Wideband Marchand Balun and Bow-tie Antenna for Sensor Aplications

Ilona Piekarz, Jakub Sorocki, Krzysztof Wincza and Slawomir Gruszczynski
AGH University of Science and Technology
Mickiewicza 30 Av., 30-059 Cracow, Poland
ilona.piekarz@agh.edu.pl

***Abstract*—A novel wideband Marchand balun and bow-tie antenna have been proposed for sensor application. The proposed balun has been designed to differentially fed bow-tie antenna and match its differential impedance. The proposed approach has been investigated and verified by electromagnetic calculations and measurements of an exemplary Marchand balun and bow-tie antenna operating at center frequency f_0 = 1 GHz. The obtained simulation and measurement results prove the usefulness of the proposed approach for utilization as sensor for healthcare application.**

Keywords—Marchand balun; differential feed; bow-tie antenna; sensor application

I. Introduction

Medical diagnosis with the use of microwaves presents a promising approach for identification of diseases such as breast cancer due to the high sensitivity for the change of tissue permittivity, since tissues affected by disease exhibit other dielectric properties than healthy ones [1]-[3]. However, in case of microwave medical diagnosis, there is a high signal attenuation caused by weak reflection from tumor. Therefore, in order to improve the reflection from the sick affected tissues, obtaining more radiation penetration into human body is required. Due to this fact, performance of the utilized antennas has the significant impact on the performance of the entire measurement system. In literature, several types of antennas have been described for sensor applications [4]-[7]. For reason of ease and cost of production, low weight antennas printed on laminates are generally preferred. Among variety of planar antennas, symmetrical structure and differential feeding technique ensure stable beam direction and good radiation characteristic and therefore are the best solution for utilization in sensor application.

Single-ended to differential signal conversion and vice versa circuits (baluns) are, among other microwave components, used for many applications such as phase shifters, amplifiers and antenna feed networks [8]-[10]. In literature, many types of baluns are described [11]-[13], however Marchand type balun [14]-[15] is one of the most popular due to its simplicity and wideband performance. The planar version of Marchand balun consists of two identical coupled-line sections having electrical length equals 90º at the center frequency f_0.

This work has been supported by the Polish Ministry of Science and Higher Education under grant no. 0232/DIA/2013/42.

In this paper, a wideband Marchand balun fed bowtie antenna has been proposed for sensor application. The balun and the antenna have been designed in the same dielectric structure for further integration of both circuits. Multilayer microstrip dielectric structure has been used for the design, since it allows for achieving tight coupling of the coupled lines constituting Marchan type balun what ensures its wideband performance. Moreover, the balun utilizes multi-technique compensation [16]-[18] in order to further improve the circuit performance i.e. input match and output balance. The proposed approach has been verified by the design and measurements of Marchand balun operating at f_0 = 1 GHz. Moreover, the designed balun has been used to differentially fed bow-tie antenna allowing for utilization as microwave sensor in biomedical applications. The antenna operates at f_0 = 1 GHz, since lower frequencies allow for high penetration into human body. The entire circuit has been electromagnetically (EM) calculated and the obtained results proved the usefulness of the proposed structure.

II. Wideband Marchand Balun Design

In ideal case, when Marchand balun is composed of ideal coupled-line sections, the circuit features equal power division and 180º phase difference between balanced ports. However, the realization of the balun in microstrip dielectric structure deteriorates circuit performance, since capacitive and inductive coupling coefficients of the coupled-line sections composing balun are not equal [16]. Additionally, the realization of the balun forces the use of connecting line segment between coupled-line sections to physically separate differential ports what also have a negative influence on circuit performance [17]. Therefore, multi-technique compensation [18] need to be applied in order to improve the input match and output balance of Marchand balun.

The dielectric structure selected for the design of a wideband balun is presented in Fig. 1. The circuit converts (see Fig. 2) unbalanced port #1 impedance Z_1 = 50 Ω to differential port #2 and #3 impedance $Z_{2,3}$ = 132 Ω (differential impedance Z_{diff} = 264 Ω). Even and odd mode impedance of the coupled-line sections composing balun have been calculated as presented in [17]. Initial dimensions of the physically realized coupled-line sections have been chosen with the use of *Linpar* software [19] to be: strips width w_1 = 0.2 mm, w_2 = 0.16 mm and offset between strips o = 0.01 mm. Next, compensation technique presented in [16] can be applied, i.e. appropriate compensating elements required to equalize the capacitive and inductive coupling coefficients are added. Following, connecting line has been added to physically separate ports #2 and #3, resulting in circuit performance deterioration. Negative influence can be compensated following an approach proposed in [17]. In the presented design, both compensation techniques have been combined and utilized, in the way presented in [18], which reduces the required number of compensating elements. The final layout of a wideband, performance enhanced balun has been presented in Fig. 2. As it can be seen, the required mutual capacitance has been realized by decreasing the offset between coupled lines, whereas the self-capacitance has been realized by adding metallization pads to one line. Series inductance required to compensate the circuit has been realized by narrowing one of the coupled lines.

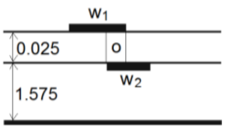

Fig. 1. Cross-sectional view of the multi-layer microstrip dielectric structure – dielectric height given in mm. Permittivity of both layers equals 3.38.

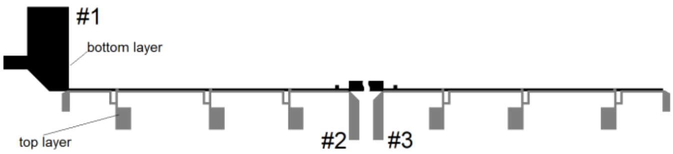

Fig. 2. Final layout of the designed balun. Compensation elements are visible.

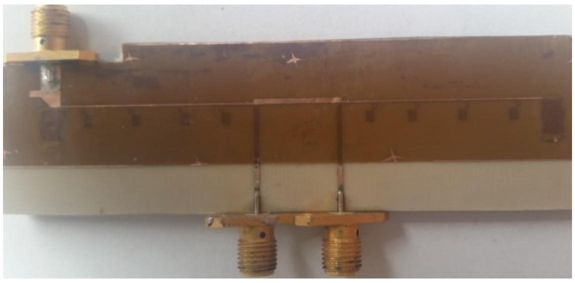

Fig. 3. Photograph of the manufactured balun.

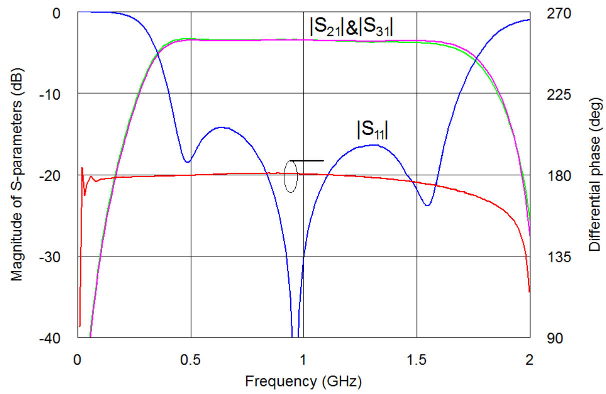

Fig. 4. Measured frequency characteristics of the designed balun.

The designed wideband balun has been manufactured and measured. Photograph of the manufactured circuit is presented in Fig. 3, whereas the measurement results are presented in Fig. 4. The measured bandwidth for reflection coefficient not worse than -14 dB equals f_{upper}/f_{lower} = 3.8. The amplitude imbalance is equal 0.03 dB at f_0 and within the bandwidth is lower than 0.8 dB whereas the output differential phase error is equal 0.2° at f_0 and does not exceed 6° within the bandwidth. As seen, the obtained measurement results prove the usefulness of the proposed balun.

III. Bow-tie Antenna Design

The bow-tie antenna is to be connected with wideband Marchand balun operating at f_0 = 1 GHz. Such band of operation has been chosen, since lower frequencies allow for high penetration into human body. For ease of integration of radiating element and feeding balun, the proposed antenna has been designed in the same dielectric structure as balun with metallization on layer w_1. Layout of the designed radiating element has been shown in Fig. 5 while its dimensions are listed in Table 1.

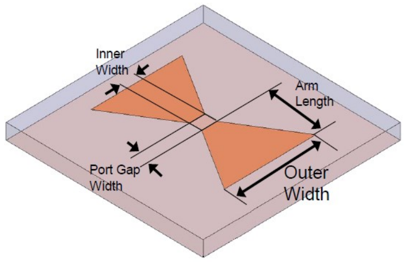

Fig. 5 Layout of the designed bow-tie antenna.

TABLE I. Bow-tie antenna dimensions

	Dimensions [mm]
Inner width	3.55
Port gap width	10
Outer width	107
Arm length	100

The proposed antenna has been electromagnetically calculated with the use of ANSYS HFSS software. Results of EM simulation with ideal feeding (return loss and far field radiation pattern) have been shown in Fig. 6 and Fig. 7, respectively. As it can be seen, the designed structure features wide operational bandwidth.

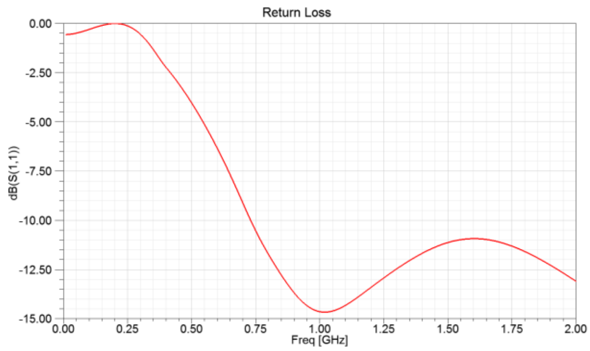

Fig. 6. EM calculated reflection coefficient of the designed bow-tie antenna with ideal feed.

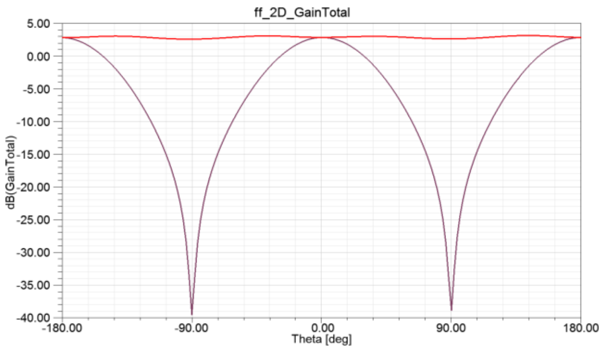

Fig. 7. EM calculated gain of the designed bow-tie antenna for different cross-sections: red line – $\Phi = 0°$, violet line – $\Phi = 90$ deg.

Moreover, the entire proposed antenna system composed of bow-tie antenna and Marchand balun has been electromagnetically verified and the calculated reflection coefficient at single-ended input has been presented in Fig. 8. As it can be seen the utilization of Marchand balun featuring wide operational bandwidth provides proper antenna feeding with simultaneous differential to single-ended signal conversion for further single analysis/excitation within very vide operational bandwidth of the antenna. The obtained results prove the usefulness of the proposed structure for sensor application.

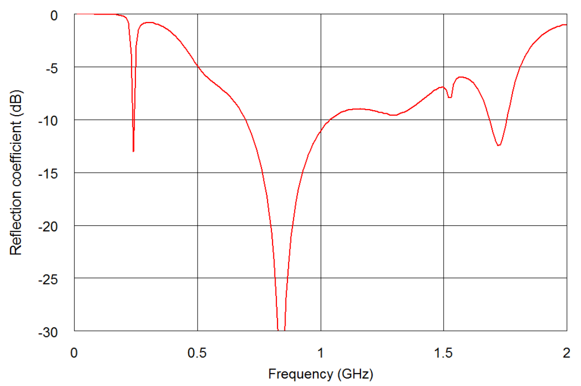

Fig. 6. Calculated reflection coefficient of the designed differentially feed bowtie antenna system.

IV. Conclusion

Wideband Marchand balun feeding bow-tie antenna has been presented. Circuit utilizes multi-technique compensation to improve balun performance. The proposed approach has been verified by the design and measurements of Marchand balun realized in multilayer microstrip dielectric structure, operating at f_0 = 1 GHz and by EM calculations of the balun integrated with bow-tie antenna. The obtained results prove the proposed structure to be suitable for sensor applications.

References

[1] X. Li, E. J. Bond, B. D. Van Veen, and S. C. Hagness, "An overview of ultra-wideband microwave imaging via space-time beamforming for early-stage breast-cancer detection," *IEEE Antennas Propag. Mag.*, vol. 47, no. 1, pp. 19–34, Feb. 2005.

[2] R. E. C. Fear, X. Li, S. C. Hagness, and M. A. Stuchly, "Confocal microwave imaging for breast cancer detection: Localization of tumors in three dimensions," *IEEE Trans. Biomed. Eng.*, vol. 49, no. 8, pp. 812–822, Aug. 2002.

[3] M. Klemm, I. J. Craddock, J. A. Leendertz, A. Preece, and R. Benjamin, "Radar-based breast cancer detection using a hemispherical antenna array- experimental results," *IEEE Trans. Antennas Propag.*, vol. 57, no. 6, pp. 1692–1704, Jun. 2009.

[4] R. Nilavalan, I. J. Craddock, A. Preece, J. Leendertz, and R. Benjamin, "Wideband microstrip patch antenna design for breast cancer tumour detection," *IET Antennas Propag. Microwaves*, vol. 1, no. 2, pp. 277–281, Apr. 2007

[5] D. Gibbins, M. Klemm, I. Craddock, A. Preece, J. Leendertz, and R. Benjamin, "Design of a UWB wide-slot antenna and a hemispherical array for breast imaging," in *Eur. Conf. Antennas Propag.* (EuCAP), Berlin, Germany, Mar. 2009, pp. 2967–2970.

[6] U. Schwarz, M. Helbig, J. Sachs, R. Stephan, and M. A. Hein, "Design and application of dielectrically scaled double-ridged horn antennas for biomedical UWB radar applications," in *Proc. IEEE Int. Conf. UltraWideband* (ICUWB), Vancouver, BC, Canada, Sep. 2009, pp. 150–154.

[7] X. Li, M. Jalivand, Y. Sit, and T. Zwick, "A compact double-layer on-body matched bowtie antenna for medical diagnostics," *IEEE Trans. Antennas Propag.*, vol. 62, no. 4, pp. 1808–1816, Apr. 2014.

[8] T. H. Chen, K. W. Chang, S. B. Bui, H. Wang, G. S. Dow, L. C. T. Liu, T. S. Lin, and W. S. Titus, "Broadband monolithic passive baluns and monolithic double balanced mixer," *IEEE Trans. Microwave Theory. Tech.*, vol. 39, pp. 1980 –1986, 1991.

[9] P. C. Hsu, C. Nguyen, and M. Kintis, "Uniplanar broadband push-pull FET amplifier," *IEEE Trans. Microwave Theory. Tech.*, vol. 45, pp. 2150 –2152, 1997.

[10] B. A. Munk, Balun, J. D. Kraus and R. J. Marhefka (Eds.), *Antennas for all applications*, 3rd ed., McGrawHill, New York, 2002, ch. 23

[11] B. J. Minnis and M. Healy, "New broadband balun structures for monolithic microwave integrated circuits," in *IEEE MTT-S Int. Microw. Symp. Dig.*, Jun. 1991, pp. 425–428

[12] A. M. Pavio and A. Kikel, "A monolithic or hybrid broad-band compensated balun," in *IEEE MTT-S Int. Microw. Symp. Dig.*, May 1990, pp. 483–486.

[13] D. Kuylenstierna and P. Linner, "Design of broad-band lumped-element baluns with inherent impedance transformation," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 12, pp. 2739–2745, Dec. 2004.

[14] N. Marchand, "Transmission line conversion transformers," *Electron.*, vol. 17, no. 12, pp. 142–145, Dec. 1944.

[15] K. S. Ang, Y. C. Leong, and C. H. Lee, "Analysis and design of miniaturized lumped-distributed impedance-transforming baluns," *IEEE Trans. Microw. Theory Tech.*, vol. 51, no. 3, pp. 1009–1017, Mar. 2003.

[16] S. Gruszczynski and K. Wincza, "Generalized methods for the design of quasi-ideal symmetric and asymmetric coupled–line sections and directional couplers," *IEEE Trans. Microw. Theory Tech.*, vol. 59, no. 7, pp. 1709–1718, Jul. 2011.

[17] I. Piekarz, J. Sorocki, S. Gruszczynski, K. Wincza, „Input match and output balance improvement of Marchand balun with connecting line," *IEEE Microw. Wireless Compon. Lett.*, vol. 24, no. 10, Oct. 2014.

[18] I. Piekarz, J. Sorocki, I. Slomian, K. Staszek, K. Wincza, S. Gruszczynski, "Marchand balun with connecting segment designed with the use of multi-technique compensation," *14th Mediterranean Microwave Symposium (MMS) 2014,* Dec 2014

[19] A. Djordievic et al., *Matrix Parameters for Multiconductor Transmission Lines, Software and User's Manual,* Norwood, MA: Artech House, 1990.