

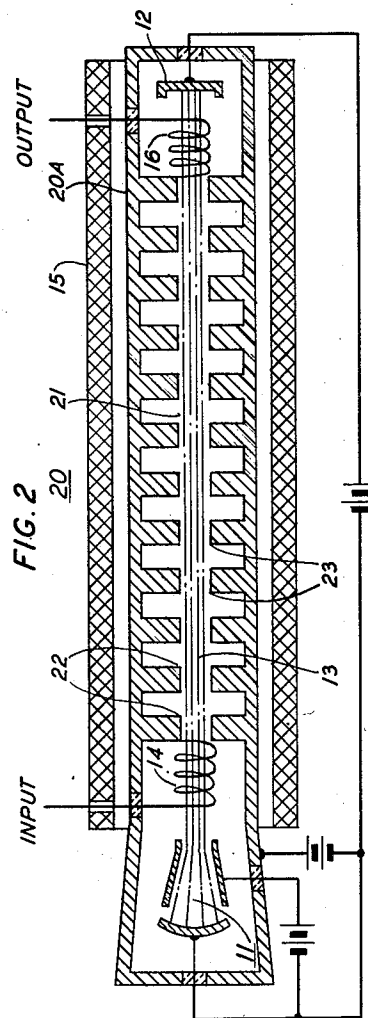
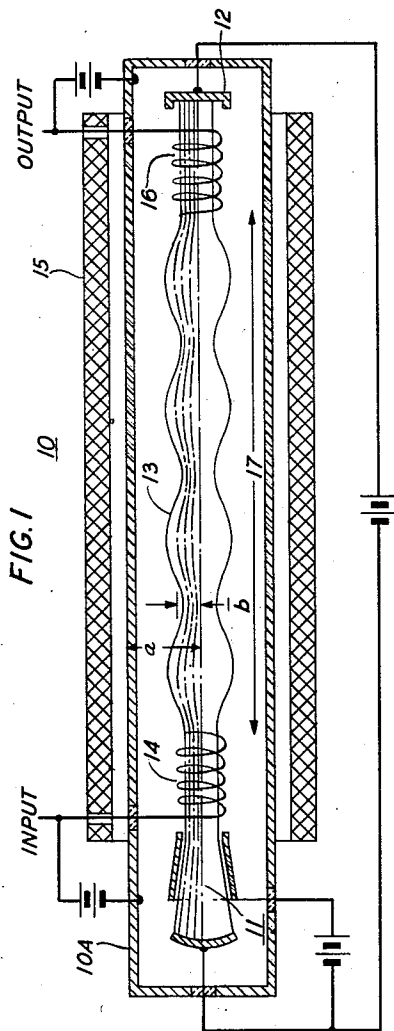
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R. C. FLETCHER
SPACE CHARGE AMPLIFIER

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2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 3

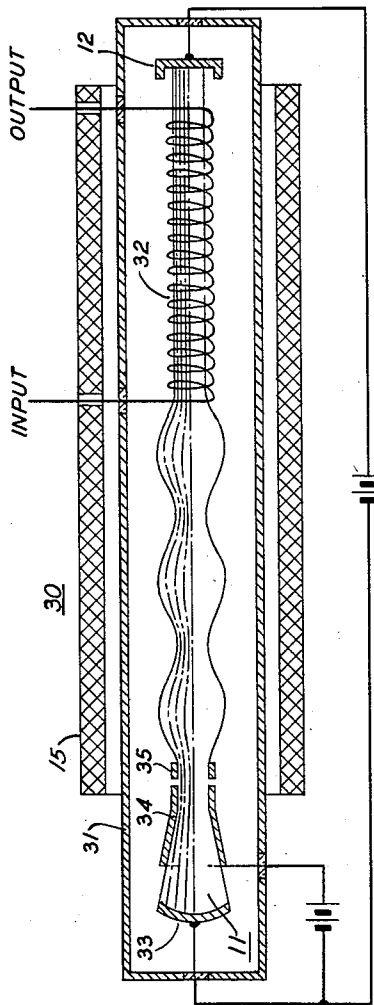
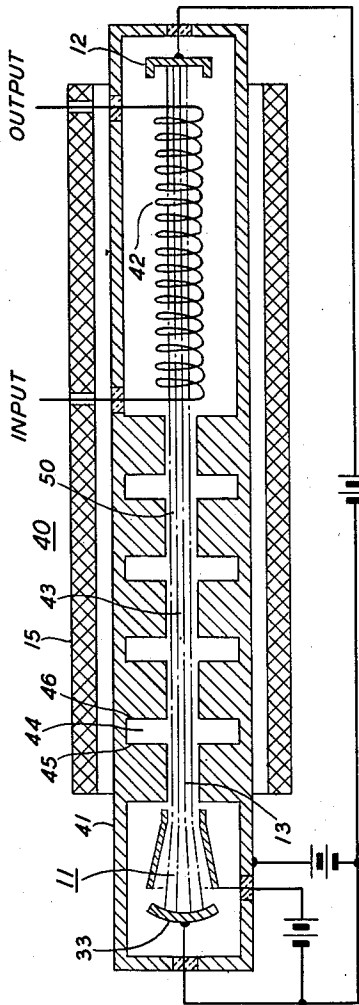


FIG. 4



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SPACE CHARGE AMPLIFIER

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This invention relates to space charge devices and, more particularly, to devices which utilize for amplification the growth of space charge waves in an electron stream. When an electron stream is velocity modulated by some impressed excitation, this excitation will be propagated along the stream by means of "space charge waves."

Hitherto, the amplitudes of space charge waves in an electron stream have been amplified by arrangements including wave propagating circuits, such as in traveling wave tubes, and electron streams with distributed or different velocities, such as in double stream tubes, for example. Additionally, it is known that by a suitable combination of decelerations and accelerations of the electron stream the amplitude of space charge waves associated therewith can be increased without any of these other expedients. In particular, amplifiers employing this method are known in which the electron stream is made to traverse successive stages, each comprising one short low-velocity drift space (i. e. a region free of external accelerating fields) and one long high-velocity drift space, and there is secured thereby amplification of space charge waves associated with the electron stream. It has also been known that by arrangements of this last general type space charge waves can be attenuated as well as amplified and that consequently, where noise exists on the electron stream in the form of space charge waves, this noise content can be reduced.

In accordance with the present invention, as in the arrangements of the last-mentioned general type, amplification of space charge waves associated with a single stream is achieved without wave propagating circuits or space charge produced velocity differences. However, in accordance with the present invention, amplification is secured by modulating periodically the trajectory of the electron stream and/or the separation of the stream from conductive surrounding walls.

In practice, it is found that an electron stream can, for purposes of analysis, be characterized as having average or D.-C. velocity and current components about which fluctuate signal or A.-C. velocity and current components. It is characteristic of the previously known arrangement which uses combinations of gradual decelerations and sudden accelerations that the amplification is secured effectively by the periodic modulation of the D.-C. velocity component of the electron stream while maintaining the D.-C. current density constant. In such arrangements, it is important to maintain parallel electron flow and so to avoid defocusing effects that tend to occur at the accelerating and decelerating gaps and in the low-velocity drift space regions. To these ends, it then becomes necessary to utilize uniform rectilinear electron flow in which initial electron velocities are all made to be substantially identical and unidirectional. Transverse space charge forces are annulled by the application of very strong magnetic fields. However, for high density electron streams, such rectilinear flow requires strong magnetic fields. Accordingly, in more conventional amplifiers it is generally inconvenient to resort

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to such flow and it is usually preferable to employ Brillouin type flow for focusing of the stream. In such flow, electrons are caused to enter a uniform magnetic field with drift space initial velocities, having no components transverse to the magnetic field which is adjusted so that the radial space charge force on each electron is balanced by the centripetal force due to its angular motion and the field. Flow of this kind is described in more detail on page 152 et seq., in a book entitled "Theory and Design of Electron Beams," written by J. R. Pierce and published by D. Van Nostrand Company, Inc., New York (1949). It is a characteristic of such flow that for magnetic fields which differ from the critical value required for constant beam diameter there results a sinusoidal oscillation of the radius of the electron beam with a frequency which is related to the strength of the magnetic field. It is a feature of one embodiment of the present invention that amplification of space charge waves on the beam is achieved by modulation of the electron beam radius. Moreover, it is a further advantage of this embodiment that it can incorporate combinations of low velocity and high velocity drift regions along the electron stream to secure additional gain and, moreover, to avoid the usual requirement for rectilinear flow in previously known arrangements of this general kind.

The invention will be better understood from the following more detailed description taken in connection with the accompanying drawings in which:

Fig. 1 shows a space charge amplifier which utilizes modulation of the beam radius by the natural oscillation in a longitudinal magnetic field, in accordance with the invention;

Fig. 2 shows a space charge amplifier which utilizes modulation of the separation between an electron beam and its surrounding conductive envelope, in accordance with the invention;

Fig. 3 shows a traveling wave amplifier wherein is incorporated a noise attenuation section which utilizes modulation of the beam radius, in accordance with the invention; and

Fig. 4 shows a traveling wave amplifier wherein is incorporated a noise attenuation section which utilizes modulation of the separation between an electron beam and its surrounding envelope in accordance with the invention.

For a better understanding of the principles of the invention, it will be helpful to analyze first the problem of amplification of space charge waves associated with a single stream.

The general problem of space charge interaction in a cylindrical beam of a varying D.-C. velocity, beam diameter, and surrounding conductive wall distance, is of too great complexity to be described in detail profitably here. However, it is possible to treat conveniently special cases which suggest the general nature of the results which would be obtained in more complex cases. By way of example, the case to be considered in detail here is that in which the D.-C. velocity, the beam diameter and the wall distance remain constant along the electron path except for sharp discontinuities at particularly chosen periodic intervals. Consideration of this case has the further advantage that in a more general analysis this mode of variation can be shown to give maximum gain.

An analysis of the space charge waves in a beam of constant diameter reveals that there exists in the beam an infinite number of propagating waves with propagation constants β of the form

$$\beta = \frac{\omega}{u} \pm \beta_p \quad (1)$$

where ω is the radian frequency of the impressed excitation, u the D.-C. velocity of the beam, and β_p a constant

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which is characteristic of each wave and which, for convenience, can be designated the space charge propagation constant. In a one dimensional analysis, it can be shown that

$$\beta_p = \sqrt{\frac{e}{\epsilon_0 m} \frac{i_0}{u^3}} \quad (2)$$

where e and m are the charge and mass of an electron, respectively, ϵ_0 the dielectric constant of free space, and i_0 and u the D.-C. current density and velocity of the electron stream, respectively. In this one dimensional analysis, there are just two waves which satisfy Equation 1. The infinite number is necessary for the three dimensional beam in order to satisfy the boundary conditions which may vary across the diameter of the beam. For the three dimensional case, it is found that the one dimensional value of β_p is reduced by a factor $\sqrt{R}$ which for convenience will be termed the space charge reduction factor and which is defined by

$$\sqrt{R} = \frac{\left(\beta - \frac{\omega}{u}\right)}{\frac{\omega_p}{u}} \quad (3)$$

where ω_p is the plasma radian frequency and is given by

$$\omega_p = \sqrt{\frac{e}{m \epsilon_0} \frac{I}{\pi b^2 u}} \quad (4)$$

where b is the radius of the electron stream and I the total D.-C. current. If we confine our attention to boundary conditions which do not vary appreciably over the diameter of the beam and consider only the waves for which $\sqrt{R} > 1$, the wave with the largest β_p will predominate, and therefore we need henceforth consider only this wave.

There can now be investigated the relation between the A.-C. current i and velocity v of a particular space charge wave. We will consider the velocity of an electron at a radius r , less than the beam radius b . In the case both of Brillouin flow and uniform rectilinear flow, for low level operation where the A.-C. quantities are small in comparison with the D.-C. quantities, to a good approximation the relationship between the current i and velocity v is given by

$$\frac{i}{v} = \frac{\omega}{\omega_p} \frac{I}{u} \sqrt{R} \left[\frac{2u J_1\left(\frac{\mu \omega b}{u}\right)}{\mu \omega J_0\left(\frac{\mu \omega r}{u}\right)} \right] \quad (5)$$

where J_0 and J_1 are Bessel functions of the zero and first order, respectively, and μ , the effective index of refraction of the electron beam, is given by

$$\begin{aligned} \mu &= \sqrt{R-1} \text{ for rectilinear flow} \\ \mu &= \sqrt{-1} \text{ for Brillouin flow} \end{aligned} \quad (6)$$

By analysis of the expression in brackets of Equation 5, it can be shown that, for small values of

$$\frac{\omega_b}{u}$$

the expression approaches unity, and, for large values of

$$\frac{\omega_b}{u}$$

it ranges both below and above unity depending on r . A reasonably good approximation is that this expression is equal to unity for all values of

$$\frac{\omega_b}{u}$$

The remaining expression in front of the brackets is similar to one which would be obtained from a one-

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dimensional analysis except for the space charge reduction factor $\sqrt{R}$. Thus, in both the expression for the space charge phase constant β_p and the ratio

$$\frac{i}{v}$$

the factor $\sqrt{R}$ is the factor by which the plasma frequency is reduced in going from a beam of infinite radius to one of finite radius.

This reduction has the following physical significance: the space charge repulsion force, which together with the inertia of the electrons brings about the plasma frequency and the resultant space charge waves, can be effectively shorted. Thus, a beam in free space is in parallel with the reactance of empty space, which tends to short out the lines of force. However, since the bunches in the beam are spaced a distance of

$$2\pi \frac{u}{\omega}$$

the fields due to any radial reactance tend to fall off radially as

$$e^{-\frac{ur}{\omega}}$$

Thus, the reactance only affects a surface layer approximately

$$\frac{u}{\omega}$$

deep; i. e., it has an appreciable over-all effect only if the beam is small compared to

$$\frac{u}{\omega}$$

This shorting effect is greatly enhanced by putting a conducting cylinder of zero reactance around the beam.

Consider now the boundary conditions at one of the discontinuities which we have been postulating. From the principle of conservation of charge it can be assumed that the A.-C. current i is continuous across a discontinuity. Furthermore, from the principle of conservation of charge, it can be shown that if second order quantities are neglected the product of the A.-C. and D.-C. velocity components of the stream is continuous across a discontinuity. Thus, if u and v represents the D.-C. and A.-C. velocities of the stream, respectively, and subscripts 1 and 2 denote opposite sides of a discontinuity, then this requires that

$$u_1 v_1 = u_2 v_2 \quad (7)$$

Let us now consider alternate drift regions which are each

$$\frac{\pi}{2} \frac{u}{\omega} \sqrt{R}$$

or a quarter space-charge wavelength in length with a discontinuity in u , a , and b , the D.-C. velocity, the tube radius, and the beam radius, respectively, at the end of each drift region. Two waves will then exist, one which has a velocity maximum and a current null at the first discontinuity, a velocity null and a current maximum at the second discontinuity, etc., and the other having nulls and maxima when the first has maxima and nulls. Let us examine one of these waves. If subscripts 1 and 2 represent values before and after a velocity maxima (located at $z=0$) respectively, we can represent the velocity and currents "before" with the aid of Equation 5 as

$$v_1 = v_{1m} \cos\left(\frac{\omega_{p1}}{u_1 \sqrt{R_1}} z\right) e^{j\left(\omega_1 - \frac{\omega_2}{u_1}\right)} \quad (8)$$

$$i_1 = i_{1m} \sin\left(\frac{\omega_{p1}}{u_1 \sqrt{R_1}} z\right) e^{j\left(\omega_1 - \frac{\omega_2}{u_1}\right)} \quad (9)$$

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where v_{1m} and i_{1m} are the amplitudes of the voltage and current before the velocity maximum. From Equation 5 and the subsequent discussion we find that

$$\frac{i_{1m}}{v_{1m}} = \frac{\omega}{\omega_{p1}} \sqrt{R} \frac{I}{u_1} \quad (10)$$

Similar expressions for voltage and current relationships apply after the discontinuity at the velocity maximum with subscripts 2 instead of 1.

Now, by using the continuity of the product of the A.-C. and D.-C. velocity at the discontinuities, there can be developed the relation

$$\frac{i_{2m}}{i_{1m}} = \frac{u_1^{3/2} b_2 \sqrt{R_2}}{u_2^{3/2} b_1 \sqrt{R_1}} \quad (11)$$

If at the next discontinuity (a velocity null), the values of u , a and b are restored to those before the first discontinuity, since the current is here continuous, we find that we have experienced a net gain as given by Equation 11.

In physical terms, to achieve gain, we need do one or any of the following at a point of velocity maximum or current minimum:

(1) Decrease the D.-C. accelerating voltage to reduce the D.-C. velocity u ;

(2) Increase the beam radius b ;

(3) Increase the space charge reduction factor $\sqrt{R}$, i. e. decrease the radius of the conductive surrounding tube. Moreover, if, instead, it is desired to attenuate a particular space charge wave, this is achieved by reversing the change in these parameters at a similar point of velocity maximum or current minimum.

The analysis given above is easily extended to include any length of drift space. If L_1 and L_2 are the lengths corresponding to drift space regions of D.-C. velocities u_1 and u_2 , respectively, and the gain G in nepers is defined as

$$e^G = \frac{i_{2m}}{i_{1m}} \quad (12)$$

Then it can be shown that

$$\cosh G = \left| -\cos \left(\frac{\omega_{p1} L_1}{u_1 \sqrt{R_1}} \right) \cos \left(\frac{\omega_{p2} L_2}{u_2 \sqrt{R_2}} \right) + \frac{1}{2} \left(\frac{u_1^{3/2} b_2 R_2^{1/2}}{u_2^{3/2} b_1 R_1^{1/2}} + \frac{u_2^{3/2} b_1 R_1^{1/2}}{u_1^{3/2} b_2 R_2^{1/2}} \right) \sin \left(\frac{\omega_{p1} L_1}{u_1 \sqrt{R_1}} \right) \sin \left(\frac{\omega_{p2} L_2}{u_2 \sqrt{R_2}} \right) \right| \quad (13)$$

Equation 13 indicates that in general the greatest gain is obtained by the maximum modulation of the factor

$$\frac{u^{3/2}}{b \sqrt{R}} \text{ i. e., } \beta_p u^3$$

Equation 13 has real values for the gain parameter G when $\beta_{p1} L_1$ and $\beta_{p2} L_2$ are each approximately an odd multiple of

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

the value of G increasing with maximum departure of

$$\frac{\beta_{p1} u_1^3}{\beta_{p2} u_2^3}$$

from unity, i. e. with increasing modulation. If λ_r is used to designate the sum of L_1 and L_2 , and so represents the repetition distance or wavelength of one cycle of modulation.

$$\lambda_r = L_1 + L_2 = \frac{n_1 \pi^{1/2}}{\beta_{p1}} + \frac{n_2 \pi^{1/2}}{\beta_{p2}} \quad (14)$$

where n_1 and n_2 are odd integers. Over a modulation cycle the average space charge propagation constant $\bar{\beta}_p$ is approximately

$$\bar{\beta}_p = \frac{\beta_{p1} L_1 + \beta_{p2} L_2}{L_1 + L_2} \quad (15)$$

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$$\bar{\beta}_p = \left(\frac{n_1 + n_2}{2} \right) \frac{\pi}{\lambda_r} \quad (16)$$

Since both n_1 and n_2 are odd their sum is even and

$$\left(\frac{n_1 + n_2}{2} \right)$$

is an integer n . Therefore

$$\bar{\beta}_p = n \frac{\pi}{\lambda_r}$$

Since

$$\bar{\beta}_p = \frac{2\pi}{\lambda_p}$$

15 where λ_p is the average space charge wavelength

$$\lambda_r = \frac{n}{2} \lambda_p \quad (17)$$

Therefore, it can be seen that a condition for gain is that the average space charge wavelength λ_p be modulated with a repetition distance λ_r which is an integral multiple n of one-half the average space charge wavelength λ_p .

One convenient arrangement for modulating the beam diameter is to utilize the natural oscillations of Brillouin type electron flow in a magnetic field. In the Pierce book mentioned above, it is shown that in Brillouin type electron flow the electrons oscillate transversely along the electron path with a radian frequency equal to the average plasma radian frequency $\bar{\omega}_p$. From the definitions of λ_p and λ_r , it can be seen that

$$\lambda_p = \sqrt{R} \lambda_r \quad (18)$$

so that the condition for gain given by Equation 17 reduces to

$$\sqrt{R} = \frac{2}{n}$$

For an oscillatory beam of this sort, the value of the space charge reduction factor $\sqrt{R}$ is approximately that for a beam of Brillouin type flow of the same average radius $\bar{b}$. It can be shown that the value of the factor $\sqrt{R}$ for such a flow always exceeds 1. Accordingly, to meet this condition and also to satisfy Equation 18, the integer n must have a value of 1, and the factor $\sqrt{R}$ will have a value of 2. For a beam in free space, i. e. in a tube whose conductive walls are remote, this corresponds to a value of

$$\frac{\omega_b}{u}$$

of approximately .9. For maximum gain per unit length, u should be as small as possible. This requires ω_b^2 to be correspondingly small. It can be seen that the higher the frequency of operation, i. e. the higher ω , the smaller should then be the average beam radius $\bar{b}$. Since thin beams are thus required at high frequencies, it may then be preferable for higher powers to utilize flat or hollow beams. For such beams, the same analysis as that developed above is applicable.

As is described on page 156 in the previously identified book of J. R. Pierce, the average cross section dimension $\bar{b}$ of an electron stream for oscillatory transverse modulations varies inversely, as the value of the uniform magnetic field B_0 . Accordingly, one technique in accordance with the invention for adjusting to the condition of gain for a given frequency range of operation and D.-C. electron velocity is by means of the appropriate magnetic field to provide the necessary beam dimensions.

In accordance with another aspect of the invention, Equation 13 indicates that gain can be also achieved by modulation of the separation from the beam of conductive walls of a beam envelope while maintaining the beam diameter and D.-C. velocity constant.

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Analysis of Equation 13 shows that for the case of constant beam radius b , D.-C. velocity u , and periodic modulation of the wall separation of the electron beam in the conductive envelope, maximum gain is achieved when the lengths L_1 and L_2 of the two drift spaces forming the two portions of a repetition cycle are each a quarter wavelength of the space charge wavelengths λ_{p1} and λ_{p2} , corresponding to their respective wall separations r_1 and r_2 . Here again, it is desirable to utilize small values of D.-C. beam velocity u and small values of

$$\frac{\omega_b}{u}$$

However, very small values of

$$\frac{\omega_b}{u}$$

result in large values of the space charge reduction factor $\sqrt{R}$ and consequently require longer drift space lengths. Accordingly a value of

$$\frac{\omega_b}{u}$$

equal to 1 usually represents a good compromise.

Now that there has been developed some theoretical basis for the principles of the invention, it will be convenient to describe more particularly some characteristic embodiments thereof.

In Fig. 1 there is shown a space charge amplifier 10 which utilizes both a succession of high velocity and low velocity regions, or voltage jumps, as in arrangements of the prior art together with modulations of the electron stream radius in accordance with one aspect of the present invention. The evacuated tubular envelope 10A, which for example, is of a non-magnetic metal such as copper, houses at opposite ends, an electron gun 11 and a collector electrode 12 in target relationship for defining a path therebetween for the electron stream 13. Such an electron gun customarily includes an electron emissive cathode surface, a heater unit, and various electrodes for focusing and accelerating the stream, which have not been shown here for the sake of simplicity, since various suitable forms therefor are known in the prior art. It is important, however, for this embodiment that the electron stream produced be adaptable for Brillouin type flow, as will be described in more detail later. For example, in a copending application Serial No. 168,202, filed June 15, 1950, by C. C. Cutler there is described a suitable gun for achieving Brillouin type flow. Input radio frequency signals are then impressed upstream on the electron path by a suitable transducer, for example, as is shown, by a short helix circuit 14, to which is applied the input signal waves for propagation therealong and interaction with the electron stream whereby signal modulations are impressed on the electron stream in the form of A.-C. velocity and current components on the corresponding D.-C. components in the manner generally characteristic of helix-type traveling wave tubes. By suitable voltage supply means the helix is maintained at a high D.-C. potential with respect to the envelope which encloses the drift space region 17 along the electron path beyond the end of the input helix and so defines a high velocity region.

Several considerations are important in fixing the optimum length of this input circuit 14. It is generally advantageous to provide sufficient length to insure adequate bunching of the electron stream whereby spurious space charge waves are made negligible. Additionally, in this illustrative embodiment the downstream end of the circuit forms a decelerating gap, being the starting point of a low-velocity drift space, where the beam radius is to be permitted to expand in accordance with the invention. Throughout the specification and the claims, the term "downstream" is used to denote a point or location closer to the collector than the point or lo-

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cation with which it is being compared. Conversely, the term "upstream" denotes a point or location closer to the gun than the point with which it is being compared. Accordingly, this end point should be adjusted to be approximately at a region of A.-C. velocity maximum or current minimum of the space charge wave to be amplified, consistent with the principles developed above. Alternatively, the input circuit can be terminated sooner so long as the high velocity region is extended by suitable electrode means to a region of A.-C. velocity maximum. In any case, it is generally desirable to terminate the input circuit in a way to avoid undesirable reflection effects. It is, of course, necessary to adjust the D.-C. voltage and the geometry of the input circuit so that the D.-C. velocity of the stream and the axial velocity of the desired space charge wave are sufficiently alike for interaction. Additionally, to minimize partition effects of the input circuit on the electron stream and to provide the desired transverse modulation of the electron stream diameter, magnetic flux producing means, as for example a solenoid 15, surrounds the envelope to produce a longitudinal magnetic field. In accordance with one aspect of the invention, the D.-C. velocity and current density components of the electron stream in the region through the input circuit and the strength of this magnetic field are chosen so that Brillouin type flow exists therethrough. Moreover to this end, the electron gun 11 is adjusted so that the electron stream is inserted into the longitudinal magnetic field with no transverse components, as is important for Brillouin flow. Then, beyond the end of the input circuit 14 where the beam is in a low-velocity drift space in the field of the low D.-C. voltage on the tube envelope, the conditions for Brillouin type flow are no longer satisfied and the beam radius will first expand and then oscillate in accordance with the principles set forth above, with an average radius $\bar{b}$, which is related to the strength of the magnetic field provided by the solenoid 15. For maximum gain, it is desirable that along this low velocity drift space region the value of the space charge reduction factor $\sqrt{R}$ be 2, as discussed above. From this relationship, there can be derived operating conditions for maximum gain. Beyond this input region the radius of the electron stream 13 will oscillate transversely, as shown, along the electron path. Downstream along the electron path, a suitable output transducer, for example, a helix circuit 16 of a kind similar to that which forms the input transducer, derives radio frequency waves from the A.-C. components of the electron stream in the manner known for helix-type traveling wave tube operation. In accordance with a feature of the invention, Brillouin type flow is provided through this output helix 16 as through the input helix 14. To this end, for example, the output helix is operated at the same D.-C. potential as the input helix. To minimize transverse components, the electron stream is injected into the output helix at a node thereof. Additionally, since this output circuit is also at a high D.-C. potential with respect to the envelope, there is formed an accelerating gap between the intermediate drift section and the high velocity output section as in prior art arrangements.

In this embodiment being described, gain is realized both from the deceleration and acceleration occurring at the end of the input circuit and the start of the output circuit, respectively, as in prior art arrangements, and also by the periodic modulation of the radius of the electron stream 13 along the intermediate low velocity drift space 17 in accordance with the invention. By the use of a uniform longitudinal magnetic field adjusted to a value as described above the periodic modulation will be sinusoidal. Alternatively, it is in accordance with the invention to shape the magnetic field to be non-uniform along the intermediate drift space to effect more rectangular modulation of the beam radius to achieve more closely the idealized case analyzed.

It is consistent with the invention to modify the space charge amplifier described to include additional decelerating and accelerating gaps between the input and output circuits for increased gain. In such an amplifier, a series of electrodes along the electron path divides the intermediate drift space 17 into a series of low-velocity and high-velocity drift spaces. In accordance with the principles set forth, for example, these electrodes can be maintained at the D.-C. potential suitable for Brillouin type electron flow to provide accelerating gaps at points of A.-C. velocity nulls and decelerating gaps at points of A.-C. velocity maximums. Outside the field of these electrodes, the radius of the electron beam is permitted to increase as set forth above.

In accordance with another aspect of the invention, amplification can be secured by periodically varying the diameter of the envelope in the drift space intermediate the input and output transducers. Fig. 2 shows a space charge amplifier 20 which secures amplification in this way. As in the amplifier of Fig. 1, an electron gun 11 projects an electron stream 13 longitudinally through a conductive non-magnetic cylindrical envelope 20A towards a target electrode 12. Along the stream, at opposite ends are located input and output electromagnetic wave transducers, for example, the helix circuits 14 and 16, respectively. Between the input and output transducers extends a drift space region 21. In this amplifier for gain, the radius of the envelope, i. e. the separation distance between the axis of the electron beam and the envelope wall is modulated in rectangular fashion along the electron path in accordance with the principles set forth above, the tube diameter being increased at points 22 along the stream corresponding to D.-C. velocity nulls and being decreased at points 23 corresponding to A.-C. velocity maximums. This arrangement is to be distinguished from wave transmission circuits used in filter-type traveling wave tubes, in that in the present structure the envelope forms a drift space region, which means that along this region the only fields acting on the electrons are the space charge waves associated with the electron stream and there is an absence of any other traveling wave for interacting with the electron stream. As a consequence, the present tube has a much broader band width than is characteristic of filter type traveling wave tubes. In its simplest form, all the amplification is achieved by modulating the envelope radius in this way. In this case, it is preferable to utilize Brillouin flow throughout the D.-C. potentials on the input and output transducers 14 and 16 as well as on the envelope 20A, and the longitudinal magnetic field provided by the flux producing solenoid 15 are adjusted for Brillouin type flow along the entire electron path. Alternatively, additional gain can be secured by means of decelerating and accelerating gaps, for example, at the end of the input transducer and the start of the output transducer, respectively, as in the amplifier of Fig. 1. In this case, as there, the input and output transducers would be operated at higher D.-C. potentials than the envelope which encloses the drift space region 21. In that case, moreover, it is possible to vary the beam radius along the electron path to secure gain by this expedient too as in the arrangement of Fig. 1. Additionally, for still greater gains, it is possible to include additional decelerating and accelerating gaps along the drift space.

In addition to use for amplification of space charge waves which are excited by impressed waves, the principles of the invention can be applied to the attenuation of noise waves which are invariably present at the input end of the electron stream and which otherwise tend to be amplified in the same way as the signal intelligence. Initial thermal fluctuations inherent in conventional electron beam sources and partition effects of accelerating and focusing electrodes are among the most significant factors which ordinarily prevent complete homogeneity of the electron stream at the point of insertion into the

region of first interaction with the input transducer means. Such non-homogeneities in the electron stream introduce noise space charge waves which thereafter react as regular signal space charge waves, producing A.-C. velocity and current noise components on the electron stream. For a good signal-to-noise ratio it is important to cancel or remove such noise components from the electron stream before the impression of signal components.

To this end, attenuation of noise can be effected if at regions of noise velocity nulls or minima, we do one or more of the following: increase the D.-C. accelerating voltage to increase the D.-C. velocity; decrease the average beam radius; and decrease the space charge reduction factor, as by increasing the radius of a conductive surrounding envelope. Similarly, attenuation can be effected by opposite changes at regions of noise velocity maxima or current minima.

Fig. 3 shows a traveling wave tube 30 in which there is incorporated a noise space charge attenuation section in accordance with this aspect of the invention. As in traveling wave tubes of the kind well known in the art, within an evacuated envelope 31, which can as above be of some suitable non-magnetic metal, such as copper, or even a dielectric material such as glass an electron gun 11 and a target electrode 12 define a path for an electron stream 13. Along the amplifier portion of the path there extends a wave transmission circuit, for example, a helix 32 for propagating electromagnetic waves for interaction with the stream. Radio frequency waves are applied by suitable input means to the upstream end of the wave circuit 32 and derived by suitable output means for utilization at the downstream end of the wave circuit. Magnetic-flux producing means, for example a solenoid 15, external to the envelope are used to provide a longitudinal magnetic field which cooperates with the D.-C. potential on the wave circuit to effect Brillouin type electron flow past the wave circuit. A noise attenuation drift space section is inserted along the path of electron flow intermediate between the cathode emissive surface 33 of the electron gun and the input end of the wave transmission circuit. In accordance with the present invention, attenuation of the noise space charge waves on the electron stream is achieved by modulating the electron stream radius, as discussed above in the embodiment of Fig. 1, except that now increases and decreases in beam radius are made to coincide instead with noise velocity nulls and maxima, respectively. It should be evident that a variety of ways can be devised to this end. In the arrangement shown, the electron stream, once beyond the field of the principal various focusing and collimating electrodes of the electron gun, shown schematically as the electrode 34, is inserted in a high-velocity drift space enclosed by the hollow conductive cylindrical electrode 35 which extends along a portion of the electron path which can be an anode of the gun structure. The potential on this electrode is adjusted for Brillouin type flow therethrough. Beyond this electrode, the stream is inserted into a low-velocity drift space. To secure attenuation of the noise space charge waves, the transition point between the high-velocity drift space and the low-velocity drift space, i. e. the decelerating gap, should be a point of noise velocity null or current maximum since it is a point both of increasing beam radius and decreasing D.-C. velocity. At the end of this low-velocity drift space, the beam enters into the field of the wave circuit 32 which is maintained at a high D.-C. potential. In the low-velocity drift space, intermediate between the high potential electrode and the wave circuit, the beam radius is made to oscillate in accordance with the invention whereby attenuation of the noise space charge waves is accomplished. It is further advantageous to have the electron stream enter the wave circuit 32 at a noise velocity maximum to avoid amplification of the noise at the transition point which acts as an accelerating gap.

Fig. 4 shows a traveling wave tube 40 in which there

is incorporated an alternative arrangement for attenuating noise space charge waves. Within a conductive non-magnetic envelope 41, an electron gun 11 and a collector electrode 12 define a path for an electron stream 13. Along an amplifier portion of the path there extends a suitable wave transmission circuit, such as the helix 42, which is provided with suitable input and output transducers shown schematically here. Magnetic-flux producing means 15, external to the envelope, provide a longitudinal magnetic field which cooperates with the D.-C. potential on the wave circuit to effect Brillouin type flow therpast. As above, a noise attenuation drift space section 43 is inserted between the cathode surface 33 of the electron gun and the input end of the wave circuit. In this embodiment, attenuation of the noise space charge wave is secured by modulating the separation between the electron stream and the conductive envelope 41 in the drift space 43 to vary the space charge reduction factor therealong in accordance with the principles set forth above. To this end, the inside surface of the envelope is provided with a series of lateral slots or corrugations 44 along the path of electron flow. For attenuation of a particular noise wave, the slots are positioned so that the separation to the beam axis increases at points 45 of noise velocity maxima and decreases at points 46 of noise velocity nulls. To simplify the focusing problem, it is generally advantageous to provide for Brillouin type flow through this attenuation section, and accordingly, the D.-C. potentials on the wave transmission circuit and the envelope can be substantially equal. It should be evident that the corrugated conductive envelope surrounding the drift space region need not be integral with the tube envelope but can instead be a separate electrode.

It should be evident that, just as for amplification there can be utilized combinations of beam radius changes, conductive wall separation changes and D.-C. velocity changes, so too for attenuation there can be employed equivalent combinations. Moreover, it can also be seen that the noise attenuation arrangements of the invention find application in any of the various devices which utilize the amplification of space charge waves impressed on an electron stream, including arrangements which obtain amplification in accordance with principles of the invention.

It is further to be understood that the arrangements described specifically above are merely illustrative of the principles of the invention. Other embodiments may be devised by a worker skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a microwave device, an electron source and target electrode defining a path for an electron stream which is initially characterized by D.-C. velocity and current components on which are superimposed cyclical space charge variations in the form of noise velocity and current components, signal input means along said path, signal output means downstream relative to said input means, means for maintaining the transverse dimensions of said stream substantially uniform while traversing the input and output means, conductive envelope means upstream relative to said input means forming a drift space along the electron path and characterized by a periodic series of lateral slots, the separation between the envelope and the axis of the stream increasing at points of noise velocity maximum and decreasing at points of noise velocity minimum.

2. In a microwave device, an electron source and target electrode defining a path for an electron stream which is characterized by D.-C. velocity and current components on which are superimposed cyclical space charge variations in the form of noise velocity and current components, signal input means along said path, signal output means downstream relative to the input means, means for

maintaining the transverse dimensions of said stream substantially uniform while traversing the input and output means, envelope means upstream relative to the input means forming a drift space of the electron path and characterized by a periodic series of lateral slots along the electron path, the separation between the axis of the stream and envelope increasing at points of noise velocity maximum and decreasing at points of noise velocity minimum.

3. In a microwave device, an electron source and target electrode defining a path for an electron stream which is characterized initially by D.-C. velocity and current components on which are superimposed cyclical space charge variations in the form of longitudinal noise velocity and current components, signal input means along said path, signal output means downstream relative to the input means, means for maintaining the transverse dimensions of said stream substantially uniform while traversing the input and output means, envelope means upstream relative to the input means forming a drift space of the electron path to the signal input means, and magnetic means for modulating periodically the diameter of the electron stream through the drift space, the diameter increasing at points of noise velocity minimums and decreasing at points of noise velocity maximum.

4. In a microwave device, an electron source and target electrode defining a path for an electron stream which is characterized initially by D.-C. velocity and current components on which are superimposed cyclical space charge variations in the form of longitudinal noise velocity and current components, signal input means along said path, signal output means downstream relative to the input means, means for maintaining the transverse dimensions of said stream substantially uniform while traversing the input and output means, envelope means upstream relative to input means forming a drift space which extends to the signal input means at a region of noise velocity maximum, voltage supply means for maintaining the D.-C. field acting on the electron stream in the drift space negative with respect to the D.-C. field acting on the electron stream along the signal input means, and magnetic means providing a magnetic field along the electron path adjusted for cooperating with the D.-C. field in the drift space for periodically increasing the diameter of the electron beam at points of noise velocity minimums and decreasing at points of noise velocity maximum and in the region of and cooperating with the D.-C. field along the path of the signal input means for maintaining constant beam diameter.

5. In a microwave device, an electron source and a target electrode defining a path for an electron stream capable of supporting cyclical space charge variations, signal input means upstream along the path for superimposing longitudinal alternating velocity and current components on said stream for travel therealong, means for maintaining the transverse dimensions of said stream substantially uniform while traversing said input means, signal output means downstream along the path for deriving amplified waves from said longitudinal alternating velocity and current components, magnetic electron-stream collimating means, at least one means forming a drift-space along the electron path upstream from said output means including an envelope surrounding and extending axially along said electron stream, and means for cyclically varying the relative transverse-to-the-electron-path spacing between said envelope and said electron stream periphery for obtaining a desired amplification characteristic along the drift-space the periodicity of the cyclical variations being an integral number of half wavelengths of the average cyclical space charge variations in said stream.

6. In a microwave device, the combination as claimed in claim 5 wherein the means for cyclically varying the spacing between the envelope and the electron stream periphery comprises a periodic series of lateral slots in the envelope wall.

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7. In a microwave device, the combination as claimed in claim 5 wherein the means for cyclically varying the spacing between the envelope and the electron stream periphery comprises a periodic series of lateral slots in the envelope wall, said slots being located at points of A.-C. velocity minimum of the electron stream.

8. In a microwave device, the combination as claimed in claim 5 wherein the means for cyclically varying the spacing between the envelope and the electron stream periphery comprises a magnetic field in the drift space for modulating the beam diameter.

9. In a microwave device, the combination as claimed in claim 5 in further combination with voltage supply means for maintaining the D.-C. fields in the drift space region negative with respect to the D.-C. fields in the signal input and output regions.

10. In a microwave device, an electron source and target electrode defining a path for an electron stream, said stream being characterized in that it has cyclical space charge variations, signal input means along the path, signal output means downstream relative to said input means, means for maintaining the transverse dimensions of said stream substantially uniform while traversing the input and output means, conductive envelope means upstream relative to said input means forming a drift space along the electron path and characterized by a periodic series of lateral slots for modulating the envelope separation to the axis of the electron stream, said conductive envelope means being a non-propagating member and said input and output means being coupled to other than said envelope means, the periodicity of said slots being an integral number of half wavelengths of the average cyclical space charge variations in said stream.

11. In a microwave device, an electron source and target electrode defining the path for an electron stream capable of supporting cyclical space charge variations, signal input means positioned upstream along said path for coupling an input signal to the electron stream in the proper phase for desired interaction to impress upon

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said stream longitudinal alternating velocity and current componets, means for maintaining the transverse dimensions of said stream substantially uniform while traversing said input means, signal output means positioned downstream along said path at such point that the electron stream is coupled to it in the proper phase for desired signal output, an envelope surrounding the electron path along a drift-space whose separation from the electron stream is a predetermined function of distance along said path and of the average cyclical space charge variations in said stream, said envelope along said drift-space being a non-propagating member, and means forming within said envelope a magnetic field parallel to the electron path and of such intensity that space-charge waves corresponding to said input signal will propagate along the stream.

12. A microwave device comprising means for producing an electron beam which has cyclical space charge variations, means for varying the amplitude of the space charge variations between two points on the beam path, said last-mentioned means comprising means abruptly introducing the beam into a drift region of low potential from a region of high potential to periodically vary the diameter of the beam, the periodicity of the diameter variations being an integral number of half wavelengths of the average wavelength of the space charge variations, and means for maintaining the diameter variations during transversal of the drift region by the beam, and input and output means for coupling signals to and from said beam.

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