April 16, 1968 L. S. NAPOLI ETAL 3,378,723

FAST WAVE TRANSMISSION LINE COUPLED TO A PLASMA

Filed Jan. 2, 1964 3 Sheets-Sheet 1

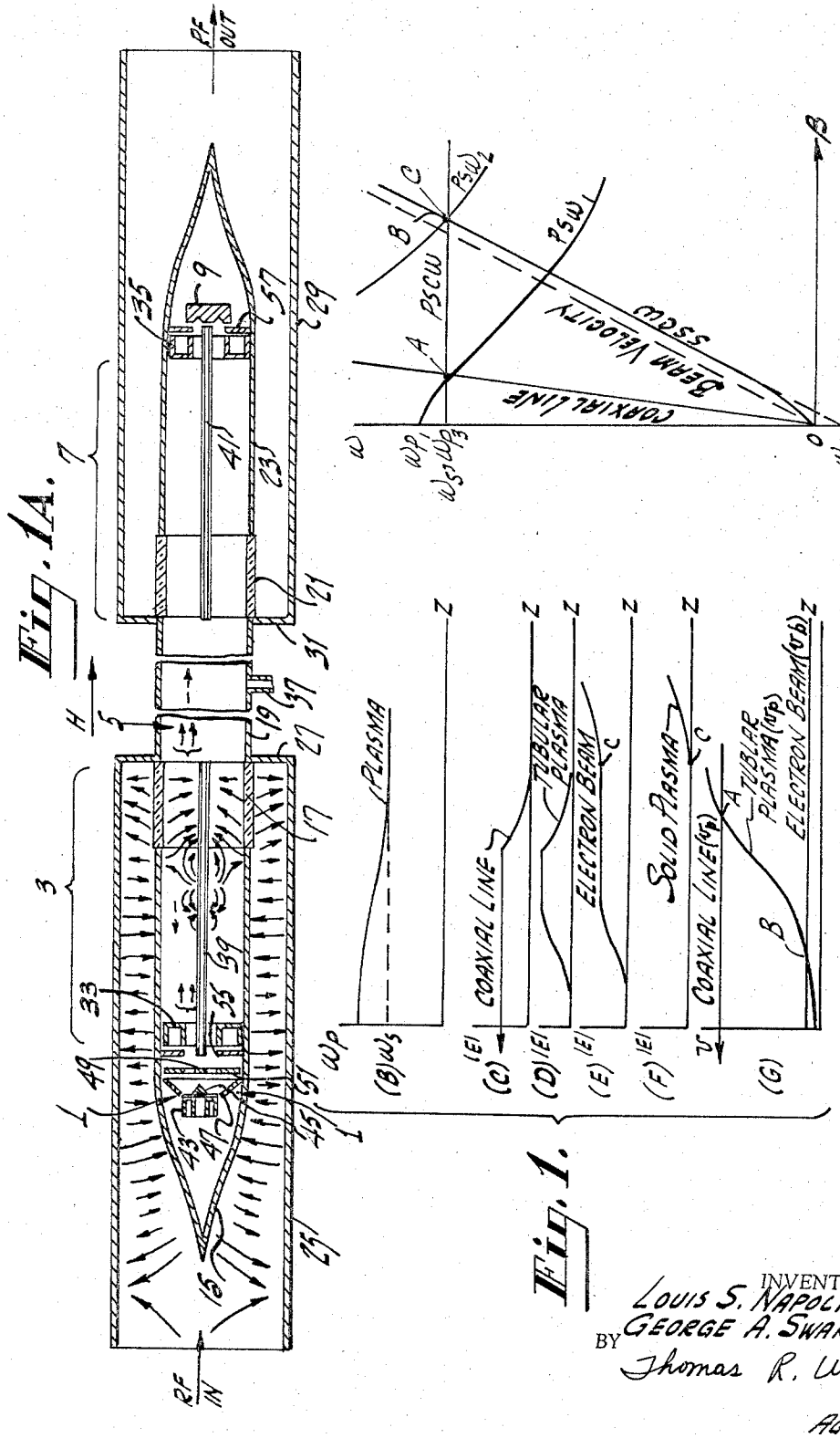


Fig. 1A.

Fig. 2.

Fig. 1.

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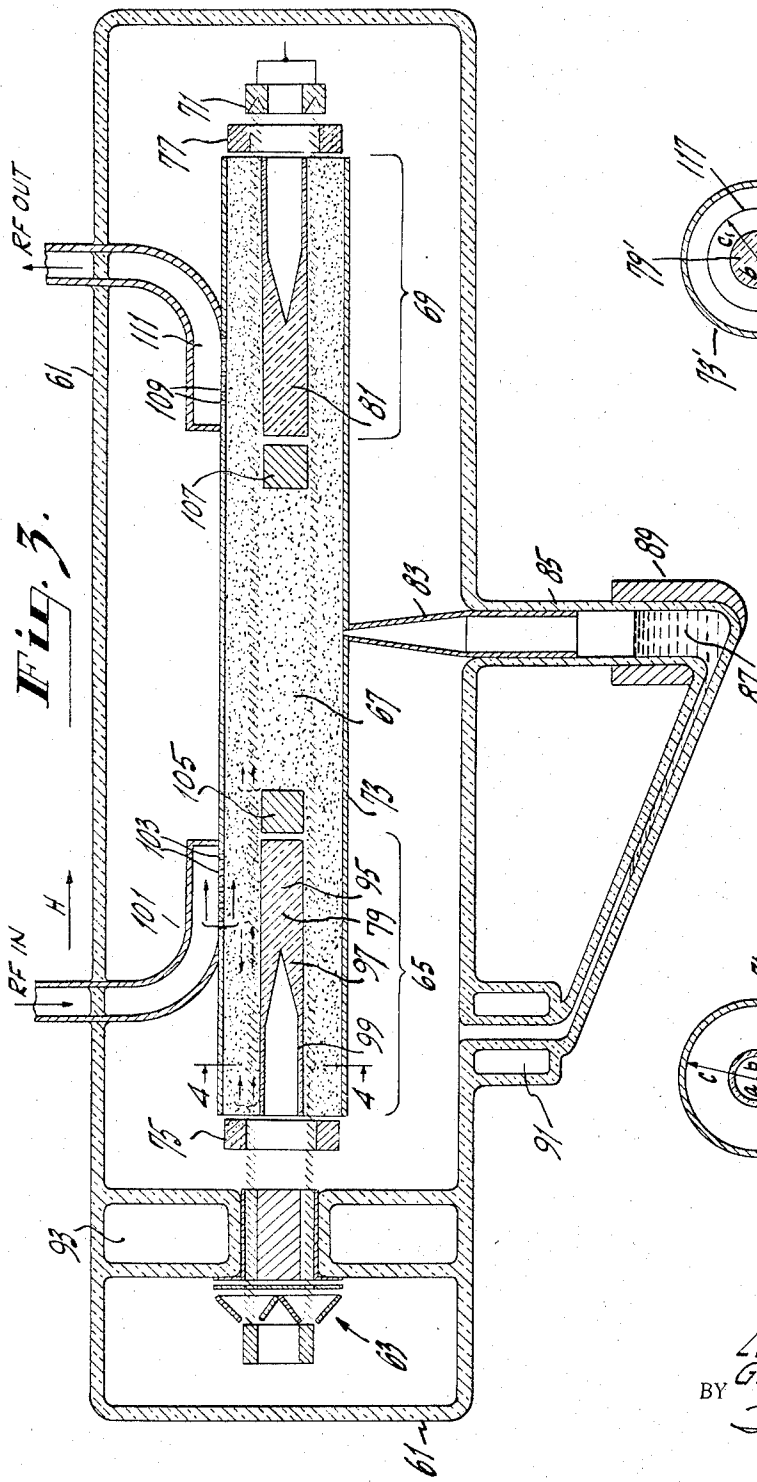


Fig. 3.

Fig. 7.

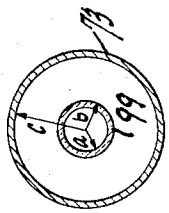


Fig. 4.

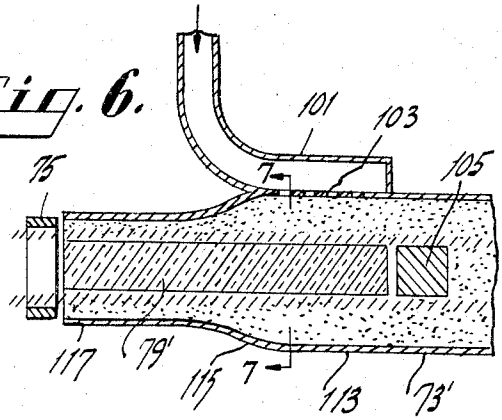
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Fig. 6.



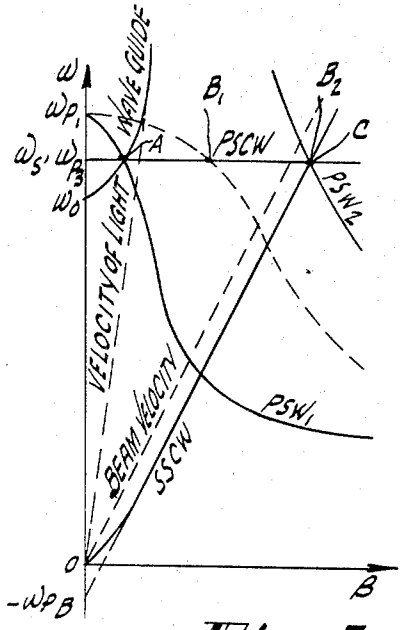


Fig. 5.

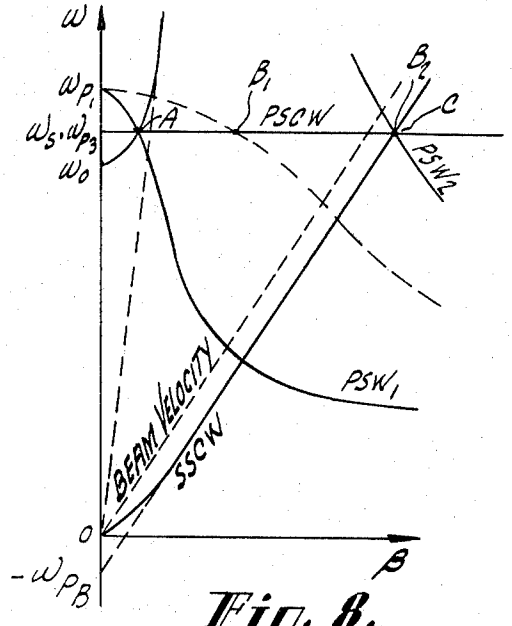


Fig. 8.

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FAST WAVE TRANSMISSION LINE COUPLED TO A PLASMA

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Filed Jan. 2, 1964, Ser. No. 335,139
10 Claims. (Cl. 315—39)

The present invention relates to plasma coupling means, and particularly to means for coupling a fast wave transmission line to the plasma in a plasma tube, such as a beam-plasma interaction tube.

A beam-plasma interaction tube is an electron tube in which an electron beam or stream is projected through a plasma region for interaction with the plasma to amplify or generate an RF signal. In an amplifier, the RF signal is coupled to and modulates the beam prior to injection thereof into the plasma. In an oscillator, the RF signal is generated by the beam-plasma interaction. The amplifier requires both input and output coupling means, whereas the oscillator requires only an output coupling means. Thus, a beam-plasma interaction tube requires:

(1) Means for generating a plasma, or neutral mixture of charged particles;

(2) Means for generating and projecting a stream of electrons through the plasma; and

(3) Means for coupling the electron stream to at least one fast wave RF transmission line, such as a waveguide or coaxial line.

Beam-plasma interaction normally occurs at or near the plasma frequency f_p of the electrons in the plasma. f_p is a function of the electron density n as follows:

$$f_p=\sqrt{\frac{ne^2}{\pi m}}=8{,}980\ \sqrt{n}$$

where e and m are the charge and mass, respectively, of the electron. The angular plasma frequency ω_p is equal to $2\pi f_p$. For example, operation at a signal frequency of 300 kmc., or 1 mm., wavelength, requires an electron density just above 10^{15} electrons per cm.^{3}. Since the beam-plasma interaction tube does not involve any periodic structures in the interaction region, the operating frequency, and power output are limited only by the available electron density.

The input and output coupling heretofore used in beam-plasma tubes have necessarily been slow-wave structures or klystron type gap structures, which are limited in their power capabilities, especially at very high frequencies. Some of the limitations of such structures are:

(1) The diameter of the slow-wave structure is limited to about a wavelength because of moding difficulties;

(2) For a given dimension the power output is limited by the ability of the structure to dissipate the heat produced by beam interception and RF heating;

(3) The voltages on the structure are limited by breakdown and multipactor effects;

(4) High power output is often incompatible with bandwidth requirements because of the dispersion of the RF structure;

(5) The RF losses increase with frequency; and

(6) Gap structures are inherently narrow band with coupled cavity resonators and very inefficient without resonators.

An object of the present invention is to provide improved means for coupling a fast wave transmission line to a plasma.

A further object is to provide improved means for coupling an electron stream in an electron tube to a fast wave input or output transmission line.

Another object is to provide means utilizing the plasma in a beam-plasma interaction tube to couple a fast wave transmission to the beam, and vice-versa.

A further object is to provide an improved beam-plasma interaction tube.

These and other objects are accomplished in accordance with the present invention by producing a plasma in a given region, coupling a fast wave input signal transmission line to the plasma in a first portion of the region to excite a fast wave on the plasma at the signal frequency for propagation to a second portion of the region, projecting a stream or beam of electrons through the region parallel to the direction of propagatin of the fast wave, changing the phase velocity of the fast wave during propagation to a second portion of the region, projecting a stream or beam of electrons through the region parallel to the direction of propagation of the fast wave, changing the phase velcity of the fast wave during propagation to a lower value at the signal frequency in a second portion of the region for exciting a slow wave of signal frequency on the electron stream, directing the signal modulated stream through a third portion of the region for amplifying interaction with the plasma, and then coupling the stream to a fast wave output transmission line in the same manner that the input line is coupled to the stream. The fast wave transmission lines may be coaxial lines or waveguides capable of propagating waves to or near the velocity of light. The phase velocity of the fast wave on the plasma may be reduced in any suitable manner, as by:

(1) Increasing the density of the plasma in the direction of propagation;

(2) Decreasing the effective capacitance of a dielectric rod forming one boundary for the plasma;

(3) Decreasing the effective inductance of the plasma between the dielectric rod and the conductive boundary; and

(4) A combination of (1) with (2) or (3).

In the accompanying drawings:

FIG. 1A is an axial section view of a beam-plasma amplifier tube incorporating one embodiment of the present invention;

FIGS. 1B through 1G are graphs showing the variation of plasma frequency, electric field and velocity with distance along the axis of the tube of FIG. 1A;

FIG. 2 is an ω–β diagram for FIG. 1A;

FIG. 3 is an axial section view of another beam-plasma amplifier tube incorporating another embodiment of the invention;

FIG. 4 is a transverse section view taken on line 4—4 of FIG. 3;

FIG. 5 is an ω–β diagram for FIG. 3;

FIG. 6 is a fragmentary axial section view of a modification of FIG. 3;

FIG. 7 is a transverse section view taken on line 7—7 of FIG. 6; and

FIG. 8 is an ω–β diagram for FIG. 6.

The beam-plasma amplifier tube illustrated in FIG. 1A comprises an electron gun 1, a tubular plasma input coupling section 3, a beam-plasma interaction section 5, a tubular plasma output coupling section 7, and a beam collector 9. The tube envelope is made up of a first metal section 15 of circular cross section surrounding section 1 and part of section 3, a first tubular wave-permeable window 17, e.g., of ceramic, surrounding the rest of section 3, a second tubular metal section 19 surrounding section 5, a second tubular wave-permeable window 21 surrounding part of section 7, and a third metal section 23 of circular cross section surrounding the rest of section 7 and section 9. A tubular metal member 25 and radial metal ring connecting member 27 to section 19 cooperates with the metal section 15 to form an input transition section from a waveguide to a coaxial line, for coupling a signal

wave through section **17** to the plasma in section **3**. The section **15** is shaped to transform a TM_{01} wave in the waveguide portion to a TEM wave in the coaxial line portion, as shown by the field arrows in FIG. 1A. A tubular metal member **29** and metal ring member **31** form a similar output transition section with the section **23**, for coupling the amplified signal from section **7** to an output waveguide. Members **25** and **27** and section **3** constitute a coaxial input coupler; and section **7** and members **29** and **31** constitute a coaxial output coupler.

A dense plasma is produced in the region made up of sections **3**, **5** and **7** by a Penning type discharge between two thermionic cathodes **33** and **35**, mounted at the ends of the region, and the intermediate hollow cylindrical metal section **19**, which serves as the anode for this discharge. A controlled amount of an alkali metal vapor, such as cesium, for plasma production is provided within the tube, as for example by means of a tubulation **37** connected to a controllable vapor source (not shown). In operation, a discharge voltage of 4–10 volts is applied between the two cathodes **33**, **35** and the anode **19** to produce positive cesium ions and additional electrons in the plasma region by electron-vapor collisions. A strong axial magnetic field is maintained along the length of the tube by a conventional means, such as a solenoid, as indicated by the arrow H, to confine the electrons and ions to substantially axial movement. Moreover, in order to produce a plasma having an extremely high density and percent ionization, the anode **19** may be made of a material, such as tungsten, having an electron work function higher than the ionization potential of the vapor used (e.g., 3.9 volts for cesium) in which case the anode should be heated to a temperature sufficient to produce positive ions at the surface thereof by contact ionization. Cesium plasmas having densities greater than 10^{14} particles/cm^3. at 50% ionization have been produced in this manner.

The plasma density, and hence, the plasma frequency ω_p along a Penning type discharge, such as that shown in FIG. 1A, varies along the length thereof, being higher near each end near the cathodes **33** and **35** than in the middle along the interaction region **5**, as shown by the curve for ω_p in FIG. 1B. This property of the plasma is utilized in the coupling system shown in FIG. 1A. A cylindrical dielectric rod **39** which is axially mounted in the input coupling section **3**, forms the inner boundary of a tubular coupling plasma. The outer boundary of this coupling plasma is formed by the portion of the metal section **15** extending between the cathode **33** and the window **17**. For example, an increase of 160% in plasma density along the tubular plasma results in an increase in ω_p of about 60%. A similar dielectric rod **41** is axially mounted in the output coupling section **7**.

A tubular plasma between dielectric and conductive boundaries supports propagation in a backward wave mode, that is, in a mode wherein the phase and group (energy) velocities are in opposite directions. The transmission line formed by the dielectric rod **39**, metal member **15** and plasma therebetween may be termed a tubular plasmaguide.

The electron gun **1** comprises an annular thermionic cathode **43**, focusing electrodes **45** and **47**, and accelerating electrodes **49** and **51**, for projecting a hollow electron beam or stream through the entire plasma region (sections **3**, **5** and **7**) to the collector **9**. The plasma cathodes **33** and **35** may be shielded from the electron gun **1** and collector **9** by apertured discs **55** and **57**, respectively. The beam velocity is necessarily only a fraction of the velocity of light, hence it is necessary to greatly reduce the phase velocity of the fast signal wave before coupling to the beam.

As stated above, the input signal wave is converted to a TEM mode wave in the coaxial line formed by members **15** and **25**. This wave is coupled through window **17** to the tubular plasma in section **3** and excites a backward wave therein which propagates toward the plasma cathode **33**, toward the left as indicated in FIG. 1A by the broken arrow for its group velocity. The transfer of electrical energy from the coaxial line to the tubular plasma is shown by the electric field curves |E| in FIGS. 1C and 1D. The density of the tubular plasma in the part of section **3** next to the window **17** is adjusted to make the phase velocity v_p of the backward wave therein equal to that of waves in the coaxial line (the velocity of light) at the signal frequency at a point such as point A in FIG. 1G at which maximum coupling occurs.

As the backward wave propagates (to the left in FIG. 1A) its phase velocity v_p decreases, due to the increase in plasma density and plasma frequency ω_p described above, as shown by the curve AB in FIG. 1G. Moreover, the backward wave is converted during such propagation from a wave having predominantly transverse electric fields to a wave having substantial longitudinal fields, as shown by the electric field arrows in FIG. 1A. The velocity of the electron beam is adjusted to synchronize with the reduced forward phase velocity of the backward wave at a point B in section **3**, in order that the backward wave will excite a forward signal wave on the beam. This coupling is indicated in FIG. 1A by the bracketed solid arrows for the phase velocities of the two waves in section **3**. The transfer of energy from the plasma wave to the beam wave is shown in FIGS. 1D and 1E.

After being thus signal modulated the forward wave on the beam propagates to and through the interaction section **5** in which it interacts with a space charge wave in the solid plasma therein to amplify the signal.

FIG. 2 is an "ω–β diagram," which is a conventional means for graphically showing the wave propagating characteristics of wave propagating media such as transmission lines, electron streams and plasmas. Since ω is the angular velocity and β is the phase shift per unit length along the medium, each point on the graph represent a particular phase velocity as determined by the ratio ω/β at that point, and each straight line through the origin represents the locus of points of equal phase velocity. In FIG. 2, the curve labeled PSW_1, is the wave propagating characteristic for surface waves on the tubular plasma in the first part of coupling section **3**, for an example in which quartz is used for the dielectric rod **39**. As shown, this curve intersects the characteristic for waves in the coaxial line at point A, corresponding to point A in FIG. 1G. This means that a signal of frequency ω_s in the coaxial line will induce or excite a PSW_1 wave of the same frequency on the tubular plasma. Curve PSW_2 is the wave characteristic for the same surface wave after propagation to the higher density portion of section **3** to point B of FIG. 1B. The beam velocity v_b (and the group velocity of waves on the beam) is shown by the dashed line, and the wave characteristic of slow space charge waves on the beam is shown by the curve labeled SSCW. This curve is substantially straight and parallel to the beam velocity line, except near the origin as shown. The extension of the straight portion intersects the $-\omega$ axis at $-\omega_{pB}$, the plasma frequency of the beam. The beam velocity is adjusted to make the SSCW curve intersect the PSW_2 curve at ω_s, at point B in FIG. 2, in order to couple the signal wave PSW_2 on the tubular plasma to the forward wave SSCW on the beam at signal frequency.

The plasma frequency ω_{p_1} of the tubular plasma at point A (FIG. 1G) is shown in FIG. 1B to be a little higher than the signal frequency ω_s. However, in the interaction section **5** the plasma frequency ω_{p_3} of the solid plasma is substantially equal to ω_s. Thus, the modulated beam interacts with a space charge wave in the solid plasma at that frequency. The plasma frequency ω_{p_2} of the decelerated waves PSW_2 (the intersection of curve PSW_2 with the ω-axis) is too high to be shown on FIG. 2. The wave characteristic of the plasma space charge wave is the solid horizontal line, labeled PSCW, through ω_s,

A and B, in FIG. 2. Coupling between the modulated beam wave SSCW and plasma wave PSCW occurs at point C in FIG. 2 and begins near point C in FIGS. 1E and 1F, which show the growth or amplification of the electric field |E| in the electron beam and the plasma, respectively. Points B and C indicate RF coupling in two separate regions in FIGS. 1G and 1F, although they are superimposed at the same velocity point in FIG. 2.

After being amplified in passing through the interaction section **5**, the signal wave on the beam is coupled in output section **7** to a slow plasma surface wave, which in turn is accelerated and coupled to a fast wave in the output line, in exactly the same manner as in the input coupling system, except in reverse.

Instead of utilizing only changes in plasma density to change the phase velocity of the coupling waves, other properties of the structure may be varied, alone or in combination with changes in plasma density for this purpose. Also, other types of input transmission lines can be used. FIGS. 3 and 4 show an embodiment in which hollow wave guides are coupled to tubular plasmaguides, the wave propagating characteristics of which are varied by varying the structure of the dielectric rods. The tube comprises a sealed envelope **61**, e.g., of glass, containing an electron gun **63**, a tubular plasma input coupling section **65**, a beam-plasma interaction section **67**, a tubular plasma output coupling section **69** and a collector **71**. The three plasma sections **65**, **67** and **69** comprise a hollow cylindrical metal anode member **73**, annular plasma cathodes **75** and **77** at the ends of member **73**, a dielectric rod **79** in coupling section **65**, and a dielectric rod **81** in coupling section **69**. Cesium vapor is supplied to the space within anode **73** through a tubing **83** connected to a generally U-shaped by-pass tubing **85** containing liquid cesium **87**. The cesium reservoir is heated, as by a coil or tape **89**, to maintain a vapor pressure of 10^{-2} to 1 torr in the anode. A water jacket may be provided at **91** to control the cesium condensation. A cold trap **93** may be provided between the electron gun **63** and the rest of the tube to maintain a lower pressure in the gun region.

The density of the tubular plasma in the coupling section **65** increases in the direction from the interaction region toward the plasma cathode **75**, as in FIG. 1A. Moreover, in order to produce a greater change in phase velocity of waves on the plasma, the dimensions of the dielectric rod **79** are varied while maintaining the internal diameter c of anode **73** constant. The rod **79** has a uniform external diameter and is made up of a solid first portion **95** at the end adjacent the interaction section **67**, a tapered internal diameter section portion **97** and a thin-walled hollow portion **99** connected to the solid first portion **95** by the tapered second portion **97**. The dielectric rod constitutes a distributed capacitance forming part of the transmission line. Since $v=\omega/\beta$ and

$$\beta \sim \frac{1}{\omega\sqrt{LC}}$$

for backward waves, the decrease in capacitance from section **95** to section **99** produces a decrease in phase velocity of waves propagated along the line, which adds to the decrease in phase velocity due to the increase in plasma density.

The input RF signal to be amplified is introduced to the tube through a generally rectangular hollow input waveguide section **101** having its end portion parallel to the input tubular plasmaguide **65** and coupled through apertures **103** in the anode **73** to the first portion of the plasmaguide, viz. the part including the solid dielectric portion **95**. The coupling operation for an example in which the dielectric rod **79** is of ceramic is illustrated by the ω–β diagram of FIG. 5. The characteristic curve for the input waveguide **101** is a parabola crossing the ω-axis at ω_o, the cutoff frequency, and merging at high frequencies with the dashed line showing the velocity of light. At the signal or operating frequency of the tube, the phase velocity in the waveguide is somewhat higher than the velocity of light, at point A. In order to couple input waves of frequency ω_s to the plasmaguide coupler **65**, the density of the plasma in the first portion of the coupler is adjusted to make the characteristic curve PSW_1 of the backward waves intersect the waveguide curve at ω_s, or point A, as in FIG. 2. If the plasma density (and ω_p) were constant throughout the tubular plasmaguide coupler, the effect of the change in dielectric material between portions **95** and **99** would be to shift the PSW_1 curve to the right, as shown by the dashed curve PSW_2 in FIG. 5, which intersects the horizontal W_s line at point B_1, and shows the wave characteristic for the condition where b/a is nearly unity in FIG. 4. However, since the plasma density (and ω_p) also varies, the net effect of the two variations is curve PSW_3, the characteristic of backward surface waves in the third portion of the coupler, which curve intersects the ω_s line at point B_2. The beam velocity is adjusted to couple the backward wave PSW_2 to a slow space charge wave SSCW on the beam at the signal frequency ω_s, at point B_2. As shown, the beam velocity required is considerably below that required for coupling at point B_1. After being modulated by the input signal, the beam wave SSCW interacts with the solid plasma in interaction section **67** as in FIGS. 1 and 2. Preferably, additional plasma cathodes **105** and **107** are provided, at the ends of dielectric rods **79** and **81**, to maintain uniform plasma density in section **67**. As in FIG. 1, the anode is preferably made of a high work function metal and is heated to produce additional cesium ions by contact ionization. After amplification, the RF signal on the beam is coupled to a backward surface wave in the output plasmaguide section **69**, which wave is accelerated and coupled through apertures **109** in anode **73** to an output waveguide section **111**.

FIGS. 6 and 7 show a modification of FIG. 3 in which the dielectric rod **79'** is solid throughout its length ($a=0$) and the diameter of the surrounding conducting surface varies between c_1 to c_2 at the ends of the rod **79'**. Thus, the anode **73'** comprises a first section **113** of large diameter, a tapered second section **115**, and a third section **117** of smaller diameter. The effect of the reduction in diameter is to reduce the thickness of the tubular plasma, which reduces the distributed inductance contributed by the plasma to the transmission line and thereby reduces the phase velocity of the backward waves on the tubular plasma. The effect of this reduction in phase velocity without any change in plasma density is shown by the dashed curve PSW_2 in FIG. 8, where PSW_1 is the characteristic curve for backward waves in the first section **113**. The net effect of the reduction in plasma thickness and the increase in plasma density along the tubular plasmaguide is shown by the curve PSW_3 for backward waves in section **117**. Comparison of FIG. 8 with FIG. 5 shows that the plasma thickness variation is more effective than the dielectric material variation. The remainder of the operation is the same as described for FIGS. 3 to 5.

It will be understood that FIGS. 3 and 6 could be combined, by using the variable dielectric rod of FIG. 3 with the variable anode diameter of FIG. 6, to reduce the phase velocity still further. Moreover, the change in plasma density may be increased in any of FIGS. 1, 3 and 6 by dividing the outer conductive wall of each tubular plasmaguide into at least two insulated sections and applying different DC potentials thereto. If the section nearest the cathode is biased more positive than the other section (nearest interaction region), ions will flow to the other section and reduce the overall plasma density in that region with respect to the plasma density in the cathode section.

What is claimed is:

1. Means for coupling a fast wave transmission line to a plasma at a given frequency, comprising:

(a) means for producing a plasma in a given region;

(b) means for coupling a fast wave transmisison line to the plasma in a first portion of said region to excite a fast backward wave at said frequency on said plasma for propagation to a second portion of said region; and

(c) means for changing the phase velocity of said fast backward wave during said propagation to a different value at the some frequency in said second portion.

2. Means for coupling a fast wave transmission line to an electron stream at a given frequency, comprising:

(a) means for producing a plasma in a given region;

(b) means for coupling a fast wave transmission line to the plasma in a first portion of said region to excite a fast backward wave at said frequency on said plasma for propagation to a second portion of said region;

(c) means for projecting a stream of electrons through said region in a direction opposite to the direction of propagation of said fast backward wave; and

(d) means for changing the phase velocity of said fast backward wave during said propagation to a lower value at the same frequency in said second portion, for exciting a slow forward wave of said lower phase velocity at said frequency on said electron stream.

3. Means for coupling a fast wave transmission line to a plasma at a given frequency, comprising:

(a) means for producing a plasma in a given region;

(b) means for coupling a fast wave transmission line to the plasma in a first portion of said region to excite a fast backward surface wave having predominantly transverse electric fields at said frequency on said plasma for propagation to a second portion of said region; and

(c) means for converting said fast backward surface wave during said propagation to a similar wave having substantial longitudinal electric fields at said frequency in said second portion.

4. Means for coupling a fast wave transmission line to an electron stream at a given frequency, comprising:

(a) means for producing a plasma in a given region;

(b) means for coupling a fast wave transmission line to the plasma in a first portion of said region to excite a fast backward wave having predominantly transverse electric fields at said frequency on said plasma for propagation to a second portion of said region;

(c) means for projecting a stream of electrons through said region in a direction parallel to the direction of propagation of said fast backward wave; and

(d) means for converting said fast backward wave during said propagation to a backward wave having a lower phase velocity and substantial longitudinal electric fields at the same frequency in said second portion, for exciting a slow space charge wave of said lower phase velocity having substantial longitudinal electric fields at said frequency on said electron stream.

5. Means for coupling a fast wave transmission line to a plasma at a given frequency, comprising:

(a) a hollow conductive member;

(b) an elongated dielectric member coaxially disposed within said hollow member;

(c) means for producing a plasma in the space between said members;

(d) means for coupling a fast wave transmission line to the plasma in a first portion of said space to excite a fast backward wave of given frequency on said plasma for propagation to a second portion of said space; and,

(e) means for changing the phase velocity of said backward wave during said propagation to a different value at the same frequency in said second portion.

6. Means for coupling a fast wave transmission line to an electron stream at a given frequency, comprising:

(a) a hollow conductive means;

(b) an elongated dielectric means coaxially disposed within said hollow means;

(c) means for producing a plasma in the space between said conductive and dielectric means;

(d) means for coupling a fast wave transmission line to the plasma in a first portion of said space to excite a fast backward wave of given frequency on said plasma for propagation to a second portion of said space;

(e) means for projecting a stream of electrons through said space in a direction opposite to said backward wave; and

(f) means for changing the phase velocity of said backward wave during said propagation to a lower value at the same frequency in said second portion for exciting a slow space charge wave of said lower phase velocity at said frequency on said electron stream.

7. Coupling means as in claim 6, wherein said hollow means is a cylindrical member, and said dielectric means comprises a solid portion extending along said first portion, a thin hollow portion extending along said second portion, and a hollow transition portion of tapered internal diameter connecting said solid and hollow portions.

8. Coupling means as in claim 6, wherein said dielectric means is a cylindrical member, and said hollow means comprises a cylindrical portion of given diameter extending along said first portion, a cylindrical portion of smaller diameter extending along said second portion, and a transition portion of tapered diameter connecting said cylindrical portions.

9. Coupling means as in claim 6, wherein said last-named means comprises means for establishing an increasing plasma density gradient between said first portion and said second portion.

10. A beam-plasma interaction tube comprising:

(a) means for producing a plasma in a given region;

(b) means for coupling a fast wave transmission line to the plasma in a first portion of said region to excite a fast backward wave at said frequency on said plasma for propagation to a second portion of said region;

(c) means for projecting a stream of electrons through said region in a direction parallel to the direction of propagation of said fast backward wave;

(d) means for changing the phase velocity of said fast backward wave during said propagation to a lower value at the same frequency in said second portion, for exciting a slow forward wave of said low phase velocity at said frequency on said electron stream;

(e) means for directing said electron stream from said second portion to a third portion of said region, for interaction with the plasma therein to increase the amplitude of said slow forward wave; and

(f) means for coupling said amplified slow forward wave to a fast wave transmission line.

References Cited

UNITED STATES PATENTS

3,111,604	11/1963	Agdur	315—39
3,257,620	6/1966	Roberts	315—3.5
3,270,244	8/1966	Ayaki	315—3.5
3,317,785	5/1967	Ferrari	330—41 X

OTHER REFERENCES

"Space Charge Waves in Cylindrical Plasma Columns," by Gould et al., Journal of Applied Physics, vol. 30.

"Slow Wave Propagation in Plasma Waveguides," by Trivelpiece-Technical Report No. 7, California Institute of Technology.

HERMAN KARL SAALBACH, *Primary Examiner.*

ELI LIEBERMAN, *Examiner.*

S. CHATMON, *Assistant Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,378,723 April 16, 1968

Louis S. Napoli et al.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, lines 14 to 17, cancel "to a second portion of the region, projecting a stream or beam of electrons through the region parallel to the direction of propagation of the fast wave, changing the phase velcity of the fast wave during propagation"; line 26, "to" should read -- at --. Column 5, line 7, after "1F," insert -- respectively, --; line 50, "section" should read -- second --. Column 7, line 8, "some" should read -- same --.

Signed and sealed this 14th day of October 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents