6.5 A Plasma Guide Microwave Selective Coupler

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A new type of microwave coupler, the plasma guide coupler, has been investigated. The coupling of microwave power via this plasma guide coupler can be varied electronically over a range greater than 30 db over an entire waveguide band. Pulsed power levels of more than 100 watts can be handled. When operated as a switch, a switching time of 5 μ sec has been observed. The plasma guide coupler is shown in Fig. 1.

In one mode of operation, which has been observed earlier[1] and is investigated in detail here, a discharge tube is surrounded by a metal sleeve. Trivelpiece and Gould[2] have demonstrated that such a stationary plasma column without external magnetic field can propagate electromagnetic energy, provided the plasma density exceeds a critical value, determined by the operating frequency and the dielectric constant of the tube containing the discharge. We believe that this plasma surface mode of propagation is the mechanism by which power transfer between guides is achieved. At densities below the critical value, the guides are decoupled. As the plasma density is raised above the critical value by increasing the discharge current, the coupling between the guides is increased, until it eventually approaches a constant value. Figure 2 shows a plot of coupled microwave power vs. discharge current. Because of this characteristic, the assembly can be used as an electronically variable attenuator or waveguide switch.

To verify the plasma coupler theory experimentally, the critical plasma densities were measured and found to agree approximately with the values predicted. By the use of mode filters and a radial probe, it was found that the principal mode of propagation along the plasma had one angular variation, as can be expected by the method of coupling used. Wavelength measurements showed that at high densities, the wavelength along the column was approximately the free space wavelength.

An X band mercury vapor plasma coupler, operated as a switch, had the following properties:

a) Insertion Loss - 8.5 db, with improvement possible through better impedance matching.
b) Isolation - 40 db.
c) Power handling ability - 128 watts of 1 μ sec pulsed power, with 30 db isolation.
d) Switching time - 5 μ sec.

Figure 3 shows the response of the switch to a 2 μ sec, 44 volt pulse. Of interest is the time delay between switching and microwave pulses. The switching power required was 88 watts.

In an alternate mode of operation, the metal sleeve around the plasma is made large. Now, when the plasma density is very low, the plasma guide will conduct in a hollow waveguide mode. Increasing the plasma density increases the cut-off frequency of this mode, similar to that of a plasma-filled rectangular waveguide.[3] When this cut-off frequency passes beyond the operating frequency, propagation ceases, and the guides are decoupled. In this transition region the plasma guide again becomes an electronically controlled attenuator or switch.

By combining the two modes of operation, the system will alternately couple, attenuate, and couple, as the current is monotonically increased, as shown in Fig. 4.

The plasma guide properties can be demonstrated further in combination with a non-linear plasma property. By observing the pulsed voltage across a resistor in series with the discharge, the system can operate as a high level detector of pulsed microwaves.[4] The sensitivity of the detector as a function of quiescent discharge current is shown in Fig. 5 and agrees qualitatively with that predicted by the plasma guide theory. The greatest sensitivity occurs in the transition region, where the plasma guide is propagating, but where the penetration depth of the microwaves into the plasma is the greatest.

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[1] T. Sekiguchi and R. C. Herndon, "Thermal Conductivity of an Electron Gas in a Gaseous Plasma," Phys. Rev., vol. 112, pp. 1–10, October 1, 1958.

[2] A. W. Trivelpiece and R. W. Gould, "Space Charge Waves in Cylindrical Plasma Columns," J. Appl. Phys., vol. 30, pp. 1784–1793; November, 1959.

[3] L. Goldstein and N. L. Cohen, "Behavior of Gas Discharge Plasma in High Frequency Electromagnetic Fields," Electrical Communications, vol. 28, pp. 305–321; December, 1951.

[4] See also, for example, B. J. Udelson, "Effect of Microwave Signals Incident Upon Different Regions of a D. C. Hydrogen Glow Discharge", J. Appl. Phys., vol. 28, pp. 380–381; March, 1957.

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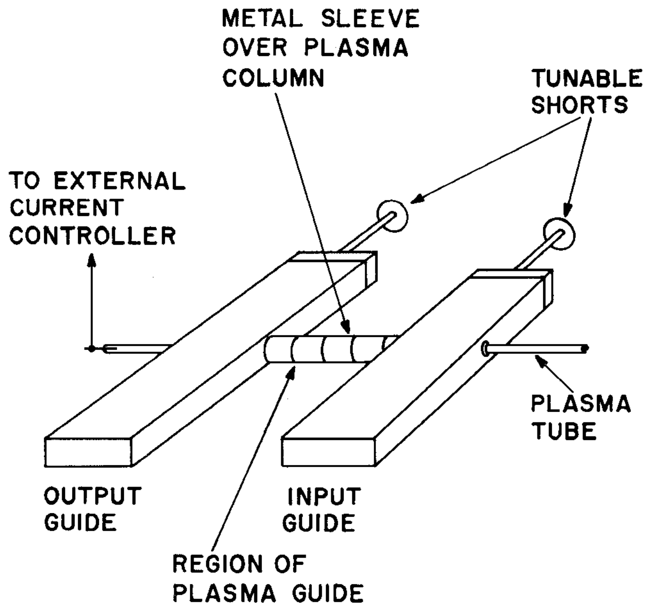

Figure 1 - Plasma Guide Microwave Selective Coupler.

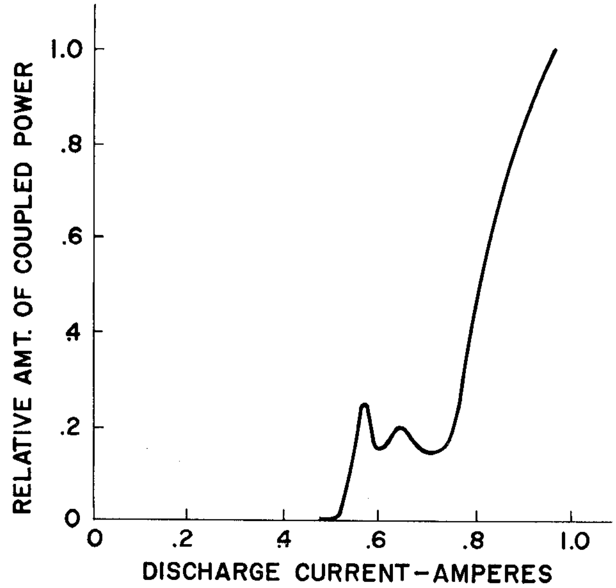

Figure 2 - Coupled Microwave Power vs Discharge Current; f = 8.346 Gc.

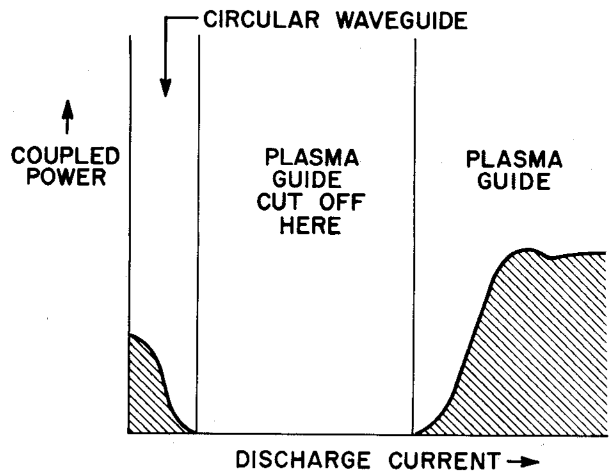

Figure 4 - Combination of Two Modes of Operation of Plasma Guide Coupler.

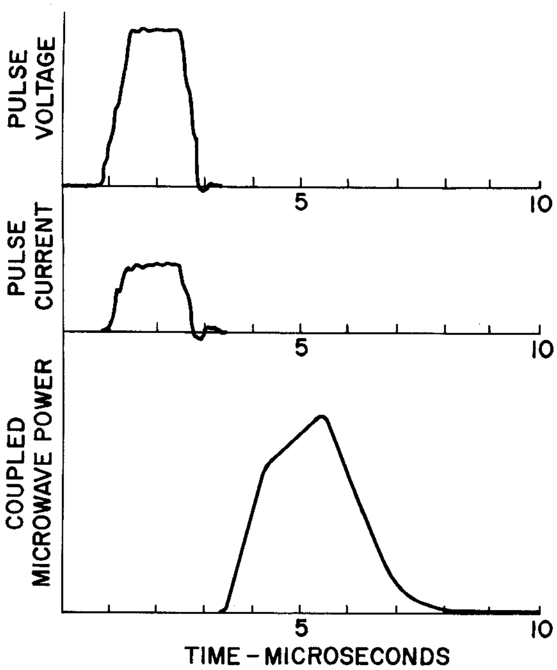

Figure 3 - Response of Plasma Coupler to Two Microsecond Pulse.

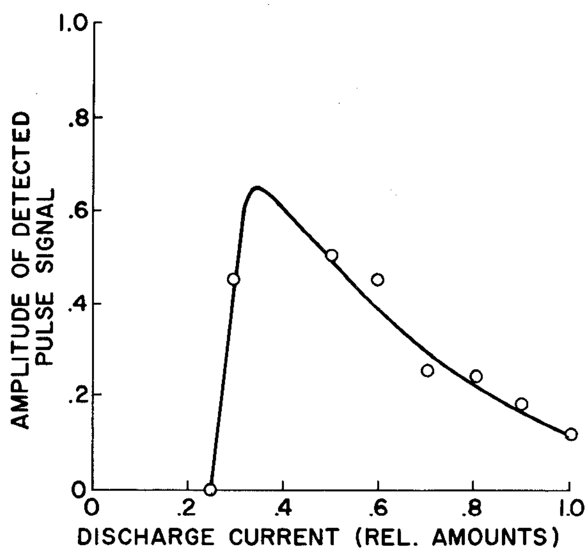

Figure 5 - Nonlinear Characteristics of Plasma Coupler. Fixed Microwave Input Power.