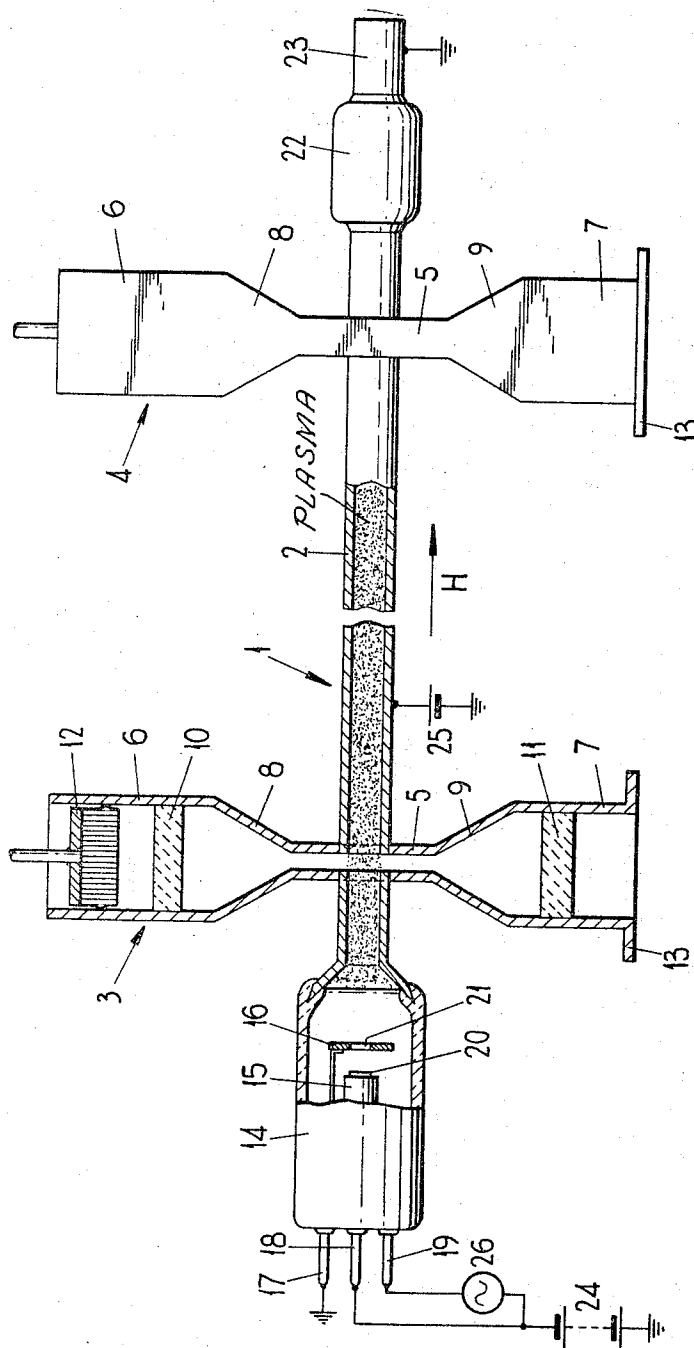


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TRAVELLING WAVE TUBE USING A PLASMA-FILLED
WAVEGUIDE AS A SLOW WAVE STRUCTURE
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TRAVELLING WAVE TUBE USING A PLASMA-FILLED WAVEGUIDE AS A SLOW WAVE STRUCTURE

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It is known that a hollow metal waveguide filled with a plasma (that is a region of ionised gas containing substantially equal concentrations of positive ions and free electrons) and disposed in a magnetic field directed parallel to the longitudinal axis of the waveguide may be used as a delay device, since it will propagate space charge waves with a phase velocity considerably less than the velocity of light at certain frequencies below the normal cut-off frequency of the waveguide in the absence of the plasma. In particular, provided the value of the plasma density in the waveguide is sufficiently high, the device will propagate waves in a range of frequencies extending below both the normal cut-off frequency of the waveguide and the cyclotron frequency corresponding to the magnetic field established in the waveguide, the propagation being of the forward wave type for which the phase velocity increases with decreasing frequency.

It has been proposed to provide a travelling wave tube incorporating such a delay device, together with means for projecting an electron beam along the length of the interior of the waveguide so as to interact with waves propagated along the delay device. We have now found that in putting this proposal into practice it is possible to use the electron beam itself to generate the plasma by ionising a gas filling in the waveguide, and that satisfactory operation of such a tube as a forward wave amplifier may then be obtained provided that the pressure of the gas filling lies within a specific range, which may vary in value from one gas to another. For pressures immediately below this range it is found that there is considerable generation of spurious oscillations in the tube itself, these oscillations masking the desired output signal; on the other hand, if the pressure is made too high useful amplification is not obtained due to the high degree of attenuation of the waves propagated along the delay device.

Thus, according to the present invention a travelling wave tube for use as an amplifier includes a sealed envelope filled with gas, a length of hollow metal waveguide the whole of the interior of which forms part of the interior of the envelope, a first radio frequency connector for feeding an input signal to the waveguide, a second radio frequency connector for deriving an output signal from the waveguide, the two connectors being spaced apart along the length of the waveguide, and an electron gun for projecting an electron beam along the length of the interior of the waveguide so as to pass the first and second connectors in that order, the electron gun being capable of providing an electron beam of sufficient density to generate within the wave guide, by ionisation of the gas therein, a plasma of density such that, with the waveguide disposed in a magnetic field directed substantially parallel to its longitudinal axis, the waveguide is capable of propagating space charge waves in a forward wave mode or over a range of frequencies extending below both the cyclotron frequency corresponding to said magnetic field and the normal cut-off frequency of the waveguide in the absence of the plasma, and the pressure of the gas filling lying within a range such that, with a given set of operating conditions involving appropriate values of the strength of the magnetic field, the mean

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velocity and density of the electron beam, and the electrostatic potential difference between the waveguide and the cathode of the electron gun and with an input signal having an appropriate frequency within said range of frequencies applied to the first connector, there may be obtained at the second connector an amplified output signal which is not masked by oscillations generated in the tube.

Broadly speaking, for any given arrangement of waveguide and electron gun and any given composition of gas filling, the appropriate range of pressures may be determined by firstly determining the pressure at which the saturated signal output power level is just equal to the output power level of oscillations generated within the tube at frequencies close to the signal frequency; by the saturated signal output power level is means the maximum output signal power which is obtained as the input signal power is increased from zero. The pressure thereby determined, which will be noted as P_0 , is substantially independent of the operating conditions over a wide range of operating conditions. A suitable range of pressures for the gas filling may then be taken as 1.0–2.25 times P_0 ; within this range, as the pressure is increased the gain obtainable from the tube decreases while the stability of operation of the tube is improved, and it will therefore normally be preferred to use a pressure near the centre of the range in order to achieve a suitable compromise between these factors.

In one preferred embodiment of the invention the gas filling is deuterium at a pressure in the range 0.12–0.27 torr (preferably about 0.2 torr). As compared with other gases, the use of deuterium results in improved stability of operation of the tube and enables somewhat higher voltages to be used for accelerating the electron beam without the risk of occurrence of a gas discharge between the electrodes of the electron gun.

In a travelling wave tube in accordance with the invention, the length of waveguide may form part of the envelope or may be separate from, and disposed within, the envelope.

One arrangement in accordance with the invention will now be described by way of example with reference to the accompanying drawing, which is a side elevation, partly in section, of a travelling wave tube suitable for amplifying signals having frequencies in the range 7,000–11,000 mc./s.

The travelling wave tube has a sealed envelope which is filled with deuterium at a pressure of 0.2 torr and which is primarily constituted by a copper shell 1. Parts of the shell 1 effectively form a length of waveguide 2 of circular cross-section having an internal diameter of three millimetres, that is such that the normal cut-off frequency of the waveguide 2 is about 59,000 mc./s. The waveguide 2 has a length of about eight centimetres and is provided with two radio frequency connectors 3 and 4 which are also formed by parts of the shell 1 and are respectively disposed about one centimetre from opposite ends of the waveguide 2. Each connector 3 or 4 includes a length of waveguide 5 of rectangular cross-section having internal dimensions 0.15 x 2.29 centimetres which is disposed so as to cross the waveguide 2 at right angles with the longitudinal axis of the waveguide 2 passing centrally through the broad faces of the waveguide 5, the interiors of the waveguides 2 and 5 communicating with each other where they cross. Each connector 3 or 4 also includes two further lengths of waveguides 6 and 7 of rectangular cross-section having internal dimensions 1.02 x 2.29 centimetres, which are respectively connected to opposite ends of the waveguide 5 by tapered rectangular waveguide sections 8 and 9, and which respectively have sealed across them members 10 and 11 of ceramic material which preserve the continuity of the envelope; for each connector 3 or 4, the waveguide 6 is provided

at its outer end with an adjustable tuning plunger 12 which provides a short circuit across the waveguide 6, while the waveguide 7 is provided at its outer end with a coupling flange 13 for connecting it to an external waveguide (not shown).

At the ends of the waveguide 2 the shell 1 is flared outwardly, and the flared end nearer the connector 3 is sealed to a glass bulb 14 which forms part of the envelope and within which is disposed an electron gun consisting of an indirectly heated thermionic cathode 15 and an anode 16; the bulb 14 has sealed through it leads 17, 18 and 19 which are respectively connected to the anode 16, the cathode 15 and one end of the cathode heater (not visible in the drawing), the other end of the heater being connected to the cathode 15. The electron emissive portion of the cathode 15 is in the form of a porous block 20 of sintered tungsten impregnated with alkaline earth metal compounds, the emissive surface being in the form of a circle of diameter two millimetres which is disposed perpendicular to, and with its centre lying on, the longitudinal axis of the waveguide 2 and so as to be spaced about one centimetre from the adjacent end of the waveguide 2. The anode 16 is in the form of a metal plate disposed parallel to the emissive surface of the cathode 15 between this surface and the adjacent end of the waveguide 2, the spacing between the emissive surface and the adjacent main face of the anode 16 being two millimetres and the anode 16 having formed in it a circular aperture 21 of diameter two millimetres which is disposed exactly opposite the emissive surface of the cathode 15.

The end of the shell 1 remote from the bulb 14 is sealed to one end of a short length of glass tubing 22, the other end of which is sealed to the mouth of a metal cup 23 which completes the envelope and which in operation of the tube serves as a collector electrode.

In operation, the travelling wave tube is disposed between the poles of an electromagnet (not shown) so that a uniform magnetic field H having a flux density of about 4000 gauss (for which the corresponding cyclotron frequency is about 11,000 mc./s.) is established in a direction parallel to the longitudinal axis of the waveguide 2. The anode 16 and the collector electrode 23 are earthed, the cathode 15 is maintained at a potential in the range 1-3 kilovolts negative with respect to earth by means of a source 24, the shell 1 is maintained at a potential in the range 0-12 volts positive with respect to earth by means of a source 25, and a suitable voltage source 26 is connected between the leads 18 and 19 to heat the cathode 15.

The electron gun generates an electron beam which travels longitudinally through the interior of the waveguide 2, the beam being maintained in a coherent form by the focussing action of the magnetic field H and finally impinging on the collector electrode 23; it should be noted that the spacing between the anode 16 and cathode 15 is sufficiently small to ensure that no gas discharge takes place between these electrodes at operating voltages within the range indicated above. As it travels through the waveguide 2 the electron beam ionises the gas filling so as to produce a plasma within the waveguide 2, and the beam current density is arranged to be such that the plasma density has an appropriate value for the propagation of space charge waves along the waveguide 2 in a forward wave mode to be possible over a range of frequencies extending below the cyclotron frequency referred to above; the beam current density (and hence the plasma density) increases with an increase of either the anode-cathode voltage supplied by the source 24 or the temperature of the cathode 15, so that for any given anode-cathode voltage the plasma density may be adjusted to a desired value by adjustment of the voltage supplied to the cathode heater from the source 26. It should be noted that the plasma density also increases with an increase of the value of the positive bias voltage applied

to the waveguide 2 from the source 25, so that variation of this latter parameter affords a further measure of control over the propagation characteristics of the waveguide 2.

A suitable range of operating conditions is such that the plasma density on the axis of the waveguide 2 corresponds to a plasma frequency having a value in the range 1-3 times the cyclotron frequency; with the specific arrangement described above operation within this range may be obtained by arranging the electron gun operating conditions so that the total beam current lies in the range 3-8 milliamperes, while setting the bias voltage applied to the waveguide 2 at an appropriate value within the range indicated above.

A signal to be amplified is fed via an external waveguide to the connector 3, so as to excite a space charge wave which travels along the waveguide 2 to the connector 4, from which an output signal is derived via a second external waveguide. Assuming the operating conditions to have been correctly chosen in relation to the signal frequency, as is explained further below, as it travels along the waveguide 2 the space charge wave is amplified by interaction with the electron beam in a manner similar to that operative in conventional travelling wave tubes.

In order to obtain the desired interaction, the mean velocity of the electron beam, which is determined by the value of the anode-cathode voltage, must be substantially the same as the phase velocity of the space charge wave, which as indicated above increases with decreasing signal frequency. For any given value of the signal frequency, this phase velocity depends on the precise values of the cyclotron frequency and the plasma density, increasing with an increase of either of these parameters. Thus to obtain the necessary condition of synchronism for any particular signal frequency, it is necessary to select a suitable set of values of the magnetic field strength, the anode-cathode voltage, the bias voltage applied to the waveguide 2, and the total beam current (which for a given anode-cathode voltage depends on the voltage applied to the cathode heater); for example, a suitable set of operating conditions for the tube described above at a signal frequency of 8,690 mc./s. is as follows:

Magnetic field	-----gauss--	3,920
Anode-cathode voltage	-----kilovolts--	2.24
Waveguide bias voltage	-----volts--	1.5
Beam current	-----milliamperes--	6.29

It will of course be appreciated that it is not necessary in practice to vary simultaneously all of the parameters referred to above in order to tune the tube for operation at different signal frequencies.

I claim:

1. A travelling wave tube for use as an amplifier, including a sealed envelope filled with gas, a length of hollow metal waveguide the whole of the interior of which forms part of the interior of the envelope, a first radio frequency connector for feeding an input signal to the waveguide, a second radio frequency connector for deriving an output signal from the waveguide, the two connectors being spaced apart along the length of the waveguide, and an electron gun for projecting an electron beam along the length of the interior of the waveguide so as to pass the first and second connectors in that order, the electron gun being capable of providing an electron beam of sufficient density to generate within the waveguide, by ionisation of the gas therein, a plasma of density such that, with the waveguide disposed in a magnetic field directed substantially parallel to its longitudinal axis, the plasma frequency is at least as great as the cyclotron frequency corresponding to said magnetic field, and the waveguide is capable of propagating space charge waves in a forward wave mode over a range of frequencies extending below both the cyclotron frequency corresponding

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to said magnetic field and the normal cut-off frequency of the waveguide in the absence of the plasma, and the pressure of the gas filling lying within a range such that, with a given set of operating conditions involving appropriate values of the strength of the magnetic field, the mean velocity and density of the electron beam, and the electrostatic potential difference between the waveguide and the cathode of the electron gun and with an input signal having an appropriate frequency within said range of frequencies applied to the first connector, there may be obtained at the second connector an amplified output signal which is not masked by oscillations generated in the tube.

2. A travelling wave tube according to claim 1, in which the gas filling is deuterium at a pressure in the range 0.12-0.27 torr.

3. A travelling wave tube, for use as an amplifier, including: a sealed envelope filled with gas; a length of hollow metal waveguide the whole of the interior of which forms part of the interior of the envelope; a first radio frequency connector for feeding an input signal to the waveguide; a second radio frequency connector for deriving an output signal from the waveguide; the two connectors being spaced apart along the length of the waveguide; an electron gun for projecting an electron beam along the length of the interior of the waveguide so as to pass the first and second connectors in that order, and generate a plasma within the waveguide by ionisation of the gas therein; and a magnetic field source for producing a magnetic field directed substantially parallel to

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the longitudinal axis of the waveguide; the density of the plasma generated within the waveguide is so related to the strength of the magnetic field that the plasma frequency is at least as great as the cyclotron frequency corresponding to said magnetic field, and the waveguide propagates space charge waves in a forward wave mode over a range of frequencies extending below both the cyclotron frequency corresponding to said magnetic field and the normal cut-off frequency of the waveguide in the absence of the plasma; and the pressure of the gas filling lying within a range such that, with a given set of operating conditions involving appropriate values of the strength of the magnetic field, the mean velocity and density of the electron beam, and the electrostatic potential difference between the waveguide and the cathode of the electron gun and with an input signal having an appropriate frequency within said range of frequencies applied to the first connector, there is obtained at the second connector an amplified output signal which is not masked by oscillations generated in the tube.

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