A Compact, Wide-Tuning Range, Dual TE_{111} Mode Preselector

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Abstract—This paper describes the development of a dual TE_{111} mode cavity preselector that is centrally loaded with a large, nonferrous, metallic perturbation plug. The cavity tunes over the 6 to 8 GHz range. Dual mode operation reduces the size of the cavity to one-half the size of a conventional cavity. The perturbing plug increases the separation between the desired TE_{111} mode and the undesired, next higher TM_{011} mode from 15 percent to 33 percent. The result is a 29 percent tuning range that is free from unwanted modes. The preselector exhibits a 3 dB bandwidth of 60 MHz, a 40 dB bandwidth of about 400 MHz, and an insertion loss that is no more than 1 dB.

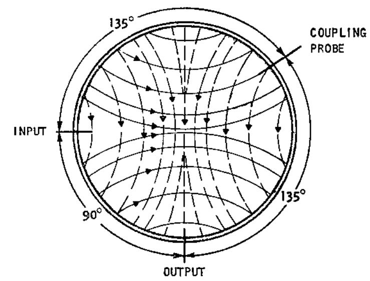

Fig. 1. *E*-field lines of orthogonal TE_{111} modes in a cavity.

I. Introduction

In the past, use of higher-order modes in preselectors was limited because of the large physical size of the preselectors and the short frequency range between the desired mode and next higher mode. For a preselector to be useful, it should be free from unwanted modes throughout the tuning range. Articles have appeared in the literature describing the excitation of a multiple higher-order mode as a means of achieving multisection performance from a single cavity [1]–[4]. For instance, when two orthogonal TE_{111} modes are excited in a cavity the cavity will exhibit the skirt selectivity of a two-section filter. This dual mode may be excited by mounting the input and output probes at right angles to each other and mounting a coupling screw at 135 degrees from each probe. Such an arrangement is shown in Fig. 1 which also shows the E-field lines of the orthogonal TE_{111} modes produced. In spite of its multisection performance, the dual TE_{111} mode preselector was seldom used because of its small out-of-band attenuation (typically 35 to 40 dB maximum for a 3 dB bandwidth of about 40 MHz) [4]. For larger bandwidths, the out-of-band attenuation was smaller still. This limit on attenuation, previously attributed to direct coupling, is also due to the high density of modes. The out-of-band attenuation can be significantly improved by centrally loading the cavity with a perturbation plug. The plug increases the frequency separation between the desired TE_{111} mode and the unwanted, next higher (TM_{011}) mode. The separation of modes reduces the density of modes, and one would then expect the out-of-band attenuation to be increased. This is indeed what happens.

The advantages of a perturbed, dual TE_{111} mode cavity were investigated in a 6 to 8 GHz tunable filter. The cavity was loaded with a large, nonferrous, metallic plug. The result is a preselector that is half the size of a conventional higher-order-mode preselector of an equivalent number of sections. The 3 dB bandwidth is about 60 MHz, and the 40 dB bandwidth is about 400 MHz. The insertion loss is no more than 1 dB over the tuning range. The frequency separation between the TE_{111} mode and the unwanted next higher (TM_{011}) mode is 33.3 percent (this percent separation corresponds to half an octave). For an unperturbed cavity of equal diameter, the separation would be only 15 percent. The usable mode-free tuning range achieved with this experimental preselector is 29 percent.

The discussion which follows explains how the size and shape of the perturbation plug was determined. The design of the empty cavity is then presented, and an experimental procedure for determining the optimum position of the plug, input and output probes, and coupling screw is explained. The discussion concludes with the measured performance of the experimental preselector.

II. The Mode Shifting Plug

In order to determine a position and size of a mode shifting plug it is convenient to have in mind Slater's perturbation equation [5] which describes the effect of small perturbations on a cavity. Although the mode shifting plug is not small, Slater's equation is helpful to determine qualitatively the effect of various perturbations on the various modes of interest in the cavity. The first step in the analysis was to write the equations of the various modes in the cavity. These can be found in a fairly general form in Ramo and Whinnery [7] and [10]. An initial examination of the field equations indicated that a good place for a mode shifting plug would be along the axis of the cavity. The field variations of the modes of interest along the axis are plotted in Fig. 2.

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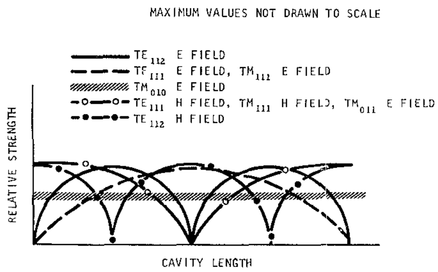

Fig. 2. Field strength of several different modes along axis of empty cylindrical cavity.

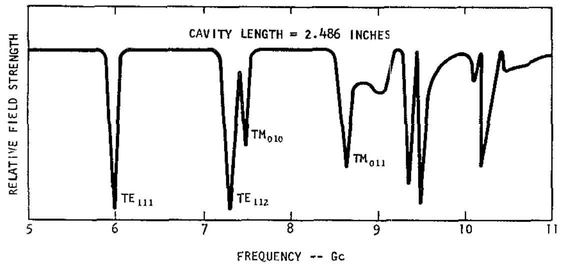

Fig. 3. Position of modes in an empty cavity.

Before analyzing the effect of a perturbing metallic object, it is useful to note the positions of the modes in an empty cavity. These are shown in Fig. 3, which is a measured plot of the modes in the cavity and indicates the magnitude of coupling to the other modes as well as frequency. The frequencies can be calculated fairly closely from equations in Ragan [4] and Ramo and Whinnery [7] or the mode chart in Ginzton [8].

An analysis of the field equations for the various modes in a cavity 1.087 inches long and 1.26 inches in diameter with a mode shifting plug approximately in the center gave the following results. The TE_{111} and TM_{010} modes have strong E fields in the region of the plug. The TM_{011} mode has a small E field in that region, and the TM_{110} and TE_{112} modes have weak fields. This implies that the plug will cause the TE_{111} and TM_{010} modes to be shifted down in frequency a larger amount than the TM_{011}, TE_{112} and TM_{110} modes. A few plug sizes were then tried, one of which increased the percent distance between the TE_{111} mode and the next mode from about 15 to 33 percent. The distance from the TM_{010} below the TE_{111} mode to the TM_{011} mode is about 40 percent with the plug inserted.

Figure 4 shows the measured frequencies for the important resonances for an empty and perturbed 1.082 inch-long cavity. For the empty cavity, the TE_{111} mode is tuned to 7.6 GHz. The frequencies of the modes before and after the insertion of the plug are as follows.

	Empty Cavity	*Perturbed Cavity*
TE_{111}	7.65 GHz	6.00 GHz
TM_{010}	7.19 GHz	5.59 GHz
TM_{011}	8.89 GHz	8.37 GHz
TM_{110}	10.4 GHz	9 80 GHz
TE_{112}	12.4 GHz	11.8 GHz

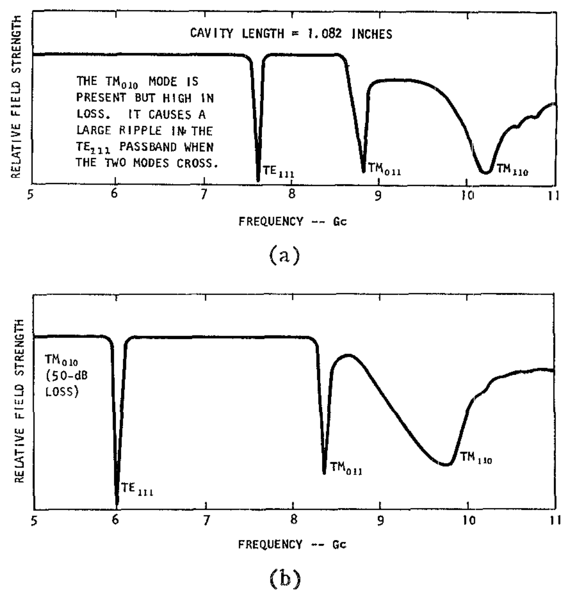

Fig. 4. Position of modes in an empty and perturbed cavity. (a) The empty cavity. (b) Perturbed cavity.

The TE_{111} mode is tuned higher in frequency by moving the end wall. A mode chart is useful in determining approximate tuning rates of the modes [8].

III. Design of the Dual TE_{111} Mode Cavity Preselector

Design of the dual TE_{111} mode preselector includes the following: a) determining the dimensions of the empty cavity, b) determining the size and location of the perturbing plug, and c) determining the position of the input and output probes. The first of these was determined analytically, the other two were determined experimentally.

For the cavity dimensions, the mode charts referenced earlier in the report are helpful. One chooses a diameter-to-length ratio in the frequency range of interest which offers the greatest separation between the TE_{111} mode and the TM_{011} mode. In this design, the D/L ratio was 0.496 at 6 GHz. With this ratio, one can find the cutoff frequency f_c from the equations

$$D = \frac{0.586}{f_c\sqrt{\mu\epsilon}}$$

and

$$L = \frac{c}{2f\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}.$$

With f_c determined, the diameter of the cavity is determined from the first equation above. A useful equation, derived from the equation for D and L and the ratio $D/L = 0.496$, is

$$D\,(\text{cm}) = \frac{19.1}{f_l(\text{GHz})}$$

where f_l is the lowest frequency in the tuning range. This equation may be used to determine the diameter of a cavity for another tuning range. The ratio of diameters may then be used as a scaling factor for the new length, position, and size of the perturbing plug, and position of the probes.

The ratio $D/L=0.496$ was a good choice, but not necessarily the optimum choice. With this ratio, a half-octave separation between the TE_{111} mode and the TM_{011} mode was achieved with the perturbation. For the optimum ratio, one would have to experiment with several values in the neighborhood of 0.496. The wide separation between modes is defeated, however, when the D/L ratio deviates appreciably from 0.496. A much smaller diameter would necessitate a longer cavity which, in turn, would necessitate a longer perturbation plug. A longer plug could result in TEM modes in the tuning range. A much larger diameter would reduce the separation between the TM_{010} and the TE_{110} modes and, thus, reduce the mode-free tuning range.

An experimental method was used to determine the position and size of the perturbing plug and the position of the probes and coupling screw. Figure 5 shows the setup. A cavity was built with both ends open to which were fitted choke-joint plungers. Openings were made in the cavity wall for probes and coupling screw. This setup provided an easy means of varying the position of the perturbing plug and the position of the cavity with respect to the probes. The setup also provided a convenient means for testing different sizes of perturbing plugs. When measurements indicated that satisfactory performance had been achieved, the cavity was cut and the choke-joint plunger holding the plug was replaced with a permanent plate. To determine the optimum position of the perturbing plug, the cavity was tuned for a TE_{111} mode and the position of the plug varied until maximum separation between the TE_{111} mode and the next higher (TM_{011}) mode was achieved.

The optimum location of the cavity with respect to the probes and coupling screw was determined as follows. After the optimum position of the perturbing plug was determined, the plug was fixed to its plunger and the plunger position was varied. At each position of the plunger the cavity was tuned with the tuning plunger and the 3 dB bandwidth was measured at 6 GHz and 8 GHz. When the 3 dB bandwidths at 6 and 8 GHz were equal, the optimum location of the cavity with respect to the probes was determined. Trials conducted on the size of the perturbation showed that increasing the diameter of the plug while holding its length constant improves the separation between the desired and unwanted mode. One cannot make the plug's diameter too large, however, because the plug eventually begins to interfere with the motion of the tuning plunger and reduces the tuning range. The optimum size of the plug was not determined; rather, the trials ended when measurements on mode separation, bandwidth, and tuning range approached the desired goals.

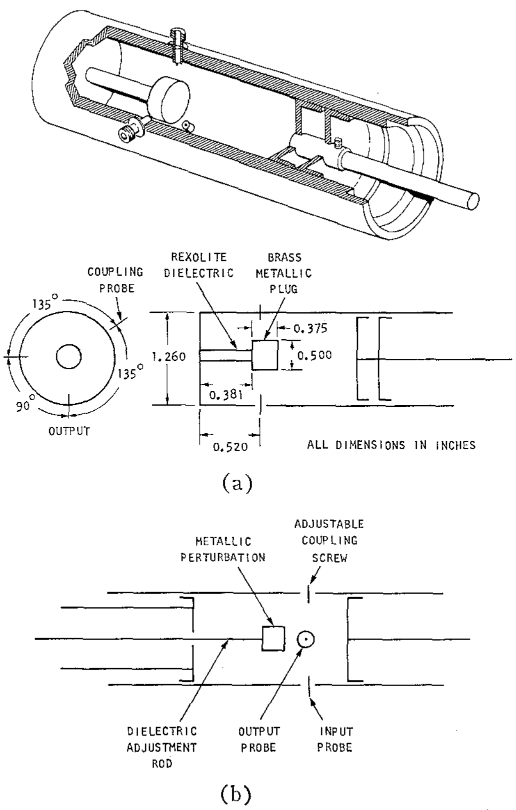

Fig. 5. (a) Design of dual TE_{111} mode cavity preselector. (b) Experimental setup employed in the design of the dual TE_{111} mode cavity preselector.

The bandwidth is also affected by the type of coupling from line to cavity. Probe inputs provide a much larger range of bandwidths than a waveguide-iris input. Bandwidths of the order of 3 percent are possible with a probe input, whereas an iris produces about 0.44 percent bandwidth maximum. The minimum bandwidth possible is determined from the maximum insertion loss tolerated and the maximum possible unloaded Q.

The experimental method described above is a convenient method for determining size and position of the perturbation and the location of the cavity with respect to the probes. The dimensions of the cavity and its component parts determined in this way are described in Section IV. If desired, one may scale from the dimensions cited to other tuning ranges; however, by scaling the position of the probes one may expect variations in bandwidth of the order of 20 percent.

IV. Construction and Performance of the Dual TE_{111} Mode Cavity Preselector

Dimensions of the experimental dual-mode cavity preselector are shown in Fig. 5. The cavity tunes from 6 to 8 GHz, has a 3 dB bandwidth that is fairly constant over the tuning range, and has an insertion loss that is no more than 1 dB. Its skirt selectivity is equivalent to

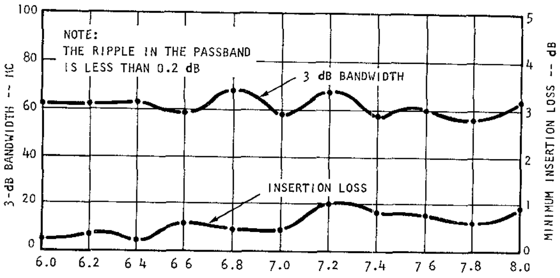

Fig. 6. 3 dB bandwidth and insertion loss as a function of frequency.

that of a conventional two-section filter at low attenuation levels, and equivalent to a three-section filter at high attenuation levels. Figure 6 shows its 3 dB bandwidth over the tuning range. For an empty cavity, the ratio of the 3 dB bandwidth at 8 GHz to that at 6 GHz would be 4 to 1. For the perturbed, experimental cavity the ratio is 1. Figure 6 also shows the insertion loss over the tuning range. The loss increases from the low to the high end of the range, but does not exceed 1 dB. Insertion loss measurements were made on the experimental cavity shown in Fig. 5. Measurements on a production model did not exceed one-half dB. The production cavity had an unpolished silver plate finish. The unloaded Q was somewhat better than 5000 over most of the tuning range as determined from the bandwidth and insertion loss data given, noting that the insertion loss in the production unit was roughly half of that indicated in Fig. 6.

Figure 7 shows the selectivity of the experimental cavity compared with that of a two pole, maximally flat, two section filter when tuned to the low end of the tuning range. This characteristic is much the same throughout the tuning range for attenuation levels up to 30 dB. The skirts of the experimental filter are seen to be steeper at high attenuation levels. In fact, the bandwidth at the 50 dB level is the same as that of a three-pole, three-section cavity filter when the cavity is tuned to 6 GHz. The selectivity at the high attenuation levels falls off and approaches two cavity performance as the cavity is tuned to 8 GHz. The reason for the steepness of the skirts at high attenuation levels is due to the effects of other modes on the primary mode, a condition generally neglected in two-pole theory. The skirts are steeper than that predicted by theory because there is an attenuation peak between any two modes [9]. This peak would be infinite if the cavity were lossless. This can be seen most directly by writing out the impedance function for a cavity with two or more resonant modes tuned to different frequencies.

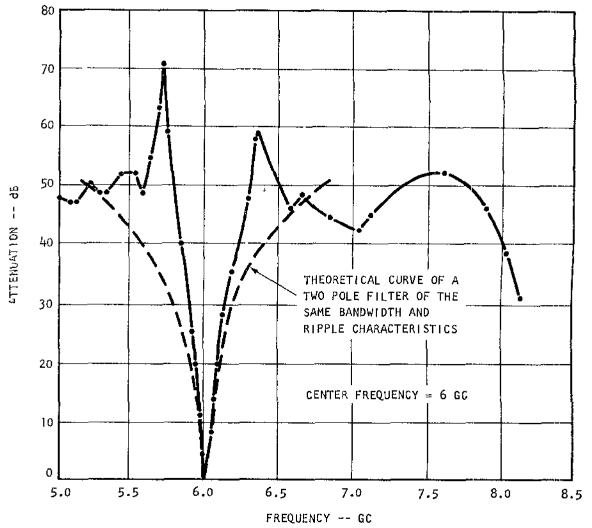

Fig. 7. Attenuation characteristic as a function of frequency compared with theoretical pass band of a conventional, two-section cavity filter.

V. Conclusions

The addition of the plug in the cylindrical cavity increases the mode free range from 15 percent to 33.3 percent. Larger increases are possible by optimizing the size of the cavity and perturbing plug. The dual-mode experimental preselector described in this report is small in size and simple in construction. Ths cost of producing similar preselectors in quantity would be less than the cost of conventional two-section cavity preselectors of equal performance. The principle of loading a cavity to increase the mode-free tuning range may be applied to other types of cavities as well.

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