Int. J. Electron. Commun. (AEÜ) 69 (2015) 851–855

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Compact Marchand balun circuit for UWB application

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ARTICLE INFO

Article history:
Received 10 December 2014
Accepted 10 February 2015

Keywords:
Marchand balun circuit
Balun circuit
Multilayer technology
UWB application
Double layer substrate

ABSTRACT

This article presents the development of a miniaturized differential coupler for UWB application using the Marchand balun circuit in multilayer technology. The new technique employs double layer substrate where on the bottom layer the two $\lambda/4$ short-circuited stubs with balanced outputs are developed and on the top layer the $\lambda/2$ open-circuited stub for unbalanced input is etched. These three transmission lines of the Marchand balun circuit are capacitively coupled using overlapping microstrip lines. To demonstrate this technique, a Marchand balun circuit using multilayer technology is designed, simulated, fabricated and measured. The circuit size is about 2.8 mm × 3.7 mm × 0.63 mm excluding the feeding ports. The results from the simulation and measurement show good agreement.

1. Introduction

Balance–unbalanced (BALUN) passive circuits can be defined as a transformer which converts a single ended signal to a differential signal and vice versa. Based on their fundamentally balanced characteristics, these circuits are capable of reducing the radiation to and from the system. In addition, rejecting the even harmonics caused by the dynamic range of the microwave circuits. Therefore, the BALUN circuits have been widely used in microwave circuits and modules which included power amplifier (PA), phase shifters, and -balanced filters for balanced input and output purpose. Several balun circuits have been deeply explained and analyzed for low and high-speed RF application. One of the most commonly used is the Marchand balun circuit, where various types of it were studied and fabricated. The published one in [1] and [2] were used to enhance a wideband passband coupler. A design of a three-section microstrip-slot coupler aimed for operation in the UWB passband limits has also been reported in [3]. Based on a composite right/left-handed (CRHL), a super compact UWB balun is introduced in [4]. Using broadside coupled microstrip lines, [5] proposed the development and fabrication techniques of ultra-wideband baluns in multilayer liquid crystal polymer flex (LCP). Coplanar waveguide and coplanar stripline structures have also been reported in [6]. In [7], a miniaturized circuit was investigated on a multilayer structure. Advanced technologies such as laminated multi-chip modules and low-temperature co-fired ceramics (LTCC) offer services for implementing compact high-density RF multilayer devices [8–10]. Recently, [10] proposed a balun and power divider based on multilayer ring resonator (MRR) realized in LTCC technology. However, the baluns resulting have either complicated design or large size not practical for low cost small UWB wireless communication systems.

In this work, a technique for a significant miniaturization UWB balun circuit using the Marchand balun circuit in multilayer technology is proposed. The basic structure of the proposed Marchand balun circuit is explained first. Then, a UWB design example using single layer is investigated. After that, this example is developed and fabricated using multilayer technology. The results from the simulation and the measurement are also compared and discussed.

2. UWB Marchand balun circuit

2.1. The basic structure of Marchand balun circuit

Fig. 1 shows the basic configuration of the traditional Marchand balun circuit [11]. The Marchand balun consists of three transmission lines patterned as three port network. One port is connected to $\lambda/2$ open-circuited stub and two ports are connected to $\lambda/4$ short-circuit stubs. The transmission lines can be realized as two $\lambda/4$ coupled lines at the center frequency of a specified bandwidth.

The coupling coefficient (k) between the coupled lines is the most important because the realized bandwidth and the insertion loss are dependent on the coupling coefficient. From the principles, a coupling coefficient can be related to the band edge frequencies of the required bandwidth [12], as well it can be defined in terms of even-mode and odd-mode impedances of the coupled line [13]:

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \quad (1)$$

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http://dx.doi.org/10.1016/j.aeue.2015.02.005
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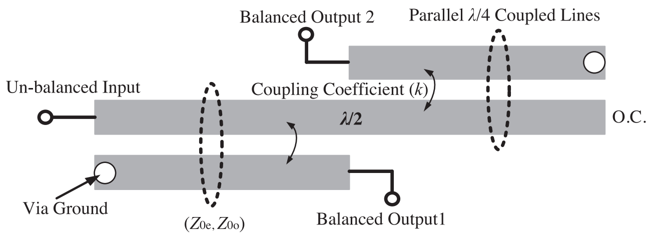

Fig. 1. Conventional Marchand balun structure.

$$k = \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}} \tag{2}$$

where the even-mode and odd-mode characteristic impedances can be given as

$$Z_{0e} = Z_0 \sqrt{\frac{1+k}{1-k}} \tag{3}$$

$$Z_{0o} = Z_0 \sqrt{\frac{1-k}{1+k}} \tag{4}$$

where Z_0, Z_{0e}, and Z_{0o} represent the 50 Ω input/output characteristic impedance, the even-mode impedance, and the odd-mode impedance of the coupled line respectively.

In theory, a single layer Marchand balun circuit can be used to realize UWB bandwidth performance but, in this case the strip width and the coupling gap of the coupled lines have to be reduced to obtain high even-mode impedance and low odd-mode impedance for the coupled lines. This will be lead to a strong coupling and hence high bandwidth for UWB application. For a further illustration, the above observation is studied with the following design example.

In order to design UWB Marchand balun circuit, the band edges frequencies of the UWB bandwidth are considered with f_1 = 3.1 GHz and f_2 = 10.6 GHz. Once the band edge frequencies are specified, the required coupling coefficient k = 0.84 is calculated using Eq. (1). From Eqs. (3) and (4), the even-mod and odd-mod impedances are calculated and found to be Z_{0e} = 169.55 Ω and Z_{0o} = 14.74 Ω respectively. Using the above information and by the aid of the momentum in ADS software [14], the circuit was simulated with parallel coupled lines having physical dimensions ℓ_1 = 4.55 mm, w = 0.039 mm, and coupling gap g_c = 0.0017 mm. The circuit was designed using a grounded substrate Rogers Ceramic TMM10I (ε_r = 9.8) having thickness h = 0.381 mm. As shown in Fig. 2(a), the balun can offer an insertion loss of about −3 dB balance outputs over a wide passband ranging from 2.95 GHz to 11.17 GHz and a return loss better than 10 dB. The phase difference, between the two balance outputs is 180° across the concerned bandwidth, as illustrated in Fig. 2(b). Practically, however, the circuit dimensions are not realisable using standard photolithograph unless special technique is used for fabrication process.

2.2. Multilayered UWB Marchand balun circuit

In the previous section, it is shown that the practical UWB balun circuit cannot be realized with single layer because of the coupling strength limitation which is required to achieve enhanced bandwidth. To overcome this problem, the three transmission lines of the microstrip Marchand balun circuit are realized in a double layer structure, Fig. 3. The two λ/4 short-circuited stubs with balanced outputs are patterned on the bottom layer and the λ/2 open-circuited stub with unbalanced input is patterned on a second layer. The strength of the coupling coefficient between the broadside coupled lines can be controlled and adjusted through the thickness of the second dielectric layer, Fig. 3.

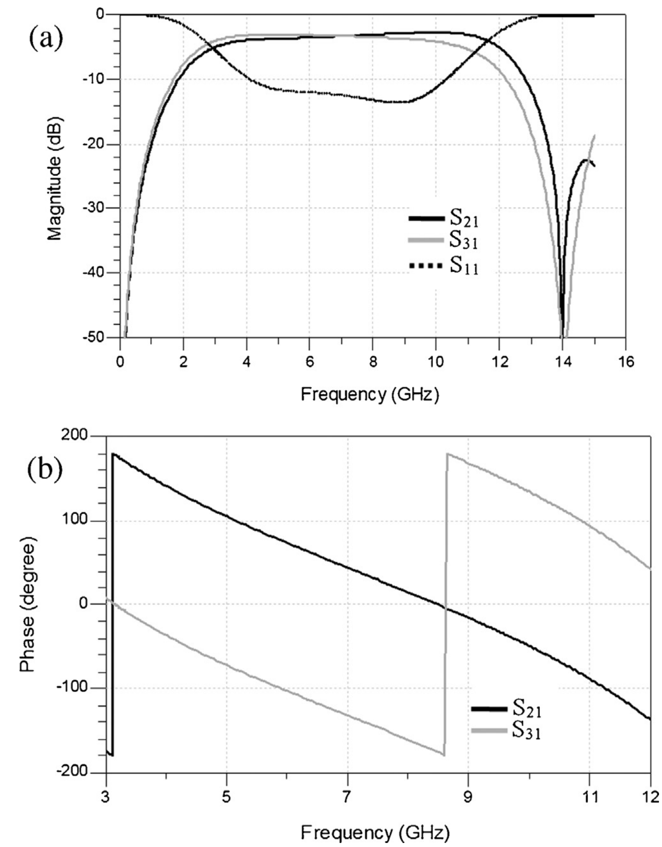

Fig. 2. (a) Insertion and return losses from simulation for the microstrip Marchand balun circuit in Fig. 1 and (b) phase difference between the balanced outputs.

To demonstrate the above observation in practice, the two balanced outputs are designed with two λ/4 short-circuited stubs having layout dimensions ℓ_1 = 4.08 mm, $w_1 = w_3$ = 0.44 mm, and 50 Ω balanced output ports of w_{p1} = 0.37 mm fabricated on a grounded substrate Rogers Ceramic TMM10I (ε_{r1} = 9.8) having thickness h_1 = 0.381 mm. The un-balanced input λ/2 open-circuited stub etched on the second layer has a width of $w_2 = w_4$ = 0.44 mm and length of ℓ_2 = 8.56 mm obtained at the center frequency 6.85 GHz of the operation bandwidth and connected to 50 Ω imbalanced input port width of w_{p2} = 0.6 mm. The top dielectric layer is defined by h_2 = 0.254 mm thick Rogers RT Duriod 6010LM (ε_{r2} = 10.2). In the circuit structure, Fig. 3, the un-balanced input λ/2 open-circuited stub is configured as a hairpin resonator shape and the broadside coupled length is ℓ_{bc} = 3.78 mm. The proposed balun

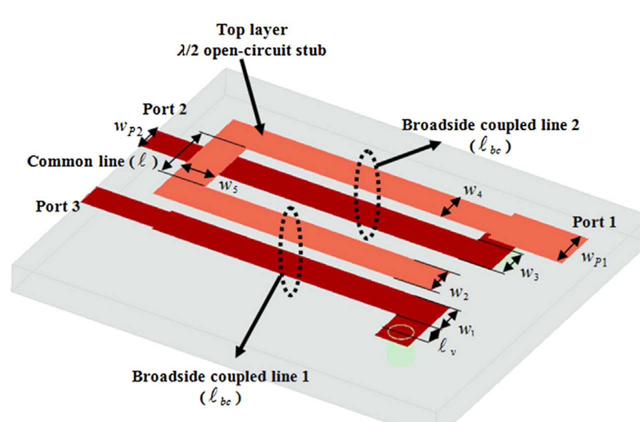

Fig. 3. Conductor layout of a broadside coupled Marchand balun circuit.

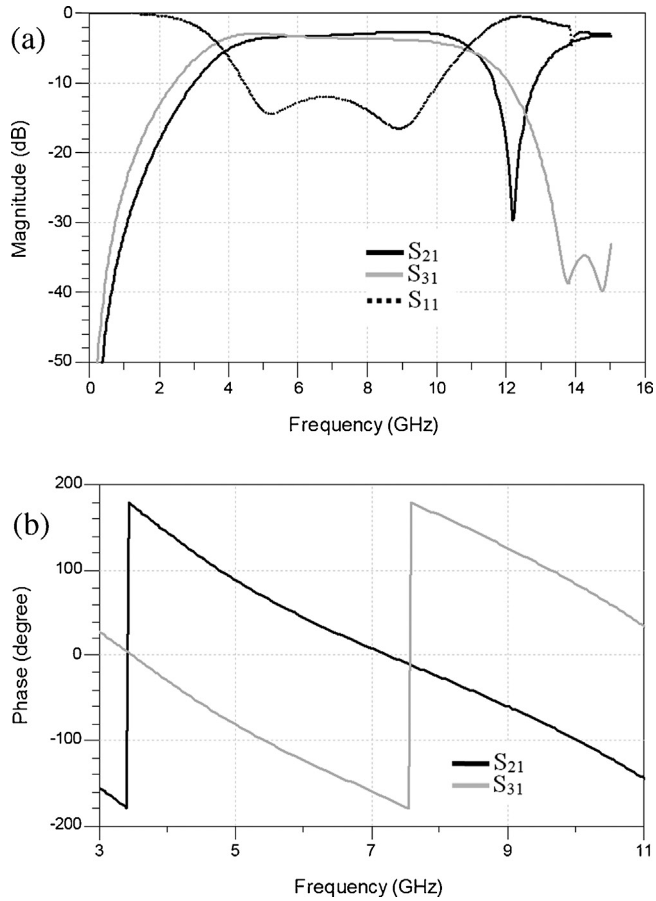

Fig. 4. (a) The insertion and return losses from simulation for the broadside coupled lines Marchand balun circuit, Fig. 3 and (b) phase difference between the balanced outputs.

circuit, Fig. 3, is simulated using the momentum in ADS software [14], and its results are plotted in Fig. 4. From Fig. 4(a), the return loss is found to be better than −12 dB over the frequency band from 4.3 GHz to 10 GHz. Also, it is clear that there is small imbalance in the amplitude of the output signals, i.e. port2 and port3, around the center frequency and gradually increased over a wide frequency range. The phase-difference, Fig. 4(b), between the balanced output ports shows that the output signals have out of phase close to 180° over the whole UWB bandwidth (3.1–10.6 GHz). The size of the balun in this case is 2.92 mm × 3.78 mm × 0.635 mm excluding the feeding ports.

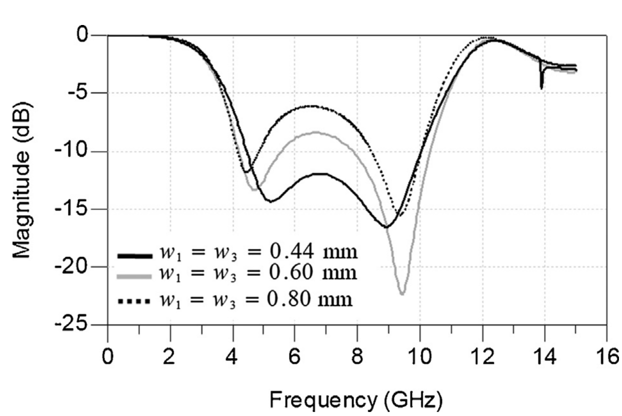

Fig. 5. Simulated return loss of broadside Marchand balun circuit, Fig. 3, in which the width of the bottom broadside coupled lines, w_1 and w_3, are varied.

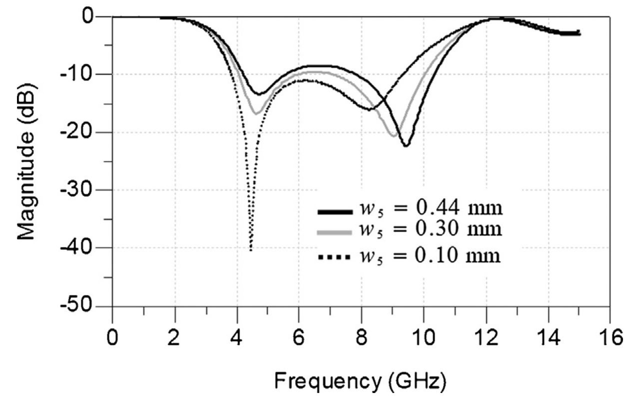

Fig. 6. Simulated return loss of broadside Marchand balun circuit, Fig. 3, in which the width of the top common line, w_5, is varied. In this case w_1 and w_3 are fixed at 0.60 mm.

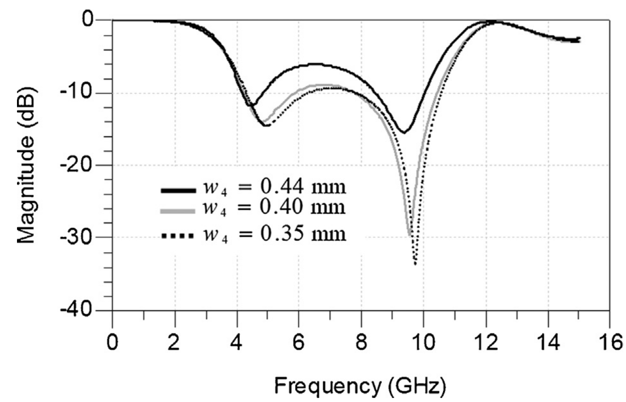

Fig. 7. Simulated return loss of broadside Marchand balun circuit, Fig. 3, in which the width of the top broadside coupled lines, w_4, is varied. In this case w_1 and w_3 are fixed at 0.60 mm.

In order to find a good match leading to satisfactory return loss for practical use, the widths of the broadside coupled lines (w_1, w_2, w_3, and w_4) and the width of the common line between the two broadside coupled lines (w_5) in the top layer are varied and their effects are plotted in Figs. 5–8. Firstly, the return loss was investigated with the variation in widths of w_1 and w_3 as shown in Fig. 5. The reflection response shows that increasing w_1 and

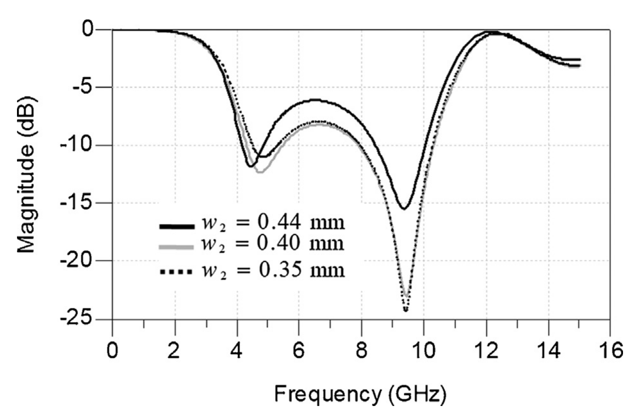

Fig. 8. Simulated return loss of broadside Marchand balun circuit, Fig. 3, in which the width of the top broadside coupled lines, w_2, is varied. In this case w_1 and w_3 are fixed at 0.60 mm.

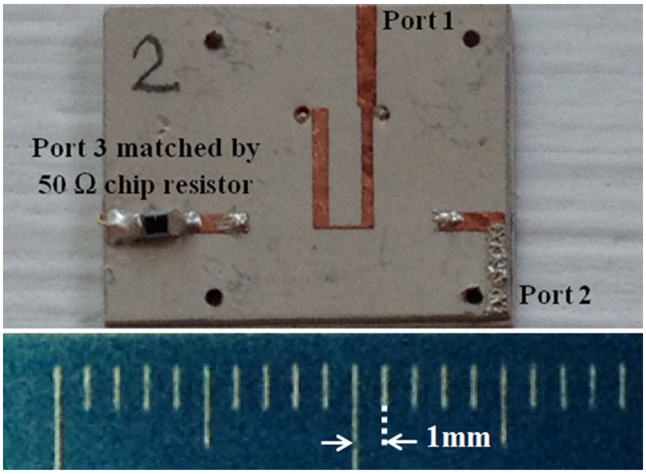

Fig. 9. Photograph of the fabricated UWB Marchand balun circuit.

w_3 leads to improvement in two transmission poles in the operation bandwidth, of course at the expense of circuit mismatch. At $w_1 = w_3 = 0.60$ mm, the reflection coefficient was studied changing w_5 as shown in Fig. 6. In this case decreasing w_5 gives rise to a deep transmission pole from the lower band edge at $w_5 = 0.10$ mm. As well as the above investigation, the physical widths w_2 and w_4 are also varied and the results are shown in Figs. 7 and 8 respectively. However, the simulated return loss for both cases shows that the reduction in width improves the circuit matching with a deep transmission pole from the upper band edge of the specified bandwidth.

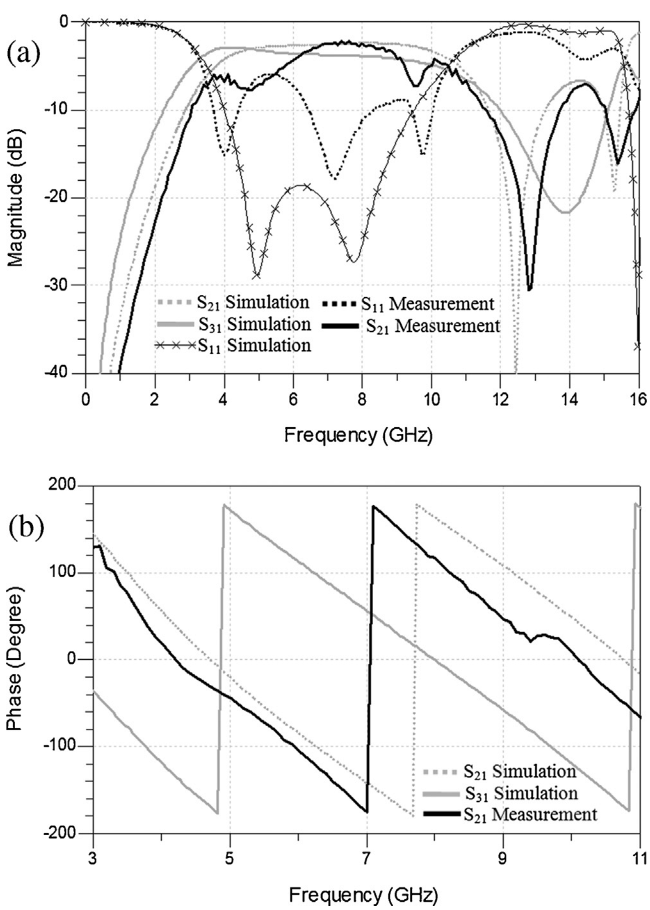

Fig. 10. (a) Insertion and return losses from simulation and measurement of the fabricated UWB Marchand balun circuit, Fig. 7 and (b) the phase difference.

3. Simulation and experimental results

From the above information, the final tuned broadside Marchand balun circuit, Fig. 3, was tested using the momentum in ADS software with $\ell_{bc} = 3.78$ mm, ℓ=1 mm, $\ell_v = 0.30$ mm, $w_1 = 0.60$ mm, $w_2 = 0.50$ mm, $w_3 = 0.80$ mm, $w_4 = 0.35$ mm, and $w_5 = 0.10$ mm, fabricated and measured using a wideband test fixture connected to a network analyzer. The responses from simulation and measurement are plotted in Fig. 10. The graph clearly indicates that the simulated return loss response is improved with two transmission poles exceeding −18 dB over the passband from 4.5 GHz to 8.5 GHz. The two circuits of the balun are photographically etched and then stacked together as one circuit, Fig. 9. Network analyzer with two ports can be used for the characterization of a balun. For the measuring purpose, port 3 was matched by 50 Ω chip resistor, Fig. 9. As shown in Fig. 10(a), the return and insertion losses from simulation and measurement are in well agreement. The phase difference, between the two balance outputs is 180° across the concerned bandwidth, as illustrated in Fig. 10(b). The circuit has overall size of 2.83 mm × 3.78 mm × 0.635 mm excluding the feeding ports.

4. Conclusion

A development of a miniaturized differential coupler for integrated UWB communication system using Marchand balun circuit was concerned. The Marchand balun circuit was developed with a double layer structure (broadside Marchand balun) in order to obtain a strong coupling coefficient which is needed for a broadband balun design. In order to achieve a good match, the physical dimensions of the broadside Marchand balun (the width of the broadside coupled lines) were investigated. Based on this study, the return loss was optimized and improved with two transmission poles over the concerned passband. Finally the proposed circuit was demonstrated with a practical measurement. The results from the simulation and measurement were in good agreement. The circuit size is very small about 2.8 mm × 3.7 mm × 0.63 mm excluding the feeding ports.

References

[1] Sun J, Chen G, Huang S, Huang C. The wideband Marchand balun transition design,. In: IEEE international symposium on antenna, propagation, & EM theory conference. 2006.
[2] Jung K, Campbell RL, Hanaway P, Andrews MF, McCuen C, Eisenstadt WR, et al. Marchand balun embedded probe. IEEE Trans Microw Theory Tech 2008;56(May (5)):1207–14.
[3] Seman N, Bialkowski M. Design and analysis of an ultrawideband three-section microstrip-slot coupler. Microw Opt Technol Lett 2009;51(August (8)):1889–92.
[4] Azuma Y, Horii Y. A super-compact wideband balun composed of multi-layered CRLH transmission line. In: Proceedings of Asia pacific microwave conference. 2009. p. 1000–3.
[5] Chen A, Chen M, Pham A. Design and fabrication of ultra-wideband baluns embedded in multilayer liquid crystal polymer flex. IEEE Trans Adv Packag 2007;30(August (3)):533–40.
[6] Yeung LK, Cheng W, Wang YE. A dual-band balun using broadside-coupled coplanar striplines. IEEE Trans Microw Theory Tech 2008;56(August (8)):1995–2000.
[7] Tzyh-Ghuang M, Yu-Ting C. A miniaturized multilayered Marchand balun using coupled artificial transmission lines. IEEE Microw Wirel Compon Lett 2009;19(July (7)):446–8.

[8] Lee B, Park D, Park S, Park M. Design of new three-line balun and its implementation using multilayer configuration. IEEE Trans Microw Theory Tech 2006;54(April (4)):1405–14.
[9] Chen Y, Lin H. Novel broadband planar balun using multiple coupled lines. In: IEEE MTT-S int. microw. symp. dig. 2006. p. 1571–4.
[10] Hashemi SK. Balun and power divider based on multilayer ring resonators. In: Proceedings of Asia pacific microwave conference. 2010. p. 1244–7.
[11] Marchand N. Transmission-line conversion. Electronics 1944;(17):142–5.
[12] Hong JS, Lancaster MJ. Microstrip filters for RF/microwave applications. New York: Wiley; 2001.
[13] Pozar DM. Microwave engineering. New York: Wiley; 1998.
[14] Advanced design system (ADS) 2008A. Palo Alto, CA: Agilent Technol.; 2008.

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