OPTIMIZED DESIGN OF WIDEBAND WILKINSON BALUN USING COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINE

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Abstract:

In recent years, metamaterials has become very popular, not only in microwave field but also others field, such as optical metamaterials, mechanical metamaterials etc. the popularity of metamaterials is result of special properties, which does not exist in natural materials (right-handed materials). Negative refractive index (NRI) is the most utilized property in RF field. This property is outcome of negative phase. Utilizing the opposite phase shift property of a microstrip line (MSL) and a Composite Right/Left-Handed Transmission Line (CRLH TL), the wideband Wilkinson balun is designed. The CRLH TL branch is designed using an interdigital capacitor and cross connection of the end-fingers through vias to ground. The CRLH TL gives phase-advanced response properties, when unit-cell is balanced because of negative phase velocity, whereas a conventional MSL has a phase-lag response. This property of a wideband CRLH TL branch applies to the implementation of wideband balun. The proposed balun is compared with balun implemented using Pure Left-Handed (PLH) TL [3]. The optimized balun has a good return loss below -14.09 dB and good isolation between output ports over range 2.2 GHz to 5.4 GHz. and equal-power division (-2.87 dB to -3.53 dB) the phase difference is 180±10° over

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range 2.34 GHz to 5.37 GHz and fractional bandwidth of 84.17 % and size 28.52 mm X 20.3 mm.

Keywords: *Wideband Balun, Composite Right/Left-Handed, Metamaterials, HFSS*

1. INTRODUCTION

A balun is a 3-port device which converts unbalanced (single ended) signal to balanced (two ended) signal. There is no change in characteristics of the signal, i.e. information carried over the signal is not affected. Second most used application area of a balun is impedance transformation. This paper deals with optimized design of a 1:1 (means 50 ohm to 50 ohm impedance transformation) balun for antenna applications, where for example a dipole antenna has to be fed with coaxial cable (which is unbalanced). Balancing of signal is required before it is fed to a dipole antenna, for symmetrical radiation. These baluns are also used for image rejection mixers, balanced mixers, balanced modulators, push-pull amplifiers, and so on. Conventional microstrip baluns are narrow band at their differential output phase. Composite right/left-handed transmission lines have inherent broadband responses and they have phase-advance characteristics, thus they are utilized to design wideband balun. The balun proposed in this paper has high bandwidth (also Fractional BW), low group delay and almost half size as compared to [3]. In this paper a wideband balun is designed using a conventional microstrip transmission line and a composite right/left-handed (CRLH) transmission line. A CRLH TL is formed using very compact interdigital capacitor (IDC) [18] and shorting its end digits to ground. The conventional microstrip line (MSL) branch is fixed and the CRLH line is realized as phase-adjusting line, which is done by varying IDC digits' lengths, widths or spacing's between them.

2. COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINE

Figure 1 shows the unit cell structure of CRLH TL. Unit cell is composed of an interdigital capacitor with two vias shorting end digits to ground, left handed forming inductance for CRLH TL. The figure 2a shows the equivalent circuit diagram of IDC with parameters C_s called shunt capacitance (the capacitance of IDC with respect to the ground), L called series inductance (due to right handedness of the IDC) and C called series capacitance (capacitance due to couplings between the fingers).

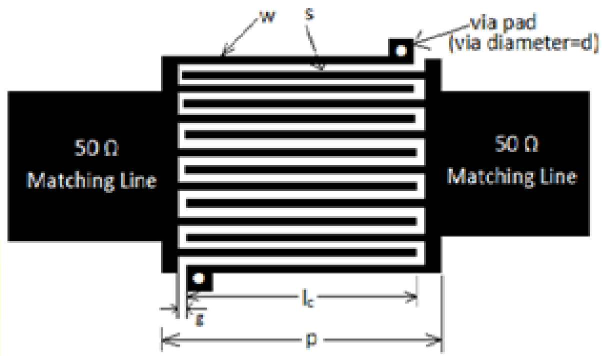


Figure 1 Unit cell structure of CRLH TL, (w = 0.1 mm, s = g = 0.1 mm, l_c = 3.3 mm, p = 4.2 mm, number of fingers used in IDC is 10)

Figure 2b shows the equivalent circuit of a CRLH unit cell. Correlations are as follows:

L_R (right-handedness inductance) = L,

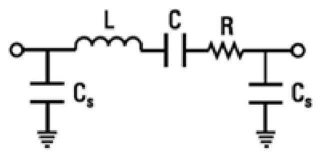
L_L (left-handed inductance) = inductances of the vias,

C_L (left-handed capacitance) = C and

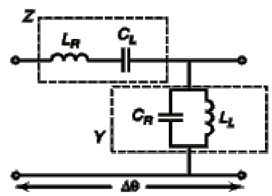
C_R (right-handed capacitance) = 2*C_S

Table 1: Extracted parameters of CRLH unit-cell

Parameter	IDC Parameters				Shorted Digit	f_{c1} (lower cut-off)	f_{c2}(upper cut-off)
	C_L	L_R	C_R	Z_0	L_L		
Value	1.98 pF	1.1 nH	0.72 pF	47 Ω	2.54nH	1.84GHz	5.91GHz



(a)



(b)

Figure 2 Equivalent circuit of (a) IDC and (b) CRLH Unit cell

Series inductance of IDC, $L = \frac{Z_0\sqrt{\varepsilon_{re}}}{l} c$ (1)

Where, c is velocity of light, *l* is length of each finger in meters, ε_{re} is effective dielectric constant Z_0 is characteristic impedance [2].

Shunt capacitance of IDC, $C_s = \frac{1}{2}\frac{\sqrt{\varepsilon_{re}}}{Z_0 l} c$ (2)

Series capacitance of IDC, $C = 2\varepsilon_{re}\varepsilon_0 \frac{K(k)}{K'(k)}(N-1)l$ (3)

N is number of finger pairs and K(k) is complete elliptic integral of first kind and $K'(k)$ is its complement. The balancing of the unit cell is done and values are extracted using parameter extraction [1], as given in table 1. Series frequency (f_{se}) and shunt frequency (f_{sh}) thus calculated are 3.41GHz and 3.72GHz.

2. Wideband Wilkinson Balun

As already said, MSL and balanced CRLH transmission lines have opposite phase shift. Using this property a wideband balun is designed. Figure 3 shows phase responses of two branches are opposite to each other. Figure 4 shows the schematic diagram of the wideband Wilkinson balun. The proposed broadband balun is realized by a conventional

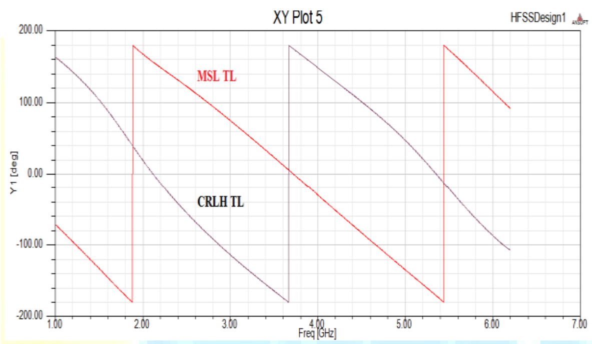


Figure 3 Phase response of CRLH TL and MSL TL lines

Wilkinson power divider with two phase shift transmission lines, such as a CRLH TL and a MSL. CRLH unit cell is realized using interdigital capacitor and balancing of the unit cell is done by varying width, length of fingers, spacing between fingers and number of fingers. The center frequency of f_0 is set to be 3.6 GHz. The input feed line is implemented using a 50 Ω MSL with width of 1.74 mm and length of 3 mm. Two λ/4 MSL branches in the Wilkinson divider are implemented using 70.7 Ω MSLs with the following parameters; width of 0.92 mm and length of 8.64 mm. The unit-cell dimensions of the CRLH TL are the same as mentioned in Figure 1. The matching section between the CRLH unit and the Wilkinson divider is employed as a 50 Ω. To have the same phase slope with that of the CRLH TL with a 180° phase difference, the dimensions of the MSL are set to be, length L = 17.75 mm and width 1.74 mm. The balun is designed using FR-4 substrate having relative permittivity (ε_r) 4.8 and height of substrate is 0.983 mm. Input and output lines are matched to 50 Ω ports. Geometry of the optimized balun is shown in the figure 5. Copper tracks are used for design. A cylindrical copper wire is used and assigned lumped resistor for value 100 Ω, at the output ports of Wilkinson Balun.

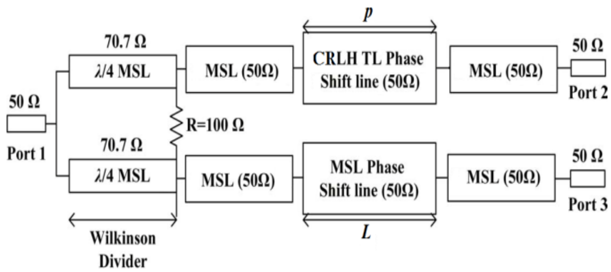


Figure 4 Block diagram of wideband Wilkinson balun

3. Simulation Results

The simulation design is shown in figure 5. The length of 50Ω microstrip lines used to connect Wilkinson divider outputs to output ports through CRLH and MSL phase-shift lines is 12.89 mm each.

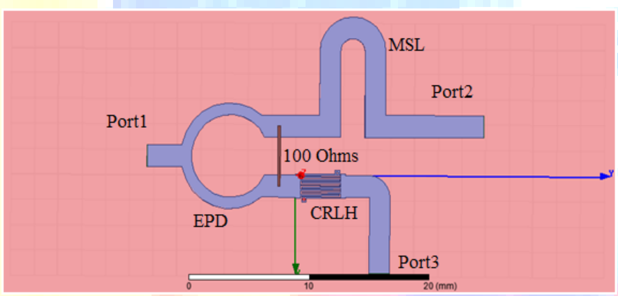


Figure 5 Schematic of wideband Wilkinson balun

Simulation tool used is Ansoft's HFSS. Figure 6 shows simulated return loss (S_{11}, red) and insertion loss (S_{12} and S_{13}). Simulated return loss is below 14.09 dB in band of operation (2.34 GHz to 5.37 GHz). Power is equally split to the two output ports i.e. simulated S_{12} and S_{13} values are -3 ± 0.53 dB and these values are -3.53dB and -2.87dB respectively (i.e. maximum imbalance is 0.53dB).

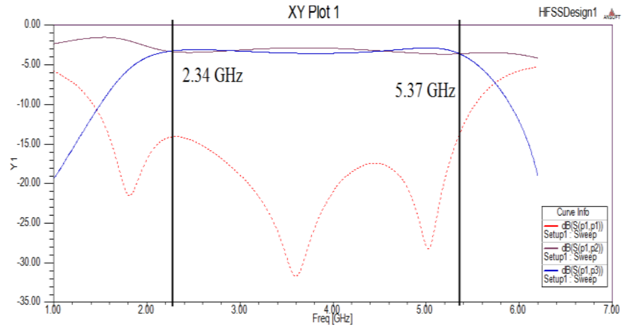


Figure 6 Simulated S-Parameters

Figure 7 shows the simulated phase differences between two output ports. The simulated phase differences between two output ports is 180° ± 10° over band of operation (2.34 GHz to 5.37 GHz) is designed using CRLH and conventional MSL opposite phase shift lines unlike the conventional MSL Wilkinson balun are designed using two branches of -90° and -270° phase shift MSL. The differential output phase is shown to be flat in the operation band designed balun. Bandwidth of 3.03GHz (FBW 84.17%) is achieved. Table 2 shows the comparison between the optimized balun using CRLH and balun using PLH [3]. Consequently, the wideband Wilkinson balun based on a CRLH TL has good properties, such as group delay (0.3ns), return loss, isolation, and broad frequency range and very small size (28.52 mm X 20.3 mm).

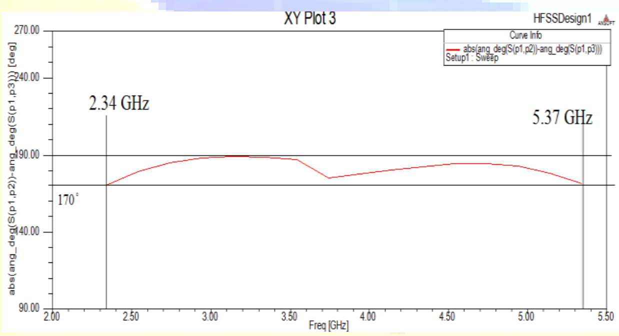


Figure 7 Differential phase between two outports

A comparison is made between the optimized blun and broadband balun using PLH (and modified PLH) TL [7].

Table 2: Comparison table

Parameter	Optimized	Balun	Balun

	Balun using CRLH	using PLH [7]	using Modified PLH [7]
S_{11}	Below -14.1 dB	Below -11.5 dB	Below -13.1 dB
S_{12} and S_{13}	-3.53dB and -2.87dB	-3.72dB and -3.43dB	-3.23dB and -3.51dB
Phase Difference	180° ± 10°	180° ± 10°	180° ± 10°
Group delay	0.3ns	0.72ns	0.81ns
Size	28.52 mm X 20.3 mm	42.3mm X 43.4mm	~ 52mm X 53mm
Bandwidth	3.03 GHz	1.62GHz	2.62 GHz
FBW	84.17%	71%	107%

4. Conclusion

A broadband Wilkinson balun is designed using a CRLH TL. A balanced CRLH TL gives inherently phase-advanced response because of a negative phase velocity. It has the capability of arbitrarily synthesizing the transmission phase response. These properties apply to the implementation of wideband baluns. The balun has good return loss, good isolation, equal-power division, and a 180° phase difference between two output ports in the wide frequency range. The optimized balun has a good return loss below -14.09 dB and good isolation between output ports over range 2.2 GHz to 5.4 GHz. and equal-power division (-2.87 dB to -3.53 dB) the phase difference is 180±10° over range 2.34 GHz to 5.37 GHz and fractional bandwidth of 84.17 % and size 28.52 mm X 20.3 mm.

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