

July 27, 1948.

Filed Oct. 14, 1942

J. H. FREMLIN ET AL
ELECTRON DISCHARGE DEVICE OF
THE VELOCITY MODULATION TYPE

2,445,771

3 Sheets-Sheet 1

FIG. 1.

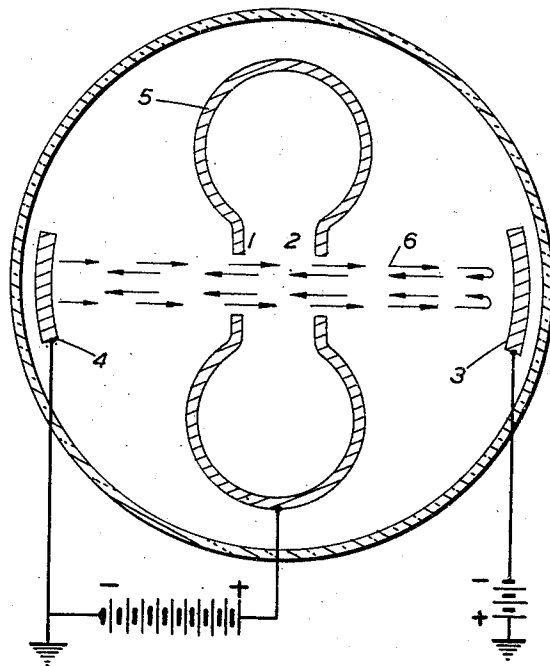
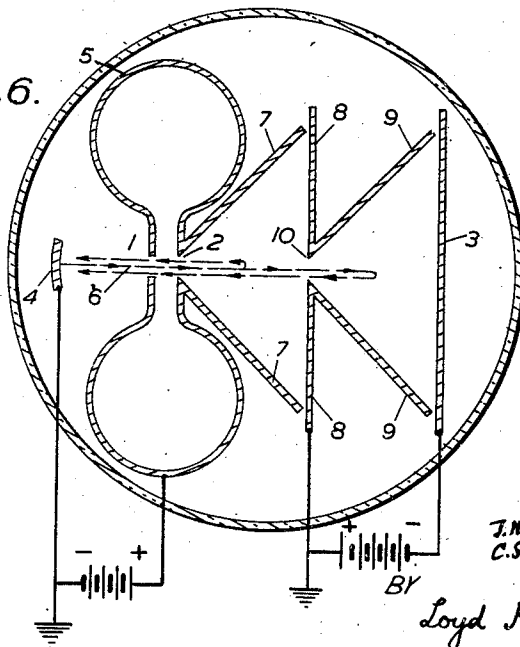


FIG. 6.



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FIG. 2.

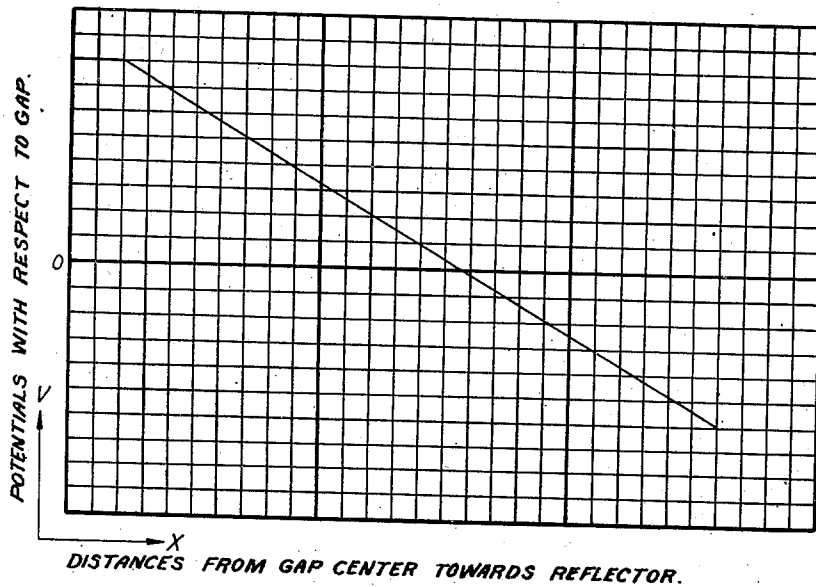
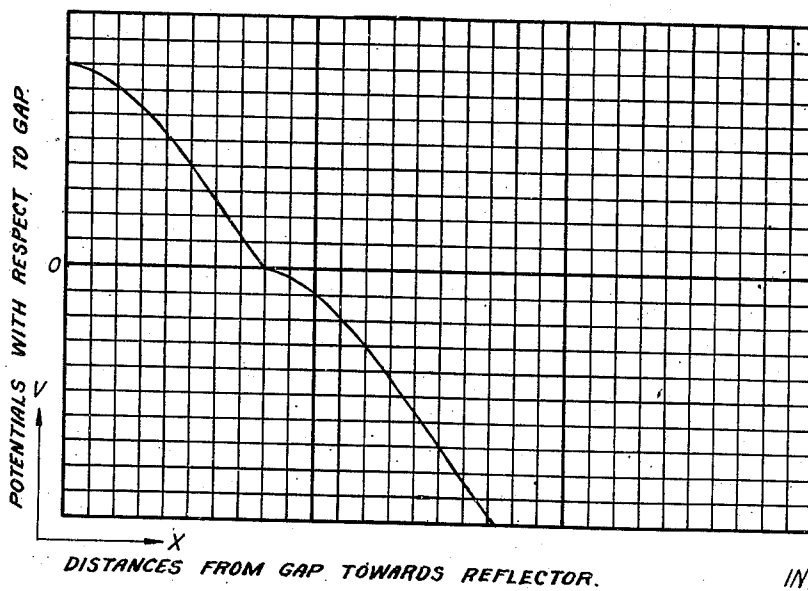


FIG. 4.



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FIG. 3.

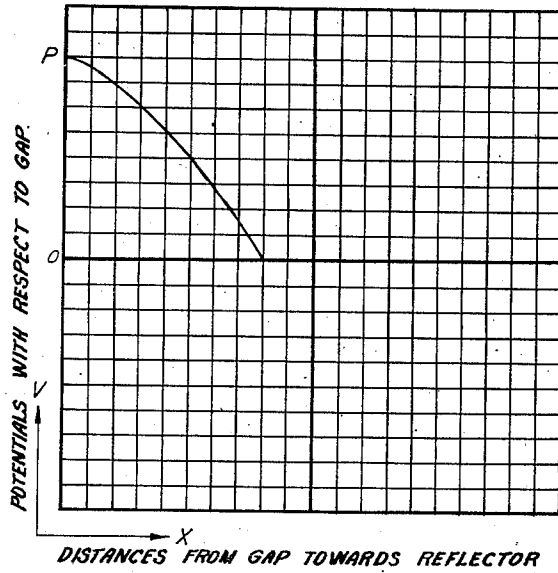
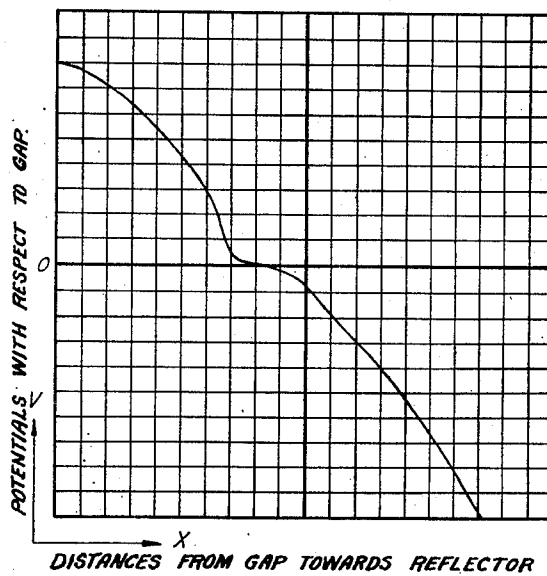


FIG. 5.



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ELECTRON DISCHARGE DEVICE OF THE
VELOCITY MODULATION TYPE

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Application October 14, 1942, Serial No. 462,028
In Great Britain December 12, 1941

6 Claims. (Cl. 315-5)

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The present invention relates to electron discharge devices for operation at ultra high frequencies and of the electron velocity modulation kind in which a reflected electron beam crosses the same ultra high frequency electric field during its incident and reflected paths.

The invention is particularly though not solely applicable to ultra high frequency oscillators of the velocity modulation kind comprising a single ultra high frequency electric resonant chamber provided with an aperture in the conducting wall thereof and a beam of electrons arranged to pass said aperture in one direction and a reflector to reflect said beam to pass said aperture in the reverse direction.

The invention is equally applicable to electron discharge devices as described and claimed in the specification of application Serial No. 462,029 of John Heaver Fremlin or to electron discharge devices having more than two gaps so long as the beam is reflected back across one of said gaps to give up energy.

In the devices of the kind specified, the electron beam is velocity modulated to some degree during its first passage across the final electric field, that is, the field immediately before the reflecting field which may be the only field functioning as the modulating and/or energy abstracting field, and is then bunched during its passage from the final field to the reflector and back to the final field and during its second passage across the final field the bunched beam gives up energy to this field.

In the design of velocity-modulated oscillators to work at short wavelengths with any considerable efficiency there are two requirements that are difficult to reconcile. Firstly, it is necessary that the electron beam after modulation by the first or modulating oscillatory field should be well bunched before crossing the second or energy-extracting field. This is the case because the losses in any particular circuit are proportional to the square of the amplitude of oscillation. The efficiency of bunching in a circuit of given resonant impedance at the point of application of the electron beam can be determined by measuring the current I_{s1} at which oscillations just begin, or the current necessary for oscillation just to be maintained, and herein called the starting current. If bunching is inefficient this starting current will necessarily be high. In order, therefore, to reduce the effect of losses it is necessary to make the bunching as efficient as possible. The more definite the bunches become, the more efficient the bunching is, and the bunching action

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may go beyond this stage, the bunching becoming less definite and the efficiency of the device begins to decrease. This state is called overbunching.

Secondly, the greater the second or energy extracting high frequency field the more efficient does the extraction of energy become. This means that a large high frequency field compared to the modulating field must be obtained in the output or energy extracting circuit without overbunching of the electron stream by the modulating field. Other factors remaining constant this overbunching is due to over modulation of the electrons, in other words the modulating field is too great. Now it is easily seen that where the ratio of the amplitudes of the modulating and energy extracting fields is fixed as in oscillators of the type specified, particularly the single gap type, this requirement of large field clashes with the requirement for low starting current described above. Thus oscillators which start easily would never give a very high efficiency.

The particular object of this invention is to provide an oscillator of the reflected beam type and particularly of the single-gap type in which the two said requirements are reconciled. This object is attained by means of the present invention by rendering the bunching in the reflected path independent of the amplitude of the final field.

According to the invention, in an electron discharge device of the electron velocity modulated reflected beam type, a potential distribution is set up between the final oscillatory field and the reflector, said distribution being substantially parabolic to a point beyond in the direction of initial electron travel, at or near zero potential or the potential of the electron source of the beam producing means, that is, the cathode of an electron gun. In the case of a single gap oscillator, the bunching by very small oscillatory fields may be appreciable and the device operates on a low starting current.

The invention will be better understood from the following description of a single-gap oscillator embodying the invention and taken in conjunction with the accompanying drawings. In Fig. 1 of the accompanying drawings is shown a diagrammatic representation of a known single gap reflected beam, oscillator, and in Fig. 2 is shown the curve representing a potential distribution such as might be obtained in a practical tube of the type specified. In Figs. 2 to 5 the abscissae represent distances from the gap towards the reflector and the ordinates represent

potentials with respect to the gap taking the cathode as zero potential. In Fig. 2 the horizontal portion of the graph represents the constant potential in the gap 1, 2 having finite dimensions. In Figs. 3, 4 and 5 the curves are ideal assuming a gap of zero dimensions. It will be observed from simple dynamical considerations that if there is a constant retarding field as shown in Fig. 2 the transit time of an electron from the modulating gap 1, 2 of Fig. 1 out to the point of reflection 3 and back to the gap again will depend upon the velocity of the electron when it enters the retarding field. The transit time will be proportional to this velocity and inversely proportional to the retarding field. The initially uniform beam, therefore, after velocity-modulation and reflection, will no longer be uniform but will be bunched. It is clear that for this system with a constant retarding field there is the conflict of the two desirable requirements described above, since for a low starting current a weak retarding field and a long path is required, whilst to prevent overbunching when the modulating oscillatory field which is also the energy extracting field becomes large a large retarding field and short path are required.

Now consider the retarding field distribution shown in Fig. 3, where the potential distribution is parabolic down to $V=0$ and afterwards constant. At the point at which the potential is zero the potential distribution has a point of inflection, i. e., a change of curvature from concave to convex or conversely. Then the value of the retarding field will be proportional to the distance x from the apex P of the parabola which may be made to coincide with the edge 2 of the modulating gap 1, 2 of Fig. 1. In this case the transit time is independent of the initial velocity, all electrons have the same transit time and no bunching occurs so long as the velocity of the electrons is insufficient to reach the point of zero potential. All electrons of greater velocity than this will reach the collector without reflection. Then whatever the amplitude of modulation if the value of the constant transit time is $n + \frac{1}{2}$ cycles out to the reflector and back, the electrons which pass through the modulating field in the retarding half cycle will arrive on return after reflection during a retarding half cycle and all will be made to lose further energy.

The simplest embodiment of the invention therefore consists of the provision in an oscillator of the type specified, of a parabolic potential distribution between the modulating gap and reflector at cathode potential. Assuming a homogeneous electron stream the starting current would then be zero and the theoretical maximum efficiency would be

$$\frac{2\alpha}{\pi}$$

or $63\alpha\%$ where α is the ratio of the peak ultra high frequency voltage across the gap to the direct current voltage between cathode and modulator. In practice initial velocity variation would lead to the existence of a starting current but experiment shows that this is small.

This simple embodiment of the invention has two drawbacks; firstly one portion of the electrons is not used and secondly, secondary electrons are released by the accelerated incident electrons striking the collector and these secondary electrons reduce the efficiency.

An improvement is obtained by setting up the potential distribution shown in Fig. 4. As before

the first part of the potential distribution is parabolic but in this case the lower part is so arranged that all the accelerated electrons are also reflected, their transit times being equal and an odd number of $\frac{1}{2}$ cycles greater than that of the retarded electrons. The same considerations of efficiency and starting current apply as stated in connection with Fig. 3 but no electrons are collected at the reflector and no secondary emission consequently produced. Furthermore, although the accelerated electrons contribute nothing to the oscillation, they return to the final field energy which they received during the incident journey through that field.

The optimum potential distribution in the region of negative potential can be calculated mathematically and it can be proved that the resulting complete distribution gives the greatest possible efficiency that can be obtained with a single narrow modulating gap.

It will be understood that in practice the exact potential distributions described may not be set up but sufficiently close approximations may be obtained. One such distribution is shown in Fig. 5, which was obtained with the help of the well known electrolytic trough that is rubber sheet analogy model. By these distributions a very considerable advantage may be obtained in all forms of single gap reflected beam velocity-modulated oscillators. These distributions are obtained by suitable formation of the electrodes used.

Fig. 6 shows diagrammatically one practical arrangement of electrodes for producing a suitable potential distribution substantially similar to that shown in Fig. 5. In Fig. 6 the resonant chamber or modulator is indicated at 5, having an aperture or gap 1, 2 across which the beam of electrons 6 is directed from a cathode 4 towards a reflector 3 maintained at a negative potential with respect to the cathode. The resonant chamber 5 is provided at the edge of the gap opposite to the cathode 4 with diverging flanges 7 and is maintained at positive potential with respect to the cathode 4. The potential distribution along the beam path formed by these flanges 7 is approximately that shown above the zero line in Fig. 5. Between the ends of flanges 7 and the reflector 3 is placed a plate member 8 provided with an aperture 10 to allow of the passage of the beam. The edges of the aperture 10 perpendicular to the plane of the paper are provided with diverging flanges 9 projecting towards the reflector 3. The plate 8 and flanges 9 are maintained at zero or cathode potential. The potential distribution within the space bounded by the flanges 9 and reflector 3 is somewhat as shown by the lower half of the curve shown in Fig. 5.

The more slowly moving electrons are returned before reaching the gap 10 at zero potential and the faster moving electrons are reflected back after passing through gap 10 and before reaching the plate 3, with the improvement explained in connection with Fig. 4.

What is claimed is:

1. An ultra high frequency electron discharge apparatus of the velocity modulation type comprising a hollow electrically conducting body adapted to contain standing electromagnetic waves, means including a source of electrons for producing an electron beam and for projecting the beam in a path through said body, said beam supplying energy toward maintaining a field of standing electromagnetic waves therein, a reflector external to said body adapted to reflect

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the electrons back into said field, a first electrode element located at a point intermediate said hollow body and said reflector having means for applying the potential of said electron source thereto, said first element being adapted to produce a potential distribution with a point of inflection at said first-mentioned point, and a second electrode element located between said hollow body and said first element having means for applying a potential with respect to that of said cathode thereto, said second electrode element being shaped to produce a potential distribution of substantially parabolic form from the aperture in said hollow body to said intermediate point.

2. An ultra high frequency electron discharge apparatus according to claim 1 in which said second electrode element is electrically connected to said hollow body and said means for applying a potential thereto comprises means for applying a potential positive with respect to that of said electron source.

3. An ultra high frequency electron discharge apparatus of the electron velocity modulation type comprising a hollow electrically conducting body adapted to contain standing electromagnetic waves, means including a source of electrons for producing an electron beam and for projecting the beam through said body, said beam supplying energy toward maintaining a field of standing electromagnetic waves therein, a reflector external to said body adapted to reflect the electrons back into said field, a first electrode element located at a point intermediate said hollow body and said reflector having means for applying the potential of said electron source thereto, a second electrode element located between said hollow body and said first electrode element having means for applying a potential with respect to that of said electron source thereto, said second electrode element being shaped to produce a potential distribution of substantially parabolic form from the aperture in said hollow body to said intermediate point, and a third electrode element

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located between said first electrode element and said reflector, said third electrode element being shaped to produce a non-linear potential distribution between said intermediate point and said reflector, said distribution of potential having a point of inflection at said intermediate point.

4. An ultra high frequency electron discharge apparatus according to claim 3 in which said third electrode element is electrically connected to said first electrode element.

5. An electron discharge apparatus according to claim 4 characterized in that said reflector has means for applying thereto a potential negative with respect to that of said electron source for producing an increasingly negative potential distribution between said first electrode element and said reflector.

6. An ultra high frequency electron discharge apparatus according to claim 5 characterized in that said third electrode element is shaped similar to said second electrode element for producing a potential distribution of substantially parabolic form from said first electrode element to said reflector.

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