4.4: AN ELECTRONICALLY TUNABLE BAND PASS MICROWAVE FILTER

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A new type of tunable band pass microwave filter using the dipole resonance of a plasma column has been investigated. The center frequency of the pass band can be electronically tuned over a large portion of the S band. Over this range the insertion loss at the center frequency is less than 2 db and the isolation for frequencies outside the pass band is at least 12 db. The typical 3 db bandwidth of the filter is 150 Mc/s at S band.

Several workers[1] have shown that a long plasma column can exhibit a dipole resonance at a frequency given by

$$\omega_r = \omega_p \left[1 + K_{eff} \right]^{-1/2} \tag{1}$$

where

ω_r = resonant frequency,

ω_p = plasma frequency = $5.6 \times 10^4 \times$ (number of electrons/cc)$^{1/2}$,

K_{eff} = effective relative dielectric constant of the region surrounding the plasma[2].

The physical picture of this resonance is that of an electron cloud oscillating about the stationary ion cloud and forming surface charges at the periphery of the column. The internal electric field lines are parallel; the external field is that of a line of dipoles.

For a short plasma column surrounded by air and of radius a and length ℓ an infinite set of such dipolar resonances exists, at resonant frequencies defined by

$$\omega_r = \omega_p \left\{ 1 - \left(\left. \frac{\frac{\partial}{\partial r}\left[K_1\left(\frac{m\pi r}{\ell}\right)\right]}{\frac{\partial}{\partial r}\left[I_1\left(\frac{m\pi r}{\ell}\right)\right]} \right|_{r=a} \right) \left(\frac{I_1\left(\frac{m\pi a}{\ell}\right)}{K_1\left(\frac{m\pi a}{\ell}\right)} \right) \right\}^{-1/2}, \quad m=1,2\ldots \tag{2}$$

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Here I_1 and K_1 are modified Bessel functions.

For values of $\ell/a \simeq 20$, the lower orders of these modes lie close to the value of ω_r/ω_p defined by (1).

The principal mode, m = 1, is easily excited by inserting the column through the narrow walls of a rectangular guide, so that the column is perpendicular both to the incident E field and to its direction of propagation. Because of the dipolar nature of the resonance, the plasma column can be made into a band pass filter by coupling to the near fields of the plasma, as shown in Figure 1. The pickup probe is positioned so that it

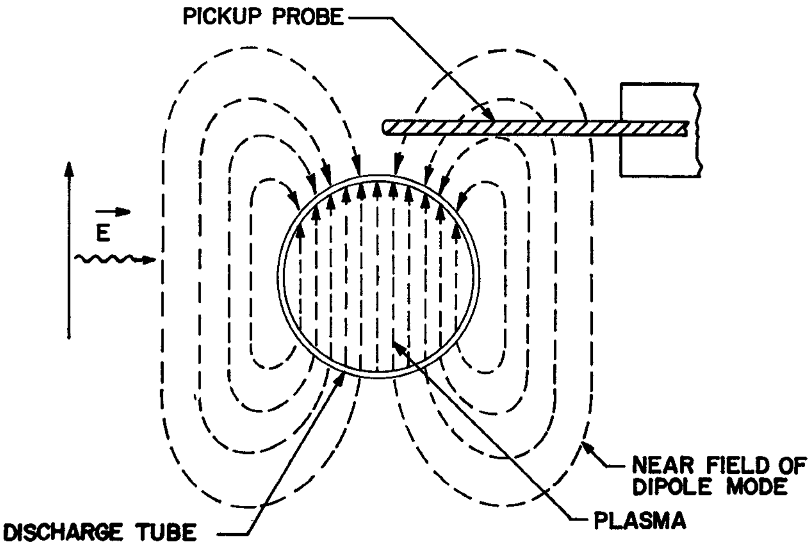

Fig. 1. Coupling to the near field of the dipole resonance.

is not excited by the incident field but will couple strongly to the dipole resonant field. The pickup probe is then only excited when the incident frequency corresponds to that given in (2), with m = 1. By electronically changing the discharge current, the plasma frequency and hence the center frequency of the pass band of the filter can be varied. The width of the pass band is determined by the Q of the plasma dipole resonance.

Filters of this type have been built and experimentally tested at S band. Waveguide output filters and coaxial output filters as shown in Figures 2 and 3 have been constructed.

A narrow pass band filter of low insertion loss should have a high unloaded Q, Q_u, and should be over-coupled, so that Q_u is several times

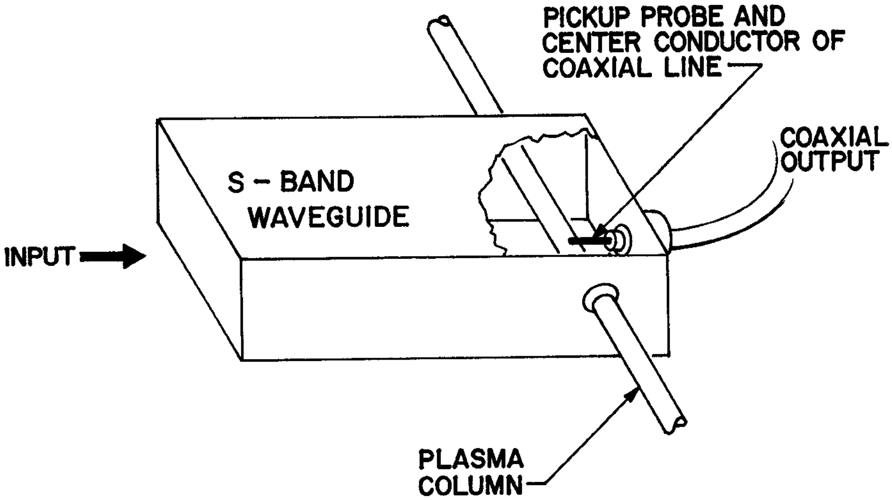

Fig. 2. Plasma filter with coaxial output (exposed view).

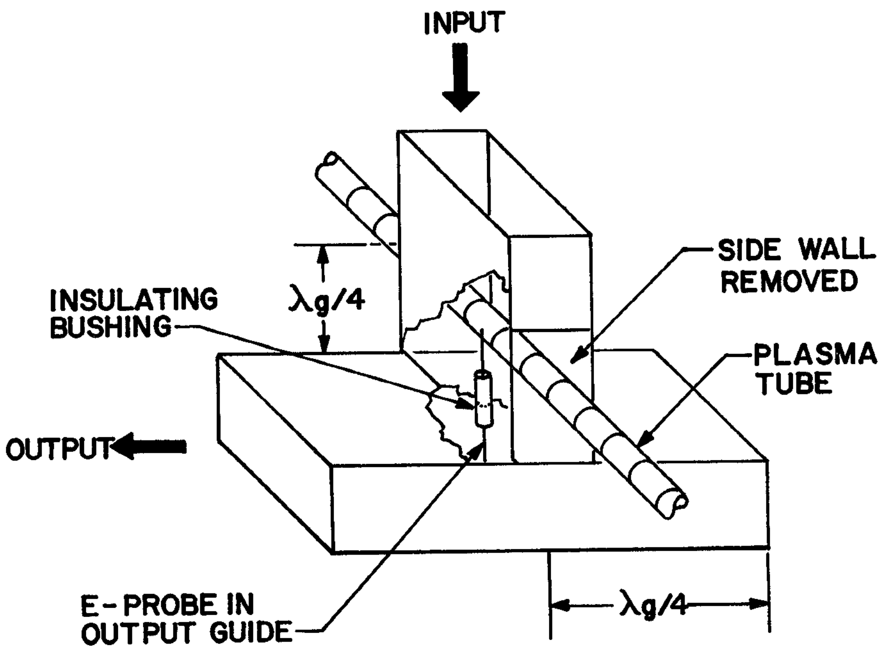

Fig. 3. Plasma filter with waveguide output (exposed view).

larger than Q_e, the external Q. For a tunable filter, this requirement must be met over the entire band of operation. This has been achieved by placing the plasma column $\lambda_g/4$ (at midband) from the end wall and placing the pickup probe very near the column. Insertion loss data is discussed below.

For the experimental investigation we used mercury vapor quartz discharge tubes, with thyratron type hot cathodes. The tubes were of 8 mm O.D. and 6 mm I.D. The discharge was maintained by a d.c. voltage supplied through series ballast resistors. The center frequency of the filter was controlled by changing the discharge voltage and hence the plasma density in the column.

Figure 4 shows typical frequency response curves of the waveguide output filter at two values of discharge current. Initially some coupling

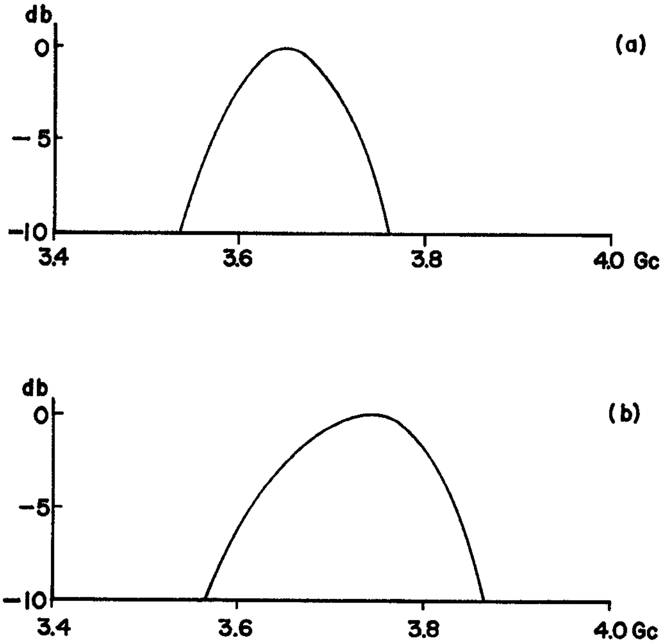

Fig. 4 Response of waveguide plasma filter with discharge current of: (a) 0.48 amp, (b) 0.53 amp

to the m = 3, 5 . . . modes of (2) was observed, but this was minimized by opening the waveguide wall, as shown in Figure 3. Besides the modes of (2), minor resonances at higher values of ω_r than given by (1) have been observed [1]. Coupling to these was down at least 12 db from the desired dipole mode.

For the discharge voltage adjusted to place the dipole resonance at various frequencies throughout the S band range, the 3 db bandwidth of the waveguide output filter was measured. The results are shown in Table I. The insertion loss at the center frequency of the same device is shown as a function of the center frequency in Figure 5. The loss is less than 2 db over a large portion of S band. The increase in insertion

TABLE I

BANDWIDTH OF PLASMA FILTER AT S BAND

Center frequency	3 D. B. bandwidth	Discharge current	Insertion loss
3295 Mc/s	320 Mc/s	0.5 amp.	
3400	230	0.51	
3499	140	0.52	< 2 db over entire range
3589	170	0.57	
3695	125	0.64	
3789	150	0.68	
3891	130	0.70	
3982	80	0.77	

loss at low and high frequencies is attributed to the decrease in input loading as the distance between the plasma tube and the waveguide short becomes greater or less than $\lambda/4$.

The Q_u of the plasma column is the ratio of the operating frequency to the collision frequency ($Q_u = \omega/\nu_c$). Calculations show our mercury discharge to have a value of ν_c much higher than for some other gases. It is expected, therefore, that the performance of the filter can be improved by the use of such other gases.

The plasma filter requires no magnetic field, as do ferrite devices[3] and can be easily tuned electrically. Because it is not subject to some of the limitations of ferrite devices, it may find application in frequency ranges not covered by the latter.

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1. For example, see A. Dattner, "The Plasma Resonator," Ericcson Technics (Stockholm), No. 2, 310-350 (1957).

2. G. D. Boyd, "Experiments on the Interaction of a Modulated Electron Beam with a Plasma," Nonr 220 (13) Technical Report No. 11, Calif. Inst. of Tech. (May, 1959).

3. P. S. Carter, Jr., "Magnetically-Tunable Microwave Filters Using Single-Crystal Yttrium-Iron-Garnet Resonators," Trans. IRE MTT-9, 252-260 (1961).

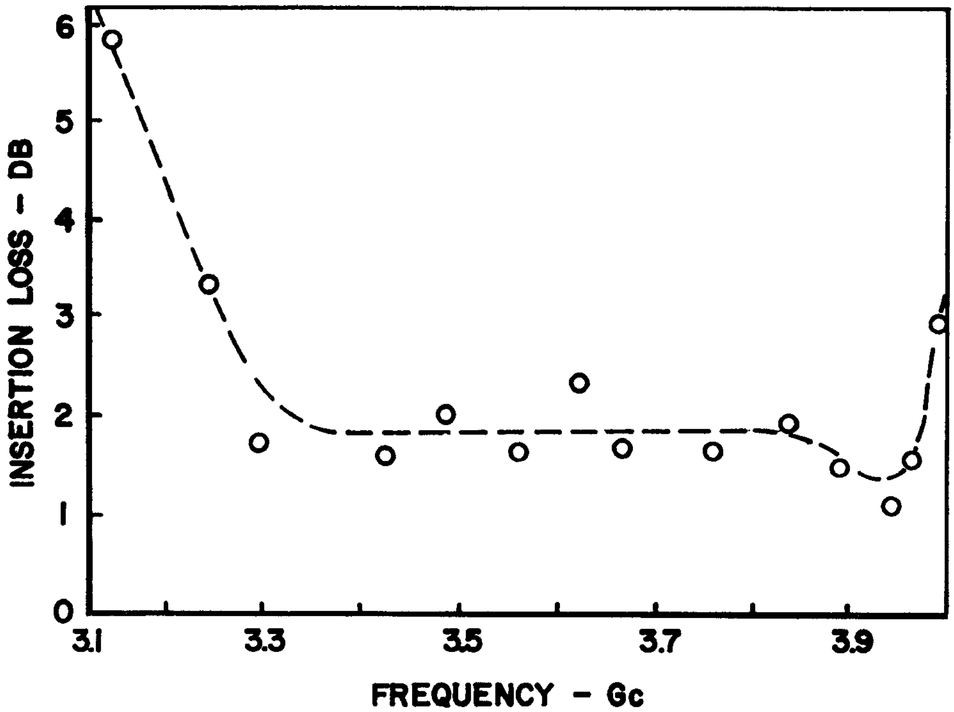

Fig. 5. Insertion loss at center frequency vs. center frequency for waveguide output filter.