July 6, 1948. E. FEENBERG 2,444,434

VELOCITY MODULATION DISCHARGE TUBE APPARATUS

Filed Jan. 22, 1943

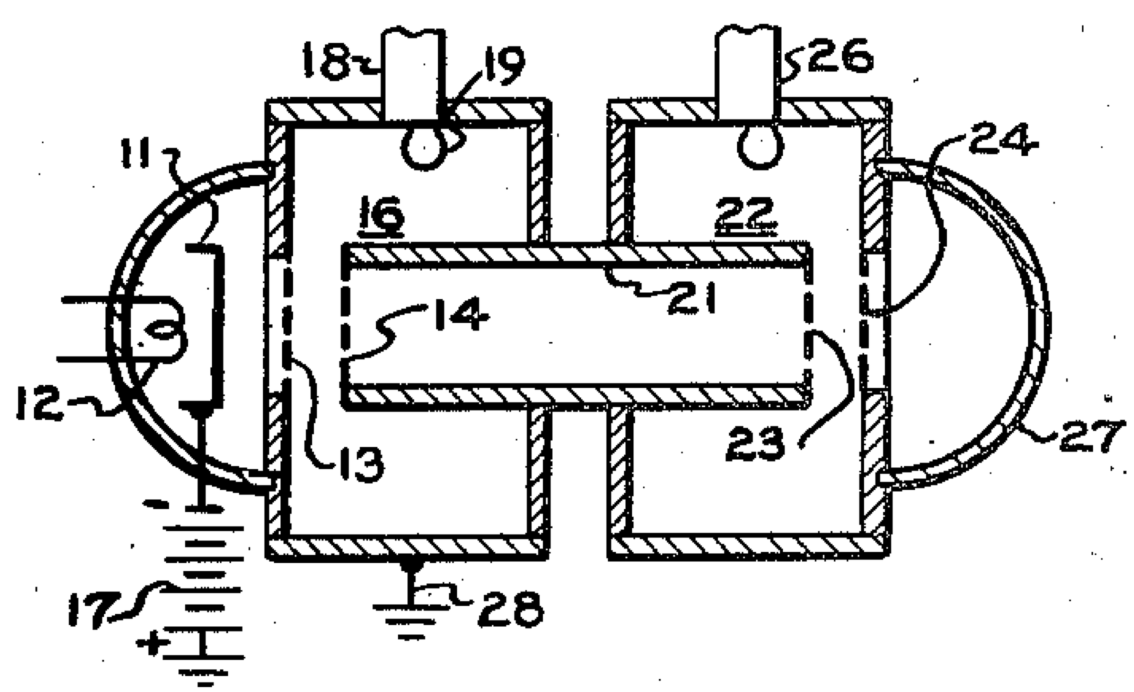


Fig. 1

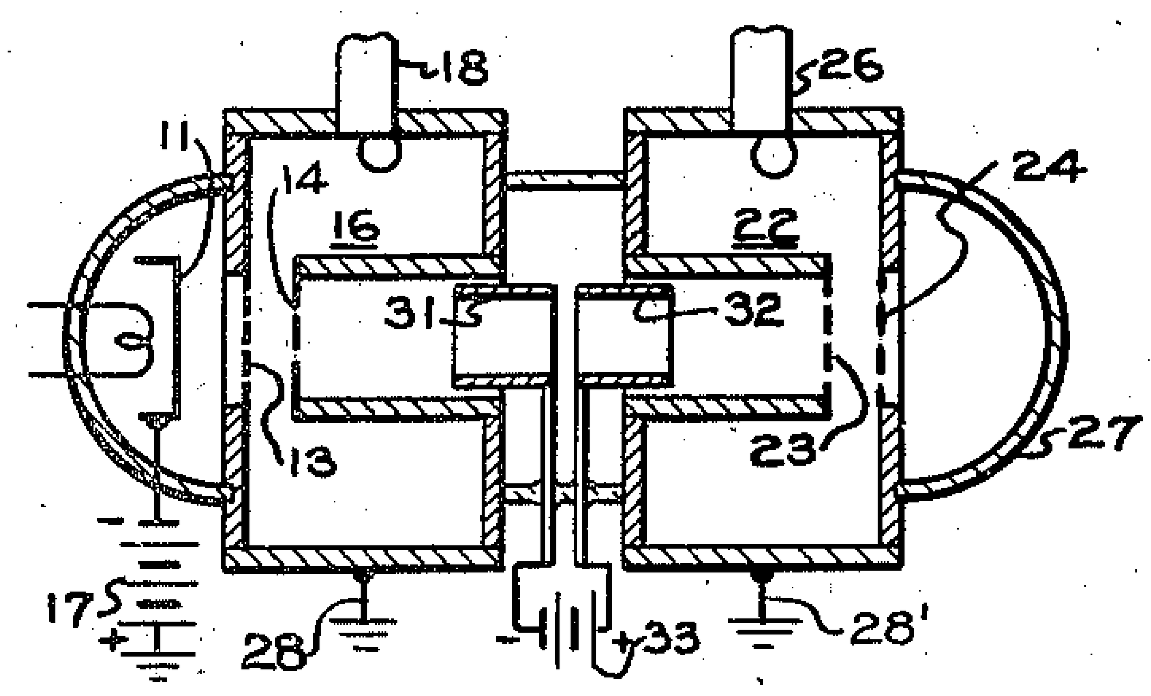


Fig. 3

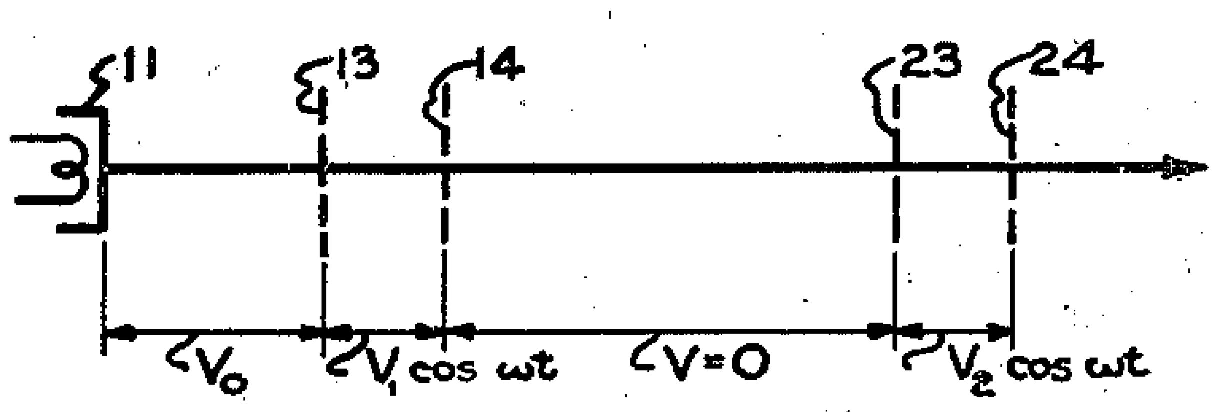


Fig. 1A

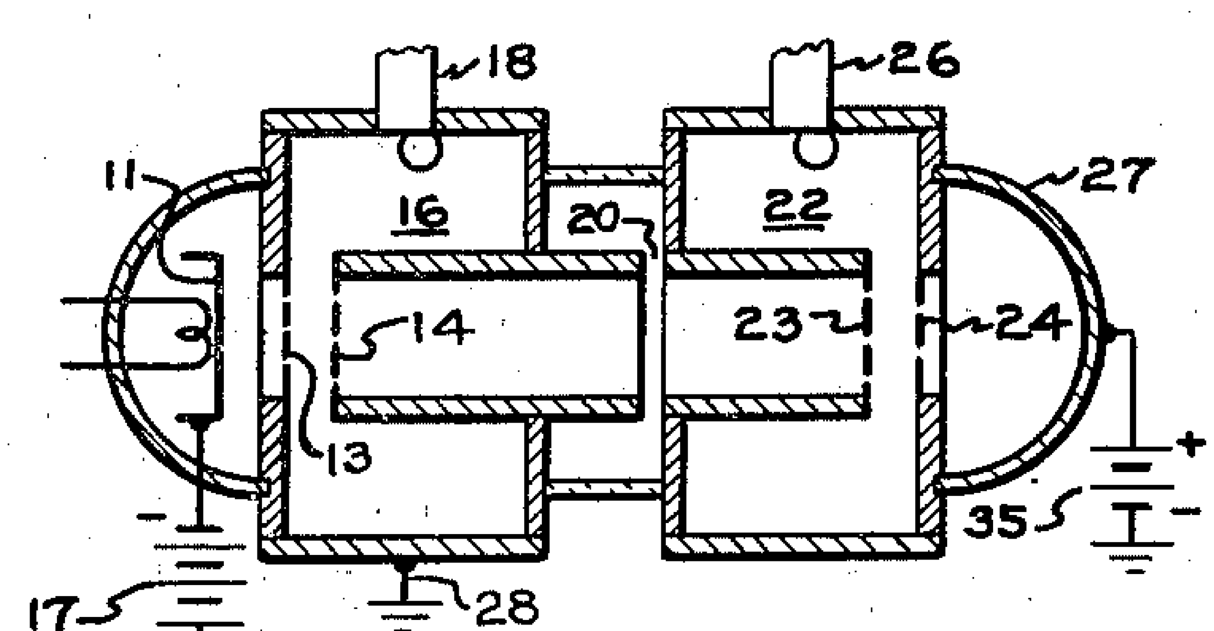


Fig. 4

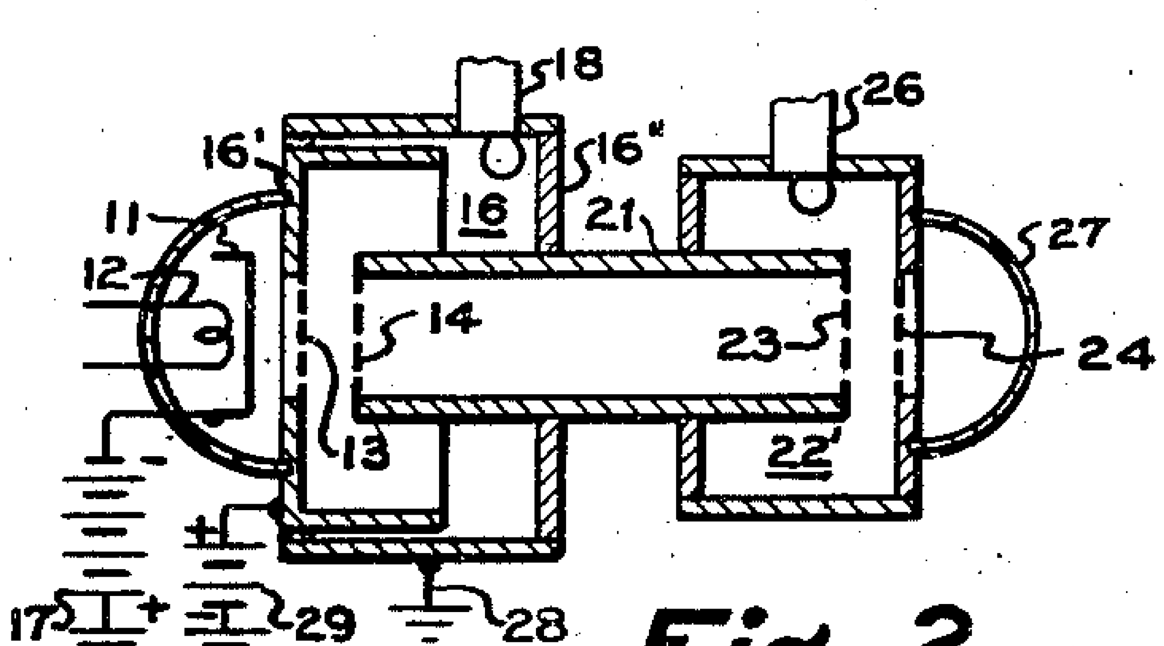


Fig. 2

Fig. 5

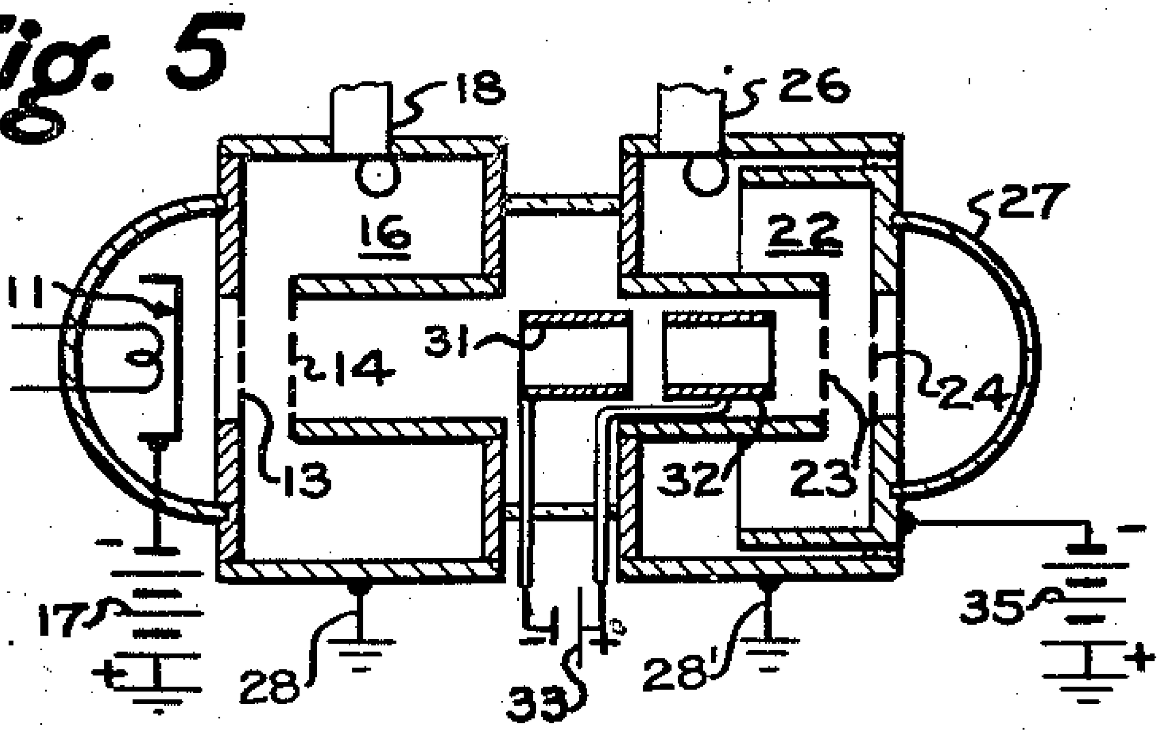


Fig. 5A

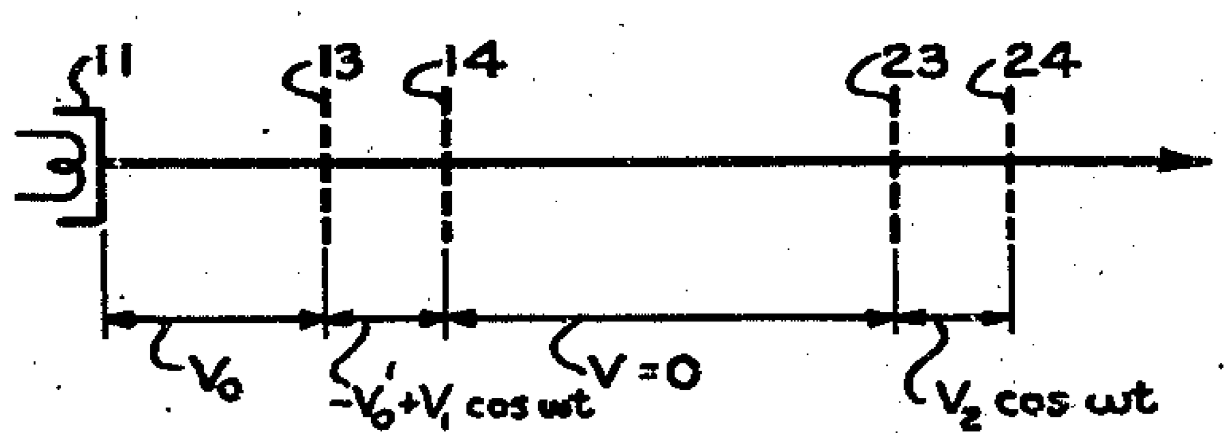
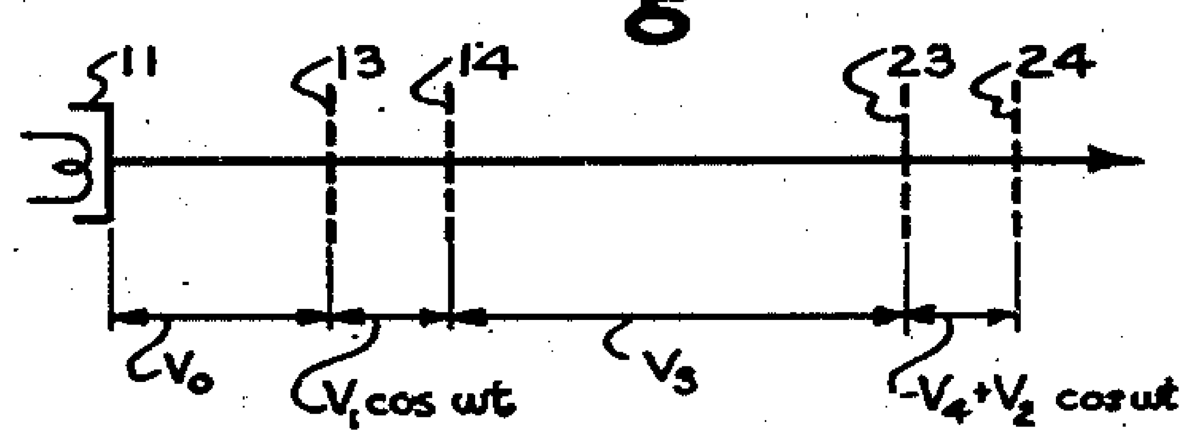


Fig. 2A



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Patented July 6, 1948

2,444,434

UNITED STATES PATENT OFFICE

2,444,434

VELOCITY MODULATION DISCHARGE TUBE APPARATUS

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Application January 22, 1943, Serial No. 473,265

6 Claims. (Cl. 315—6)

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The present invention relates to the art including velocity variation electron discharge devices such as of the type shown in Varian Patent 2,242,275 issued May 20, 1941. The present invention relates more particularly to improvements on such devices for reducing losses, increasing effective input shunt impedance, and permitting larger power outputs.

The present invention is applied to a velocity variation device, in which an electron beam is projected through the alternating electromagnetic field of a hollow cavity resonator containing a confined electromagnetic field. The interaction of the electron beam with this field recurrently varies the velocities of the electrons. These velocity-varied electrons are then projected through a field-free drift space in which the faster electrons are permitted to overtake the slower electrons thereby producing recurrent bunching of the electrons in the beam. The bunched beam is then passed through a second cavity resonator of the same type, and gives up high frequency energy to this second "catcher" resonator. The first or "buncher" resonator may be separately excited, in which case the device acts as an amplifier to produce an amplified output from the catcher resonator. Alternatively, a portion of the output from the second or "catcher" resonator may be fed back to the "buncher" resonator, and the device thereupon will generate sustained oscillations. By slight modifications, the device may also act in many other capacities, such as a regenerative amplifier, a modulator, a detector, frequency multiplier, superheterodyne mixer or other wave translating apparatus.

In order to produce satisfactory operation at the ultra high frequencies, such as of the order of 10^8 cycles per second or higher, it is necessary to provide relatively high electron velocities, since the power capacity and output of the device depends upon the current of the electron beam, and since certain of the losses within the resonators are greater for smaller electron velocities. However, such high electron velocities require unduly long drift spaces to permit a satisfactory bunching of the electron beam. In order to be able to utilize reasonable and convenient sizes for such apparatus, it is necessary to reduce the drift space length in some way. This can be done according to the present invention, in which, instead of operating the entire "buncher" resonator at a single static potential as in previously known devices, the "buncher" resonator is split into two parts isolated from one another with respect to static

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potentials, but closely capacitively coupled so as not to impair the action of the device as a useful hollow cavity resonator. Each of these parts may then be provided with an electron-permeable grid for coupling the resonator with the electron beam. The entrance grid adjacent the cathode is operated as an accelerating grid at a high positive potential with respect to the cathode, whereby a high-velocity electron beam and therefore high beam current is produced. The second or exit grid of the bunching resonator is operated at a lower direct potential than the entrance grid, whereby a retarding field is produced between the two grids, causing deceleration of the electrons and a resultant lowered electron exit velocity. The electrons enter the drift space with this lowered velocity whereby the drift space may be materially shortened over previous tubes having the same beam current or entrance electron velocity.

The present device also has further advantages over the prior art devices illustrated by the above cited Patent 2,242,275. Thus an electron beam in passing through the "buncher" resonator absorbs a definite, if small, amount of energy from the field within the resonator in order to produce the recurrent variations in electron velocity. This energy loss is dependent upon the electron transit time within the resonator; that is, the longer the transit time and the greater the transit angle, up to a half cycle of the operating frequency, the greater will be this power loss. To prevent this loss, it is desirable to have high electron velocities permitting reduced transit times and transit angles within the resonator.

In the prior art devices, this condition was incompatible with the desired low average electron velocity within the drift space permitting a shortened drift tube. By the present invention, however, the lowered electron velocity in the drift tube is obtained without the formerly necessary concurrent increase in the electron transit angle, since the average velocity of the electrons in the resonator is now much greater than its velocity in the drift space, permitting the advantages of both the shortened drift tube and the decreased power loss, contrary to teaching of the prior art devices.

The present device has a further advantage over prior art devices in that by the use of the split buncher resonator, a smaller high frequency driving voltage between the grids of the resonator will produce an equal output effect. In this way, lower buncher field intensities may be used, further reducing losses within the resonator and its dielectric. This is equivalent to an increase in the effective input shunt impedance of the device, especially where it operates as an amplifier, and permits its use where input impedance requirements would prevent the use of ordinary electron discharge devices of this type.

Accordingly, it is an object of the present invention to provide an improved velocity variation electron discharge device having smaller overall dimensions than previously obtainable with devices of the same character.

It is another object of the present invention to provide an improved velocity-variation discharge device having decreased power losses and consequently increased efficiency.

It is a further object of the present invention to provide an improved velocity variation discharge device requiring decreased driving or buncher voltage and having increased input shunt impedance.

It is a still further object of the present invention to provide an improved electron velocity-variation discharge device utilizing a split resonator having insulated portions operating at different static potentials.

It is still another object of the present invention to provide an improved electron velocity-variation discharge device having decreased electron transit time within the resonators thereof, without sacrificing compactness and efficiency.

Further objects and advantages will become apparent from consideration of the following specification and drawings, wherein

Fig. 1 shows a schematic diagram of a prior art type of velocity variation electron discharge device.

Fig. 1A shows a diagram useful in explaining the operation of the device of Fig. 1.

Fig. 2 shows a schematic representation of a modification of the device of Fig. 1 incorporating some of the advantages of the present invention.

Fig. 2A is a diagram useful in explaining the operation of the device of Fig. 2.

Fig. 3 shows a schematic representation of a modified form of the present invention.

Figs. 4 and 5 show schematic representations of further modified forms of the invention, and

Fig. 5A shows a diagram useful in explaining the operation of the device of Fig. 5.

Considering Fig. 1, there is shown schematically an electron velocity variation discharge device of the type disclosed in the above-mentioned Varian Patent 2,242,275. This device includes a suitable thermionic cathode 11 energized by a heater 12 and providing an electron beam which is projected toward one grid 13 of a first or "buncher" resonator 16, by means of a suitable accelerating voltage derived from a battery 17. The electrons passing between grids 13 and 14 of resonator 16 have their velocities recurrently and periodically varied by the resonator electromagnetic field existing between grids 13 and 14. This field may be supplied to resonator 16 from any suitable source, including the output of the present device, by means of a suitable coupling connection 18 illustrated as being a concentric transmission line with a coupling loop 19 at its end within resonator 16. The velocity-varied electrons passing through grid 14 then proceed within a field-free drift space defined by drift tube 21, having a length suitable to permit the faster electrons to overtake the slower electrons to produce recurrent bunching of the electron beam.

The bunched electron beam then passes through the second or "catcher" resonator 22, by way of its grids 23 and 24, and gives up its high frequency energy to the field within resonator 22. This energy may then be directed toward any desired utilization device by way of a similar coupling connection 26. Electrons passing through grid 24 are then collected by any suitable electrode such as 27.

Resonators 16 and 22 are formed as totally enclosed conducting housings defining their respective resonant cavities and operating at a single static potential. Generally, these members are connected to ground as illustrated in the drawing at 28, the cathode 11 being insulated therefrom and operated at a high negative potential with respect to ground by means of battery 17.

If high frequency energy is supplied to resonator 16 from an external source, by coupling 18, the device will operate as an amplifier to produce an amplified version of this energy at output 26. If desired, resonator 22 may operate at or be resonant at a harmonic of the resonant frequency of the resonator 16, whereby the device will operate as an amplifier and frequency multiplier simultaneously. If energy is supplied to resonator 16 from resonator 22, as by coupling connectors 26 and 18 together by suitable means, possibly including a phase adjustor, the device will act as a self-excited oscillator, and will produce sustained oscillations which may be supplied to any desired utilization device, either by connector 26 or by a similar independent connector coupled to resonator 22. By further modifications of the apparatus, it may operate as a regenerative amplifier, as a modulator, as a detector, or as a super-regenerative detector, all of which have been described in prior art patents and publications.

To reduce the beam power loss within the bunching resonator 16, caused by the absorption of energy from the resonator to produce the variation of the velocity of the electrons of the beam, it is desirable to space grids 13 and 14 close together and to provide a high electron velocity, thereby producing a low transit time or transit angle within resonator 16. Such high velocity electrons, however, require a long drift space to produce the proper bunching of the beam in order that it may efficiently give up energy to the catcher resonator 22. This unduly increases the overall length of the device, which is undesirable for reasons of compactness and adaptation to various applications of use of the device.

Accordingly, it is desirable to provide means for reducing this power loss while retaining the advantages of reasonable length of drift tube. This may be done by the device of Fig. 2. In this case, the casing of resonator 16 has been divided in two separate portions 16′ and 16″, respectively insulated from one another but closely capacitively coupled, whereby the resonator continues to operate fully satisfactorily as a resonant enclosure for the high frequency electromagnetic field, but permitting different static potentials to be applied by means of a battery 29 to the respective grids 13 and 14 connected to these portions 16′ and 16″ of resonator 16.

As shown in Figs. 2 and 2A cathode 11 is still maintained at a negative potential by battery 17 whereby grid 13 is maintained at a high positive potential with respect to cathode 11, this potential being indicated as V_0 in Fig. 2A and being the sum of the voltages of the batteries 17 and 29.

Grid 14, being connected to the grounded section 16'' of resonator 16, now has a static potential V'_0 with respect to grid 13, as well as an alternating potential $V_1 \cos \omega t$ produced by the high frequency field within the resonator 16. If desired, of course, battery 17 alone could have potential V_0, so that grid 13 could be at ground potential, and grid 14 at a negative potential of an amount V'_0. This contrasts with the situation in Fig. 1 and Fig. 1A, where the only potential between grids 13 and 14 is the alternating potential $V_1 \cos \omega t$.

In Fig. 2 the static potential between grids 13 and 14 produces a retarding field upon the electron beam and is therefore indicated by a negative sign in Fig. 2A. As a result of this condition, the exit velocity of the electrons from grid 14 is materially reduced with respect to their entrance velocity, permitting a shortened drift space, while the average velocity of the electrons within the resonator, that is, between grids 13 and 14, which determines the electron transit time within the resonator 16, is materially increased over the corresponding electron velocity in the device of Fig. 1 necessary to produce the same drift space velocity. As discussed above, this carries the concurrent advantages of decreased power loss in the bunching resonator 16 and reduced drift tube length.

The electron beam in the apparatus of Fig. 2 proceeds from the drift tube 21 to the second resonator 22' to give up its energy thereto. In the present illustration resonator 22' is shown as having a resonant frequency which is a harmonic of the resonant frequency of resonator 16, whereby the device will act as a frequency multiplier. It is to be understood, however, that this is shown so for illustrative purposes only, and that the invention of Fig. 2 may be applied equally to an amplifier, oscillator, detector, modulator, or other type of velocity variation translating device.

The power loss described above occurring in the buncher resonator due to the electron transit time therein also occurs in the catcher resonator, such as 22. A similar splitting of the catcher resonator into two insulated portions operating at differing static potentials may be utilized, as shown and described in copending Hansen application Serial No. 417,229, for High frequency tube structure, filed October 31, 1941, and assigned to the same assignee as the present application.

The same advantages as exist in this Hansen application may be obtained by accelerating the electrons of the beam before they reach the catcher resonator. This may be done as shown in Fig. 3 by providing a pair of electrodes 31, 32 coupled to the beam and maintained at different static potentials by means of a battery 33 whereby the electric field between these two electrodes 31, 32 will accelerate the electron beam passing therethrough. These electrodes 31, 32 are illustrated as being coaxial cylinders surrounding the beam and are preferably but not necessarily thus formed and arranged. Actually electrodes 31, 32 may be ring electrodes or grid electrodes or any other electrodes suitable for coupling to an electron beam without impeding the flow of the electrons thereof. Preferably also, the accelerating action of these accelerating electrodes 31, 32 is produced near the entrance grid 23 of the catcher resonator 22.

Instead of utilizing separate electrodes 31, 32, the drift tube 21 of Fig. 1 may be split into two portions providing a gap 20 therebetween as shown in Fig. 4. By maintaining these two portions, connected respectively to resonator 16 and resonator 22, at differing static potentials by battery 35, the same accelerating effect may be produced. These two portions may be of differing diameters if desired.

It is to be noted that the present arrangement offers several advantages over the split catcher resonator arrangement of the abovementoned application Serial No. 417,229. First, the transit time of the electrons in the space between catcher grids 23 and 24 is reduced, since the average velocity in the grid space is materially increased. In this way, the resultant losses in the resonator 22 are reduced, as discussed above.

Furthermore, the accelerating arrangement also provides or may be adapted to provide some focusing action. As is well known, electrons in an electron stream, being of the same charge polarity, tend to repel one another whereby the beam is dispersed and defocused. This has a harmful effect upon the operation of electron beam tubes, especially of the present type, and must be avoided. Arrangements of the types shown in Figs. 3 and 4 will act to focus the beam and prevent it from dispersing. If desired, cylinders 31 and 32 of Fig. 3 may be made of differing diameters whereby increased focussing is obtained by electron lens action. Similarly, the sections of drift tube 21 shown in Fig. 4 may be made of different sizes to produce similar focussing action.

This focussing action becomes especially advantageous in very high frequency tubes, in which case the grids 23 and 24 may be completely omitted, sufficient coupling between the resonator and the electron beam being obtained merely by passing the beam through the opening where the grid ordinarily would be. With such a gridless catcher resonator, the focussing action of the accelerating electrodes on the beam permits a smaller diameter beam passing through the tube. In gridless resonators, the effective electron transit time or effective transit angle through the resonator is proportional to the radius of the opening. Smaller beam diameters therefore permit a smaller opening which, in turn, reduces the equivalent electron transit time and reduces the losses discussed above.

As a further advantage, the increased potential difference through which the electron beam falls increases the available high frequency energy which may be derived from the beam.

If desired, of course, the accelerating action of the apparatus shown in Figs. 3 and 4 could be combined with the split catcher of the prior application Serial No. 417,229, and a retarding field applied to the catcher thus split into two sections, as shown in Fig. 5. In this way, the electron transit time loss and other resonator losses are further reduced, thereby increasing the efficiency and power output.

Fig. 5A shows the potential arrangement for the tube of Fig. 5, having the split catcher resonator 22. Here an accelerating voltage V_0 between cathode 11 and entrance grid 13 of resonator 16 is provided, as by the accelerating battery 17. The alternating electromagnetic field within buncher resonator 16 produces the potential $V_1 \cos \omega t$ between grids 13 and 14 and thereby velocity modulates the electron beam passing therethrough. In the drift space between grid 14 and grid 23 a potential V_3 is applied from battery 33 to electrodes 31 and 32 forming a field providing further acceleration of the electrons.

By splitting the catcher resonator 22 and applying a retarding field V_4 between grids 23 and 24 thereof, the potential between grids 23 and 24 will be

$$-V_4+V_2 \cos \omega t$$

as indicated in Fig. 5A, the voltage V_2 being the instantaneous maximum amplitude of the output voltage. Because of the accelerating and retarding fields produced by voltages V_3 and V_4, the electrons have a decreased transit time in resonator 22 with respect to the situation in Fig. 1 if the same voltage V_0 is used, and decreased losses and improved power output occur.

It is also to be understood that the apparatus of Figs. 3 and 4 may incorporate the split buncher resonator of Fig. 2, if desired, and that apparatus just described is not restricted to any particular type of apparatus but may be used with all types of velocity modulation electron discharge tubes.

In this way, there is provided an improved velocity variation electron discharge device providing higher efficiency and greater power outputs than heretofore obtainable.

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

Having described my invention, what I claim and desire to secure by Letters Patent is:

1. High frequency apparatus comprising means for producing a stream of electrons, means along the path of said stream for velocity modulating said stream, means providing a field-free drift space around the path of said modulated stream to permit said electrons to become grouped, and means along the path of said grouped stream for utilizing said grouped electron stream, said modulating means comprising a hollow cavity resonator having a pair of electron permeable grids as portions of the walls thereof, said grids being insulated from one another with respect to direct currents and positioned in high frequency coupling relation to said stream, said modulating means further comprising means connected thereto for producing a retarding unidirectional electric field between said grids acting on said stream, whereby said drift space may be reduced in size and the losses in said resonator decreased.

2. High frequency apparatus comprising means for producing a stream of electrons, means along the path of said stream for velocity modulating said stream, and means along said stream path for utilizing said modulated stream, said modulating means comprising a hollow cavity resonator having a pair of electron-permeable walls insulated from each other and positioned in high frequency coupling relation to said stream, said modulating means further comprising means connected thereto for producing a retarding unidirectional electric field between said walls acting on said stream.

3. High frequency apparatus comprising means for producing a stream of electrons, means along the path of said stream for velocity modulating said stream, and means along said stream path for utilizing said modulated electron stream, said modulating means comprising a pair of electron permeable grids positioned along said stream path, means coupled thereto for impressing an alternating high frequency field between said grids, and further means coupled thereto for impressing a retarding unidirectional electric field on said stream between said grids.

4. High frequency apparatus for producing a low-velocity, velocity-modulated electron stream, comprising means for producing a stream of electrons, a hollow cavity resonator having a pair of electron-permeable grids along the path of said stream and insulated from one another with respect to direct currents, means coupled to said resonator for exciting said resonator with ultra-high-frequency energy, and means coupled to said grids for impressing a unidirectional electron-retarding electric field between said grids.

5. High frequency apparatus for producing a low velocity, velocity-modulated electron stream, comprising means for producing a stream of electrons, a pair of electron permeable grids along the path of said stream, means coupled thereto for impressing an alternating high frequency voltage between said grids, and means coupled thereto for producing a unidirectional electron-retarding electric field between said grids, whereby said electrons are velocity-modulated by said alternating voltage and have their average velocity lowered by said unidirectional field.

6. High frequency apparatus, comprising means for producing a stream of electrons of predetermined velocity, means along the path of said stream for velocity modulating said stream, means defining a field-free drift space enclosing the path of said modulated stream, and means along said stream path for reducing the average velocity of the electrons in said drift space to less than said predetermined velocity, said last-named means including electrode means for impressing a retarding electric field on said stream simultaneously with the velocity modulation thereof.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,242,249	Varian et al.	May 20, 1941
2,242,275	Varian	May 20, 1941
2,244,747	Varian et al.	June 10, 1941
2,269,456	Hansen et al.	Jan. 13, 1942