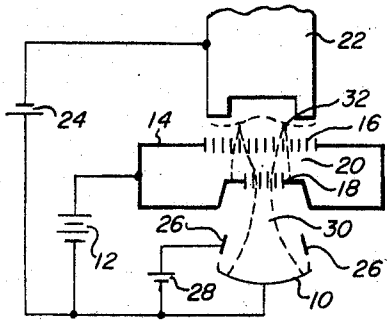
Jan. 28, 1969 J. J. HAMILTON 3,424,996

VOLTAGE JUMP KLYSTRON OSCILLATOR

Filed Aug. 29, 1967 Sheet 1 of 3

FIG. 1

PRIOR ART



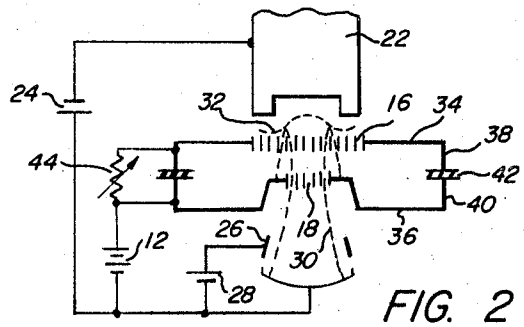


FIG. 2

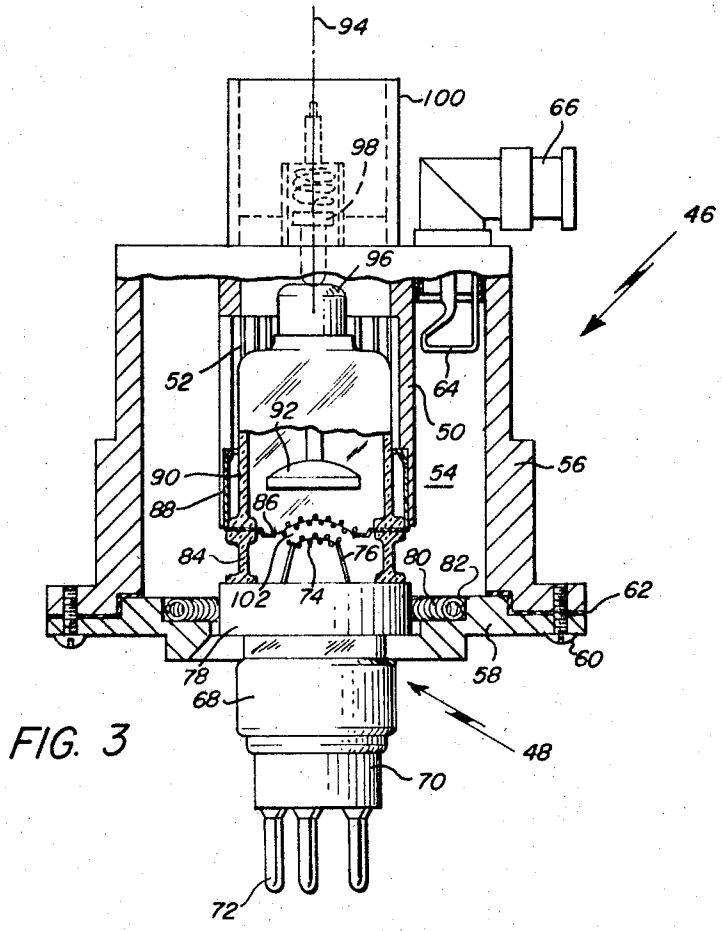
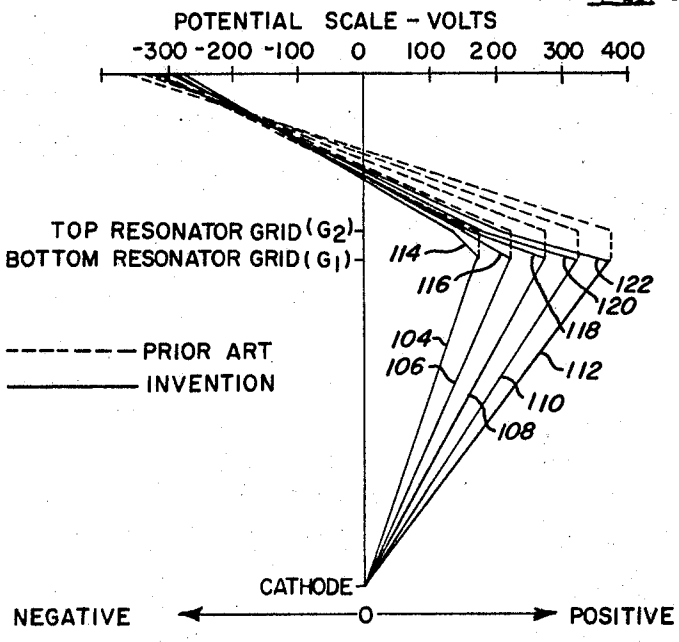


FIG. 3

INVENTOR
JEROME JOHN HAMILTON
BY Edgar O. Rost
ATTORNEY

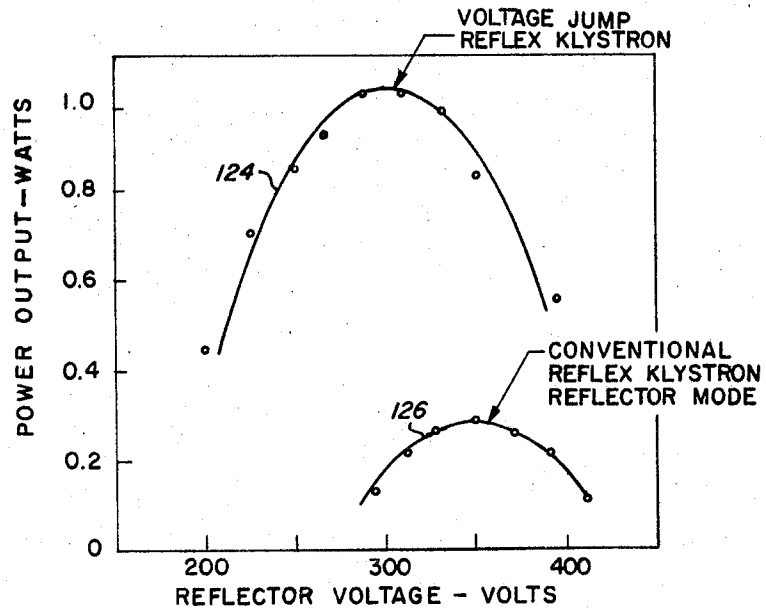
VOLTAGE JUMP KLYSTRON OSCILLATOR

FIG 4



D C POTENTIAL PROFILES

FIG. 5



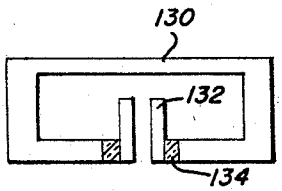


FIG 7A

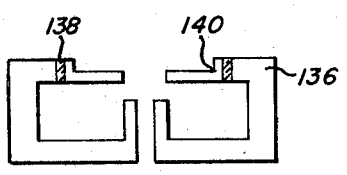


FIG. 7B

INVENTOR
JEROME JOHN HAMILTON

BY Edgar O. Root

ATTORNEY

VOLTAGE JUMP KLYSTRON OSCILLATOR

Filed Aug. 29, 1967 Sheet 3 of 3

FIG 6A

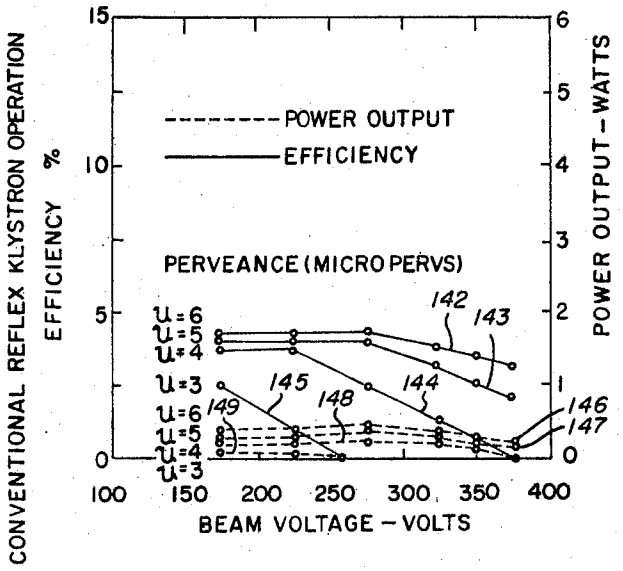
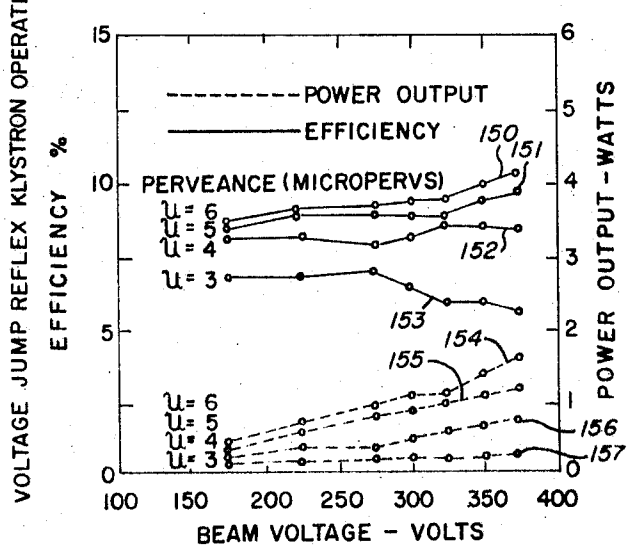


FIG 6B



INVENTOR
JEROME JOHN HAMILTON
BY Edgar O. Rost
ATTORNEY

United States Patent Office 3,424,996
Patented Jan. 28, 1969

3,424,996

VOLTAGE JUMP KLYSTRON OSCILLATOR

Jerome John Hamilton, Bedford, Mass., assignor to Raytheon Company, Lexington, Mass., a corporation of Delaware

Filed Aug. 29, 1967, Ser. No. 664,101
U.S. Cl. 331—84 4 Claims
Int. Cl. H03b 9/06

ABSTRACT OF THE DISCLOSURE

An oscillator device having severed electrically isolated cavity resonator circuits disposed along the path of an electron beam with an independently variable DC electric field applied across the resonator interaction gap. Improvements in the reflector field effectiveness parameter arising from better synchronization of RF phase relationships in the reflected electron bunches, together with improved beam bunching and focusing, afforded by the velocity jump, lead to the attainment of substantially higher operating efficiencies.

Background of the invention

In the field of electron discharge devices, particularly of the reflex klystron oscillator type, over-all tube operating efficiencies in the area of 2–3% have been deemed acceptable in the industry over the period of the last two decades. The possible areas for the improvement in such devices have been hampered somewhat by certain required design parameters. For example, the reflector electrode phase aberrations and space charge effects exert disruptive forces on the phenomenon of electron bunching along the electron beam path. In considering the fact that the electrons are reflected for a second traversal through the radio frequency gap to interact with the resonator circuit, many factors therefore contribute to the inefficiencies. To achieve higher electron bunching effectiveness low voltage electron gun assemblies are preferred, particularly where such reflex klystrons are required to have a wide electronic tuning range. It is necessary in order to provide adequate interaction between the radio frequency oscillatory circuits and the electron beam to have a plurality of grids coupled to the resonator interaction gap. Interception of electrons by the grid elements accounts for a considerable loss of useful current estimated to be in the realm of 15 to 45%, depending upon the actual transparency of the grids. Another factor contributing to the exceedingly low efficiency of reflex klystron oscillators is the radio frequency circuit losses in cavity resonator structures conventionally employed in such devices. Secondary electron emission from the resonator grids has also been observed to contribute to the inefficiencies in electron beam trajectories. A need has arisen, therefore, for a radically new approach in the design parameters of klystron oscillator tubes to achieve higher efficiencies in performance over that heretofore realized with prior art configurations.

Summary of the invention

In accordance with the teachings of the present invention a microwave oscillator having a re-entrant cavity resonator structure defining an internal interaction gap for impressing an alternating current component on a DC electron beam to result in velocity modulation is provided with DC isolation in the resonator circuit. Vernier adjustment of an independently variable DC voltage across the isolated members is provided to result in a variable DC voltage applied in close proximity to the interaction region of the velocity modulated electrons and alternating RF circuit components. Over-all tube operating efficiencies may be enhanced several times in magnitude relative to

present day known microwave oscillator devices. By the variation of the applied DC voltages across the severed RF resonator circuit the spread of the electron beam may be notably reduced. Interaction of the electrons with the RF circuit is thereby measurably improved by the disclosed technique of providing a voltage jump across the resonator gap.

Gridded cavity resonator interaction gap structures wherein transparency of the electron permeable grids is a vital contributing factor to the velocity modulation parameter of the electron beam are considered in the ensuing description. Optimization of the reflector field for electron bunching and separate optimization of the RF phase relationships of individual bunches is afforded by the severed resonator configuration and DC voltage jump adjustment Fixed tuned as well as tunable structures may be utilized and while low power reflex klystron oscillators are discussed, the invention is equally applicable to gridless, high voltage, relatively high power oscillators as well. Experimental data is qualitatively analyzed of selected illustrative embodiments showing relative comparable power outputs obtained at operating beam voltages of approximately one-half the beam voltages required of prior art microwave oscillators delivering the same output at the similar microwave frequencies. Comparative efficiency curves of prior art and embodiments of the voltage jump klystron indicate improvements in efficiency in the latter by a factor of 3 and higher.

Brief description of the drawings

The invention, as well as the details of the construction of a preferred illustrative embodiment, will be readily understood after consideration of the following detailed specification and reference to the accompanying drawings, in which:

FIG. 1 is a diagrammatic representation of a prior art reflex klystron microwave oscillator;

FIG. 2 is a diagrammatic representation illustrative of the features of the structure of the present invention;

FIG. 3 is a side elevation view partially cross-sectioned of an illustrative embodiment of the present invention;

FIG. 4 is a DC potential profile for different values of beam voltage of an illustrative embodiment of the invention incorporating the voltage jump technique as well as a prior art reflex klystron oscillator;

FIG. 5 is a comparative plot of the power output reflector modes of the embodiment of the invention and a conventional oscillator device;

FIGS. 6A and 6B are curves of power output and efficiency versus beam current for different gun perveance values of prior art klystrons and the illustrative embodiment of the invention;

and FIGS. 7A and 7B are cross-sectional views of cavity resonator structures having alternate DC isolation means.

Description of the preferred embodiment

Referring now to FIG. 1, an exemplary embodiment of a prior art reflex klystron will be described. An emitter or cathode electrode **10** is provided with a highly negative bias from a voltage supply **12** while the cavity resonator **14** is positively biased by the same source. The cavity resonator **14** is provided with electron permeable structures in the form of grids **16** and **18** disposed within the openings in oppositely disposed reentrant walls of the cavity resonator defining therebetween an interaction gap **20**. Adjacent to the top resonator grid **16** is a highly negatively biased reflector electrode **22** connected to voltage potential source **24**. Focusing means **26** adjacent to the electron emitter **10** may be biased at a slightly positive potential by source means **28** to achieve a convergent electron beam trajectory indicated by the dotted line **30**.

In the general operation of the reflex klystron the stream of electrons is returned for a second transit through the interaction gap **20** by the reflector electrode **22**. The overall operation and efficiency of such oscillators is considerably influenced by the transit time of the electrons in the region between the reflector electrode and top resonator grid. The dotted line **32** indicates an approximation of the electric field potential line in this region where the rapid change from one of accelerating electrons to one of decelerating electrons takes place. This potential line is generally referred to as the zero equipotential line or electron reflection plane.

Referring next to FIG. 2, the present invention will now be described, reference numerals referring to similar structure shown in FIG. 1 being similarly numbered. The cavity resonator has now been severed to thereby provide two discrete sections **34** and **36** with a resultant split in the resonant circuit along the boundary walls **38** and **40**. An RF bypass **42** is provided between the cavity resonator sections. It will be noted that the cavity resonator is now DC isolated. An independently variable voltage potential may now be applied between the cavity resonator sections **34** and **36** by, for example, providing a variable negative bias supply or variable voltage dropping resistor **44** to thereby bias the section coupled to the top resonator grid at a lower positive voltage potential. A separate positive bias supply of predetermined magnitude may also be employed. The RF bypass can be rigidly and permanently affixed to the cavity resonator structure or may comprise a ring of any inexpensive resistively loaded insulating material which will absorb the highly directive low level power radiation. In addition, a choke may be inserted as a lumped element in combination with the respective cavity resonator sections for further RF isolation. With the two isolated cavity sections the RF field is concentrated strictly within the resonator gap **20** and it is possible to vary the control of the electron beam trajectories by manipulation of the voltages applied to the top resonator grid with respect to the bottom resonator grid. A DC voltage jump is realized along the beam path as the effect of the introduction of a velocity jump across the interaction gap.

Referring next to FIG. 3, an exemplary embodiment of the invention is illustrated and designated **46**. This reflex klystron oscillator is of the external resonant cavity resonator type wherein the tube portion designated **48** is plugged in to the reentrant wall portion **50** defining a plurality of circumferentially disposed contact fingers **52**. The cavity resonator **54** comprises mating sections **56** and **58** removably secured by screws **60** of insulating material with a quarter-wavelength bypass of an insulating material **62** disposed therebetween. Output energy is coupled from the cavity resonator by means of a conventional loop **64** together with a coaxial line **66**.

The reflex klystron tube comprises a plurality of metallic flanged sections together with intermediate dielectric portions to collectively define the tube envelope and support the gridded electrode structures. A conventional electron gun assembly is contained within the section **68** with a base **70** and pins **72** for connection of the cathode electrode components to external circuitry. The first grid electrode **74** is supported by a frustoconical member **76**. A flanged portion **78** is coupled to the external resonator cavity section **58** by a contact spring **80** disposed within the recess **82** in the bottom wall of section **58**. Cylindrical envelope section **84** is hermetically sealed to the flange **78** and supports the top resonator grid **86** with the flanged portion **88** contacting fingers **52** for external circuit connection.

A dielectric member **90** encloses the top portion of the overall tube envelope and supports the reflector electrode **92** along the axial path **94** with a top cap **96** hermetically sealed to the envelope **90**. The external connection of the reflector electrode to the appropriate voltage supply source is achieved through a spring connector **98** and a coaxial line **100**. By appropriate control of the voltage supplies in accordance with the teachings of the present invention a voltage jump is provided across the interaction gap **102** defined between the resonator grids **74** and **86**.

The embodiment disclosed in FIG. 3 is of the type employed in low frequency microwave transmission systems and the electron transit time is generally in the 1¾ reflector mode for generation of the desired oscillations. Other reflector modes of course are utilizable depending on the beam optics and applicable voltage potentials.

Referring next to FIG. 4, a DC potential profile of the exemplary embodiment, as well as conventional prior art gridded structures, are illustrated. The potential profile along the electron beam path is shown with the cathode at the zero or reference potential and a gradually increasing positive voltage applied in the direction adjacent to the bottom resonator grid (G_1) as indicated by the plot lines **104**, **106**, **108**, **110** and **112**. The operating gun structure had a perveance of 4 microperv and the individual profile lines reflect different values of the beam voltage. Commencing with the bottom resonator grid, the dotted lines now reflect the prior art reflex klystron field profiles approaching the reflector field following a DC-wise field free interaction gap space where the decelerating field is noted and the profile swings from the positive to the negative potential values. As the value of the top resonator grid G_2 voltage is varied in accordance with the invention, the slopes of the curves no longer have a steep rise but rather indicate that at an optimum setting as the beam voltage is increased the retarding field within the resonator gap effectively controls the transit time and phase adjustments of the beam, while the reflector field is set for optimum electron bunching and RF energy exchange between the resonator gap and the reflected beam. A gradual blending of the solid lines **114**, **116**, **118**, **120** and **122** between the resonator grids G_1 and G_2 represents the independent optimization of the retarding field within the interaction gap and reflector field for maximum power output efficiency.

The slope of the curves with the embodiment of the invention clearly provides a new dimension in the design of tube parameters and reflects the interesting phenomenon that the reflector field region and its potential gradient remain substantially fixed at an optimum setting as the beam voltage is increased. The comparison of the reflecting field of a tube employing the voltage jump technique with the conventional reflex klystron operation contributes to an understanding of the increased efficiencies realized in the practice of the invention to the level where approximately a half of the beam voltage required by conventional klystrons is required to deliver the substantially same power output at a particular frequency. It also contributes to the understanding of the severalfold increase in efficiency observed at the same beam voltage and electron gun perveance conditions. This phenomenon has been examined and noted similarly in a study of the integral resonator structures as well as the external cavity resonator type.

Attention is now directed to FIG. 5 wherein some exemplary data recorded on an embodiment of the invention as illustrated in FIG. 3 is plotted. Other selected data had indicated the optimum ratio of the voltage applied to the G_2 resonator grid with respect to that applied to G_1 was in the area of .5 or substantially one-half of the voltage applied to G_1 which is conventionally in the vicinity of 300 to 400 volts. In the embodiment under consideration a voltage of 175 volts was applied to the top resonator grid G_2 and the beam voltage was approximately 325 volts with a perveance of 5 micropervs. The reflector mode of operation was $N=1¾$. It is evident that with the application of the voltage jump technique output power as high as 1 watt was realizable, whereas in the conventional reflex klystron .2 to .4 watt appears to be normally acceptable. The presence of the

decelerating voltage applied to the G_2 grid therefore apparently results in a higher power output represented by the curve **124** in comparison with the output of conventional prior art reflex klystrons represented by the curve **126**. It is believed and suggested that one of the contributing factors to this increased output may be the reduction in the current interception by the top resonator grid. This results in a greater transparency of the grid element in the path of the electron beam which is thereafter decelerated to traverse the top grid electrode again for the normal second traversal before eventual collection.

Referring to FIG. 6A, measurements of power output and efficiency for a number of reflex klystrons operated in the conventional manner is shown. The solid lines **142, 143, 144** and **145** represent typical values of efficiency for four different values of the beam perveance. The dotted lines **146, 147, 148** and **149** represent the power output. Performance was in the 1¾ reflector mode.

FIG. 6B indicates comparative results for the same parameters of power output and efficiency for the same type reflex klystron oscillators operated in accordance with the voltage jump principles herein contained. The reflector voltage, the G_2 grid voltage and external RF load was optimized for maximum power output similar to operating conditions reported in FIG. 6A. Solid lines **150–153** inclusive indicate the efficiency values and lines **154–157** the power output. The notable improvement of all the parameters under consideration is evident, particularly the efficiencies which increased from a range of 1–4% to 4–12%.

As suggested earlier in this detailed description, numerous modifications in the RF bypass to provide the DC isolation between the cavity resonator sections may be practiced. Referring next to FIGS. 7A and 7B, some illustrative modifications are shown. In FIG. 7A a cavity resonator **130** is provided with the RF isolation path adjacent to the reentrant portion **132** of the cavity resonator section. The RF isolation material **134** is therefore disposed closely adjacent the electron beam path. Radiation losses due to the RF bypass will be minimal for most microwave frequencies and an alternative location of the RF bypass is shown in FIG. 7B. In this embodiment the cavity resonator **136** is severed and the RF bypass with the appropriate material **138** is located in an opposing wall, thus locating this component in closer proximity to the top resonator grid which is conventionally disposed in the recessed portion **140**. It will of course be noted by those skilled in the prior art that the radiation of the bypass at the center frequency may be kept at tolerable limits which if exceeded may be further restricted with externally mounted resistively loaded materials as well as choke arrangements.

This completes the description of the voltage jump microwave oscillator which represents what is believed to be the first highly significant improvement since their inception in achieving higher efficiencies in such devices. The application of the principles enumerated herein will be equally applicable to all other velocity modulation electron beam devices including gridless as well as coupled cavity varieties. Many other modifications, alterations or variations will be evident to those skilled in the art other than those enumerated herein. Accordingly, it is my intention that such modified embodiments be considered within the spirit and scope of the invention.

What is claimed is:

1. A reflex klystron oscillator comprising:
an evacuated envelope;
an electron gun for directing a beam of electrons along the longitudinal axis of said envelope;
cavity resonator interaction means and a reflector electrode positioned along said axis;
said cavity resonator means comprising two electrically isolated metallic members defining a hollow cavity section and oppositely disposed openings in axial alignment with said beam;
top and bottom resonator grid members disposed across said openings and defining therebetween an interaction gap;
and means including a voltage source for applying a DC electric field jump between said grid structures.

2. A reflex klystron oscillator according to claim **1** wherein said top resonator grid member is biased at a positive potential substantially lower than that applied to said lower resonator grid member.

3. A reflex klystron oscillator according to claim **1** wherein said cavity resonator members are separated by resistively loaded high frequency energy absorbing material.

4. In a reflex klystron oscillator tube having an electron emitter at one end for directing an electron beam along a path, a plurality of electron permeable grids defining an interaction gap therebetween and a reflector electrode, independent electrically isolated metallic members coupled with each of said grid structures and collectively defining a cavity resonator means for the generation of high frequency oscillations;
and DC voltage biasing means connected to each of said cavity resonator members whereby the voltage differential is established across said interaction gap.

References Cited

UNITED STATES PATENTS

2,425,748	8/1947	Llewellyn	331—83
2,853,646	9/1958	Geisler	315—5.21

ROY LAKE, *Primary Examiner.*

S. H. GRIMM, *Assistant Examiner.*

U.S. Cl. X.R.

315—5.18, 5.51