United States Patent

Scott

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[54] **MICROWAVE GENERATOR WITH INTERLEAVED FOCUSING AND INTERACTION STRUCTURES**

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[51] **Int. Cl.**.....**H01j 25/34**

[58] **Field of Search**.....315/5.34, 3.5, 3.6, 39.3; 331/82

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[57] **ABSTRACT**

A microwave generator comprising an electron beam focused by a novel focusing means is described. The lines of the focusing means are interleaved with a microwave interaction structure that assists in the focusing function. Klystron and travelling wave tube configurations are depicted with the interleaved focusing and interaction structures printed on ceramic sheets in one preferred embodiment. The ceramic sheets may be notched around and between the printed lines of the focusing and interaction structures to reduce radio frequency and DC arcing.

19 Claims, 8 Drawing Figures

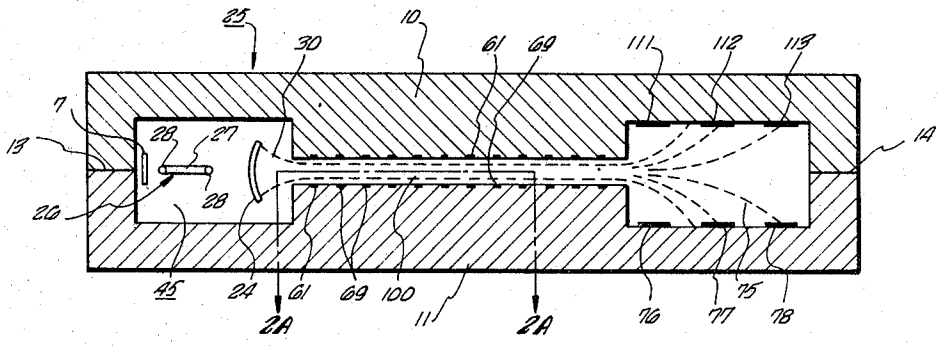
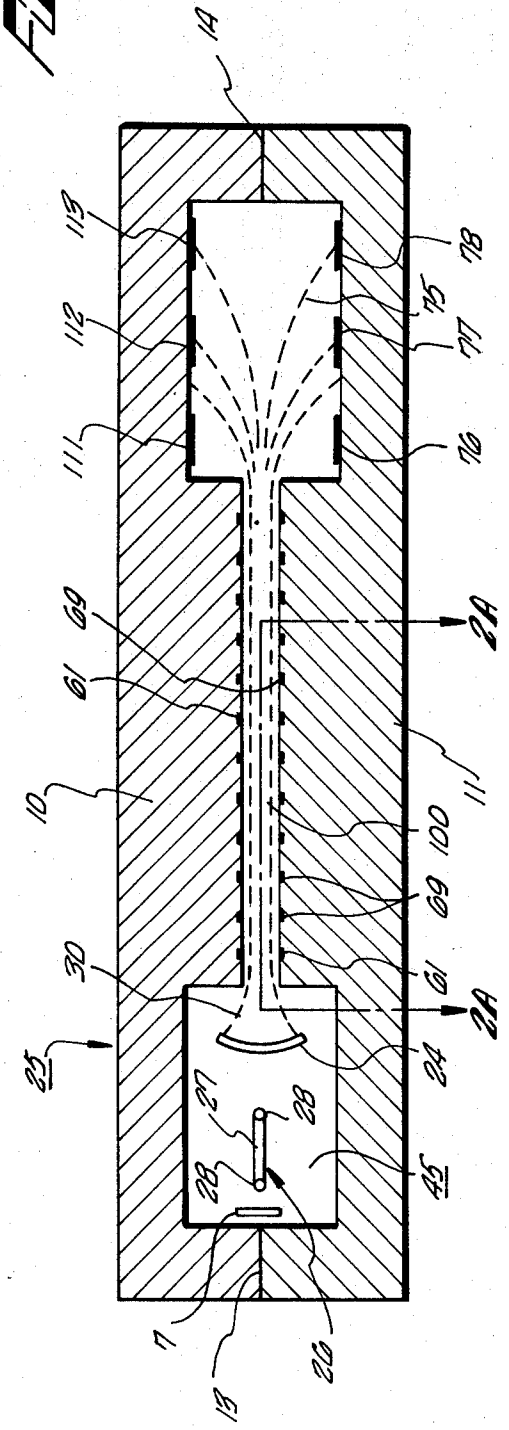


FIG. 1



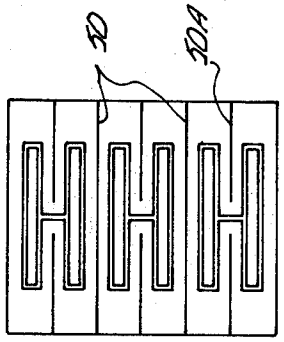


FIG. 4C

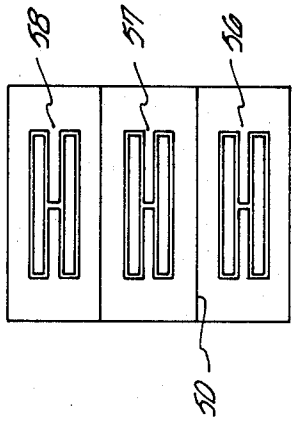


FIG. 4B

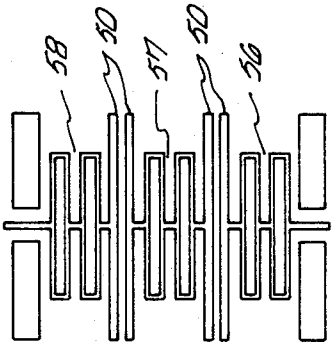


FIG. 4A

FIG. 3

FIG. 5

FIG. 2A

FIG. 2B

MICROWAVE GENERATOR WITH INTERLEAVED FOCUSING AND INTERACTION STRUCTURES

CROSS-REFERENCES TO RELATED APPLICATIONS

This is an improvement application over my patent which is entitled INTEGRAL MICROWAVE RADIATING AND GENERATING UNIT, having U.S. Pat. No. 3,448,384, issued June 3, 1969.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The fields of the invention include ultra-high frequency generators for commercial, industrial and military applications.

2. Description of My U.S. Pat. No. 3,448,384

In my above-identified patent, a new microwave generator utilizing printed electrostatic focusing members and a printed microwave interaction structure on a ceramic vacuum enclosure is described and claimed. Microwave power is generated in either of two operating modes; i.e., a travelling wave mode or a klystron mode. Both my klystron and travelling wave tubes include electrostatic focusing lines to focus the electron beam. A microwave structure interacts with the focused electron beam and generates microwave output power from the tube. In my patent in FIGS. 5A through 5C, several microwave interaction structures for both the operating modes mentioned above are depicted. During the course of perfection of my patented microwave tube inventions, I chanced upon an unusual and surprising discovery in that when an electrostatic focusing means is interleaved with an interaction structure on a common surface of a ceramic, or dielectric sheet, highly improved operating results are obtained.

SUMMARY OF THE INVENTION

I obtain my improved results by arranging the geometry of the printed microwave interaction structure and the geometry of the electrostatic focusing means so that neither degrades from the functions performed by the other. I interleave and print these two items on a single side of a ceramic sheet and thus provide a simpler tube design which exhibits more power output than known prior art approaches.

Various combinations of electrostatic focusing means and interaction structures are described and claimed in this patent application. Any choice of such combinations depends upon the peculiar design criteria for the printed circuit tube. In any selected combination, however, it is of significance to note that the individual lines of my electrostatic focusing means and the lines which form my interaction structure, are interleaved in such a manner than a dual function is performed by the interaction structure. Thus in my invention the microwave interaction structure serves not only to interact with the electron beam, but it also serves as part of the focusing means to focus the electron beam. My new and improved dual function for my tube is possible because I alternate a single focus line at one potential, with a portion of an interaction structure at another potential so that together they focus an electron beam. These potentials for the interaction structure and the focusing lines are selected above and below the average voltage for the electron beam, as will be described in more detail hereinafter.

I have obtained further advantages in my microwave tube invention by notching the ceramic material between the lines of the focusing means and the lines forming the interaction structure. Such notching of the ceramic material forms narrow tortuous islands upon which the printed focusing lines and the lines of the printed interaction structures reside. The remaining un-notched portion of the ceramic sheets may be made as thick as necessary to serve, for example, as a vacuum envelope for the tube. This additional thickness of a ceramic sheet is available without decreasing the microwave field strength at the lines of the interaction structure on the ceramic islands. Furthermore, notching the ceramic sheets decreases both the microwave field gradients and the electric field gradients along the ceramic surface. Any possibility of radio frequency and/or DC arcing is markedly reduced by the ceramic islands.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view taken along the longitudinal axis of a microwave generator in accordance with the principles of this invention;

FIGS. 2A and 2B respectively show a plan and a sectional view of an enlarged portion of FIG. 1, and depict notches in a ceramic sheet to form islands for the printed lines of the focusing means and microwave interaction structure;

FIG. 3 depicts a double width travelling wave meander line interleaved with a focusing means in accordance with the principles of my invention;

FIG. 4A depicts a distributed interaction klystron from my patent which shows a single interaction structure with shorting bars; and FIGS. 4B and 4C depict distributed interactions klystron configurations with focusing lines interleaved with the interaction cavity structures in accordance with the principles of my invention; and

FIG. 5 is a plan view of a combination klystron and travelling wave tube interaction structure having interleaved focusing means in accordance with the principles of my invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 depicts a sectional view taken along a longitudinal axis of the ultra-high or microwave frequency generating unit **25**. Several perspective views of typical units are shown in my patent and thus a perspective view is not deemed necessary. A pair of opposed planar dielectric sheets **10** and **11** are joined by butt joints **13** and **14**. These sheets may be of any suitable dielectric material such as ceramic, glass, Pyroceram or other similar dielectrics capable of receiving and supporting printed circuitry. Both halves **10** and **11** are identical in shape thus simplifying the manufacturing techniques. Both ceramic halves **10** and **11** may be joined together around their entire periphery so that they form an airtight seal. Numerous techniques are known in the art for sealing such ceramic sheets together and any suitable manner of forming such airtight seals may be employed.

With the ceramic sheets suitable sealed in an airtight fashion for generator **25** the cavities **45**, **75** and **100** are rough vacuum pumped. Final vacuum pumping may be accomplished by activating getter **7** in a well-known

manner. Voltage and current to active getter **7** (and to supply the same to all other active components as well) may be supplied through feedthrough electrical connectors extending from the outside of the ceramic sheets into the various cavities. Suitable means for such electrical connections are described in my patent and need not be repeated herein.

Positioned at one end of unit **25** is an electron beam forming cavity **45**, and at the other end is an electron beam collecting cavity **75**. Interconnecting these two cavities **45** and **75** is a narrow flat beam cavity **100**. In the description herein a flat sheet electron beam will be described because it offers significant advantages when my invention is employed in certain uses such as microwave ovens and other similar heating units. By no means, however, is my invention limited to a flat sheet electron beam since the principles described and claimed herein apply with equal force and significance to a round, elliptical or other shape electron beam.

Housed within the beam forming area **45** is a cathode **24** which may be mounted in any suitable manner with a concave surface facing the electron cavity **100**. Positioned behind the cathode **24** is a filament heater **26**. Voltage and current to operate these components of the generator **25** are supplied in the manner indicated earlier. Filament heater **26** may any known heating unit which comprises, for example, a high resistance wire **27** such as tungsten, wrapped around ceramic rods **28** which are supported in the cavity **45** by any suitable means. When voltage is applied to the tungsten wire, it forms heat which in turn heats the cathode **24**.

Cathode **24** may be any conventional gun fabricated, for example, from a nickel strip, which strip has been sprayed with an electron emissive surface. When heated, electrons are emitted from the concave surface of cathode **24**. The emitted electrons are guided by suitable focusing electrodes as are described in my patent, into a flat sheet electron beam **30**, shown in dashed lines.

A flat electron beam, as is true of any electron beam, regardless of shape, tends to spread in thickness, due to mutual repulsion of each and every one of the electrons forming the beam. In my invention, beam **30** is held into its predetermined shape (flat, round, elliptical, etc.) by interleaved electrostatic focusing means and interaction structures **61** and **69**, respectively.

Digressing from a more detailed explanation of the principles of my invention for a moment, it should be understood that it is general practice in electrostatic focusing to utilize a pair of focusing electrodes as formed, for example, by two interleaved ladder focusing arrays shown in FIG. **4**A of my patent. Each ladder array is connected to a different voltage. An electron beam, of course, has an average voltage. The voltages for the ladder focusing arrays are selected both above and below this average beam voltage. Such voltages establish field gradients which alternately attract and repulse the electron beam toward and away from the focusing arrays. The net result of such a field gradient is an inwardly directed electric field that keeps the electron beam focused substantially into a flat sheet beam in its beam cavity.

In my present invention, I have discovered that if one voltage is connected to a focusing line which is interleaved with the lines forming an interaction structure, and another second voltage is connected to the interaction structure, then these two voltages together form an inwardly directed field gradient which focuses the electron beam with a much simpler and more economical structure.

According to the principles of my invention, an interaction structure may be present on both the upper and lower ceramic sheets facing the electron beam. By symmetrically printing the interaction structure **69**, FIG. **1**, on both the upper and lower ceramic sheets **10** and **11**, the effective strength of the microwave field at the electron beam is at least doubled. In a similar manner the focusing lines **61** are printed on both the upper and lower ceramic sheets **10** and **11** and these focusing lines are also symmetrical.

Microwave unit **25**, FIG. **1**, may be of the travelling wave tube type or of the klystron type as mentioned hereinbefore. Both types in my invention include microwave interaction structures **69** interleaved with focus lines **61**. The difference in operation of the two types depends upon the type of interaction structure employed and the input and output conditions for the interaction structure. Several forms of interaction structures for both types of operation are depicted in FIGS. **2**, **3** and **4**.

For example, a travelling wave tube interaction structure is shown in plan view in FIG. 2A. The interaction structure **69** of FIG. 2A is known as a meander line. Meander line **69** is interlaced with a focusing line **61**. The voltages shown exemplify a typical operation. Thus, it is assumed that the interaction structure is electrically grounded, and the cathode **24** in the beam formation area **45** of FIG. **1** is at a high negative potential. In such an instance the focusing lines **61** are connected at a less negative voltage, i.e., at a voltage between ground and the high negative voltage for cathode **24**.

In FIG. 2A this voltage gradient is shown simply at (+) or (−) relative to the average electron beam voltage. Accordingly the interaction structure **69** is at a positive electrical potential and it is followed by a negative electrical potential of focusing lines **61**. The interleaved focusing lines **61** and the periodic sections of meander line **69** accordingly establish alternate voltage polarities as is necessary to continually attract and repulse electron beam **30**, FIG. **1**, as it traverses the beam cavity **100** between ceramic sheets **10** and **11**. In spite of prior art consideration against such an approach, my tests prove that the single meander line interaction structure **69** and the interleaved focusing lines **61** over a suitable wide frequency range, exhibit all expected microwave interaction properties, just as if the focus lines **61** were not included.

Accordingly my invention provides a simple meander line travelling wave tube which is provided with a wide operating frequency range. In this regard, a particularly important advantage of my travelling wave tube of FIG. 2A is that losses in the meander line travelling wave interaction structure have less effect on the overall efficiency of the tube than is true in certain of the distributed interaction structures of the klystron tube types to be described hereinafter. Since one typical use for my microwave generator will be in a microwave oven operating at approximately 2,450 megacycles per second, such a highly efficiency

travelling wave tube for this frequency range is provided in a simple and reliable manner.

A side elevation of one embodiment cut through the ceramic sheet **11** of FIG. **2A** along the line indicated is shown in FIG. **2B**. Thus in FIG. **2B** the notched ceramic areas **67** are shown in profile and the printed focusing lines **61** and the interaction lines **69** are shown positioned on the islands created by the notches in the ceramic sheet.

Notching the ceramic material between the focus lines **61** and the interaction structure **69** offers numerous advantages. For example, I discovered that the impedance of the interaction structure at the beam location is proportional to the thickness of the ceramic material. With the interaction structure **69** printed on the ceramic islands **70**, this dependence on ceramic thickness as far a microwave field strength is concerned is lessened substantially. At the same time, the remaining thickness of ceramic sheet **11** may be selected as necessary to serve, for example, as a rigid vacuum envelope for the entire tube.

Another advantage afforded by notches **67** between the printed circuit lines **69** of the interaction structure and focus lines **61** is that the dielectric loading is reduced. Thus if the ceramic material is not removed from between the focus and interaction lines the dielectric loading is increased and such loading reduces the tube's efficiency. With notches **67**, a wider circuit for any given frequency range is possible and such a wider circuit yields a higher power level because the electron beam can be spread over a wider area.

Notching also serves to reduce problems of arcing. When a ceramic sheet **11** includes notches **67**, the microwave field gradients between the lines of the interaction structure **69** are greatly reduced. The reduction of these fields reduces the possibility of radio frequency arcing and allows a more compact and higher frequency tube.

In a similar manner, the DC voltage applied to the focusing lines **61** is normally in the order of several hundred volts. Notches **67** again reduce the possibility of any direct current arcing between the interleaved tongues of the focus line and the lines of the interaction structure **69**.

FIG. **2A** depicts a single meander line interaction structure **69** for travelling wave tube mode. This meander line has matched impedances at both its input end and its output end. It is not resonated to form cavities (as is true in a klystron operation) but rather it forms a broadband travelling wave tube. The power output for such a tube may be doubled by the use of a double meander line circuit as illustrated in FIG. **3**. In FIG. **3**, the meander line **69** is divided into a right and a left side. Focus lines **61** again are positioned at the same location as was true for the travelling wave tube configuration of FIG. **2**. This arrangement provides double output power for only a slightly more complicated printed circuit configuration. Again it should be noted that the interaction structure **69** and the focusing lines **61** of FIG. **3** may be present on both surfaces of ceramic sheets **10** and **11**, FIG. **1**, for improved results.

FIGS. **4B** and **4C** show two different versions of a distributed interaction klystron mode in accordance with my invention. For the sake of comparison, FIG. **4A** shows a similar interaction structure as depicted in FIG. **5C** of my aforementioned patent. In such klystron operations, as is well-known, there is no interaction between the interaction structure and the electron beam as it moves from one cavity to another. Rather the beam drifts between the cavities free of interaction and is maintained in its predetermined shape by the potential difference in the manner discussed hereinbefore.

In FIG. **4A** shorting lines **50** between cavities **56, 57** and **58** are depicted. Such cavities simply mean that the length of the interaction structure is selected so that the interaction circuit resonates at a resonant frequency. Rather than using printed shorting lines **50** on a separate interaction structure as in FIG. **4A**, the shorting line functions are now performed by my interleaved focus lines **50** which are positioned between cavities **56, 57** and **58** in FIG. **4B**. FIG. **4C** depicts a similar distributed interation klystron interaction and focusing arrangement with a double meander line configuration for each cavity. Again, focus lines **50** between cavities **56, 57** and **58** serve as shorting bars. In FIG. **4C** the focus lines **50** terminate the cavities and focus lines **50A** are also printed within the cavities. The focusing lines **50** and **50A** depicted in FIG. **4C** may thus be spaced much closer together. The period of the electrostatic focusing structure of FIG. **4C** is thereby reduced and greater electron beam current may be concentrated within the beam cavity **100**, FIG. **1**. This technique of focusing of FIG. **4C** generates more output power than is true for the klystron mode generated by the circuitry of FIG. **4B**.

FIG. **5** depicts a plan elevation of a combination klystron and travelling wave tube interaction structure with the interleaved focusing lines as described hereinbefore. The klystron cavity design exhibits a minimum length structure when compared with a travelling wave tube design. The klystron has a poorer efficiency due to microwave losses in each of the printed cavities because a fraction of the generated power is dissipated in the cavities themselves. A travelling wave tube interaction structure on the other hand is continuous and is highly efficient. It, however, has the disadvantage of considerable length as compared to the shorter length for klystron cavities. A maximum efficiency microwave unit for the interaction structure and the focusing lines is thus depicted in FIG. **5** wherein two klystron cavities **57** and **58** form the input sections for the microwave generator and a travelling wave tube section **59** forms the output section for the microwave tube.

It should be recognized that all of the structures discussed hereinbefore whether of the travelling wave tube type or the combination type shown in FIG. **5** are all generally classed as microwave amplifiers. Any of them may be converted to an oscillator by coupling a small sample of the output power and feeding it back through a bandpass filter to the input section. A filter **60** is thus shown connected in a feedback loop from the output section to the input section in FIG. **5**. This filter **60** may be external to the unit or it may be a printed microwave coupler and filter as is thoroughly described in my patent.

In FIG. **5**, a single printed collection plate **79** is shown as opposed to the three collection plates **76, 77** and **78** of FIG. **1**. The use of single or multiple collec-

tion plates is simply a matter of design choice based on the operating parameters of the microwave tube. If the multiple collection plate technique of FIG. 1 is employed, different voltages and different size collection plates are employed for each one of the collection plates 76, 77 and 78.

A plurality of collection plates offers additional advantages in certain instances for collection of an electron beam 30. For example, when electron beam 30 interacts with certain ones of the microwave structures described in this application, various classes of different velocity electrons are established in the electron beam 30. The slower velocity electrons are deflected earlier than the faster moving electrons when they enter the beam collection cavity 75, FIG. 5. The different areas of the different collection plates thus serve to collect the various classes of velocities of the electrons of beam 30. The employment of different area collection plates provides improved heat transfer for the heat created when the electrons are collected by the plates. Heat formed by such electron beam collection is conducted through the ceramic sheet 11 and is dissipated by radiation and natural convection from unit 25. It is, of course, entirely possible that additional cooling fans may be required for certain high power microwave tubes.

As used herein a single meander line interaction structure is depicted in FIG. 2A. It has a repetitive period in which it starts longitudinally along one side of a beam, traverses the beam width once and extends longitudinally along the beam length a short distance before it again traverses the beam width a second time, and travels longitudinally again in its original direction. Thereafter the meander line continually repeats its pattern, or period.

A double meander line interaction structure is a mirror image of a single meander line with both images sharing a common connection positioned substantially at the middle or at the central longitudinal axis of an electron beam.

Focusing line arrays for the single meander lines comprise single-sided ladder circuits with the lateral lines (rungs) interleaved between the periods of the meander lines. Focusing line arrays for the double meander line comprises a double-sided ladder circuit with broken lines, or rungs, at the common connections of the longitudinal axis of the beam.

Distributed interaction klystron cavities include essentially two periods of a double meander line. Such cavities do not include the common connection down the middle or longitudinal axis of an electron beam because they are purposely designed to resonate at a tuned frequency for the cavity. Again, the focus lines are best described as ladder circuits. In certain configurations, the focus line (rungs) extend across the beam width (FIG. 4B) and in other instances the focus lines are laterally broken short of the full width to accommodate the common longitudinal connection of a double meander line in each cavity (FIG. 4C).

It is to be understood that the foregoing features and principles of this invention are merely descriptive, and that many departures and variations thereof are possible by those skilled in the art, without departing from the spirit and scope of this invention.

What is claimed is:

1. An ultra-high frequency electron beam generator comprising:

means forming a vacuum enclosure shaped in a predetermined manner to match the desired shape of said electron beam;

a dielectric surface as part of said vacuum enclosure forming means and having a surface conforming to said desired shape and facing said electron beam;

an electrostatic focusing means;

a microwave interaction structure for interacting with the electrons in said beam for generating microwave energy;

said generator characterized in that:

said focusing means comprises a circuit printed on said dielectric surface facing said electron beam and adapted for connection to a source of focusing potential for focusing said electron beam, said focusing circuit geometrically oriented relative to said microwave interaction structure for freedom of operational interference with the microwave generating operation of said microwave interaction structure; and

said microwave interaction structure comprises a circuit printed on the same surface of said dielectric member as is said printed circuit of said focusing means;

said microwave interaction circuit is adapted for connection to another source of potential and is geometrically oriented relative to said focusing circuit for freedom of operational interference with the focusing operation of said focusing means.

2. An ultra-high energy generator in accordance with claim 1 and further characterized in that said beam forming means is configured to form a flat elongated sheet beam of electrons having an average electron beam voltage potential and

said first source of potential is selected either positive or negative relative to said average electron beam voltage potential, and

said second source of potential is chosen of opposite polarity relative to said chosen potential of said first source and also is either positive or negative relative to said average electron beam voltage potential, and further characterized in that said focusing circuit includes at least one continuous longitudinal printed lead on said dielectric surface at an area adjacent the outer edge of the flat sheet beam and substantially parallel to the longitudinal axis of the electron beam for focusing the edge of said flat sheet beam.

3. An ultra-high energy generator in accordance with claim 2 and further characterized in that

said focusing circuit comprises a second continuous longitudinal printed lead on said dielectric surface at an area adjacent the opposite outer edge of said flat sheet beam and substantially parallel to said one continuous printed lead, and further comprising means connecting both of said longitudinal printed leads together and to said second source of potential.

4. An ultra-high frequency generator in accordance with claim 1 wherein said forming means comprises:

a dielectric member having defined therein a predetermined elongated cavity for said electron beam.

5. An ultra-high frequency generator in accordance with claim 4 further comprising:
means at one end of said elongated cavity for emitting an electron beam; and
means at the other end of said elongated cavity for collecting said electron beam.

6. An ultra-high frequency generator in accordance with claim 4 wherein the focusing means and the interleaved interaction structure are printed on a surface of said dielectric member defining said elongated cavity and facing said electron beam.

7. An ultra-high frequency generator in accordance with claim 6 wherein said dielectric member comprises:
a pair of opposed dielectric sheets defining therebetween said elongated cavity.

8. An ultra-high frequency generator in accordance with claim 7 wherein said elongated cavity is substantially flat and is defined by a pair of opposed flat planar dielectric sheets sealably joined at a raised periphery thereof.

9. An ultra-high frequency generator in accordance with claim 1 wherein said interaction structure comprises:
a single meander line having at least a pair of repetitive periods; and
said focusing means comprises a single-sided ladder circuit with a focus lines interleaved between the periods of said meander line.

10. An ultra-high frequency generator in accordance with claim 1 wherein said interaction structure comprises:
a double meander line having a plurality of repetitive periods; and
said focusing means comprises a pair of single-sided ladder circuits with focus lines from each ladder circuit interleaved between the periods of said double meander line.

11. An ultra-high frequency generator in accordance with claim 1 wherein said interaction structure comprises:
at least a pair of distributed klystron cavity resonators; and
said focusing means comprises at least one focus line positioned between said pair of cavity resonators.

12. An ultra-high frequency generator in accordance with claim 1 wherein the interaction structure defines a combination klystron and travelling wave tube mode and said interaction structure further comprises:
an input section and an output section with said input section comprising at least one klystron cavity resonator and said output section comprising a meander line having a plurality of repetitive periods; and
said focusing means further comprises a focus line separating said klystron cavity resonator and said meander line and further comprising focus lines positioned between the periods of said meander line.

13. An ultra-high frequency generator in accordance with claim 12 wherein said input section comprises:
at least a pair of klystron cavity resonators having at least three focus lines with one focus line extending laterally in front of the first cavity of said pair;
a second focus line extending laterally and separating the pair of cavities; and
a third focus line extending laterally following the second cavity of said pair.

14. An ultra-high frequency generator in accordance with claim 13 wherein each klystron cavity resonator includes a double meander line resonant circuit having two periods and further comprising:
at least a focus line broken in the middle and extending laterally into the cavity resonator section at the period points for said double meander line of said one klystron cavity resonator.

15. An ultra-high frequency generator in accordance with claim 14 wherein said output section comprises:
a double meander line and said focusing means comprises a double sided ladder circuit with broken lateral lines extending into the double meander lines at its period locations.

16. An ultra-high frequency generator in accordance with claim 6 wherein the printed focusing means and interaction structure are positioned on dielectric islands formed by upraised portions of the dielectric member.

17. An ultra-high frequency generator comprising:
dielectric means having an evacuated electron beam cavity of a predetermined shape;
means for forming an electron beam of said predetermined shape in said cavity and including a printed circuit electrostatic focusing means on said dielectric and adapted to be connected at one predetermined potential for forming said beam cavity; and
a microwave interaction structure interleaved with said focusing means and also printed on the same side of said dielectric surface as said printed electrostatic focusing means and electrically connected to a second potential for sharing in the focusing of said beam and for interaction with said beam to generate microwave power.

18. An ultra-high frequency generator in accordance with claim 17 wherein said focusing means and said microwave interaction structure comprise:
separate elements each printed on a common side of the dielectric means which faces said electron beam.

19. An ultra-high frequency generator in accordance with claim 18 wherein:
said dielectric means is notched on said one side in such a configuration that the focusing means and interaction structure are printed on raised dielectric islands for reducing direct current and radio frequency arcing between said focusing means and said interaction structure.

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