# FULL WAVE DESIGN OF MULTI-HOLE BACK-TO-BACK MICROSTRIP COUPLERS

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## ABSTRACT

The design of multi-hole back-to-back microstrip couplers is described, combining standard design methods initially developed for rectangular waveguide multi-aperture couplers and full wave spectral domain techniques for the planar circuits. The couplers consist of two microstrip lines on different sides of a common ground plane. Coupling is achieved through a number of holes (slots) in the ground plane between both microstrip lines. Theoretical and experimental results of a 8-hole coupler with a coupling value of 3 dB for 5 GHz are presented.

## INTRODUCTION

Using a back-to-back microstrip configuration with two microstrip circuits on different sides of a common ground plane, two separated microstrip circuits can be combined in a very compact way without any coupling between both circuits. For some applications however, certain coupling between both microstrip circuits may be required. This can be obtained by holes (slots) in the common ground plane placed between two microstrip lines. A first example for directional couplers of this kind is a quarter-wave line coupler with one longitudinal slot of quarter wavelength [1]. Generally, quarter-wave line couplers have a low coupler directivity due to the different phase velocities of even and odd mode.

In analogy to rectangular waveguide technique, a multi-hole structure is possible, too. Fig. 1 shows top view and longitudinal section of such a coupler with eight holes. In a first approach, a four-hole coupler with equal holes was designed and fabricated using full wave analysis and computer optimization [2]. In this contribution, the systematic design of multi-hole couplers in back-to-back microstrip techniques is described. As an example, theoretical and experimental results of a 3-dB coupler with eight hole are presented.

## DESIGN

The design of a multi-hole back-to-back microstrip coupler is based on standard design methods for rectangular waveguide multi-aperture couplers [3] combined with full wave spectral domain techniques [2]. The scattering parameters of a complete coupler can be defined as superposition of the twoport scattering parameters of half the structure resulting from even (**e**) or odd (**o**) mode excitation only:

$$S_{11} = \frac{S_{11e}+S_{11o}}{2} \qquad S_{31} = \frac{S_{11e}-S_{11o}}{2}$$

$$S_{21} = \frac{S_{21e}+S_{21o}}{2} \qquad S_{41} = \frac{S_{21e}-S_{21o}}{2}$$

Since the odd mode (microstrip mode) is matched, i.e. $S_{11o} = 0$, good match and isolation of the complete coupler can be obtained by designing a well-matched filter for the even mode structure which can be described by a chain circuit of hole reactances (inverters) and microstrip resonators. Simultaneously, the transmission parameters for even and odd mode, i.e. $S_{21e} = \exp(j\phi_e)$ and $S_{21o} = \exp(j\phi_o)$, must satisfy the coupling condition

$$k = |S_{41}| = \left| \frac{1}{2} \left( e^{j\phi_e} - e^{j\phi_o} \right) \right| .$$

For the filter design, the single hole structure is analysed using a spectral domain method [2]. In Fig. 2, magnitude and phase of the even mode reflection coefficient versus slot width (slot length l=1mm) is shown. With these curves, all neccessary dimensions of the holes and the spacing between all holes can be determined. Following [3], half-wave filter design can be applied [4]. By varying the product $R$ of all hole VSWRs iteratively until filter and coupling condition are satisfied, the final coupler dimensions can be determined.

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## RESULTS

A 8-hole coupler for 5 GHz with a coupling value of 3 dB and maximum flat characteristic was designed, fabricated and tested. The substrat material was RT/Duroid 5880 with a relative permittivity of 2.2 and a substrat height of 1.57 mm. In Fig. 3 results of a network simulation of the coupler are compared to results obtained by the full wave analysis of the complete coupling structure. The decrease of isolation by the full wave analysis mostly is due to coupling effects by higher order modes which are not included in a network simulation.

Even without optimization, simulated return loss and isolation were better than 50 dB. Fig. 4 shows measured results of the fabricated coupler for return loss, transmission, isolation and coupling. The decreased values of match and isolation compared to the simulated values are due to the insufficient match of the coax–to–microstrip connectors.

## CONCLUSION

The combination of standard design methods for rectangular waveguide multi–aperture couplers with full wave spectral domain techniques results in an efficient straightforward design procedure for multi–hole back–to–back microstrip couplers. As an example, a 3 dB–hole coupler with 8 holes was designed and tested. Measured results agree well with those predicted theoretically.

## REFERENCES


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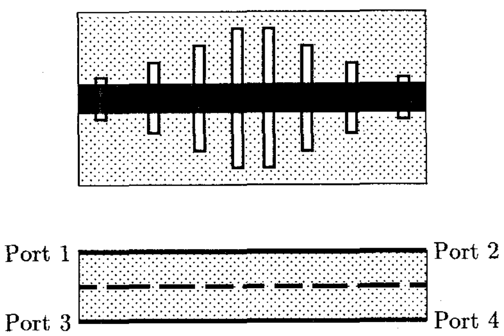


Figure 1: Top view and longitudinal section of the microstrip 8–hole–coupler: $\epsilon_r = 2.2$, $h = 1.57\,mm$, $w = 4.6\,mm$.

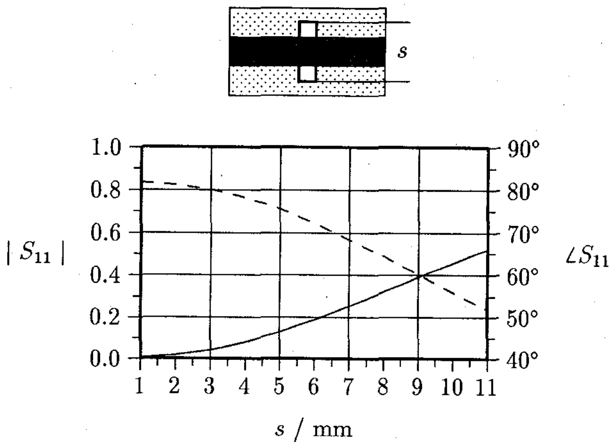


Figure 2: Magnitude (—) and Phase (– –) of $S_{11}$ versus slotwidth $s$ for the one–hole–structure with even mode excitation only.

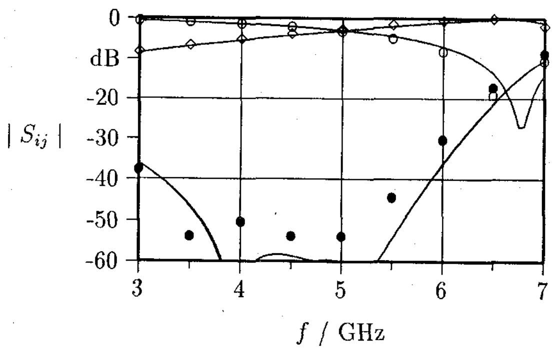


Figure 3: Comparison of network simulation (—) and spectral domain analysis (○ ● ◇) of the complete 8–hole–structure.

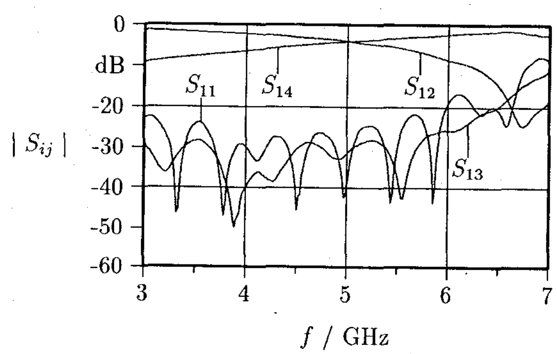


Figure 4: Measured magnitudes of return loss, transmission, isolation and coupling of the 8–hole–coupler.