

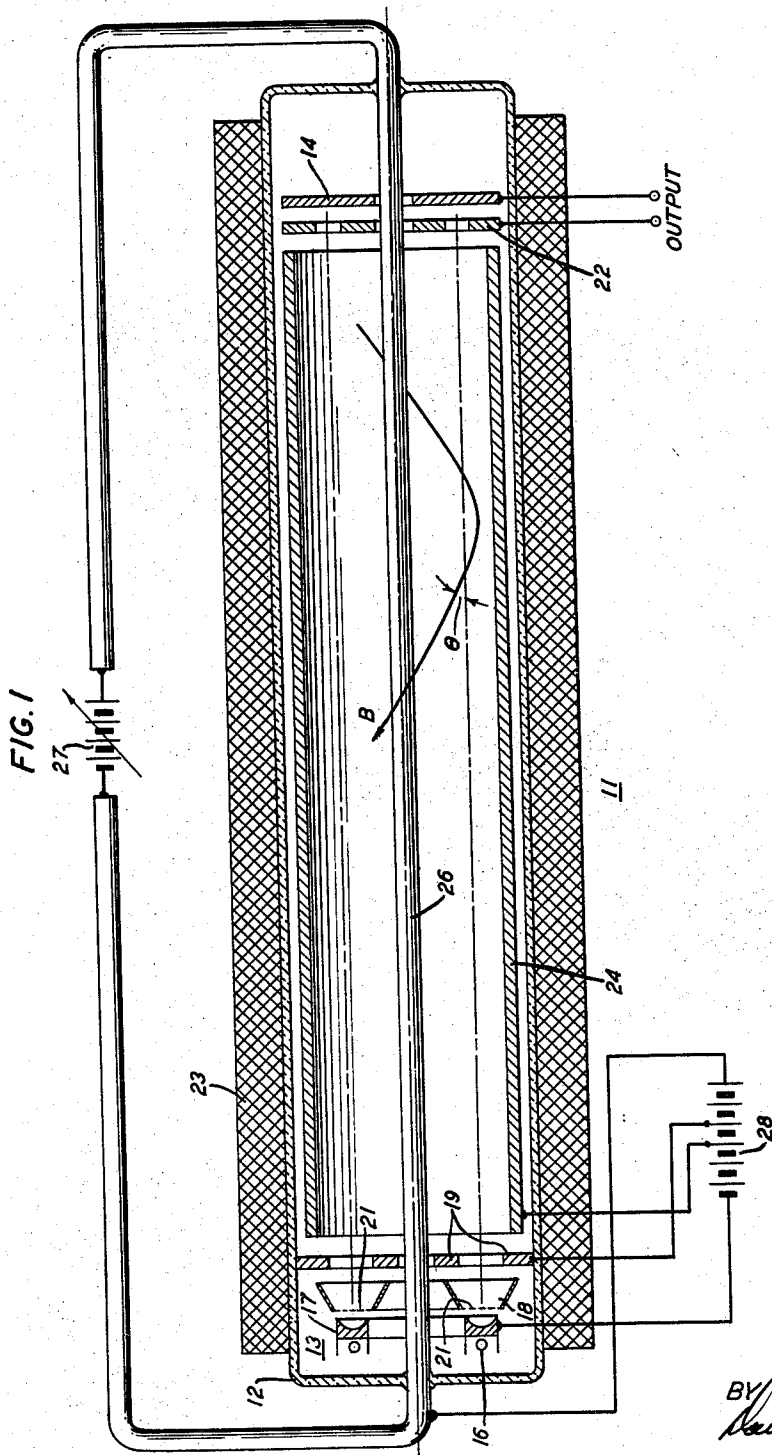
Nov. 8, 1960

C. C. CUTLER
ELECTRON DISCHARGE DEVICE

2,959,706

Filed June 23, 1958

2 Sheets-Sheet 1



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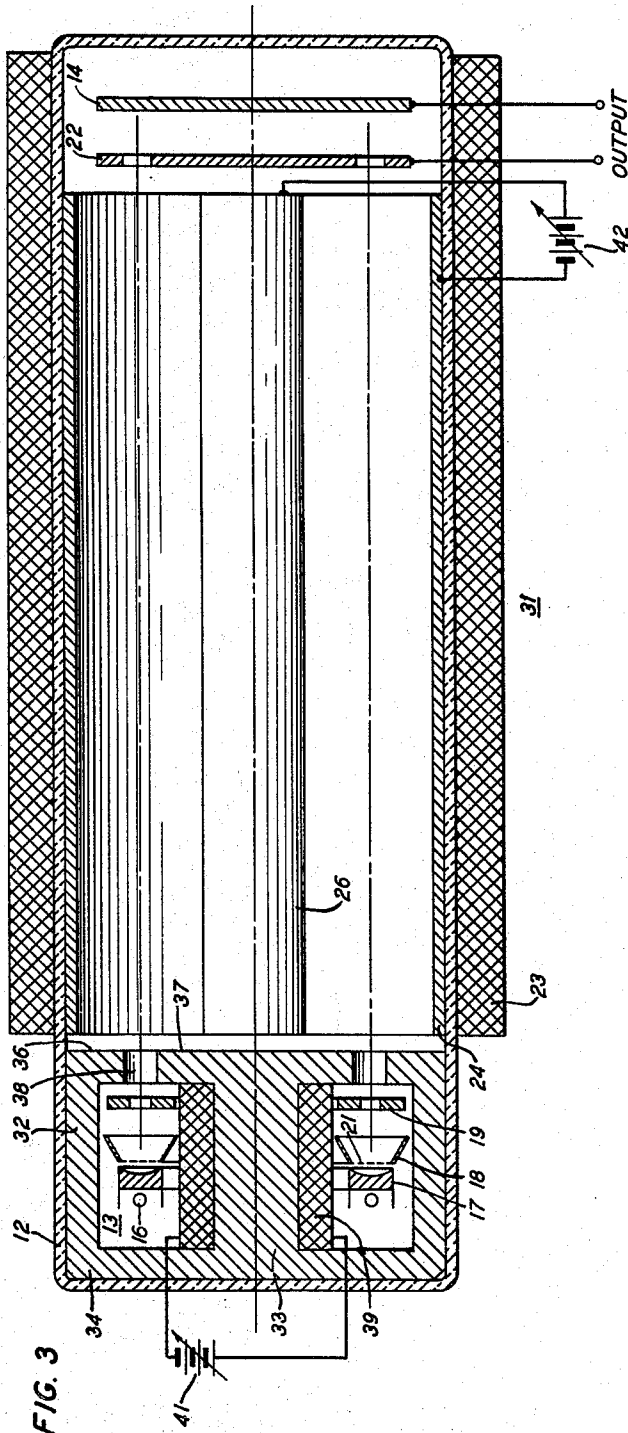
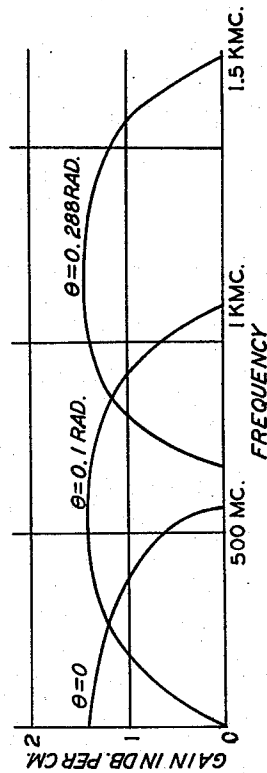


FIG. 2



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2,959,706

ELECTRON DISCHARGE DEVICE

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Filed June 23, 1958, Ser. No. 743,671

11 Claims. (Cl. 315—3)

This invention relates to electron discharge devices and, more particularly, to such devices which utilize an electron beam to achieve signal amplification.

In my Patent 2,927,243, issued March 1, 1960, there is disclosed a novel type of high gain, broad band amplifier which relies upon the exponential growth of wave disturbances on a thin electron beam to produce amplification. The invention disclosed in that application involves projecting an annular or ribbon electron beam having a thickness which is small compared to its circumference or width into a colinear magnetic field for flow along an extended path in the direction of the magnetic field. Signals to be amplified are applied to the beam in the form of circumferential or transverse modulations so that different electrons around the circumference or across the width of the beam are influenced to different extents by the applied signals. Such modulation is in a plane transverse to the magnetic field and, as a result of this and because of the presence of space charge forces, the electrons develop a transverse displacement which, in turn, produces a sinusoidal modulation circumferentially of or across the width of the beam. As the modulated beam travels along the longitudinal path defined by the magnetic field, an exponential growth of these sinusoidal disturbances on the beam takes place. If the beam travels a sufficient distance the circumferential or width configuration of the beam tends to be broken into a plurality of discrete clusters of spirally rotating electrons, a series of "spiral nebulae." By proper positioning of an output transducer along the beam path an amplified replica of the input signal may be obtained at the output of the device. In such operation, the beam itself travels a straight path between input and output, and the amplification phenomenon is to be clearly distinguished from such devices which rely upon deflection of the beam from its path to produce amplification.

The significant advantages realized with such a device operated in the foregoing manner are that amplification is achieved over a wide band of frequencies from very low frequencies up to hundreds of megacycles, and the amplification is achieved without benefit of interaction or wave propagation circuitry as in klystrons and traveling and traveling wave tubes, other than the input and output transducers.

A disadvantage inherent in such operation, however, is the fact that maximum gain is achieved at low frequencies, the theoretical maximum being at direct current, and, although the bandwidth may be several hundred megacycles it is not as great as it could be if the maximum gain occurred at a frequency other than zero, assuming a symmetrical gain-bandwidth curve. Another disadvantage of such operation is that because maximum gain occurs at direct current, despite the large bandwidth, there is left a significant gap of frequencies where no such order of gain and bandwidth is practically obtainable between the maximum attainable with such opera-

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tion and the frequencies of operation of various other microwave devices.

Accordingly, it is an object of the present invention to achieve in a single device high gain over an exceedingly broad band of frequencies from very low frequencies into the kilomegacycle frequency range.

It is another object of my invention to produce high gain, broad bandwidth amplification over any preselected band of frequencies from zero frequency through several kilomegacycles.

It is still another object of my invention to produce maximum amplification at any desired frequency within a broad band of frequencies from zero frequency through several kilomegacycles.

The present invention is based upon the discovery that a thin sheet beam or a thin annular beam can, under certain conditions, be made to flow in a magnetic field which is oriented diagonally with respect to the direction of flow of the electrons in the beam. It has also been found that there is a direct relationship between the angle between the magnetic field and direction of flow and the frequency at which maximum gain is obtainable, such that for a given angular relationship, provided the angle is small, the remaining parameters being fixed, the frequency of maximum gain, or the midband frequency, is uniquely determined. It has further been found that, inasmuch as the gain of such a device is independent of the angular relationship, a change in the angular relationship does not alter the gain obtainable, and such an arrangement can, therefore, be made to function as an amplifying band pass filter, the pass band of which can be shifted along the frequency scale by the simple expedient of changing the angular relationship of the magnetic field and the direction of flow.

Accordingly, it is a feature of my invention that a thin sheet or annular electron beam, which has been modulated in a transverse or circumferential direction, is projected along a path of flow in a magnetic field and at an acute angle to the magnetic field.

It is another feature of my invention that the midband operating frequency of such an arrangement is varied by varying the angular relationship between the electron beam and the magnetic field.

These and other features of my invention are achieved in a first illustrative embodiment thereof which comprises an evacuated envelope having axially disposed therein at opposite ends an electron gun for forming and projecting a thin hollow beam and a collector electrode for collecting the electrons in the beam. Located adjacent the electron gun is an input transducer means for modulating the electron beam with signal energy to be amplified and located adjacent the collector electrode is an output transducer means for converting modulations on the beam into electromagnetic wave energy. Surrounding the envelope and extending longitudinally thereof parallel to the path of electron flow is an electromagnetic solenoid for establishing a magnetic field along and parallel to the path of flow. Within the envelope and surrounding the electron beam is a first shielding electrode. Along the axis of the beam and surrounded thereby is a second electrode comprising a metallic conducting rod or tube. Means are provided for producing a current flow in the rod such that there is produced in the region of the beam a transverse magnetic field. This field adds to the longitudinal field of the solenoid to produce a resultant helical magnetic field. Thus, a magnetic field is produced which is at an angle to the path of electron flow. By varying the current flow in the second electrode, the pitch of the helical field, and hence the angle thereof can be varied to produce changes in the midband operating frequency of the device. The shield-

ing electrode and the rod are maintained at a potential difference with respect to each other such that the beam does not deviate from its path of flow under the influence of the magnetic field.

In another illustrative embodiment of my invention, an electron gun is utilized which imparts a rotational component to the beam, causing the electrons to travel helical paths. As a consequence, the direction of flow of the electrons is at an angle to the magnetic field. The angular relationship between the field and the electrons can be varied by altering the degree of rotation imparted to the beam.

The present invention will be more readily understood from the following description, taken in conjunction with the accompanying drawing, in which:

Fig. 1 is a sectional view of an amplifier tube embodying the principles of the present invention;

Fig. 2 is a graph which depicts the relationship between gain and frequency for various angles between the magnetic field and the electron flow; and

Fig. 3 is a sectional view of another amplifier tube embodying the principles of the present invention.

Turning now to Fig. 1 there is shown, by way of example, an amplifier tube 11 comprising an evacuated envelope 12 of glass or other suitable material enclosing an electron gun 13 for forming and projecting an annular electron beam, and a collector electrode 14 for collecting the beam at the downstream end of the tube. As used hereinafter, the terms "upstream" and "downstream" will be used to designate points less remote or more remote, respectively, from the electron gun with respect to other points. Gun 13 includes a heater element 16, an annular cathode 17, an apertured beam forming electrode 18, and an accelerating anode 19 apertured for passage of the beam therethrough.

In order that the annular beam may be modulated with signals to be amplified, an input transducer comprising grids 21 extending across the aperture in the beam forming electrode 18 are provided. This transducer may advantageously be of the form shown in Figs. 3A and 3B of my aforementioned patent. A source of signals, which, for simplicity, has not been shown, is connected between the cathode and grids 21. Such an arrangement produces a density modulation circumferentially of the beam which, in turn, produces a circumferential sinusoidal modulation in a manner clearly explained in the aforementioned patent. While the input transducer shown in Fig. 1 is of a specific form, it is to be understood that any one of a number of input transducers may be utilized to modulate the beam in the desired manner. Examples of some of the various types of input transducers which might be utilized are shown in my aforementioned patent. At the downstream end of the tube adjacent the collector 14 is an output transducer 22 which functions in conjunction with collector 14 to produce an output signal. While the output transducer here shown takes the form of the output transducer shown in Fig. 9 of my aforementioned patent, it is to be understood that it may take any one of a number of forms, examples of which are disclosed in that patent.

Surrounding the envelope and closely adjacent thereto is a solenoid 23 for establishing a magnetic field which extends along the beam path parallel to the direction of flow of the beam. Solenoid 23 functions in a manner to be explained more fully hereinafter to help produce a magnetic field along the beam path which is at an angle to the path of flow of the electrons in the beam, in accordance with the features of this invention. Within the envelope 12 and surrounding the beam path is a hollow cylindrical shield electrode 24 of conducting material. Extending along the axis of the tube and through the ends thereof is a second electrode 26 which, as here shown, comprises a rod of conducting material. As shown in Fig. 1, a variable source of potential 27 is connected to the ends of the rod 26 for creating a current

flow through the rod. As is well known, when current flows in a conductor a transverse magnetic field is created about the conductor. In the tube of Fig. 1 the current flowing in rod 26 in the interior of the tube creates a magnetic field which extends transversely to the path of flow. This field thus created combines with the longitudinally extending magnetic field established by solenoid 23 to produce a magnetic field having a spiral or helical configuration in the region of the electron beam, as designated by the arrow B in Fig. 1. It can readily be seen that such a magnetic field has a component which is at an angle to the direction of flow of the electrons in the beam.

A voltage source 28 is utilized to apply a potential difference between shield electrode 24 and rod 26. The magnitude and direction of the electric shield thus created by the electrodes 24 and 26 are such that any tendency of the beam to be defocused or deflected because of the angular configuration of the magnetic field is overcome and the beam maintains its hollow cylindrical configuration throughout the path of flow. While certain important voltage sources have been shown in Fig. 1, for simplicity various other voltage sources for properly biasing various of the other electrodes of the tube, as well as the signal source for applying modulations to the beam, have been omitted.

In operation, signals to be amplified are applied to the grids 21 which produce a density modulation of the beam around the circumference thereof, which in turn creates a circumferential sinusoidal modulation of the beam due to the resulting space charge fields created by the density modulation. The beam thus modulated travels along the length of the tube 11 toward the output transducer 22. As explained in the foregoing and as more fully explained in the aforementioned patent, these circumferential sinusoids on the beam grow in amplitude as the beam travels along the length of the tube. Thus, at the output transducer the modulations on the beam represent an amplified version of the signal which was impressed on the grids 21. Output transducer 22 and collector 14 convert these modulations on the beam into an output signal which is then abstracted for use.

In order that the significant features of my invention and the advantages thereof may be more readily appreciated and understood, the following analysis is presented.

This analysis is directed toward a thin sheet beam, but it is equally applicable to a hollow cylindrical beam of electrons inasmuch as a hollow cylindrical beam may be regarded as a special case of a thin sheet beam. It can be shown that the solution of the differential equations of motion for electrons in a thin sheet beam under the influence of an electric field and a magnetic field parallel to the Z axis is given by

$$x = (C_1 + C_2 + C_3 + C_4 + C_5 t + C_6) e^{[W_{1,2,3,4,5,6} - (\gamma X + \beta Z)]} \quad (1)$$

where C is a constant, t is time, and W is given by

$$\left(\frac{W}{\omega_c}\right)^2 = \frac{1}{2} \left[1 - \frac{\omega_p^2}{\omega_c^2} \gamma b \left[\frac{1}{T} - T \left(1 + \frac{\beta^2}{\gamma^2} \right) \right] \right] \quad (2)$$

$$\left\{ 1 \pm \sqrt{1 + \frac{4 \left[\frac{\omega_p^2}{\omega_c^2} \gamma b \right]^2 \left[1 - \frac{\beta^2}{\gamma^2} \left(\frac{\omega_c^2 T}{\omega_p^2 \gamma b} - 1 \right) \right]}{\left[1 - \frac{\omega_p^2}{\omega_c^2} \gamma b \left[\frac{1}{T} - T \left(1 + \frac{\beta^2}{\gamma^2} \right) \right] \right]^2}} \right\} \quad (3)$$

and,

$$\frac{W^2}{\omega_c^2} = 0$$

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where

W is the propagation constant of a disturbance on the beam relative to the charge,

ω_c is the cyclotron radian frequency,

ω_p is the plasma radian frequency,

γ is the propagation constant in the X direction of a disturbance on the beam,

b is one-half the beam thickness which, in the case of an annular beam, is one-half the difference between the inside and outside radius,

β is the propagation constant in the Z direction of a disturbance on the beam, and

$$T = \tanh \frac{\left(\sqrt{1 - \frac{\gamma^2}{\beta^2}} \gamma a \right)}{\sqrt{1 - \frac{\gamma^2}{\beta^2}}}$$

where a is one-half the separation between the inner and outer electrodes (24 and 26 in Fig. 1). Equations 1 and 2 are more general solutions for the dynamics of such a system than have hitherto been available. They are readily verifiable by reference to an article entitled "Instability of Hollow Beams" by J. R. Pierce, I.R.E. Transactions on Electron Devices, vol. E.D. 3, No. 4, October 1956, where it can be seen that for small or large plate separations, Equation 2 reduces to Equation 27 or 52 respectively of that article.

Equation 1 describes the wave propagation in terms of displacement parallel to the X axis and the subscripts refer to the roots of Equation 2. In the frame of reference chosen in arriving at Equation 1, X and Z are coordinates which move with the average electron velocity and Z is parallel to the magnetic field. It is necessary, therefore, to convert these coordinates to a stationary frame of reference. Taking the Z axis to be parallel to the direction of the beam, and using θ to designate the angle between the Z axis and the magnetic field, the new coordinates X_1 and Z_1 are given by

$$X = X_1 \cos \theta + Z_1 \sin \theta - Ut \sin \theta \quad (4)$$

$$Z = X_1 \sin \theta - Z_1 \cos \theta - Ut \sin \theta \quad (5)$$

where U is velocity in meters per second of the electrons in the beam and the subscript 1 indicates the stationary coordinate system. In a like manner the propagation constants become

$$\gamma_1 = \gamma \cos \theta - \beta \sin \theta \quad (6)$$

$$\beta_1 = \beta \cos \theta + \gamma \sin \theta \quad (7)$$

$$\frac{\omega}{U\gamma_1} \cong \frac{\frac{\beta}{\gamma} \cos \theta + \sin \theta}{\cos \theta - \frac{\beta}{\gamma} \sin \theta} \quad (8)$$

which is approximately

$$\frac{\omega}{U\gamma_1} \cong \frac{\beta}{\gamma} + \tan \theta \quad (9)$$

or

$$f \cong \frac{U\gamma_1}{2\pi} \left(\frac{\beta}{\gamma} + \tan \theta \right) \quad (10)$$

which defines the frequency in terms of the angle θ and the parameters β and γ .

From Equation 2 it can be seen that the maximum gain obtains when

$$\frac{\beta}{\gamma} = 0$$

When θ is equal to zero, as in my aforementioned patent, β is proportional to frequency and it follows that maxi-

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imum gain occurs at zero frequency. In the instant case, however, maximum gain still occurring at

$$\frac{\beta}{\gamma}$$

equal to zero in accordance with Equation 1, it can be seen from Equation 10 that the frequency of maximum gain is above zero, or more precisely, is given by the expression

$$f_{\text{mid-band}} = \frac{U\gamma_1}{2\pi} \tan \theta \quad (11)$$

Also from Equation 1, it can be shown that

$$\text{Gain/unit length} = -8.68 \frac{\omega_c}{U\gamma} \frac{W_{3,4}}{\omega_c} \quad (12)$$

provided θ is not larger. It will be noted that the expression for gain is independent of the angle θ and is therefore the same for all values of θ including zero, where the magnetic field is colinear with the beam.

As pointed out in the foregoing, the preceding analysis was directed to a thin sheet beam, but is equally applicable to a hollow electron beam arrangement as shown in Fig. 1. In Fig. 2 there are plotted gain versus frequency curves for a strip beam arrangement such as is shown in Fig. 12 of my aforementioned patent for a number of values of θ , including zero, and for the following values of the other parameters.

$$\left(\frac{\omega_p}{\omega_c} \right)^2 = 0.1$$

Beam current $I_0 = 0.050$ amp.

$\gamma_b = 0.1$

Beam voltage $V_0 = 200$ volts.

Beam thickness $2a = 0.5$ mm.

Beam width = 1 cm.

Magnetic field $B_0 = 876$ gauss.

The voltage between the two electrodes on either side of the beam is varied as the angle θ is varied to achieve maximum focusing. It can be seen from the curves of Fig. 2 that while the maximum gain obtainable is not affected by the angle of the magnetic field, the frequency band over which gain is obtainable is dependent upon the angle θ , as is the frequency at which the maximum gain is obtained. It can further be seen that for a given set of parameters and values of θ equal to or greater than 0.1 radian, the band of frequencies over which gain is obtained is at least twice as great as the frequency band where the magnetic field is colinear with the electron beam. From the foregoing it is readily apparent that by a proper choice of the angle θ , the desired operating frequency band and the desired midband frequency may be obtained without impairing the gain obtainable. As was pointed out in the foregoing, in the arrangement of Fig. 1, the angle of the magnetic field relative to the path of the electron can be adjusted by adjusting the amount of current flowing in the rod 26. Inasmuch as the angular field is the resultant of a longitudinal field and a transverse field, the angle may also be determined by varying the current in the solenoid 23. It can readily be seen from Fig. 2, therefore, that the device of Fig. 1 can be operated at any midband frequency within a large range by the expedient of varying the current in either rod 26 or solenoid 23, or both.

In the arrangement of Fig. 1, the angle of the magnetic field relative to the electron flow is varied to achieve the desired operating characteristics by varying the orientation of the field itself. In Fig. 3 there is shown a device wherein this angular relationship is achieved in a different manner. For simplicity, elements of the device of Fig. 3 which are the same as those of Fig. 1 are designated by the same reference numerals. The arrangement of Fig. 3 comprises an amplifier tube

31 having an evacuated envelope 12 at one end of which is disposed an electron gun 13 and at the other end of which is a collector electrode 14. For reasons which will be apparent hereinafter, gun 13 is preferably of the type shown and described in an article entitled "Axially Symmetric Electron Beam and Magnetic Field Systems" by L. A. Harris, Proceedings of the I.R.E., June 1952, pp. 700 through 708. Such a gun comprises an annular cathode 17 and a heater element 16. Adjacent cathode 17 is an apertured annular beam forming electrode 18 having grids 21 disposed in the aperture for modulating the beam with signals to be amplified from a source of signals, not shown. Such modulation is of the type disclosed in my aforementioned patent and produces a circumferential modulation of the beam. Adjacent beam forming electrode 18 is an accelerating anode 19 for accelerating the modulated beam. For simplicity, the various connections for supplying the proper operating potentials to the elements of the gun 13 have not been shown. The gun as thus far described is surrounded by a member 32 of magnetic material and a member 33 extending inside of cathode 17, electrode 18, and anode 19. Members 32 and 33 are connected together behind cathode 17 by a transverse magnetic member 34. Member 32 has an inwardly extending flange 36 and member 33 has an outwardly extending flange 37. Together flanges 36 and 37 define an annular gap 38 which is aligned with the emissive surface of cathode 17, and the apertures in electrode 18 and anode 19. Surrounding member 33 is a solenoid 39 which is supplied with current from a variable voltage source 41. Members 32, 33, and 34, flanges 36 and 37, and gap 38 define a magnetic circuit for the magnetic field generated by solenoid 39. It can be seen that within gap 38 there is a magnetic field which is transverse to the path of electron flow as the electrons enter the gap 38. As is explained in the aforementioned Harris article, as the electrons pass through the transverse field in the gap, there is imparted to their motion a transverse component such that the electrons follow helical paths around the circumference of the beam after emergence from the gap. Located within envelope 12 and surrounding the path of the beam is an electrode 24 of conducting material, and extending along the axis of the envelope is a second electrode 26. Electrodes 24 and 26 are maintained at a potential difference with respect to each other by a variable voltage source 42 so that there is established between them a transverse electric field. Surrounding envelope 12 is a solenoid 23 which establishes a longitudinally extending magnetic field along the path of flow. By a proper choice of the voltages on electrodes 24 and 26, the electrons in the beam can be made to follow helical paths along the length of the tube such that they travel at an angle with respect to the magnetic field established by solenoid 23. At the downstream end of the tube is an output transducer 22 which functions with collector 14 to produce an output signal. Transducer 22 can take any one of a number of forms disclosed in my aforementioned patent.

In operation, the angle between the electron paths and the magnetic field can be adjusted by varying the current in solenoid 39 so that any desired angle, and hence any desired midband operating frequency may be realized so long as the angle is small.

The devices of Figs. 1 and 3 both utilize annular beams. It is to be understood, however, that the principles of the present invention are equally applicable to strip beam amplifiers utilizing thin flat sheet beams such as the type disclosed in my aforementioned patent.

The specific embodiments herein disclosed are intended to be illustrative of the principles of the present invention. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. An electron discharge device for amplifying signals over a broad band of frequencies comprising, in combination, means for forming and projecting an electron beam along a path, said beam having a first dimension transverse to the direction of flow which is small compared to a second transverse dimension, means for producing a plurality of distinct transverse bunches of electrons in the beam, said means including input means upstream along the path of flow for modulating the beam periodically along a transverse dimension with a signal to be amplified, output means downstream along the path of flow responsive to the modulations on said beam for producing an output signal, said input and output means being separated by a drift region, and means for maintaining the transverse dimensions of said beam substantially constant within said drift region between said input and said output comprising means for establishing in said drift region a magnetic field, said field being at an angle θ with the electron paths in said beam, such that the midband operating frequency of said device is given by the expression

$$f = \frac{U\gamma_1}{2\pi} \tan \theta$$

where U is velocity in meters per second of the electrons in the beam, and γ_1 is the propagation constant transverse to the axis of the beam of the signal disturbance on the beam, and $\tan \theta$ is approximately equal to θ .

2. An electron discharge device for amplifying signals over a broad band of frequencies comprising, in combination, means for forming and projecting a hollow cylindrical electron beam along the path, the thickness of said beam being small compared to its diameter, means for producing a plurality of distinct transverse bunches of electrons in the beam, said means including input means upstream along the path of flow for modulating the beam periodically around the circumference thereof with a signal to be amplified, output means downstream along the path of flow responsive to the modulations on said beam for producing an amplified output signal, said input and output means being separated by a drift region, and means for maintaining the transverse dimensions of said beam substantially constant within said drift region between said input and said output comprising means for establishing in said drift region a magnetic field, said field being at an angle θ with the path of electrons in said beam, such that the midband operating frequency of said device is given by the expression

$$f = \frac{U\gamma_1}{2\pi} \tan \theta$$

where U is velocity in meters per second of the electrons in the beam, and γ is the propagation constant transverse to the axis of the beam of the signal disturbance on the beam.

3. An electron discharge device as claimed in claim 2 wherein the means for establishing a magnetic field comprises a first means establishing a longitudinal magnetic field along the path of flow and a second means for establishing a transverse magnetic field along the path of flow.

4. An electron discharge device as claimed in claim 2 wherein the means for forming and projecting the beam comprises means for imparting to the electrons a transverse component of velocity such that the electrons in the beam follow helical paths around the circumference of the beam, and the means for establishing a magnetic field comprises means for establishing a longitudinal magnetic field along the path of flow.

5. An electron discharge device for amplifying signals over a broad band of frequencies comprising, in combination, means for forming and projecting a hollow cylindrical electron beam along a path, the thickness of said beam being small compared to its diameter, means

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for producing a plurality of distinct transverse bunches of electrons in the beam, said means including input means upstream along the path of flow for modulating the beam periodically about the circumference thereof with a signal to be amplified, output means downstream along the path of flow responsive to the modulations on said beam for producing an amplified output signal, means for establishing a drift region between said input means and said output means, and means for maintaining the transverse dimensions of said beam substantially constant within said drift region between said input and said output comprising means for establishing in said drift region a magnetic field, said last-mentioned means comprising magnetic means surrounding the envelope and establishing in said drift region a longitudinal magnetic field and conducting means extending along the axis of said envelope, means for producing a flow of current in said conducting means whereby a transverse magnetic field is established in said drift region, the magnitude of said longitudinal field and said transverse field being such that the resultant magnetic field is at an angle θ with the electron paths in said beam such that the mid-band operating frequency of said device is given by the expression

$$f = \frac{U\gamma_1}{2\pi} \tan \theta$$

where U is velocity in meters per second of the electrons in the beam, and γ is the propagation constant transverse to the axis of the beam of the signal disturbance on the beam.

6. An electron discharge device as claimed in claim 5 wherein said means defining a drift region comprises a hollow cylindrical member of conducting material surrounding said beam path, in further combination with means for maintaining said hollow cylindrical member at a potential difference with respect to said conducting member.

7. An electron discharge device for amplifying signals over a broad band of frequencies comprising, in combination, means for forming and projecting a hollow cylindrical electron beam along the path, the thickness of said beam being small compared to its diameter, said means including means for imparting to the electrons in the beam a transverse component of velocity whereby they flow in helical paths around the beam circumference, means for producing a plurality of distinct transverse bunches of electrons in the beam, said means including input means upstream along the path of flow for modulating the beam periodically about the circumference thereof with a signal to be amplified, output means downstream along the path of flow responsive to the modulations on said beam for producing an amplified output signal, means for establishing a drift region between said input means and said output means, and means for maintaining the transverse dimensions of said beam substantially constant within said drift region between said input and said out-

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put comprising means for establishing in said drift region a longitudinal magnetic field, such that the magnetic field is at an angle θ with the electron paths in said beam such that the midband operating frequency of said device is given by the expression

$$f = \frac{U\gamma_1}{2\pi} \tan \theta$$

where U is velocity in meters per second of the electrons in the beam, and γ is the propagation constant transverse to the axis of the beam of the signal disturbance on the beam.

8. An electron discharge device as claimed in claim 7 wherein the means establishing a drift region comprises a hollow, cylindrical member of conducting material surrounding said beam path and a longitudinally extending member of conducting material disposed along the beam path within the annular beam, and means for maintaining said outer cylindrical member and said longitudinal extending member at a potential difference with respect to each other.

9. An electron discharge device for amplifying signals over a broad band of frequencies comprising, in combination, means for forming and projecting a thin electron beam, means for producing a plurality of distinct transverse bunches of electrons in the beam, said means including means for causing wave disturbances transverse to said thin beam in accordance with input signals, means defining a drift region, means for maintaining the transverse dimensions of said beam substantially constant within said drift region, said means including means for generating a linear magnetic field in said drift region for exponential growth of said wave disturbances, said linear magnetic field being at a small angle to the direction of the electrons in said beam and said angle being within the range wherein the angle is substantially equal to the tangent of the angle.

10. An electron discharge device in accordance with claim 9 wherein said means for generating said magnetic field includes a first means for generating a linear magnetic field parallel to the axis of said beam and second means for generating a magnetic field transverse to said beam axis.

11. An electron discharge device in accordance with claim 9 wherein said means for forming and projecting said beam includes means for imparting to the electrons in said beam a transverse component of velocity whereby they flow in helical paths in said drift region.

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