Microstrip to Parallel Strip Balun as Spiral Antenna Feed

Kalyany Vinayagamoorthy*, Jacob Coetzee†, Dhammika Jayalath‡
Queensland University of Technology
Brisbane, QLD 4000, Australia
E-mail: k.vinayagamoorthy@qut.edu.au*, jacob.coetzee@qut.edu.au†, dhammika.jayalath@qut.edu.au‡

Abstract—This paper presents the design and implementation of a microstrip to parallel strip balun which are frequently used as balanced antennas feed. This wideband balun transition is composed of a parallel strip which is connected to the spiral antenna and a microstrip line where the width of the ground plane is gradually reduced to eventually resemble the parallel strip. The taper accomplishes the mode and impedance transformation. This balun has significantly improved bandwidth characteristics. The entire circuit was fabricated on RT Duriod 5880 substrate. The circuit designs were simulated and optimised using CST Microwave Studio and the simulated results are compared with the measured results. The back-to-back microstrip to parallel strip has a return loss of better than 10 dB over a wide bandwidth from 1.75 to 15 GHz. The performance of the proposed balun was validated with the spiral antenna. The measured results were compared with the simulated results and it shows that the antenna operates well in wideband frequency range from 2.5 to 15 GHz.

Index Terms- Tapered microstrip line, parallel strip, Wideband Balun, spiral antenna, Back-to-back balun

I. INTRODUCTION

The demand for high-speed data services for portable devices has become a driving force for the development of advanced broadband access technologies. Despite recent advances in this technologies, there remain a number of critical issues to be resolved. The spiral antenna has been used extensively for broadband applications due to its planar structure, wide bandwidth characteristics and circular polarisation. However, the practical implementation of spiral antennas is challenged by its high input characteristic impedance and the need for balanced feeding structures. This paper presents a wideband balanced feeding structure for spiral antenna with matching impedance capabilities.

A baluns is a transformer used to convert the signals from an unbalanced circuit structure to a balanced configuration. In recent years, a number of wideband antennas fed by wideband baluns such as coplanar waveguide to coplanar stripline balun [1] - [2], and microstrip to coplanar stripline balun [3] - [4], have been reported. However, most balun configurations are limited in bandwidth.

This paper presents a microstrip to parallel strip balun with wideband characteristics. The geometry of the microstrip to parallel strip transition was obtained by implementing a Chebyshev taper in [5]. Another recent example for the microstrip to parallel strip balun was designed using a Hecken taper in order to minimize the return losses and to remove

the discontinuity at the end of a microstrip line in [6]. However, the profile length for both designs is large and has relatively limited in bandwidth. In this study, the balun geometry is optimised in order to be used as a feeding system for a wideband antenna. A compact and integrated design is proposed. The proposed balun is integrated with the spiral antenna to validate the practical performance as antenna feed. CST Microwave Studio was used to simulate the performance and to find the optimum parameters of the tapered microstrip line to parallel strip balun and the spiral antenna. All these designs are tested using a Vector Network Analyser.

II. MICROSTRIP TO PARALLEL STRIP BALUN

In this section, a modified planar back-to-back tapered microstrip to parallel strip balun is proposed, as shown in Fig. 1. The proposed balun consists of two sections. One section is the parallel strip which is connected to the antenna, where the impedance of the parallel strip equal to the antenna input impedance. The other section consists of a microstrip line, while the width of the ground plane is gradually reduced to eventually resemble a parallel strip. The taper accomplishes the mode and impedance transformation.
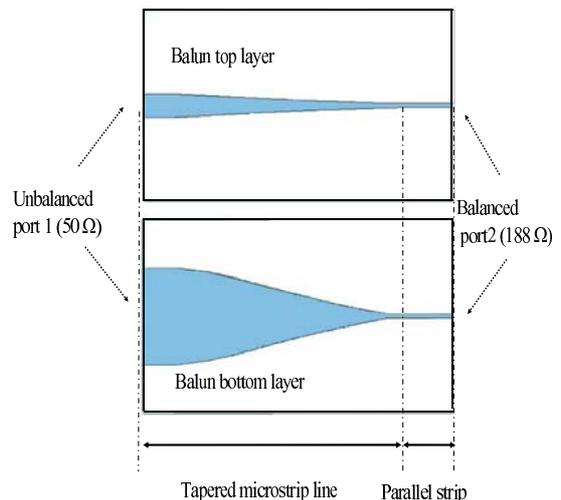
Fig. 1. A single microstrip line to parallel strip balun

The input and output impedance of the microstrip line is 50 Ω (Z_0) and 188 Ω, where the output impedance of the microstrip line is equal to parallel strip impedance (Z_L).

A typical microstrip to a parallel strip balun with a smooth transition is shown in Fig. 1. When a microstrip line is joined to a parallel strip, there is a step discontinuity between the ground plane of the microstrip line and the bottom parallel strip. Furthermore, a step discontinuity exists between the top strip conductors of these two lines. Therefore, a transmission line taper is applied to both the top and bottom conductors to achieve a good impedance match between the two lines [7].

The initial width of the microstrip line, w_1, is calculated to yield a 50 Ω characteristic impedance. The top strip width of the microstrip line is calculated using characteristic impedance equation given in [8]. The ground plane width is found using parameters sweep method with the aid of CST simulation. This procedure is repeated to achieve the parallel strip impedance of 188 Ω. For a total length of the taper, L, and the two characteristic impedances (Z_0 and Z_L) along the line, the position z along the taper can be calculated using an exponential taper equation given in [9].

Let us consider the impedance of $Z = 110$ Ω. The position z along the taper is 29.8 mm, as shown in Fig. 2(a). The dimensions of the microstrip line (w and w') for corresponding length (z) can be derived from the dimension graph given in Fig. 2(b). Table I contains the width of microstrip top and

Fig. 3. Configuration of a tapered microstrip to parallel strip with SMA connector

bottom conductors for different impedance of the transition. Once the width has been calculated, these lines are connected together as shown in Fig. 3. The relation between t_i (the length of each tapered length as shown in Fig. 3) and z_i (the position along the taper) is given in the following equation:

$$z_i = \sum_{k=1}^{i} t_k \tag{1}$$

Two single balun structures were joined at the balanced port in a back-to-back configuration to validate the balun performance (Fig. 4).To check the balun's current balance, two H-field probes were placed at the centrer of the parallel strip outputs (on top and bottom conductors).

Fig. 2. (a) The impedance profile for the balun (b) The dimensions graph for the balun
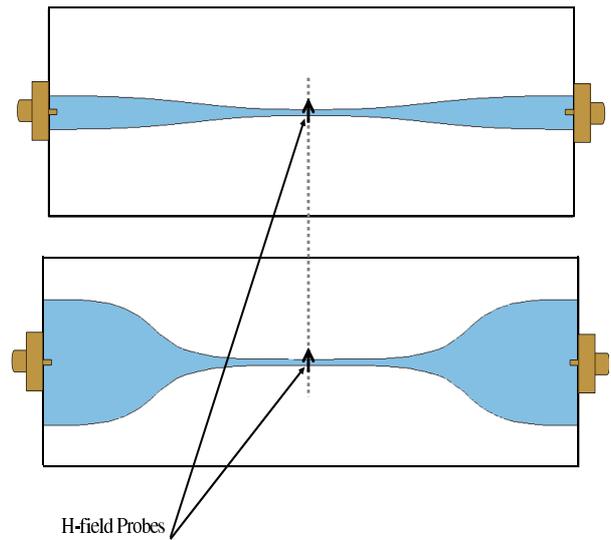
Fig. 4. Back-to-back connection of the balun with two H-field probes
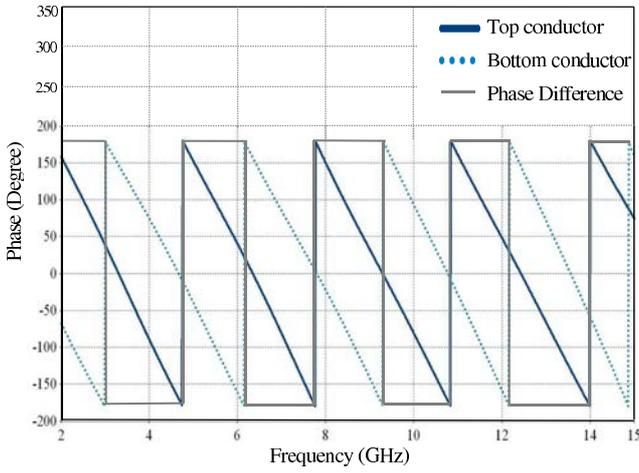
Fig. 5. Phase difference for H-field probes
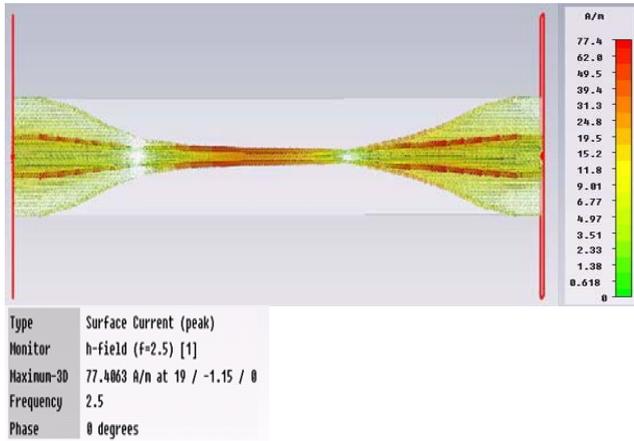
Fig. 6. Surface current distribution at 2.5 GHz of the microstrip to parallel strip balun

Fig. 5 presents that the two H-field probes have a 180° phase difference over the bandwidth (180° phase difference difference from 1.75 to 15 GHz). In addition, the common mode rejection of the balun was confirmed by inserting a long balanced section and a short balanced section in the centre. The S-parameter magnitude results for these both cases show no difference. We can therefore conclude that the balun is effective in transforming the fields to a balanced configuration.

The simulated surface current distribution of the microstrip to parallel strip balun is shown in Fig. 6. It can be seen that the distribution of current on the parallel strip are symmetrical for the frequency of 2.5 GHz. Furthermore, it shows that balun accomplishes field matching between the coaxial transmission line and the parallel strip at the frequency of 2.5 GHz.

The balun structures were constructed on the RT Duroid 5880 substrate with the dielectric constant $\epsilon_r = 2.2$ and a height $h = 1.5748$ mm. Fig. Two test samples of same profile for top strip and equal length, and different ground shapes for microstrip line are shown in Fig. 7.

The simulated results were compared with the experimental

TABLE I
THE DIMENSIONS OF THE TAPERED MICROSTRIP TO PARALLEL STRIP BALUN

z_i coordinate (mm)	w_i (mm)	w'_i (mm)	Impedance (Ω)
5	4.8	18	50
12.7	2.6	16	70
22.2	1.76	7	90
29.8	1.2	2	110
41.5	1.1	1.8	150
46.2	0.92	0.98	170
50	0.88	0.88	188
70	0.88	0.88	188

results (Fig. 7), which were obtained using a Rohde Schwarz ZVL vector analyser (frequency range: 300 kHz to 15 GHz). Good agreement between simulation and experimental results were obtained for the both balun structures. However, the measured $S11$ has some variation with the simulated results due to improper soldering, and the difficulty to align the top and bottom conductors of the balun printed on the same substrate. From the S-parameters results, structure B was selected as an optimum balun to feed the spiral antenna. This microstrip to parallel strip balun exhibits wideband performance from 1.75 to 15 GHz with an insertion loss less than 3 dB and a return loss of better than 10 dB (as shown in Fig. 7) for the back-to-back transition with a significant size reduction. Table II shows the comparison of each balun.

TABLE II
THE COMPARISON OF THE WIDEBAND BALUNS

Microstrip to Parallel strip Balun	Bandwidth (GHz)	Area (mm^2)
Chebyshev Tapered Balun in [5]	1 - 4	90 x 24
Hecken Tapered Balun in [6]	0.45 - 2	115 x 8.6
Balun 'A' (as shown in Fig. 7)	2 - 14.3	70 x 18
Balun 'B' (as shown in Fig. 7)	1.75 - 15	70 x 18

III. CONFIGURATION OF THE SPIRAL ANTENNA WITH BALUN

A self complementary two-arm circular Archimedean spiral antenna, where the spacing between adjacent arms s (0.86 mm) and width of the arms w (0.86 mm) is equal to inner radius r_1 (0.86 mm) is shown in Fig. 8. The input impedance of the antennas is 188 Ω. A microstrip to parallel strip balun was optimised to provide impedance matching between 50 Ω and 188 Ω. The spiral antenna design parameters are taken from [10], where r_2 (28.3 mm) is a outer radius of the spiral and N is a number of turns (in this case, $N = 8$). Fig. 9 shows that the spiral antenna integrated with the microstrip to parallel strip balun on RT Duroid 5880 substrate material. The overall dimension for proposed spiral antenna is 60 mm x 60 mm x 70 mm or 0.34 λ_L x 0.34 λ_L x 0.39 λ_L where λ_L is the wavelength of the spiral at the low frequency f_L of 1.69 GHz.

(a)
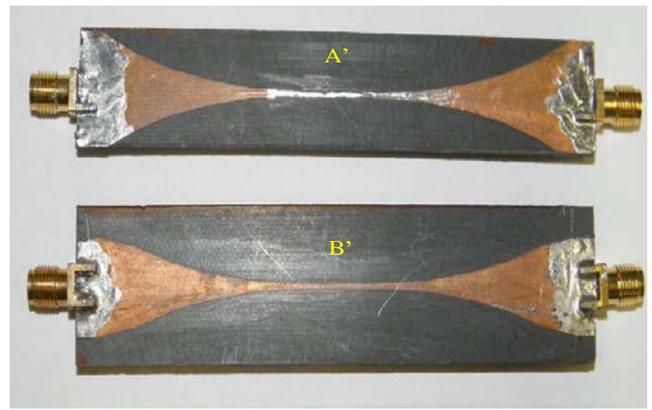
(b)
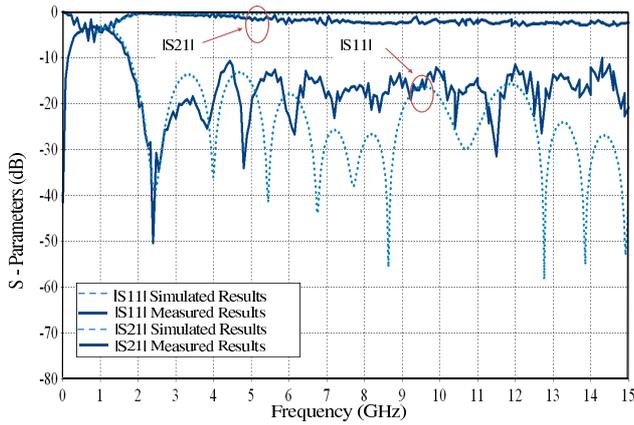
(c)
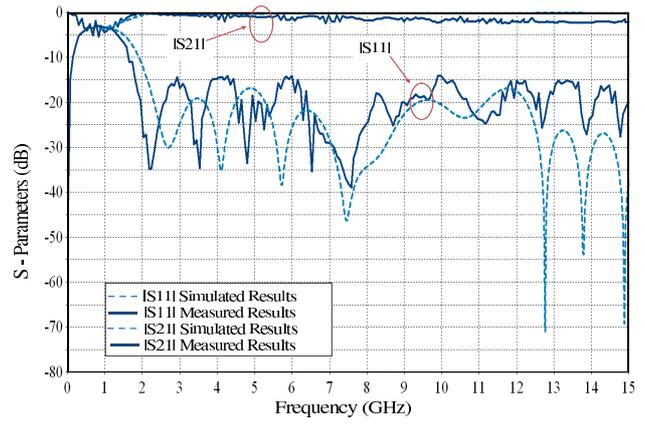
(d)

Fig. 7. Examples of CST optimized back-to-back connection of the tapered microstrip line to parallel strip balun (50 - 188 Ω) (a) Top View of the Balun (b) Bottom View of the Balun (c) Experimental and simulated S-parameters for structure A (d) Experimental and simulated S-parameters for structure B
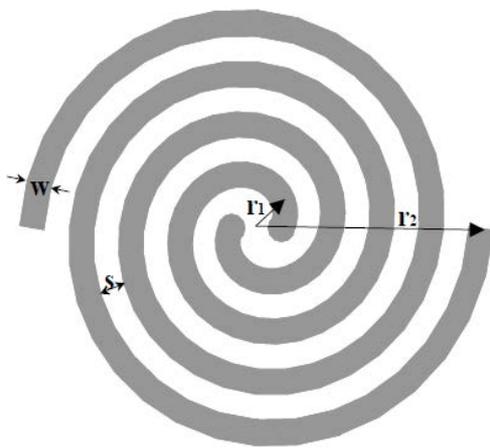
Fig. 8. Geometry of the two-arm Archimedean Spiral
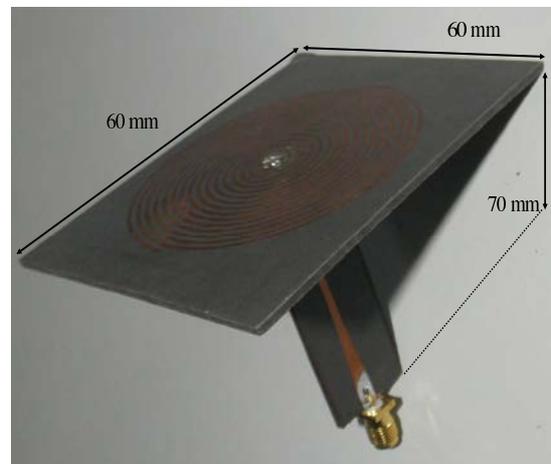
Fig. 9. The geometry of the Spiral antenna with the Balun

The measured and simulated scattering parameters results for the spiral antenna are given in Fig. 10. It shows that the antenna has good impedance matching over the entire frequency range. The antenna operates well from 2.5 to 15 GHz with return loss better than 10 dB.

The spiral was set up with a horn antenna (as a receiver, frequency range: 1 to 18 GHz) to measure the radiation patterns at different frequencies. The measured results of the spiral antenna radiation patterns are compared to the simulated results at the frequency of 10 GHz which is shown in Fig. 11.
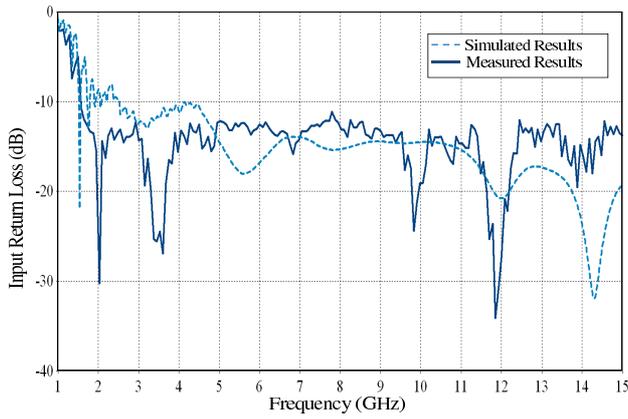
Fig. 10. Measured and simulated S-parameters results for spiral antenna

The measured results agree reasonably well with simulations. However, the measurement set up was subject to external reflections which can affect the radiation pattern significantly.
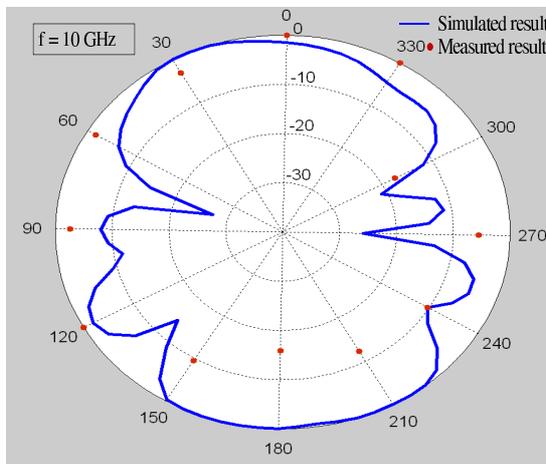
Fig. 11. Measured and simulated radiation patterns for the spiral antenna at 10 GHz

The HPBW (Half-Power Beam Width) of the antenna is presented in E and H-planes in Table III. It can be seen that the values for HPBW are decreasing with the frequency increases. The gain of the antenna therefore is increasing with the frequency.

TABLE III
HPBW OF THE SPIRAL ANTENNA IN E AND H PLANE

Freq/(GHz)	HPBW at E-plane(^{o})	HPBW at H-plane(^{o})
2	94.6	81.8
2.5	93.5	78.5
3	86.4	78.3
4	73.3	70.2
5	64.9	67.1
6	61	60.7
10	53.8	47.3
15	42.6	34.4

IV. CONCLUSION

In this paper, the design of a microstrip to parallel strip balun using CST Microwave Studio is presented. Two samples were tested and results validated the theory. Computation results reveal a significant size reduction of the balun with a lower insertion loss and a better reflection coefficient. Structure B shows better performance than structure A. The measured bandwidth of the balun is from 1.75 to 15 GHz. The proposed balun was integrated with a spiral antenna to validate its performance as antenna feed. The measured results of the return loss and radiation patterns of the spiral antenna show reasonable performance and agreement with simulated results from the CST Microwave studio simulations. The antenna has a measured bandwidth from 2.5 to 15 GHz for a return loss better than 10 dB. The proposed balun performs well over a wide frequency band and is able to achieve both field and impedance matching.

REFERENCES

[1] J. Thaysen, K. Jakobsen, and J. Appel Hansen, "A Wideband Balun-How Does it Work?," *Applied Microwave and Wireless*, vol. 12, no. 10, pp. 40–50, October 2000.
[2] K. Tilley, D. Wu, and K. Chang, "Coplanar waveguide fed coplanar strip dipole antenna," *Electronics Letters*, vol. 30, no. 3, pp. 176–177, 1994.
[3] Y.-H. Suh and K. Chang, "A wideband coplanar stripline to microstrip transition," *IEEE Microw. Wireless Compon. Lett*, vol. 11, no. 1, pp. 28–29, January 2001.
[4] Y. Guo, Z. Zhang, L. Ong, and M. Chia, "A new balanced UWB planar antenna," *Microwave Conference, 2005 European*, vol. 3, pp. 4–6, October 2005.
[5] R. Sefa and A. Maraj, "Analysis and design of microstrip to balanced stripline transitions," *Telecommunications and informatics, Electronics and Signal Processing*, May 2011.
[6] P. Carro, J. de Mingo, P. Garcia-Ducar, and C. Sanchez, "Synthesis of hecken-tapered microstrip to paralell-strip baluns for UHF frequency band," in *Microwave Symposium Digest (MTT), 2011 IEEE MTT-S International*, June 2011, pp. 1–4.
[7] R. Mongia, I. Bahl, and P. Bhartia, *RF and Microwave Coupled-Line Circuits*. Artech House, Inc, 1999.
[8] I. J. Bahl and D. K. Trivedi, "A designer's guide to microstrip line," *Microwaves*, May 1977.
[9] M. Kobayashi and N. Sawada, "Analysis and Synthesis of Tapered Microstrip Transmission," *IEEE Trans.Microwave Theory Tech.*, vol. 40, no. 8, pp. 1642–1646, August 1992.
[10] D. Shively and W. Stutzman, "Wideband arrays with variable element sizes," *Microwaves, Antennas and Propagation, IEE Proceedings H*, vol. 137, no. 4, pp. 238–240, August 1990.