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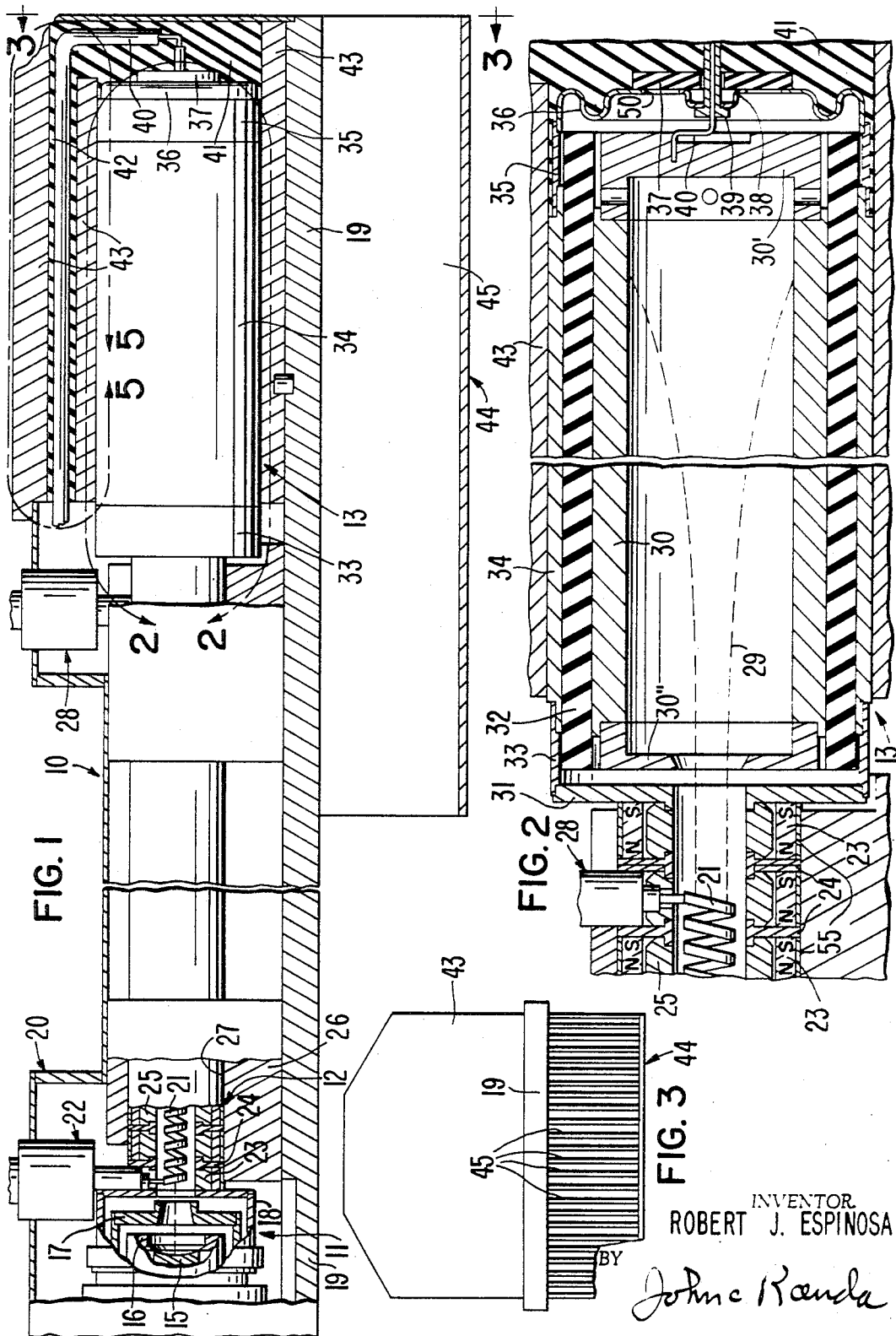
R. J. ESPINOSA

3,471,739

HIGH FREQUENCY ELECTRON DISCHARGE DEVICE HAVING AN
IMPROVED DEPRESSED COLLECTOR

Filed Jan. 25, 1967

2 Sheets-Sheet 1



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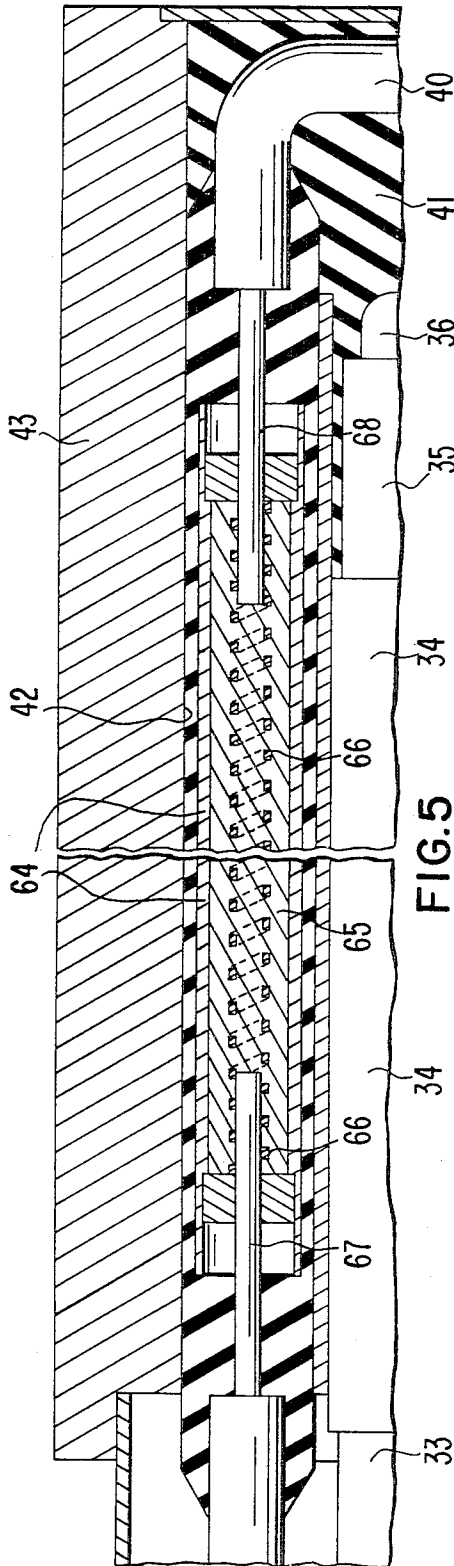


FIG. 5

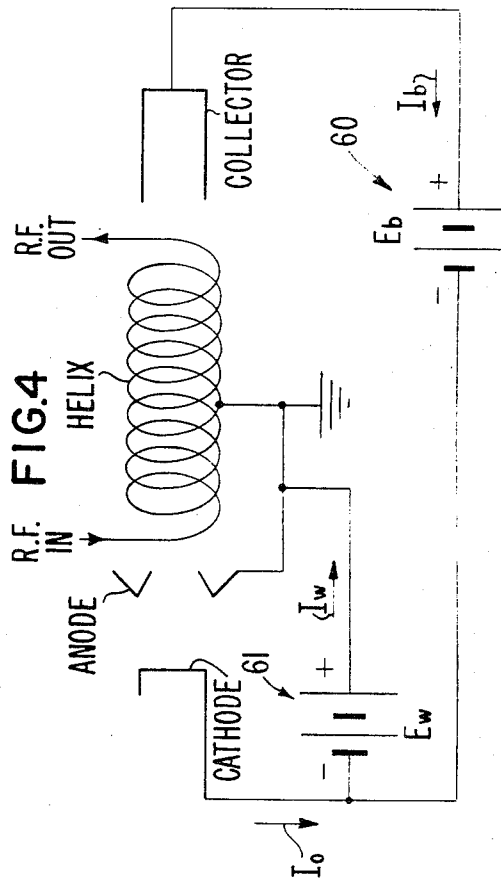


FIG. 4

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HIGH FREQUENCY ELECTRON DISCHARGE DEVICE HAVING AN IMPROVED DEPRESSED COLLECTOR

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7 Claims

ABSTRACT OF THE DISCLOSURE

A high frequency electron discharge device, e.g. a traveling wave tube, klystron etc. having an improved depressed collector which is characterized by having a tubular insulator disposed about the collector bucket and within the vacuum envelope of the device. The tubular insulator forms a coaxial line with the collector bucket as the inner conductor and couples R.F. into a lossy R.F. attenuating D.C. insulator region to minimize R.F. radiation from the device.

This invention relates in general to the field of high frequency electron discharge devices e.g. the traveling wave tubes and klystrons and more particularly to such devices incorporating depressed collectors for improving the operating efficiency of the device.

The general theory and usefulness of depressed collectors in traveling wave tubes and klystrons as means for improving operating efficiency is well established as is the general theory and operation of the traveling wave tube and klystron. This invention represents an improved depressed collector approach which provides a number of advantages over the present state of the art. In particular, where the device is to be utilized in a system environment wherein R.F. radiation from the tube is undesirable due to any of a number of reasons such as the adverse effect on other system components the present invention provides a simple and highly effective attenuation mechanism for practically speaking eliminating such radiation problems in high frequency electron discharge devices utilizing depressed collectors. The present invention also provides a design which permits high frequency electron discharge devices having depressed collectors to operate in airborne vehicles at extreme altitudes without increased danger of tube failure due to voltage breakdown across the insulator. The present invention also permits efficient heat transfer between the collector bucket and the exterior peripheral regions of the collector by utilization of materials having advantageous thermal conductivity properties. In addition the utilization of the collector bucket as the inner conductor of a coaxial line permits efficient R.F. coupling into a lossy R.F. attenuating D.C. insulator region which also provides the D.C. isolation for the collector bucket voltage lead in conductor.

An improved modification of a portion of the R.F. attenuating D.C. insulator region includes a helical wire center conductor section which is embedded in carbonyl iron powder and a suitable insulating sleeve. This modification has provided over 100 db of attenuation in a 2 inch length.

It is therefore an object of the present invention to pro-

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vide a high frequency electron discharge device incorporating an improved collector.

A feature of the present invention is the provision of a high frequency electron discharge device with an insulated collector which is non-radiating and capable of being operated at a relatively high body to collector voltage differential in a high altitude environment by virtue of disposing the collector insulator within the vacuum envelope of the device and coupling residual R.F. energy to an R.F. attenuating and D.C. insulating region.

Another feature of the present invention is the provision of a high frequency electron discharge device incorporating an insulated collector including a thermally conductive collector bucket disposed within a tubular insulator sleeve coaxially disposed about said collector and forming a coaxial line for coupling residual R.F. energy from the interaction collector regions into an R.F. attenuating and D.C. insulating region which supports a collector potential source lead in conductor for providing a depressed collector.

These and other features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a fragmentary partly cut-away and partly in elevation view of a traveling wave type of high frequency electron discharge device incorporating the teachings of the present invention.

FIG. 2 is a cross-sectional view of the portion of the device depicted in FIG. 1 encompassed by the lines 2—2.

FIG. 3 is a sectional view of the device depicted in FIG. 1 taken along the lines 3—3 in the direction of the arrows.

FIG. 4 is a schematic representation of a D.C. bias arrangement for depressed collector operation of a TWT.

FIG. 5 is an enlarged cross-sectional view of a modified version of a portion of the R.F. attenuator region of the collector in the region encompassed by lines 5—5 of FIG. 1.

Turning now to FIG. 1 a traveling wave type of high frequency electron discharge device 10 is depicted which includes a conventional electron beam forming and projecting means 11 disposed at the upstream end portion of the device, beam-wave interaction means 12 disposed along the intermediate portion of the device and beam collector means 13 disposed at the downstream end portion of the device.

The electron discharge device 10 is specifically a traveling wave tube amplifier utilizing periodic permanent magnet focusing but is representative of a general class of high frequency electron discharge devices operable in the microwave spectrum such as klystrons and hybrid tubes which can advantageously benefit from insulated depressed collector operation with regard to improving operating efficiency.

The utilization of a depressed collector, that is a beam collector bucket which is provided with a potential which is optimum of a value such as to collect all electrons at a reduced velocity and thus eliminate thermal losses due to the conversion of kinetic energy on electron impact into heat energy and maximize efficiency requires the utilization of a collector bucket (the term bucket includes both singular and plural collector surfaces and potentials) which is provided with a potential greatly reduced rela-

tive to the beam accelerating voltage. This potential difference requirement presents problems of properly insulating the collector from the tube main body which is generally at anode potential and grounded. The presence of the insulator introduces problems of residual R.F. energy generated in the device and in the collector itself radiating through the insulator and externally of the device if proper shielding means are not introduced. Add to the above the desirability of designing a tube which can function under diverse environmental conditions without undergoing insulator breakdown and the problem is magnified. Add the further criterion of providing for an efficient means for transferring residual R.F. energy to a suitable loss medium incorporated in the tube and providing good thermal conductivity between the collector bucket and the exterior peripheral portions of the collector and the design problem is further magnified and especially so if minimizing tube weight for airborne system operation is also a design constraint. These problems have all found a solution in the present invention as the detailed explanation provided hereinafter will exemplify.

The beam forming and projecting means 11 includes a cathode emission surface 15, focusing electrode 16, accelerating anode 17 incorporated in a suitable housing structure 18 forming a part of the vacuum envelope of the tube and supported on a suitable base plate 19 of good thermal conductivity such as aluminum, copper, etc. Any conventional heater-cathode gun circuitry may be utilized to advantage and the operating potentials supplied by lead in conductors in a manner well known in the art. A suitable cover 20 may be provided over the upstream end portion of the device as shown. Electromagnetic wave energy in the microwave spectrum which is to be amplified is introduced to a helix slow wave interaction circuit 21 via a conventional coaxial coupler 22 as shown. The electron beam is focused along the length of the helix by use of the well known periodic permanent magnetic focusing technique which incorporates a plurality of axially spaced and polarized permanent magnets 23 of semi-cylindrical shape coupled to a series of high permeability pole pieces 24 as of e.g. soft iron which in turn are bonded to a plurality of non-magnetic spacer rings 25 as of e.g. Elkonite to form a vacuum envelope for the interaction portion of the device. See for example U.S. patent application Ser. No. 256,748 filed Feb. 6, 1963 by A. Fiedor et al. now U.S. Patent 3,297,905 and assigned to the same assignee as the present invention for more details if desired. Suitable non-magnetic spacers such as copper rings 55 as seen best in FIG. 2 may be disposed about the magnets to retain them in the proper position between the pole pieces. The entire circuit-focusing assembly is disposed within a shell 26 having a cylindrical bore 27 and mounted on the support plate 19 as shown.

Electromagnetic wave energy is extracted at the downstream end portion of the device via any conventional coaxial coupler 28. The electron beam denoted by dotted lines 29 continues into the collector region 13 where it undergoes space charge debunching and spreads out to be collected on the interior walls of a copper or the like collector bucket 30. The upstream end of the collector bucket has an inwardly directed copper or the like flange portion 30' which aids in preventing secondary electrons from returning down the tube axis from the collector region. As discussed previously, if the collecting surfaces of the collector bucket 30 are maintained at a negative (potential or potentials, if a segmented plural potential collector is used) relative to the accelerating anode or beam voltage which is generally at body voltage (anode 17, body 18, focusing assembly, shell 26 etc. are all typically grounded) with the cathode adequately shielded to minimize the hazards due to high voltage differentials between cathode and anode regions of the beam forming and projecting means, improved efficiency is at-

tained. However, the use of a depressed collector requires that body to collector insulation means be incorporated in the device with the attendant problems resulting therefrom as discussed above.

As shown in FIG. 4 in which a schematic representation of a typical depressed collector D.C. bias arrangement is depicted the collector D.C. bias lead 40 is tied to any suitable power supply such as a battery 60 which in turn is tied to the cathode to provide a depressed collector voltage E_b relative to the cathode. A separate D.C. bias voltage source such as battery 61 is coupled between anode and cathode as shown to provide the D.C. accelerating potential E_w . The helix slow wave circuit is tied to the body and grounded. Intercepted beam current on the helix is denoted by I_w whereas total beam current is denoted by I_o and collector current I_b as shown. A typical set of parameters for a 100 watt tube operable in the 2-4 GHz. region CW as the following:

$E_w \approx 3050$ volts
 $E_b \approx 1800$ volts
 $I_o \approx 340$ milliamps
 $I_w \approx 20$ milliamps
 $I_b \approx 320$ milliamps

As best seen in FIG. 2 the collector 13 is coupled to the downstream end portion of the interaction circuit via a high permeability magnetic pole piece 31 e.g. soft iron which forms a portion of the vacuum envelope of the device. An insulator sleeve 32 as of alumina (Al_2O_3), beryllia (BeO) which are a few examples of insulators having good voltage breakdown characteristics and excellent thermal conductivities as far as insulating materials are concerned is coaxially disposed about the collector bucket 30 and suitably bonded thereto e.g. by a metal to ceramic bond. The bond obtained by metalizing the ceramic and brazing it to the copper cylinders eliminates the high temperature gradient which is usually observed across unbonded joints. The material of the collector bucket 30 should be of good thermal conductivity to provide good axial heat flow properties such that the heat transfer to the ceramic insulator is more uniform. Copper fills the requirements. Also sleeve 34 can be advantageously made of copper for good thermal conductivity to heat transfer block 43 and to permit a good pressure fit therebetween.

The pole piece 31 has a Kovar or the like thin thermal expansion ring 33 bonded thereto, e.g., brazing, welding, to form a continuation of the vacuum envelope about the ceramic insulator 32 and permit thermal expansion of the collector in operation without rupture of the vacuum seal. The metal sleeve 34 is coaxially disposed about and bonded to the insulator sleeve 32 and bonded to the other end of the expansion ring 33 as shown. Another Kovar or the like expansion ring 35 is brazed or the like to the other end of the metal sleeve 34 and in turn has a flexible dimpled stem ring 36 e.g. of copper or the like brazed thereto as shown. The inner edge of the ring 36 has a ceramic insulator ring brazed or the like thereto and a copper or the like cup 38 is brazed to the inner surface of the insulator ring to serve as a support for a copper or the like conductor support sleeve 39 brazed thereto. A conductor 40 is coupled from the collector bucket back wall 30' through the sleeve 39 and insulator ring 37. This conductor is used to supply a potential to the collector bucket portion which is lower than the beam potential to reduce the electron's impact velocities and thus reduce thermal losses and enhance tube operating efficiencies. The conductor 40 extends into a lossy R.F. attenuation region 41 as shown and through a bore 42 in a solid heat transfer block 43 e.g. of copper or aluminum which is mounted on the base plate 19 by e.g. brazing, bolting etc. The conductor 40 is coupled to any suitable power supply e.g. tapped off the anode supply to obtain the desired voltage depression. To improve convection cooling heat transfer characteristics a cooling fin section 44 in-

cluding a plurality of spaced cooling fins 45 is coupled to the bottom of the base plate 19 as shown best in FIG. 3.

The lossy attenuating region 41 is filled with a suitable D.C. insulation R.F. attenuation material to provide both insulation for the collector potential source lead in conductor 40 and to absorb R.F. energy coupled through the coaxial conductor formed between collector bucket 30 and vacuum envelope conductor 34 separated by insulator 32. The aperture 50 between stem ring 36 and cup 38 permits iris coupling of the R.F. into the lossy attenuator region 41. A suitable lossy R.F. attenuator material for region 41 is carbonyl iron particles dispersed in RTV Silicon Rubber, or any other suitable binder which forms a suitable encapsulation about collector end and functions as a D.C. insulator. Since the ceramic insulator 32 is disposed within the vacuum envelope and thus is maintained at pressures of 10^{-7} torr or lower it is possible to operate the tube at elevations in the 65,000 to 100,000 ft. range without encountering voltage breakdown across the dielectric 32 which would be a particular problem at these altitudes if the insulator 32 were at atmospheric pressure since the breakdown voltage for air at these levels is reduced to as low as 400 volts in comparison to around 10 kilovolts per inch at sea level or 300 kv./inch under high vacuum conditions such as 10^{-7} torr.

A traveling wave tube constructed in accordance with the teachings of the present invention for operation in the 2-4 GHz. range at over 100 watts CW with -2000 volts between body and collector bucket or across the ceramic 32 was successfully operated with better than 20 db reduction in radiated R.F. power with the lossy R.F. attenuation in situ as opposed to leaving the region 41 empty.

In FIG. 5 a modified R.F. attenuator is depicted which has considerably enhanced R.F. attenuation characteristics. The modification includes converting the section of conductor 40 in bore 42 which is parallel but radially removed with respect to the device axis into a D.C. insulated helical wire attenuator end section. The modification includes a Teflon or other suitable insulating tube or sleeve 64 having its interior filled with carbonyl iron powder 65 within which a helix 66 of molybdenum copper etc. is embedded. The ends of the helix are coupled e.g. brazed to terminated center conductors 67, 68 of the coaxial line formed between the interior walls of the bore 42 and the conductor 40 used to supply the desired D.C. potential to the collector as described previously. A pair of Teflon bushings may be used to center the helix 66 in the insulating tube 64. The sleeve 64 is preferably embedded in a suitable organic encapsulating material e.g. an epoxy resin to provide increased D.C. isolation. A two inch long helix with a mean diameter of 55 thousandths of an inch and 80 turns provided over 100 db of attenuation with respect to R.F. leakage without any attenuation mechanism. The helix section acts as a mode converter and transforms the TEM coaxial into a helix propagation mode with its accompanying slow wave characteristics and thus the carbonyl iron powder attenuation properties are greatly increased due to the time delay introduced by the helix. Because of the excellent effectiveness of the helix attenuator section the region 41 may be simply filled with RTV Silicon Rubber or any other organic insulating binder with the carbonyl iron powder R.F. attenuation means and adequate attenuation is still achieved.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A high frequency electron discharge device for operation in the microwave spectrum including electron beam forming and projecting means disposed at an upstream end portion of the device, a beam-wave interaction section

disposed along the device axis and beam collector means disposed at the downstream end portion of said device, said beam forming and projecting means, beam-wave interaction section and collector means forming an integrated structure and a portion of a vacuum envelope for said device, said collector means including a collector bucket disposed about the device axis, said collector bucket having a tubular ceramic insulator sleeve coaxially disposed thereabout and maintaining said collector bucket in D.C. isolation with respect to said beam-wave interaction section, a metal sleeve disposed about said ceramic insulator sleeve and forming the outer conductor of a coaxial line with said collector bucket forming the inner conductor for coupling residual R.F. energy from said interaction section and collector along the axial extent of said collector bucket, lossy R.F. attenuation means disposed at the downstream end portion of said collector bucket and in R.F. coupled relationship with respect to said coaxial line such that R.F. energy traversing said coaxial line is absorbed in said lossy R.F. attenuating means and conductor means for providing said collector bucket with a potential below the potential of said metal sleeve disposed about said ceramic insulator.

2. An evacuated high frequency electron discharge device comprising a vacuum envelope having a metal portion, a beam forming and projecting means disposed within said envelope at the upstream end portion of said device, a beam-wave interaction means disposed within said envelope along the device axis and a collector bucket disposed at the downstream end portion of said device, a ceramic insulator means disposed about said collector bucket and maintaining said collector bucket in D.C. isolation with respect to said beam forming and projecting means and said beam-wave interaction means, said collector bucket and said ceramic insulator means being disposed internally of said metal portion of the vacuum envelope of said device and forming therewith a coaxial conductor means for R.F. energy, lossy R.F. attenuator means disposed at the downstream end portion and externally of said collector bucket and in R.F. coupled relationship with respect to said coaxial conductor means for absorbing R.F. energy.

3. The device defined in claim 2 wherein said lossy R.F. attenuator means is a D.C. insulator comprising an organic insulating material having high permeability metal particles dispersed therein.

4. The device defined in claim 2 wherein said beam wave interaction means is disposed within a vacuum envelope formed from a series of non-magnetic spacers and high permeability pole pieces and wherein the last pole piece at the downstream end portion of said series of pole pieces has a larger cross-sectional dimension than the cross-sectional dimensions of said collector bucket, a metal sleeve coupled to said last pole piece and forming a portion of said vacuum envelope of the device, said metal sleeve being coaxially disposed about said ceramic insulator sleeve and forming the outer conductor of a coaxial line with said collector bucket forming the inner conductor.

5. The device defined in claim 4 wherein said metal sleeve is disposed within a metal block forming a thermal heat sink for said collector bucket, ceramic insulator and metal sleeve, said metal block being mounted on an elongated metal base plate which is rigidly secured to the remaining portions of said device, said metal base plate having a plurality of cooling fins protruding therefrom.

6. An evacuated high frequency electron discharge device comprising a vacuum envelope having a metal portion, a beam forming and projecting means disposed within said envelope at the upstream end portion of said device, a beam-wave interaction means disposed within said envelope along the device axis and a collector bucket disposed at the downstream end portion of said device, a ceramic insulator means disposed about said collector bucket and maintaining said collector bucket in D.C. iso-

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lation with respect to said beam forming and projecting means and said beam-wave interaction means, said collector bucket and said ceramic insulator means being disposed internally of said metal portion of the vacuum envelope of said device and forming therewith a coaxial conductor means for R.F. energy, lossy R.F. attenuator means disposed at the downstream end portion and externally of said collector bucket and in R.F. coupled relationship with respect to said coaxial conductor means for absorbing R.F. energy, said lossy R.F. attenuator means including a helix conductor embedded in lossy R.F. material and having one end electrically connected to said collector bucket.

7. The device defined in claim 6 wherein said helix conductor is disposed parallel to and radially removed from

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the axis of the device, whereby a direct current source may be connected to the free end thereof.

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