

Microstrip hybrid wideband 10 dB coupler

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Abstract

In this paper, the design, simulation, optimization and testing of a Microstrip Hybrid 10 dB Wideband Coupler was presented. The aim of the project was to introduce a new coupler design and to achieve stable operation for as wide bandwidth as possible. For this proposed design simulated results are as follows: 3.8 GHz Bandwidth and Coupling Amplitude balance of 1 dB across it. Coupler is then produced using LPKF ProtoMat 104s machine and it is tested with Vector Network Analyzer at Istanbul Technical University.

Keywords: Microstrip, Coupler, Hybrid Coupler, Microstrip Coupler, Wideband, 10 dB

1. Introduction

The frequency range from 100 MHz up to 1000 GHz is reserved for radio and microwave engineering. For microwave engineering, the range from 3 to 300 GHz is reserved. Microwaves are a form of energy in the electromagnetic (EM) spectrum. The electromagnetic spectrum runs from DC voltage to light and beyond. Waves have several components: amplitude, wavelength and frequency [1]. Couplers and power dividers are passive devices which are used for sampling incident and reflected microwave power, conveniently and accurately, with minimal disturbance to the transmission line [2]. Recently, the considerable attention is directed to couplers, which may have arbitrary output power division at the two operation bands [3]. An essential feature of directional couplers is that they only couple power flowing in one direction. Power entering the output port is coupled to the isolated port but not to the coupled port [4]. Couplers have wide usage possibilities in the microwave applications, as well as in radio frequency through devices like power amplifiers, antenna feeders and balance mixers [5]. Those microwave devices are used in various Industries such as military and automotive [6]. The most popular configuration of a directional coupler is the standard coupled-line directional coupler, which allows the realization of quite a compact coupler with good bandwidth [7]. Couplers are designed to achieve coupling at desired frequency range, such that they separate and transmit radio frequency signals into two output ports [8]. Couplers can be divided into 3-port and 4-port devices, and Hybrid Coupler is a 4-port device, which is used for either splitting power into two parts, or for combining signals. Hybrid couplers are giving two output ports with 90 degrees phase difference [9]. Compact hybrid couplers are used in literature for their smaller geometries [10]. A standard coupler (Figure 1) has four ports and they are usually defined as follows:

Port 1: Input (incident)

Port 2: Transmitted

Port 3: Coupled, forward coupled port

Port 4: Isolated, reverse coupled port.

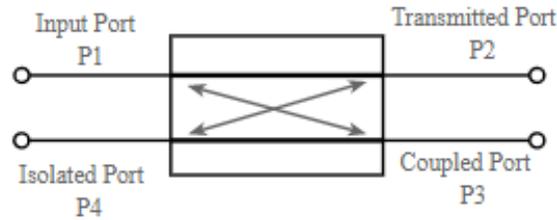


Figure 1. Standard Coupler Diagram [11]

The microstrip technology utilizes 3 layers, a solid dielectric below, a metallization layer and air above – making it an inhomogeneous system [12]. Microstrip devices are the most usable ones because of their low cost, planar structure and their easiness of integration [13]. Hybrid couplers are very popular in literature [14]. Analysis and simulations were done in planar 3D electromagnetic software called Sonnet suites [15]. Main characteristics of the design are given as follows:

- Dielectric constant $\epsilon_r=4.4$ (FR4)
- Frequency range of 2.4 GHz to 6.24 GHz
- Box size 25x20 mm
- Cell size 0.1x0.1 mm
- Coupler size 13.1x20 mm
- Metal width: 1.5 mm
- Separation between metal lines: 0.1 mm

2. Design

The procedure of designing a 10 dB Hybrid Microstrip Coupler consisted of several steps. First, the appropriate geometry was chosen and dimensions were set to get the initial results. As a starting point for this design, the design of coupler for motion-detection systems was taken, in order to have some example and idea where to go next. To achieve wide bandwidth, one normally uses more than one section of couplers [21]. After initial simulation results, some changes to the design were made. Firstly, width of metal part of the coupler was chosen to be 1.5 mm, and separation between two coupled lines 0.1 mm. Then, symmetrical indentation in the middle was introduced. The 3D view of the final design of the proposed coupler can be seen in Figure 2. The design consists of two parts, a bottom substrate and upper metal part which can be seen in the top view of the design shown in Figure 3. The upper, metal part is made of two metal lines which are symmetrical with respect to y-axis, with an indentation at the center. All dimensions shown are in millimeters.

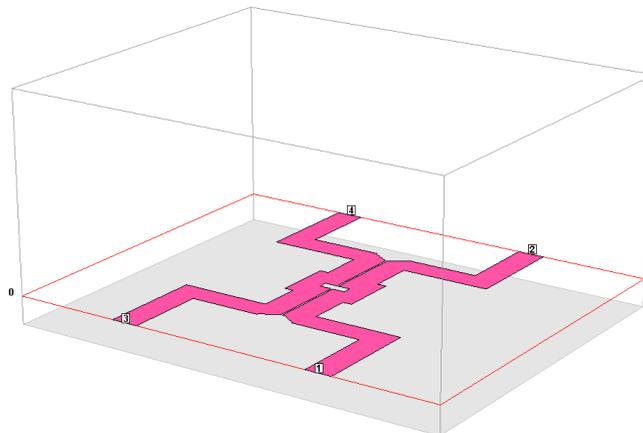


Figure 2. 3D representation of the geometry

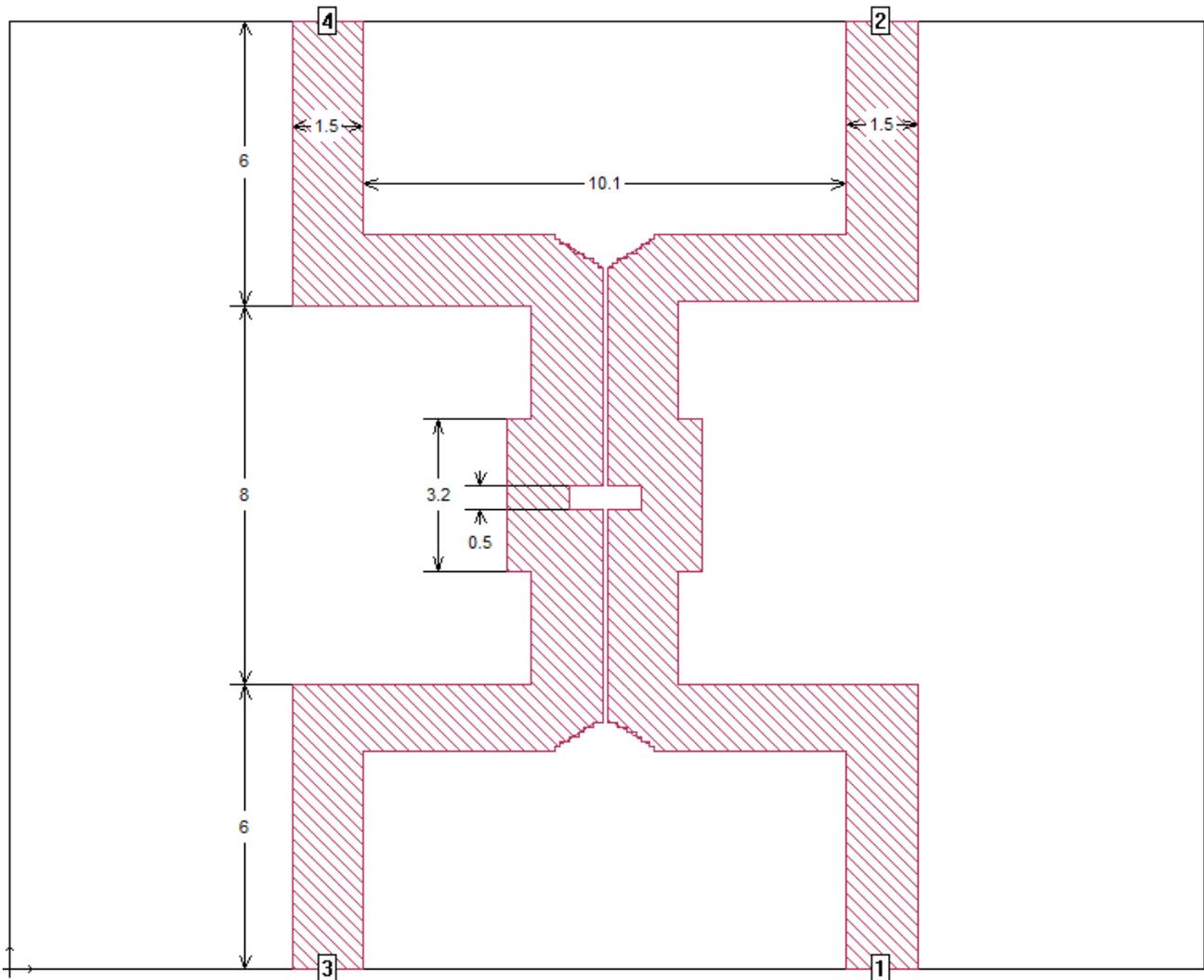


Figure 3. Top view of the geometry of the coupler

The Box size is chosen to be 25 x 20 millimeters, while the designed geometry is 13.1 by 20 millimeters in size. After that, the next step was to choose the right parameters. For dielectric, FR4 substrate with $\epsilon_r = 4.4$, and 1.55 mm thickness was chosen, while metal part is chosen to be copper. FR4 is the most common material used for PCBs [16], while it can also be used in the construction of relays, busbars, switches, transformers, etc. Air layer with $\epsilon_r = 1$ was chosen to be 11.5 mm thick. As mentioned above, air layer thickness is 11.5 mm, which is more than seven times thicker than dielectric thickness, and we know that air layer has to be at least five times thicker than dielectric layer in order to get the right response.

3. Simulation results

Simulation results were presented in this section. S-parameters of input match, coupling, thru port and the isolation is shown [17]. In Figure 4, simulation results of the final design, in the frequency range of 1 to 7 GHz, are shown. In the graph S-parameters are represented, where S11 is reflection, and S12, S13 and S14 represent the coupling throughout the frequency range, from ports 2, 3 and 4 to port 1. We can see that the coupling (S13) is around -10 dB with $\pm 5\%$ for very wide frequency band of almost 4 GHz (2.4 to 6.24 GHz), which is quite large bandwidth.

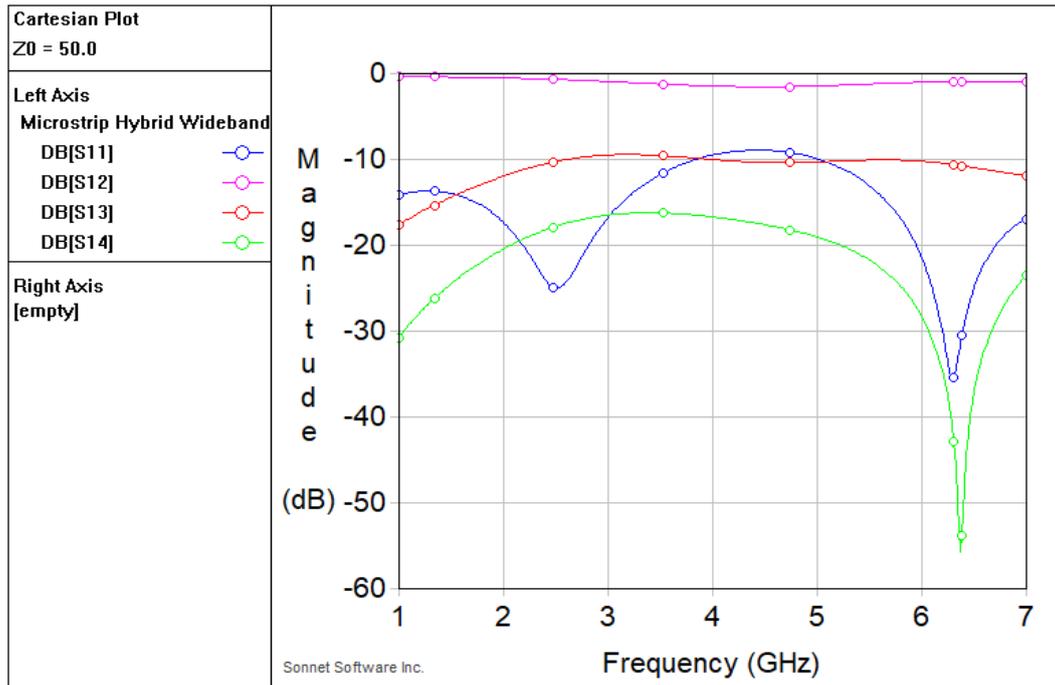


Figure 2. Simulation results

Next, the parametric study is done. Parametric study consists of changing the dimensions of the design, thickness and width of materials used, air layer thickness, etc. It helps us in optimizing the device and it's useful to understand what affects the response of the device and in what way. It is a process which consists of many simulations, tuning and optimization. In the table below, we can see that the Amplitude balance and Bandwidth are highly affected by separation between metal lines and center part width and separation, where it is found that separation between lines of 0.1 mm, center part separation of 0.5 mm and center part width of 1.5 mm gives the best Bandwidth of almost 4 GHz and Amplitude balance of almost exactly 1 dB across the band. What can be observed here, is that the separation between the lines is dictating the Amplitude balance, while other two parameters are affecting the Bandwidth.

Table 1. Amplitude balance and bandwidth with respect to separation of metal lines and center part separation and width

Sep. (mm)	Center separation (mm)	Center width (mm)	Amplitude balance (dB)	Bandwidth (GHz)
0.1	2.1	0.7	0.91	1.78
0.1	1.7	0.7	0.95	3.34
0.1	1.5	0.5	1.02	3.78
0.2	1.8	0.7	2.44	2.66
0.3	1.7	0.3	3.16	2.78

In the following table, the effect of width of metal lines on Bandwidth and Amplitude balance is observed. It is commonly known that higher coupling in conventional microstrip couplers can be achieved by tightening the spacing between the coupled lines which is limited by fabrication tolerance [18]. The width of metal lines dictates the easiness of production and it also dictates the cost of production. We can conclude that if we decrease the width of the metal, Bandwidth is going to increase, but Amplitude balance decreases. Similarly, if we increase the width of the metal Bandwidth is increasing, but Amplitude balance is getting worse.

Table 2. Amplitude balance and bandwidth with respect to metal lines width

Metal width (mm)	Amplitude balance (dB)	Bandwidth (GHz)
1.5	1.02	3.78
1.3	1.48	4.02
1.1	2.21	4.56
1.6	1.08	3.76
1.8	1.19	3.8
2.0	1.7	4.22

4. Measured results

After the design process is done, and optimization and the parametric study are conducted, coupler is then taken to production in the lab. Using LPKF ProtoMat 104s, machine used for RF and Microwave PCBs production, coupler is physically produced, and four SMA connectors are soldered to ports. SMA connectors are developed in the 1960s and they have 50Ω impedance. They can operate in the frequency range from 0 to 12 GHz, although there are some connectors which can operate at 26.5 GHz. There are two major types of SMA connectors, male and female. A standard male connector has a center pin with 0.9 mm diameter.

After the production and soldering the SMA connectors, coupler is then sent to Turkey, to Istanbul Technical University, in order to test and measure real-life results using Vector Network Analyzer. Network analyzer is a device which is used to measure the network parameters of electrical networks. It's used to measure s-parameters (reflection, transmission, coupling, etc.). This device can measure the response of not only active, but also passive devices. Measuring the transmitted and reflected signals across the band of interest, and often beyond, enables the characteristics of a device to be determined [19]. One problem occurred there. The Network Analyzer couldn't measure the s-parameters because SMA connectors are too close to each other and there are interferences between signals.

5. Conclusion

In this paper, Microstrip Hybrid Wideband 10 dB Coupler is designed, simulated and optimized, and its behavior is observed while changing geometry and some other parameters. In parametric study conducted, it can be seen that changes in separation between two metal lines affect the results the most, as well as the width of the metal, as well as center part separation and width, while angles of cut corners didn't affect results at all. Final design that was found to have the best simulated results is then produced in the lab using LPKF ProtoMat 104s machine and it is tested with Vector Network Analyzer, where some problems occurred. It was found that ports are too close to each other, and it is making problems with interference of signals. This design has very good simulated coupling of 10 dB in a quite wide bandwidth of almost 4 GHz frequency band. What could be done next is to try to make the distance between the ports larger, optimize the response of the coupler, and then produce it again in order to see the coupler in real-life application.

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References

- [1] Ferrite Microwave Technologies, A Microwave Technique Company. Accessed on: Jan. 25, 2021. [Online]. Available: <http://ferriteinc.com/wp-content/uploads/2017/03/Understanding-Microwaves-and-Microwave-Devices.pdf>
- [2] Krytar, Broadband Microwave Components & Equipment. Accessed on: Jan. 25, 2021. [Online]. Available: <https://krytar.com/resources-3/applications/primers/directional-coupler-primer/>
- [3] Purdy's I., Oborzhytskyy V "Design of Dual-Band Two-Branch-Line Couplers with Arbitrary Coupling Coefficients in Bands" Radioengineering, vol. 23, no.4, 2014.

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- [4] Electronics-notes, Accessed on: Jan. 25, 2021. [Online]. Available: <https://www.electronics-notes.com/articles/radio/rf-combiner-splitter-coupler-hybrid/what-is-an-rf-directional-coupler.php>
- [5] K.C. Dalar, M. Yildirim, M. A. Aydin, Ş. T. Imeci, 3 dB Hybrid Coupler, 28th Annual Review of Progress in Applied Computational Electromagnetics, April 10-14, 2012 - Columbus, Ohio, 2012.
- [6] J. Corsini, J. Malaver, S. Lushllari, 90 Degree Hybrid Coupler, Worcester Polytechnic Institute, April 25, 2013.
- [7] G. Sanna, G. Montisci, Z. Jin, A. Fanti, G. A. Casula, Design of a Low-Cost Microstrip Directional Coupler with High Coupling for a Motion Detection Sensor, Electronics, 2018.
- [8] S.S. Pai, M. Kumar, K. Singh, Design and Performance Analysis of lumped and distributed 6-dB micro strip coupler topologies at Sband, International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE) vol. 6, no. 5, May 2017.
- [9] G. Breed, "Classic Design for Lumped Element and Transmission Line 90-Degree Coupler," High Frequency Electronics, pp. 62-66, 2007.
- [10] Singh S., Kumar A., Kumar K., Singh Tomer, R. Kumar P. "Extended Port Dual Band Planar Branch Line Coupler", International Journal of Emerging Technology and Advanced Engineering, vol. 4, Special Issue 1, February 2014.
- [11] Electronic-notes, Accessed on: Jan. 25, 2021. [Online]. Available: <https://www.electronics-notes.com/articles/radio/rf-combiner-splitter-coupler-hybrid/what-is-an-rf-directional-coupler.php>.
- [12] M. Bucu, M. Kunovac, A. Mesanovic, Design and Simulation of a High-Frequency 10 dB Directional Microstrip Coupler, Computational Methods and Telecommunication in Electrical Engineering and Finance, May 6-9, 2018, Sarajevo, Bosnia and Herzegovina, 2018.
- [13] Rezaei, A and Noori, L. Microstrip Hybrid Coupler with a Wide Stop-Band Using Symmetric Structure for Wireless Applications. J. Microw. Optoelectron. Electromagn. Appl., vol.17, no.1, pp. 23-31, 2018.
- [14] T. Jayachitra, V.K Pandey and A. Singh, Design and Development of Hybrid Coupler with FR4, International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE) vol. 2, no. 12, December- 2013
- [15] Sonnet suites, version 16.54, www.sonnetsoftware.com
- [16] Technologies, Avago, PCB Layout Guidelines for Designing with Avago SFP+Transceivers, 2005
- [17] Products Simulation Technology, Accessed on: Jan. 25, 2021. [Online]. Available: <http://www.ansys.com/Products/Simulation+Technology/Electromagnetics/High-Performance+Electronic+Design/ANSYS+HFSS>.
- [18] S. N. Burokur and M. Latrach, A novel type of microstrip coupler utilizing a slot split-ring resonator defected ground plane, Microwave Opt. Technol. Lett., vol. 48, no. 1, pp. 138-141, 2006.
- [19] Electronic-notes, Accessed on: Jan. 25, 2021. [Online]. Available: <https://www.electronics-notes.com/articles/test-methods/rf-vector-network-analyzer-vna/what-is-a-vna.php>.