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IMPROVED SELECTIVITY IN CYLINDRICAL TE_{011} FILTERS BY TE_{211}/TE_{311} MODE CONTROL

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ABSTRACT

A new method is presented for the design of low loss cylindrical TE_{011} mode resonators whereby transmission nulls can be placed near the TE_{011} resonance by controlling the TE_{211} and TE_{311} modes that are naturally excited in the same resonator. The frequency of the nulls are controlled by the angular offset of the sidewall coupling apertures and the relative amplitude of the TE_{011} mode compared with the TE_{211} and TE_{311} modes. It is also shown that a lumped constant circuit model can be used to accurately represent the multimode response of the resonator.

Introduction

The high unloaded Q of the cylindrical TE_{011} mode is attractive for low loss filters, especially at the higher microwave frequencies where transmitter power and receiver sensitivity are often limited and expensive. The design of cylindrical TE_{011} mode filters is complicated, however, by the large number of modes that resonate at frequencies close to or degenerate with the TE_{011} mode. The TM_{111} mode is of particular concern because it is degenerate with the TE_{011} mode in the right cylindrical resonator. The TE_{112}, TE_{211}, TE_{311}, TM_{011}, TM_{012}, TM_{110} and TM_{210} modes can also seriously affect the filter performance depending on the particular application and the filter design.

The relative frequencies of the resonances of the TE_{011} and the other modes, with the exception of the degenerate TM_{111}, can be controlled, within limits, by the choice of the diameter to length ratio of the cavity[1]. Large changes in the diameter to length ratio however, can result in significant reduction in the unloaded Q. Atia and Williams[2] have shown that the TM_{111} resonant frequency can be separated from the TE_{011} resonance by thin metal posts or by dielectric material on the cavity end walls. Thal[3] has shown that a similar effect can be obtained from shaping the cavity by chamfering the edges. The degree of shaping can also be used to control the relative frequencies of the modes without degrading the unloaded Q of the TE_{011} mode. Cavity shaping is particularly attractive because it permits all the resonators of a filter to have different shapes, so that when they are synchronously tuned to the TE_{011} mode they are not synchronously tuned for the other modes.

Suppression and control of the unwanted modes is still necessary, though, even with cavity shaping. TM modes can be suppressed by using narrow rectangular apertures that are oriented to favor coupling to the TE modes. The TE_{112} mode can be suppressed by using sidewall coupling at the center of the resonator since the mode possesses odd symmetry about the center. The most difficult modes to control are the TE_{211} and TE_{311} modes. Atia and Williams[2] achieved excellent results in suppressing these modes, apparently aided in part by using a combination of endwall and sidewall coupling. The use of endwall coupling is, however, not always possible because of configuration and other constraints. Thal[3] and others[1] attempted to control the TE_{211} and TE_{311} modes in sidewall-coupled cavities by using angular offsets between the coupling apertures rather than having the apertures directly opposite one another in the resonator. This permits one aperture to be at a location of low field strength for the unwanted modes excited by the other aperture. This has been of limited success as it usually results in asymmetrical rejection characteristics due to TE_{211}/TE_{311} mode contamination.

TE_{211}/TE_{311} Mode Control Considerations

The coupling of a cylindrical resonator is solely magnetic for the TE_{011} mode and predominantly magnetic for the TE_{211} and TE_{311} modes. It is easier, however, to visualize the fields at the center of the cavity in terms of electric fields rather than magnetic fields. Figure 1 shows the electric fields oriented for excitation by an input aperture with magnetic coupling. As can be seen in Figure 1, there is no angular variation of the TE_{011} electric fields, so coupling through the resonator should not be a function of the angular relationship of the input and output coupling apertures. The coupling through the TE_{211} and TE_{311} modes, however, will vary with the angular offset of the coupling apertures. Minimum magnetic coupling occurs at offset angles of 45° and 135° for the TE_{211} mode and at angles of 30°, 90°, and 150° for the TE_{311} mode.

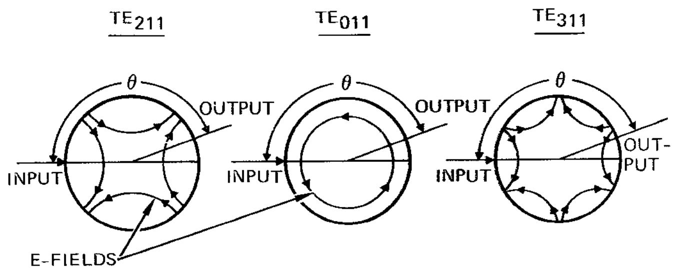

Figure 1. Electric Field Configurations Of Modes

The angular offset of the apertures affects not only the magnitude of the coupling, but also the relative phase. Figure 1 shows that for the angle θ the response for the TE_{011} and TE_{211} modes would be in phase at the output port, but the TE_{011} and TE_{311} modes would be out of phase. Other angular relationships permit these phase relationships to be reversed, or for the TE_{011} to be simultaneously in phase or out of phase with both the TE_{211} and TE_{311} modes. The angular offset of the coupling apertures can thus control not only the relative amplitude of the response, but also the relative phase.

Experimental Data on Single Cavity Resonators

Three single cavities (cylindrical, shaped, sidewall-coupled) were constructed and tested to obtain data on the effect of variation of the angular offset of the coupling apertures. The cavities used shaping, as described by Thal[3], and had a moveable endwall on one end to adjust the resonant frequency. The three cavities were identical with the exception of the angular offsets of the coupling apertures. Angular offsets of 130°, 140° and 150° were used.

The insertion loss measurements, made on the three cavities with a Hewlett-Packard R8747A K_a band transmission and reflection test unit, are shown in Figure 2. As expected, the response of the TE_{011} mode, shown in the center of the frequency range, does not vary with changes in the angular offset of the coupling apertures. There are, however, large changes in the response of the TE_{211} and the TE_{311} modes shown respectively on the

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lower and the upper ends of the frequency range. Also visible in Figure 2 is a small response just below the frequency of the TE_{311} resonance. The response is the TE_{112} mode which is not fully suppressed. This is believed to be due to asymmetries introduced by the moveable endwall tuner.

The responses of the TE_{211} and TE_{311} modes are not those of single resonators. Each resonance appears to be that of two resonators which are overcoupled and whose coupling coefficient is a function of the angular offset of the coupling apertures. The nulls that appear between the TE_{011} resonance and the TE_{211} and TE_{311} resonances are of even greater interest. The frequency of the nulls and even the existence of a null is a function of the angular offset of the apertures.

Transmission Nulls Due to Mode Interaction

Consider the response of a single circuit, or mode, that is resonant at frequency f_1, as shown in Figure 3a. The circuit has an amplitude response shown by the solid line and a phase response shown by the dotted line. The resonator has a small, but significant, response at frequency f_2, but the phase has changed by almost 180° in passing through the resonance. The response of a second identical circuit, but resonant at f_2, is shown in Figure 3b. If both circuits are modeled as series resonant and connected in parallel, the response of the combined circuit will have a null between f_1 and f_2, as shown in Figure 3c. The null is due to the fact that the amplitudes are identical at that frequency but there is a 180° difference in phase, thus creating a null. This case is similar to that between the TE_{011} and TE_{211} modes for the angle θ as shown in Figure 1. As depicted, the fields at the output aperture are in phase according to the mode configuration. At frequencies between the TE_{211} and TE_{011} resonances these fields associated with the two modes are actually out of phase because one is above resonance and the other is below resonance.

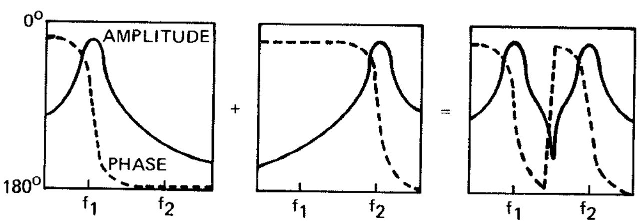

Figure 3. Response of Two Interacting Modes. (a) First Mode. (b) Second Mode. (c) Sum of Mode Responses.

Refer again to Figure 1 and the relationship of the TE_{011} and TE_{311} modes. In this case the fields at the output apertures are depicted as out of phase. At frequencies between these two resonances, however, one mode is above resonance and the other is below, thus giving an additional 180° phase shift. The total phase shift is thus 360°, so the fields are in phase and there is no null.

Lumped Constant Circuit Model

Bandpass filters, with coupling only between adjacent resonators, can be conveniently analyzed by using lumped constant series resonant circuits with impedance inverters used to adjust the coupling between the resonant circuits. This model can be extended to cylindrical TE_{011} resonators by the addition of resonant circuits to represent the TE_{211} and TE_{311} modes as shown in Figure 4. Circuit representations of the TE_{211} and TE_{311} modes are placed in parallel with the circuit representing the TE_{011} mode. The TE_{211} and TE_{311} modes are modeled as two series resonant circuits coupled by an impedance inverter and with one of the resonators shunted by a small capacitor. A unity-coupled ideal transformer was placed in each of these circuits to effect the 180° phase shift, relative to the TE_{011} mode, that occurs as the angular offset between the coupling apertures is varied. The relative coupling between the modes is controlled by the L to C ratios.

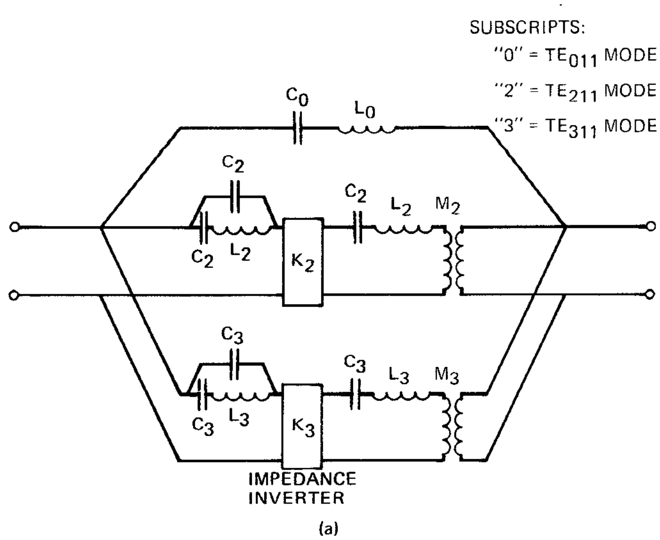

Figure 4. Lumped Constant Circuit Model.

The transmission characteristics of the TE_{011} mode resonator were calculated using this circuit model. Since one of the purposes of the calculation was to show correlation with the experimental data, an additional coupled resonator circuit was added to represent the TE_{112} mode. Rough circuit values were determined from experimental and other data. The calculations were performed by a Hewlett-Packard 2100S computer using the Opnode circuit analysis program. The circuit values were then modified to produce a calculated response that more closely represented the experimental data. The calculated transmission characteristics are shown in Figure 5.

The calculated amplitude characteristics of Figure 5 correlate very well with the experimental data of Figure 2. The calculated phase characteristics, the dotted line in Figure 5, clearly show the 180° phase reversals that are necessary to provide the transmission nulls.

References

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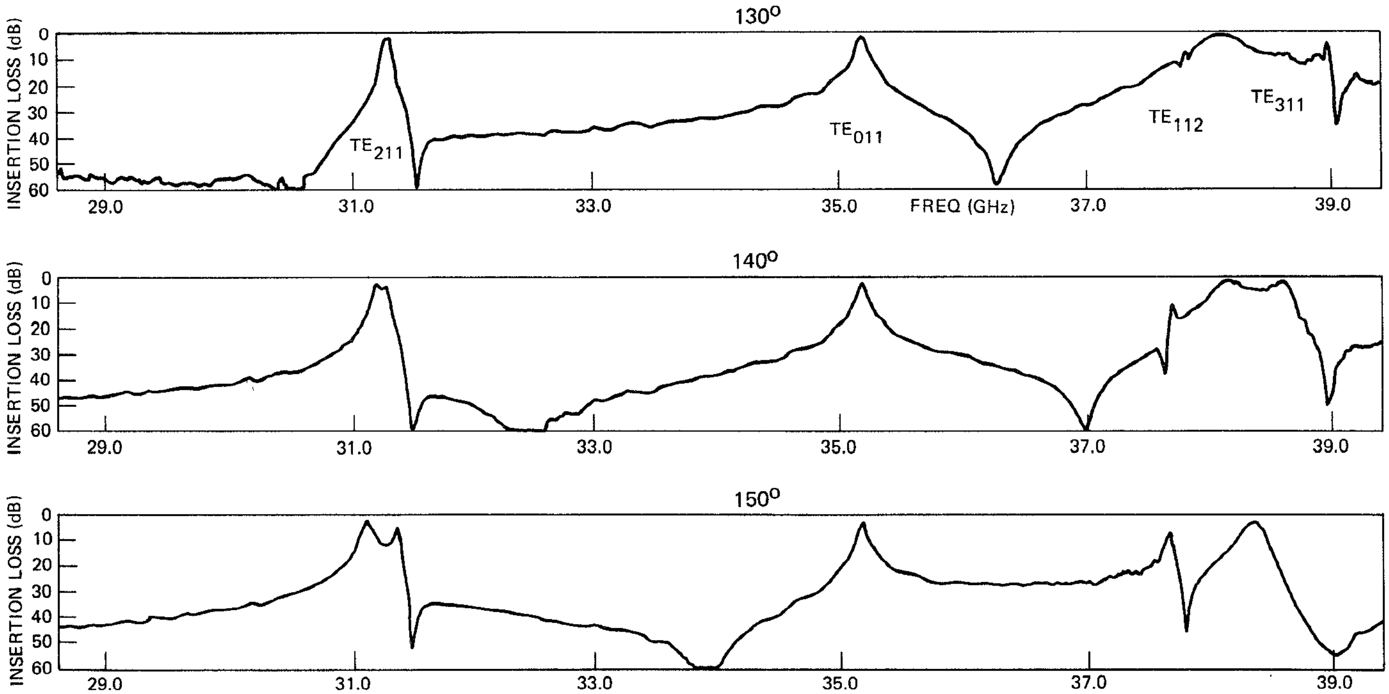

Figure 2. Measured Insertion Loss of Single Cavity Resonators With Various Aperture Offset Angles.

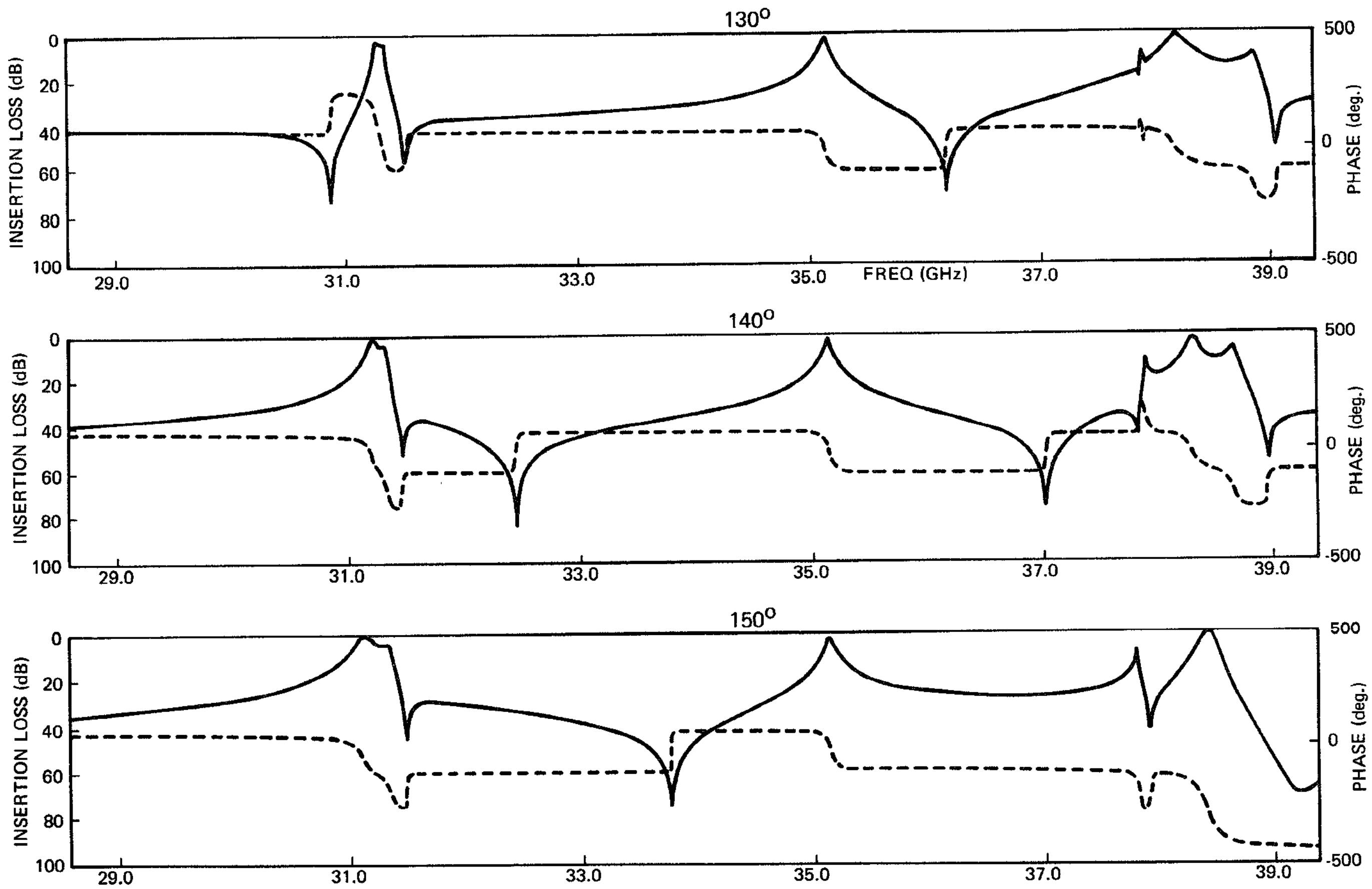

Figure 5. Calculated Transmission Characteristics of Single Cavity Resonators With Various Aperture Offset Angles.