March 21, 1950 W. W. HANSEN 2,500,944

HIGH-FREQUENCY TUBE STRUCTURE

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FIG. 1

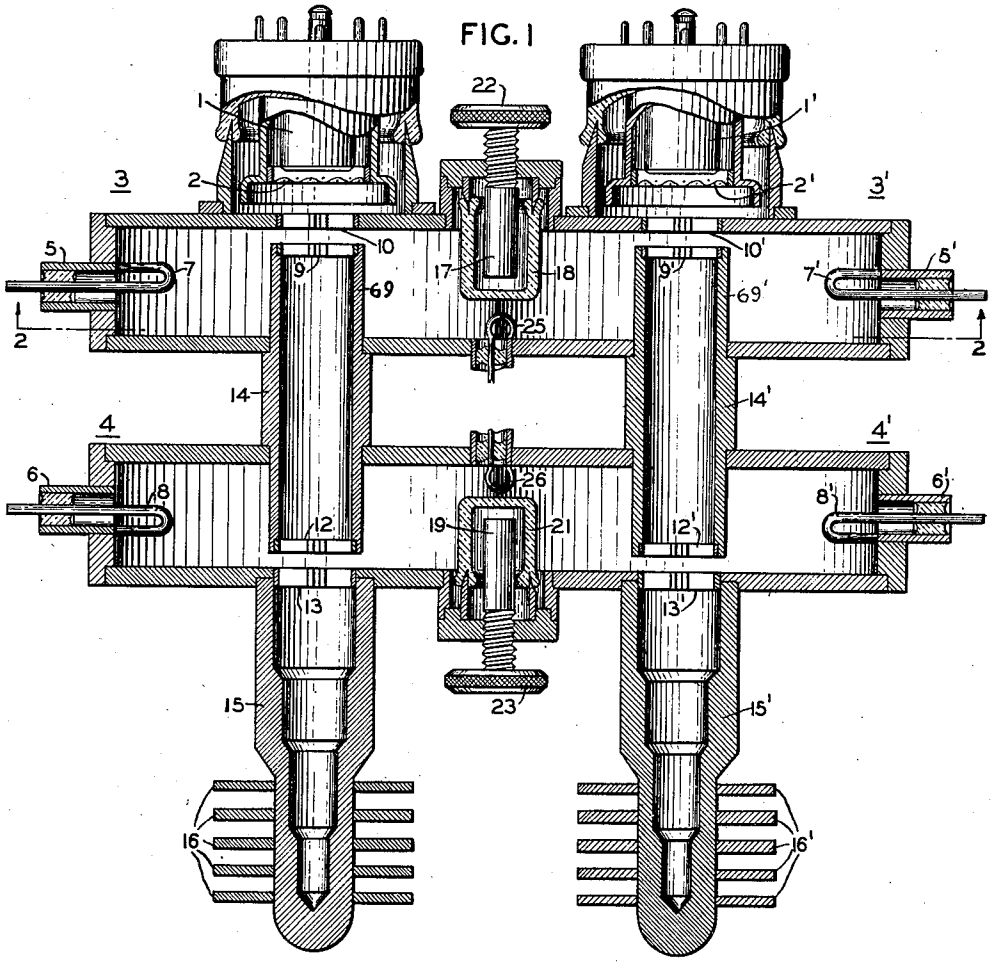
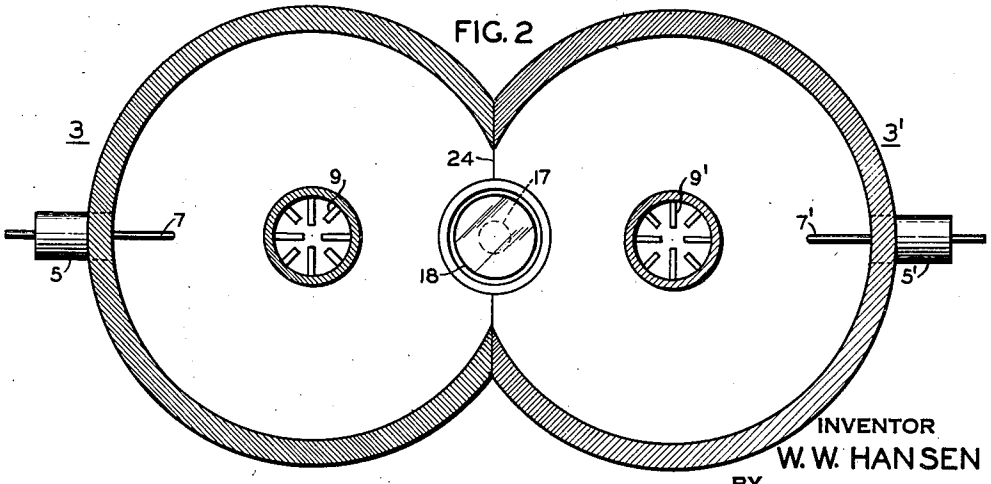


FIG. 2



INVENTOR
W. W. HANSEN
BY
Paul B. Hunter
ATTORNEY

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FIG. 3

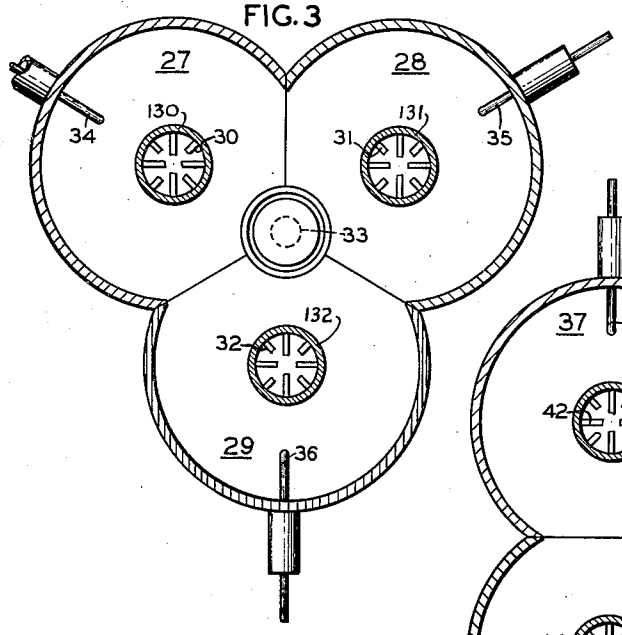


FIG. 4

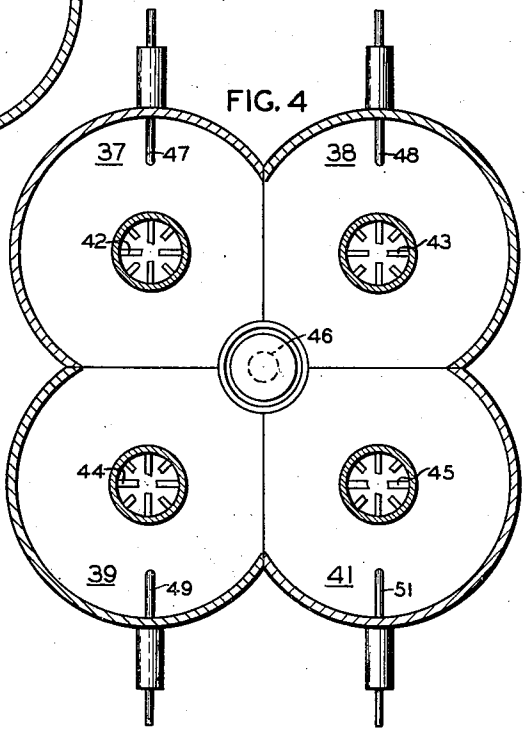


FIG. 5

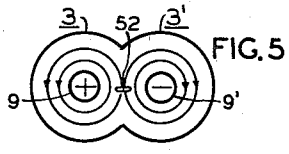


FIG. 6

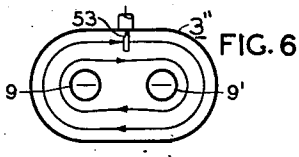


FIG. 7

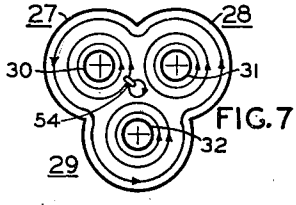


FIG. 8

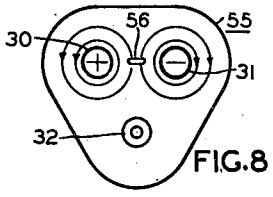


FIG. 11

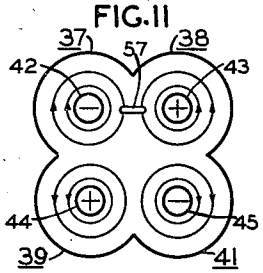


FIG. 9

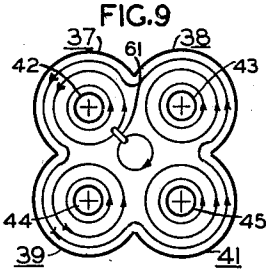
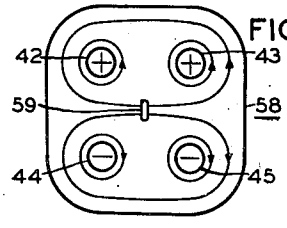


FIG. 10



INVENTOR
W. W. HANSEN
BY
ATTORNEY

Patented Mar. 21, 1950

2,500,944

UNITED STATES PATENT OFFICE

2,500,944

HIGH-FREQUENCY TUBE STRUCTURE

William W. Hansen, Garden City, N. Y., assignor to The Sperry Corporation, a corporation of Delaware

Application July 21, 1942, Serial No. 451,796

19 Claims. (Cl. 315—6)

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This invention relates, generally, to ultra high frequency electron beam velocity modulating vacuum tube devices, and, more specifically, to a novel type of high frequency device useful as a push-pull amplifier or oscillator. In general, the operation of electron beam velocity modulating devices with attached resonators has been described in prior Patents No. 2,242,249, issued May 20, 1941, in the names of Sigurd F. Varian and William W. Hansen for "Electrical converter" and No. 2,242,275, issued May 20, 1941, in the name of Russell H. Varian for "Electrical translating system and method."

The present invention discloses electron beam velocity modulating tube structures using two or a plurality of electron beams passing through two or a plurality of reentrant grid supporting structures in the associated pair of resonators. When a two beam device of this type is operated in push-pull, the device has the advantage of affording twice as much grid area for the beam current as does a conventional single beam velocity modulation tube. The catcher resonator is given an impulse twice every cycle, instead of once a cycle as in a single beam tube, so that more extreme loading of the catcher resonator can be allowed; or, for a given loading of the catcher, a resonator of only about a half of the Q of the catcher resonator used in a single beam electron beam velocity modulating tube is needed. Also, all even harmonics in the catcher voltage are eliminated. The device may be operated push-push if desired, but this has only the advantage of affording twice as much grid area. In general, the greater the number of electron beams used, the greater is the elimination of harmonics in the catcher voltage.

It is therefore the principal object of the present invention to provide an ultra high frequency electron beam device utilizing a plurality of electron beams.

Another object is to provide a push-pull amplifier, oscillator, or frequency multiplier velocity modulating tube of greater power output and freedom from harmonic distortion in the output.

A further object of the present invention is to provide improved ultra high frequency apparatus utilizing hollow cavity resonators and having a plurality of electron beams interacting therewith.

Still another object of the present invention is to provide electron beam velocity modulation apparatus useful as amplifiers, oscillators, or frequency multipliers, and having a plurality of velocity-modulated electron beams interacting with

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one or more cavity resonators having a corresponding plurality of electron permeable energy-interchanging gaps.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 is an elevation cross-section view of a generic form of the present invention.

Fig. 2 is a cross-section view of the paired resonators 3, 3' of Fig. 1 taken along the line 2—2 of that figure.

Fig. 3 is a cross-section view of a device similar to Fig. 1 having three reentrant portions in each resonator and using three electron beams.

Fig. 4 is similar to Fig. 3, but has four reentrant portions in each resonator, and uses four electron beams.

Figs. 5 to 11 are explanatory drawings showing the instantaneous relation of the magnetic fields to the electric fields in resonators of two, three, and four portions and utilizing two, three, and four electron beams, respectively.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

Figs. 1 and 2 show a preferred form of the present invention using two electron beams and having reentrant portions in each of the two portions of each resonator 3, 3', 4, 4'. The resonators 3, 3', 4, 4' are similar in type to those shown in application Serial No. 420,770, filed November 28, 1941 in the names of William W. Hansen and Russell H. Varian, entitled "Electric tuning control", issued April 13, 1948, as U. S. Patent No. 2,439,387. The configuration of the resonator portions 3, 3', 4, 4' constitutes electromagnetic field phase control means. The discontinuities present in the side walls of the resonator portions 3, 3', 4, 4' are effective for providing the desired phase relationship among the voltages existing at the gaps defined by the respective grids 9, 10, 9', 10', 12, 13, 12', 13'. Electrons emitted from hot cathodes 1, 1' are accelerated by voltages impressed between the cathodes 1, 1' and entrance grids 10, 10', and are projected through grids 10, 10'. In the spaces between grids 10 and 9, 10' and 9', the electrons are velocity modulated by an ultra high frequency electric field existing between these grids. The distance from exit grids 9, 9' to catcher resonator entrance grids 12, 12', respectively, is made such that the velocity modulation of the beam has resulted in subsequent density modulation or group-

ing of the electrons by the time they reach the space between grids 12, 13 and 12', 13', respectively. Arrival of these bunches of electrons in the catcher grid interspaces results in maintaining electromagnetic oscillations in the associated resonator portions 4, 4' in the well known manner.

Concentric lines 5, 5' and loops 7, 7' may be used to introduce ultra high frequency energy into resonator portions 3, 3' under some circumstances, or loop 25 may be used as a common means of excitation of both portions 3, 3' of the buncher resonator. Likewise, concentric lines 6, 6' and loops 8, 8', or loop 26 may be used to excite the portions 4, 4' of the catcher resonator or to extract energy therefrom.

Any desirable modulation voltage may be applied to grids 2, 2' adjacent to cathodes 1, 1' to control or modulate the electron beam current therefrom. Tuning of the buncher resonator 3, 3' may be accomplished by movement of a conducting or dielectric cylinder 17, which is enclosed in a glass vacuum envelope 18, the movement being obtained by rotation of knob 23. The action of tuning cylinder 17 has been described in the last referred to application Serial No. 420,770 to be that of causing distortion of the electromagnetic field in the resonator 3, 3' in such a manner as to alter the resonant frequency of the resonator. Likewise, tuning of resonator 4, 4' may be effected by tuning cylinder 19 by rotation of knob 23, or by any other well known method.

As shown in Figs. 5 and 6, there are two possible modes of oscillation of the two-portion resonators 3, 3' and 4, 4' shown in use in Fig. 1. In the case of the two-beam resonator as shown in Fig. 5, if the instantaneous polarities of the exit grids 9, 9' of the resonator 3, 3' are opposite, the magnetic lines of force in the resonator appear instantaneously more or less concentric about the two poles 69, 69', run in opposing directions, and may be coupled with by a loop placed at 52. The loop at 52 is intended to be at right angles to the plane of the drawing, in the same position as the loop 25 of Fig. 1. If the attached sides of the resonator 3, 3' are made smooth, such as is shown at 3'' in Fig. 6, the type of mode shown in Fig. 6 can be more readily excited. Here, the exit grids 9, 9' always have instantaneously the same polarity. In this case, the lines of magnetic force travel around both poles in the manner shown and may be coupled with by a loop such as 53. The plane of loop 53 is intended to be at right angles to the plane of the drawing. It may be also placed in the position of loops 7, 7' of Fig. 1. The mode shown in Fig. 6 may also be excited in a resonator shape like that shown in Fig. 5. In general, these two modes will have different resonant frequencies for a given set of resonator dimensions, so that the resonator sizes will be different for a given frequency. These same considerations also apply to resonators 4 and 4'.

Referring again to Fig. 1, if resonators 3, 3' and 4, 4' are made to operate in the mode shown in Fig. 5, a push-pull device results which operates as an amplifier, energy being introduced by loop 25 and extracted after amplification from loop 26. If resonator 4, 4' is dimensioned to resonate at a harmonic of the resonant frequency of resonator 3, 3' a push-pull frequency multiplier results, whose operation is similar to that of the electron beam velocity modulating devices described in copending application Serial

No. 416,170, entitled "High frequency tube structure," filed October 23, 1941, patented Aug. 19, 1947 under Patent Number 2,425,738. Again, if resonators 3, 3' and 4, 4' are made to operate on the mode of Fig. 5 and at substantially the same frequency, and if loops 7 and 8 and 7' and 8' are connected together by concentric line means, a push-pull oscillator results. Energy may best be removed from the concentric line attached to loop 26.

In the device shown in Fig. 1, when it is used as a push-pull amplifier, the large area of the opening between the two portions of each of the resonators affords the necessary high coupling between the two portions of that resonator. Separate single beam electron beam velocity modulating amplifiers may be used in push-pull, but two such separate amplifiers would require very accurate adjustment of frequency and power output to keep them operating in push-pull. Also, in the two-beam device, harmonic distortion of the output frequency is avoided, especially in case of high power input and extreme output loading.

The device may be also operated in push-push connection, if desired, by operating the catcher resonator in the mode shown in Fig. 6, in which case the electron beam voltages or the beam drift tube transit times or both are adjusted to cause both beams to give up energy to the catcher resonator..

Polyphase devices similar to that shown in Fig. 1 may be made using three, four, or a larger plurality of electron beams traversing a pair of resonators in which three, four, or a corresponding plurality of reentrant grid-mounting poles exist. In Fig. 3 is shown the cross-section of a resonator with three portions 27, 28, and 29, in each of which is centrally positioned a reentrant tube mounting grid structures 30, 31, 32, respectively, through which respective electron beams are projected. Tuning may again be accomplished by a centrally positioned axially movable conducting cylinder, as at 33, the metal slug being placed so that the poles 130, 131, 132 of the resonator are placed symmetrically about it. Concentric lines attached to loops 34, 35, 36, placed in planes at right angles to the plane of the drawing, may be placed in each of the resonator portions 27, 28, 29, respectively, as needed.

In a resonator of this shape, three modes of oscillation are possible. In one mode, as shown in Fig. 7, all of the exit grids of the resonator have the same instantaneous polarity. In this case the lines of magnetic force are more or less concentric to the poles 130, 131, 132, and all run in the same sense at any given instant. This mode may be coupled to by a loop 54 placed at right angles to the plane of the drawing, as shown in Fig. 7, or by either of two similar loops placed at 120° from the loop 54.

Another type of mode possible in a three pole resonator is shown in Fig. 8, this mode being essentially a three-phase excitation. A certain instantaneous picture of the electromagnetic field for this mode shows one pole positive and increasing, one negative and decreasing, and one at zero potential. After lapse of one-third of the period of the operating frequency, the conditions of these particular poles will rotate through a 120°, etc. As the sense of rotation may be in either direction, there are actually two possible frequencies due to this mode, although they may lie exactly on top of each other, that is, be equal. Either of these modes may be ex-

cited by means of a loop at right angles to the plane of the drawings as shown at **56**. It is also evident that there are two other symmetrically located and equivalent possible positions for this loop.

It is seen that a three beam polyphase device of the type shown in Fig. 1 may be made by using two resonators of the construction of Fig. 3 having modes shown in Fig. 8 substituted for the resonators of Fig. 1, or that similar polyphase devices may be made by using two such resonators having modes of the type shown in Fig. 7.

Polyphase devices may be made by using four electron beams passing through four reentrant poles containing grids such as exit grids **42**, **43**, **44**, **45** in resonator portions **37**, **38**, **39**, and **41**, respectively, as shown in Fig. 4 in cross-section. Tuning may again be accomplished by means of metal or dielectric slug **46**, and ultra high frequency energy may be coupled into or out of the resonator portions by means of loops **47**, **48**, **49** and **51**.

In the case of the four pole resonator, there are four possible types of excitation. Fig. 9 shows a mode in which the polarity of all of the poles is instantaneously the same, the lines of magnetic force being more or less concentric circles around the poles, all directed in the same sense. This mode may be coupled to by means of a loop as at **61** or by any of three other loops placed in analogous symmetrical positions.

Fig. 10 illustrates another mode of excitation of such four pole resonators in which an instantaneous picture shows two of the poles of one polarity and two of the poles of the opposite polarity. Such a mode may be excited, for example, by a loop placed at **59**. A third mode, whose frequency may be exactly the same as that of the resonator of Fig. **10**, is produced by rotation of the fields and the loop **59** through 90° in resonator **58**. The fourth mode of excitation is shown in Fig. 11 in which the diagonally opposite poles **42** and **45** are of one polarity and diagonally opposite poles **43** and **44** are of the opposite polarity at any given instant. This mode may be coupled to by a loop placed at **57** or at any one of three other analogous and symmetrically located positions. It is seen that the exact form of the resonator may aid in determining the type of excitation of the resonator, as is shown in each of these groups of illustrations depicting modes of oscillation of the two, three, and four pole resonator. It is also seen that, if desired, any of these modes may be set up by use of external coupling loops such as **7** and **7'** of Fig. 2; **34**, **35**, **36** in Fig. 3, etc., if these loops are excited in the proper phase relative to one another, by means of concentric lines or by use of wave guides.

Push-pull devices similar to that of Fig. 1 may be made by the use of two resonators having modes of oscillation similar to that shown in Fig. 10 or two similar to that shown in Fig. 11. Push-push devices may be made using two resonators oscillating in the mode shown in Fig. 9.

In accordance with the provision of the patent statutes, there is described herein the principal operation of the invention, together with the apparatus which is now considered to represent the best embodiment thereof. It is to be understood, however, that the apparatus shown is only illustrative and that the invention can be carried out by other means. Also, while it is designed to use the various features and elements in the combination and relations described, some of these may be altered and others omitted without interferring with the more general results outlined, and the invention extends to such use.

What is claimed is:

1. A high frequency electron discharge tube structure comprising a plurality of cathodes each for emitting an electron beam, a buncher cavity resonator adjacent said cathodes and having a corresponding plurality of reentrant portions with electron-permeable grids therein and each adapted to interact with a respective electron beam, a catcher cavity resonator adjacent said buncher cavity resonator and also having a corresponding plurality of reentrant portions with electron-permeable grids therein, each adapted to interact with a respective electron beam after passage thereof through the corresponding reentrant portion and grids of said buncher resonator, means defining a field-free space surrounding the path of each of said beams between said resonators, means coupled to said buncher resonator for exciting said buncher resonator with a high frequency field, and means coupled to said catcher resonator to abstract energy therefrom.

2. High-frequency electron-discharge apparatus comprising means for producing a plurality of parallel electron beams, means along the paths of said beams for velocity-modulating each of said beams cophasally in response to the same high frequency wave, an output resonator along the paths of all of said beams tuned to said wave and having a plurality of separate gaps respectively corresponding to each of said beams, said output resonator having substantially symmetrically disposed discontinuities in the side wall thereof for producing a mode of oscillation with progressively different phases of voltage at said gaps.

3. Apparatus as in claim 2 wherein said resonator has an output coupling loop located symmetrically with respect to said gaps.

4. High frequency electron discharge apparatus comprising means for producing a plurality of electron beams, means along the paths of said beams for simultaneously and periodically varying the velocities of the electrons of each of said beams at the same frequency and at the same phase, said last named means including means defining a first electromagnetic field region having a like plurality of electron traversal spaces registering with said beam paths, means defining a field-free drift space surrounding the path of each of said electron beams for causing said velocity-varied electrons to become density-modulated, means along the path of said beams and beyond said drift spaces defining a second electromagnetic region having a like plurality of further electron traversal spaces registering with said beam paths, and means providing predetermined phase displacement among the voltages resulting across said further traversal spaces of said second region due to the passage of one of said beams through said second region.

5. High frequency electron discharge apparatus as in claim 4, in which said predetermined phase displacements are relatively equally spaced.

6. High frequency electron discharge apparatus comprising a first cavity resonator means having a plurality of reentrant portions each defining an electron-permeable gap, a second cavity resonator means spaced from said first resonator and also having a plurality of reentrant portions each defining an electron permeable gap, means adjacent one of said cavity resonators for producing a plurality of electron beams and for projecting each of said beams successively through a

respective gap of said first resonator means and a respective gap of said second resonator means, means defining a field-free space surrounding the path of each of said beams between said two resonator means, means in said apparatus for producing voltages of respective progressively different phases across said gaps of said first cavity resonator, and means including side wall discontinuities of said second resonator means for providing predetermined phase displacements among the voltages existing across said gaps of said second resonator means due to the passage of one of said electron beams through said second resonator means.

7. High-frequency electron-discharge apparatus comprising a first cavity resonator means having electron-permeable wall portions defining a plurality of mutually-spaced electron-permeable gaps for velocity-modulating electrons, a second cavity resonator means spaced from said first resonator and also having electron-permeable wall portions defining a plurality of mutually-spaced electron-permeable gaps for extracting energy from electrons, means adjacent one of said cavity resonators means for producing a plurality of electron beams and for projecting each of said beams successively through a respective gap of said first resonator means and a respective gap of said second resonator means, means defining a field-free space surrounding the path of each of said beams between said two means, and electromagnetic field phase control means in said apparatus for producing respectively phase displaced voltages across said gaps of said first resonator means, said last-named means including means coupled to said first resonator means for exciting said first resonator means with electromagnetic energy, said second resonator means having a mode of oscillation producing cophasal voltages across all its gaps.

8. High-frequency electron-discharge apparatus comprising a first cavity resonator means having electron-permeable wall portions defining a plurality of mutually-spaced electron-permeable gaps for velocity-modulating electrons, a second cavity resonator means spaced from said first resonator means and also having electron-permeable wall portions defining a plurality of mutually-spaced electron-permeable gaps for extracting energy from electrons, means adjacent one of said cavity resonators means for producing a plurality of electron beams and for projecting each of said beams successively through a respective gap of said first resonator means and a respective gap of said second resonator means, means defining a field-free space surrounding the path of each of said beams between said two resonators means, and electromagnetic field phase control means in said apparatus for providing phase displacements of a polyphase relationship among the voltages across said gaps of said resonator means, said phase control means including means coupled to said first resonator for exciting said first resonator means with electromagnetic energy, said second resonator means having a different mode of oscillation producing voltages across its gaps of phase relation different from that of said first resonator means voltages.

9. High-frequency electron-discharge apparatus comprising a first cavity resonator having a plurality of mutually-spaced reentrant portions each defining an electron-permeable gap, a second cavity resonator spaced from said first resonator and also having a plurality of mutually-spaced reentrant portions each defining an electron-permeable gap, means adjacent one of said cavity resonators for producing a plurality of electron beams and for projecting each of said beams successively through a respective gap of said first resonator and a respective gap of said second resonator, means defining a field-free space surrounding the path of each of said beams between said two resonators, said second resonator having discontinuities in the side walls thereof for effecting extraction of energy of differing and equally separated phases from said plurality of beams.

10. A high frequency push-pull amplifier comprising means for producing a pair of electron beams, means for velocity modulating said beams simultaneously by a high frequency signal to be amplified, said velocity-modulating means including a first cavity resonator means having a pair of mutually-spaced electron-permeable gaps, means surrounding the paths of said beams for causing said velocity modulated beams to become bunched, means at the other end of the paths of said beams for extracting amplified energy from said bunched beams, said extracting means including a second cavity resonator means having a pair of mutually-spaced electron-permeable gaps, beam phase control means in said apparatus providing predetermined phase displacements between the electron bunches arriving at said gaps of said second resonator means, and means including side wall discontinuities of said second resonator for providing a 180° phase displacement between the voltages resulting across said gaps of said second resonator means due to the passage of one of said beams through said second resonator means.

11. Cavity resonator apparatus comprising a plurality of cylindrical shells, at least two of said shells being joined along and communicating with one another through a common chord thereof, and a plurality of reentrant portions symmetrically placed within said shell and parallel to the axis thereof providing a plurality of symmetrically positioned gaps.

12. Apparatus as in claim 11 further including coupling means coupled to at least one of said shells and arranged upon excitation thereof to produce cophasal voltages across said gaps.

13. Apparatus as in claim 11 further including coupling means coupled to at least one of said shells and arranged when excited to produce progressively differing and equally separated phases of voltages at said gaps.

14. Cavity resonator apparatus comprising a plurality of cylindrical-shell wall portions joined together and communicating with one another along common chords thereof, and a like plurality of reentrant portions symmetrically located within said shell portions providing a plurality of symmetrically positioned gaps.

15. Apparatus as in claim 14 further including a coupling means located symmetrically with respect to said reentrant portions.

16. Apparatus as in claim 14 including a coupling means located symmetrically with respect to two of said reentrant portions, whereby said resonator may be excited to have opposite phases of voltage for said two gaps.

17. Cavity resonator apparatus comprising a pair of cylindrical shells joined along and communicating with one another through a common chord thereof, and a pair of end walls having apertures along the axis of each of said cylindrical shells and adapted to permit passage of electron streams therethrough.

18. Apparatus as in claim 17 further comprising a coupling loop in one of said end walls located symmetrically with respect to and substantially between said apertures in one of said end walls.

19. Apparatus as in claim 17 further including a coupling loop in said side wall and located in a plane symmetrically placed with respect to said walls.

WILLIAM W. HANSEN.

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The following references are of record in the file of this patent:

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Certificate of Correction

Patent No. 2,500,944 March 21, 1950

WILLIAM W. HANSEN

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 8, line 15, after the word "means" insert *at one end of the paths of said beams*;

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of June, A. D. 1950.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.