SCANNING ANTENNA WITH GASEOUS PLASMA PHASE SHIFTER

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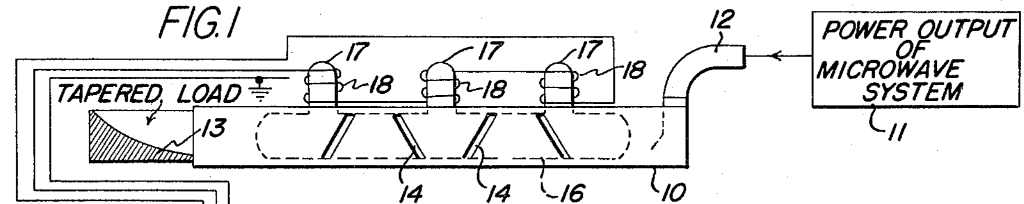
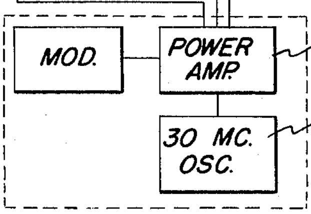
FIG. 1





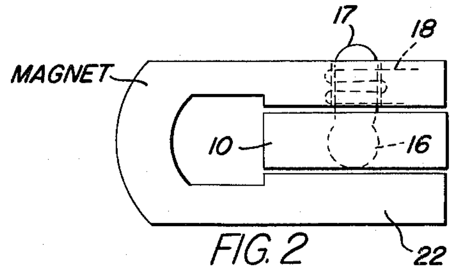


FIG. 2

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SCANNING ANTENNA WITH GASEOUS PLASMA PHASE SHIFTER

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The present invention relates generally to antennas and more particularly to scanning antennas employing gaseous plasma resonant devices and cyclotron plasma resonant devices as variable phase-shift devices which vary the directivities of the radiation patterns of the antennas.

Electrically steerable or scanning antennas are known per se. The presently known scanning mechanisms are, however, inherently complex and lacking in flexibility and versatility and are restricted in speed of scan. By utilizing phase shifters to the plasma resonance types, or of the cyclotron plasma resonance type, in scanning antennas, it is feasible to fabricate scanning antennas of various types, which are simple and versatile, and in which extremely high scanning rates can be achieved.

In accordance with various embodiments of the invention, both linear scanning and circular scanning may be achieved. In the linear scanner energy is transmitted along a wave guide or transmission line, to phase-separated radiating elements. These may be slots in the case of wave guide, and rods in the case of transmission lines. Either the lines themselves or containers located therein may be filled with a gaseous medium capable of being excited to resonance, either plasma resonance or cyclotron resonance. Phase delays of different relative magnitudes, in energy emanating from the radiating elements, may then be induced by varying the exciting voltages or currents utilized to excite the gaseous medium, and the magnetic field distributions employed to achieve cyclotron plasma resonance.

It is, accordingly, a broad object of the present invention to provide a novel scanning antenna system, employing plasma resonance or cyclotron plasma resonance phenomena in phase shifting elements of the system.

It is a further object of the invention to provide a linear scanning antenna employing plasma resonance phase advance elements.

Another object of the invention resides in the provision of a linear scanning antenna employing cyclotron plasma resonance phase advance elements.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a schematic representation of a linear scanning antenna array, employing plasma resonance controllable phase shift elements;

FIGURE 2 is a schematic diagram of a modification of the system of FIGURE 1, which employs cyclotron-plasma resonance controllable phase shift elements.

In wide band transmission media, such as transmission lines and wave guides, the wave length of electromagnetic waves in the media is a function of the dielectric constant of the insulating medium employed, for any fixed frequency. Effectively, this is becadse the velocity of such waves is a function of dielectric constant. The relation of wave length in a free space, is given by

$$\lambda d=\frac{\lambda c}{\sqrt{\epsilon d}} \quad (1)$$

where λd is wave length in a medium, λc is wave length in free space, and ϵd is dielectric constant of the medium.

For wave guides and transmission lines, wave length is further affected by line or guide constants, but for a given line or guide wave length can be controlled as a function of d.

It is pointed out in U.S. Patent No. 2,641,702, issued to Cohen et al., that λd in a wave guide or transmission line may be varied if the dielectric material is a gaseous plasma by varying electron density in the plasma, and that this may be accomplished by varying the amplitude of an excitation voltage. In accordance with the teachings of this patent the excitation voltage is direct. According to the present invention H type excitation may be employed, i.e., excitation due to R.F. current flow in a coil. This current flow may exist at about 30 mc. for example only. In accordance with the teaching of the patent, moreover, a beam of constant direction is maintained as R.F. frequency is varied. According to the present invention, R.F. frequency remains constant, and scanning of the beam is accomplished, as a function of amplitude of excitation.

Referring now more particularly to FIGURE 1 of the accompanying drawings, the reference numeral **10** denotes a section of wave guide, which may be coupled at one end to a source of R.F. energy at about 3 kmc., by menas of a conventional coupling device **12**. This energy travels down the wave guide in the TE_{10} mode to a tapered load **13**, which prevents reflections. Obviously, any other mode may be utilized. In the edges of the wave guide **10** are located slits **14**, to permit egrees of R.F. energy in controlled phase relation. The distances between slits **14** are selected to provide a desired radiation pattern extending generally perpendicular to the plane of the slits.

Located within the wave guide **10** is a glass, Pyrex or quartz tube **16**, which extends longitudinally beyond the slits, and preferably substantially fills the wave guide **10** transversely, although this is by no means essential. The tube **16** includes three vertical extensions **17**, about each of which is wound a few turns of wire, to form coils **18**. The coils **18** are energized at 3 mc. from an oscillator **19**, which feeds the coils **18** via a power amplifier **20**, the output of the latter being controlled by a relatively low frequency modulator, say at frequencies below 100,000 c.p.s.

The gas in the tube **16** may be one of He, Ar, Kr, Xe, or other inert gas, at a density of .1 to several millimeters of mercury. When excited by current flowing in coils **18** a resonance plasma is formed, which has a dielectric constant which is a function of degree of excitation, i.e., of current in coils **18**. By varying this current periodically, wave velocity of R.F. energy in the wave guide **10** is likewise varied, and accordingly the phase relations of R.F. energy components reaching the respective slits. Thereby, the directivity of the radiation pattern of energy emitted from the slits is altered.

In one practical embodiment of the invention, a section of S-band wave guide was employed, having four slits as radiators. A gas tube **16** about thirteen (13) inches long was employed, the tube being fabricated of 1" D. Pyrex glass. The glass tube was carefully baked out and evacuated, and then filled with 1.5 mm. Hg of spectroscopically pure argon gas. Four turns of copper tubing were used to excite each excitation column **17**, and fed in series with 100–600 watts of about 29 mc. signal, to produce the gaseous plasma. A radiation pattern shift of about 15° was obtained, as excitation of the 29 mc. signal was varied in amplitude. Possibility of radical improvement is indicated, on theoretical considerations, by decreasing gas pressure, utilizing a larger active column, and better slit design.

In accordance with a modification of the present invention, illustrated in FIGURE 2 of the accompanying drawings, use of a magneto-static field, impressed across the gas tube **16**, accompained by decreased gas pressure, results in radically increased performance by virtue of the principle of cyclotron-plasma resonance. The systems of FIGURES 1 and 2 are identical except for inclusion of a magnetic field source **22** in FIGURE 2 and the use of reduced gas pressure. Advantages are (1) lower power loss, (2) less deterioration of noise figure and (3) greater band width.

The term "plasma resonance" indicates that the electrons in a gaseous plasma are moving in oscillatory motion, at a rate such that there exists mechanical resonance of the electrons with the frequency of the R.F. field. This term is synonymous with the term "plasma oscillations" which Tonks uses to describe the phenomena in volume 33, pages 195 ff. of the "Physical Review," 1929. Plasma-cyclotron resonance, on the other hand, implies that motion of the electrons occurs in paths affected by a magneto-static field. The latter causes the electrons to travel in spiral paths, while being oscillated in the plasma resonance mode, somewhat in the manner of ionized particles in a cyclotron.

It has been determined that at high frequencies the dielectric constant of a gaseous discharge plasma depends on the electronic charge density in the plasma. The relation between dielectric constant and electron charge density is

$$\epsilon_c = \epsilon_o \left[1 - \frac{ne^2}{m\epsilon_o} w^2 \right] \quad (2)$$

where ϵ_c is dielectric constant of the plasma, ϵ_o the dielectric constant of free space, *ne* electron charge density, *e/m* the rates of charge to mass of the electron, and *w*, an R.F. signal frequency passing through the plasma. The electrons of the plasma have a natural angular resonance frequency

$$\sqrt{\frac{ne^2}{m\epsilon_o}}$$

This frequency is precise, but in fact collisions take place, which impart to the plasma a relatively wide response curve. The plasma in this respect acts like a singly resonant electrical circuit having losses.

In the presence of collisions, the expression w^2 in the above formula is replaced by w^2+v^2.

In sum, the plasma acts like a singly resonant filter for some frequency *w*. This frequency can be changed by changing *n*, the electron density. If the R.F. energy has a frequency adjacent to the resonant frequency, the phase of the R.F. energy suffers rapid shifts in passing through the plasma, just as the phase of a signal passing through a singly resonant circuit would change were the filter slightly detuned with respect to the frequency of the signal. Where cyclotron resonance is added, several possibilities exist. The cyclotron effect is equivalent to the addition of another tuned circuit. By proper selection of the frequency of the latter, the effect of a double-tuned circuit may be accomplished. Still further, by employing nonuniform excitation of the gas in the plasma and plasma cyclotron, a range of values of *n* is provided, which has the effect of broad-banding the resonant response band of the plasma.

While I have described and illustrated several specific embodiments of my invention, it will be clear that varia-

tions of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. A system for providing a scanning radiation pattern, said system including a plurality of radiators, a constant frequency source of radio frequency energy, means coupling said source of radio frequency energy to said radiators, at least one plasma resonance phase advance device arranged to provide a phase advance of radio frequency energy of extent determined by amplitude of excitation of said plasma, said at least one plasma resonance phase advance device being included in said means coupling said source of radio frequency energy to said radiators, and a source of control energy coupled in exciting relation to said plasma resonance phase advance device, said source of control energy being of such amplitude and frequency as to excite the electrons of said plasma into resonance, and means for continuously varying the amplitude of said control energy.

2. The combination according to claim **1** wherein said plasma resonance device is a cyclotron plasma resonance device.

3. An antenna array comprising plural antennas, a source of radio frequency energy, means coupling said antennas to said source in parallel, each means including in series a plasma resonant phase advance unit, and means for controlling the excitation of said plasma resonant phase advance units so as to vary the radiation pattern of said array, said last named means including a source of control energy applied to said units, said energy source being of such amplitude and frequency as to excite the electrons of said plasma into resonance.

4. A variable phase shift circuit for a source of electromagnetic energy including a closed tube of dielectric material containing an ionizable gas, means for coupling the energy of said source to said tube, means exciting said gas electromagnetically at a frequency of approximately thirty megacycles per second to excite said gas to plasma resonance, and means for varying the intensity of the electromagnetic excitation to vary the phase shift of the energy from said source, wherein is further provided a source of magnetostatic field coupled with said gas and of intensity sufficient to establish cyclotron plasma resonance in said gas.

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