Sonnet in Directional Coupler Design

Abdullah Eroglu

RF/Microwave Laboratory, Department of Engineering
Indiana University – Purdue University Fort Wayne, Fort Wayne, IN 46814, USA
Email : eroglua@ipfw.edu

Abstract: Planar electromagnetic simulator Sonnet has been used to design, simulate, and validate the measurement results for the microstrip type directional couplers to sense forward and reflected power in RF power amplifier applications. Two directional couplers for this purpose have been designed, simulated, and their results are compared with the experimental results. The accuracy of the planar electromagnetic simulator Sonnet has been tested on two-line symmetrical and multi-layer three line directional couplers. It has been shown that Sonnet provides accurate results within acceptable error, and hence, can be used in a microstrip directional coupler design for RF power amplifier applications.

Keywords: Directional Couplers, Sonnet, Planar, Electromagnetic Simulators.

1. Introduction

Microstrip type directional couplers are of great interest to RF engineers due to several advantages including design flexibility, implementation, and cost. They have been used commonly in communication systems, semiconductor wafer processing, and medical resonance imaging (MRI) applications.

The most common type microstrip directional couplers that have been employed in practice are symmetrical two-line and three-line directional couplers [1-7]. There are ,also, multi-layer microstrip directional couplers that are designed to increase the directivity of the couplers [8]. In the design of the microstrip directional coupler, directivity, isolation, coupling level, and VSWR at the input and output ports are important design parameters. Directional couplers are designed to pick up a signal at a certain magnitude from the main line. This requirement identifies the amount of coupling needed between the main line and the coupled lines. The purity in the signal content is dictated by the directivity level of the coupler. This design parameter has a direct relation with the isolation that exists between the ports of the coupler. Hence, the design of the coupler has to be performed thoroughly to meet with all the requirements including coupling level, directivity, and isolation. Although the analytical formulation of the micrsotrip directional couplers is well established [1-7], it is not a straightforward method to finalize and implement the coupler design that performs as expected. It may require several prototypes and design changes unless a tool such as an electromagnetic simulator is used. The use of an electromagnetic simulator expedites the design time, and improves the performance of the directional couplers. Their use ,also, eliminates the need for several prototypes before a directional coupler is built since the design is performed and implemented in the virtual laboratory environment.

In this paper, we design, simulate, and validate our results with the existing measurement results for two-line and multi-layer microstrip type directional couplers for high power RF amplifiers at the MF (Medium Frequency) –UHF (Ultra High Frequency) range. Simulation of the couplers has been performed using Sonnet V12.56. The analytical, simulation, and measurement results have been compared and found to be in close agreement.

2. Design and Simulation of Directional Couplers

In this section, design and simulation of two-line and multi-layer three-line directional couplers have been presented using Sonnet V12.56. The simulation results have ,also, been compared with the experimental results.

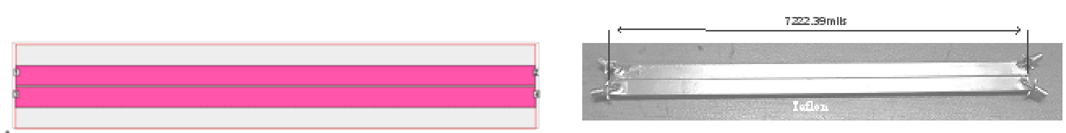
A) Two-Line Symmetrical Directional Coupler Design at UHF

The design of two-line directional couplers is described in detail in the literature. Based on the analytical results, Table I illustrating the physical dimensions and the corresponding coupling levels for several materials is given below [7].

Table 1 - Physical dimensions for two-line directional couplers

Material	ε_r	Coupling (dB)	w/h	s/h	$l(mils)$
Teflon	2.08	-10	2.6103	0.0352	6782.78
RO4003	3.38	-10	1.9281	0.0771	5846.63
FR4	4.4	-10	1.6117	0.1094	5348.79
RF-60	6.15	-10	1.257	0.1595	4743.29
Alumina	9.8	-10	0.2375	0.8379	3965.26
Teflon	2.08	-15	3.0727	0.2576	7222.39
RO4003	3.38	-15	2.2426	0.3687	6061.05
FR4	4.4	-15	1.8621	0.4343	5508.25
RF-60	6.15	-15	1.4412	0.5202	4868.32
Alumina	9.8	-15	0.9592	0.6359	4076.97
Teflon	2.08	-20	3.243	0.8216	7248.97
RO4003	3.38	-20	2.3522	0.9557	6040.04
FR4	4.4	-20	1.9479	1.0267	5514.46
RF-60	6.15	-20	1.504	1.1129	4876.99
Alumina	9.8	-20	0.9998	1.2184	4071.45

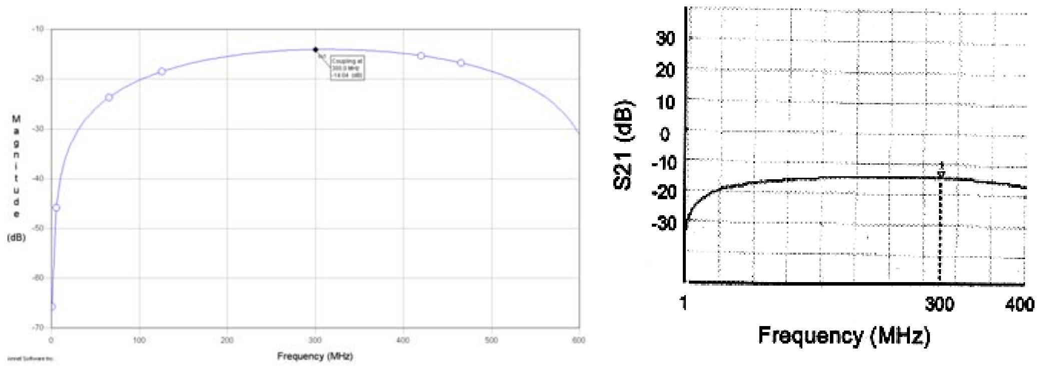
The results in Table 1 can be used as baseline numbers to design two-line directional couplers with planar electromagnetic simulators. The simulation of –15dB coupler on Teflon is performed using the physical dimensions given in Table 1 with Sonnet at 300MHz. The layout of the two-line symmetrical directional coupler that is simulated and manufactured is illustrated in Fig. 1.



(a) (b)

Fig.1. The layout of the (a) simulated (b) manufactured two-line symmetrical directional coupler.

The simulation and experimental results are shown in Fig. 2a and 2b, respectively. Based on the simulation and experimental results, the overall difference between Sonnet and the measurement results is around 0.5dB. The simulated coupling level at 300MHz is found to be -14.04dB, whereas the measured coupling level is measured to be –14.562dB.



(a) (b)

Fig.2. Measurement and simulated coupling level for two-line symmetrical directional Coupler (a) Simulated results (b) Measurement results.

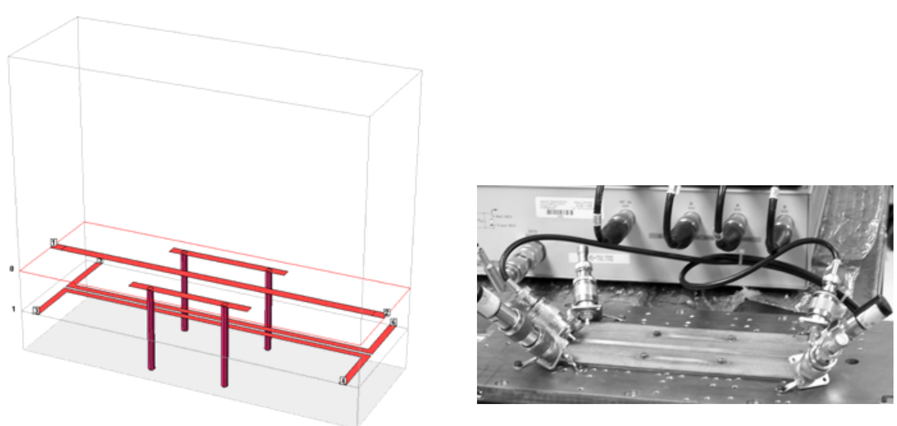
B) Multi-Layer Three Line Directional Coupler at UHF

In this part, we give the design and simulation of a multi-layer three line directional coupler at 300MHz using Sonnet. The required coupling level for the directional coupler is –10dB. Based on the analytical results, the physical dimensions of the coupler are given in Table 2.

Table 2 – Physical dimensions of –10dB coupler at 300MHz

L1	**L2**	**L3**	**L4**	**L5**	**L6**	
7250	1225	1375	2107	2736	646	
W1	**W2**	**W3**	**W4**	**W5**	**h1**	**h2**
150	75	225	75	150	60	60

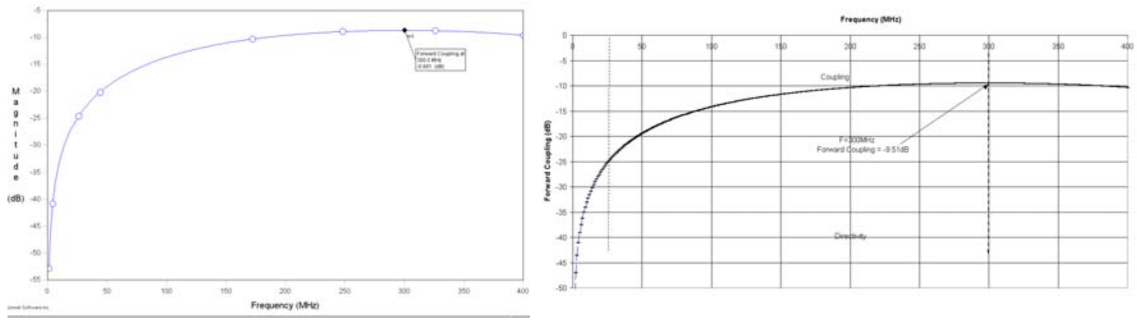
The layout of the directional coupler that is simulated and manufactured is given in Fig. 3.



(a) **(b)**

Fig.3. The layout of the (a) simulated (b) manufactured multi-layer three-line directional coupler.

The simulated and measured results have been depicted in Fig. 4. Based on the results, the difference between the simulated and measured results is –0.82dB.



(a) **(b)**

Fig. 4. Coupling level for three-line directional coupler (a) Simulated results (b) Measurement results.

3. Conclusions

In this paper, the design and simulation of different types of microstrip directional couplers including single layer two-line symmetrical structure and a multi-layer three-line configuration have been performed using planar electromagnetic simulator Sonnet V12.56. Directional couplers that are designed, simulated, and built are used for high power applications as part of RF power amplifiers. The accuracy of Sonnet has been verified for each type of directional coupler with the experimental results. Sonnet, in each case, provided results that are very close to the measurement results within acceptable error margin. It has been shown that the planar electromagnetic simulator such as Sonnet can be used in the design of microstrip type directional couplers with different configurations as part of RF power amplifier system.

References

[1] Pavlidis, D., and Hartnagel, H. L., “The design and performance of three-line microstrip directional couplers,”*IEEE Trans. Microwave Theory Tech.*, no. 10, pp. 631-640, 1976.

[2] Tripathi, V.K., “On the analysis of symmetrical three-line microstrip circuits,” *IEEE Trans. Microwave Theory Tech.*, no. 9, pp. 726-729, 1977.

[3] Abdallah, E., and El-Deeb, N., “On the analysis and design of three coupled microstrip lines,” *IEEE Trans. Microwave Theory Tech.*,no. 11, pp. 1217-1222, 1985.

[4] T.G. Bryant and J.A. Weiss, “Parameters of microstrip transmission lines and coupled pairs of microstrip lines,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, no.12, pp. 1021-1027, Dec. 1968.

[5] M. Kirschning and R.H. Jansen, “Accurate wide-range design equations for frequency-dependent characteristic of parallel coupled microstrip lines,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-32, no.1, pp. 83-90, Jan. 1984.

[6] S. Akhtarzad, T.R. Rowbotham, and P.B. Jones, “The design of coupled microstrip lines,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, no.7, pp. 486-492, June 1975.

[7] A.Eroglu, J.K. Lee, “The complete design of microstrip directional couplers using the synthesis technique,” *IEEE Transactions on Instrumentation and Measurement*, vol. 57, no. 12, pp. 2756-2761, Dec. 2008.

[8] A. Eroglu, R. Goulding, P. Ryan, J. Caughman, D. Rasmussen , “Novel broadband multilayer microstrip directional coupler,” *2010 IEEE AP-S International Symposium and USNC/CNC/URSI National Radio Science Meeting*, pp.1-4, Toronto, July 11-17, 2010.