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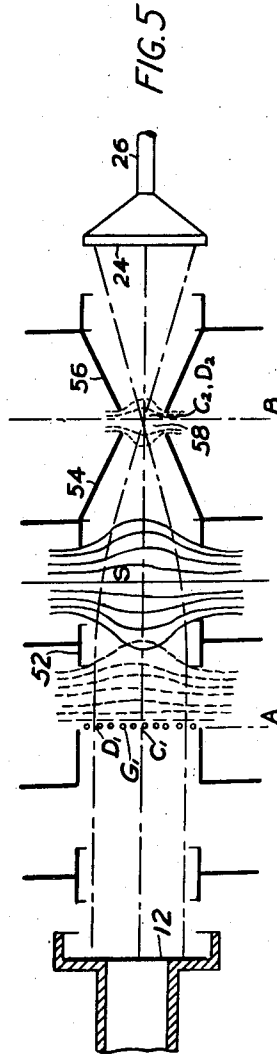
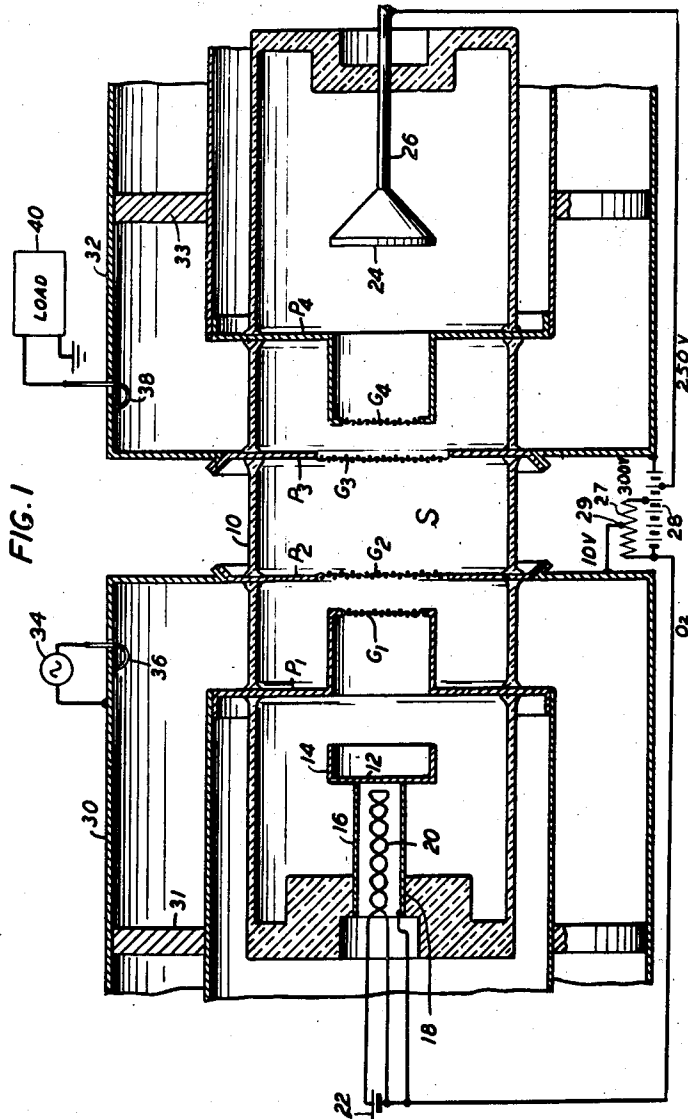
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ELECTRON TRANSIT TIME TUBE

Filed Nov. 15, 1946

3 Sheets-Sheet 1



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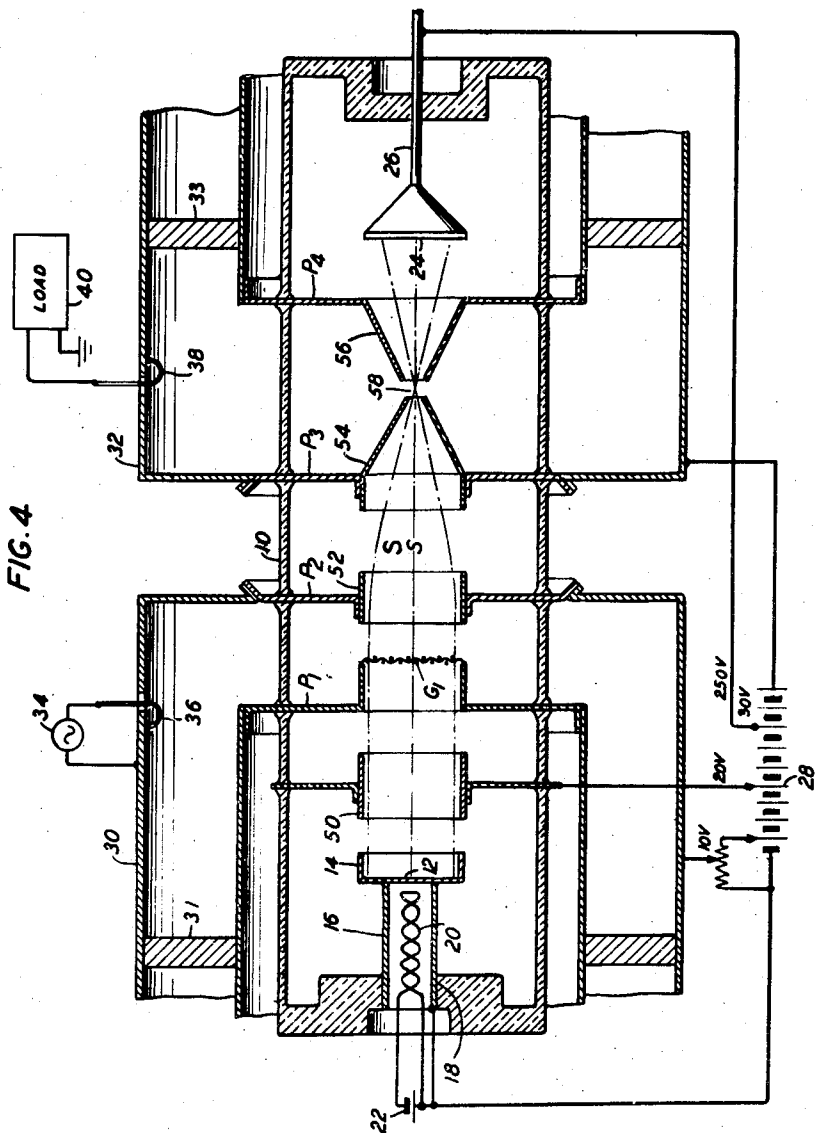
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UNITED STATES PATENT OFFICE

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ELECTRON TRANSIT TIME TUBE

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Application November 15, 1946, Serial No. 709,925

18 Claims. (Cl. 332-13)

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This invention relates to electronic apparatus intended for use at frequencies so high that electron transit time effects play a controlling part in the operation.

This application is a continuation-in-part of my copending application for Noise reduction in transit time tubes, Serial No. 422,502, filed December 11, 1941, since forfeited.

A principal object of the invention is to improve the signal-to-noise ratio of such apparatus. A related object is to reduce the loading of a signal source by such apparatus. Another object is to provide a system under which electrode spacings of such apparatus may be less critical than has hitherto been possible.

In the adaptation of electron discharge devices to ever higher frequencies remarkable results have already been obtained by the use of so-called electron velocity variation devices. In general, the mode of operation of these devices is that an electron stream is projected through a short input region or "gap" across which there exists a high frequency electric field sustained, preferably, by a cavity resonator coupled thereto and to which the input signal is applied. Electrons which traverse the gap while the field is in a direction to assist them are accelerated and electrons which traverse the gap one half cycle later when the field is in a direction to retard them are decelerated. Thus the electron stream issuing from the gap, while it is of substantially even density, issues with speed variations impressed upon it.

The electron stream is next caused to pass through a region, usually field-free termed a "drift space," in which the faster electrons overtake the slower ones, until substantial density variation, termed "bunching" or "grouping," results. The bunched electron stream then passes through or otherwise influences suitable output loading means from which the signal energy carried by the bunches is withdrawn. Such output loading means may comprise, for example, a short gap similar to the input gap to which an output cavity resonator may be coupled.

Devices of this character have been open to the objection that they are excessively "noisy"; that is to say, the desired output signals are admixed with large amounts of unwanted noise signals having their origin in the device itself. These noise signals are believed to originate in part at the cathode where the thermionic emission is unavoidably random in character with respect to speed, direction and rate of emission; and in part due to random interception of electrons by the

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grids which usually bound the input gap and the output gap, and also by any accelerating or decelerating grids which may be present. They are for the most part independent of the desired signal and, when the latter is weak, may entirely mask it.

So far as is known to applicant, no means have heretofore been proposed for eliminating or reducing this objectionable noise; rather, it has been generally accepted as an inherent defect in or objection to this type of apparatus.

With the apparatus of the invention the unwanted noise components in the output of the device are drastically reduced. The invention is based upon the discovery that by modifying existing apparatus in a small but important particular, the signal frequency components of the noise energy delivered to the electromagnetic field in the input gap by random fluctuations in the velocity and density of the incoming electron stream may be caused to cancel out in the course of the traversal of the gap. To this end the length and potential of the input gap are so adjusted that the electron transit angle across it is not the small fraction of a half cycle of the applied signal frequency as heretofore employed, but is, on the contrary, a full signal cycle or a multiple, preferably a large multiple, thereof.

It is by no means obvious that a device so adjusted will operate satisfactorily either with respect to its signal translating capacity or with respect to noise reduction. More specifically, it is by no means obvious that its input impedance and/or its transconductance will have satisfactory values, or that any noise reduction will result. Such, however, is the case, as will be apparent from the detailed description of the mode of operation of the device which ensues.

The invention will be fully understood from the following detailed description of a preferred embodiment thereof, taken in conjunction with the appended drawings, in which:

Fig. 1 is a broken cross-sectional view of a translating device embodying the principles of the invention;

Fig. 2 is a diagram of assistance in understanding the operation of the invention;

Fig. 3 is a schematic view of a part of the apparatus of Fig. 1;

Fig. 4 shows a modification of the apparatus of Fig. 1 and

Fig. 5 is a diagrammatic view of parts of the apparatus of Fig. 4 showing potential distributions therein.

Referring now to the figures, Fig. 1 illustrates the invention as applied to a system in which a

compact air-tight envelope serves to define an evacuated space in which the working electrons may be thermionically produced and undergo their proper movements, the comparatively large cavity resonators which serve as tuned circuits being disposed outside of the envelope. Thus a cylindrical evacuated envelope 10 having re-entrant end walls is provided, within which are mounted in axial succession a cathode, grids of an input gap, a drift space, grids of an output gap, and a collecting anode. The cathode may comprise a flat plate 12, suitably treated on its outer face with thermionically emissive material and surrounded with a stream-directing flange 14. It may be mounted on a conducting sleeve 16 which passes through the reentrant end wall of the envelope, being sealed into the latter in air-tight fashion, as at 18. The cathode may be maintained at a suitable temperature for emission by a heater element 20 mounted immediately behind it, which element may have heating current fed to it from an external source 22 through conductors which pass through the sleeve 16.

Since the function of the cathode is merely to provide a stream of electrons whose evenness, both as to velocity and density is as great as possible, any cathode construction which meets these requirements may be employed. An eminently suitable one is described in detail in applicant's United States Patent 2,406,850, issued September 3, 1946.

The anode 24, whose function is merely to collect the electrons whose high frequency energies are spent, may be similarly mounted in the opposite end of the envelope 10, being supported, for example, on a conducting member 26 which is sealed into the envelope wall, over which operating anode potential may be supplied, as from a suitable potential source 28.

Spaced along the path of the electron stream between the cathode and the anode are placed grids G_1 , G_2 , G_3 , G_4 of which G_1 and G_2 define the input gap and G_3 and G_4 define the output gap. The output gap is spaced from the input gap by a drift space S . The grids may be in the form of wire mesh screens, perforated plates, or an array of slats, as preferred. The primary consideration dictating the grid form is that they shall act to the least extent possible as obstacles to the electrons of the stream and yet be substantially perfect shields, confining the electromagnetic fields entirely within the gaps. Each of the grids may be mounted centrally in an aperture of a plate P_1 , P_2 , P_3 , P_4 of conducting material which extends through the envelope wall to provide a point or line of contact with an external circuit, for example a cavity resonator. Thus the supporting plates P_1 , P_2 of the grids G_1 , G_2 make firm contact with the walls of an input cavity resonator 30 and the plates P_3 , P_4 which support the grids G_3 , G_4 make similar contact with the walls of an output cavity resonator 32. In order to concentrate the electric fields as much as possible in the gaps, one plate of each gap, for example the plates P_1 and P_4 , may be given a re-entrant form, the grids G_1 and G_4 being mounted at the reentrant central portions thereof.

Signal energy may be supplied to the input resonator from a high frequency signal source which is symbolically represented by the generator 34 by means of a coil or loop 36 which extends within the cavity 30 through a hole in the cavity wall in position to link a small amount of the magnetic field within the cavity. Signal energy may be withdrawn from the system by a loop

38 similarly coupled to the output resonator 32 and supplied to any suitable load, symbolically represented by the block 40. The resonators 30, 32 may be tuned by adjustment of the position of conducting rings 31, 33. As is well known, when such resonators are excited, high frequency electric fields exist between the grids which define the gaps, in a substantially axial direction, which fields interact with the electrons in their movements across the gap to cause variations in their velocities. The output gap, defined by the grids G_3 , G_4 , may be short, and may be maintained at a comparatively high potential, as by connection to a suitable point of the source 28, in order that the electron transit angle across it may be short. Following their passage across the output gap, in which their high frequency energies are delivered to the electromagnetic field of the resonator 32, the spent electrons are collected by the anode 24. To prevent the emission of secondary electrons from the anode due to bombardment of it by the primary electrons of the stream and also to minimize heating of the anode, the potential of the anode 24 should be maintained at a suitably low value, as by connection to a suitable point of the source 28.

In accordance with the invention the transit angle across the input gap defined by the grids G_1 , G_2 is preferably an integral number of complete cycles at the signal frequency. Furthermore, it is preferably more than one full cycle, i. e., it is 4π , 6π , 8π , etc., radians. This result is preferably secured by maintaining the electrodes which define the gap at a low potential so that the passage of electrons across it is slow, rather than by giving it greater geometrical length. Accordingly, it is shown in Fig. 1 as occupying no more space than the output gap, but is maintained at a much lower potential, for example 10 volts as compared with 300 volts for the output gap. This simplifies manufacture by permitting the input and output gap electrodes to be constructed to the same specifications. To provide this low input gap potential and to permit of its precise adjustment, a potentiometer 27 is connected across a part of the source 28, a movable contact element 29 thereof being connected to the input cavity resonator 30.

If desired, however, large geometrical length may be resorted to as a means for obtaining large electrical length.

One effect of the novel arrangement is greatly to reduce the noise output of the apparatus. Consequently, to reap its full advantage it is preferable to reduce, in so far as is possible, all sources of noise at the input. To this end a separate accelerating grid between cathode and input gap has been eliminated, electron impacts on such a grid being one of the worst sources of noise in devices of this character. Instead, reliance is placed on the steady voltage of the input gap grid G_1 to draw the electrons from the cathode 12 and into the gap. The field strength in this cathode-to-grid space must not be so low that the electrons merely drift away from the cathode in all directions. They should, rather, be given a positive acceleration toward the gap. Otherwise, especially with high cathode emission, space charge effects might occur, for example, a virtual cathode might be formed so close to the input gap as to alter the operation of the apparatus. To obtain positive accelerations in the cathode space and still not cause the electron stream to reach high velocities at the gap, the cathode should preferably be placed close to

the gap; for example about 1 millimeter distant therefrom.

In the operation of this apparatus, the electrons, being accelerated in the cathode space from which all high frequency fields are excluded by the shielding effect of the grid G₁, move toward the latter and enter the input gap in a continuous, low velocity stream and proceed to traverse it. As they do so they are acted upon by the high frequency field which at one time is in a direction to accelerate their forward movement and one half cycle later in a direction to impede their progress.

From elementary kinematic considerations it might be thought that when the transit time within the gap occupies a whole number of cycles, the effects of the velocity variations due to the field would "average out"; more precisely, that their integral over the transit time would vanish. For example, it might be expected that there would be an effect similar to the aperture effect familiar in the sound film field, by virtue of which no signal can be obtained from a sound film with an aperture whose length is equal to a whole number of wave-lengths of the sound track. Such, however, is not the case as may be seen from the following considerations.

The electrons are all injected into the input gap with the same initial velocity, which depends only on the voltage of the gap measured with respect to the cathode. They proceed to travel across the gap. While in the gap they are alternately accelerated and retarded by the signal frequency electric field. Therefore their velocities are alternately increased and decreased, fluctuating about some mean value. Now if at the instant at which a certain electron enters the gap the field is of a polarity such as to accelerate the electron, its mean velocity throughout the gap will exceed its initial velocity, while if the field polarity is such as to retard the electron, its mean velocity through the gap will be always less than its initial velocity. The electrons are injected into the gap in a substantially constant stream, so that for those entering at one instant their mean velocities exceed their initial velocities and for those entering at another instant, for example, one half cycle later at the signal frequency, their mean velocities are less than their initial velocities. The effects of differences in mean velocity are cumulative over the gap length whereas the effects of the oscillating velocities are not. Under these conditions the electrons having greater mean velocities tend to overtake those having lesser mean velocities so that a grouping or bunching of electrons takes place within the input gap itself.

More precisely, neglecting space charge effects, an electron in an electric field moves in accordance with the law

$$eE = ma \quad (1)$$

where

e = electronic charge

E = electric field strength

m = electronic mass

a = acceleration.

If the field E is a simple oscillating function of time, of amplitude E_1 and periodicity ω , (1) may be written

$$a = \frac{e}{m} E_1 \cos(\omega t) \quad (2)$$

This may be integrated to give the velocity

$$v = \frac{eE_1}{m\omega} \sin(\omega t) + C \quad (3)$$

where C is a constant of integration. But (3) must hold throughout the transit, i. e., it must hold at the commencement of the transit when the electron enters the gap at a time t_a with a velocity u_0 . Thus, as a special case of (3)

$$u_0 = \frac{eE_1}{m\omega} \sin(\omega t_a) + C \quad (4)$$

whence

$$C = u_0 - \frac{eE_1}{m\omega} \sin(\omega t_a)$$

so that (3) may be rewritten as

$$v = \frac{eE_1}{m\omega} \sin(\omega t) + u_0 - \frac{eE_1}{m\omega} \sin(\omega t_a) \quad (5)$$

For any particular electron which enters the gap at $t = t_a$, (5) describes a velocity which oscillates sinusoidally in time with a periodicity ω about an average velocity which is independent of time but depends on the phase of the field at the instant of entry.

Referring to Fig. 2, which shows the positions of two electrons as functions of time in the input gap, both electrons enter the gap with an initial velocity u_0 , given by the initial slopes of their curves. Electron A enters when the field, as indicated by the curve E of Fig. 2, is zero and increasing in a direction to retard it. Hence this initial velocity is the greatest velocity which the A electron ever attains. Assuming that two full periods of the field oscillation are required for the transit, its velocity will oscillate, as it crosses the gap, between this initial greatest value given by

$$v_{\max. a} = u_0 \quad (6)$$

and a value given by

$$v_{\min. a} = u_0 - \frac{2eE_1}{m\omega} \quad (7)$$

the average being given (from (5)) by

$$v_{av. a} = u_0 - \frac{e}{m} \frac{E_1}{\omega} \quad (8)$$

It is otherwise with the electron B, which enters an odd number of half cycles later when the field is again zero and increasing in a direction to accelerate it. It enters, again, with the initial velocity u_0 but the latter is now the least velocity which this electron ever attains, the velocity oscillating between

$$v_{\min. b} = u_0 \quad (9)$$

and

$$v_{\max. b} = u_0 + \frac{2eE_1}{m\omega} \quad (10)$$

its average being

$$v_{av. b} = u_0 + \frac{eE_1}{m\omega} \quad (11)$$

Similarly, for electrons entering at various other instants of the signal cycle, their average velocities are dependent on the phase of the signal at the instant of entry into the gap.

It is evident from the diagram of Fig. 2 that, if t_a' and t_b' be the instants of emergence from the gap for the A and B electrons respectively, $t_b' - t_a' < t_b - t_a$. In other words, after the electrons have traveled the full length of the gap in Fig. 2, they are closer together than they were when they entered the gap, thus creating a group or region of increased charge density. The same phenomenon will occur in like manner with others of the electrons which may enter at instants between t_a and t_b , their courses lying be-

tween that of the A electron and that of the B electron. Similarly, an electron C, which enters the gap at an instant t_c a full cycle later than the A electron, will follow a course like that of the A electron but at a later time and therefore the time between the emergence from the gap of the C electron and that of the B electron will be greater than the time elapsing between their entries, i. e., $t_c' - t_b' > t_c - t_b$ so that a spread between these electrons will have occurred, resulting in a region of reduced charge density.

Repetition or multiplication of this process for all the electrons of the stream evidently results in a bunching or grouping of electrons at the output end of the input gap, i. e., at the grid G_2 . In case there is any residual velocity variation as the electrons pass this grid, the grouping due to the velocity variations imparted to them in the gap may be accentuated as the electrons pass through the drift space S, which may cause additional grouping. This, however, is not relied upon, the grouping secured in the input gap being by itself sufficient to constitute an alternating conduction current which, on passage through the output gap defined by the grids G_3 and G_4 induces fluctuations in the fields of the output cavity resonator 32. It is of interest to note the effect on velocity variation of an input gap whose transit angle is adjusted, in accordance with the invention, to a whole number of cycles. For small signals this condition is symbolized to a good approximation by putting, in (5), $\omega t = 2n\pi + \omega t_a$. Thus

$$v' = \frac{eE_1}{m\omega} \sin [2n\pi + \omega t_a] + u_0 - \frac{eE_1}{m\omega} \sin \omega t_a$$

$$= u_0 + \frac{eE_1}{m\omega} [\sin 2n\pi \cos \omega t_a + \cos 2n\pi \sin \omega t_a - \sin \omega t_a]$$

or

$$v' = u_0 \quad (5a)$$

so that the electrons all emerge with the same speed, i. e., the speed u_0 with which they enter, and therefore with the same energy $\frac{1}{2}mu_0^2$. This is due to the fact that accelerations received at one part of the input gap are compensated by equal decelerating forces received at another part of the gap. Thus no network is done by the input signal on any electron.

Thus, ideally, apart from variations in the injection speed u_0 , the electron stream as it emerges from the input gap is devoid of velocity variation, accelerating forces received by the electron at one part of the gap and at one instant of the cycle being counterbalanced and nullified by equal and opposite decelerating forces received by it in a further part of the gap and at a later instant of the cycle.

In reality, the transit angle for some of the electrons across the input gap is somewhat in excess of $2n\pi$ radians while for others it is somewhat less. Therefore, the Expression 5a which was derived by disregarding these departures, is inaccurate. The inaccuracy, however, is small, and is indeed negligible for the small signals with which the apparatus of the invention is intended to operate.

The current of the electron stream is nevertheless varied in accordance with the signal and this variation appears in the form of density variations from point to point of the stream, i. e., in a change in the space distribution of the electrons without a corresponding change in their energies. That such is the case follows immediately from Equation 5 and may easily be seen by considering

the distance to which various electrons will travel in the time occupied by a full signal cycle, depending on the phase of the field at the instant of entry into the input gap. The investigation is most easily carried out by integration of the electron velocity v as given by (5) with respect to time, between the limits t_a and $t_a + T$; thus

$$x = x_0 + \int_{t_a}^{t_a+T} v dt$$

where x_0 is the starting point of the electron at the time $t = t_a$ and x is its position after the lapse of an interval

$$T = \frac{2n\pi}{\omega}$$

i. e., at the time $t = t_a + T$.

Since the effective starting point is the entrance plane of the input gap,

$$x_0 = 0$$

and therefore from (5)

$$x = \int_{t_a}^{t_a+T} v dt = \int_{t_a}^{t_a+T} \left[\frac{eE_1}{m\omega} \sin \omega t + u_0 - \frac{eE_1}{m\omega} \sin \omega t_a \right] dt \quad (5b)$$

$$x = u_0 t \Big|_{t_a}^{t_a+T} - \frac{eE_1}{m\omega} (\sin \omega t_a) t \Big|_{t_a}^{t_a+T} - \frac{eE_1}{m\omega^2} \cos \omega t \Big|_{t_a}^{t_a+T}$$

$$= u_0 T - \frac{eE_1 T}{m\omega} \sin \omega t_a - 0 \quad (5c)$$

since the integral of $\sin \omega t$ over a full cycle is zero, while the integral of $\sin \omega t_a$, which is independent of t , is not zero.

Therefore, in the interval

$$T = \frac{2n\pi}{\omega}$$

some of the electrons will have travelled further than others, in dependence on the phase of the electromagnetic field across the input gap at the instant of entry t_a . Such differences in the distance travelled represent a bunching or grouping of the electrons at the exit plane of the input gap, i. e., a density variation in the stream which, as appears from Equation 5c, is proportional to T , the transit time across the input gap.

In the foregoing estimate of the density variation of the stream at the exit plane of the input gap, as in the earlier investigation of its velocity variation, an approximation is involved, inasmuch as it was assumed that all electrons of the stream remain in the gap for an exact whole number of signal cycles, whereas in reality the faster ones remain in the gap for shorter times and the slower ones for longer times. The inaccuracy involved, however, is small and it in no way affects the behavior of the novel system. Because the signal is represented only by a rearrangement of the electrons of the stream, without any transfer of energy from the input circuit to the stream, the input resistance of the apparatus as a whole is very high. This offers considerable advantages in some circumstances, especially when the apparatus is to be employed as an amplifier of low-level signals derived from a high impedance signal source.

In accordance with another aspect of the invention it is desirable that the output transit angle be as short as possible. To this end the electrons are accelerated in the space S between the grids G_2 and G_3 by the steady voltage between these electrodes, for example, 290 volts in the example shown, so that they may enter and

cross the output gap G_3-G_4 at high speeds. In addition, the gap is preferably made geometrically as short as possible consistently with the maintenance of substantial electromagnetic coupling between the space defined by the grids G_3 , G_4 and the body of the cavity resonator 32.

An electrical explanation of the phenomena diagrammatically depicted above and heretofore explained dynamically is best given in mathematical terms. It is known that with an infinitesimal input gap followed by a conventional field-free drift space, the current at the exit side of the drift space due to bunching or grouping therein is given by

$$I = \frac{I_0 \theta V_1}{2V_0} e^{i(\omega t + \frac{\pi}{2} - \theta)} \quad (12)$$

where

$$i = \sqrt{-1},$$

I_0 = injected electron beam current,

V_0 = direct current potential of input gap with respect to cathode,

θ = transit angle across drift space,

$$\omega = 2\pi f$$

f = signal frequency, and

$V_{1e^{i\omega t}}$ = alternating current voltage across the input gap expressed as a complex quantity.

This is shown with other symbols in an article by W. C. Hahn and G. F. Metcalf published in the Proceedings of the Institute of Radio Engineers for February 1939 at page 106.

Fig. 3 represents in highly schematic fashion the long transit angle input gap and the short transit angle output gap of the invention. The gap lengths as shown are not to be taken as indicating their geometrical lengths but only their electrical lengths. The input gap is maintained at a comparatively low potential with respect to the cathode 12 by a source B_1 and the output gap is maintained at a comparatively high potential by the source B_2 . The bounding grids G_1 and G_2 of the input gap are connected by an external circuit C_1 which, for the purposes of the analysis replaces the input cavity resonator 30. A similar circuit C_2 corresponds to the output cavity resonator 32. An electron stream indicated by broken lines, originated at the cathode 12, approaches the input gap at substantially uniform velocity, traverses it, and passes out to the right and travels to the output gap.

Consider a differential element of the input gap of length dx , located at a distance x from the exit grid G_2 . If l is the length of the gap and $V_{1e^{i\omega t}}$ is the alternating voltage across it, then the voltage across the differential gap is

$$dV = \frac{V_1 dx}{l} e^{i\omega t} \quad (13)$$

and from (12) the contribution to the total current from the variation imparted in this differential gap is

$$dI = \frac{I_0 \theta_x}{2V_0} \frac{V_1}{l} dx \cdot e^{i(\omega t + \frac{\pi}{2} - \theta_x)} \quad (14)$$

where θ_x is the transit angle from the plane x to the plane of G_2 , and the other symbols have the same meanings as before.

Now if u_0 is the injection velocity,

$$\theta_x = \frac{\omega x}{u_0}$$

Making this substitution and integrating over the length l of the input gap, there is obtained

$$I = \frac{I_0}{2V_0} V_1 e^{i(\omega t + \frac{\pi}{2})} \left[\left(i + \frac{1}{\theta_0} \right) e^{-i\theta_0} - \frac{1}{\theta_0} \right] \quad (15)$$

where θ_0 is the transit angle across the whole input gap, as an expression for the alternating current at the exit grid G_2 of the input gap due to the velocity variations imparted to the electron stream throughout the length of this gap.

If, as is contemplated will be the case, the transit angle θ_0 is large, for example two cycles or 4π radians, then to a good approximation the terms in

$$\frac{1}{\theta_0}$$

in (15) may be neglected, giving

$$I = \frac{I_0}{2V_0} V_1 e^{i(\omega t + \pi - \theta_0)} \quad (16)$$

This expression corresponds to a transconductance (ratio of output current to input voltage) of

$$Sm_2 = \frac{I_0}{2V_0} e^{i(\pi - \theta_0)} \quad (17)$$

or

$$Sm_2 = -\frac{I_0}{2V_0} e^{-i\theta_0} \quad (18)$$

It will be observed that, unlike the transconductance of the case of the short gap followed by a drift space as given by (12), the magnitude of the transconductance for the long input gap is simply

$$\frac{I_0}{2V_0}$$

and is independent of the transit angle θ_0 , which appears only in the phase angle factor $e^{-i\theta_0}$. From this it results that the system of the invention is considerably less sensitive to fluctuations to input velocity u_0 , D. C. gap voltage V_0 , and frequency than are the more conventional systems.

The current which is actually utilized in exciting the output gap is the current as it appears between the grids G_3 and G_4 , i. e., at a plane between these grids whose exact position is unimportant since the transit angle across the output gap is very short. Disregarding the bunching effect due to the space S , the contribution to the transconductance at the plane of G_3 due to drift section in the input gap may be shown to be

$$Sm_3 = -\frac{I_0}{2V_0} e^{-i(\theta_0 + \theta_s)} \quad (19)$$

where θ_s is the transit angle across the space S . It will be observed that the magnitude of this transconductance is unchanged, the effect of θ_s being merely to alter its phase angle. Thus the system is highly insensitive to fluctuations in the direct current voltage of the output gap and variations in the length of the space S on both of which the transit angle θ_s depends.

The actual transconductance of the apparatus as a whole is given by

$$Sm = Sm_3 + S'm$$

where Sm_3 is given by (19) and $S'm$ is the transconductance due to bunching in the space S . This term is complex in detail, but has a form similar to (12), i. e.,

$$S'm = \alpha \frac{I_0 \theta_s}{2\sqrt{V_0 V'}} e^{i(\frac{\pi}{2} - \theta_s - \frac{\theta_0}{2})} \quad (20)$$

75 where V' is the steady voltage of the output

gap, α is a factor relating the velocity at the grid G_2 to the velocity in an infinitesimal gap, and the other symbols are defined as before. The factor α is much less than unity for long input transit angles, and is indeed zero when the transit angle across the input gap is precisely a whole number of full cycles; i. e., when there is no velocity variation at the output plane of the input gap. This term $S'm$ is small compared with the term Sms , both because α is very small, because θ_0 is small in comparison with usual velocity variation practice, and because $\sqrt{V_0 V}$ is comparatively large. It may therefore be neglected giving, to a good approximation, for the transconductance of the apparatus as a whole

$$Sm = Sm_s = -\frac{I_0}{2V_0} \epsilon^{-i(\theta_0 + \theta_0)} \quad (21)$$

In addition to the advantages above alluded to, other advantages which follow from a transconductance of this sort will be further discussed hereinafter.

Coming now to a most important feature of the invention, namely the noise reduction feature, a brief mathematical analysis will first be given, following which the analysis will be interpreted in so far as is possible, in physical terms.

Referring again to Fig. 3, the current of the injected electron stream may be regarded as consisting of two components, an unvarying mean component and a component representing departures from this mean, i. e.,

$$q = q_0 + \sum q_n \epsilon^{i p_n t} \quad (22)$$

where

q_0 is the mean component,

q_n the amplitude of the alternating component of periodicity p_n ,

$i = \sqrt{-1}$

$t = \text{time}$

$p = \text{periodicity}$

and n takes on all values. The symbols q_n and q_0 are here used for the electron stream current components in order to distinguish from a circuit current which will appear below.

Since the system is sharply tuned to a periodicity ω , only those alternating components whose periodicities are equal or close to ω will have any effect. It is therefore sufficient to consider the effect of a single term of the summation of Equation 22, i. e.,

$$q_1 \epsilon^{i \omega t} \quad (23)$$

and components whose periodicities differ but little from ω .

The current component $q_1 \epsilon^{i \omega t}$ represents departures from the current mean in the frequency range of interest. It may be due to variations in the density, as in the shot effect, or to variations in velocity due, for example, to some of the electrons having been intercepted or deflected by the wires of a grid, or to variation in cathode temperature or the like.

The electrons are injected into the gap at an average velocity u_0 . At a distance x from the plane of entry, i. e., from the grid G_1 in the figure, the alternating conduction current due to electrons which started earlier and, traveling at the speed u_0 , have reached the point x , is therefore

$$q_1 \epsilon^{i \omega \left(t - \frac{x}{u_0} \right)} \quad (24)$$

The effect of departures from the speed u_0 will be subsequently considered. The charge density at the same point x , for this part of the conduction current, is

$$\rho_1 = \frac{\text{current}}{\text{velocity}} = \frac{q_1}{u_0} \epsilon^{i \omega \left(t - \frac{x}{u_0} \right)} \quad (25)$$

In a distance of length dx and unit cross section the electric charge at the instant t will be

$$dQ_1 = \rho_1 dx = \frac{q_1}{u_0} \epsilon^{i \omega \left(t - \frac{x}{u_0} \right)} dx \quad (26)$$

Now it is known that the current induced in an external circuit connected to a conductor by a moving charge in the neighborhood of the conductor is given by

$$QE_1 v \quad (27)$$

where Q is the charge, v its velocity and E_1 is the field at the charge due to a potential of one volt on the conductor. This has been shown in an article by W. Shockley published in the Journal of Applied Physics for October 1938 at page 635.

Now in the gap the field is substantially uniform and equal to

$$\frac{V}{l}$$

where V is the potential difference between the grids G_1 and G_2 and l is their separation. Therefore for a potential of one volt,

$$E_1 = \frac{1}{l}$$

Thus the circuit current due to the charge dQ_1 of (26) is

$$dI = dQ_1 \cdot \frac{1}{l} \cdot u_0 \quad (28)$$

$$= \frac{q_1}{u_0} \cdot \frac{u_0}{l} \epsilon^{i \omega \left(t - \frac{x}{u_0} \right)} dx$$

$$= \frac{q_1}{l} \epsilon^{i \omega \left(t - \frac{x}{u_0} \right)} dx \quad (28a)$$

The total circuit current due to the charges distributed throughout the gap is therefore the integral of (28a) over the gap length or

$$I = \frac{q_1}{l} \int_0^l \epsilon^{i \omega \left(t - \frac{x}{u_0} \right)} dx \quad (29)$$

$$= \frac{q_1 \epsilon^{i \omega t}}{\left(\frac{-i \omega l}{u_0} \right)} \left(\epsilon^{-i \omega \frac{l}{u_0}} - 1 \right) \quad (29a)$$

Since, of course, I will vary with time at the same rate as q , we may put

$$I = I_1 \epsilon^{i \omega t} \quad (30)$$

so that

$$I_1 = \frac{u_0}{i \omega l} \left(1 - \epsilon^{-i \omega \frac{l}{u_0}} \right) q_1 \quad (31)$$

or

$$I_1 = \frac{1 - \epsilon^{-i \theta_0}}{i \theta_0} q_1 = M q_1 \quad (31a)$$

where

$$\frac{\omega l}{u_0} = \theta_0 \quad (31b)$$

and

$$M = \frac{1 - \epsilon^{-i \theta_0}}{i \theta_0} = \frac{2 \sin \frac{\theta_0}{2}}{\theta_0} \epsilon^{-i \frac{\theta_0}{2}} \quad (31c)$$

Evidently M is a complex coupling factor which expresses the amount of energy transferable from the input circuit current to the electron stream and vice versa.

Now Equation 31c shows that M is zero for $\theta_0 = 2\pi, 4\pi, 6\pi$, etc.; so that, if matters are so adjusted that the electron transit angle across the input gap has any of these values, no circuit current will be induced even by a large input conduction current q_1 , the electrons of which travel with a speed u_0 . Furthermore, since the coupling factor M is small for values of θ_0 near to $2\pi, 4\pi, 6\pi$, etc., the circuit current due to electrons whose velocities are near to u_0 will be small. As a consequence, when these adjustments are made, fluctuations of the injected current about its mean value have no sensible effect on the electric field in the input gap and therefore produce no substantial noise distortion in the modulation of the stream.

It is also apparent that a given departure of the transit angle from the correct value is of less importance, from the noise standpoint, when the transit angle is a large number of cycles than when it is a small one. This is a direct consequence of Equation 31c, as may be seen by substituting

$$\theta_0 = 2n\pi + 2\delta$$

where 2δ is the error or departure from the correct value. When this substitution is made, Equation 31c becomes

$$M = \frac{\sin(n\pi + \delta)}{n\pi + \delta} e^{-in\pi} e^{-i\delta} \\ = \frac{\cos n\pi \sin \delta}{n\pi + \delta} (\pm 1) e^{-i\delta} \\ = \frac{(\pm 1)(\pm 1)\delta}{n\pi} e^{-i\delta}$$

Thus the magnitude of the coupling factor is given by

$$|M| = \frac{\delta}{n\pi} \quad (31d)$$

Thus a departure 2δ , for $n=3$, for example, gives rise to a noise coupling factor which is only one third as great as that given rise to by the same departure for $n=1$.

Thus far the stream fluctuations considered have been associated with electrons traveling at a speed u_0 , and an investigation should be made to determine how large a proportion these are of the whole number. It is known that the electrons emanating from the cathode will have various velocities at the plane of entry, the velocity distribution being the well-known "Maxwellian distribution of velocities." A particular part of the current is carried by electrons whose velocities lie in each particular range. Thus a part

$$dI_0 = I_0 \frac{m}{kT_c} v e^{-\left(\frac{mv^2}{2} - eV\right)/kT_c} dv \quad (32)$$

of the total current I_0 is carried by electrons whose velocities lie within the range dv about the velocity v . In this equation m is the mass of an electron, e its charge, k Boltzmann's constant, T_c the absolute temperature of the cathode, and V the potential of the input gap with respect to the cathode. By integration of this equation it may be shown that by far the greater part of the current is carried by electrons which lie in a very narrow range. For example, by integrating between $0.99u_0$ and $1.01u_0$, it appears that

99 per cent of the total current is carried by electrons whose velocities lie in a range of 1 per cent on either side of the mean velocity u_0 . Therefore while the coupling factor M of (31c) is identically zero for electrons of velocities exactly u_0 and M is very nearly zero for all electrons of the range $.99u_0$ to $1.01u_0$, M has substantial values only for the very small minority of 1 per cent of all the electrons, so that the circuit current induced by those electrons whose velocities depart widely from the mean velocity u_0 is correspondingly small.

The above discussion holds in the absence of a signal. In the presence of a signal the electron velocities in the gap will no longer be the same, but will be modified in the course of the modulation process as above described. This will cause a slight departure from the condition that they require a whole number of signal cycles to traverse the gap and the coupling factor M will no longer be zero for all of them. This, however, is not a serious defect because the noise thus introduced will be negligible with small signals, becoming great only with signals too strong to be masked by the noise.

Fig. 4 shows modified apparatus in which advantage is taken of the improvement in noise reduction rendered possible by the invention to eliminate all possible sources of noise. An evacuated vessel 10 is provided with a cathode assembly and an anode assembly, an input and an output cavity resonator, circuits coupled to these resonators and a source of operating potential. Each of these portions of the structure may be similar to those described above in connection with Fig. 1 and like parts are indicated by like reference characters.

In the space between the cathode and the input gap, an accelerating electrode 50 may be provided. It may be connected to a suitable point of the potential source 28, preferably at a higher potential than the input gap, so that the electrons after passing this accelerating electrode 50 are retarded and enter the input gap at low speeds. This electrode 50 is preferably not a grid but preferably has a form such that it offers entirely free passage to electrons at all parts of the beam cross section. It is included merely in order to assure passage of all electrons emitted from the cathode away from the cathode surface and toward the input gap, in order to avoid any possibility of the formation of a virtual cathode in this space. Although helpful to this end, it is not a necessary element and the simpler construction of Fig. 1 may be employed if preferred, in which case acceleration of the electrons away from the cathode surface is secured by the electrostatic field existing between the cathode and the grid G_1 of the input gap as in the case of Fig. 1.

As with the apparatus of Fig. 1, the input gap is bounded on its input side by a grid G_1 . In contrast to Fig. 1, however, the input gap is bounded on its output side by a tubular electrode, for example, a cylindrical annulus 52 offering free passage to electrons at all parts of the beam cross section. The output gap is likewise devoid of grids, being bounded on each side by a tubular electrode, for example, annuli 54, 56. The output gap electrodes 54, 56 may be tapered toward each other to form a narrow aperture 58 onto which the electron stream may be focussed. For a beam of initially circular cross section this aperture may be circular. If preferred, the beam may be focussed into the form of a sheet, either before

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passing the input gap or afterwards, in which case the narrow aperture of the output gap may be in the form of an elongated rectangle, having its long dimension aligned with that of the beam.

Thus there is but a single grid, i. e., the grid G_1 , in the path of the electron stream between the cathode and the anode. This construction minimizes all possibility of interception or deflection of electrons by grid conductors, which effects, when they are present, introduce spurious random variations in electron velocity and consequent addition to the noise in the output of the device.

Were it possible to do so, the grid G_1 would be eliminated as well since, of all the grids, G_1 , G_2 , G_3 , and G_4 of Fig. 1, the first grid G_1 introduces the greatest amount of noise. This is because it is placed at the injection side of the input gap, i. e., at a point in the electron stream ahead of the point where the signal is impressed upon it. However, it is believed that removal of this grid G_1 would be attended with disadvantages which would more than offset its advantages, inasmuch as the input gap would then be unshielded on its cathode side so that the electrostatic field within the gap would "reach out," so to speak, into the cathode space in a manner such that modulation of the beam would be different at different parts of the beam cross section with various unfortunate results. However, it has been found that the electrostatic field within the input gap may be permitted to reach out into the space S between the input gap and the output gap without serious harmful results. This permits the use of an annular electrode 52 at the output side of the input gap which is devoid of a grid, so that noise due to interception of electrons at this point is entirely eliminated.

Both of the bounding electrodes of the output gap may be constructed without grids. This is the case especially when the tubular electrodes 54, 56 which bound the output gap are tapered toward one another as shown to provide a narrow aperture 58 for the electron stream. The electric field in the output gap will, of course, "reach out" of this gap both into the space S and toward the anode; but this reaching out is far less serious with a small aperture than with a large one.

It is possible to employ this small aperture 58 in the output gap on account of the fact that this gap is intended to be maintained at a high positive potential with respect to the cathode 12 so that the electrons pass through it at high speeds. They are much more widely separated, on the average, while traversing the output gap, than they are while traversing the input gap, which they do at low speeds. Therefore a much greater contraction of the beam cross section may be tolerated at the output gap than can be tolerated at the input gap, without bringing the electrons of the stream into such close proximity with each other as to produce departures from their intended movements through the action of the mutual repulsions between them.

By reason of the fact that the input gap is maintained at a comparatively low potential while the output gap is maintained at a comparatively high potential, an electron lens exists between the electrodes 52 and 54 which tends to converge the electron stream to a focus. Principles are well known whereby such a focus may be caused to occur at a desired point of the electron path, and in accordance with the invention, use is made of these principles to produce at least a partial focus of the beam in the center of the output gap

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aperture 58, after which the electron paths may diverge again before the electrons are intercepted by the anode 24. Thus the aperture 58 of the output gap may be very small in comparison with that of the input gap while substantial beam current may be passed through it without danger of the beam electrons striking its bounding surfaces and being deflected from their proper courses.

The way in which it comes about that a considerable lack of definition of the output plane of the input gap, or in other words, a considerable departure of the equipotential surfaces from plane surfaces, may be tolerated while the same may not be tolerated at the input side of the input gap may be understood from the following considerations.

It is desirable that electrons in all parts of the beam cross section which are injected into the input gap at a given instant shall arrive at the output gap in phase with each other. Referring to Equation 21 it is seen that this result will be secured when the sum of θ_0 , the transit angle across the gap, and θ_s , the transit angle across the space S has the same value at various parts of the beam cross section, independently of what may be the relative values of these two transit angles. Therefore, as long as the entrance plane of the input gap is defined, as by the grid G_1 , and some suitable plane, for example, the central plane, of the output gap or aperture 58 is defined, it is of little consequence that the input gap should merge gradually into the intervening space S as will be the case when it is terminated with an annulus 52 as shown in Fig. 4 instead of with a grid G_2 as shown in Fig. 1.

Fig. 5 is a diagram of the electrodes of the input and output gaps of Fig. 4 in simplified schematic form, showing the equipotential surfaces which appear between these electrodes when the apparatus is in operation. The steady or direct current equipotentials are shown in light full lines and the high frequency equipotentials in broken lines. As explained above, the phase factor of the transconductance of the device as a whole depends upon the transit angle between the point of electron stream injection and the point at which energy is removed therefrom, i. e., between the planes A and B of Fig. 5. The paths of two electrons, assumed to have started from the input plane A at the same instant, are indicated, one of these being an electron in the approximate center of the beam and the other electron being close to the periphery of the beam. The central or C electron starts at the point C_1 of the A plane and delivers its energy at the point C_2 of the B plane. The peripheral or D electron starts at the point D_1 of the A plane and delivers its energy at the point D_2 of the B plane. In the figure the points C_2 and D_2 are shown as coincident. In actual practice they will be very close together. Since all points of the A plane are at the same potential and all points of the B plane are at the same potential, different from that of the A plane, the two electrons will have reached the same total velocity by the time they reach the B plane, independent of the paths they have followed. Therefore, to a good approximation, they will arrive at the B plane in phase with each other even though the exit from the input gap and the entrance to the space S be undefined.

It will be understood that the invention described above offers a number of distinct and decided advantages which may be secured either

separately or together as desired. In the first place, a principal source of the noise inherent in velocity variation tubes of conventional construction is greatly reduced by reason of the fact that the apparatus is highly insensitive to fluctuations in the injected electron stream current while still permitting the constant component of this current to be easily and effectively varied in accordance with an input signal. The reduction of the coupling factor between injected electron stream fluctuation and the input gap circuit is achieved by adjustment of the gap length and potential such that the transit angle across the gap is equal to a whole number of cycles at the signal frequency. This effect is exhibited by Equations 31a, 31b and 31c.

In the second place, the long transit angle input gap and the low voltage at which the latter is maintained result in a transconductance across this gap whose magnitude is independent of the transit angle, which transit angle appears only in a phase factor, as shown by Equations 17 and 18. From this it results that the transconductance of the system is of improved stability in the presence of fluctuations in the entrance velocity v_0 of the electron stream and variations in the direct current gap voltage and signal frequency as compared with the more conventional systems whose transconductance, for example, is given by Equation 12.

In the third place, the transconductance of the apparatus as a whole, measured from the entrance plane of the input gap to a suitably chosen plane of the output gap is given by Equations 19 and 21 in which, again, the magnitude is independent of the transit angles. Thus the system is comparatively insensitive to fluctuations in the direct current voltage of the output gap and variations in the separation between the input gap and the output gap, on both of which the transit angle θ_s depends.

Finally, and as a consequence of the features exhibited by Equations 19 and 21, the phase factor of the transconductance of the apparatus is independent of the separate values of the input gap transit angle and the drift space transit angle individually, depending only on the sum of these two quantities. From this it follows that as long as the entrance plane of the input gap and a suitable plane of the output gap are defined, the exit plane of the input gap may be undefined without in any way altering the transconductance of the apparatus as a whole. Therefore, the exit grid of the input gap may be entirely removed from the apparatus as in Fig. 4, with the result that noise which originates from interception of electrons by this grid is eliminated thus still further reducing the noise in the output. At the same time the effective plane of the output gap to which the transit angle of the apparatus as a whole is measured is sufficiently well defined without any grids, inasmuch as this output gap may be of relatively small aperture, the electrons of the beam being focussed upon it and traversing it at high speed. This result is secured at some sacrifice of the noise reduction in the input gap on account of the fact that, when the exit grid is removed therefrom, the transit angle across the input gap is no longer exactly defined; that is to say the electrical length of the input gap may be different for axial electrons than for peripheral electrons so that the coupling factor M of Equation 31c cannot be made exactly equal to zero for electrons at all parts of the beam cross section. Therefore in

any particular case a compromise may be made between the advantages and the disadvantages which follow from the elimination of the exit grid of the input gap. In any event it is feasible that the output gap should be devoid of grids if its aperture is small as in the embodiment of Fig. 4.

In the analyses and results discussed above, space charge effects have been neglected. Detailed calculations show that the behavior of the apparatus, both with respect to noise reduction and with respect to transconductance, is the same in kind though differing somewhat in degree when space charge effects are taken into account as long as the charge density of the electron stream is not excessive at any point of its path. Therefore the invention is by no means limited to apparatus based on the principles of velocity variation in accordance with which faster electrons may overtake and pass slower electrons. Nor is it limited to apparatus based on the consideration of space charge effects as a principal factor, in accordance with which faster electrons may not pass slower electrons.

The apparatus of the invention as described above is an amplifier. It may be rendered regenerative, degenerative, or self-oscillatory as desired by feeding back energy from the output resonator 32 to the input resonator 30 in suitable amounts and phase. Means for so doing are well known in the art.

While the invention has been described primarily in connection with pure electron discharges, the principles of the invention are equally applicable to the control and conversion of currents involving charged particles other than electrons. For example, if due regard be taken to the dimensional changes required by the different velocities and masses involved, a direct application of the invention may be made to discharge devices utilizing positive ion currents. It is intended in the appended claims to cover all variations in structure and application which fall within the true spirit and scope of the foregoing disclosure.

What is claimed is:

1. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, means for producing a substantially uniform electron stream, signal input means for imparting velocity variations to said stream in accordance with a periodic signal, and means for recovering energy from density variations of said stream resulting from said velocity variations, said signal input means including a region traversed by said electron stream and means for establishing a signal frequency electric field throughout said region and longitudinally thereof, the length of said region in the direction of traversal being such that traversal thereof by an electron occupies a period substantially equal to a whole number of periods of said signal.

2. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, a signal input gap, a resonant circuit coupled to said gap, means for injecting a stream of electrons having a mean current value into said gap, means including said resonant circuit for imparting velocity variations to said stream within said gap in accordance with a signal having a stipulated frequency, means for recovering energy from density variations of said stream resulting from said velocity variations, and means including means for adjusting the electron transit angle across said gap to a desired

value, for rendering said circuit unresponsive to signal frequency variations in the current of said electron stream as injected into said gap, whereby unwanted components in the output of said apparatus are greatly reduced.

3. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, a signal input gap, a resonant circuit coupled to said gap, means for injecting a stream of electrons having a mean current value into said gap, means including said resonant circuit for imparting velocity variations to said stream within said gap, means for recovering energy from density variations of said stream resulting from said velocity variations, and means including means for adjusting the electron transit angle across said gap to a desired value, for minimizing the response of said circuit to variations in the current of said injected electron stream from said mean value, whereby unwanted components in the output of said apparatus are greatly reduced.

4. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, means for producing an electron stream, signal input means for imparting signal frequency velocity variations to said stream in dependence on a periodic signal, and means for recovering signal frequency energy from density variations of said stream resulting from said velocity variations, said signal input means including a region traversed by said electron stream, means for establishing a signal frequency electric field throughout said region and longitudinally thereof, said energy recovery means including another region traversed by said stream, and means for so adjusting the mean velocity of said stream at said input and recovery regions, respectively, that the transit angle across said input region is long in comparison with the signal period and the transit angle across said recovery region is short in comparison with said period.

5. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, means for producing an electron stream, signal input means for imparting velocity variations to said stream in dependence on a periodic signal, and means for recovering energy from density variations resulting from said velocity variations, said signal input means including an electrode defining an input region of long transit angle and means for maintaining said electrode at a low positive potential with respect to said stream producing means, said energy recovery means including another electrode defining an output region of short transit angle and means for maintaining said other electrode at a high positive potential with respect to said first-named electrode.

6. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, means for producing an electron stream, signal input means for imparting velocity variations to said stream in dependence on a periodic signal, and means for recovering energy from density variations of said stream resulting from said velocity variations, said signal input means including a region traversed by said electron stream and bounded on one side by a grid and on the opposite side by an open tube of large aperture, said energy recovery means including a region traversed by said stream and bounded on each side by an open tube of small aperture.

7. In high frequency translating apparatus of the type in which electron inertia effects play a

controlling part, means for producing an electron stream, signal input means for imparting velocity variations to said stream in dependence on a periodic signal, means for recovering signal energy from density variations of said stream resulting from said velocity variations, said signal input means including a region of large aperture and long transit angle from end to end of which there exists a signal frequency field and traversed by said stream, said signal energy recovery means including a region of small aperture and short transit angle traversed by said stream and means intermediate said input means and said recovery means for increasing the average speed of said stream to a value such that its average density in said output region is substantially equal to its average density in said input region.

8. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, a signal input gap of relatively large aperture, a signal output gap of relatively small aperture, means for injecting a stream of electrons into said input gap, said stream having a cross section such as substantially to fill said input gap aperture, means for causing said electrons to traverse said input gap at relatively low speeds, means for converging said stream to a cross section not exceeding that of said output gap aperture, means for causing said electrons to traverse said output gap at relatively high speeds, means for modulating said electron stream within said input gap, and means for withdrawing signal energy from said stream at said output gap.

9. In high frequency translating apparatus of the type in which electron inertia effects play a controlling part, a signal input region of substantial length bounded on its input side by a plane equipotential surface, said region being open on its output side, a short signal output region, means for injecting a low speed electron stream through said plane surface and into said input region, means for modulating said stream within said input region in dependence on a periodic signal, said modulating means including means for establishing a signal frequency electric field longitudinally of said input region, which field is spatially uniform throughout said region, means for causing said stream to traverse said output region with relatively high velocity, and means for withdrawing energy from electrons of said stream within said output region.

10. High frequency translating apparatus which comprises means for projecting a substantially uniform and steady stream of moving charges along a prescribed path, signal input means for imparting a longitudinal velocity variation in one direction to the charges of said stream and thereafter imparting to said charges an equal velocity variation in the opposite direction, said charges meanwhile becoming grouped by drift action to emerge from said input means as a stream of substantially uniform velocity and varying density, and output means spaced along said path for abstracting signal frequency energy from said density-varied stream.

11. High frequency translating apparatus which comprises means for projecting a substantially uniform and steady stream of moving charges along a prescribed path, a signal input gap in the path of said stream, means for establishing longitudinally of said gap a substantially uniform electric field of signal frequency, means for adjusting the velocity of said stream across said gap to a value such that said charges in their passage across said gap occupy a time

equal to a whole number of periods of said signal, whereby velocity increases received by said charges from said field in one part of said gap are nullified by equal velocity reductions received by said charges from said field in another part of said gap, while said charges become grouped by drift action prior to said nullification, and means spaced along said path from said input gap for abstracting signal frequency energy from said grouped charges.

12. In high frequency signal amplifying apparatus of the type in which electron inertia effects play a controlling part, means for producing an electron stream, signal input means for imparting signal frequency velocity variations to said stream in dependence on a periodic signal, and means for recovering signal frequency energy from density variations of said stream resulting from said velocity variations, said signal input means including a region traversed by said electron stream, means for establishing a signal frequency electric field throughout said region and longitudinally thereof, said energy recovery means including another region traversed by said stream, and means for so adjusting the mean velocity of said stream at said input region that the transit time across said input region is long in comparison with the signal period.

13. The method of translating the electric signal of a signal source without abstracting energy from said source, which comprises projecting along a prescribed path a stream of moving charges which is substantially uniform in initial velocity and density, imparting a longitudinal velocity variation in one direction to the charges of said stream under control of the source signal and thereafter imparting to said charges an equal velocity variation in the opposite direction under control of said source signal, said charges meanwhile becoming grouped by drift action to escape the influence of said source signal as a uniform velocity stream of charge groups, and abstracting energy from said moving charge groups.

14. The method of translating the electric signal of a signal source without abstracting energy from said source, which comprises projecting along a prescribed path a stream of moving charges which is substantially uniform in initial velocity and density, imparting energy of said source to said charges at one part of said path, causing said charges to restore said energy to said source at another part of said path, said charges meanwhile becoming grouped by drift action to escape the influence of said source as a uniform velocity stream of charge groups, and abstracting energy from said charge groups.

15. High frequency translating apparatus

which comprises means for projecting a stream of moving charges along a prescribed path, signal input means spaced along said path from said projecting means, for longitudinally rearranging the charges of said stream in their positions in accordance with a signal without imparting energy thereto or taking energy therefrom, and signal output means spaced along said path from said input means, for abstracting signal frequency energy from the movements of said rearranged charges.

16. High frequency translating apparatus which comprises means for projecting a stream of moving charges along a prescribed path, signal input means spaced along said path from said projecting means, for grouping the charges of said stream into bunches without imparting energy thereto or taking energy therefrom, said input means being non-responsive to irregularities in said stream, and output means spaced along said path from said input means, for abstracting signal frequency energy from said moving charge bunches.

17. High frequency translating apparatus which comprises means for projecting a stream of moving charges along a prescribed path, signal input means spaced along said path from said projecting means, for rearranging the longitudinal space distribution of the charges of said stream without imparting energy thereto or taking energy therefrom, and output means spaced along said path from said input means, for abstracting signal frequency energy from the movement of said charge distribution.

18. The method of translating the electric signal of a signal source without abstracting energy from said source, which comprises projecting along a prescribed path a stream of moving charges which is substantially uniform in initial velocity and density, longitudinally rearranging the relative positions of the charges in the stream under control of the signal of said source, without modifying their velocities, to produce a sequence of charge groups all moving with said initial velocity, and abstracting energy from successive charge groups.

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