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ELECTROMAGNETIC WAVE GENERATING AND TRANSLATING APPARATUS

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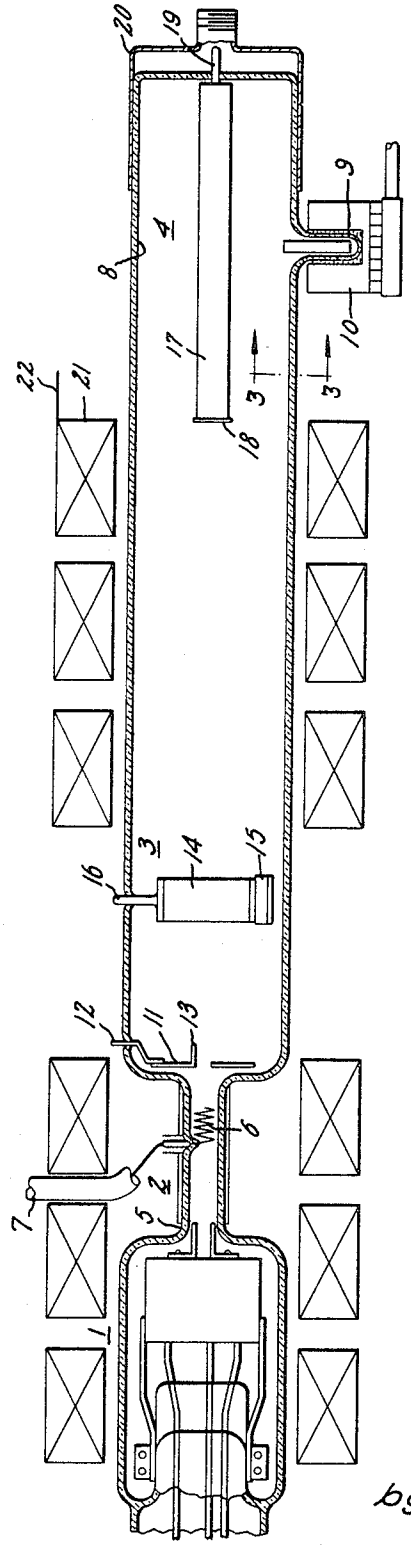


Fig. 1.

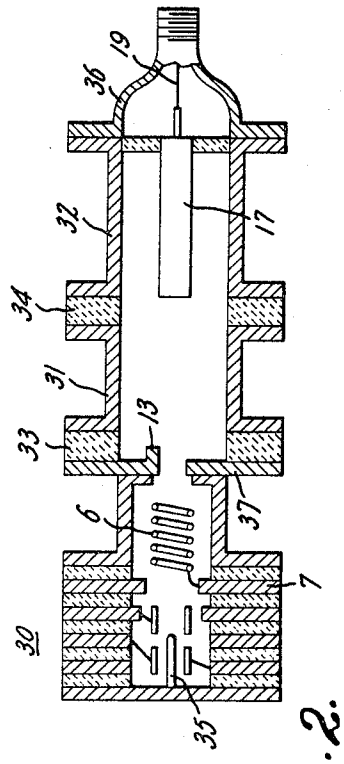


Fig. 2.



Fig. 3.

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ELECTROMAGNETIC WAVE GENERATING AND TRANSLATING APPARATUS

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ABSTRACT OF THE DISCLOSURE

An apparatus wherein a beam of density modulated electrons restricted to longitudinal movement traverses a plasma column having longitudinal and radial gradients. An interaction occurs between the beam and plasma in a section in the plasma column having a resonant frequency approximately equal to the driving frequency of the electron beam thereby permitting an electromagnetic wave to radiate out from the plasma. A cathode positioned inside a circular wave guide enclosing the plasma acts as an inner conductor of a coaxial wave guide while the outer conductor is coupled to the circular wave guide.

Our invention relates to electromagnetic wave generating and translating apparatus and particularly to such apparatus using a resonant or near resonant plasma which interacts with an electron beam allowing an electromagnetic wave to radiate out of said plasma to a coaxial wave guide output.

It has been suggested that if a space charge wave interacts with a fully ionized plasma having a resonant frequency near that of the electron beam driving frequency, under certain conditions the fast space charge wave may be amplified and radiated out of the plasma.

It has been demonstrated that the interaction of the slow space charge wave with magnetically confined nonresonant plasmas exhibits power gain. In these instances, the slow space charge wave is still contained within the plasma and to be useful must be converted to a fast wave by an output coupler. These couplers are usually helices or cavities. For high power and very high frequency applications, the size and power handling capabilities of the coupler limits the efficiency of power transfer and frequency of utility.

It is a primary object of our invention to provide a new and improved electromagnetic wave generating and translating apparatus employing a density modulated electron beam which interacts with a plasma having a resonant frequency approximately equal to the electron beam driving frequency thereby allowing a fast wave to radiate directly out of the region of interaction and thereby eliminating the need for output helices or cavities.

Another object of our invention is to provide a wave guide structure and integral output coupler associated with the region of interaction which permits microwave energy generated through the interaction a density modulated electron beam and a plasma to be translated directly to an output coaxial type wave guide.

Briefly stated, in carrying out our invention, we inject a solid or hollow beam of density-modulated electrons restricted to longitudinal movement into a magnetically compressed plasma having both radial and longitudinal (axial) density gradients and having a region in which the resonance frequency is the same as the driving frequency of the electron beam thereby causing interaction and radiation of electromagnetic waves from the plasma to a wave guide structure which translates such waves to an output coaxial line.

The novel features which we believe to be characteristic of our invention are set forth with particularity in the appended claims. The invention itself, however, may best be understood with reference to the following description taken in connection with the accompanying drawing in which:

FIGURE 1 is a schematic longitudinal view of our electromagnetic wave generating and translating apparatus, and

FIGURE 2 is a schematic view of a portion of a device capable of operating in the millimeter wave region.

FIGURE 3 illustrates a cross-sectional view of the device along lines 3—3 of FIGURE 1.

The apparatus illustrated in FIGURE 1 comprises an electron emitter region **1**, a density modulated wave generating region **2**, a plasma tube **3**, and an output region **4**. The electron emitter region **1** may comprise a conventional electron gun and is illustrated as a Pierce-type electron gun, the details of which are well known and which supplies a narrow beam of electrons to a constructed portion **5** of the glass envelope for the wave generating and translating apparatus. Construcited portion **5** includes a helix **6**, preferably of tungsten wire, through which the direct current beam from the electron gun passes. High frequency potentials are supplied to helix **6** over a coaxial input cable **7** from a conventional external oscillator (not shown). The frequency of these potentials may be, for example, of the order of 9,000 gigacycles. The helix **6** operates as a quarter or half wave resonant structure. In such operation, as the electron beam traverses the helix **6**, the beam is modulated in a well-known fashion to produce as described in simple terms a group of low velocity electrons and a group of high velocity electrons. The group of low velocity electrons is produced every half cycle of the modulating wave and the group of high velocity electrons is produced every alternate half cycle. The velocity modulated electron beam emerging from the helix **6** eventually converts to density modulation as the fast electrons catch up with the slow electrons, so that a density-modulated beam is introduced into plasma tube **3**.

The plasma tube **3** comprises an enlarged portion of the glass envelope of the apparatus, which portion is coated with a conducting material such as, for example, silver paint **8**, to provide a conductive cylinder or circular wave guide. In order to interrupt circumferential currents generated by variations of the confiing magnetic field produced by surrounding coils **21**, as well as to provide a means for viewing the characteristics of the discharge within plasma tube **3**, longitudinal slots are provided in the paint on the side of the tube **3** in a well-known manner. However, when the confiing magnetic field of coils **21** is operating on a steady state basis, circumferential currents will be non-existent and hence the circular wave guide can be made of metal.

Attached to the right-hand end of the plasma tube **3** is an appendage **9** which contains a source of ionizable vapor for the tube **3**. The ionizable vapor may comprise, for example, mercury vapor, cesium vapor, or any other suitable gaseous medium. In the modification illustrated, appendage **9** contains mercury whose vapor pressure within the tube **3** is controlled by a thermoelectric cooler **10**.

Located within plasma tube **3** is a plasma generator of a well-known type and referred to as a Penning discharge or alternatively as a Philips-ionization-gauge type discharge. This discharge device includes a nonsymmetrical arrangement of electrodes comprising a disc washer cathode **11**, to which operating potentials are supplied by lead **12** and to which is attached an eccentric starting needle **13**. Cathode **11** may comprise, for example, a split disc of molybdenum and the starting needle, like-

wise, may comprise molybdenum. Spaced from cathode **11** is an anode ring **14** which may comprise a split molybdenum cylinder having the proper dimensions to encourage the propagation of the TM_{01} circular guide mode and the principal coaxial TEM mode. A flash getter ribbon **15** is attached to the anode cylinder **14** for conventional gettering purposes. Likewise, as is well known, arms (not shown) loacted on the outside of the anode cylinder **14** may be provided to suppress the formation of unwanted modes such as, for example, the TE_{11} mode. Operating potentials for anode **14** are supplied from an input terminal or lead **16**.

Spaced on the opposite side of anode **14** from cathode **11** is a second cold cathode **17** in the form of a cylinder of a high conductive material. Cylinder **17** is aligned along the axis of plasma tube **3** and is provided on its end facing anode **14** with a material **18** such as, for example, molybdenum, which possesses a high secondary emission coefficient. Cylinder **17** itself may comprise, for example, stainless steel. So positioned, cathode **17** serves the following five functions:

(1) To supply ion induced secondary emission electrons for the Penning discharge;

(2) As an electron collector for the main electron beam from gun **1**;

(3) As a second terminating point for the plasma column;

(4) As a smooth transition zone from the plasma to coaxial line for the electromagnetic wave generated; and

(5) As an inner conductor of a coaxial line located within tube **3**, the outer conductor of such coaxial line comprising the coating **8** on the surface of tube **3** and sleeve **20**.

The right-hand end of cathode **17** terminates in a conductor **19** which comprises the inner conductor of an external coaxial transmission line. The outer conductor of such external transmission line comprises a sleeve **20** which is slipped over the end of tube **3** and makes physical contact to coating **8**, best seen in FIGURE 3, on tube **3**. The external coaxial transmission line, of course, may be connected to any desirable utilization circuit.

Surrounding and extending along the outside of the entire tube configuration thus far described is a magnetic structure comprising a plurality of Helmholtz type coils **21**. Currents for energizing coils **21** may be supplied by means of conductor **22** from any suitable external source such as, for example, a capacitor bank and a spark gap (not shown) to provide a critically damped magnetic wave having a short rise time, or a direct current supply to generate a steady state magnetic field.

In the modification of FIGURE 2, there is illustrated a tube structure capable of operating in the millimeter wave region. In this structure a metal-ceramic envelope is used rather than the glass envelope of FIGURE 1. The electron emitter portion **30** and helix **6** may be similar to those of FIGURE 1 or other conventional structures suitable for this purpose. The Penning discharge arrangement is similar to that of FIGURE 1, the difference being that instead of using a glass cylinder coated with a metallic conductor, a plurality of metallic cylinders **31, 32** are employed being hermetically sealed to ceramic members **33, 34**. Another feature of the electron emitter of FIGURE 2 comprises a bias pin **35** provided to produce and control the size of a hollow beam supplied to slow wave structure **6**. The generator arrangement terminates at its right-hand end into an external coaxial transmission line comprising conductor **19** which forms a continuation of cathode **17** and the central conductor of such transmission line. The outer conductor comprises tapered sleeve or adapter **36** having a wide end which abuts and is conductively connected to cylinder **32** and a narrow end which has the same diameter as the external coaxial transmission line to which it is to be connected. In this modification metal member **31** may comprise the anode for the Penning discharge. The two cathodes operative with anode **31** comprise a metal member or disc **37**, bearing eccentric needle cathode **13**, and cathode **17**.

In the operation of our high frequency wave generator, the electron gun **1** injects an unmodulated beam into helix **6**, which is provided with high frequency potentials of the order, of, for example, 9000 gigacycles. As electrons traverse helix **6**, they are velocity modulated to produce a group of low electrons and a group of high velocity electrons, so that the velocity-modulated electron beam emerging from the helix eventually converts to density modulation as the fast electrons catch up with and pass the slow electrons. The density-modulated beam is passed through a magnetically compressed plasma having radial and axial electron density gradients. The magnetic field established by coils **21** suppresses the radial movement of the electrons in tube **3** but permits longitudinal movement therein.

A fully ionized or nearly fully ionized plasma is produced by the cold cathode Penning type discharge located within circular wave guide **3**. The plasma column is generated by the use of the nonsymmetrical arrangement of electrodes in which needle point cathode **13** is displaced from the axis of circular wave guide **3** while extending parallel with that axis. Through the operation of cathode **17** at the opposite end of plasma tube **3** and anode **14** positioned between the two cathodes and constructed to suppress the formation of undesired modes, a plasma column is produced having a diameter equivalent to cathode **17**. The initial column diameter is determined by needle cathode **13** and soon grows by diffusion to cathode **17** size.

A radial cross-section of the plasma column will show a uniform and high level density of electrons across the center portion of the column, falling off to essentially zero density at the edges as electrons diffuse out of the column.

An axial cross-section will show a high density at cathode **11** and a decreasing density gradient therefrom.

One theory explaining the operation by which the density-modulated electron beam interacts with the plasma section having a resonant frequnecy matching the beam driving frequency (herein 9000 gigacycles as an example) to produce an electro-magnetic wave which is radiated to the wave guide formed by the coated cylinder **3**, is to consider the density modulated electrons as passing through a multiplicity of resonant sections in the plasma as it traverses the plasma column.

When the density modulated beam passes into a plasma section of proper length and electron density which resonates at the driving frequency of the beam, violent plasma oscillations are induced. Because the magnet field established by coils **21** restricts radial motion of the electrons and allows longitudinal motion only, plasma induced oscillations are longitudinal acting like dipoles which radiate a fast TM_{01} wave out of the plasma and into the wave guide.

If the electron beam diameter is made equal to the plasma column diameter, a cylindrical ring of oscillating dipoles will be formed within an annular section of the plasma column, which dipoles radiate a fast TH_{01} electromagnetic wave into the circular wave guide formed by the coating **8** on tube **3**.

For electromagnetic radiation out of the plasma to be most effective, the annular section and therefore the ring of dipoles should be located at the outer periphery of the plasma column with electron density decreasing from the center of the column radially outward. At the interface region of the plasma medium some of the fast waves are reflected back into the plasma, some radiate normal to the plasma, and some radiate in a forward direction. For any of the forward and normal waves to escape the plasma region requires that the plasma in the escape zone be below resonance. In other words, a decreasing radial gradient of electron density is necessary to allow most of the fast waves to escape at forward and normal angles.

The TM_{01} waves radiated out of the plasma and into

the wave guide travel to the second cold cathode **17** which also constitutes a coaxial terminal for the coaxial line and sleeve **19, 20**. The TM_{01} wave is converted at this transition section into a TEM coaxial line mode and conducted out of the tube.

In the operation of the generator to establish the plasma, a current pulse is supplied to anode **14** to initiate the generation of the plasma. This pulse may be obtained by discharging a conventional resistance capacitive network (not shown). At the same time, a rapidly rising current is supplied to magnet coils **21** to compress or delineate the plasma region creating a positive ion trap in that region. While neutral gas molecules will be present in tube **5**, such moecules are ionized by the electron beam and eccelerated into the gun **1** while the free electrons are returned to tube **3** to enhance the Penning action.

While in the foregoing, we have shown and described particular embodiments of our invention, it will, of course, be understood that we do not wish to be limited thereto, since various changes and modifications may be made without departing from the invention and we contemplate by the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. An electromagnetic wave generating and translating apparatus comprising

a circular enclosing member;

plasma defining means including

a needle-point cathode positioned at one end of said circular enclosing member and displaced from and extending substantially parallel with the axis of said circular enclosing member;

an anode spaced apart from said cathode;

a source of ionizable vapor;

said plasma defining means for establishing and magnetically delineating within said circular enclosing member a plasma column having an axial density gradient which decreases from said needle-point cathode and a radial density gradient which decreases from the center of said plasma column;

electron beam means for injecting and density modulating a hollow electron beam into said plasma column adjacent said needle-point cathode, said electron beam means also providing said hollow electron beam with a predetermined driving frequency approximately equal to the resonating frequency of an annular section of said plasma column having the axial and radial density gradients;

said plasma defining means also providing a magnetic field which restricts the radial and permits the longitudinal motion of the electrons in said hollow electron beam wherein the interaction between said hollow electron beam and the plasma in said section establishes an annular section of a resonating plasma and causes an electromagnetic wave to radiate from the annular section to said circular enclosing member; and

an inner conductor of a coaxial line positioned within said circular enclosing member opposite said needle-point cathode, said circular enclosing member further comprises as a portion thereof an outer conductor of the coaxial line, said inner and outer conductors respectively contacting corresponding inner and outer conductors of an external coaxial line.

2. The apparatus of claim **1** in which said inner conductor is also a cathode.

3. The apparatus of claim **1** in which said circular enclosing member further comprises a glass tube with the inside surface thereof coated with a conducting material and a sleeve which contacts both said coated inside surface and the corresponding outer conductor of the external coaxial transmission line.

4. The apparatus of claim **1** wherein said circular enclosing member further comprises a plurality of metallic cylinders separated by ceramic members, said outer conductor having one end approximately the same diameter as and conductively connected to one of said metallic cylinders and having the other end approximately the same diameter as and conductively connected to the corresponding outer conductor of the external transmission line.

5. The apparatus of claim **4** wherein said inner conductor is also a cylindrical cathode and said anode is one of said metallic cylinder, said apparatus further including means to adjust the size of said hollow electron beam.

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