A Novel Aperture Coupled Microstrip "Magic-T"

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Abstract—**A novel "Magic-*T*" type constructed in microstrip technology using aperture coupling is proposed and investigated. The goal is to obtain optimum coupling, phase, and isolation characteristics over a certain bandwidth for its future use in planar multilayer microwave integrated circuit applications. Preliminary results are presented and they successfully demonstrate the concept and show good agreement between theory and measurements.**

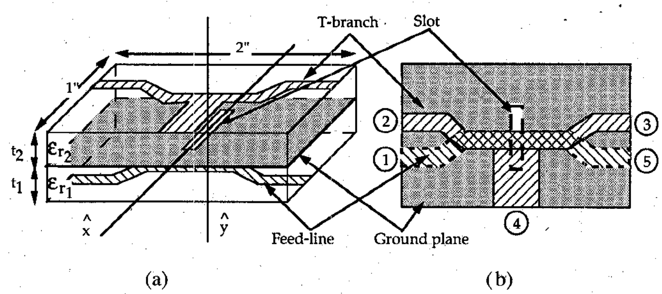

Fig. 1. Configuration of the aperture coupled microstrip "Magic-T." (a) 3-D view. (b) Top view.

I. Introduction

There are a number of advantages to aperture coupling including the separate integration of top and bottom layer circuitry, whereby the ground plane provides the isolation of the respective layer circuitry. As the trend for using multilayered structures for printed circuits continues to grow, the need to electrically connect different layers will increase. Aperture coupled microstrip lines have been proposed to achieve RF power coupling [1]–[4]. By proper design, these microstrip lines can effectively couple the input power from the feed-line to the output ports on the top substrate.

The objective of this letter is to propose a configuration for the aperture coupled "Magic-T" in microstrip as shown in Fig. 1. For this device to perform as a "Magic- T," ports 2 and 3 would be the sum and difference output ports for proper magnitude and phase inputs to the feed-line and port 4 of the T-branch. Isolation must also exist between the feed-line and port 4 of the T-branch.

II. Method Of Analysis

With reference to Fig. 1, the orthogonal property of the third line (port 4) of the T-branch, and the unidirectional z-directed E field at the slot, suggest that the feed-line and port 4 are isolated [1], [4]. Hence, as a first-order approximation, the analysis of the T-junction can be treated independently from the feed-line at the bottom. This implies that the analysis of the "Magic-T" can be divided into two separate problems: the T-junction at the top, and the coupling through the slot from the feed-line at the bottom to the parallel line at the top. The T-junction has been previously studied in detail [5]. For the slot coupling the modal analysis technique, which is based on the use of modal expansion, the reciprocity and Poynting theorems [1], is used.

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The parameters of interest are:

1) coupling through the slot, from the feed-line to ports 2 (S21) and 3 (S31) (outputs at ports 2 and 3 should be equal in magnitude but 180 degrees out of phase);
2) isolation magnitude of port 4 line (T-branch) from the feed-line (port 1);
3) power division and phase relations at ports 2 (S24) and 3 (S34) resulting from input at port 4 (ideally, power input at port 4 should divide equally in magnitude and in phase to ports 2 and 3).

Slot coupling curves were generated from computations based on modal analysis to determine slot dimensions (primarily the length) for optimum coupling in a certain frequency range.

III. Experimentation And Results

A number of prototypes were built and tested with variations in slot, T-branch and feed-line dimensions. The main objective was to optimize the slot coupling without distorting the phase relations, and to produce equal power division in the T-branch. Also high isolation between the feed-line and port 4 line (T-branch) was targeted while minimizing power reflected from all ports.

As expected, good results were obtained with narrow slots, since with wider slots the field structure at the slot changes and coupling from the feed-line to the port 4 line (T-branch) as well as phase distortion at ports 2 and 3 increases. A more accurate assessment of these effects requires further study of the aspect ratio of the slot.

Measured results of the slot coupling (|S21| and |S31| are similar but 180 degrees out of phase) and isolation are shown in Fig. 2 over the 2–26-GHz frequency range. A 50-ohm load termination was used at the end of the feed-line (port 5). The ripples in the curves can be attributed to errors in the dimensions, mismatch at the connectors and microstrip

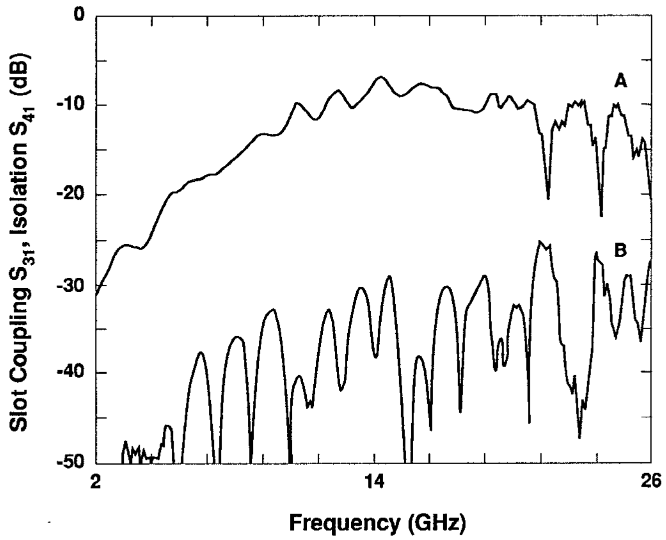

Fig. 2. Curve A: Slot coupling S31. Curve B: Isolation S41. $\epsilon r1 = \epsilon r2 = 10.2, t1 = t2 = 0.635$ mm, *W* (*T*-branch) = *W* (feed-line) = 0.7 mm, *W* (port 4 line) = 1.9 mm. Slot Parameters: *Lx* = 3.6 mm, *Lz* = 0.6 mm.

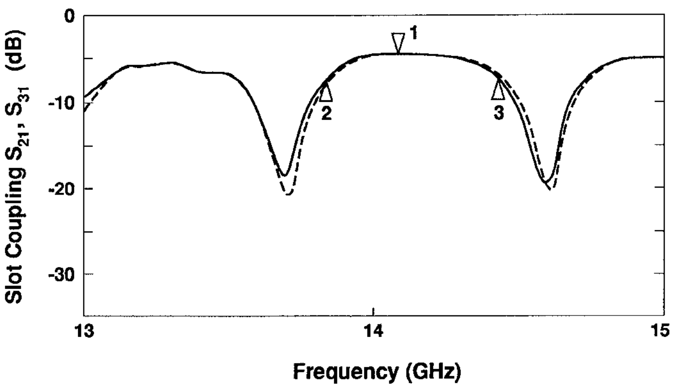

Fig. 3. Slot coupling S21 (- - - -), S31 (——). Marker 1 : -4.5 dB, 14.1 GHz, Markers 2 and 3 : 3-dB Bandwidth (0.6 GHz) about Marker 1.

bends. But overall, the expected general characteristics of the "Magic-*T*" are visible.

Further refinement of the results was achieved by attaching a short circuit to the other end of the feed-line (port 5) and optimizing the performance over a narrower frequency range. The resultant standing wave maximized the power through the slot (Fig. 3) in the 13–15-GHz frequency range. The isolation was better than -30 dB over this frequency range. Reflection levels at the 14.1-GHz center frequency was better than -20 dB. Phase error was less than 5 degrees over the 3-dB bandwidth centered on the maximum coupling (markers 2 and 3). The coupling curve dips are the results of the effects of phase variation due to differing line sections (i.e., stub length) and previously discussed errors.

The sum and difference output characteristics of the "Magic-*T*" at ports 2 and 3 were verified as seen from Fig. 4. To obtain these results, equal power provided by a power divider was supplied to the feed-line (terminated with a short circuit at port 5) and port 4 (*T*-branch). A phase shifter was attached to the feed-line and adjusted to compensate for any electrical line length discrepancies between the feed-line and *T*-branch in order to ensure phase addition at port 2 (sum curve). The difference output at port 3 was then measured using the identical phase shifter setting. In general, the desired performance in terms of addition and subtraction of input signals is evident over a narrow-band of frequencies.

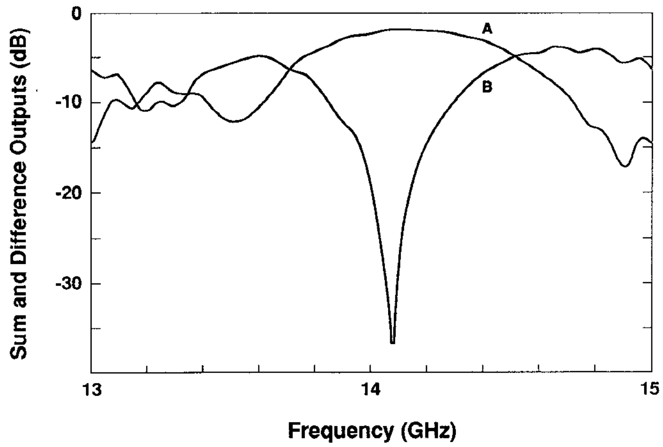

Fig. 4. Curve A : Sum output (port 2). Curve B: Difference output (port 3).

IV. Conclusion

A novel "Magic-*T*" type construction in microstrip using aperture coupling is introduced. Preliminary results verify the presence of the general characteristics of a "Magic-*T*." About 5%-bandwidth is achieved with the present structure which includes a short circuit at port 5, at a distance greater than six wavelengths from the slot. The bandwidth is expected to increase with the short circuit located closer to the slot. Further analysis is required to produce an equivalent circuit which can be used to optimize the slot parameters and the *T*-junction.

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