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HIGH FREQUENCY AMPLIFIER

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FIG. 1A

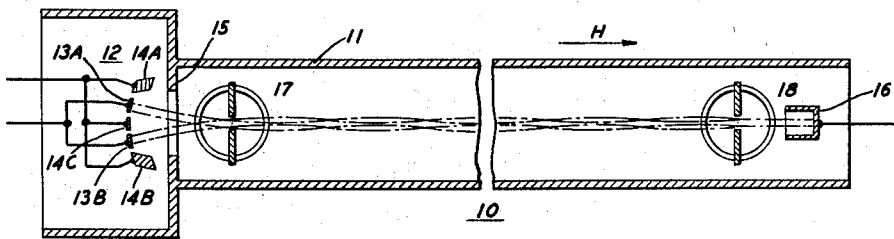


FIG. 1B

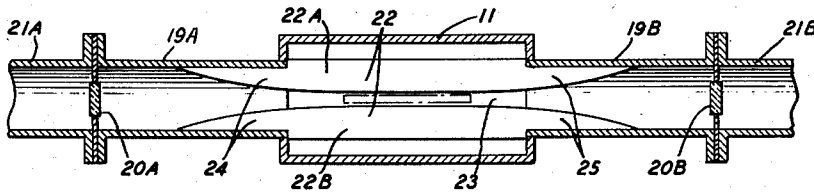


FIG. 2A

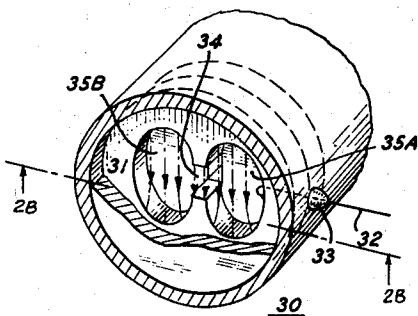
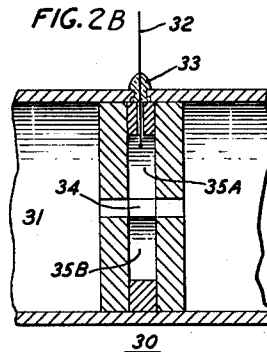


FIG. 2B



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HIGH FREQUENCY AMPLIFIER

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5 Claims. (Cl. 315-5.15)

This invention relates to apparatus for amplifying high frequency signals, and more particularly to apparatus which utilizes the interaction in an electron beam of two groups of electrons having different transverse velocities.

The use of the interaction in an electron beam between two discrete groups of electrons having different velocities in the longitudinal direction to provide gain to a space charge wave applied on one of the groups of electrons is now well known. Amplifiers which make use of this principle are described as "double stream amplifiers." The principles of such amplifiers are discussed in my book entitled "Traveling Wave Tubes," chapter XVI, published by D. Van Nostrand Company, Inc., New York (1950). However, in the operation of amplifiers of such kind it is often found difficult to provide conveniently in an electron beam two such groups of electrons of sufficient density to provide high power level operation.

In contradistinction to such prior art amplifiers, in the present invention there is utilized for amplification an electron beam which includes two groups of electrons which have substantially the same velocity in the longitudinal direction but different velocities in a transverse direction. By the use of such a beam, the design of apparatus utilizing for amplification the interaction between different groups of electrons in a beam is facilitated.

The present invention is based on the discovery of the principle that two groups of electrons, which are given substantially the same velocity in the longitudinal direction but different velocities in a transverse direction, and which are confined so that the two groups form a beam in which they cross over one another periodically with travel in the longitudinal direction, will, when the current density is sufficiently high, interact in such a way that a space charge wave, applied as modulation on the beam, will be amplified with travel along the beam. In particular, it is found that the amplification of the space charge wave is enhanced if the space charge wave is applied on the beam in an asymmetric mode. In this respect, too, an amplifier in accordance with the present invention is in contradistinction to prior art double stream amplifiers in which the modulation is applied on the beam symmetrically.

The invention finds particular application in amplifiers of the kind now generally described as "distributed" or "traveling wave" klystrons. The principles of such amplifiers are described in an article entitled "The Duplex Traveling-Wave Klystron," published in the Proceedings of the Institute of Radio Engineers, March 1952, pages 308 through 315. In such an amplifier, a first extended input wave guide serves as a "buncher" for impressing signal modulation on a uniform electron beam projected transversely therethrough parallel to the electric vector in the wave guide and a second extended output wave guide which is spaced apart parallel to the first wave guide downstream along the beam path serves as a

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"catcher" in which signal waves are induced by the previously modulated electron beam which is projected transversely therethrough.

As an illustrative embodiment of the present invention, in a distributed klystron the electron beam which is projected through the buncher and catcher elements is made to have two groups of electrons of high current density and having different transverse velocities, whereby the signal space charge wave set up initially by the buncher action on the beam is amplified before the beam passes through the catcher so that the electromagnetic wave induced in the catcher by the beam is of larger amplitude than it would be if the tube had employed, as in the prior art devices, a uniform electron beam. Moreover, in order to excite the electron beam in an asymmetric mode, as is found advantageous for amplification of the kind described, the electron beam is projected past the input and output wave guides in a manner to be transverse to the electric vector in such wave guides. In this respect, too, such an embodiment of the invention is in contradistinction to prior art distributed klystron devices in which the electron beam is projected past the buncher and catcher wave guides in a direction parallel to the electric vector of such wave guides. To implement the excitation of the electron beam in an asymmetric mode, in a preferred embodiment of the invention each of the buncher and catcher wave guides is a fin line (to be described below) which provides a strong transverse electric field in a localized region through which is projected the electron beam. The use of fin lines as the transducers for converting electromagnetic waves to space charge waves and vice versa reduces the longitudinal dimension of the region of beam and signal wave interaction and avoids the complications arising when individual electrons encounter a widely varying phase of the electric field of the signal wave in passing through the buncher and catcher wave guides.

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

Fig. 1A shows a longitudinal cross section of an amplifier in accordance with the invention;

Fig. 1B shows a transverse section of the transducer used as the buncher and catcher elements in the amplifier shown in Fig. 1A; and

Figs. 2A and 2B show a resonant element arrangement for coupling to the electron beam in an asymmetric mode, as is advantageous in the practice of the invention.

With reference now more particularly to the drawing, in the amplifier 10 shown in Figs. 1A and 1B, an evacuated envelope 11, typically of a suitable nonmagnetic conductor such as copper, serves to house the various tube elements. The envelope preferably has a substantially rectangular cross section along its length except in the regions where there are provided lateral extensions used for the input and output signal terminals.

At one end of the envelope, an electron gun 12 is arranged to provide a flat electron beam comprising two groups of electrons with substantially the same velocity in the longitudinal direction parallel to the tube axis but with different velocities in the direction transverse to the beam axis in the plane of the drawing of Fig. 1A. Advantageously, this difference in transverse velocities corresponds to a transverse component of velocity in each of the two groups of electrons which is equal in magnitude but opposite in direction along the tube axis. To produce an electron beam of this kind, the cathode of the electron gun preferably is split and comprises two elongated segments 13A, 13B in parallel relation. The beam focusing electrode 14 also is split and comprises a pair

of outer sections 14A, 14B and a section 14C intermediate between the two cathode segments 13A, 13B. An accelerating anode 15 which is made integral with the tube envelope is also included in the gun electrode system. Each of the elements of the gun extends lengthwise normal to the plane of the drawing. In the interest of simplicity, conventional details such as spacer and support elements have been omitted from the drawing.

The inclination of the two separate cathode segments 13A, 13B relative to the tube axis and the various potentials applied to the beam focusing electrode sections 14A, 14B and 14C and the accelerating anode 15 are adjusted so that the two groups of electrons emitted from the separate cathode segments have equal velocities in the longitudinal direction (parallel to the tube axis) but opposite components of transverse motion. The two groups of electrons, however, are emitted towards a common focal point and combined into a single beam for travel along the major portion of the tube's length.

The separate cathode segments are each biased by suitable lead-in connections to a potential slightly positive to the beam focusing electrode and appreciably negative with respect to the accelerating anode and tube envelope, whereby the beam is projected longitudinally towards the opposite end of the envelope where it is collected by a suitably biased target electrode 16.

Moreover, to limit excessive transverse motions by the electrons, the beam path is immersed in a longitudinal magnetic focusing field illustrated schematically by the vector H provided by a suitable magnetic system not here shown. Magnetic focusing systems suitable for such purposes are well known. Typically, the beam path portion of the tube may be surrounded by a solenoid, a practice known in the traveling wave tube art. Along the beam path, both because of their initial difference in transverse velocities and as a result of the confining effect of the applied magnetic field, the two groups of electrons are continually crossing over in their flow but divergence from the beam is inhibited.

Spaced apart at least several electronic signal wave lengths along the beam path are the input transducer 17 and the output transducer 18. (An electronic wave length is the wave length of the space charge wave on the electron beam.) Input signal wave energy is applied to the input transducer 17 and there used to set up signal space charge waves thereon which will be amplified by the interaction of the two groups of electrons in the beam. The amplified signal space charge waves thereafter are converted to signal wave energy by the output transducer 18 from which it is abstracted for utilization.

A sectional view of each of the transducers 17, 18, used in the preferred embodiment is shown in Fig. 1B. This view represents a transverse section taken perpendicular to the beam path. As shown, each transducer comprises sections of hollow wave guide of circular cross section which extend laterally on opposite sides from the rectangular portion 11 of the envelope to form extensions 19A and 19B. Alternatively, extensions 19A and 19B may be sections of rectangular wave guide. Vacuum-tight glass windows 20A and 20B are provided at respective ends of the wave guide extensions. Extensions 19A and 19B are connected by way of these glass windows to wave guide connections 21A and 21B, respectively.

A fin line is used to couple the wave guide extensions to the electron beam. The fin line comprises a pair of conductive fins 22A, 22B which are coplanar and spaced apart a short distance for forming of the interspace 23 therebetween a wave guiding path. In this interspace the electric vector of a propagating wave extends between the two fins in the plane of the fins and normal to the direction of wave propagation. The transverse dimension of the conductive fins in the direction normal

to the plane of the drawing of Fig. 1B is advantageously a small fraction of the wave length of the signal wave in the path. The fin line comprises both an intermediate region in which the separation between the fins is uniform with a spacing less than the wave length of the signal in the path, and impedance matching end sections 24 and 25 formed by tapering each of the fins 22A, 22B smoothly into diametrically opposite portions of the wave guide walls. The general principles of the use of fin lines are discussed in copending application Serial No. 485,672, filed February 2, 1955, by H. T. Friis and S. D. Robertson. Effectively, the fin line described serves to convert the wave energy between the dominant mode characteristic of the circular or rectangular wave guides to a transverse electric field mode characteristic of the fin line.

Each of the input and output transducers is positioned in the tube so that the plane of its fin line is normal to the longitudinal direction of beam flow, and the beam is projected past each transducer through the interspace 23 which forms the wave guiding path of the fin line. Accordingly, the electric vector characteristic of the fin line will be normal to the longitudinal direction of beam flow, and the upper and lower portions of the beam in passing through the fin line will be in regions of different radio frequency potentials. This means, in turn, that the upper and lower portions of the beam will be coupled to the fin lines asymmetrically, as is found advantageous for maximum amplification of the space charge wave set up on the beam.

In operation, the input transducer 17 is used as the buncher for converting signal waves applied thereto to corresponding space charge waves on the electron beam. For use in this way the wave guide connection 21A is supplied with a signal energy from a suitable signal source and the wave guide connection 21B is terminated in its characteristic impedance to be substantially reflectionless. Alternatively, when two signals are to be mixed the different connections 21A, 21B may be supplied from separate signal sources. Additionally, the output transducer which is positioned downstream along the path of flow converts the amplified space charge waves on the electron beam to electromagnetic wave energy which can be used by utilization apparatus. For such use, in the output transducer the wave guide connection 21A is terminated in its characteristic impedance to be substantially reflectionless, and the wave guide connection 21B supplied the utilization apparatus. The practice of supplying the input signal and abstracting the output wave at opposite ends of the buncher and catcher wave guides in this way is characteristic of a distributed klystron.

As is also characteristic of the distributed klystron, the transverse dimension of the beam, which is the dimension parallel to the direction of wave propagation along the buncher and catcher elements and the dimension which fixes the extent of interaction between the beam and the wave generally is several wave lengths long at the operating frequency. Accordingly, the tube being described finds particular application as an amplifier of millimeter wave where a transverse dimension for the electron beam which is several times the operating wave length is convenient. The principal limitation imposed on this transverse dimension of the beam is one of convenience, and where high power level operation is desired this dimension of the beam may be chosen appropriately large.

It can be seen from the foregoing description that a tube of the kind depicted is in other respects also especially well adapted for the amplification of very short wave lengths. There is an absence of circuit elements which must be of minute dimensions as is characteristic of many forms of millimeter wave amplifiers. The fin lines used for coupling between the signal electromagnetic waves and the beam can readily be fabricated and will be rugged

even when dimensioned for operation at millimeter wave lengths. Moreover, inasmuch as the transverse dimension of the beam can readily be a large number of wave lengths long as previously discussed, little difficulty will be had in providing sufficient beam current for high level operation.

It is also feasible to employ alternative expedients as the transducers in the place of each of the fin lines incorporated in the amplifier shown in Figs. 1A and 1B. In particular, one such alternative transducer is shown in Fig. 2A in perspective. A transverse section of this transducer taken through plane 2B—2B of Fig. 2A is shown in Fig. 2B. The transducer 30 shown in these figures is a resonator whose resonant chamber 31 has the upright bar bell configuration shown and which is excited to resonate in an antisymmetric mode. Coupling between the resonant chamber 31 and an external wave transmission line 32 is provided by a coupling loop which passes through a dielectric bead 33 in the wall of the resonator. The electric field in the resonant chamber advantageously has the pattern depicted, which is characterized by the fact that the direction of the electric field is transverse in the narrow bar portion 34 intermediate the two separate bell portions 35A, 35B. The orientation of the electron beam is adjusted so that the two groups of electrons in the beam have different transverse motions in a direction parallel to that of the electric field in passing through portion 34 so that the beam is excited asymmetrically. In this embodiment, a beam of circular cross section may be used.

Similarly, various other forms of transducers may be employed to provide the desired asymmetric excitation of the beam.

Accordingly, it is to be understood that the various arrangements described are intended to be illustrative of the general principles of the invention. Various other embodiments may be provided by one skilled in the art without departing from the spirit and scope of the invention.

Additionally, the principles set forth above do point up the fact that in tubes of the traveling wave type in which interaction between groups of electrons with different transverse motions is not employed usefully, care should be taken to avoid such transverse motions if the noise of the tube is to be minimized.

What is claimed is:

1. A traveling wave tube comprising an input transducer, an output transducer separated from said input transducer, first and second cathode means for projecting distinct ribbon electron beams at different transverse angles to the axis between said input and output transducers but at the same longitudinal velocity along said axis, all of the electrons in the beam from the first cathode means having substantially the same component of transverse velocity and all of the electrons in the beam from said second cathode means having substantially the same component of transverse velocity differing from the transverse velocity component of the electrons in the first mentioned beam, and means for causing said distinct electron beams to follow distinct paths between said input and output transducers and to cross said axis a plurality of times between said input and output transducers, said input and output transducers each including wave guiding means extending transverse to the direction of longitudinal flow and oriented so that the electric vector in its wave guiding path is normal to the direction of longitudinal velocity and parallel to the direction of dif-

ferent transverse velocities of said distinct electron beams.

2. A traveling wave tube in accordance with claim 1 wherein said wave guiding means are fin lines.

3. A traveling wave tube in accordance with claim 1 wherein said wave guiding means are resonant elements which are excited so as to produce an electric field across the electron streams.

4. A traveling wave tube comprising an input transducer, an output transducer separated from said input transducer, first and second cathode means for projecting distinct ribbon electron beams at different transverse angles to the axis between said input and output transducers but at the same longitudinal velocity along said axis, all of the electrons in the beam from the first cathode means having substantially the same component of transverse velocity and all of the electrons in the beam from said second cathode means having substantially the same component of transverse velocity differing from the transverse velocity component of the electrons in the first mentioned beam, and means for causing said distinct electron beams to follow distinct paths between said input and output transducers and to cross said axis a plurality of times between said input and output transducers, said means including magnetic means for limiting the excursions of said distinct electron beams along said distinct paths transverse to said axis.

5. A traveling wave tube comprising a first electron gun means for emitting a first distinct ribbon electron beam, a second electron gun means for emitting a second distinct ribbon electron beam, means for focusing and accelerating said distinct electron beams to a common focal point with substantially equal longitudinal velocities, all of the electrons in said first beam having substantially the same transverse velocity and all of the electrons in said second beam having substantially the same transverse velocity different from the transverse velocity of electrons in said first beam, an input transducer positioned adjacent said focal point and in energy transfer relationship with both said distinct electron beams for bunching said electron beams in an asymmetric mode in accordance with an input wave applied thereto, an output transducer positioned along the path of flow of said distinct electron beams downstream from said input transducer and in energy transfer relationship with both said distinct electron beams for converting the electron bunches into an output wave for utilization, and means for causing said distinct electron beams with initial different transverse velocities at said focal point to follow distinct paths between said input and output transducers and to cross the axis between said input and output transducers a plurality of times.

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