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MICROWAVE AMPLIFIER TUBE

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2 Sheets-Sheet 1

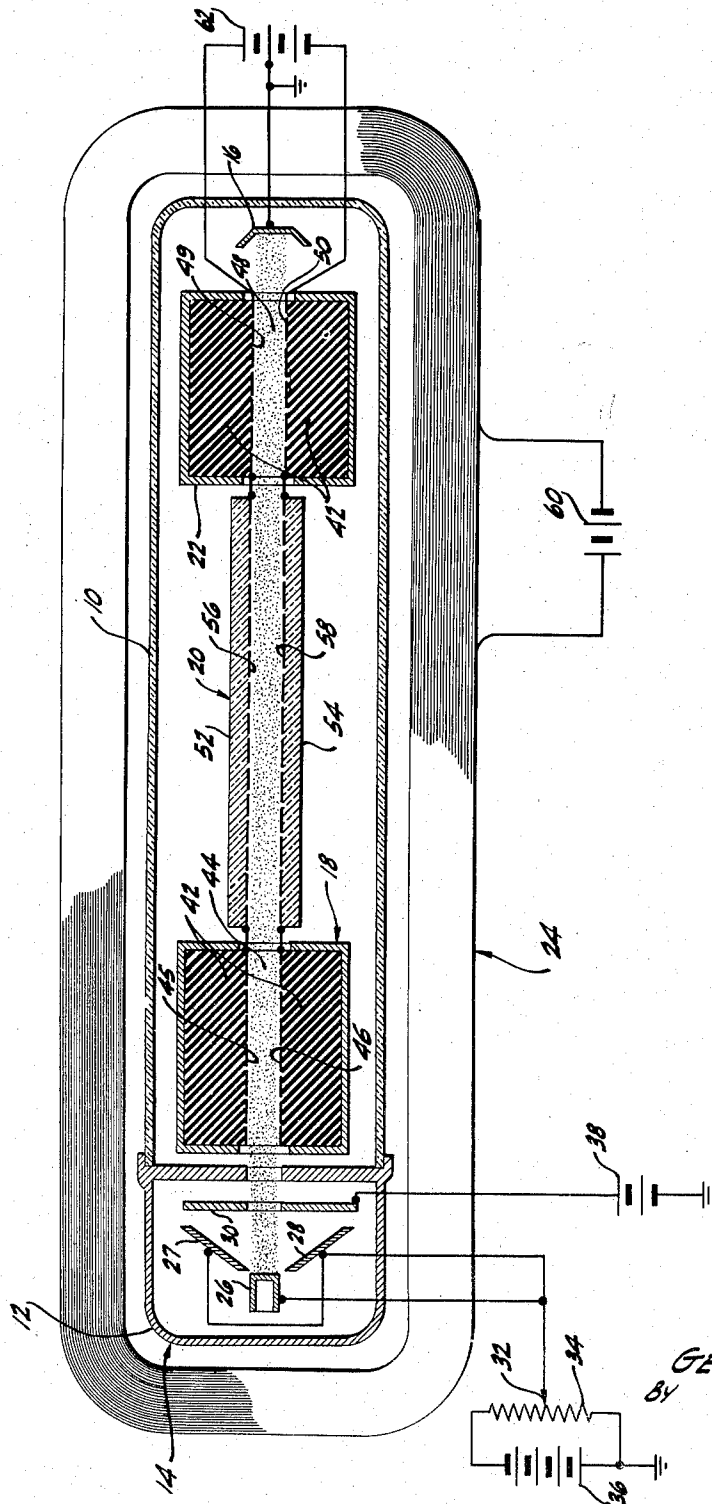


FIG. 1.

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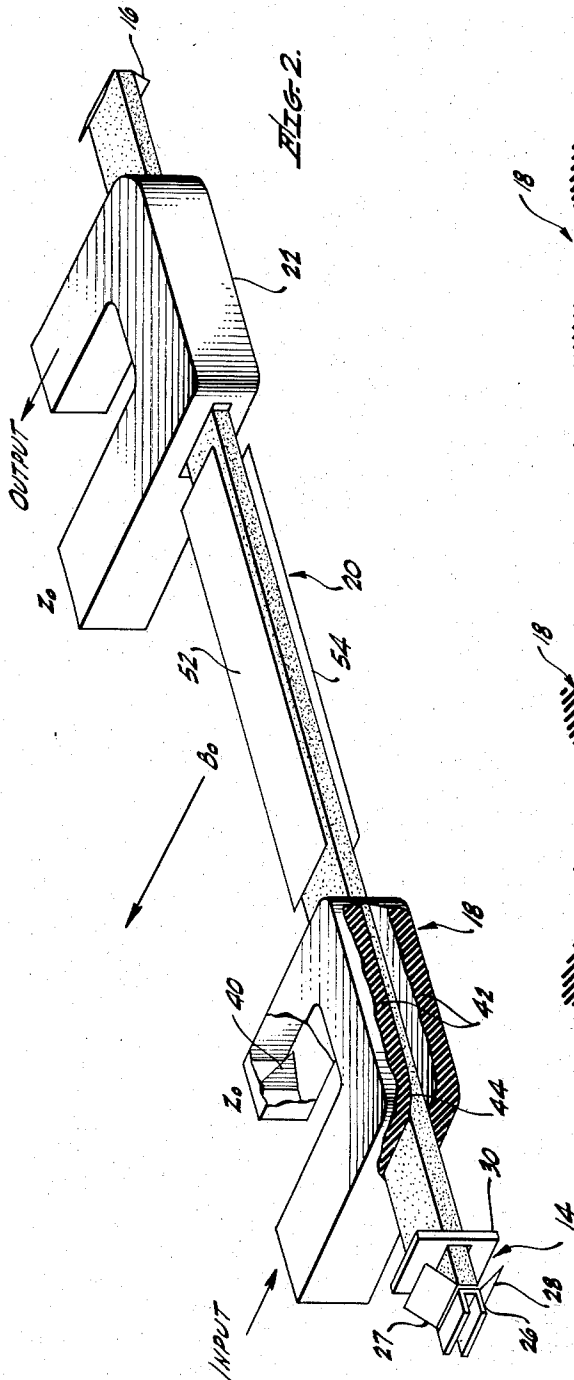
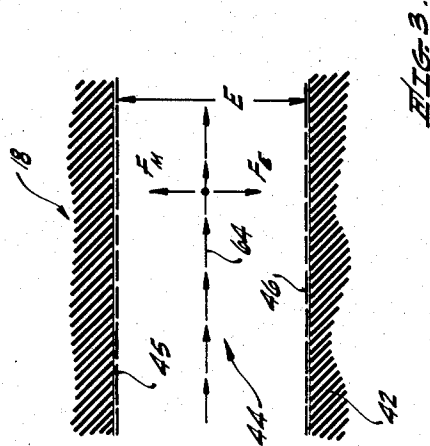
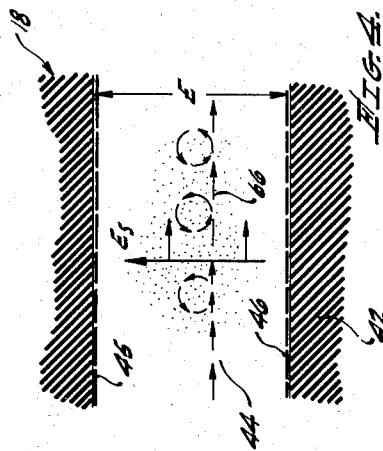
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MICROWAVE AMPLIFIER TUBE

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6 Claims. (Cl. 315—3.6)

This invention relates to stream-type tubes for amplifying microwave signals and more particularly, to an apparatus for modulating or demodulating an electron stream with a microwave signal at millimeter wavelengths.

It is well known that one of the principal problems in the construction of a stream-type device for amplifying millimeter wavelength signals lies in coupling to and from the electron stream. One of the more satisfactory circuits presently in use capable of effecting the excitation of an electron stream from a microwave signal is the helix. Helices, however, become very small when adapted to operate at millimeter wavelengths, thus making their construction very difficult.

In accordance with the present invention, an apparatus for modulating an electron stream with millimeter wavelength signals is provided which comprises a rectangular waveguide partially filled with dielectric material to reduce the phase velocity of the wave in the guide to substantially the same velocity as that of an electron stream directed longitudinally through the guide. The transverse electric fields of the signal wave within the guide excite transverse vibrations in the motion of the electrons of the stream. A steady magnetic field is produced that is normal to the direction of electron flow which serves to convert the transverse vibrations of the electrons into a motion having both longitudinal and transverse components. It is also to be noted, however, that a magnetic field thus produced will cause the electrons to flow along a curved path. Therefore, if it is desired that the electrons continue to flow along a rectilinear path, it is necessary to produce a transverse electric field across the flow of electrons of such magnitude as to produce a transverse force on the electrons that counterbalances the average transverse forces produced by the magnetic field.

After being modulated in the aforementioned waveguide, the electron stream is directed between two resistive sheets to effect amplification of the longitudinal and thus the transverse oscillations of the electrons. Amplification of the modulations of an electron stream in this manner, called Resistive Wall Amplification, is disclosed in Patent No. 2,740,917 entitled, "Electron Stream Amplifier Tube" issued to Andrew V. Haeff on April 3, 1956 and assigned to the assignee of the present application. After amplification, an output signal may be derived from the modulations of the stream in a manner similar to that in which they were excited.

It is therefore an object of the present invention to provide a stream-type device capable of amplifying microwave signals.

Another object of the invention is to provide an apparatus capable of modulating and demodulating an electron stream with millimeter wavelength signals.

Still another object of the invention is to provide apparatus that is comparatively simple to construct for coupling millimeter wavelength signals to and from an electron stream.

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The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

Fig. 1 is a cross-sectional view of an embodiment of the device of the present invention together with associated circuitry;

Fig. 2 is a schematic representation of the device of Fig. 1 shown in perspective; and

Figs. 3 and 4 are illustrative views of the path of a modulated and undemodulated electron in the device of Fig. 1.

Referring now to the drawings, Fig. 1 shows a vertical cross section taken along the longitudinal axis of the device of the present invention, together with associated circuitry. The device comprises an elongated evacuated envelope 10 having a ferromagnetic housing 12 disposed at its left extremity, as viewed in the drawing, to enclose an electron gun 14 capable of producing an electron sheet beam. This electron sheet beam is directed along a predetermined path through the envelope 10 to the extremity thereof farthest from the gun 14 where it is intercepted and collected by a collector electrode 16. A waveguide input section 18, an amplification section 20 and a waveguide output section 22 are disposed in the order named intermediate the housing 12 and the collector electrode 16 along the path of the electron sheet beam in the direction of electron flow. A solenoid 24 is disposed lengthwise about the evacuated envelope 10 and the housing 12 in a manner to produce a magnetic field along the predetermined path, commencing from the housing 12, that is transverse to the path and parallel to the plane of the electron sheet beam. Fig. 2 shows the arrangement of the principal elements of the device of the present invention in perspective.

More particularly, the envelope 10 is sealed to the housing 12 which is composed of a metal having ferromagnetic properties such as, for example, "Kovar." The housing 12 completely encloses the electron gun 14 except for an aperture of sufficient size to permit the electron beam to pass. Thus, the housing 12 shields the electron gun 14 from the transverse magnetic field produced by the solenoid 24.

The electron gun, for producing the electron sheet beam, comprises a rectilinear cathode 26, focusing electrodes 27 and 28, and an accelerating electrode 30. The focusing electrodes 27, 28 are plane electrodes which may be disposed at an angle of the order of 67.5 degrees with respect to the direction of electron flow, as shown in the drawing. The electrodes 27, 28 together with the cathode 26 are maintained at a common adjustable potential of the order of 1000 volts negative with respect to ground. This is accomplished by means of connections therefrom to a common tap 32 of a potentiometer 34 which is in turn connected across the terminals of a battery 36, the positive terminal of which is referenced to ground. The accelerating electrode 30 has an oblong aperture of suitable dimensions to permit passage of the electron beam and is maintained at a potential of the order of 200 volts positive with respect to ground. This is effected by means of a connection therefrom to the positive terminal of a battery 38, the negative terminal of which is connected to ground.

Disposed at the extremity of the predetermined path farthest from the housing 12 is the collector electrode 16. The electrode 16 is maintained at ground potential by

means of an appropriate connection thereto. Intermediate the electron gun 14 and the collector electrode 16, the input waveguide section 18, the amplification section 20, and the output waveguide section 22 are disposed in the manner shown particularly in Fig. 2. The input waveguide section 18 approaches the path of the electron sheet beam at normal incidence and in the plane of the beam. After crossing the width of the beam, the section 18 extends along the path thereof in the direction of its flow for several guide wavelengths at the operating frequency. The section 18 is then turned at right angles away from the path of the electron beam and terminated in its characteristic impedance, Z_0 . The waveguide may be terminated, for example, by disposing a conductive sheet across the extremity thereof and a triangular resistive vane 40 along its center portion parallel to the electric field of its dominant mode of propagation. Further, the waveguide section 18 is loaded with a dielectric material 42 to decrease the phase velocity of a propagated wave to the extent that it is substantially equal to the velocity of the electron beam. A suitable aperture 44 is provided to accommodate the electron stream. In addition, resistive layers 45, 46 (Fig. 1) are disposed above and below the electron beam within the aperture 44. Layers 45, 46 have a resistance of the order of from 100,000 to 200,000 ohms per square so as to permit coupling of an electromagnetic wave propagated by the section 18 with the electron beam and yet maintain the entire upper and lower surfaces of the aperture 44 at substantially uniform predetermined potentials.

The output waveguide section 22 is similar to the section 18 being loaded with the dielectric material 42 and having an aperture 48 to accommodate the electron beam with resistive layers 49, 50 on the surfaces above and below the beam. The extremity of section 22 nearest the electron gun 14 is terminated with the characteristic impedance, Z_0 , of the waveguide.

Intermediate the input and output waveguide sections 18, 22 along the path of the electron beam is the amplification section 20. In order to amplify millimeter wavelength signals, section 20 is preferably of the resistive-wall type disclosed in the aforementioned Haeff application. Accordingly, amplification section 20 comprises two sheets 52, 54 of dielectric material such as, for example, glass disposed contiguously along the upper and lower portions of the electron sheet beam. Resistive layers 56, 58 of the order of from 500 to 5000 ohms per square are disposed on the sheets 52, 54, respectively, on the sides thereof immediately adjacent the electron beam. The resistive layers 56, 58 may, for example, constitute a film of stannous oxide on glass sheets.

The solenoid 24, which is disposed lengthwise about the length of the tube, is energized by appropriate connections to a battery 60 to produce a magnetic field of $\vec{B}_0$ webers per square meter parallel to the plane of the electron sheet beam and transverse to the path along which it flows. The ferro-magnetic housing 12 shields the electron gun 14 from magnetic field thus produced by solenoid 24. As is well known, however, the magnetic field $\vec{B}_0$ will exert a force on the beam electrons that is normal to the direction of flow. This force may be represented as follows:

$$\vec{F}_m = e\vec{u}_0 \times \vec{B}_0 \quad (1)$$

wherein

$\vec{F}_m$ is a vector representative of the magnitude and direction of the force on an electron due to the magnetic field;

$\vec{B}_0$ is a vector representative of the direction and the flux density of the magnetic field produced by the solenoid 24;

$\vec{u}_0$ is the magnitude and direction of the velocity of the beam electrons in meters per second; and

e is the charge of an electron in coulombs.

In order to have the electron beam flow along the predetermined path, it is necessary to counteract the force $\vec{F}_m$ with an equal and opposite force. This equal and opposite force may be produced electrostatically by impressing suitable voltages across the resistive layers 45, 46; 49, 50; and 56, 58. This may be accomplished by interconnecting the layers 45, 49 and 56 and the layers 46, 50 and 58. The resistive layers 49, 50 are then connected to the positive and negative terminals, respectively, of a battery 62, an intermediate terminal of which is referenced to ground. The mean potential predominating along the path of the electron beam relative to the potential of the cathode 26 determines the average velocity of the electrons therealong. The electrostatic force exerted on each electron, on the other hand, is determined by the magnitude of the electric field produced across the path. This force may be represented as:

$$F_E = Ee \quad (2)$$

wherein

F_E is the force exerted on an electron of the beam due to the electrostatic field and;

E is the magnitude of the electrostatic field produced across the path in volts per meter.

In operation, F_E is made equal and opposite to F_m by either adjusting the current flow through solenoid 24 or by varying the magnitude of the electrostatic field, E . The average electron velocity is then

$$u_0 = \frac{E}{B_0}$$

Referring to Figs. 3 and 4, there is illustrated the manner in which the device of the present invention modulates the electron beam. These figures show an enlarged portion of the aperture 44 through the input waveguide section 18. A magnetic field $\vec{B}_0$ exists normal to the plane of the drawings and the electrostatic field E exists between the resistive layers 45, 46. When no signal is being propagated by the waveguide section 18, an electron of the beam will proceed along a straight path therethrough as indicated by the dashed line 64 of Fig. 3.

When the waveguide section 18 is energized with a signal wave, however, a transverse electric field, E_s , representative of the signal wave is propagated along the waveguide at a velocity substantially equal to that of the electron stream. Hence, an electric vector of the electric field, E_s , acts upon only one group of electrons within the electron beam. The effect of the electric field E_s is to unbalance the forces on the electrons and to accelerate them transversely either towards the resistive layer 45 or the resistive layer 46, depending on the instantaneous polarity of E_s . During the portion of the cycle of the signal wave where the magnetic force on the electrons dominates the electrostatic forces, the electrons will commence rotating and proceed along a path such as indicated by the dashed line 66 of Fig. 4. Thus, as the transverse components of velocity are continually converted into longitudinal components, it is evident that the transverse electric field, E_s , of the signal wave imparts both transverse and longitudinal components of velocity to the electrons of the sheet beam.

In proceeding through the amplification section 20, the transverse modulations of the beam are not coupled to the resistive layers 56, 58. The longitudinal modulations of the beam, however, induce currents in the resistive layers 56, 58 which in turn generate electric fields which interact with the electrons of the beam in a manner to increase the amplitude of these modulations. A more detailed description of the amplification of the longitudinal velocity components of the electrons of a stream by means of a resistive wall is presented in the aforementioned Haeff application. After amplification, the signal energy is extracted from the electron beam by the output waveguide section 22 in a manner similar to the operation of the input waveguide section 18.

What is claimed is:

1. In a microwave amplifier having means for producing an electron beam, and means for directing said electron beam along a predetermined path, apparatus for modulating said electron beam with an electromagnetic signal wave, said apparatus comprising: means for producing a magnetic field through said electron beam transverse to said predetermined path, and means including a rectangular waveguide partially filled with dielectric material for propagating said signal wave transversely across a portion of said path at a velocity substantially equal to the velocity of the electrons of said beam, the electric field vector of said wave being normal to said predetermined path and said magnetic field whereby both transverse and longitudinal velocity components representative of said signal wave are imparted to the electrons of said beam.

2. The microwave amplifier as defined in claim 1 which includes additional means for increasing said longitudinal velocity components of the electrons of said beam representative of said signal wave, whereby said transverse velocity components are also increased, and means for deriving an output signal from said transverse velocity components of the electrons of said beam.

3. In a microwave amplifier having means for producing and launching an electron beam along a rectilinear path, apparatus for modulating said electron beam with an electromagnetic signal wave, said apparatus comprising: means for producing a magnetic field transverse to said path whereby a first force having a direction transverse to said magnetic field and said path is exerted on the electrons of said beam, means for maintaining an electric field across said electron beam to produce a second force equal and opposite to said first force on the electrons of said beam, whereby said electron beam proceeds along said rectilinear path, and means including a rectangular waveguide partially filled with dielectric material for propagating the signal wave transversely across a portion of said path at a velocity substantially equal to the velocity of said electron beam, the electric vector of said wave being parallel to said electric field, whereby said electron beam is modulated with transverse and longitudinal velocity components representative of said signal wave.

4. A device for amplifying millimeter wave signals, said device comprising means for producing and launching an electron beam along a rectilinear path, means for producing a magnetic field transverse to said path whereby a first force having a direction transverse to said magnetic field and said path is exerted on the electrons of said beam, means for maintaining an electric field across said electron beam to produce a second force equal and opposite to said first force on the electrons of said beam, whereby said electron beam proceeds along said rectilinear path, means including a waveguide at least partially filled with dielectric material for propagating a signal wave transversely across a first portion of said path at a velocity substantially equal to the velocity of said electron beam, the electric vector of said wave being parallel to said electric field thereby to modulate said electron beam with transverse and longitudinal velocity components representative of said signal wave, a member having a resistive surface disposed contiguously

along a second portion of said path for increasing the magnitude of said longitudinal velocity components whereby the magnitude of said transverse velocity components is also increased, and means disposed along a third portion of said path for deriving an output signal from said increased transverse velocity components of said electron beam representative of said signal wave.

5. In a microwave amplifier having means for producing an electron beam, and means for directing said electron beam along a predetermined path, apparatus for modulating said electron beam with an electromagnetic signal wave, said apparatus comprising: means for propagating said signal wave transversely across a portion of said path at a velocity substantially equal to the velocity of the electrons of said beam, said means for propagating including a section of rectangular waveguide adapted to propagate said signal wave in the fundamental transverse electric mode, said section of waveguide being disposed transversely across said path with the broad-sides thereof being parallel thereto, said section of rectangular waveguide having apertures in the narrow sides thereof adapted to allow for passage therethrough of said electron beam, and said section of rectangular waveguide additionally being partially filled with dielectric material to retard the velocity of propagation of said signal wave transversely across said path substantially to that of the electrons of said beam; and means for propagating said signal wave transversely across a portion of said path at a velocity substantially equal to the velocity of the electrons of said beam, the electric field vector of said wave being normal to said predetermined path and said magnetic field whereby both transverse and longitudinal velocity components representative of said signal wave are imparted to the electrons of said beam.

6. A microwave amplifier for the millimeter wave region comprising: modulating means including a rectangular waveguide partially filled with dielectric material and disposed to propagate microwave energy along the path of an electron stream to decrease the velocity of said energy to substantially the velocity of said stream, said dielectric material being apertured to permit passage of said stream and the aperture being lined with a resistive material; a dielectric member having a resistive wall positioned adjacent said modulating means along the path of the beam to be amplified; and output means including a second rectangular waveguide also filled with dielectric material adjacent said dielectric member having a resistive wall amplifier and positioned further along the path of the stream and being also apertured to permit passage of said stream, the aperture being lined with a resistive material.

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