

UWB stripline coupler with low loss and ripple

Ali Agharasuli

Dept. Electrical and Computer
Engineering
Iran Science and Technology
University
Tehran, Iran
ali_gharasooli@elec.iust.ac.ir

Mehdi Karimi Mehr

Dept. Electrical and Computer
Engineering
Iran Science and Technology
University
Tehran, Iran
m_karimimehr@elec.iust.ac.ir

Omid Manoochehri

Dept. Electrical and Computer
Engineering
University of Illinois at
Chicago
Chicago, IL, United States
omanoo2@uic.edu

Danilo Erricolo

Dept. Electrical and Computer
Engineering
University of Illinois at
Chicago
Chicago, IL, United States
derric1@uic.edu

Abstract— An asymmetric multi-section ultra-wide band stripline coupler with two coupled parallel stripline is proposed. The primary features of the coupler include operating frequency from 2 GHz to 18 GHz to cover S, C, X, Ka and Ku bands; coupling coefficient below -18 dB; return loss of -20 dB for all the ports; minimum directivity of 25 dB; small size and low losses, which make it appropriate for applications, where the available space is limited. The coupler parameter values are obtained after a two step optimization process using i) a genetic algorithm with Matlab; and, ii) a particle swarm algorithm with HFSS software. The whole structure is simulated, fabricated and measured. There is an excellent agreement between measured and simulated results.

Keywords— directional couplers; microstrip coupler; wide band couplers.

I. INTRODUCTION

A stripline coupler operating at the S, C, X, Ka and Ku bands (from 2 GHz to 18 GHz) is designed and fabricated to be used for satellite transponder applications and direction-finding systems, where it is required to sample high-power and ultra-wide band (UWB) signals with high accuracy [1-7]. Direction finding systems can detect range of the target from the transmitted signal power. A wideband coupler with a smooth coupling coefficient should be used to measure the target signal power. This can minimize the target range estimation errors. The traditional design of a microwave coupler was based on two microstrip lines that are coupled, where the undesired radiation field could introduce ripples in the coupling coefficient and losses in the insertion loss coefficient [8]. The number of microstrip sections controls the amount of coupling. In the case of using a single section, the bandwidth is about (5 to 7) %, which is not enough for making an UWB coupler [8]. In fact, in satellite communication systems, microstrip couplers cannot be used because they cannot handle high power levels, due to their losses [7]. Other types of microwave couplers such as those based on ferrites and waveguides cannot be considered because they occupy large volumes [9]. Hence, we start from a multi section stripline coupler to achieve the UWB requirements and a flat coupling coefficient. To the best of our knowledge, there is no directional coupler in the literature that meets all the features described above. This paper proposes an asymmetric stripline coupler with a smoother coupling

coefficient and lower insertion loss. Its coupling coefficient is below -18 dB and this feature presents the advantage of eliminating the attenuator at the coupling port when sampling in high power applications is required. Augmenting the number of coupling sections increases the frequency bandwidth [10].

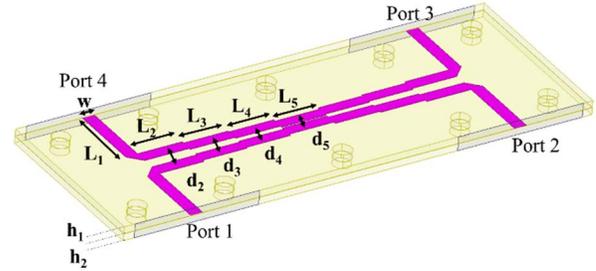


Fig. 1. Geometry and parameters of the stripline directional coupler. The actual values of the dimensions are given in Table 1.

TABLE I. PHYSICAL DIMENSIONS OF THE COUPLER

Parameter	L_1	L_2	L_3	L_4	L_5
Dimension (mm)	8	5.22	5.24	5.22	5.23
Parameter	d_2	d_3	d_4	d_5	w
Dimension (mm)	1.35	0.95	0.64	0.2	2.81
Parameter	h_1	h_2			
Dimension (mm)	0.787	0.787			

The design solution is based on applying seven asymmetric sections to obtain wider frequency bandwidth. The optimum parameter values are obtained by using genetic algorithm with Matlab and then all parameters are optimized again with HFSS simulation software by using the particle swarm algorithm to achieve better results in a full-wave simulation.

II. COUPLER DESIGN

The proposed stripline coupler consists of two stacked Rogers 5880 substrates ($\epsilon_r = 2.1$ and $\tan \delta = 0.0002$) as illustrated in Fig. 1. We choose 7 sections to obtain minimum possible coupling and through ripples. It is interesting to mention that when the number of the sections increases, the coupling and insertion loss has less ripple but the through passes loss increases. So, there is a trade-off between the ripple values and the coupler losses. The minimum section number to obtain at least 1 dB coupling ripple is seven when all the sections have the same length [11]. However, the transmission line model proposed in [8] cannot be applied to model the coupler responses only because for example the microstrip line fringing fields are not considered. Moreover, the mutual coupling among the coupler sections and the frequency resonance due to the metal box used to cover the substrates increases the coupling and through ripples. So, using a full-wave simulation and an optimization method is inevitable. We used two optimization steps to find the best parameters values for the coupler. In the first step, a goal function for coupling coefficient in the whole frequency bandwidth as given in [8] is defined;

$$\begin{aligned} \text{Goal function} &= \left| \frac{V_3}{V_1} \right| & (1) \\ &= 2 \sin \theta e^{-j\theta} [C_1 (1 \\ &\quad + e^{-2j(N-1)\theta}) + \\ &\quad C_2 (e^{-2j\theta} + e^{-2j(N-2)\theta}) + \dots + C_M e^{-j(N-1)\theta}] \end{aligned}$$

$$M = (N+1)/2 \quad N = \text{number of sections} \quad (2)$$

$$C_0 = \left| \frac{V_3}{V_1} \right|_{\theta=\pi/2} \quad (3)$$

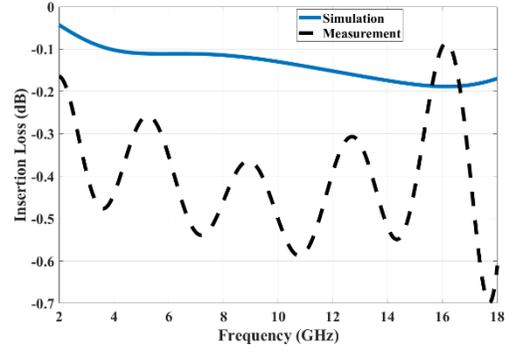
$$Z_{0e}^n = \sqrt{\frac{1-C_n}{1+C_n}} \quad (4)$$

$$Z_{0o}^n = \sqrt{\frac{1+C_n}{1-C_n}} \quad (5)$$

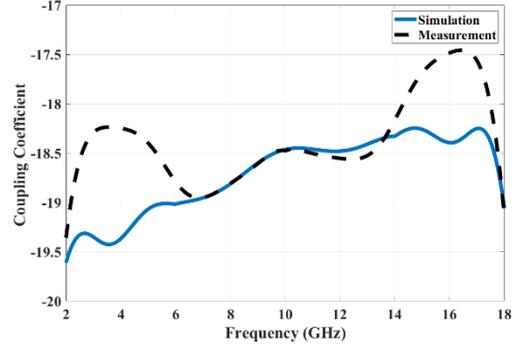
where θ is the electrical length of each section, C_n is the coupling coefficient of each section and Z_{0e}^n, Z_{0o}^n are even characteristic impedances of even and odd modes for each section.

The unknown variables of the goal function are C_1, C_2, C_3, C_4 and θ and by using a genetic algorithm with Matlab, these unknown variables are calculated to achieve minimum variations in goal function for the whole frequency bandwidth. Then, from (4) and (5) odd and even characteristic impedances are obtained. The parameters d_2, d_3, d_4 and d_5 can be obtained based on the $Z_{0e,o}^n$ values, which are computed using a

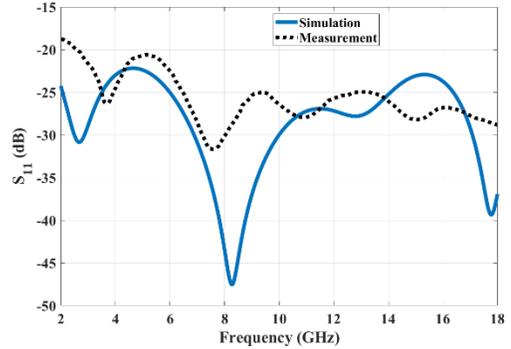
commercial microwave CAD package [8]. In the next step, the metal box with screws and four coaxial connectors are added into the model. Then, full-wave simulation with HFSS software by using particle swarm optimization improves the ripple of the coupling and insertion loss coefficients.



(a)



(b)



(c)

Fig. 2. Measured and Simulated results of (a) Insertion Loss; (b) Coupling Coefficient; and, (c) Return Loss of the coupler.

III. FABRICATION AND MEASUREMENT

The UWB stripline coupler was designed and fabricated according to the optimized dimensions reported in Table I, and it is shown in Fig. 4. As shown in the figure 4, the coupler is accommodated in an aluminum box and tied up by 10 screws to remove the air between the stacked substrates. The loose attachment between the substrates creates loss and ripple on the coupler responses at high frequencies (more than 13 GHz)

because the air destructs substrates homogeneity, which leads to an electromagnetic discontinuity.

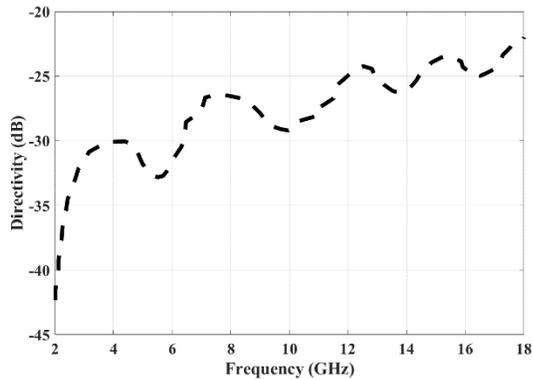


Fig. 3. Measured directivity



Fig. 4. Photo of the the coupler

Scattering parameters were measured to verify the design with a HP8722D network analyzer, where the measurement results are given in Fig. 2. The measured directivity is shown in Fig. 3 and it satisfies the design goal by exceeding the minimum requirement of 25 dB. There is an excellent agreement between the measured and the simulation results obtained with HFSS. The differences between simulation and measurements may be due to mechanical tolerances and the SMA connectors used, which are low loss connectors.

IV. CONCLUSION

A new UWB stripline coupler has been proposed. The coupler operates from 2 GHz to 18 GHz and the VSWR of each port is under 1.2 and the minimum directivity is 25 dB with a coupling coefficient of about -18.5 dB. To reduce the insertion loss and the coupling coefficient ripples, two optimization methods are used. This structure has been fabricated and an excellent agreement between measured and simulated results are achieved. In principle, this design approach is applicable to other frequency ranges, however, one should bear in mind that above 30 GHz mechanical fabrication tolerances are very challenging.

REFERENCES

- [1] O. Manoochehri, A. Emadeddin, A. Darvazehban and D. Erricolo, "A new method for designing high efficiency multi feed multi beam reflector antennas," *2017 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Verona, 2017, pp. 551-554.
- [2] A. Emadeddin, M. A. Salari, M. Zoghi, A. Darvazehban and O. Manoochehri, "A Compact Ultra-Wideband Multibeam Antenna System," in *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 1, pp. 125-131, Jan. 2018.
- [3] O. Manoochehri, A. Darvazehban, M. A. Salari, S. Khaledian, D. Erricolo, and B. Smida, "A dual-polarized biconical antenna for direction finding applications from 2 to 18 GHz," *Microwave and Optical Technology Letters*, vol. 60, no. 6, pp. 1552-1558, 2018.
- [4] A. Darvazehban, S. Khaledian, O. Manoochehri, and M. A. Salari, "Design of a high-gain omni directional microstrip dipole array with low side lobe level in the elevation plane," *Microwave and Optical Technology Letters*, vol. 60, no. 3, pp. 709-713, 201.
- [5] A. Darvazehban, A. Emadeddin, O. Manoochehri and D. Erricolo, "Wide band multi-beam cylindrical lens," *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, San Diego, CA, 2017, pp. 507-508.
- [6] A. Darvazehban, O. Manoochehri, M. A. Salari, A. Emadeddin, D. Erricolo, "A Parallel Plate Ultra-Wideband Multibeam Microwave Lens Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 66, no. 9, pp. 4878 - 4883, Sep. 2018.
- [7] D. Roddy, *Satellite Communications, (Professional Engineering)*: McGraw-Hill Professional: New York, 2006.
- [8] D. M. Pozar, *Microwave and RF design of wireless systems*: Wiley New York, 2001.
- [9] O. Manoochehri, A. Darvazehban and D. Erricolo, "UWB Double Ridge Waveguide Coupler with Low-Loss," *Microwave and Optical Technology Letters*, Vol.59, No. 8, Aug. 2017, pp. 1787-1791.
- [10] Y. Lyu, L. Zhu and C. Cheng, "Design and Analysis of Schiffman Phase Shifter Under Operation of its Second Phase Period," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 66, no. 7, pp. 3263-3269, July 2018.
- [11] S. M. Mousavi, S. A. Mirtaheri, M. A. Khosravani-Moghaddam, B. Habibi and J. S. Meiguni, "Design, fabrication and test of a broadband high directivity directional coupler," *2015 23rd Iranian Conference on Electrical Engineering*, Tehran, 2015, pp. 168-170.