

Sept. 8, 1970

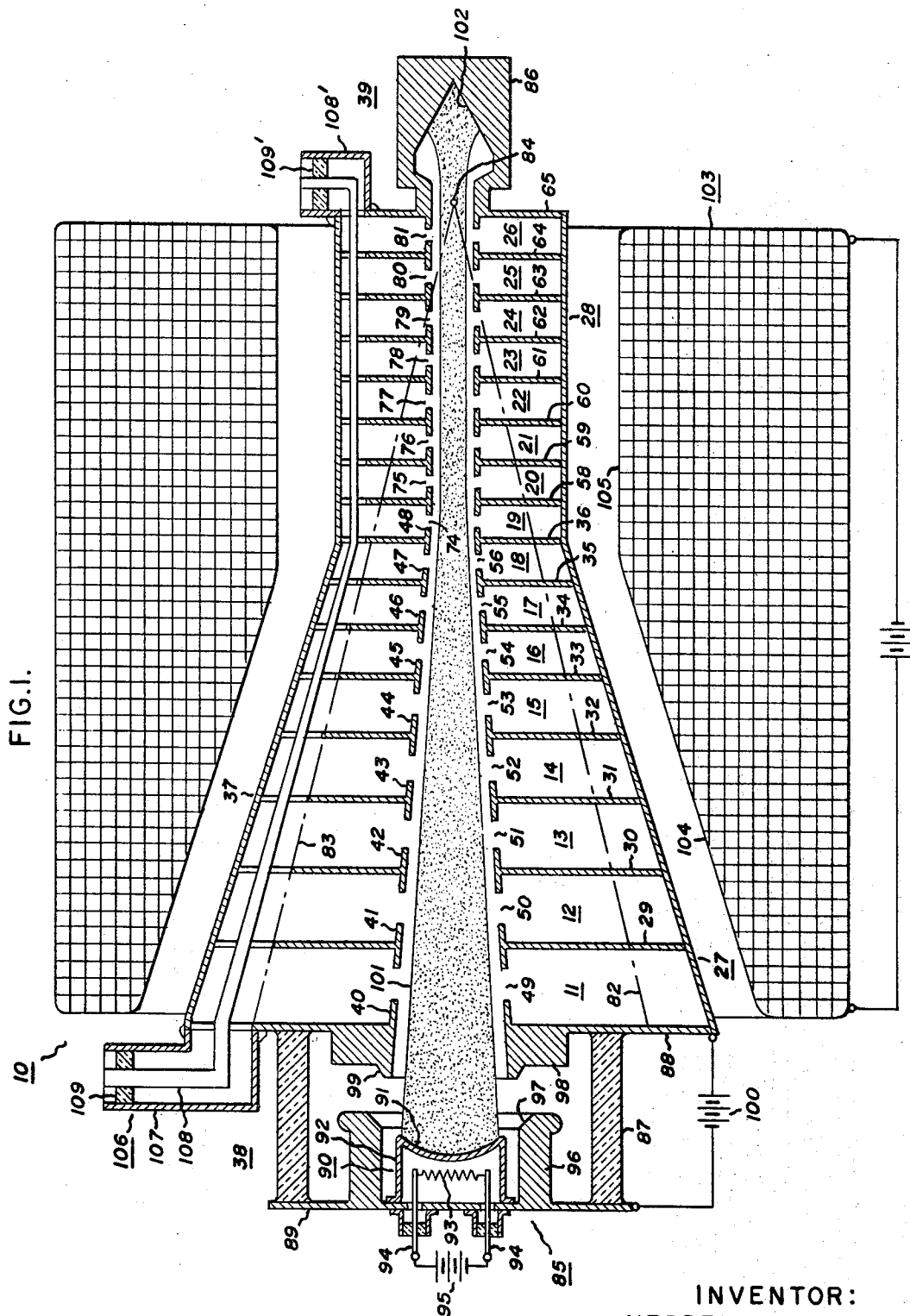
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3,527,976

LOG PERIODIC ELECTRON DISCHARGE DEVICE

Filed Sept. 29, 1966

4 Sheets-Sheet 1



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LOG PERIODIC ELECTRON DISCHARGE DEVICE

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4 Sheets-Sheet 2

FIG. 2.

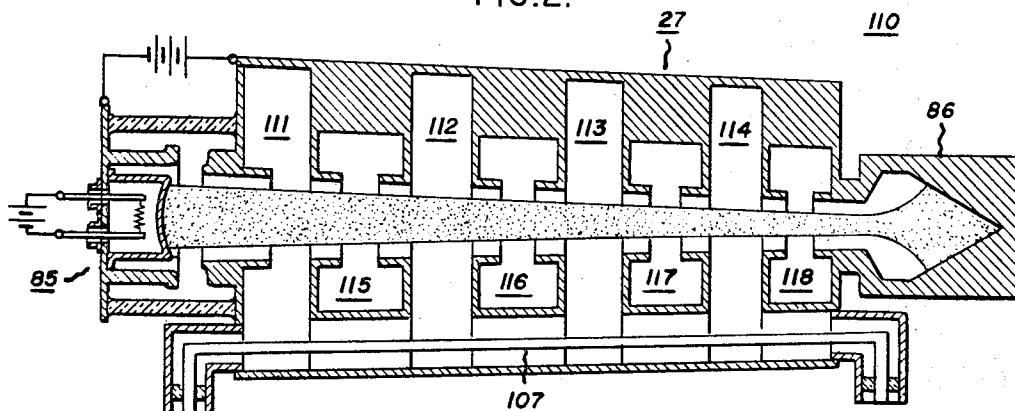
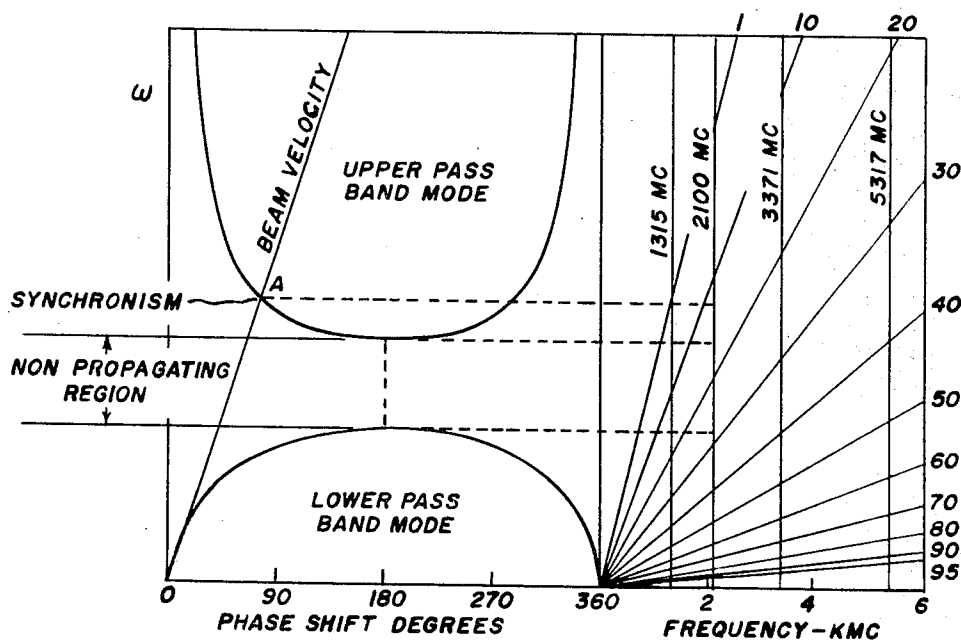


FIG. 3.



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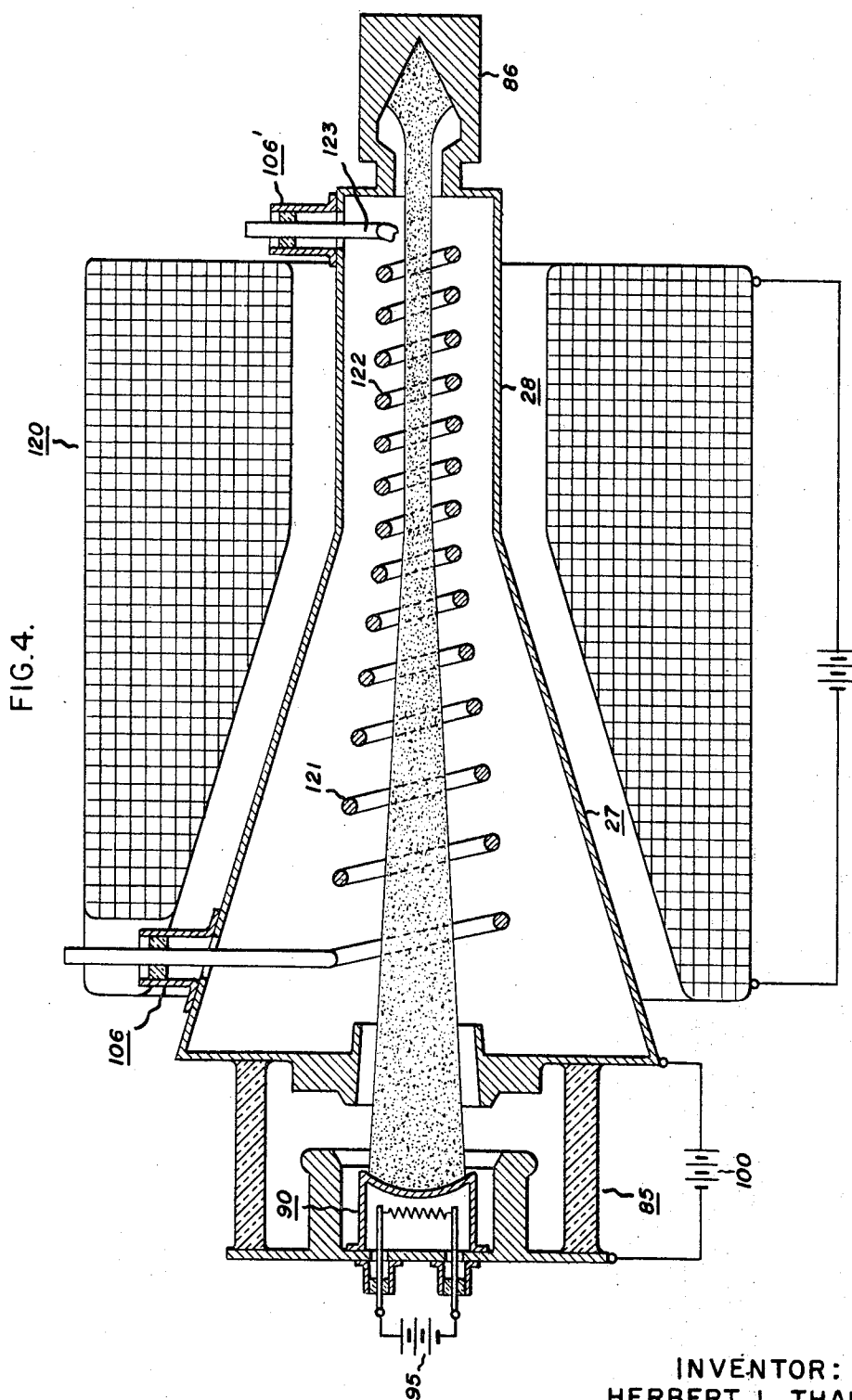
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LOG PERIODIC ELECTRON DISCHARGE DEVICE

Filed Sept. 29, 1966

4 Sheets-Sheet 3



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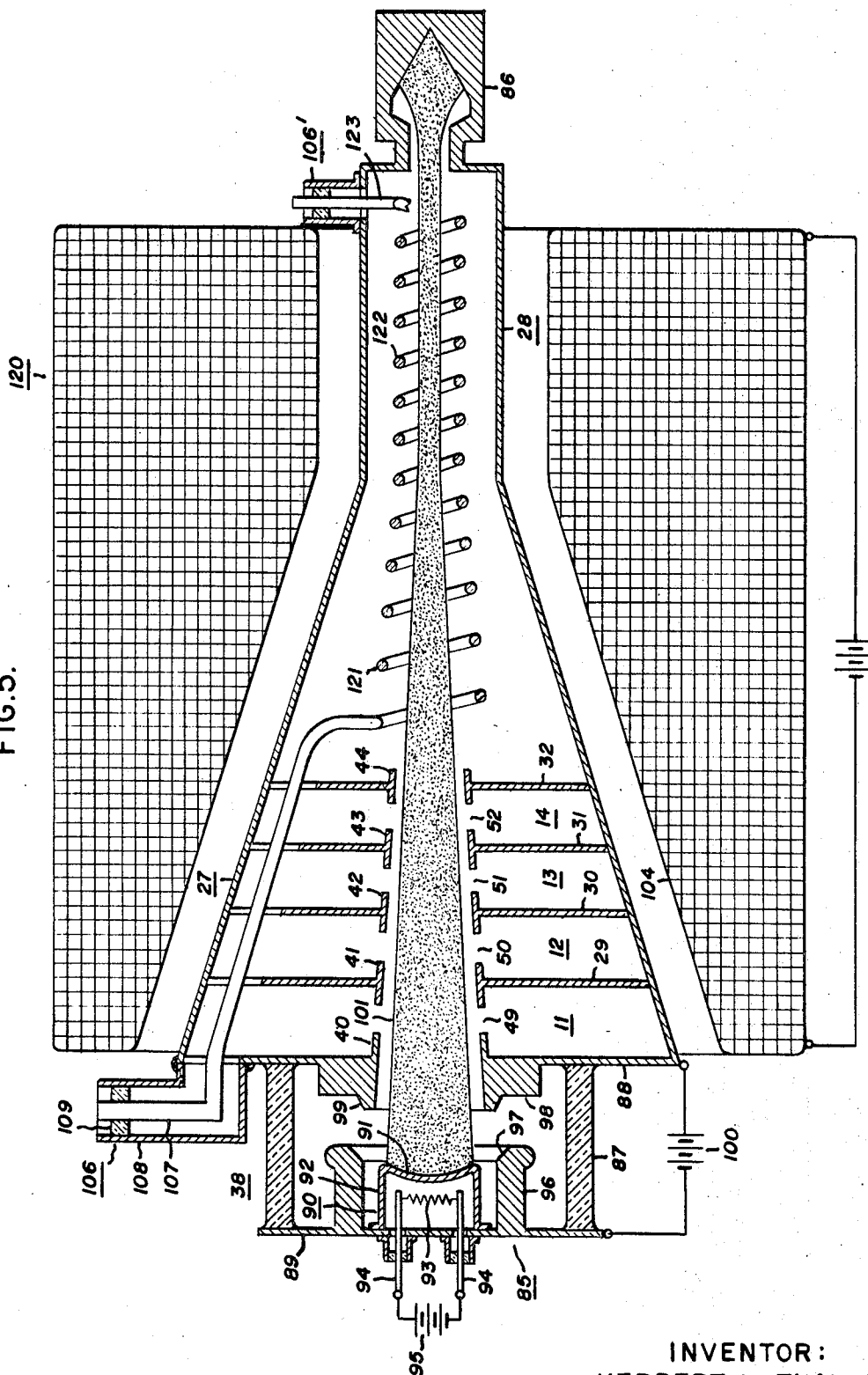
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LOG PERIODIC ELECTRON DISCHARGE DEVICE

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4 Sheets-Sheet 1

FIG. 5.



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3,527,976
LOG PERIODIC ELECTRON DISCHARGE DEVICE
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Electric Company, a corporation of New York
Filed Sept. 29, 1966, Ser. No. 582,895
Int. Cl. H01j 25/34
U.S. Cl. 315—3.6 26 Claims

ABSTRACT OF THE DISCLOSURE

An electron beam log periodic device is disclosed which in one form is an R-F amplifier including a slow wave circuit defining an electron beam path therethrough. The slow wave circuit tapers in a log periodic manner and the electron beam which passes therethrough is also correspondingly tapered in a log periodic manner. An input signal is coupled into the circuit to selectively energize a region therein based on the input signal, and the beam is modulated. This modulated beam passes into another part of the circuit to selectively energize a region therein and amplified power is taken off the circuit.

This invention relates to a log periodic electron discharge device and more particularly to a log periodic electron beam device including interaction between an interaction structure having interaction characteristics varying progressively therealong in a log periodic manner and an electron beam passing therethrough, whose interaction characteristics vary progressively therealong in a log periodic manner. Optimum interaction takes place at selected regions along the interaction structure depending on the frequency characteristics of an input signal wave to provide, for example, a very high R-F power output over a wide frequency band.

Extensive efforts have been expended to increase the operating bandwidth of microwave or R-F tubes in general. Particularly, high power R-F tubes such as velocity and/or density modulated electron beam tubes, including klystrons and traveling wave tubes, are generally compromises between inherent bandwidth limitations and power output. For example, a multicavity velocity modulated electron beam klystron usually has a very high power output in a range of up to several megawatts but with a maximum relative bandwidth of only about 10%. On the other hand typical traveling wave tubes generally have lesser power output but increased bandwidth. Hybrid combinations of klystrons and traveling wave tubes may provide more bandwidth but with a sacrifice of other prime considerations such as output, uniformity, gain, etc. Due to the continuous development of more sophisticated electron apparatus, there is an increasing demand for example for a single tube type having both a uniform high power output and a wide frequency band.

Accordingly, it is an object of this invention to provide an improved electron beam interaction device.

It is another object of this invention to provide an improved log periodic electron beam modulating device.

It is yet another object of this invention to provide an improved log periodic R-F amplifier having a high power output over a wide frequency band.

It is still another object of this invention to provide an improved log periodic klystron type amplifier.

It is yet another object of this invention to provide an improved log periodic slow wave circuit type amplifier.

It is still another object of this invention to provide a log periodic R-F amplifier utilizing a log periodic electron beam in combination therewith.

It is still another object of this invention to provide a log periodic amplifier having a tapering interaction structure and a tapering beam therein.

It is a further object of this invention to provide an improved log periodic amplifier having a conical or frustoconical interaction structure with a correlated conical or frustoconical electron beam passing therein.

It is yet another object of this invention to provide improved termination means for a log periodic interaction structure.

It has been discovered that a "log periodic" principle as applied to both an interaction structure and an electron beam therein provides a more efficient wide band device such as an R-F amplifier. In this invention, "log periodic" or "log periodic manner" are terms applied to an array of interaction circuits, elements, or regions which are dimensioned and positioned such that electrical properties, such as impedance, at each element or region repeat periodically with the logarithm of an operating frequency, e.g., input signal frequency.

Briefly described, this invention in one of its preferred forms, comprises an interaction structure, including a slow wave circuit, whose interaction characteristics therealong vary progressively in a log periodic manner. An electron beam, whose effective interaction characteristics, in combination with the interaction structure, vary therealong progressively in a log periodic manner, is caused to pass through the interaction structure in a manner such that the beam and structure variances occur in the same direction. More specifically, one preferred embodiment of this invention includes a series of spaced resonant klystron type or reentrant cavities and interaction gaps interacting with a tapering electron beam passing therethrough. Each of the resonant klystron cavities in the series spaced array differs in its effective size and resonance in geometric progression from a larger resonant cavity to a smaller resonant cavity along the extended array while the traversing electron beam correspondingly differs.

"Log periodic" is a term applied to either the interaction structure, the electron beam, or both, whose defined characteristics therealong vary periodically in geometric progression. The variance is predicated to a large extent on dimensions. For example, in an extended array of klystron type resonant cavities, each cavity is preferably an exact duplicate of its preceding cavity with the exception that significant dimensions of all parts are reduced or increased as the case may be. In this respect the drift tubes also become progressively smaller between adjacent cavities both in diameter and length, and the combined overall reduction provides geometrical axial reductions of successive interaction gaps. In a slow wave circuit utilizing a helix, which is a special case of a periodic structure, for example, successive sections or regions are progressively reduced in diameter while turn density increases. The thickness of the wire and lateral dimension may also progressively decrease. In combination the electron beam in either instance tapers or decreases in cross section along the interaction structure in the same direction.

In copending application Ser. No. 582,879, Wilbur, filed concurrently herewith, and assigned to the same assignee as the present invention, there is disclosed an electron beam device having the log periodic or geometric progression applied only to an interaction structure and not to the beam.

This invention will be better understood when taken in connection with the following description and the drawings in which

FIG. 1 is a cross sectional illustration of one preferred embodiment of this invention as a log periodic klystron amplifier;

FIG. 2 is a cross sectional illustration of a further preferred embodiment of this invention as applied to an alternate log periodic klystron type device;

FIG. 3 is a frequency-phase diagram for the invention of FIG. 2;

FIG. 4 is another modification of this invention with the log periodic principle applied to a helix-type traveling wave tube device.

FIG. 5 is a modification of this invention combining the circuits of FIGS. 1 and 4.

Referring now to FIG. 1, there is illustrated the log periodic principle of this invention as incorporated in a klystron type amplifier 10. Klystron type amplifier 10 includes an interaction structure comprising an extended array of a number of adjacent coaxial cylindrical resonant cavities 11 through 26 distributed between an illustrated tapered section 27 having cavities 11 through 18 therein, and an illustrated cylindrical section 28 having cavities 19 through 26 therein. The extended array of cavities of this invention in the tapered section 27 is based upon or embodies a logarithmic progression which provides each succeeding cavity with geometrically progressively decreasing operating characteristics with respect to its resonance. In one form of this invention the logarithmic periodicity and geometric progression is applied, in one sense, with each adjacent cavity being essentially a duplicate in all respects with a preceding cavity with the exception of being smaller in significant dimensions by a constant factor which may be denoted as ρ . This logarithmic periodicity with geometric progression is preferably extended over a substantial number of adjacent cavities in the klystron type amplifier 10 and preferably in excess of about three cavities. The logarithmic factor ρ as applied to a cavity diameter, for example, would include a first cavity having a diameter of, for example, 1.0 with the next succeeding cavity having the same position diameter of 0.9, and the next succeeding cavity of 0.81 etc. Accordingly, the geometric progression or the log factor ρ in such an instance is defined as 0.9 or alternately as a continuous 10% decrease along the array. The same factor is applied to all significant dimensions of the cavities in the geometric series.

One form of defined interaction structure in accordance with the log periodic principle includes each cavity 11 through 18 of the log periodic interaction structure having common or partition walls 29 through 36 of decreasing diameter with respect to the defining side or bounding wall 37. By reason of the decreasing diameters of the partition walls and the axial distance therebetween, the side wall 37 takes on, as a surface of revolution, a conical or tapering or frustoconical configuration. This taper, exaggerated in FIG. 1 for the purpose of clarity, includes tapering from a larger diameter at the input end 38 of the klystron type amplifier 10 to a smaller diameter in a direction toward the output end 39 of the klystron type amplifier 10. Each succeeding cavity may be smaller than a preceding cavity in stepwise progression so that a series of short cylindrical bounding wall 37 sections approximate the smooth taper in the same manner as a number of short straight lines may define a curve or circle. The noted approximation is related to configuration only since the step progression is a geometric progression.

The geometric progression also includes adjacent cavities whose density or number of cavities per unit length of interaction structure increases from the input end 38 toward the output end 39. For example, the axial dimension between adjacent cavity partition walls also decreases in a direction from the input end 38 to the output end 39. The axial distance between adjacent walls 30 and 31 for example is less than the corresponding distance between walls 29 and 30.

Cavities 11 through 18 also include as a part of their cavity construction, short tubular transverse wall sections 40 through 48 which are defined as reentrant or klystron-like drift tubes. Each of these reentrant tubes is spaced from preceding and succeeding reentrant tubes to provide well-known klystron type interaction gaps 49 through

56. Reentrant tubes 40 through 48 are formed as short frustoconical sections to define a longitudinal tapering channel or electron beam path 57 whose taper follows the log periodic principle as described for the cavities 11 through 18. However, the reentrant tubes may be short cylindrical sections of decreasing diameters in geometric progression to approximate the taper. The interaction gaps 49 through 56 which are defined between adjacent reentrant tube sections are also involved in the geometric progression principle in that their axial spacings also decrease from the input end of the tube 38 toward the output end 39 of the tube 10. These gaps decrease and become smaller in geometric progression in the same manner as the cavities become smaller.

It is understood that providing cavities in the geometric progression as described will soon involve a very great number of very small dimensions. For example, and theoretically speaking, the number and size decrease of cavities approaches infinity at the apex of the taper of a conical section. When the number of cavities becomes disproportionately large and of disproportionately smaller sizes, their effectiveness becomes greatly decreased and an arbitrary but compromising point is reached where the device 10 is terminated and the array of cavities is terminated or ended substantially before the apex point may be reached. This results in the need for a termination of a kind which will reduce end losses and other undesirable effects from the great number of disproportionately small cavities.

The axial section 27 of device 10 which is illustrated as the tapered section may be terminated in the form of a frustum where the defined array of cavities cease substantially before the apex is reached, as illustrated and described in the mentioned copending application, or by a smooth tapering frustum or apex section having a number of identical cavities with the exception of diameters.

A preferred method of termination includes a short cylindrical section 28 having a number of succeeding equal cavities therein not embodying the geometric progression. For example, section 28 includes a plurality of cavity resonators 19 through 26 all of which are similar in all respects in that their partition walls 58 through 65, drift tubes 66 through 73, and interaction gaps 74 through 81, etc., are all equal to one another. The number of resonant cavities in any terminating cylindrical section not embodying the log periodic progression is usually less than the number of cavities in the tapered section 27 but may be of an equal or greater number. A klystron amplifier as illustrated should have at least three cavities in section 27.

A common cavity wall such as wall 36 or a cavity volume may be the transition section between sections 27 and 28 depending on the number of cavities employed and their arrangement. It is desirable to have the last cavity in section 28 such as cavity 26 pass through the projected apex 84 of the tapered or conical wall 37, as indicated by the intersection of cone lines 82 and 83. Lines 82 and 83 are the equivalents of extension lines of tapered wall 37 and pass through or define apex 84. For example, as illustrated in FIG. 1, the last wall 65 of cavity 26 passes through the projected apex point 84.

In order to provide an electron beam passing through channel 57, an electron gun structure 85 is utilized at the input end 38 of klystron 10, and a corresponding electron collector 86 as well known in the art is utilized at the output end of the klystron 10. Electron gun structure 85 is exemplary of a number of suitable gun structures including for example the gun structure as disclosed in U.S. Pat. 3,046,442 Cook. See also J. R. Pierce, "Theory and Design of Electron Beams," Nostrand Co., Inc., New York, N.Y. 1949. In FIG. 1, electron gun structure 85 includes a cylindrical electrically insulating section 87 which is mounted concentrically on the input wall 88 adjacent cavity 11 and is also concentric to the electron

beam channel 57. A transverse wall 89 is attached to section 87 to support the electron gun emitter 90 therein. Electron gun emitter 90 as known in the art includes an electron emissive surface usually including a combination of a barium compound and a refractory metal matrix. This surface which is denoted as surface 91 in FIG. 1 is of a concave design ordinarily as large as or larger than the beam channel and is suitably supported by wall 92 from the transverse wall 89. A filamentary type electrical heater element 93 is suitably positioned adjacent concave surface member 91 to raise the temperature thereof for copious electron emission. Filamentary heater 93 includes electrical elements 94 which project through wall 89 in an insulating electrical relationship and are connected to a suitable source of power such as for example battery 95.

An electrical shroud or forming structure 96 having an outwardly flared lip 97 thereon circumferentially surrounds the concave emissive surface member 91 and is electrically connected to the transverse wall 89. An annular block member 98 defines the entry portion of the electron beam path 57 and is positioned concentrically thereto and concentrically with the structure of electron gun emitter 90. These structures 96 and 98, and their adjacent flared surfaces 97 and 99, are so formed so that the electric field existing therebetween exerts a controlling influence on the electron beam to control the beam shape as it enters member channel 57.

The collector 86 as well as the remaining interior parts of the klystron device 10 are electrically conductive so that transverse wall 89 is connected to the negative side of a suitable source of power, such as battery 100 while the cavities structure and the collector 86 are connected to the positive side of the battery 100. Electrons are therefore emitted from surface 91 and are suitably formed by shroud 96 and annular block 98 and the electrical field therebetween as an electron beam 101 to pass down the electron beam path 57 and to be collected by the collector 86. Collector 86 may be a suitable block member defining an electron collecting cavity or cavity surface 102 therein, and may also have suitable cooling means associated therewith as known in the art.

It is an important feature of this invention that the electron beam 101 passing through section 27 have effective interaction characteristics which vary axially along the beam from the input end 38 of device 10 toward the output end 39 in a log periodic manner. The log periodic interaction characteristics of beam 101 include the overall effects of the beam on the interaction structure, as compared to a cylindrical beam in a cylindrical path, as well as the successive beam portions along successive resonant cavities or regions of the interaction structure. In one form of this invention the log periodic characteristics are embodied in electron beam 101 by having the electron beam is provided or generated and defined in the form of a tapering, frustoconical or conical taper cross section. For example, the electron beam 101 of this invention includes a tapering or frustoconical beam whose equally axially spaced cross sections would include cross sections of progressively decreasing diameters in the manner described for the partition walls 29 through 36 for example of the tapered section 27. The tapered or frustoconical beam is one means to provide the proper degree and kind of interaction at each interaction gap.

It should be noted that a tapered beam such as a conical beam may not per se be described as including the log periodic principle in that there are no given or defined increments of length. The log periodic principle arises when the beam is in the geometric progression section of the interaction structure. In this environment, when viewing succeeding transverse sections of the circuit and beam separately, the log periodic and geometric progression is evidenced by succeeding increments of the beam of smaller dimensions, i.e., diameter and length. Suitable approximations or equivalents may be provided in the electron beam to give the desired results. For example,

the electron beam may be composed of short different axial sections, or sections having different electron concentration densities to provide an overall effect similar to a tapered beam.

The electron beam of this invention need not be tapered as it passes through the terminating cavity section of 28. However, the electron beam should be tapered over all or a substantial number of the tapered cavity section in tapered section 27. The taper should extend at least over about three successive tapering cavities and preferably over all tapering cavities. For higher overall efficiency gain and bandwidth it is preferable that the log periodic factor ρ be substantially similar for the beam as well as the interaction structure and with the beam substantially filling the defined beam channel. However, lesser ρ factors may be employed for the beam.

Means to change the cross section or provide taper of an electron beam are well known in the art. These may include magnetic electrostatic or electromagnetic or other electrical field focusing arrangements which provide the proper controlling action on the beam. In one form of this invention an electrical focusing solenoid 103 is employed which extends axially along the beam path 57. Solenoid 103 includes a tapered section 104 lying along the tapered section 27 of the amplifier 10, and the cylindrical section 105 lying along the termination cavity section 28. The number of turns or turn density of the coils of solenoid 103 is also varied along the tapered section in conformance with the taper of beam 101 to provide a beam taper which is desired. The turn density of the section 104 increases to a maximum at the cylindrical section 105 and thereafter the beam is cylindrical under the action of a uniform magnetic field. In utilizing a solenoid coil, the coil itself may be tapered or conical to provide a stronger magnetic field progressively therealong in correlation with the desired beam taper. For example, either a tapered or cylindrical coil may be employed where the number of coil turns or turn density progressively varies by increasing or decreasing toward one end of the klystron.

Permanent magnet focusing or control is equally applicable to this invention and may include one or more magnet assemblies arrayed along the axis of the klystron to provide increasing magnetic field strength toward one end of the device. A number of electromagnets, permanent magnets, or electrostatic focusing means or combinations thereof, may be employed to provide tapering of a beam whose final diameter, or the diameter in the cylindrical section 28 is for example about four times less than the diameter of the beam entering for example drift tube 40. Periodic focusing devices providing a series of straight-line approximations of a taper or other intermediate configurations such as scalloping effects may also be employed in this invention.

Applying the log periodic principle to the beam by tapering, together with a tapering beam channel provides the log periodic principle in all significant portions of the device which cooperate for power output. This unification indicates a more efficient device and accordingly increased bandwidth.

A transmission line 106 or other similar coupling means is employed to couple power into and out of the klystron amplifier 10. For example, a transmission line is illustrated in FIG. 1 in the form of an electrically conductive rod 107 which passes through the transverse walls of successive cavities in the klystron amplifier 10. At the input end 38, device 10 includes a convenient tubular input section 108 through which rod 107 passes. Rod 107 is also electrically insulated from tubular portion 108 by means of a ceramic window type seal 109 therebetween. At the output section 39 there is also provided a tubular output section 108' and ceramic window seal 109'. Rod 107 is also conveniently insulated from each of the partition walls through which it passes so that it is electrically insulated entirely from klystron device 10. A number of

loop type couplers may also be employed in this invention in lieu of the transmission line as described.

Ordinarily in the operation of the device of this invention the electron gun 85 is suitably energized to provide a significantly tapered beam 101 passing through successive cavities and interaction gaps for collection by collector 86. A power signal of given frequency is coupled into device 10 through rod 107 at the input or cathode end 38 of device 10. By means of rod 107 the input signal enters the tapered section 27 and selectively energizes a first region of one or more cavities therein whose resonant frequencies closely correspond to the frequency of the input signal. Strong interaction in a klystron manner takes place in the interaction gaps associated with these cavities and energy is coupled to the beam. At a further region along the interaction structure one or more cavities become receptive to beam power and the power from the beam is coupled back to the transmission line as amplified power output. The term "region" is employed to denote a part or section of an axially extending interaction structure and constitutes the selected one or more resonant cavities which are responsive to an input signal.

As a further example, a higher frequency signal progresses down rod 107 passing by one or more of the larger cavities which may not be resonant at the frequency of the input signal, until it reaches a portion or region of device 10 in the tapered section 27 thereof where cavities are near their resonance at the frequency of the input signal. These latter cavities which have become selectively responsive based on input frequency become effective in the known manner and strong interaction takes place in the affected interaction gaps associated with these cavities. As the input signal progresses further toward the smaller end of the device into section 28 cavities which are also not resonant, the interaction diminishes preferably to a negligible level. the amplified signal is then coupled out of device 10 through the rod at the output end.

The operation of this invention may be alternately described as follows. At a specified frequency one unit of power traveling along a semi-infinite length of the cold structure (or a properly terminated finite length) produces a particular pattern of voltage at each interaction gap. If the applied frequency is divided by ρ , the logarithmic progression, the entire pattern is moved one section to the right or toward the smaller end of the device. Provided that the beam diameter is scaled by ρ at each section while the total current and voltage remain constant, the electron beam behavior scales in the same manner as the circuit behavior. For a circuit of the type shown in the figure, interaction between the circuit wave and the beam will take place primarily in the portion of the tube where the resonant frequencies of the cavities are close to the applied frequency. In this region the cold circuit is nonpropagating and the signal is coupled from cavity to cavity by the electron beam in the manner of a klystron. As the frequency is increased this active portion moves toward the smaller end of the tube where the beam couples the amplified signal to the circuit for power output. If the tube is sufficiently long, the input and output connectors will be located in regions of weak interaction for all frequencies in the desired band. Thus, the end effects are not serious and the gain-frequency response repeats itself each time the frequency is divided by ρ . If the diameter of the cylindrical terminating section 28 is sufficiently small electrically at the highest operating frequency, it is essentially an exact mathematical equivalent for the conical section it replaces.

It is not necessary in all instances to have the coupling means or transmission line 106 operatively engage all of the individual cavities. A modification 110 of this invention is illustrated in FIG. 2. In FIG. 2 the partial axial section of the interaction structure is a part of the tapered section 27 of FIG. 1. All other remaining parts and

structures are similar to those of FIG. 1. In FIG. 2, the transmission rod 107 interconnects or is connected to such cavities as 111, 112, 113 and 114, while cavities 115, 116, 117 and 118 are not connected to the transmission line. The arrangement is one of having alternate cavities connected to the transmission line. The object of having a number of uncoupled resonant cavities included in a group of resonant cavities coupled to a transmission line is to provide a greater number of cavities responsive to the frequency of the input signal. The alternate ratio may be 1-1, as illustrated, 1-2, 2-2 or any other desirable ratio which will provide increase in efficiency and gain.

The operation of this device may be best described with reference to a modified W/BL or frequency phase shift characteristic curve as illustrated in FIG. 3. Referring now to FIG. 3 which represents information utilized in a successful computer example, the lefthand side of the diagram shows the phase shift characteristics of a uniform line. As all of the sections have similar shapes, the same diagram applies to any section if the proper frequency scale is used. The righthand portion of the diagram allows the proper frequency scaling for each section to be determined directly. The nonpropagating region of the diagram occurs when the cavities are near their resonant frequency. Consider for example the performance of this device at 2100 megacycles. An input or drive signal introduced in section 11 travels to section 17 where it is reflected since the structure no longer propagates at this frequency. In the vicinity of section 13, where the circuit impedance is relatively high, the reflected input wave is synchronous with the electron beam, and a strong bunching interaction takes place. The reflected wave is synchronous with the backward wave branch of the W/BL characteristic at point A, FIG. 3. From section 18 to section 28 there is no circuit propagation but as the beam current grows a strong interaction between the beam and the uncoupled cavities takes place. In the operation of the device of FIG. 2, because of the log periodic nature of the circuit the resonant frequency of the uncoupled but loaded cavities increases as one moves toward the output end of the tube. Thus the tuning pattern of these uncoupled cavities is similar to that found in conventional multicavity klystrons. In section 28 the circuit again propagates in the forward wave mode of the lower branch of the W/BL curve and the bunched electron beam delivers power to this output circuit which is formed by the sections from number 28 to the end of the tube.

A further modification of this invention is illustrated in FIG. 4. Referring now to FIG. 4, there is shown a traveling wave tube 120 incorporating the log periodic principle of this invention. As described for FIG. 1, an electron gun structure 85 and solenoid 103 provides a tapering electron beam passing through a typical helix structure 121 of traveling wave tube to a collector 86. The helix structure includes the log periodic principle having turns which decrease in diameter toward one end of the device, and at the same time the turn density or number of turns per unit length increasing toward the same end of the device. As also described with respect to FIG. 1, the log periodic concept may be suitably approximated by a number of diminishing straightline structures or other means which affect interaction in the log periodic manner. Since continuation of the log periodic principle leads to a theoretically infinity tapering helix, the device may be suitably terminated by a short cylindrical section of helix 122 similar in function to a cylindrical section 28 of FIG. 1, or a tapered section of constant helix. As described for FIG. 1, it is preferred that the remote or output end 122 of the helix 121 be at about the point where the helix would ordinarily have provided an apex if imaginary lines be drawn along the sides thereof to intersect at a projection point. The termination structure in this or preceding embodiments may also include the log periodic principle.

The overall or general traveling wave tube operation of the device of FIG. 4 is the same as for other traveling wave tubes. However, the log periodic principle may be applied to helix, interdigital, as well as other traveling wave tube structures and the beam affects the operation of the device in a manner similar to the effect as described for the klystron device in FIG. 1. For example, an input signal of a given frequency is introduced in the helix structure and selectively energizes a portion or region thereof responsive to the frequency of the input signal. Strong interaction at this region takes place and energy is coupled to the beam. This energy is coupled out of the beam at a region of the helix further advanced along the helix at a region where the amplified signal may again be passed to the helix. The helix interaction structure is one example of numerous similar and equivalent slow wave structures known in the art, for example, see U.S. Pats. 2,843,797 Boyd and 2,860,280 McArthur. The helix circuit is included by definition in those circuits which periodically interact with an electron beam, each turn of the helix being considered a period.

In the foregoing exemplary applications the electron beam is subject to some modulation whether velocity, density, or combination thereof. The invention is broadly applicable to beam devices where the beam passing through a structure provides significant changes in an input signal and power output may be amplified or provided with desired oscillations. As well known in the art, these devices may also act as frequency converters, rectifiers, variable conductors, etc.

This invention thus describes the specific combination of a log periodic interaction structure whether of the coupled cavity resonator type, magnetron or vane type, helix type, or other known circuits, together with a log periodic electron beam passing through the device, where the beam effective interaction characteristics vary axially therealong in a log periodic manner. In the operation of such a device the input frequency predeterminedly selects its own cavity or cavities or region of a helix or other interaction structure for interaction. The location or position of the actual cavity or section of an interaction circuit energized may change or move along the interaction structure reversibly dependent on input signal frequency. This may be described as a floating region along the interaction structure transiently localized by the particular frequency of the input signal.

The floating region may encompass one or more successive cavities of FIG. 1, or a portion of the helix of FIG. 4. In a resonant cavity device a given signal will provide effective response of one or more cavities for interaction energy exchange while other adjacent cavities may be only slightly or negligibly responsive. Where the beam couples power to the circuit a similar region of cavities are defined. These regions may be in effect immediately following each other or they may be spaced apart by cavities of negligible or no response. The peak response of the two regions are spaced apart and their axial spacing is fixedly related to each other as depending on the frequency of the input signal, and both float as above defined. Both regions are adjacent in that no effectively responsive region is apparent therebetween. The operation is similar for traveling wave structures such as helix structures, interdigital structures, etc. These latter structures may be considered to be structures periodically acting on or with an electron beam where each turn of a helix, or ring of an interdigital structure is defined as a period.

The log periodic circuit may be adapted for forward or backward wave characteristics, and for the backward type the structure is in essence reversed, i.e., the input signal is coupled into input 39 and power is coupled out of output coupling 38. In this embodiment the termination section 28 is eliminated. In a reverse structure, where the interaction structure is smaller at the cathode end and becomes larger toward the collector end, the log periodic factor ρ becomes greater than one.

Best results are obtained in this invention when the log factor is applied to the total interaction structure, not including the terminating section. However, the log factor need not be the same for all applications. For example, in an alternate arrangement of cavities such as illustrated in FIG. 2, alternate cavities may have different log factors applied. For the invention of FIG. 1 for example different axial sections may have different log factors applied thereto. Incremental differences in the log factor for example between 0.90 and 1.0 are significant with respect to operating results. A factor employed in this invention has been 0.925 and one preferred range of factors is from about 0.90 to about 0.95.

While this invention has been described with reference to particular and exemplary embodiments thereof, it is to be understood that numerous changes can be made by those skilled in the art without actually departing from the invention as disclosed, and it is intended that the appended claims include all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A log periodic electron beam device comprising in combination
 - (a) an axially extending log periodic interaction structure,
 - (b) means to provide electron beam of progressively varying interaction characteristics along its length and extending through said interaction structure,
 - (c) means to apply a power input signal to said interaction structure for energization thereof,
 - (d) termination interaction means to couple power out of said interaction structure,
 - (e) said termination interaction means to couple power out of said structure comprising a section of interaction structure not including log periodic interaction,
 - (f) and electron collector means to collect electrons from said beam after said interaction.
2. The invention as recited in claim 1 wherein said interaction structure comprises a periodically loaded slow wave R-F transmission circuit.
3. The invention as recited in claim 2 wherein said interaction circuit comprises a traveling wave tube helix structure.
4. The invention as recited in claim 3 wherein said helix tapers from a larger input end to a smaller output end.
5. The invention as recited in claim 4 wherein said helix is frustoconical.
6. The invention as recited in claim 5 wherein the turn density of said helix increases toward said smaller end.
7. The invention as recited in claim 6 wherein a short cylindrical section of helix of constant turn density terminates said frustoconical portion at the smaller end thereof.
8. The invention as recited in claim 7 wherein said cylindrical section terminates at a point no further than the projected apex of said frustrum.
9. The invention as recited in claim 2 wherein said interaction circuit includes at least in part, a plurality of klystron type cavities.
10. The invention as recited in claim 3 wherein said interaction circuit includes at least in part, a plurality of klystron type cavities.
11. The invention as recited in claim 9 wherein at least three klystron cavities are employed.
12. A log periodic power amplifier comprising in combination
 - (a) an interaction structure having a portion thereof for periodically interacting with an electron beam at different successive regions in a log periodic manner,
 - (b) means to provide a tapering electron beam in said structure for interaction therewith at said positions, with said beam taper continuing over a substantial number of successive ones of said regions,
 - (c) means to couple an input signal into said interac-

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tion structure so that said signal selectively energizes one of said successive interaction regions based upon the input frequency of said signal for amplification of said signal,

- (d) means to couple power output from said structure at a different power level from an adjacent region of said interaction structure activated by said one region,
- (e) electron collector means to collect electrons from said beam after said interaction, and
- (f) said means to couple power output from said structure including a termination interaction section part of said structure which is characterized by having interaction regions of substantially similar interaction characteristics.

13. The invention as recited in claim 12 wherein said interaction structure is an extended array of coupled cavity resonators.

14. The invention as recited in claim 12 wherein said interaction structure is terminated by an axially extending cylindrical interaction section having equal interaction characteristics therealong.

15. The invention as recited in claim 12 wherein said interaction structure comprises a combination of a traveling wave helix type circuit and a cavity resonator.

16. The invention as recited in claim 12 wherein said regions comprise coupled cavity resonators each of which have all significant dimensions smaller than those of a preceding cavity so that said cavity resonators vary in a log periodic manner along said areas.

17. A log periodic electron beam device comprising in combination

- (a) interaction circuit means defining a tapered electron beam path therethrough,
- (b) said circuit having electron beam interaction characteristics therealong which vary in a log periodic manner,
- (c) means to generate and define a tapered electron beam passing through said defined tapered beam path in said interaction circuit for interaction therewith, with the taper in said beam extending along the log periodic variation of said interaction circuit in the same nesting direction,
- (d) means to couple a power input signal to said interaction circuit to selectively energize a first region thereof based upon the frequency of said input signal, whereby power is coupled from said tapered beam to said circuit at an adjacent region fixedly related to said first region by said input frequency,
- (e) said means to couple power output from said circuit comprising a circuit termination interaction section,
- (f) means to couple power output from said interaction circuit,
- (g) and electron collector means to collect electrons from said beam after said interaction.

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18. The invention as recited in claim 11 wherein said input and output means are provided by a transmission line.

19. The invention as recited in claim 11 wherein said interaction circuit includes an axially extending array of reentrant cavity resonators whose interaction effect from interaction gap to succeeding interaction gaps progressively varies in a log periodic manner.

20. The invention as recited in claim 13 wherein each succeeding cavity resonator is smaller than its preceding cavity resonator in log periodic progression with successively smaller interaction gaps in logarithmic progression to provide a tapering interaction circuit.

21. The invention as recited in claim 13 wherein said interaction circuit and said beam path is frustoconical over a substantial portion of its length.

22. The invention as recited in claim 14 wherein means are provided to couple power into all said cavity resonators.

23. The invention as recited in claim 14 wherein means are provided to couple power into only alternate ones of said cavities.

24. The invention as recited in claim 15 wherein a cylindrical klystron circuit is positioned at the smaller end of said interaction structure to provide similar klystron cavities and interaction gaps.

25. The invention as recited in claim 18 wherein the number of cavities in said cylindrical section does not exceed the number of cavities in said interaction circuit.

26. The invention as recited in claim 19 wherein said cylindrical section terminates with a klystron cavity at a point no farther than the apex projection of said frustoconical section with centerlines passing through said cavities.

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315—3.5, 5.43; 330—43; 333—31, 34

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,527,976 Dated September 8, 1970

Inventor(s) H. L. Thal, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

3. The invention as recited in claim 2 wherein said interaction structure comprises a traveling wave tube helix circuit.

SIGNED AND
SEALED

FEB 23 1971

(SEAL)

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