

Nov. 14, 1950

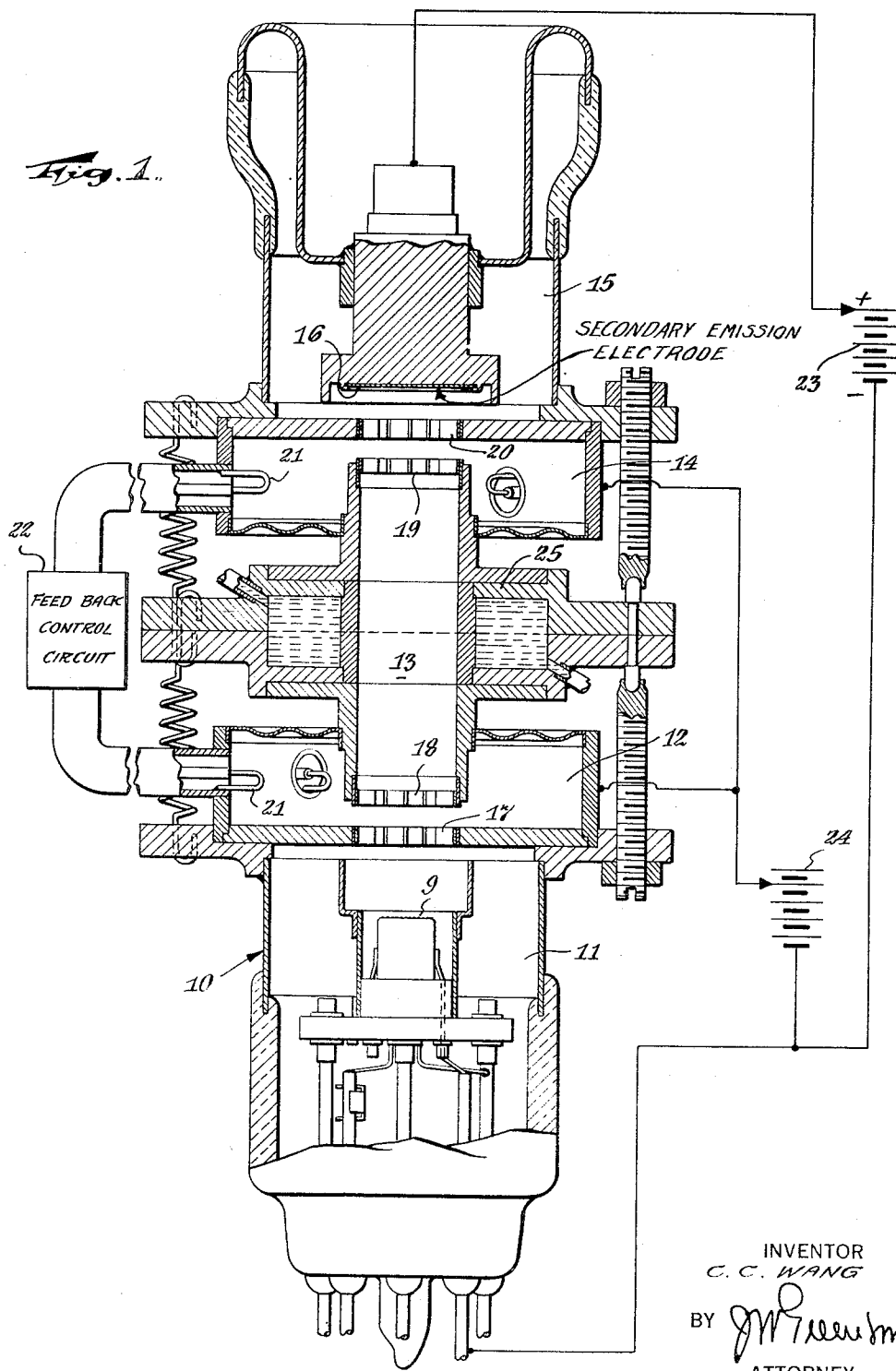
C. C. WANG

2,529,668

ELECTRON DISCHARGE DEVICE OF CAVITY RESONATOR
TYPE WITH REVERSE FLOW OF ELECTRONS

Filed Sept. 12, 1944

3 Sheets-Sheet 1



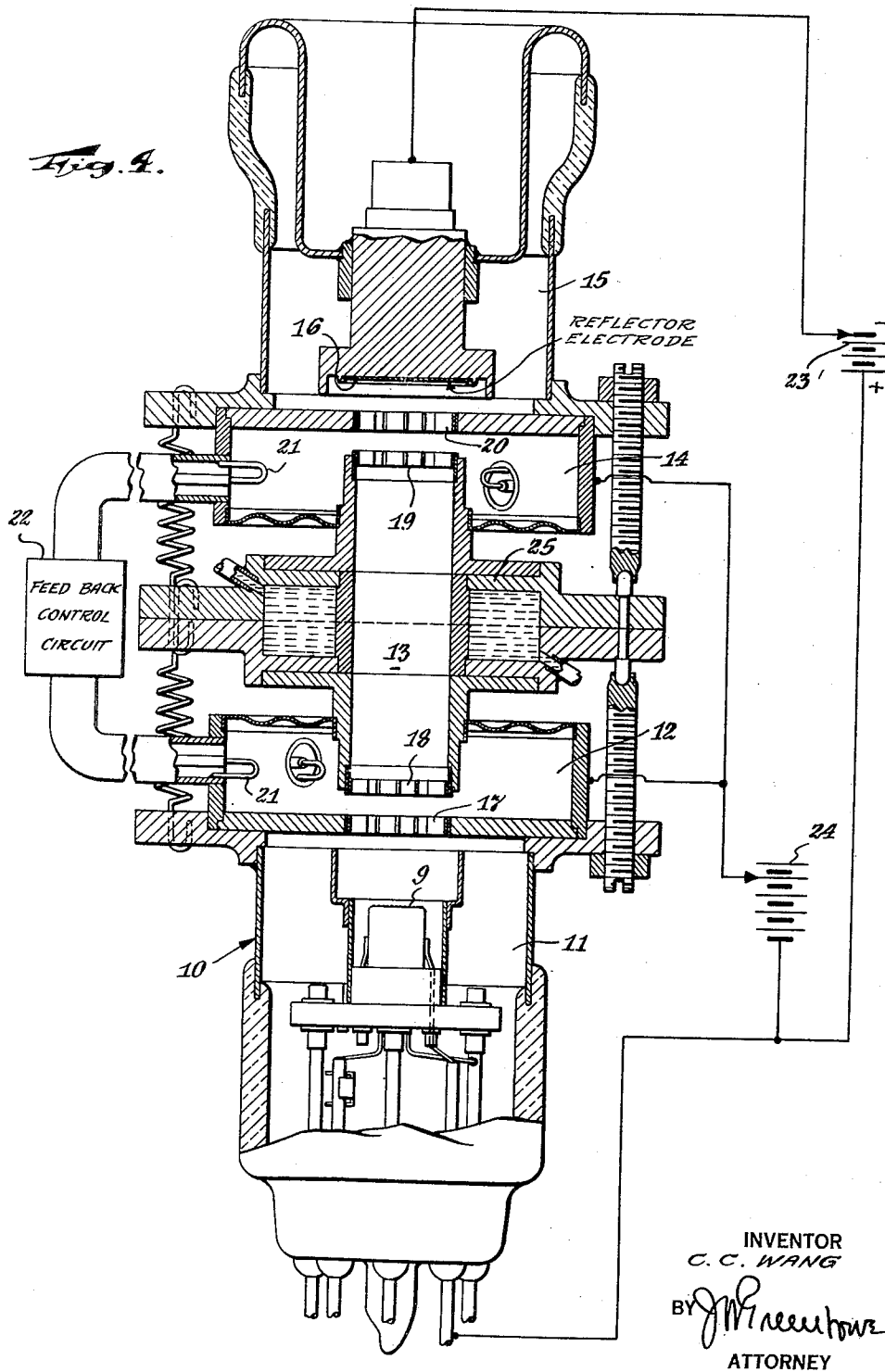
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Fig. 3.

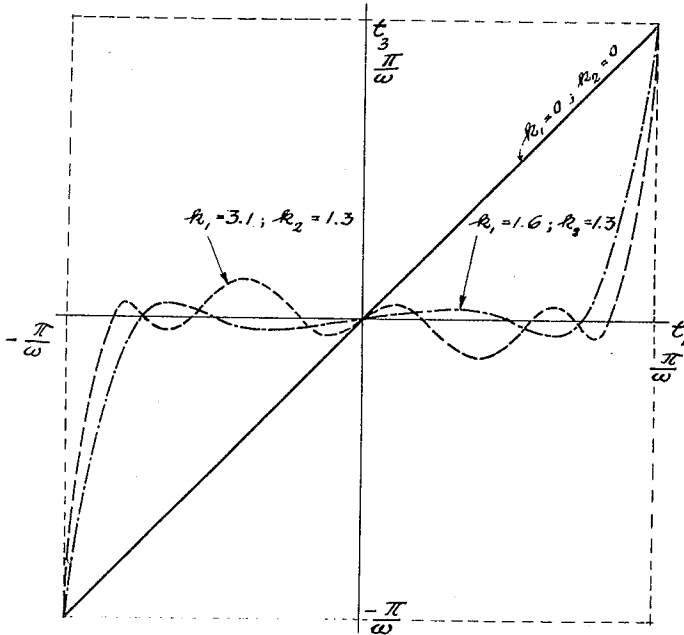
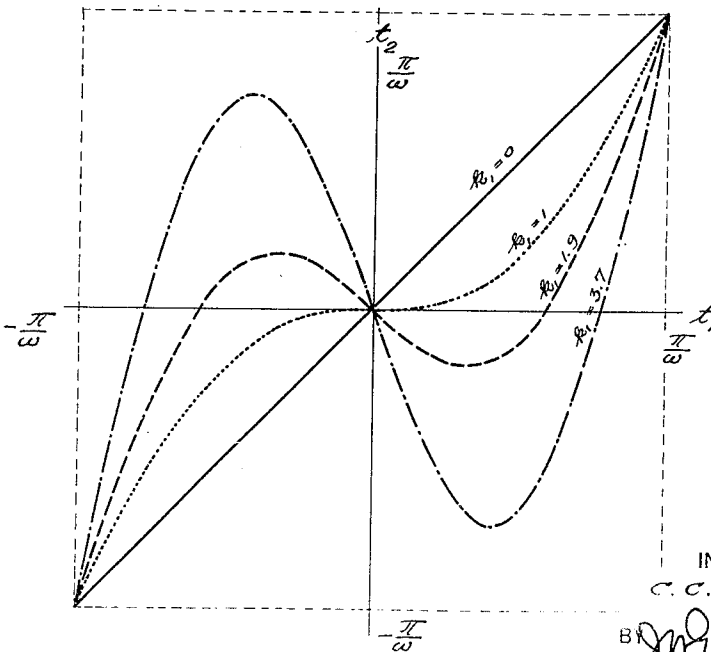


Fig. 2.



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ELECTRON DISCHARGE DEVICE OF CAVITY
RESONATOR TYPE WITH REVERSE FLOW
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3 Claims. (Cl. 315-6)

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This invention relates to electron discharge devices and particularly to such which utilize a beam of electrons.

There have been developed comparatively recently in the electronic art two related species of the general type of the above-mentioned electron discharge devices, one of which employs a plurality of resonators between the cathode and a collector, and the other of which employs a single resonator and a reflector for returning the electrons to the single resonator. Each species mentioned has certain advantages over the other.

An object of the present invention is to provide an electron discharge device of the beam type which combines advantages of the plural resonator species and the reflex species.

Another object of the invention is to overcome limitations on the magnitude of the output signal inherent in the prior art devices.

A further object of the invention is to eliminate danger of over-modulation with large output voltage.

Yet another object of the invention is to accentuate electron bunching.

Still further objects of the invention will appear to those skilled in the art to which it appertains, both by direct recitation thereof and by implication from the context as the description proceeds.

Referring to the accompanying drawing in which like numerals of reference indicate similar parts throughout;

Figure 1 is a longitudinal sectional view of an electron discharge device embodying the present invention;

Figure 2 is a graph of the time of arrival of electrons at the catcher vs. time of arrival of electrons at the buncher resonator in a double resonator device;

Figure 3 is a graph of the time of arrival of electrons at the catcher vs. the time of arrival of electrons at the buncher in a device of the present invention with two stages of velocity modulation; and

Figure 4 is a sectional view similar to Fig. 1 showing the device with a reflector for primary electrons.

In the specific embodiment of the invention illustrated in said drawing, the reference numeral 10 designates a generally cylindrical envelope in its entirety, made to provide various intercommunicating chambers and cavities as will appear hereinafter, the interior of said envelope being evacuated. At one axial end, which for convenience and because of arbitrary position de-

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icted in the drawing is herein termed the lower end of the device, is provided a cathode chamber 11. A cathode 9 providing a flat emitting surface transverse to the envelope axis and centered thereon, is mounted in said cathode chamber. Next beyond, or as here shown, above the cathode chamber is a first or buncher hollow body resonator 12 from which, and also on a common axis, extends a passage 13 constituting a field free space, the far or upper end of which opens into a second or catcher hollow body resonator 14 beyond or above which is another electrode chamber 15 within which is situated an end electrode 16. The structure permits a beam of electrons to be projected in a path parallel to the envelope axis in the region around said axis and between the cathode and end electrode.

Cross-wise of the electron path are situated a plurality of grids, one grid 17 being in the first resonator wall which divides the cathode chamber 11 from the chamber or interior cavity of the first resonator. The next grid 18 is at the end of the field free space or passage at its near end to the cathode, whereas the third grid 19 is at the far end of said passage between the same and the interior of the second resonator. A fourth grid 20 is located in the wall of the second resonator 14 between that resonator chamber or cavity and the final electrode chamber 15.

The resonators are preferably part of the envelope and are of metal, each having a flexible end wall sealed to the outside of the metallic tubing forming passage 13, whereby the spacing of the pairs of grids may be varied and tuning effected. A feed-back means 21 connects the two resonators and a phase shifting or other control circuit 22 may be, and by preference is, included in the feed-back means.

Electrode 16 may be a reflector of primary electrons as indicated in Fig. 4 by having a negative potential applied thereto as shown at 23'. However, it is preferred that said electrode shall be of a material which will emit secondary electrons, as indicated in Fig. 1, and for effectuating secondary emission said electrode is shown having a positive potential applied thereto by potential source 23. Broadly speaking, either construction may be considered as reflex since electrons travel in a path directly opposite the forward path from the cathode. It therefore follows that the construction of the present application distinguishes from the prior art by being a double cavity reflex electron discharge device.

In the usual double cavity device the maximum theoretical attainable efficiency can be shown to

be in the neighborhood of 58%. This limitation follows from the fact that in any of those devices, the electrons are velocity modulated but once.

To be specific, let us consider the case of regular double cavity velocity modulated tubes. The electron beam is accelerated to a direct current potential of V_0 volts and passes through the gap of the first cavity with radio frequency voltage of $V_1 \sin \omega t_1$, where ω is the angular frequency, t_1 is the time as observed by the electron at the first gap. The electron beam is then permitted to drift for N cycles during which the beam is bunched before it arrives at the second cavity gap at which there is the catcher voltage $-V_c \cos \omega t_2$, where t_2 is the time as observed by the electrons at the second gap. The time t_2 can be plotted against the time t_1 as in Fig. 2 for a complete period. The zero of time t_2 is so chosen that the catcher voltage is at the minimum at the center of the bunch in order to absorb the greatest amount of energy. This plot of Fig. 2 indicates the time of arrival at the second gap for different electrons uniformly indexed by the time t_1 . To get maximum efficiency, it would be ideal to have all the electrons arrive at the second gap at the same time $t_2=0$ and the more the percentage of electrons arriving at the second gap at $t_2=0$, the more efficient it is. For convenience of discussion, the curves chosen are cases in which V_1 is small in comparison with V_0 and different curves can be characterized by a parameter

$$k_1 = \pi N_1 \frac{V_1}{V_0}$$

For $k_1=0$, i. e. the case with no velocity modulation, the curve is a 45° straight line indicating that the electrons are arriving at a uniform rate at the second gap, giving as much energy to the radio frequency catcher voltage as it absorbed, with zero net energy delivered and hence zero efficiency. As the velocity modulation increases up to a point with $k_1=1$, the electrons in the neighborhood of $t_1=0$ begin to arrive simultaneously while the majority of electrons are still far away from arriving near $t_2=0$. On further increasing modulation, as in the case with $k_1=1.9$, those electrons near t_1 overshoot themselves while electrons near both ends for

$$t_1 = \pm \frac{\pi}{\omega}$$

are not having enough modulation to catch up the electrons of $t_1=0$. This is the inherent characteristic in using a sinusoidal modulation voltage. A sine voltage has the highest rate of increasing of voltage at $t_1=0$ and the rate of increasing decreases as it departs from $t_1=0$. This always results in more modulation for electrons near the point $t_1=0$. To obtain the best efficiency one has to compromise so that with moderate amount of overmodulation for electrons of $t_1=0$ and under-modulation for electrons near

$$t_1 = \pm \frac{\pi}{\omega}$$

we can bring the largest amount of electrons near to time $t_2=0$. On further increasing the modulation to the case as represented by the curve $k_1=3.7$, the loss suffered by having more electrons over-modulated is more than enough to compensate the gain in bringing the under-modulated electrons into step. Then the effi-

ciency begins to decrease. The efficiency can be approximately represented as

$$\frac{V_c J_1(k_1)}{V_0}$$

The Bessel function of the first kind J_1 has a maximum of .58 at $k_1=1.838$. The maximum efficiency, 58%, can be realized if the radio frequency catcher voltage is made equal to the direct current potential.

However, if in place of the catcher voltage, we apply a second modulation voltage $V_2 \sin \omega t_2$ and let the electron drift another period of N_2 cycles before reaching the final catcher gap at which there is the catcher voltage of $-V_c \cos \omega t_3$, where t_2 and t_3 are the times as observed by the electrons when arriving at the second and the last gap, with the zero point chosen to get the best efficiency, improved results are obtained. Since the electrons arriving at the second gap are already bunched to a certain extent, and the majority of the electrons are modulated by voltages which have less variation of rate of change of voltages, the chance of over-modulating one portion of the electrons and under-modulating the other is therefore lessened. Figure 3 shows the plot of t_3 versus t_1 for different parameters of

$$k_1 = \pi N_1 \frac{V_1}{V_0}$$

and

$$k_2 = \pi N_2 \frac{V_2}{V_0}$$

The majority of the electrons are brought much closer to the time $t_3=0$ than would be possible in the first case. The efficiency can again be expressed as

$$\frac{V_c F(k_1, k_2)}{V_0}$$

where F will be a function of the drifting parameters. Evidently, with $k_1=0$, F can be degenerated to J_1 . The maximum possible peak with respect to both k_1 and k_2 will be around 89% instead of 58%. The efficiency could be even higher if more steps of modulation are applied before the electron beam is passed on to the catcher. However, inclusion of additional steps of modulation is limited by the difficulty of tuning a number of cavities to the same resonating frequency and keeping proper phase relationship between them, and also the difficulty of sending an electron beam through a long drift distance. In fact, in order to realize the efficiency of the above double modulated beam, three cavities have to be used and are proved to be inconvenient in practice. The present device in reflecting the original beam or sending the amplified secondary electron beam back to the second cavity reduces the number of resonators to two. The beam is then modulated by the two cavities in the forward trip and the second cavity serves the dual purpose of modulator and catcher for the returned electrons. As the catcher voltage is the same as the second modulation voltage, the efficiency should be

$$\frac{V_2 F(k_1, \pi N_2 \frac{V_2}{V_0})}{V_0}$$

In order to keep efficiency high, we would like to keep V_2 as close to the direct current potential as possible without impairing the wave form too much from that expressed by the function F .

In tubes without prior modulation, as in a single cavity reflex oscillator, compromise must

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be made for the best operating efficiency in choosing the operating radio frequency voltage. With large drift period N_2 , V_2 cannot be high as it results in too much over-modulation or F is low for too high products of N_2 and V_2/V_0 . Reducing the drifting period N_2 can theoretically put V_2/V_0 nearly equal to one and with F near its maximum. However, with large modulation voltage, the theoretical efficiency obtainable is less than that predicted by the small modulation voltage theory because the above discussed over-modulation in one portion and under-modulation on the other is more accentuated. However, with proper prior modulation in the first cavity the beam suffers less unbalanced modulation, and low drifting period operation is possible with higher realizable operating efficiency. With longer drifting period, the efficiency is also higher. In other words, with proper choice of k_1 , the variation of F with respect to V_2/V_0 can be made to be very gentle and the value of F itself is higher than J_1 . This enables one to select larger V_2/V_0 in long drift time tubes, and keeping the product $(V_2/V_0) F$ higher.

As a result of the sorting action which results from the velocity differences (known as kinematic bunching), the current-versus-time wave at a given distance from the buncher can be shown to possess a certain form corresponding to the maximum rate of conversion of the direct current beam energy into radio frequency energy. This wave form is always associated with purely kinematic bunching in which the electrons undergo only one velocity modulation, and hence the limitation on efficiency associated with this type of bunching follows.

Viewed from its most simple aspect, the present device is analogous to a reflux device but having another cavity between the usual cavity of such device and the cathode. The purpose of this inserted or advance cavity is to initially velocity modulate the beam so that by the time of its arrival at the regular cavity, above-identified as catcher resonator 14, it will have been initially bunched. Now if the phase and amplitudes of the radio frequency voltages in the two cavities are properly adjusted with respect to each other, for which purpose the phase control circuit 22 is provided, the additional velocity modulation provided by the second or regular cavity resonator 14 results in a current wave on return of electrons from the final electrode 16 (reflected or secondary) corresponding to a rate of conversion of the direct current energy into radio frequency energy greater than the maximum obtainable with only one velocity modulation.

In the prior art reflex, single resonator device, the radio frequency, which is simultaneously both the output and buncher voltage, is limited as to amplitude by virtue of the fact that if its amplitude exceeds a certain value, it will over-modulate the beam to the point where the rate of conversion of direct current energy into radio frequency energy corresponding to the wave form obtained is not rapid enough to sustain the assumed voltage, and hence voltage of such magnitude cannot exist if a definite load is connected to it. That the present double cavity device wherein reflex electron flow is employed reduces the limitation on the magnitude of the output signal can be seen from the fact that the radio frequency voltage across the two gaps between the two pairs of grids are adjusted as to phase so that the center of the bunch formed by the first modula-

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tion arrives at the second gap when resonator radio frequency voltage thereat is zero and changing from negative to positive (positive meaning in such direction as to accelerate electrons toward end electrode 16). Since, under these conditions, the majority of the electrons will pass through the gap of the second resonator when the radio frequency voltage across the gap is in the neighborhood of zero, there is less danger of over-modulation. In addition, since the voltage is changing from negative to positive at the time of passage of the bunch, those electrons which are ahead of the bunch will be retarded, whereas those behind it will be accelerated, and the net effect will be an accentuation of the bunching, resulting in improved wave form and hence higher efficiency.

Although the output voltage of the device of the present invention is limited, as indicated above, by the peak direct current shell voltage, this same limitation applying to the prior art double cavity resonator beam type device, yet the improved bunching electrons described above in the herein disclosed device obtains that output voltage with less average beam current and hence with improved efficiency. This improved efficiency is even more pronounced when utilizing the end electrode as a secondary emitter which affords large secondary yield with resultant higher average beam current for producing the maximum output signal of which this type of device is capable under the theoretical limitation discussed above. The construction accordingly overcomes the deficiency of the prior art double cavity resonator beam type device in which greater percentage of electrons are intercepted in the drift space and by the grids. By keeping the primary electrons low and secondary electron yield high, larger percentage of electrons are realizable at the gap where energy is delivered and hence higher efficiency.

It should be especially noted that the relationship of the radio frequency voltage with respect to the electron bunch in the present device is basically different from that relationship in the prior art double cavity resonator beam type device, since in the latter the voltage is at a negative maximum in the output gap when the bunch is passing through, whereas in the present device the voltage across the output gap is zero when the bunch formed by the first modulation is traversing the output gap on the forward trip of the electrons.

The desired voltage, either for causing the end electrode 16 to function as a reflector of primary electrons or as an emitter of secondary electrons for reflex purposes, is obtained in suitable manner, a source 23 in Fig. 1 and source 23' in Fig. 4 being shown for the purpose. Likewise, a source 24 for a direct current voltage on both cavity resonators is shown, it being preferable to keep both resonators at the same potential. While excitation of the first resonator is shown obtained by feedback from the second, it is to be understood excitation may be utilized from a different source. It may also be stated that there is considerable conversion of electron energy to heat in the tubular wall of the passageway 13, and to dissipate the heat a water jacket 25 is shown therearound adapted to maintain a circulation of water or other cooling fluid. The showing herein is intended to be only exemplary of one embodiment of the invention, structural details being subject to change and substitution in practice without

departing from the spirit or scope of the invention.

I claim:

1. An electron discharge device of the cavity resonator beam type comprising a cathode, a pair of hollow body resonators having coaxially aligned openings therethrough aligned with the cathode for passage therethrough of an initial beam of electrons from the cathode, means beyond both of said resonators coaxially aligned with said openings and cathode opposite said cathode operable in conjunction with said initial beam for obtaining a secondary flow of electrons in a reverse direction to the flow of electrons of said initial beam, a tubular connection between said resonators coaxial with the openings thereof, said tubular connection comprising a passageway for the said initial beam and constituting both a field free enclosed drift space for the electrons of the initial beam and an anode for the electrons of said secondary reverse flow of electrons, and cooling means for said tubular connection between said resonators.

2. An electron discharge device of the cavity resonator beam type comprising a cathode, a pair of hollow body resonators having aligned openings therethrough aligned with the cathode for passage of an initial beam of primary electrons from the cathode, a secondary emissive electrode beyond both of said resonators coaxially aligned with said openings and cathode opposite said cathode operable in conjunction with said initial beam of primary electrons for obtaining a flow of secondary electrons in a reverse direction to the flow of primary electrons of said initial beam, a tubular connection between said resonators coaxial with the opening thereof, said tubular connection comprising a passageway for the said initial beam and constituting both a field free enclosed drift space for the said primary electrons of the initial beam and an anode for the second-

ary electrons from said secondary emissive electrode, and cooling means for said tubular connection between said resonators.

3. An electron discharge device of the cavity resonator type comprising a cathode, a pair of hollow body resonators having aligned openings therethrough aligned with the cathode for passage of an initial beam of primary electrons from the cathode, a reflector electrode beyond both of said resonators coaxially aligned with said openings and cathode opposite said cathode operable in conjunction with said initial beam for obtaining a reversal of direction of flow of the electrons thereof for providing a reflex beam of electrons, a tubular connection between said resonators coaxial with the openings thereof, said tubular connection comprising a passageway for the said initial beam in its initial direction of flow and constituting both a field free enclosed drift space for the electrons of the initial beam and an anode for the reflected electrons of the reflex beam, and cooling means for said tubular connection between said resonators.

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