

May 10, 1949.

P. L. HARTMAN

2,469,964

ELECTRON DISCHARGE APPARATUS

Filed May 3, 1941

3 Sheets-Sheet 1

FIG. 1

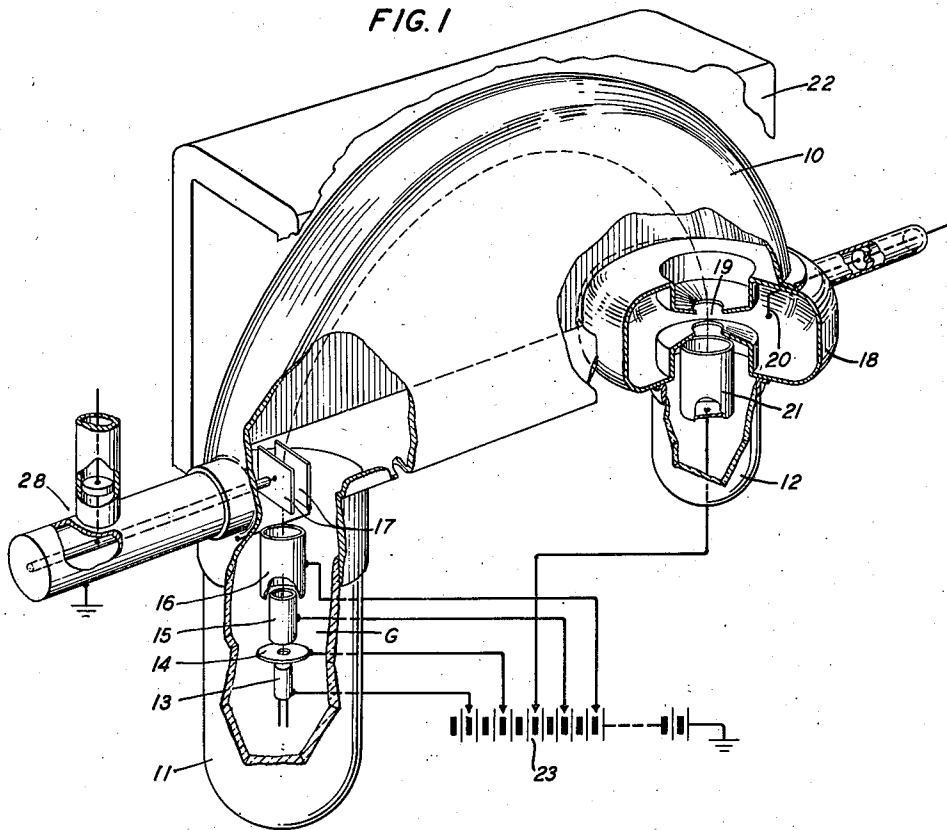
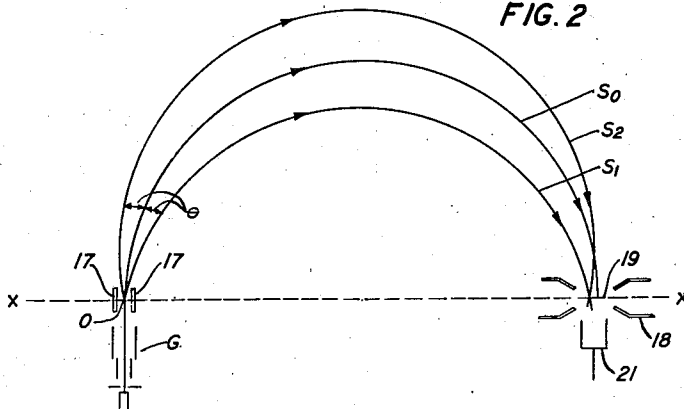


FIG. 2



INVENTOR
BY **P. L. HARTMAN**
Halter C. Kiesel
ATTORNEY

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P. L. HARTMAN

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FIG. 3

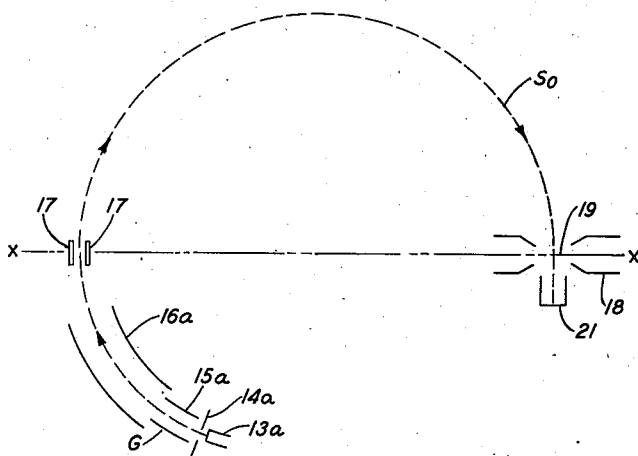


FIG. 4

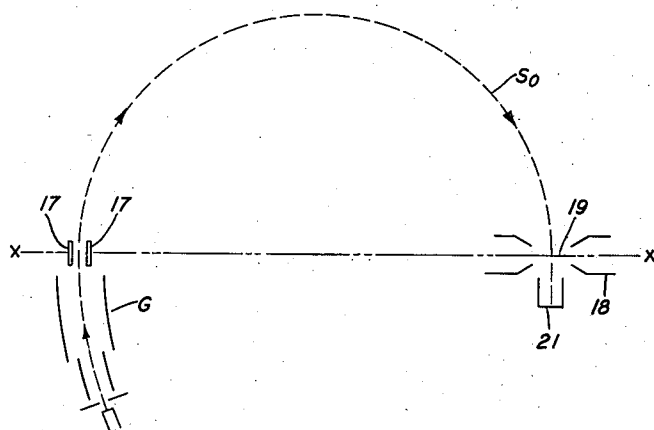
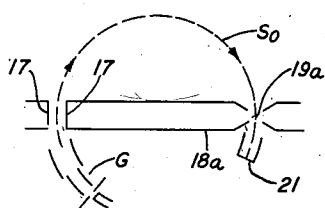


FIG. 5



INVENTOR
P. L. HARTMAN
BY

Halter C. Kiesel
ATTORNEY

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P. L. HARTMAN

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FIG. 6

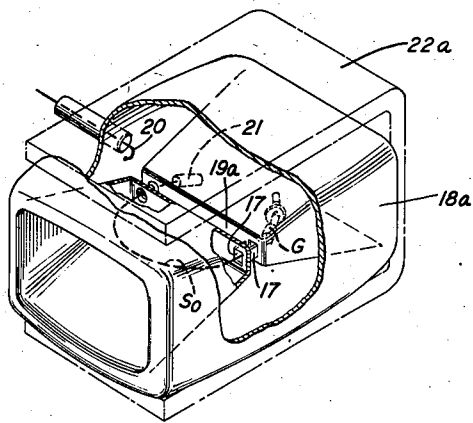


FIG. 7

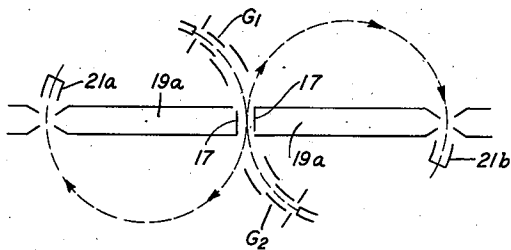
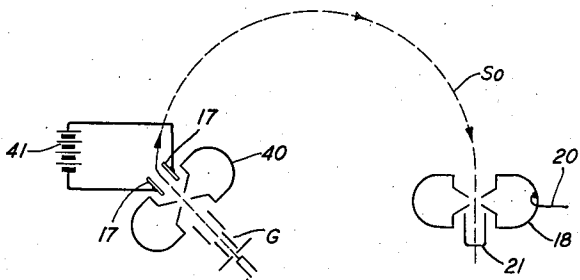


FIG. 8



INVENTOR
BY *P.L.HARTMAN*

Walter C. Kiesel
ATTORNEY

UNITED STATES PATENT OFFICE

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ELECTRON DISCHARGE APPARATUS

Paul L. Hartman, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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11 Claims. (Cl. 250—27.5)

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This invention relates to ultra-high frequency electron discharge apparatus and more particularly to electron beam discharge devices operable as amplifiers or oscillators at frequencies corresponding to wave-lengths of a few centimeters.

In one known type of electron discharge apparatus for amplifying or generating ultra-high frequency electrical impulses, an electron beam is subjected to a cyclically varying field in the direction of projection of the beam whereby velocity variations in the beam are produced. The beam then traverses a region, commonly referred to as the drift space, whereby a bunching of the fast and slow moving electrons in the beam occurs at some distance from the region of velocity variation. The bunches of electrons flow in proximity to a suitable output element and deliver power thereto by induction.

In such apparatus, the field resulting in the velocity variations is usually produced by impressing a suitable potential between a pair of electrode members having aligned restricted passageways at opposite ends of a gap through which the beam flows. The penetration of the field into the gap is limited so that the effect of the applied potential and the field due thereto upon the electrons in the gap is likewise limited. In addition, the field in the gap is non-uniform so that different electrons in the beam acquire different percentages of velocity variation and as a result sharp bunching of the electrons is not realized. Also, of necessity the beam is of small cross-sectional dimensions so that the power capacity of the apparatus is limited and space charge effects, particularly in the drift space, are fairly large so that non-uniformities in operating characteristics may result.

One general object of the invention is to enable the generation and amplification of ultra-high frequency electric signals.

More particularly, objects of this invention are to improve the operating characteristics of electron beam discharge devices of the type wherein an electron beam is subjected to a field for cyclically varying the velocity of the electrons in the beam, to obtain substantially uniform variation of all of the electrons in the beam, to increase the efficiency of the source producing the variations, to reduce space charge effects in such devices and to increase the power capacity of such devices.

In one illustrative embodiment of this invention, ultra-high frequency electron discharge apparatus comprises a pair of parallel deflector plates defining an input gap, an output element, such as a cavity resonator having a gap therein,

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and an electron gun for projecting a concentrated stream into the input gap.

In accordance with one feature of this invention, the input and output gaps are located at diametrically opposite points of a circle and means are provided for producing a magnetic field between the gaps and normal to the direction of projection of the electron beam into the input gap so that the electrons are directed along arcuate trajectories substantially along the circle in flowing from the input gap to the output gap. An electric field is produced between the deflector plates so that a velocity variation, normal to the initial electron velocity, is effected and the electron trajectories between the input and output gaps are thereby varied accordingly. The magnetic field and the field produced between the deflector plates are correlated so that a bunching of the electrons is effected and the electron bunches traverse the output gap in the proper phase relation to deliver energy to the output element.

The apparatus may be utilized as an amplifier, in which case the signal to be amplified is impressed between the deflector plates. It may be utilized also to generate ultra-high frequency oscillations, in which case the deflector plates are associated with the output element in such manner that a portion of the energy delivered to the output element is fed back to the input gap to maintain oscillations.

In a specific embodiment, the electron beam is velocity varied in the direction of its projection into the input gap, prior to its projection into the input gap, and a constant field is maintained between the deflector plates whereby the velocity variations are converted into density variations at the output gap by the trajectory variation effect upon the electron stream at the input gap.

The invention and the aforementioned and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is in part a perspective view of an electron discharge device constructed in accordance with this invention and in part a circuit diagram illustrating one manner of operating the device, a portion of the enclosing vessel of the device being broken away to show details of construction more clearly;

Fig. 2 is a diagrammatic view illustrating the relationship of the electrodes and output element in the device shown in Fig. 1 and indicating typical electron trajectories in this device;

Figs. 3 and 4 are diagrammatic views illustrat-

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ing the form and arrangement of the electrodes in modifications of the embodiment of this invention shown in Fig. 1;

Fig. 5 is a diagrammatic view illustrating an ultra-high frequency oscillation generator constructed in accordance with this invention;

Fig. 6 is a perspective view of an electron discharge device embodying the construction illustrated diagrammatically in Fig. 5;

Fig. 7 is another diagrammatic view illustrating another embodiment of this invention suitable for push-pull operation; and

Fig. 8 is still another diagrammatic view illustrating another embodiment of this invention suitable for converting velocity variations in an electron beam into density variations.

Referring now to the drawing, the electron discharge device illustrated in Fig. 1 comprises an evacuated enclosing vessel having a substantially semicircular portion 10, for example of non-magnetic metallic material, and cylindrical end portions 11 and 12, of insulating material such as glass. Mounted within the end portion 11 of the enclosing vessel is an electron gun, designated generally as G, and including a cathode 13 and a plurality of coaxial electrodes 14, 15 and 16 in axial alignment with the cathode 13 for concentrating the electrons emanating therefrom into an accelerated beam which is projected between a pair of parallel deflector plates 17 positioned on opposite sides of and equally spaced from the longitudinal axis of the electron gun. The deflector plates 17 are connected to the conductors of a tunable coaxial input line 28, the outer conductor being grounded, whereby a high frequency potential may be impressed between the deflector plates.

Adjacent the end portion 12 of the enclosing vessel is a cavity resonator 18 having therein a gap 19 substantially coplanar with the mid-point of the space between the deflector plates 17. Energy may be taken from the cavity 18 through a coupling loop 20 projecting into the cavity and connected to the wall thereof as shown. Mounted within the end portion 12 of the enclosing vessel and in alignment with the gap 19 is a collector electrode 21.

A U-shaped magnet 22, a portion only of which is shown in Fig. 1, is provided external to the enclosing vessel of the device for producing in the semicircular portion thereof a uniform magnetic field parallel to the deflector plates 17 and the gap 19 and normal to the longitudinal axis of the electron gun.

During operation of the device, the electrodes 14, 15 and 16 of the electron gun are maintained at successively higher positive potentials with respect to the cathode 13 by a suitable source such as a battery 23, and the collector electrode 21 is maintained at an intermediate potential, as by the battery.

The electrons emanating from the cathode 13 are concentrated into a beam which is projected into the magnetic field and normal to the lines of the field. At their point of injection into the field and between the deflector plates 17 the electrons in the beam have substantially the same velocity and, when the deflector plates are at the same potential, are following parallel paths at these plates. Thus, as indicated in Fig. 2, in the absence of a potential difference between the plates 17, the electrons are traveling normal to the plane X—X and normal to the magnetic field at a point O between the plates 17, the magnetic field being normal to the plane of the drawing.

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Under the influence of the magnetic field, the electrons are directed along a semicircular path S_0 and at substantially 180 degrees from the point O across the gap 19 in the cavity resonator 18, traveling with their initial velocity.

If an alternating potential is impressed between the deflector plates 17, the electron stream will be deflected accordingly and the electrons will then follow arcuate paths of the same radius, longer or shorter than the path S_0 , in flowing to the gap 19, two illustrative paths being indicated in Fig. 2 by the lines S_1 and S_2 . The effect of the deflecting potential is to vary the length of the trajectory of the electrons between the deflector plates 17 and the gap 19 periodically with time, the length being increased during one-half cycle of deflecting potential and decreased during the other half cycle. Thus, referring to Fig. 2, during one-half cycle of the alternating potential applied between the deflector plates 17, the electrons at the point O will be deflected toward the left and follow paths, such as the path S_2 , longer than the path S_0 in flowing to the gap 19; during the other half cycle of deflecting potential, the electrons at the point O will be deflected toward the right in the figure and follow a path, such as the path S_1 , shorter than the path S_0 in flowing to the gap 19. These trajectory variations may be used to produce periodic bunching of the electrons emanating from the electron gun, at the gap 19 whereby the cavity resonator will be energized and high frequency power may be taken therefrom. This will be understood from the following considerations.

Consider two electrons leaving the region O with the same velocity v , and t times

$$\frac{T}{2}$$

apart, where T is the period of the deflecting potential applied between the plates 17, and following paths S_1 and S_2 respectively. The times required for these two electrons to reach the gap 19 will be, then,

$$t_1 = \frac{S_1}{v} \text{ and } t_2 = \frac{S_2}{v}$$

respectively, and if the two electrons are to be bunched at the gap 19, i. e., pass through the gap at the same time,

$$t_2 - t_1 = \frac{T}{2} \quad (1)$$

The length of the path taken by an electron deflected at the time t can be shown to be

$$St = \frac{mv}{He} (\pi + 2\theta_t) \quad (2)$$

where St is the length of the path, m and e are the mass and charge of the electron, H is the magnetic field and θ_t is the angle of deflection at the time t . The time t_t , required for an electron traversing the path S_t in flowing from between the deflector plates 17 to the gap 19 is given by the relation

$$t_t = \frac{m}{He} (\pi + 2\theta_t) \quad (3)$$

If the extreme deflections are $\pm\theta$ coming one-half cycle apart, the difference between the two time flights may be expressed by the relation

$$t_2 - t_1 = \frac{m}{He} 4\theta \quad (4)$$

From Equations 1 and 4, then, it will be apparent that in order that bunching of the electrons

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leaving the point O at times one-half cycle apart be effected, the following relation must be satisfied:

$$\frac{4b}{H} = \frac{e}{m} \frac{T}{2} \quad (5)$$

Inasmuch as, as will be apparent, the relation

$$Hev = \frac{mv^2}{r}$$

is necessarily satisfied, the radius r of the path traversed by the electrons is

$$r = \frac{mv}{He} \quad (6)$$

it being understood that the radius of the several paths, such as S_0 , S_1 and S_2 is the same, the effect of the deflecting potential being to shift the center of curvature of the electron paths without altering the radius.

Hence, it will be seen that by properly correlating the deflection angle θ , the magnetic field H and the period T of the deflecting potential impressed between plates 17, electrons leaving the region between the plates 17 one-half cycle apart will arrive at and traverse the gap 19 in phase. Of course, all other electrons leaving this region at other times during this half cycle will tend to traverse the gap 19 in phase with one another and the two electrons leaving one-half cycle apart. Stated in another way, when the parameters noted are correlated in accordance with Equation 5, the electrons leaving the region between the deflector plates 17 during any half cycle of deflecting potential are bunched as they pass the output gap 19. Hence, the direct current beam projected between the deflector plates 17 is converted into a periodically pulsing beam traversing the gap 19 so that the resonator 18 is energized. Inasmuch as but little power need be expended in deflecting the beam projected between the plates 17 and the beam current may be large, it will be appreciated that an amplification of a signal impressed across the deflector plates 17 may be realized.

It will be understood, of course, that the spacing of the deflector plates 17 and the gap 19 should be related so that the electron beam velocity and the magnetic field employed in any particular case, the radius r as given by the Equation 6, is such that the electron stream projected between the plates 17 and trajectory varied by the alternating field therebetween will pass through the gap 19.

After the electrons traverse the gap 19 they are collected by the collector electrode 21, which may be maintained at a potential lower than that of the electrodes 15 and 16 of the electron gun in order to conserve direct current energy, the electrons being retarded before collection.

Inasmuch as the beam traverses the varying electric field between the deflector plates, the potential impressed between these plates will be highly effective upon the electron stream and a high degree of modulation will thus be produced. Furthermore, the field between the deflector plates is uniform so that all of the electrons passing therebetween at any particular instant suffer essentially the same force normal to their projected direction and thus acquire substantially the same trajectory variation whereby a high degree of bunching at the gap 19 is attained and a high transconductance is realized. Also, inasmuch as the average cross section of the beam in flowing from the region of the deflector plates to the gap 19 is relatively large, space charge

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effects in the beam will be small. Finally, it will be appreciated that a large current beam may be employed so that in ultra-high frequency devices constructed in accordance with this invention, large power outputs may be obtained.

Although in the embodiment of the invention illustrated in Figs. 1 and 2 and described above, the electron gun is mounted with its longitudinal axis normal to the diameter of the trajectory on which the deflector plates 17 and the gap 19 lie, it may be mounted in other positions, two of which are illustrated in Figs. 3 and 4. In the construction illustrated in Fig. 3, the electron gun includes the cathode 13a and curved axially symmetrical electrodes 14a, 15a and 16a, immersed in the magnetic field and constructed and arranged so that the axis of the gun lies along an arc of the same circle on which the gap 19 and the gap between the deflector plates 17 lie.

In the construction shown in Fig. 4, the gun is positioned outside of the magnetic field and the electron stream is projected into the field at a velocity much higher than that to which its velocity is reduced just before its entrance into the gap between the deflector plates 17.

The invention may be utilized also to generate ultra-high frequency oscillations, an illustrative embodiment thereof suitable for this purpose being illustrated in Figs. 5 and 6. As shown in these figures, the resonant cavity 18a is associated with the deflector plates 17, the plates, as indicated in Fig. 6, being mounted at one end of the gap 19a in the cavity 18a and energy being delivered to the cavity, by the trajectory varied electron stream, at the other end of the gap 19a. As the cavity is excited by the stream, some energy will be fed back to the deflector plates so that sustained oscillations will be produced. The requisite magnetic field is produced by the magnet 22a, shown in phantom in Fig. 6.

In the embodiment of the invention illustrated in Fig. 7, which is a modification of that illustrated in Figs. 5 and 6, the deflector plates 17 are mounted at the center of the gap 19a, two collector electrodes 21a and 21b are mounted at opposite ends of the gap 19a and two electron guns G1 and G2 are provided for projecting two electron beams between the deflector plates 17 and in opposite directions. Each stream is trajectory varied at the deflector plates 17 and energy is delivered to the resonant cavity at both ends of the gap 19a whereby oscillations are produced and maintained, the operation being push-pull in character as will be apparent.

In the embodiments illustrated in Figs. 5, 6 and 7, it will be understood that a magnetic field normal to the direction of projection of the electron stream or streams is employed, as described heretofore in connection with Figs. 1 and 2. Also, it will be noted that in the embodiments illustrated in Figs. 5, 6 and 7, the electron gun is outside of the cavity and, hence, outside of the high frequency field.

In the embodiment of the invention illustrated in Fig. 8, the electron beam projected by the gun G1 traverses the gap in a cavity resonator 40, passes between the deflector plates 17 and follows an arcuate path in the magnetic field in flowing to the gap 19 in the resonant cavity 18. A constant direct current field is produced between the deflector plates 17, as by a battery 41. Suitable means, not shown, are provided to energize the resonant cavity 40 whereby, in crossing the gap in this cavity, the electron stream is velocity

varied.

The deflection given to any electron by the field between the plates 17 as the electron passes between these plates is dependent upon the velocity of the electron as it enters this field. That is to say, an electron having a relatively small velocity when projected into this field will suffer a greater deflection than an electron projected into this field with a relatively higher velocity. Hence, when an electron stream, velocity varied by the action of the resonant cavity 40, is projected between the deflector plates 17 a trajectory variation of the beam occurs and, as will be understood from the description of the operation of the apparatus shown in Figs. 1 and 2, the electrons in the beam will be bunched as they pass through the output gap 19, so that the velocity variations produced at the gap in the cavity resonator 40 are converted into density variations effective to energize the resonant cavity 18. Energy may be taken from the cavity resonator 18 through the conductor 22.

Although specific embodiments of the invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of the invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising an input element having spaced members defining an input gap, means for projecting a stream of electrons through said gap, means for directing the electrons in said stream along an arcuate path after the electrons leave said gap, an output element inductively energizable by said electron stream having an output gap positioned substantially 180 degrees from said input gap along said arcuate path, and means for producing a periodic grouping at said output gap of the electrons in said stream including means for impressing upon said electron stream while traversing the input gap a cyclically varying velocity component normal to the direction of projection of the electron stream into said input gap and substantially in the direction of a line connecting said input and output gaps.

2. Electron discharge apparatus in accordance with claim 1 wherein said first means includes an electron gun projecting a substantially univelocity electron stream into said gap and wherein said last means includes means for impressing a high frequency potential between the spaced members defining the input gap.

3. Electron discharge apparatus in accordance with claim 1 wherein said last means includes means for producing a constant direct current field between the members defining the input gap and includes also means for velocity varying the electron stream prior to the projection thereof into the input gap.

4. Electron discharge apparatus in accordance with claim 1 comprising means for conveying energy from said output element to said input gap.

5. Electron discharge apparatus comprising means for producing a magnetic field, means for projecting an electron stream into said field substantially normal to the lines of force thereof whereby said stream is directed along an arcuate path, output means inductively energizable by said stream and having a gap positioned substantially 180 degrees along said path from the point of entrance of said stream into said magnetic field, and means for cyclically deflecting said stream adjacent said point and normal to the

lines of force of said field and in the direction of projection of said stream into said field.

6. Electron discharge apparatus comprising a cavity resonator having an elongated gap therein, a pair of deflector plates mounted at one region in said gap and energizable by said resonator, an electron gun for projecting a stream of electrons between said deflector plates, and means for producing a magnetic field normal to the direction of projection of said electron stream between said plates and of such intensity as to direct said stream along a semicircular path one end of which is located at a point in said gap and the other end of which is between said deflector plates.

7. Electron discharge apparatus comprising a cavity resonator having a gap therein, and means for energizing said resonator, said means including an electron gun for producing an electron stream at a region spaced from said gap and in a direction substantially parallel to the axis of said gap, means for producing a magnetic field having its lines of force substantially parallel to said gap and substantially normal to the initial direction of said electron stream, to direct said stream along an arc having one end adjacent said gun and its other end at said gap, and means for deflecting said stream adjacent said one end of said arc and substantially normal to the lines of force of said field.

8. Electron discharge apparatus in accordance with claim 7 comprising means for feeding back energy from said cavity to said deflecting means.

9. Electron discharge apparatus comprising a pair of deflector plates defining an input gap, a pair of output elements equally spaced from and on opposite sides of said input gap, each of said elements being located at a region substantially 180 degrees along an arcuate path from said input gap, a pair of electron guns for projecting two electron streams through said input gap in opposite directions, and means for producing a magnetic field in a region including said input gap and output elements, said field having its lines of force normal to the directions of projection of said streams into said input gap and being of such intensity to direct each of said streams along one of said arcuate paths and to the output element adjacent the corresponding path.

10. An electron discharge device comprising electrode means for producing an electron beam of constant velocity, means contiguous to the path of said beam for oscillating said beam transversely for varying the transit time of the electrons of the beam as a function of the transverse displacement of the beam and producing a density modulation, and means in the path of said beam for intercepting said beam at its point of maximum density.

11. An electron discharge device comprising electrode means for producing an electron beam of constant velocity and in an arcuate direction of constant radius, means contiguous to the path of said beam for oscillating said beam with a lateral component for varying the arcuate length of path of travel of the beam and thereby varying the transit time of the electrons of the beam as a function of the lateral displacement of the beam and producing a density modulation, and means in the path of said beam for intercepting said beam at its point of maximum density.

PAUL L. HARTMAN.

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