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Comparison of Size Reduction of Printed BALUN Transformer

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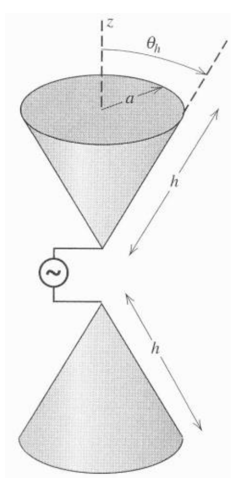
***Abstract*: In the field of RF and Microwave there are circumstances that either there is requirement of balanced antenna or circuitry designed on lumped components. Whatever may be the case it is well known that feed line is always a coaxial cable, off board feed, or a microstrip line when on board feed is required. But elements mentioned above are tow terminal and must be accommodated with a balanced line and the printed balanced line is coplanar strip line (CPS).**

The proposed work is dedicated to the design of a broadband transition which converts an unbalanced line (microstrip line) into balanced line (CPS). This thesis gives the complete idea of differences between tapered printed BALUN and compact BALUN. Tapered BALUN is larger in size as its length is dependent on the difference between the reference impedance of 50 Ω to 125 Ω. Compact BALUN generates a maximum -10 dB bandwidth of 4.15 GHz. An elliptically curved tapered BALUN is proposed which gives % bandwidth of 86. Size of this BALUN is 13.2x14.5 mm^2.

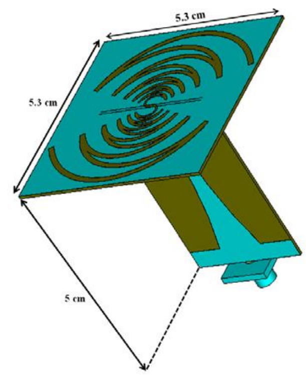
***Keywords*: BALUN transformer**

1. Need of BALUN

Need of BALUN Transformer: BALUN transformers are used in connection with antenna and implementation of the electronic circuits on PCB. Requirement of the BALUN in antenna: Broadly antenna can be divided as Balanced and Unbalanced antenna. Balanced antenna has two terminals as feed point and unbalanced antennas are with single feed point. Following figure shows the difference in balanced and unbalanced antenna.



(a)



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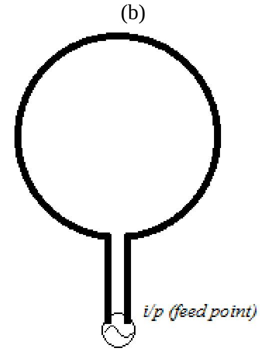
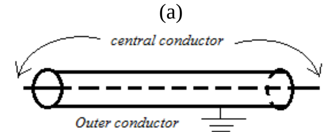


(c)

Fig. 1. Balanced antenna (a) Dipole, (b) Spiral antenna, (c) Loop antenna

It can be observed in fig. 1 all the antennas have two terminals as the input feed. To feed such antenna parallel wire cables are required. Parallel cable wires are the balanced cable as the magnitude of the voltage on both the lines are same but they are out of phase i.e. if one conductor is at +ve potential then the other is at -ve potential w.r.t. each other. But parallel cables are lossy and not preferred at larger frequency, instead coaxial cable is used.

(a)



(b)

Fig. 2. (a) Balanced Cable (b)Unbalanced Cable

But coaxial cable is unbalanced cable since outer conductor is always at ground and the central conductor carries the +ve and -ve cycle of sinusoidal signal. Therefore, this cable cannot be directly connected with the BALANCED antennas since one of the terminal will always be at ground and the antenna does not perform as per the requirement. Other than these parallel cables are lossy at higher frequency and are avoided in high frequency application. So there is requirement of a device which can convert the unbalanced coaxial feed into balanced feed (parallel feed). Approximation of coaxial feed is printed microstrip line so microstrip line is also an unbalanced line and is used to feed microstrip antenna (unbalance antenna). Microstrip line comprises of signal line and ground line (plane) just like the coaxial cable.

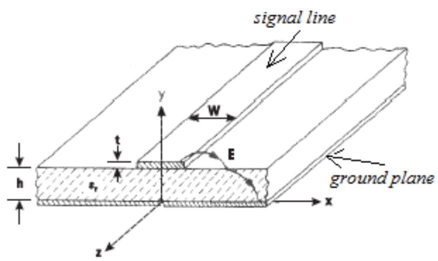


Fig. 3. Microstrip Line

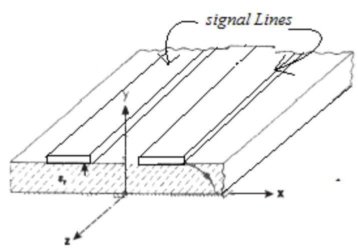


Fig. 4. Coplanar strip line

The Fig. 4 shows the coplanar line which is similar to parallel lines. Since balanced antenna cannot be fed with unbalanced line a device is required which will convert unbalanced line into balanced line i.e. balanced microstrip line to coplanar strip line. Methodology to Convert unbalanced line into balanced line:

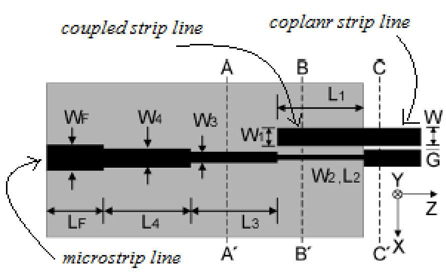


Fig. 5. Microstrip to coplanar strip line transition(BALUN).

The Figure 5 shows the construction of BALUN transformer which comprises of microstrip line, coupled strip line and coplanar strip line.

The Fig. 6 shows the field distribution in each line. It can be seen that in unbalanced microstrip line the field is distributed between signal line and ground plane, figure (a). Figure b shows that the field is divided between signal lines (two lines) and ground plane. Finally, the field is only between the two signal lines.

Research Gap: Work done so far have not given the detail about how the shape of the ground plane influences the performance of the BALUN transformer. Other than this, size reduction of the BALUN is never taken into consideration.

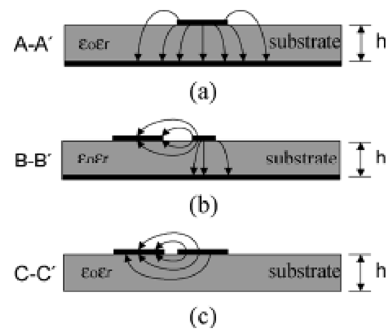


Fig. 6. Field distribution in (a) microstrip line (b) coupled strip line (c) coplanar strip line

2. Conventional and Contemporary BALUN Transformer

There are various BALUNs in practice. This chapter summarizes those BALUNs.

A. Printed microstrip line as BALUN

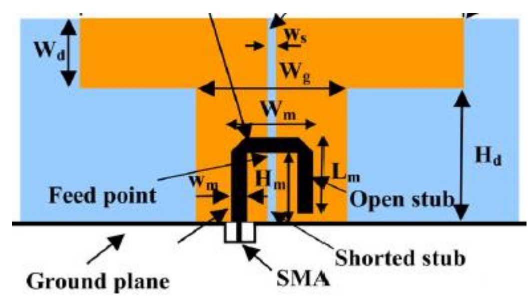


Fig. 7. A printed Dipole with printed BALUN

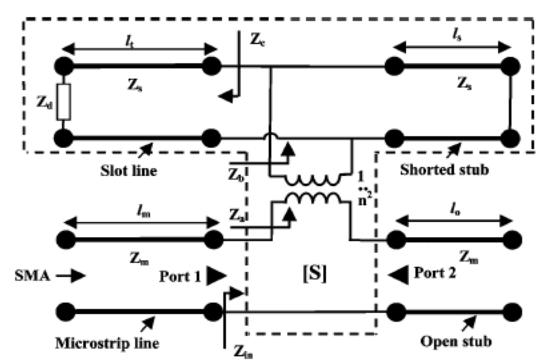


Fig. 8. Electrical equivalent of printed BALUN

A microstrip line is capable to give bandwidth of 1.5 GHz. A broader band balun is listed below.

B. Marchand BALUN

Marchand balun is capable to give an operative band of 2.5 GHz.

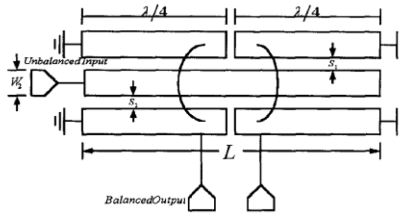


Fig. 9. Printed MARCHAND BALUN

C. CPW to CPS (Coplanar Waveguide to Coplanar strip line)

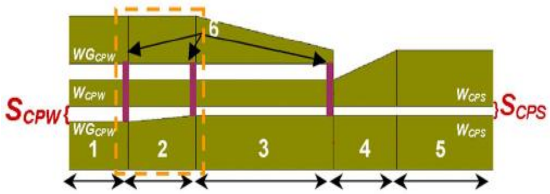


Fig. 10. BALUN using CPW for CPS transition

This transition is claimed to give a band width of 55 GHz. All these structures are suitable for the operation of conversion from balanced to unbalanced line.

Other type of BALUN used is smd BALUN. It comprises of primary winding and secondary winding. It's performance is similar to the conventional transformer.

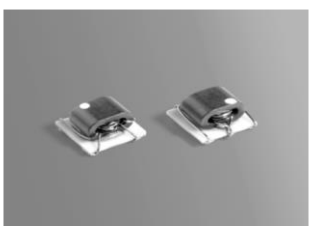


Fig. 11. SMD BALUN form coil craft company

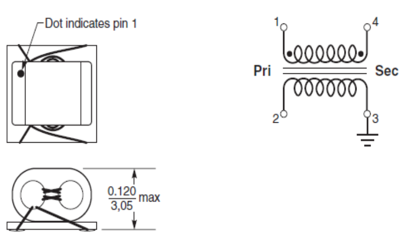


Fig. 12. Pin configuration of SMD BALUN

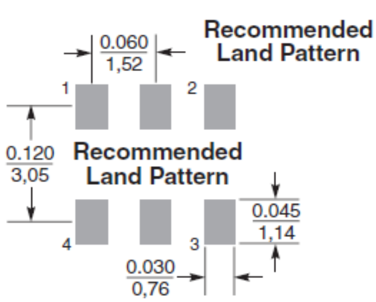


Fig. 13. PCB land pattern of SMD BALUN

SMD BALUN by coil craft is compact in size and works till 3 GHZ. This is suitable option to interface the any balanced antenna with coaxial cable.

3. Simulation of Printed BALUN

Balun transformer not only is used to convert unbalanced feed to balanced feed but it is also used to convert impedances. Length of the BALUN depends on the transformation of impedance. If the impedance difference is larger than the size of the BALUN also becomes larger. In order to have smaller size of the BALUN and at the same time to cover a larger band, Taper lines are used. Klopfenstein Taper in considered to give wider band of operation.

A. Klopfenstein Taper

The Klopfenstein taper is derived from a stepped Chebyshev transformer as the number of sections increases to infinity, and is analogous to the Taylor distribution of antenna array theory.

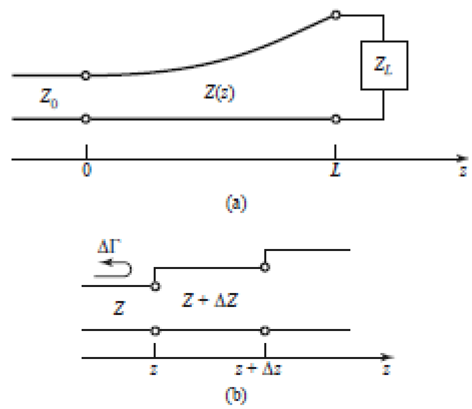


Fig. 14. A tapered transmission line matching section and the model for an incremental length of tapered line. (a) The tapered transmission line matching section. (b) Model for an incremental step change in impedance of the tapered line.

The logarithm of the characteristic impedance variation for the Klopfenstein taper is given by,

$$\ln Z(z) = \frac{1}{2} \ln Z_0 Z_L + \frac{\Gamma_0}{\cosh A} A^2 \phi(2z/L - 1,\ A) \quad \text{for } 0 \leq z \leq L,$$

where the function *φ(x, A)* is defined as

$$\phi(x,\ A) = -\phi(-x,\ A) = \int_0^x \frac{I_1(A\sqrt{1-y^2})}{A\sqrt{1-y^2}} dy \quad \text{for } |x| \leq 1,$$

where *I1(x)* is the modified Bessel function. The function has the following special values:

$$\phi(0,\ A) = 0$$
$$\phi(x,\ 0) = \frac{x}{2}$$
$$\phi(1,\ A) = \frac{\cosh A - 1}{A^2},$$

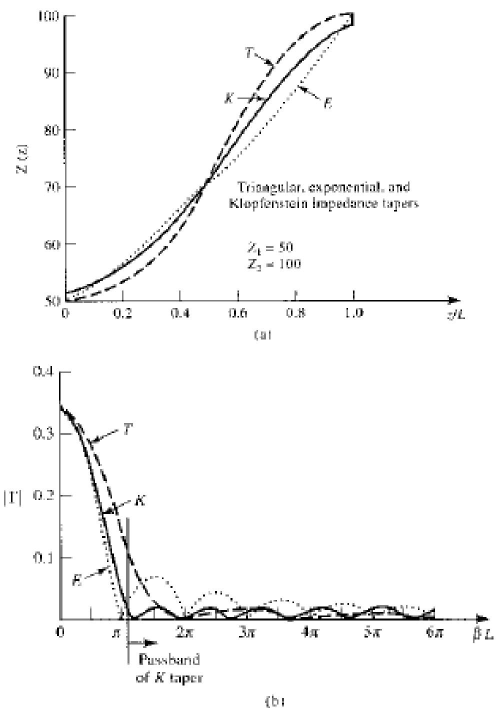


Fig. 15. (a) Impedance variations for the triangular, exponential, and Klopfenstein tapers. (b) Resulting reflection coefficient magnitude versus frequency for the tapers of (a).

As shown in the fig. b, K- transformer contains larger band with lesser ripple in the pass band. This variation in the ripple in pass band is uniform. For other transformer ripple magnitude is larger near the lower cut-off and decreases as the frequency increases.

Different techniques are applied to enhance the performance of the BALUN.

Case 1) Following is the structure of the BALUN which comprises of the microstrip line as unbalanced transmission line and then a coplanar line is added at the output of the microstrip line.

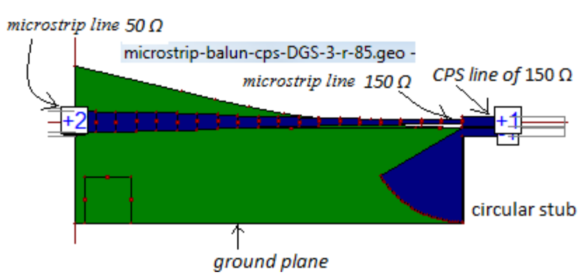


Fig. 16. BALUN for 50 Ω to 150Ω transition

A BALUN from 50 Ω to 150 Ω is designed using taper line approach.

As shown in fig. 16 (a) BALUN transformer. It is designed to transform 50 Ω unbalanced into 150 Ω balance line.

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}.$$

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\epsilon_e}} \ln\left(\dfrac{8d}{W} + \dfrac{W}{4d}\right) & \text{for } W/d \le 1 \\ \dfrac{120\pi}{\sqrt{\epsilon_e}\,[W/d + 1.393 + 0.667 \ln(W/d + 1.444)]} & \text{for } W/d \ge 1. \end{cases}$$

$$\frac{W}{d} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} & \text{for } W/d < 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \dfrac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B - 1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right\}\right] & \text{for } W/d > 2, \end{cases}$$

To determine the dimension of the 50Ω line, a dielectric material of 2.2 constant and with thickness of 0.787 mm is substituted in above equations.

In order to find out the dimensions of the Coplanar strip line (CPS) following equations are used.

$$\varepsilon_{re} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K'(k_1)}{K(k_1)} \frac{K(k_2)}{K'(k_2)} \text{ (F/unit length)}$$

$$k_1 = \frac{s}{s + 2W} = \frac{a}{b}$$

$$k_2 = \frac{\sinh(\pi a/2h)}{\sinh(\pi b/2h)}$$

$$K(k) = \frac{\pi}{2}\left\{1 + 2\frac{k^2}{8} + 9\left(\frac{k^2}{8}\right)^2 + 50\left(\frac{k^2}{8}\right)^3 + 306.25\left(\frac{k^2}{8}\right)^4 + \cdots\right\}$$

$$\text{for } 0 \le k \le 0.707$$

$$K(k) = p + (p-1)\left(\frac{k'^2}{4}\right) + 9\left(p - \frac{7}{6}\right)\left(\frac{k'^4}{64}\right) + 25\left(p - \frac{37}{30}\right)\left(\frac{k'^6}{256}\right) + \cdots$$

$$\text{for } 0.707 \le k \le 1$$

Since CPS line is balanced line one of the lines of CPS is terminated with circular stub to cover larger band. Radius of this stub is λ/4 of the lowest frequency i.e. 3 GHZ.

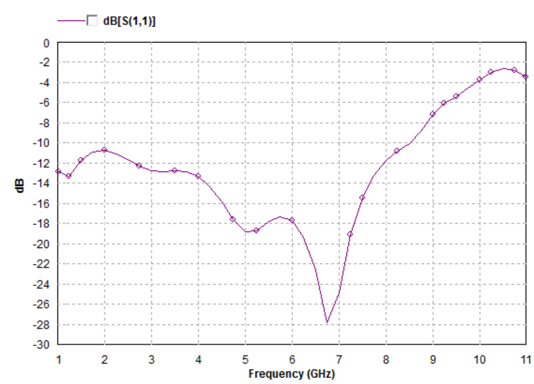


Fig. 17. Frequency V/S S11 in dB

Simulated result of the BALUN is shown in figure 17. It can be observed that the performance of the BALUN is excellent from 1 GHz to 8.5 GHz. Since the goal of the project is to obtain band from 3 GHz to 11 GHz, further modification is done in the ground structure of the BALUN and the result is analyzed.

Case2) In this case microstrip line and coplanar strip line are kept as it is and a meandered structure is introduced in the ground plane of the BALUN. Other than this ground is added with a new curvature of radius 70 mm. The proposed structure is shown in fig .18.

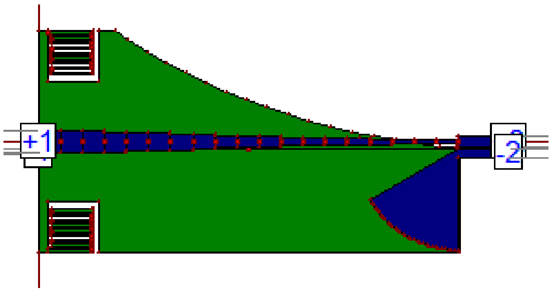


Fig. 18. BALUN with meandered structure in the ground plane

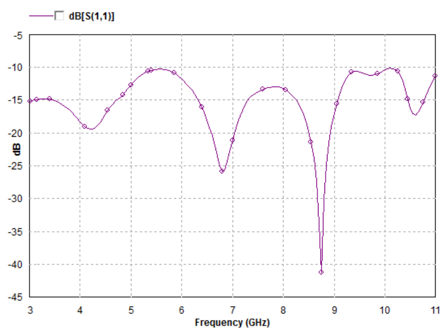


Fig. 19. Frequency V/S S11 in dB

Simulated result of the BALUN is shown in fig. 18. It can be observed that the performance of the BALUN is improved from 8.5 GHz to 11 GHz as compared to the case 1 of BALUN. But there is little problem observed in the result. S11 at 5.5 GHz is just sufficient i.e. it is -10 dB. It may happen that due to manufacturing limitation the result may get deteriorated and BALUN may have band from 3 GHz to 5.5 GHZ and then from 5.5 GHz to 11 GHz. To avoid such situation further modification is added in the BALUN.

Case 3) In this case meander structure from the ground plane is removed and a continuous ground plane with curvature of 80 mm is used, fig. 7. Rectangular portion of the ground plane is of 12.2 mm.

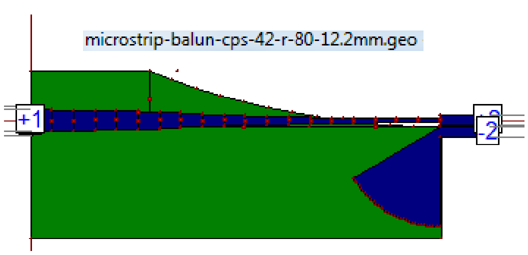


Fig. 20. BALUN with ground plane of curvature 80mm

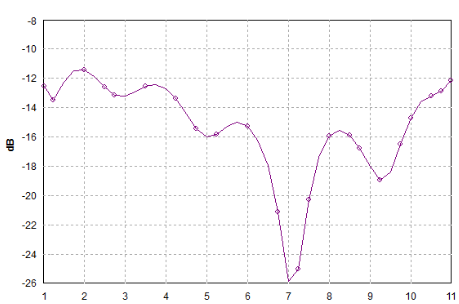


Fig. 21. Frequency V/S S11 in dB

Fig. 21 shows the simulated result of BALUN with new ground plane. It can be observed that BALUN performance is improved with the new structure of the ground plane. S11 is lesser than -11.8 dB throughout the band. Band covered by the BALUN is from 1 GHz to 11 GHz so it is sufficient to cover UWB.

Case 4) As a further improvement, BALUN is added with a fround plane with same curvature but the rectangular portion of the ground plane is of 12.2 mm.

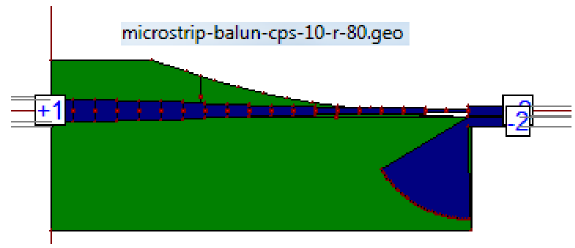


Fig. 22. BALUN with ground plane of curvature 80mm and smaller rectangular portion

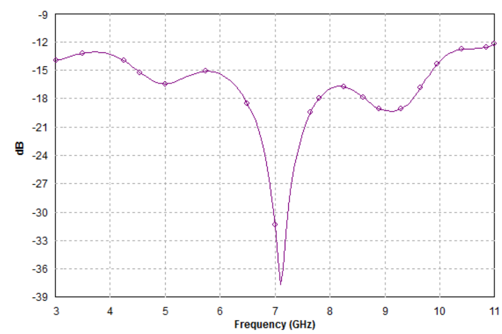


Fig. 23. Frequency V/S S11 in dB

Fig. 23 shows the simulated result of BALUN with new ground plane. It can be observed that BALUN performance is improved with the new structure of the ground plane. S11 is lesser than -13 dB throughout the band. Band covered by the BALUN is from 1 GHz to 11 GHz so it is sufficient to cover UWB.

4. Balanced printed BALUN

In order to verify the performance of the proposed BALUN a microstrip-CPS-microstrip is designed.

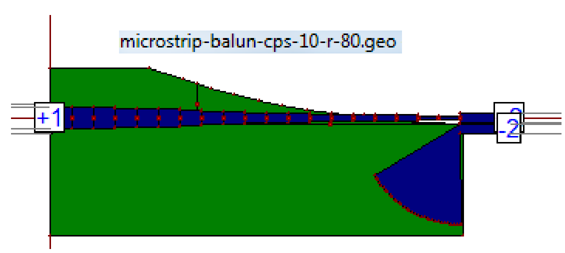


Fig. 24. BALUN with ground plane of curvature 80mm and smaller rectangular portion

Fig. 25 is the BALUN proposed in fig. 24. Same structure is duplicated to have a microstrip-CPS-microstrip configuration.

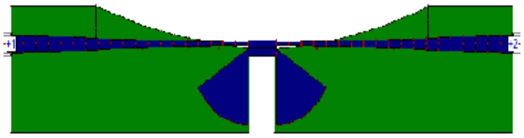


Fig. 25. A balanced microstrip-CPS-microstrip

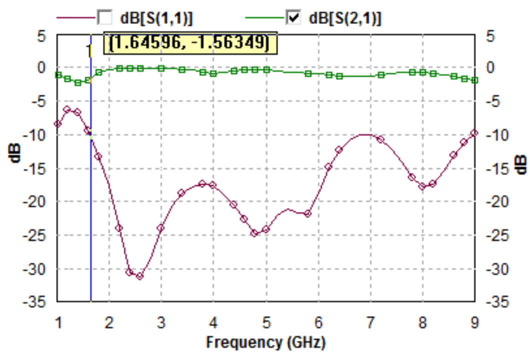
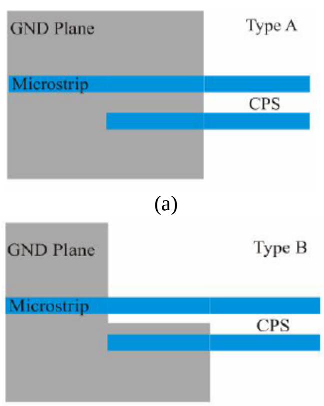


Fig. 26. Frequency V/S S11 in dB

A. Compact BALUN

Microstrip-CPS-Microstrip line gives a band from 1.64 GHz to 9 GHZ. It can be seen that the insertion loss is less than -1.65 dB. Larger structure needs larger substrate and so increases cost and at the same time larger length of the conductor causes conduction loss. So small size of BALUN is designed as shown in figure.



(a)

(b)

Fig. 27. Compact BALUN (a) Continuous ground plane and (b) Step ground plane.

The compact BALUN comprises of microstrip line section as the input port and output port to accommodate coaxial feed.

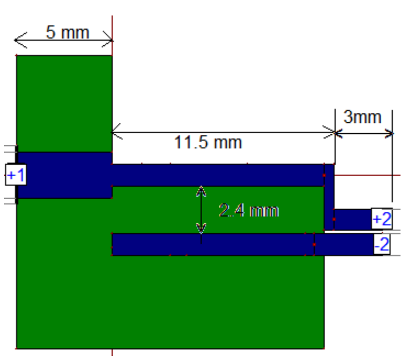


Fig. 28. Compact BALUN

The middle section is coplanar transmission line and length is 11.5 mm. Last section is 3mm and is Coplanar strip line of 125 Ω. Length of microstrip line is 5 mm and is chosen to accommodate SMA connector.

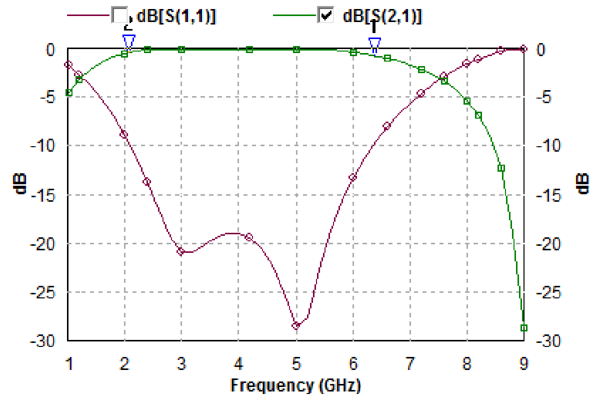


Fig. 29. Frequency V/S S11 in dB for 3mm CPS

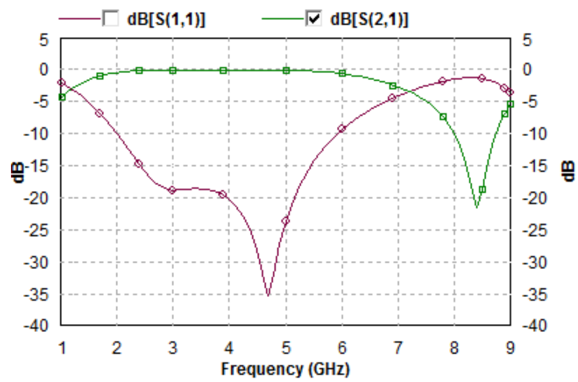


Fig. 30. Frequency V/S S11 in dB for 6 mm CPS

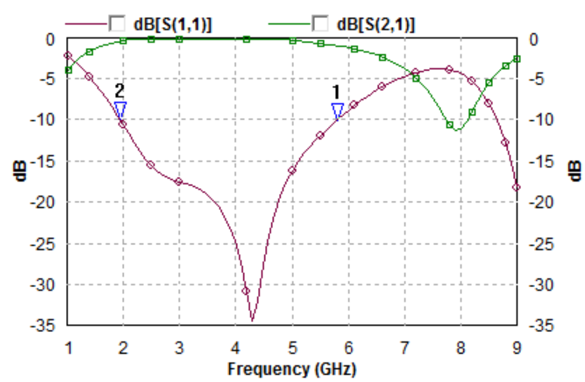


Fig. 31. Frequency V/S S11 in dB for 9 mm CPS.

Table 1
Bandwidth analysis of BALUN for different CPS length.

CPS length	Start frequency (GHz)	End frequency (GHz)	-10 dB Bandwidth
3	2.09	6.34	4.25
6	2	6	4
9	1.944	5.79	3.846

Table 1 shows that there is decrease in the bandwidth of BALUN w.r.t. CPS line length. It is observed that as the length of CPS line increases the bandwidth reduces.

IN order to test the BALUN, balanced structure is created as shown in figure 32. CPS length is optimized to 2.5 mm.

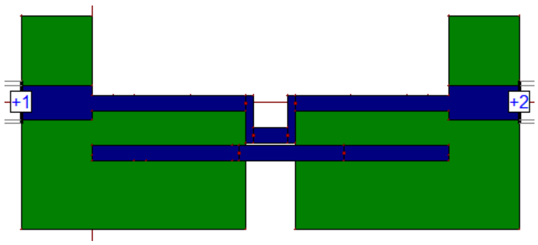


Fig. 32. Complete BALUN

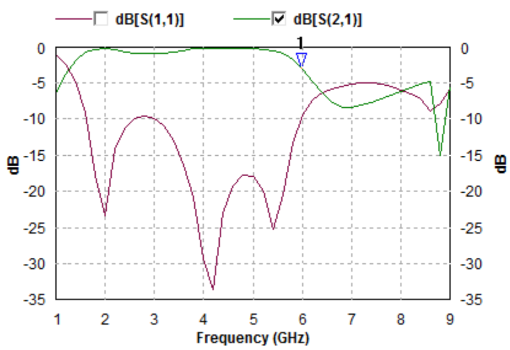


Fig. 33. Frequency V/S S11 in dB for balanced BALUN. Bandwidth of the BALUN changes as the CPS line length changes

B. *Elliptical BALUN*

A new approach is proposed as shown in figure 34. The straight structure of tapered BALUN transformer is converted to elliptical one. Elliptical structure occupies less space and overall dimension of the BALUN reduces. Other approach to reduce the overall size further is that the CPS line is not aligned along the MS line but is kept orthogonal w.r.t. MS line. The overall dimension of the BALUN is 13.2 x 14.5 mm^2.

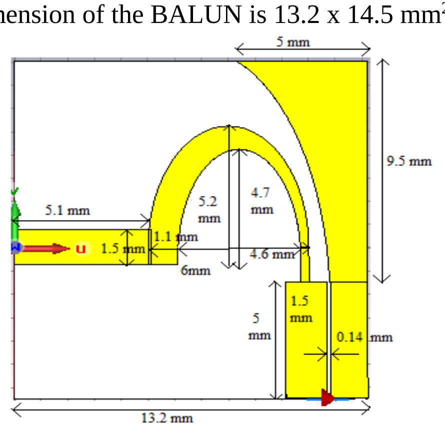


Fig. 34. Compact size BALUN

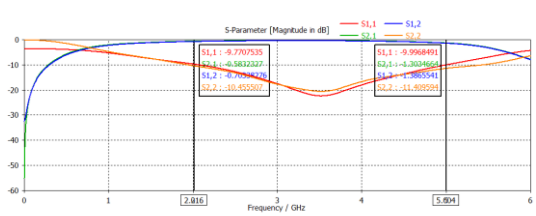


Fig. 35. S-parameters of compact size BALUN

Fig. 22. shows S-parameters if the BALUN. S11 bandwidth of the BALUN is from 2 GHz to 5 GHz. Therefore % bandwidth of the BALUN is 86%. S21 is less than – dB for the same band.

5. Conclusion

Simulated results show that the shape and size of the ground plane influences the performance of the BALUN. Tapered BALUN occupies larger substrate and so there is possibility that the production cost may increase drastically. Compact BALUN occupies smaller space and is cheaper than the tapered BALUN. Simulated -10 dB band of the compact BALUN is around 4 GHz.

Further reduction of the BALUN is elliptically tapered BALUN and the % bandwidth of the BALUN is 86 with minimum area of 13.2 x 14.5 mm^2.

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