Design of an Ultra-wideband Wilkinson Power Divider

B. Mishra[1], A. Rahman[2], S. Shaw[3], M. Mohd.[4], S. Mondal[5] and P. P. Sarkar[6]
[1,2,3,4,5] Department of Electronics & Communication Engineering
Academy of Technology, Hooghly-712121
[6]Department of Engineering and Technological Studies
University of Kalyani, Nadia-700 032
[5]santanumondal2008@rediffmail.com
[6]parthabe91@yahoo.co.in

***Abstract*— In this paper an ultra-wideband Wilkinson power divider (WPD) using binomial multi-section matching transformer is proposed. First an optimized single section WPD is designed and the output response of this power divider needs to be improved for ultra-wideband applications. Then a two and three section WPD using binomial transformer is presented that yields satisfactory input and output responses for ultra-wideband communications. This study shows the improvement of output responses due to the introduction of λ/4 multi-sections and isolation resistors. All simulations are carried out by finite integration based CST STUDIO 10 3D EM simulator. The proposed multi-section WPD can be used for 1:2 way equal power division (3 dB) in ultra-wideband range (3.1 -10.6 GHz).**

***Keywords*— Wilkinson power divider, binomial transformer, ultra-wideband**

I. Introduction

Power dividers are passive devices which are used to divide the input signal power into many output ports or vice versa according to required design. In 1960, E.J. Wilkinson connected an additional resistor at the end of two quarter-wave transmission line and it improves the isolation and return loss at the output ports [1]. The isolation resistor doesn't have any effects on the input matching. This power divider can be made with arbitrary power division [2-5] but in this paper a two way equal split (3 dB) power division [1] is considered. One of the major advantages of the ultra-wideband systems at 3.1–10.6 GHz is their high data-rate-transmission capabilities (typically 100Mbps) with low power spectral densities (41.3 dBm/MHz) [6], ensuring thereby low interference with other narrow-band wireless devices. So the research works for the design of ultra-wideband WPD are carried out extensively [7-8].

The objective of this study is the design of ultra-wideband WPD which is implemented using binomial multi-section matching transformer [9]. This paper describes the even and odd mode analysis of this power divider using transmission line modeling (TLM) [1]. The odd and even mode analysis helps to understand the design parameters of the WPD. A single section WPD is optimized and the isolation between two output ports (S_{23}) of this power divider is not suitable for ultra-wideband applications. Then the theory of multi-section [9-11] is utilized here to improve the output responses (S_{22} and S_{23}). Finally a two and three section WPD is designed for ultra-wideband communications. A comparison table for the characteristics of single, two and three section WPD is shown to represent the effects of multi-quarterwave sections and multi-isolation resistors on reflection and transmission coefficients.

II. Transmission Line Modelling of WPD

The transmission line modeling (TLM) of the 2 way equal split Wilkinson power divider is shown in Fig. 1 [1]. This power divider contains one input port, two quarterwave transmission line, two output ports and one isolation resistor across the output ports.

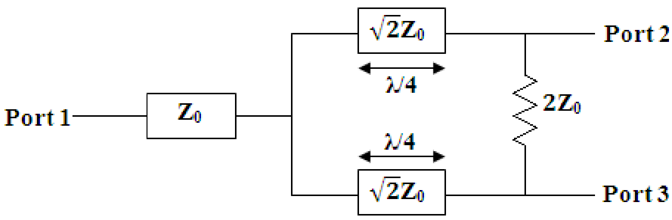


Fig. 1 Transmission line modelling of WPD

The expression of input return loss (S_{11}) and transmission coefficient (S_{21}) of WPD from the above TLM circuit [1] are

$$S_{11}(f) = \frac{-1}{(3 + j2\sqrt{2}\tan(\beta l))}$$

$$S_{21}(f) = \sqrt{\frac{(1 - S_{11}{}^2(f))}{2}}$$

The even and odd mode analysis [1] computes the output responses (S_{22} and S_{23}) of WPD very easily and a voltage excitation of V_S is applied at port 2 for the analysis of even and odd mode. The voltage excitation at port 2 and 3 for even and odd mode are Vs/2, Vs/2 and Vs/2, -Vs/2 respectively. The even and odd mode diagrams of WPD are shown in Fig. 2. From these even and odd mode analysis the derived expressions of output responses (S_{22} and S_{23}) are

$$S_{22}(f) = \frac{1}{(8\tan^2(\beta l) - j8\sqrt{2}\tan(\beta l) - 3)}$$

$$S_{23}(f) = \frac{-2 - j2\sqrt{2}\tan(\beta l)}{(-8\tan^2(\beta l) + j8\sqrt{2}\tan(\beta l) + 3)}$$

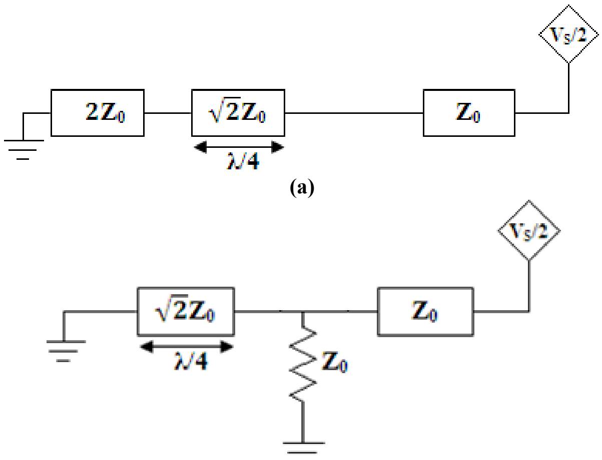


Fig. 2 TLM circuit of WPD for (a) even mode (b) odd mode analysis

To increase the bandwidth of the input and output responses of the power divider, the binomial multisection matching transformer is used in our study inspite of chebyshev multisection matching transformer to minimize the ripple levels [9]. At this point to find the characteristic impedance, Z_{n+1} of the multi-sections, starting with n = 0 is determined by the following relation [9]

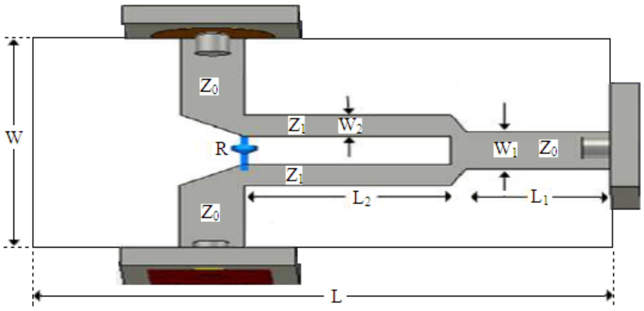
$$\ln\frac{Z_{n+1}}{Z_n} = 2^{-N} C_n^N \ln\frac{Z_L}{Z_0}$$

$$Where, C_n^N = \frac{N}{(N-n)!n!}$$

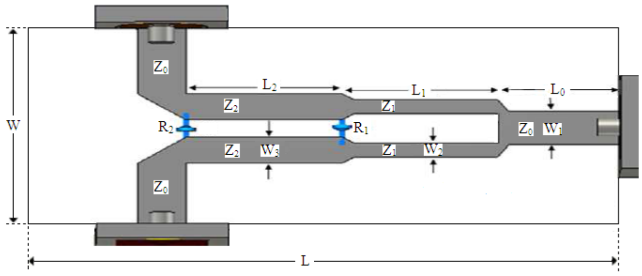
N = no of multisections, n = 0 to N-1 and for Wilkinson power divider $Z_L = 50\ \Omega$, $Z_0 = 100\Omega$.

III. DESIGN OF THE PROPOSED WPD

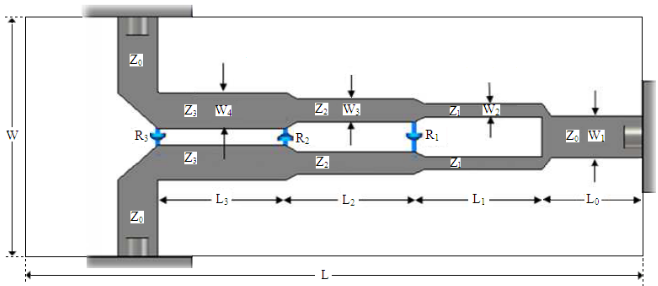
The geometry of the proposed WPD with single, two and three sections in microstrip configuration are shown in Fig. 3 and the optimized parameters of these power dividers are shown in their corresponding geometry. Fig. 3 shows the dimensions of top layer of the proposed microstrip WPD and in the middle layer RT/Duroid substrate is used. This RT Duroid substrate has dielectric constant $\varepsilon_r = 2.4$ and height h = 0.75 mm. The dimension of the bottom layer i.e. ground is denoted by W and L as shown in Fig. 3.The 50Ω SMA connector is used to feed the power divider and the isolation resistors are chip resistor of respective values as shown in the geometry. The characteristic impedance of the λ/4 line at centre frequency 6.85 GHz is determined using the formula (1) and Z_1, Z_2, Z_3 are the characteristic impedance of the multi-sections as shown in Fig. 3. The characteristic impedances for these sections of the proposed power divider are shown in Table 1. The characteristics of the proposed power divider have been studied using CST STUDIO 10 3D EM simulator.



(a) $W_1 = 2.204$ mm, $W_2 = 1.254$ mm, $L_1 = 5$ mm, $L_2 = 7.0675$ mm, W = 13 mm, L = 20 mm, R= 100 Ω



(b) $W_1 = 2.204$ mm, $W_2 = 0.9$ mm, $W_3 = 1.682$ mm, $L_0 = 5$ mm, $L_1 = L_2 = 7.0675$ mm, W = 13 mm, L = 24 mm, R_1= 100 Ω, R_2= 184 Ω



(c) $W_1 = 2.204$ mm, $W_2 = 0.75$ mm, $W_3 = 1.254$ mm, $W_4 = 1.932$ mm, $L_0 = 5$ mm, $L_1 = L_2 = L_3$ =7.0675 mm, W = 13 mm, L = 32 mm, $R_1 = 100\ \Omega$, $R_2 = 184\ \Omega$, $R_3 = 145\ \Omega$

Fig. 3 Geometry of the microstrip WPD using (a) single (b) two and (c) three sections

Table1: Characteristic impedances for λ/4 sections of the proposed power divider

No of section	Z_0	Z_1	Z_2	Z_3
Single	50 Ω	70.7 Ω		
Two	50 Ω	84 Ω	59.4 Ω	
Three	50 Ω	91.7 Ω	70.7 Ω	54.5 Ω

IV. SIMULATED RESULTS

The characteristics of the input reflection coefficient (S_{11}) for single, two and three section WPD is shown in Fig. 4.When the no of section increases, the impedance discontinuity between input line and two λ/4 line decreases resulting the input reflection coefficient improves as shown in Fig. 4. The transmission coefficient (S_{21}) yields better characteristics for more no of sections as shown in Fig. 5. The even and odd mode analysis of WPD [9] demonstrates that the output reflection coefficient (S_{22}) and isolation between two output ports (S_{23}) depend on isolation resistors. Fig. 6 shows the improvement of output reflection coefficients (S_{22}) of two and three section WPD compared to that of single section WPD. The isolation (S_{23}) between two output ports of single section WPD is not suitable for ultra-wideband applications. This isolation has been greatly improved for more no of λ/4 line and isolation resistors as shown in Fig. 7. So these characteristics reveal that the proposed WPD using binomial multi-section matching transformer is applicable for ultra-wideband applications. A comparative study for the improvement of characteristics of the proposed WPD using binomial multi-section matching transformer is shown in Table 2.

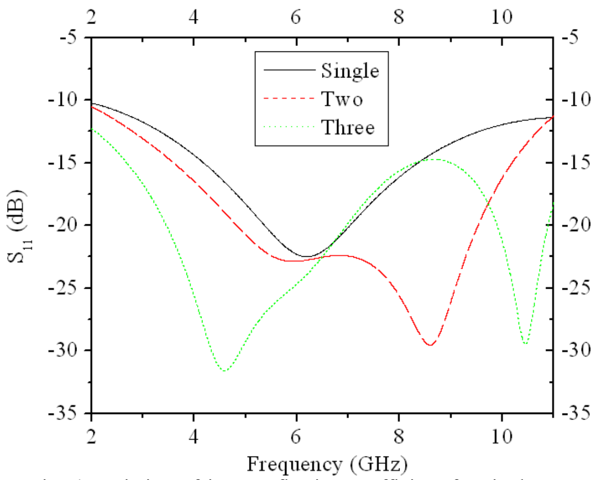


Fig. 4 Variation of input reflection coefficient for single, two and three section WPD

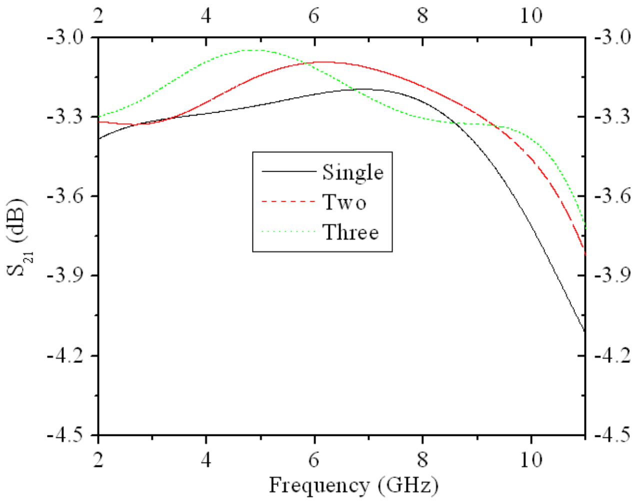


Fig. 5 Variation of transmission coefficient for single, two and three section WPD

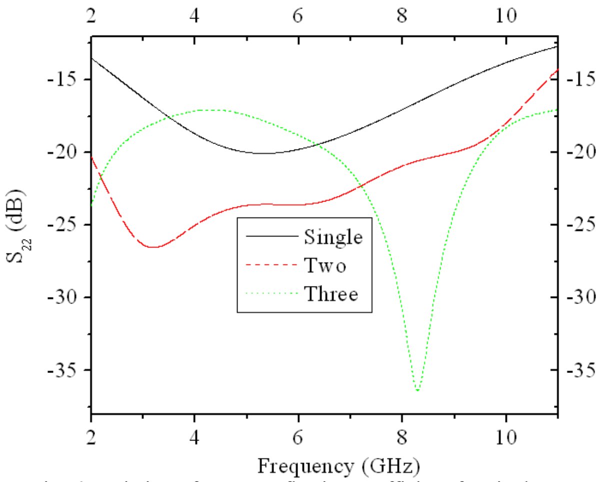


Fig. 6 Variation of output reflection coefficient for single, two and three section WPD

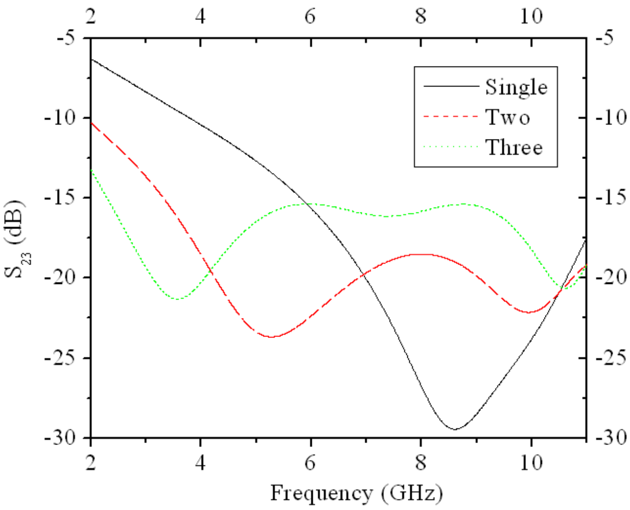


Fig. 7 Variation of isolation between two output ports for single, two and three section WPD

Table 2: Comparative study of S parameters for the proposed multi-section WPD

No of section	$\|S_{11}\|$	$\|S_{21}\|$	$\|S_{22}\|$	$\|S_{23}\|$	P-P Amplitude ripple
Single	Better than 11.51 dB	Better than 3.95 dB	Better than 13.09 dB	Better than 8.56 dB	0.757 dB
Two	Better than 12.86 dB	Better than 3.62 dB	Better than 15.69 dB	Better than 14.07 dB	0.67 dB
Three	Better than 14.72 dB	Better than 3.52 dB	Better than 17.05 dB	Better than 15.36 dB	0.518 dB

The comparative study shows that with increasing the number of section the reflection coefficient and the isolation between output ports are getting better and Peak to Peak (P-P) amplitude ripple is also decreased due to the smooth transition of the impedance for multi-section WPD.

V. CONCLUSION

In this study a Wilkinson power divider using binomial multi-section matching transformer is designed for ultra-wideband applications. The reflection and transmission coefficients of the proposed power divider with single, two and three section are studied. From these studies the effects of multi-section and isolation resistors on reflection and transmission coefficients of the power divider have been observed. The proposed power divider with λ/4 binomial multi-section matching transformer shows ultra-wideband characteristics that makes the power divider suitable for ultra-wideband communications.

REFERENCES

[1] E. J. Wilkinson, “An N-Way Hybrid Power Divider,” IRE Trans. Microwave Theory Techniques, vol. 8, no. 1, pp. 116 – 118, 1960.

[2] Wu Yongle, Liu Yuanan, Xue Quan, Li Shulan, Yu Cuiping, “Analytical Design Method of Multiway Dual-Band Planar Power Dividers With Arbitrary Power Division,” IEEE Trans. Microwave Theory Techniques, vol. 58 , no. 12, pp.: 3832 – 3841, 2010.

[3] A.M. Qaroot, N.I. Dib, “General Design of N-way Multi-Frequency Unequal split Wilkinson Power divider using Transmission line Transformer,” Progress In Electromagnetics Research C, vol. 14, pp. 115-129, 2010.

[4] C. Feng, G. Zhao, X. F. Liu, F. S. Zhang, “Planar three-way dual-frequency power divider,” Electronics Lett., vol. 44, no. 2, pp. 133 – 134, 2008.

[5] Zhou Jiafeng, K.A. Morris, M.J. Lancaster, “General Design of Multiway Multisection Power Dividers by Interconnecting Two-Way Dividers,” IEEE Trans. Microwave Theory Techniques, vol. 55, no.10, pp.: 2208 – 2215, 2007.

[6] T. K. K. Tsang and M. N. El-Gamal, “Ultra-wideband (UWB) communications systems: an overview,” IEEE-NEWCAS Conference, vol. 147, pp.381– 386, 2005.

[7] B. Menc´ıa-Oliva, A. M. Pel´aez-P´erez, P. Almorox-Gonz´alez, J. I. Alonso, “New technique for the design of ultra-broadband power dividers based on tapered lines,” IEEE MTT-S International Microwave Symposium Digest, pp. 493-496, 2009.

[8] B. Zhou, H. Wang, and W.-X. Sheng, "A modified UWB wilkinson power divider using delta stub," Progress In Electromagnetics Research Letters, vol. 19, 49-55, 2010.

[9] D. M. Pozar, “Microwave Engineering,” Wiley India Edition, 3rd Edition.

[10] L. Young, “Tables for Cascaded Homogeneous Quarter-Wave Transformers,” IRE Trans. Microwave Theory Techniques, vol. 7, no. 2, pp.:233 – 237, 1959.

[11] S. B. Cohn, “A Class of Broadband Three-Port TEM-Mode Hybrids,” IEEE Trans. Microwave Theory Techniques, vol. 19, no. 2, pp.110 – 116, 1968.