode structure while providing electrical insulation therebetween, and a second end structure providing a seal between said second pole piece and the other end of said cathode structure and providing mechanical support for said cathode structure while providing electrical insulation therebetween, said sleeve and said anode member and said rods defining a frequency determining folded resonant cavity for said device.

35. The crossed-field discharge device set forth in claim 34, wherein each of said pole pieces includes an annular inner plate in longitudinal alignment with said second axially extending space including said interaction space and substantially normal to the longitudinal axis of said device for distributing the DC magnetic flux lines therethrough, and an annular outer plate in longitudinal alignment with said first axially extending space and substantially normal to the longitudinal axis of said device for distributing the DC magnetic flux lines therethrough.

36. The crossed-field discharge device set forth in claim 35, wherein said inner plates are disposed relatively close to the adjacent ends of said anode member and said outer plates are disposed relatively remote from the adjacent ends of said anode member.

37. The crossed-field discharge device set forth in claim 34, wherein said pole pieces are formed of a substantially flat sheet of low carbon steel stamped to provide an annular inner plate in longitudinal alignment with said second axially extending space and disposed substantially normal to the axis of said device, an annular outer plate in longitudinal alignment with said first axially extending space and disposed substantially normal to the longitudinal axis of said device and outwardly with respect to the said inner plate, an annular coupling flange interconnecting the outer periphery of said inner plate and the inner periphery of said outer plate, and an annular mounting flange on the outer edge of said outer plate and disposed within the associated end of said sleeve.

38. A crossed-field discharge device comprising an anode structure including an annular sleeve and an annular anode member disposed within said sleeve and electrically connected hereto and at one end of said anode structure, said sleeve and said anode member cooperating to define a first axially extending space therebetween and said anode member defining a second axially extending space therethrough communicating with said first axially extending space adjacent to the other end of said anode structure, a plurality of axially extending anode segments on said anode member and projecting radially into said second axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of rods respectively disposed in said anode recesses and respectively spaced from the ones of said anode segments adjacent to said anode recesses, means electrically interconnecting said anode structure and said rods, an axially extending cathode structure disposed in said second axially extending space and cooperating with said anode member to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said inner anode member and adjacent to the inner portion of said interaction space, a first pole piece mounted in one end of said sleeve and spaced from the adjacent end of said anode member and hermetically sealed to said sleeve, a second pole piece mounted in the other end of said sleeve and spaced from the adjacent end of said anode member and hermetically sealed to said sleeve, a first end structure providing a seal between said first pole piece and one end of said cathode structure and providing a mechanical support for said cathode structure while providing electrical insulation therebetween, a second end structure providing a seal between said second pole piece and the other end of said cathode structure and providing mechanical support for said cathode structure while providing electrical insulation therebetween, and output connections attached to said anode structure and said cathode structure respectively for withdrawing microwave energy from said device, the end spaces between said pole pieces and the respective anode members defining inductances of predetermined value providing for a predetermined coupling of the RF energy in said device to said output connections, said sleeve and said anode members and said rods defining a frequency determining folded resonant cavity for said device.

39. The crossed-field discharge device set forth in claim 38, wherein the output connection attached to said anode structure is an outer annular conductor engaging one of said pole pieces, and the output connection attached to said cathode structure is an inner conductor disposed within said outer conductor and arranged substantially concentric therewith to provide a coaxial transmission line.

40. The crossed-field discharge device set forth in claim 38, wherein each of said pole pieces includes an annular inner plate in longitudinal alignment with said second axially extending space and disposed substantially normal to the axis of said device, an annular outer plate in longitudinal alignment with said first axially extending space and disposed substantially normal to the axis of said device and spaced longitudinally outwardly with respect to the adjacent ends of said anode members to provide a decoupling space, an annular coupling flange interconnecting the outer periphery of said inner plate and the inner periphery of said outer plate, and means connecting the outer periphery of said outer plate to the adjacent end of said sleeve, said output connection attached to said anode structure is an annular outer conductor disposed within and surrounded by the said coupling flange, and said output connection to said cathode structure is an inner conductor disposed within said outer conductor cooperating therewith to form a coaxial transmission line.

41. A microwave oscillator comprising a crossed-field discharge device including an annular anode structure defining therein an outer annular axially extending space

enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode sections and adjacent to the inner portion of said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces, said anode structure including said axially extending spaces and said radially extending passage therein defining a frequency determining folded resonant cavity for said device; means for producing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space; and means for producing a unidirectional electrical field between said anode structure and said cathode structure.

42. The microwave oscillator set forth in claim 41, and further comprising output connections respectively coupled to said anode structure and said cathode structure, said unidirectional electrical field and said resonant cavity cooperating to establish an axially extending RF wave in said axially extending spaces and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, said output connections removing RF energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields.

43. The microwave oscillator set forth in claim 41, wherein said cathode structure includes a cathode carrying said electron emissive element and a heater for said cathode disposed adjacent thereto, and further comprising a first connector commonly electrically connected both to said cathode and to one terminal of said heater, a second connector electrically connected to the other terminal of said heater, a first one of said end structures joining the one end of said anode structure and said first connector for mechanically supporting said cathode and said heater with respect to said anode structure while providing electrical insulation therebetween, and a second one of said end structures joining the other end of said anode structure and said second connector for mechanically supporting said cathode and said heater with respect to said anode structure while providing electrical insulation therebetween; said unidirectional magnetic field and said unidirectional electrical field and said resonant circuit cooperating to establish an axially extending RF wave in said axially extending spaces and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space; and output connections respectively coupled to said anode structure and said first connector for removing RF energy from said axially extending space utilizing said cathode as a probe interacting with said RF fields.

44. A microwave amplifier comprising a crossed-field discharge device including an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode sections and adjacent to the inner portion of said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces; a microwave input coupled between said anode structure and said cathode structure at one end of said device; a microwave output coupled between said anode structure and said cathode structure at the other end of said device; means for producing a unidirectional magnetic field extending axially through said axially extending spaces; and means for producing a unidirectional electrical field between said anode structure and said cathode structure; 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.

45. The microwave amplifier set forth in claim 44, wherein said microwave output includes a pair of output connections respectively coupled to said anode structure and said cathode structure, said unidirectional magnetic field and said unidirectional electrical field and said microwave input cooperating to establish an axially extending RF wave in said axially extending spaces and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space, said output connections removing energy from said axially extending space utilizing said cathode structure as a probe interacting with said RF fields.

46. The microwave amplifier set forth in claim 44, wherein said cathode structure includes a cathode carrying said electron emissive element and a heater for said cathode disposed adjacent thereto, and further comprising a first connector commonly electrically connected to both said cathode and to one terminal of said heater, a second connector electrically connected to the other terminal of said heater, a first one of said end structures joining the one end of said anode structure and said first connector for mechanically supporting said cathode and said heater with respect to said anode structure while providing electrical insulation therebetween, and a second one of said end structures joining the other end of said anode structure and said second connector for mechanically supporting said cathode and said heater with respect to the anode structure while providing electrical insulation therebetween, said microwave input being coupled between said anode structure and said second connector for supplying RF energy to said device; said undirectional magnetic field and said unidirectional electrical field and

said microwave input cooperating to establish an axially extending RF wave in said axially extending spaces and having associated therewith RF electrical fields and RF magnetic fields normal to the axis of said device and extending into said interaction space; said microwave output being coupled between said anode structure and said first connector for removing RF energy from said axially extending space utilizing said cathode as a probe interacting with said RF fields.

47. A microwave circuit comprising a crossed-field discharge device including an annular anode structure defining therein an outer annular axially extending space enclosed thereby and an inner axially extending space extending therethrough and a radially extending passage interconnecting said outer axially extending space and said inner axially extending space at the longitudinal midsection of said anode structure, said radially extending passage dividing said anode structure into a first anode section disposed adjacent to one end thereof and a second anode section disposed adjacent to the other end thereof, a plurality of axially extending anode segments on the inner surfaces of said anode sections and projecting radially into said inner axially extending space and providing a corresponding plurality of axially extending anode recesses therebetween, a plurality of axially extending first rods on said first anode section respectively disposed in the anode recesses in said second anode section and respectively spaced from the adjacent ones of said anode segments in said second anode section, a plurality of axially extending second rods on said second anode section respectively disposed in the anode recesses in said first anode section and respectively spaced from adjacent ones of said anode segments in said first anode section, an axially extending cathode structure disposed in said inner axially extending space and cooperating with said anode sections to define an axially extending annular interaction space, said cathode structure including an electron emissive element disposed within said anode sections and adjacent to the inner portion of said interaction space, and end structures enclosing both the ends of said anode structure and said axially extending spaces; means for producing a unidirectional magnetic field extending axially through said outer axially extending space and said interaction space; means for producing a unidirectional electrical field between said anode structure and said cathode structure; means for applying a modulating signal between said anode structure and said cathode structure for modulating the output of said microwave circuit.

48. The microwave circuit set forth in claim **47**, wherein said anode structure including said axially extending spaces and said radially extending passages therein defines a frequency determining folded 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.

49. The microwave circuit set forth in claim **47** and further comprising a microwave input coupled between said anode structure and said cathode structure at one end of said device; and a microwave output coupled between said anode structure and said cathode structure at the other end of said device; 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.

References Cited

UNITED STATES PATENTS

3,011,091	11/1961	Christen et al.	315—39.73
3,027,488	3/1962	Winsor	315—9.77 X
3,083,316	3/1962	Weber	315—39.73 X
3,158,780	11/1964	Gerlach	315—39.73 X
3,169,211	2/1965	Drexler et al.	315—39.51 X
3,255,422	6/1966	Feinstein et al.	315—39.3 X

HERMAN KARL SAALBACH, Primary Examiner

SAXFIELD CHATMON, JR., Assistant Examiner

U.S. Cl. X.R.

313—158; 315—39.3, 39.53, 39.71, 39.73; 330—47; 331—86; 332—7