Design and fabrication of a 6db compact directional coupler

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Abstract

In this paper we presented a planar geometry design for a 6dB compact microwave coupler and further explored and discussed the results of an electromagnetic simulation in Sonnet® Suites™ Electromagnetic simulation software. Being a compact coupler, the device features a minute circuit footprint size, while still observing the limitations of the production technologies involved in manufacturing it. The technology utilized in the paper is a 4 port microstrip copper trace on a production-friendly and extremely economical FR4 dielectric substrate. The circuit showed excellent performance in a 1.8GHz bandwidth (3.9GHz – 5.7GHz), with a loss of 6dB on the coupled port. A further advantage of this geometry is a very linear and predictable change in the S-parameter values as a result of small linear changes in the geometry.

Keywords: Microwave coupler; FR4; Microstrip; Microwave; Electromagnetics; Simulation software

1. Introduction

A microstrip coupler is a 4-port device designed to divide the power entering on one port to the two opposite ones, while leaving one port in isolation [1]. Parallel line couplers are extensively used in a plethora of wireless and microwave applications due to the ease of implementation and simple incorporation with various circuitries [2]. The coupled transmission lines are implemented with two conductive copper traces on a dielectric substrate. The behavior of coupled transmission lines can be described with S-parameters, as they reflect the coupling characteristics [3]. Important advantages of microstrip technology are its ease of production, low cost, reliability and durability, as well as the virtually limitless geometry design space, allowing for devices tailor made to their specific application requirements [5]. The efficiency of exploring this design space can be optimized by relying on a baseline design that responds well to variations, both for the purposes of developing a specific design, and for the robustness of the designed geometry with respects to the inaccuracies of the manufacturing process[6][7]. This geometry was based off a compact 3dB directional coupler developed by the Ural Federal University [4] and motivated by the formers constrained amenability to adaptations in geometry for different application specifications.

2. Design specifications

2.1. Simulation parameters

Simulation software: Sonnet EM Suite
Bottom substrate: FR4 [Erel = 4.4, Dielectric Loss Tan = 0.002, Thickness = 1.55mm]
Top substrate: Air [Erel = 1, Dielectric Loss Tan = 0]
Metallization: Copper, Thickness = 0.7mm
Simulation frequency range: 3.5GHz – 6.5GHz
Center frequency, f: 4.8GHz

Coupling, c: 6dB
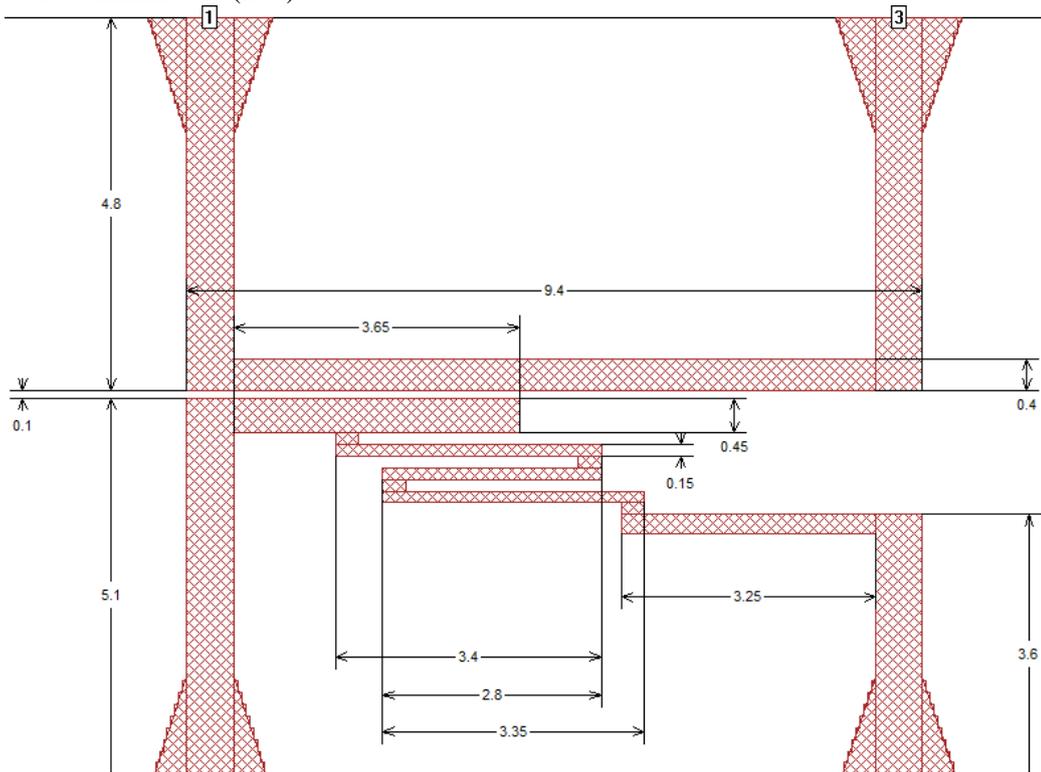Measurement units: millimeters (mm)

Figure 1. Geometry

As seen in Fig. 1, the geometry is an asymmetric one, with port 1 being the input port, port 2 being the coupling port and port 3 being the isolation port. The geometry specifications observe the limitations of the manufacturing technology, as well as the expected integration requirements [8].

3. Simulation results

The following figure depicts the simulation results by graphing the response of S-parameters across a 3000MHz range. As seen in Fig. 2, S12 coupling loss is ~6dB in a 1.8GHz bandwidth.
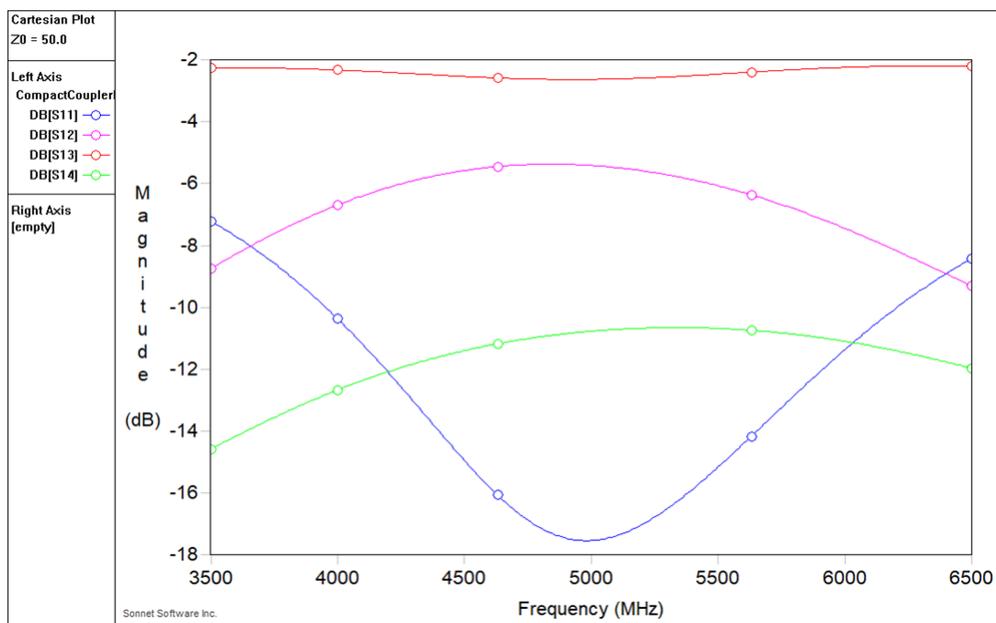

Figure 2. S-parameters

4. Response to variations

As previously mentioned, the main advantage of this geometry design is reflected in the predictable changes of the S-parameter values as a consequence of specific variations in the geometry. In Table 1 we can observe the changes in S-parameter values as we incrementally increase the lengths of the coupled lines. All lengths are expressed in millimeters, and all S-parameters in [dB]. Length L1 is the length of the primary coupling line, the one closest to the input transmission line. Lines L2, L3 and L4 represent the lengths of the following 3 lines, in descending order of proximity to the primary line.

Table 1. The changes in S-parameter values

L1(mm)	L2(mm)	L3(mm)	L4(mm)	f(MHz)	S11(dB)	S12(dB)	S13(dB)	S14(dB)
4	3	2.5	2	4580	15.34	5.74	2.56	10.58
4.5	3.5	3	2.5	4460	14.12	5.45	2.79	10.4
5	4	3.5	3	4360	13.15	5.19	3.03	10.3
5.5	4.5	4	3.5	4220	12.14	4.96	3.26	10.38
6	5	4.5	4	4100	11.32	4.75	3.48	10.53
6.5	5.5	5	4.5	4020	10.63	4.45	3.75	10.93
7	6	5.5	5	3880	9.95	4.33	3.92	11.29
7.5	6.5	6	5.5	3740	9.39	4.23	4.08	11.72
8	7	6.5	6	3600	8.93	4.16	4.19	12.16
8.5	7.5	7	6.5	3460	8.58	4.13	4.26	12.63
9	8	7.5	7	3340	8.33	4.14	4.27	13.05

For a more concise and expressive summation of the response behavior please refer to Fig. 3, where the "elongation" axis represents the uniform elongation of L1, L2, L3 and L4 from the initial lengths seen in Table 1, and the "Loss" axis shows the S-parameter values. It should be noted that Table 1 and Fig. 3 aren't meant as a representation of desirable, or even viable, parameter values, rather they are meant to illustrate a simplified but clear amenability to variations in geometry and their consequences to the response. The design depicted in this paper was obtained by empirically selecting each length to obtain the desired response. The specific implications of varying the lengths of individual lines is outside the scope of this paper, but varying the lengths individually provides tuning knobs that can be adjusted to change the coupling behavior, adjust reflection, shift the center frequency or improve isolation.
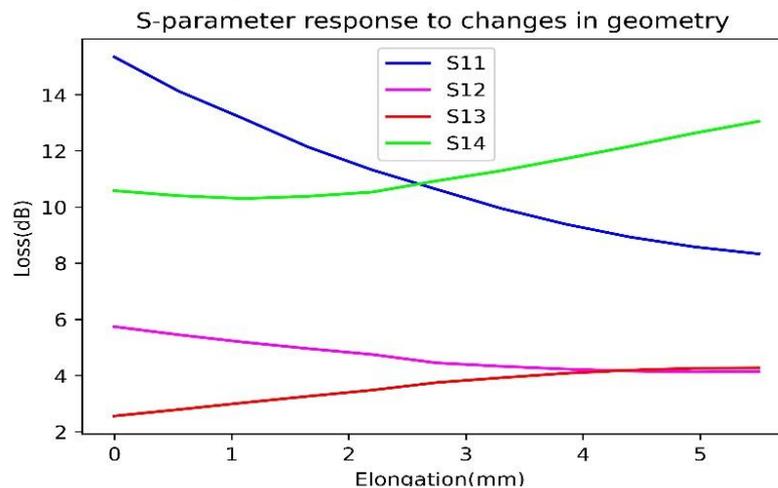

Figure 3. S parameter response to changes in geometry

5. Fabrication and testing

The production of microstrip couplers comes with its own set of difficulties and requirements [8]. Often fabrication errors manifested as dimensionality inaccuracies or discontinuities can produce testing results inconsistent with the simulation results [9]. The fabrication process went as intended and no quality errors were observed. However, other problems soon became clear. Despite a mindful approach to the geometry

design of this coupler, such that the tolerances of the design are in compliance with the tolerances of the manufacturing process, a problem arose during the testing process. This being a compact coupler, the distance between ports is quite miniscule. So miniscule, in fact, that due to the physical size of the 50 ohm terminations required to connect the coupler to the Vector Network Analyzer (VNA) the terminations couldn't properly fit, and any measurement results one might hope to collect from the testing stage were substantially degraded, as seen in Fig. 5.
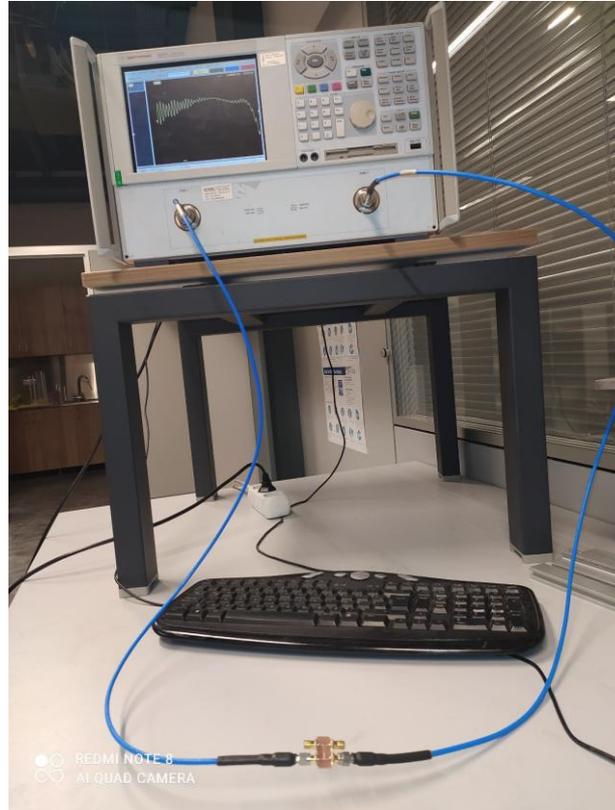

Figure 5. The measurement results degraded

6. Conclusion

In this paper we've presented a miniaturized design for a 6dB coupler and observed how the S-parameters of the coupler change in response to linear changes in geometry. While having a design that responds in a linear and predictable fashion to specific changes in geometry is useful in the development towards satisfying certain project requirements, the fact that a near infinite solution space (the geometry) is explored by human endeavors is inefficient and problematic. A more sensible solution might be to explore this space algorithmically. Since it is quite clear that the response of the system is fairly neatly related to certain characteristics of the geometry, exploring the space through a neural network model and a genetic algorithm might be a much faster approach, yielding higher quality results. This might be accomplished by instantiating multiple instances of the simulation environment across a computing space, computationally generating the geometries based on a rudimentary rule set, feeding the results and geometry parameters into a neural network for rule extraction, modifying the generative rules, and applying a genetic algorithm to the produced geometries to find the best fit, while the rules are being optimized.

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