

Aug. 5, 1947.

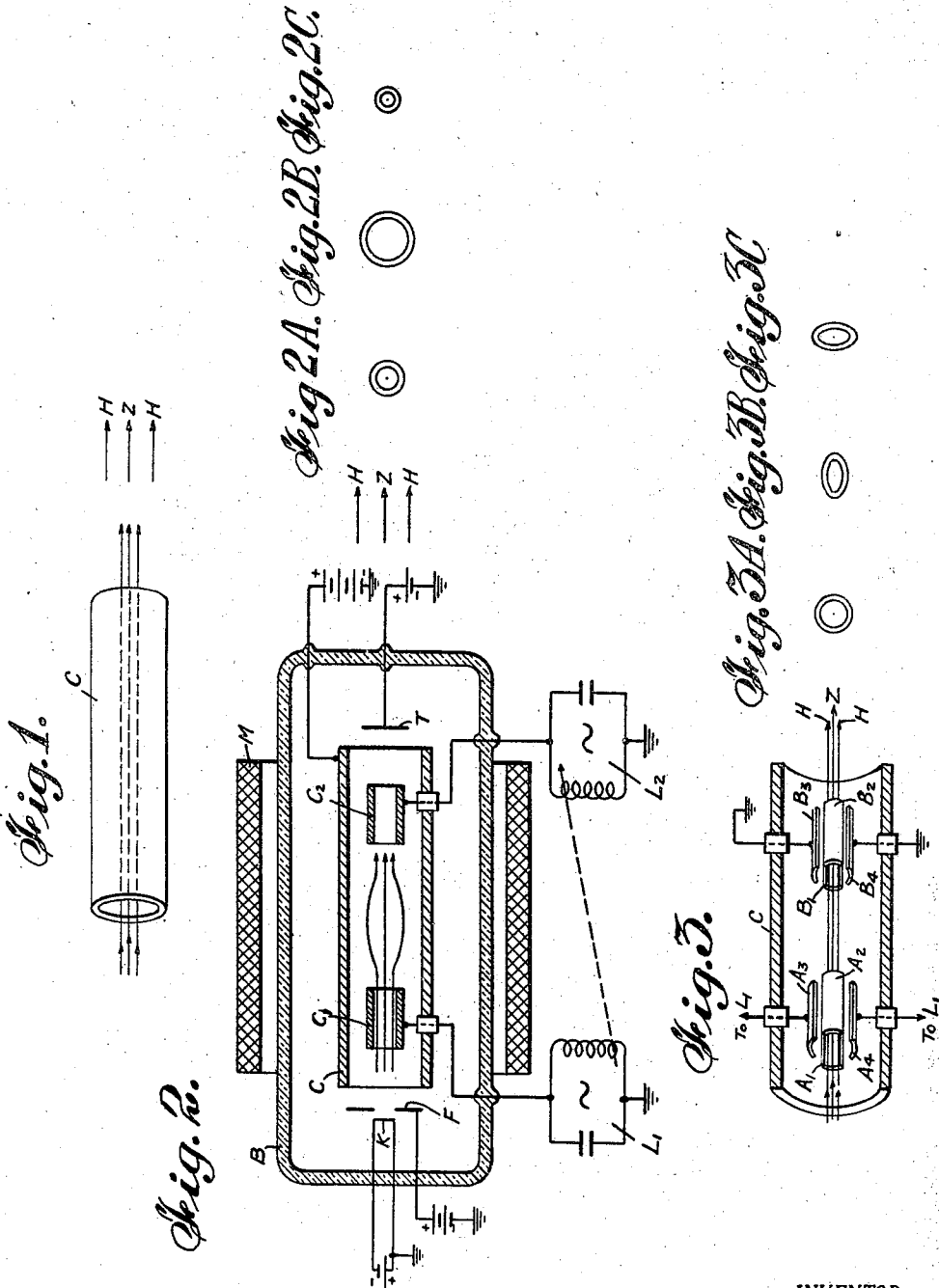
L. N. BRILLOUIN

2,424,965

HIGH FREQUENCY AMPLIFIER AND OSCILLATOR

Filed March 20, 1942

2 Sheets-Sheet 1



INVENTOR.
LEON N. BRILLOUIN

BY

R.P. Morris
ATTORNEY

Aug. 5, 1947.

L. N. BRILLOUIN

2,424,965

HIGH FREQUENCY AMPLIFIER AND OSCILLATOR

Filed March 20, 1942

2 Sheets-Sheet 2

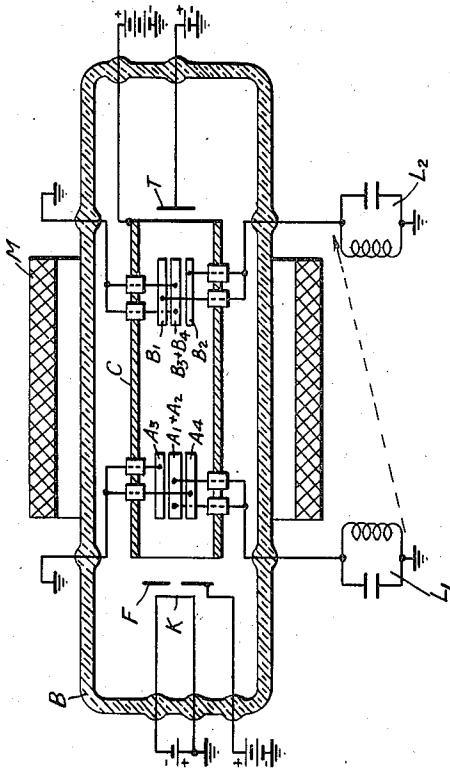


Fig. 4.

Fig. 5.

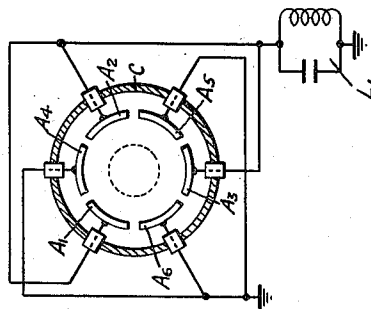


Fig. 5A.



Fig. 5B.



INVENTOR.
LEON N. BRILLOUIN

BY

R. P. Morris
ATTORNEY

UNITED STATES PATENT OFFICE

2,424,965

HIGH-FREQUENCY AMPLIFIER AND
OSCILLATORLeon N. Brillouin, Madison, Wis., assignor to
Federal Telephone and Radio Corporation, a
corporation of Delaware

Application March 20, 1942, Serial No. 435,521

8 Claims. (Cl. 250—27.5)

1

This invention relates to electron discharge apparatus and more particularly to such apparatus intended for the amplification and generation of high frequency electrical waves.

It is well known that in conventional electron discharge tubes the finite electron transit time prevents efficient operation at very high frequencies due to abnormal loading of the input circuit and consequent loss of transconductance of the tube, excessive coupling between the input and output circuits and increased losses due to the presence of large circulatory currents at high frequencies.

The principal object of my invention is to provide an improved electron discharge apparatus particularly suitable for use as an amplifier or oscillator at high frequencies.

More particularly, it is an object of my invention to provide an electron discharge device in which electron transit time is not critically related to the period of oscillation and in which high frequency losses are minimized.

The various objects and features of my invention will be more fully understood from the following detailed description of certain embodiments as shown in the accompanying drawings in which

Fig. 1 is a diagram employed to illustrate the principle upon which my invention is based;

Fig. 2 is a side-sectional view of an electron discharge apparatus showing one typical method of carrying my invention into effect;

Figs. 2A, 2B, and 2C illustrate the confines of the electron beam produced by the apparatus shown in Fig. 2;

Fig. 3 illustrates alternative electrode structures which may be used in place of the electrodes shown in Fig. 2;

Figs. 3A, 3B, and 3C illustrate the confines of the electron beam produced in the arrangement of Fig. 3;

Fig. 4 shows a side sectional view of an electron discharge apparatus according to the present invention;

Fig. 5 shows a still further electrode arrangement; and

Figs. 5A and 5B illustrate the confines of the electron beam produced by the arrangement of Fig. 5.

Theoretical investigations made by myself (Physical Review, vol. 60, 1941, p. 385) and by J. P. Blewett and S. Ramo (Physical Review, vol. 57, 1940, p. 365) have shown the formation and type of motion of an electron beam traveling inside a metallic pipe under the action of a longitudinal magnetic field.

2

Referring to Fig. 1, a metallic cylinder C is maintained at a positive potential and a constant magnetic field H is generated parallel to the axis Z of the cylinder C. Electrons enter the cylinder C with a certain longitudinal velocity v_z and rapidly build up an electronic cloud of constant density P_0 which rotates about the axis Z with a constant angular velocity ω_H ; then

$$P_0 = \frac{m\omega_H^2}{2e\pi} \omega_H = -\frac{1}{2}\mu_0 \frac{eH}{m}$$

where e represents the charge of the electron, m is the mass of the electron and $\mu_0 = \frac{1}{9} \times 10^{-20}$ in electrostatic units, ω_H is Larmor's angular velocity.

Each electron describes a helix around the axis Z, due to the superposition of the constant velocity v_z and of the rotation ω_H . The space charge density P_0 is uniform throughout the beam and the whole electronic cloud moves like a solid body, gliding along the axis Z with a velocity v_z , and at the same time spinning about the axis Z of the cylinder C with the angular velocity ω_H . This represents the stable type of motion of the electron beam.

I have found that by producing periodic changes in the cross-sectional form or area of such a beam, radial vibrations are impressed upon it and result in oscillations which may be used for the purpose of amplification or generation of high frequency waves.

A feature of my invention resides, therefore, in the provision of an electron discharge apparatus comprising a means for forming the electrons emitted by a source into a beam comprising an electronic cloud of normally constant density which rotates about a linear axis with a constant angular velocity and which simultaneously advances along this axis, and means for producing periodic changes in the cross sectional form or area of the beam at a predetermined point along the axis, means also being provided for extracting energy from the beam at another predetermined point along the axis.

Reference should now be made to Fig. 2, which shows one method of carrying out my invention. At one end of an evacuated envelope B there is mounted an electron emissive cathode K and a beam focusing and concentrating electrode F. A metal cylinder C is mounted in the envelope B parallel to the major axis of the envelope B, and a target or collector electrode T is mounted at the end of the cylinder C remote from the cathode K. Surrounding the envelope B and the cylinder C is a coil M for producing a magnetic field parallel to the axis Z.

allel to the axis of the metallic cylinder C. Near the entrance to the cylinder C adjacent the beam-forming electrodes K, F is mounted a first cylindrical electrode C₁, the radius of which is slightly greater than the radius of the beam, whereby under normal conditions electrons will not strike this electrode and no current will flow to it. A second cylindrical electrode C₂ is mounted within the cylinder C and adjacent its other end, such second cylinder C₂ also having a radius slightly greater than the radius of the electron beam. The cylinder C is maintained at a high positive potential with respect to the cathode. The focusing electrode F is also maintained at a positive potential as is customary in electron guns, whilst the collector or target electrode T is maintained preferably at a slightly positive potential with respect to the cathode. An input circuit L₁ is connected to the electrode C₁, and an extracting circuit is connected to the electrode C₂.

If an oscillating voltage is applied to the electrode C₁ from the circuit L₁, alternate radial expansions and compressions will be impressed upon the electronic beam. Fig. 2A illustrates the confines of the electronic beam in the stable condition. Fig. 2B illustrates the confines of the beam at the point where it is under the influence of the electrode C₁ when a positive half cycle is impressed thereon, and Fig. 2C illustrates the confines of the beam when under the influence of a negative half cycle impressed upon the electrode C₁. These alternating radial vibrations travel along the beam moving in the direction of the axis Z with the longitudinal velocity v_z . Since the radius of the cross section of the beam is periodically greater than the radius of the electrode C₂ groups of electrons will hit this electrode C₂, and yield an alternating current on it. The oscillations or vibrations impressed upon the electron beam by the electrode C₁ will be large if their frequency is correctly related to the angular velocity of the beam. I have found that the frequency corresponding to the type of motion described with reference to the arrangement shown in Fig. 2 is about

$$\sqrt{2} \text{ times Larmor's frequency } (\omega = \sqrt{2} \omega_H)$$

With the arrangement of Fig. 2, the radial vibrations impressed upon the electronic beam occur simultaneously in all directions of one cross section. Each cross section of the beam remains circular, but the radius of this circle is alternately larger and smaller than the normal radius of the beam. The cross section of the beam may, however, be periodically deformed by the use of other forms of electrodes. If, for example, the electrodes within the cylinder C are in the form of sets of four arcuate plates A₁, A₂, A₃, A₄, and B₁, B₂, B₃, B₄, as shown in Fig. 3 the four in each set being disposed on each side of the electron beam, A₁ opposite A₂, A₃ opposite A₄, etc., the cross section of the beam during one-half cycle of an oscillation impressed upon the electrodes A₁, A₂ will be an ellipse with its major axis horizontal, as shown in Fig. 3B, and during the succeeding half-cycle will be an ellipse with its major axis vertical, as shown in Fig. 3C. These elliptic oscillations travel along the beam within the cylinder C, and simultaneously rotate about the axis Z in accordance with the motion of the electron beam as described with reference to Fig. 1. Before leaving the cylinder C, the beam passes between the electrodes B₁, B₂, and if the longitudinal velocity of

the beam, the angular velocity ω_H , and the frequency of the oscillations impressed upon the electrodes A₁, A₂ are correctly chosen, the elliptic oscillations of the beam will result in a current on the electrodes B₁, B₂, since groups of the deflected electrons will strike these electrodes.

In Fig. 3, the electrode pairs A₁, A₂, and B₁, B₂, have been shown mounted on parallel diameters of the cylinder C. To avoid direct capacity effect between the pairs of electrodes A₁, A₂, and B₁, B₂, it is preferable to arrange these pairs of electrodes along diameters at right angles to one another. As in the preceding embodiments, the frequency of the impressed vibrations should be correctly related to the angular velocity of the electron beam.

In Figure 4 the cylinder C and the A and B electrodes enclosed therein as diagrammed in Fig. 3 are shown in an envelope B similar to that shown in Fig. 2 with the connections therethrough to cathode K, electrode F, and plate T, and the solenoid M therearound to make a more complete showing of the electron discharge device according to this invention. The figure contains elements of Figs. 2 and 3 and corresponding parts have been labeled accordingly.

More complicated structures may be used for the beam deforming and energy extracting electrodes. Each of these electrodes may be constituted by 4, 6 . . . 2n arcuate plates disposed on a circle in order to excite vibrations of more complex types along the electron beam. Fig. 5 shows one example of such an arrangement in which the electrode structure upon which the input oscillations are impressed comprises six arcuate sections, alternate sectors being connected to one side of the input circuit and the remaining sectors being connected to the other side of the input circuit. The energy extracting electrode structure is similarly constituted and connected to the energy extracting or output circuit. With such an arrangement the cross section of the electron beam is alternately deformed according to the two shapes shown in Figs. 5A and 5B.

The arrangements described will function as amplifiers of high frequency waves. If, however, a coupling is provided between the input circuit L₁ and the output circuit L₂ as shown by the dotted line arrow in Fig. 2 and Fig. 4, oscillations will be fed back from the output circuit L₂ to the input circuit L₁ and will build up, causing the device to generate high-frequency oscillations which may be extracted from the output circuit L₂.

While I have described my invention with reference to particular embodiments thereof, it will be understood that other modifications may be made by those skilled in the art without departing from the invention as defined in the appended claims.

What I claim is:

1. An electron discharge apparatus for amplifying a variable voltage comprising an envelope, means including a cathode positioned within said envelope for producing and directing an electron beam, a metallic tube positioned axially about the path of said beam within said envelope, means positioned about said tube for generating a magnetic field parallel to the axis of said tube whereby said beam is rotated about the linear axis with a constant velocity, means connected to said tube for maintaining said tube at a positive potential with respect to said cathode whereby said beam is advanced through said tube, a first pair of oppositely directed arcuate electrodes dis-

5

posed one on either side of the path of said beam and mounted in said tube adjacent the end nearest the cathode, a second pair of oppositely directed arcuate electrodes disposed one on either side of the path of said beam and mounted in said tube at a point along its axis from said first pair of electrodes, a variable voltage source connected to said first pair of electrodes for controlling a radial dimension of said beam, and an output circuit connected to said second pair of electrodes for extracting energy from said beam in the form of said variable voltage.

2. Electron discharge apparatus according to claim 1, in which said first pair of electrodes are turned 90° about said beam with respect to said second pair of electrodes.

3. An electron discharge apparatus for amplifying alternating current waves comprising, an envelope, means including a cathode positioned within said envelope for producing and directing an electron beam, a metallic tube positioned axially about the path of said beam within said envelope, means adjacent said tube for generating a magnetic field parallel to the axis of said tube whereby said beam is rotated about a linear axis with a constant velocity, means connected to said tube for maintaining said tube at a positive potential with respect to said cathode whereby said beam is advanced through said tube at a constant velocity, an even number greater than two of first electrodes mounted in said tube adjacent the end nearest the cathode and disposed substantially in a circle about said beam, an even number greater than two of second electrodes mounted within said tube, longitudinally from said first electrodes and also disposed substantially in a circle about said beam, an input circuit having two terminals, one of which is connected to alternate first electrodes and the other of which is connected to the remaining first electrodes for periodically deforming the path of rotation of said beam, and an output circuit having two terminals, one of which is connected to alternate second electrodes and the other of which is connected to the remaining second electrodes for extracting energy from said beam in the form of said alternating current waves.

4. An electron discharge apparatus comprising a metallic tube, means adjacent said tube for producing a substantially solid, generally cylindrical electron beam and directing it axially through said tube, means positioned in the vicinity of said metallic tube for generating a magnetic field parallel to the axis of the said tube whereby said beam is rotated, a first electrode mounted in said tube along the path of said beam, electrodes mounted within said tube and spaced from and co-axial with said first electrode and normally outside the path of said beam, a connection to said first electrode for applying thereto a variable voltage of frequency different from and bearing a predetermined relation to the frequency of the rotation of said beam for periodically deforming the path of rotation of said beam whereby electrons periodically strike said electrodes, and an energy extracting circuit connected to said electrodes adapted to remove energy from said electron beam.

5. Electron discharge apparatus comprising, an envelope, a metallic tube within said envelope, means in said envelope for producing an electron beam having a predetermined cross-sectional area and for directing said beam axially through said tube, means positioned in the vicinity of said metallic tube for generating a magnetic field paral-

6

lel to the axis of said tube whereby said beam is rotated, radially displaced electrodes mounted in said tube in a position about the path of said electron beam, means positioned in said tube intermediate said electrodes and said beam producing means for periodically enlarging the cross-sectional area of said beam at a frequency different from and bearing a predetermined relation to the frequency of the rotation of said beam whereby electrons periodically strike said electrodes, and an energy extracting circuit connected to said electrodes.

6. Electron discharge apparatus comprising an envelope, a metallic tube within said envelope, means in said envelope for producing an electron beam having a predetermined cross-sectional shape and for directing said beam axially through said tube, means positioned about said tube for generating a magnetic field parallel to the axis of said tube whereby said beam is rotated, electrodes mounted in said tube in a position normally outside the path of said electron beam, means in said tube intermediate said electrodes and said beam producing means for periodically deforming the cross-sectional shape of said beam at a frequency different from and bearing a predetermined relation to the frequency of the rotation of said beam whereby electrons periodically strike said electrodes, and an energy extracting circuit connected to said electrodes.

7. Electron discharge apparatus for generating high frequency oscillations comprising, an envelope, means in said envelope for producing and generally directing an electron beam including a biasing electrode, a metallic tube positioned about the path of said beam, means positioned about said tube for generating a magnetic field parallel to the axis of said tube for substantially the entire length of said beam whereby said beam is rotated, a first electrode mounted within said tube and within said envelope, a second electrode mounted within said tube intermediate said first electrode and said beam producing means, a resonant input circuit connected to said second electrode for controlling a radial dimension of said beam, said resonant input circuit being tuned to a frequency different from and bearing a predetermined relation to the frequency of the rotation of said beam, a resonant extracting circuit connected to said first electrode, and means connected to said input and extracting circuits whereby said high frequency oscillations are generated and extracted.

8. An electron discharge apparatus comprising an envelope, a metallic tube within said envelope, means positioned in the vicinity of said tube and including a cathode for producing an electron beam and directing said beam through said tube, means positioned in the vicinity of said tube for rotating said beam about a linear axis with a normally constant velocity, a first pair of oppositely directed arcuate electrodes disposed one on either side of the path of said beam and mounted in said tube adjacent the end nearest the cathode, a second pair of oppositely directed arcuate electrodes disposed one on either side of the path of said beam and mounted in said tube at a point along its axis removed from said first pair of electrodes and turned 90° about said axis with respect to said first pair of electrodes, a variable voltage source connected to said first pair of electrodes for controlling a radial dimension of said beam whereby electrons periodically strike said second pair of electrodes, and an output cir-

7

cuit connected to said second pair of electrodes for extracting energy from said beam in the form of said variable voltage.

LEON N. BRILLOUIN.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,064,469	Haefl	Dec. 15, 1936

Number

2,164,559
2,147,454
2,232,050
5 2,233,166
2,266,595
2,284,751
2,295,315
2,329,777
10 2,329,778
2,222,901
2,233,166

8

Name

Date

Wright	July 4, 1939
Morton	Feb. 14, 1939
Clavier et al.	Feb. 18, 1941
Hahn	Feb. 25, 1941
Fraenckel	Dec. 16, 1941
Linder	June 2, 1942
Wolff	Sept. 8, 1942
Nergaard	Sept. 21, 1943
Nergaard	Sept. 21, 1943
Hahn	Nov. 26, 1940
Hahn	Feb. 25, 1941