A Review: Dual Frequency Wilkinson Power Divider

Sagar Patkar, Akshay Horane and Dr. Nisha Sarwade

ABSTRACT : Recent years have seen a worldwide effort to develop dual-band Wilkinson Power Divider due to the trends of multi-band mobile phones. Hence the power dividers are changing their structures and technology so that they can be flexible with dual frequency bands. Dual frequency Wilkinson Power Dividers are used in dual band mobile phones i.e. they have main applications in L-band and S-bands (GSM, CDMA, Personnel communication systems). The recent technologies for cellular communication have motivated researchers to work on size reduction and harmonic suppression of power dividers to make them more compact and efficient. The length of transmission line, insertion loss, reflection loss, isolation between the two output ports plays a vital role in the design of dual frequency Wilkinson Power Divider. A review of recent trends in dual frequency Wilkinson Power Divider is presented in this paper.

Keywords—Dual frequency, Miniaturization, Unequal power ratio, Wilkinson Power Divider

I. Introduction

The power dividers and combiners are very important components for microwave power amplifiers, balanced mixers and antenna feeds. The conventional Wilkinson Power Divider that only operates at one design frequency is not suitable for some dual band operations, as seen in the downlink operation both at the Global System of Mobile communication band (GSM) and at the Personal Communication System band (PCS). Applications in present-day mobile communication system usually require smaller size RF devices in order to meet the miniaturization requirements of mobile units.

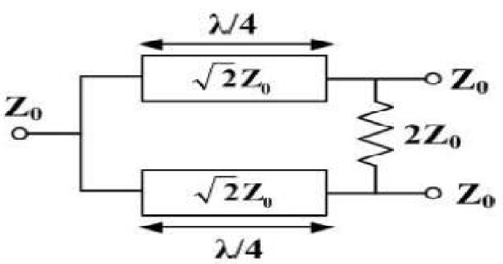

Fig 1. Conventional Wilkinson Power Divider

Sagar Patkar, Akshay Horane and Dr. Nisha Sarwade are with Department of Electrical Engineering, VJTI, Mumbai, Maharashtra, INDIA. Email: snpatkar@gmail.com

The Traditional Wilkinson Power Divider consists of two (λ/4) branches of transmission line and a termination resistor, where λ is the wavelength of the transmission line as shown in Fig.1. These two branches match all input and output ports and resistor provides a good isolation between the output ports for the power divider.

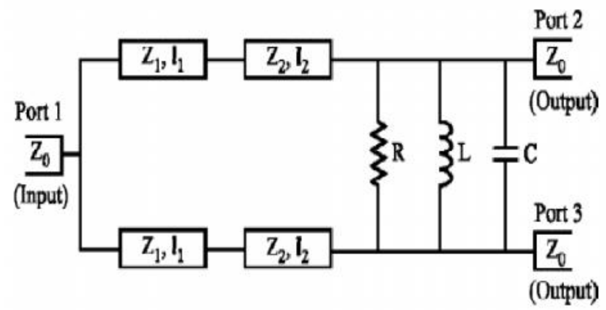

Fig 2. Dual frequency Wilkinson Power Divider

Dual frequency power divider shown in Fig.2 consists of two different branches having different electrical lengths. This power divider consists of two branches of impedance transformer, each of which consists of two sections of transmission line with different characteristic impedance, and a parallel connection of a resistor, an inductor, and a capacitor, which shunts the two output ports. The two different transmission lines in this power divider, which are subdivided into two parts having characteristic impedances Z_1, Z_2 and lengths l_1, l_2 respectively; where (Z_1, l_1) & (Z_2 , l_2) correspond to operating frequencies f_1 and f_2 .

Parallel connection of a resistor, an inductor and a capacitor is used to improve isolation characteristics of the circuit. Such a consideration is of great meaning due to the current trend of compactor, smaller, and more efficient RF front ends, e.g. the trend of multi-standard multi-frequency power amplifiers.

This paper presents a review of dual frequency Wilkinson Power Divider. The organization of this paper is as follows: Section II gives equations required for the designing followed by Section III which provides a review of recent trends of dual frequency Wilkinson Power Divider and the paper is concluded in Section IV.

II. DESIGN EQUATIONS

Dual frequency Wilkinson Power Divider is a three port network consisting of one input port and two output ports as shown in Fig 2. Basically, it divides power equally or unequally at two different operating frequencies (f_1 and f_2) depending on the application using it. The power divider is a symmetric structure, so that its analysis can be done by using even and odd mode analysis to determine the parameters of the dual band power dividers.

$$l_1 = l_2 = \frac{n\pi}{\beta 1 + \beta 2} \quad (1)$$

$$Z_2 = Z_0 \sqrt{\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + 2}} \quad (2)$$

$$Z_1 = \frac{(2Z_0^2)}{Z_2} \quad (3)$$

$$\alpha = (\tan(\beta_1 l_1))^2 \quad (4)$$

$$\beta = \frac{2\pi}{\lambda} \quad (5)$$

The above mentioned are the equations used for designing the dual frequency Wilkinson Power Divider [1].

The parameter λ denotes the wavelength and *n* is a positive integer. The l_1 & l_2 are the lengths of transmission lines as shown in Fig 2. The Z_0 is the reference impedance and Z_1, Z_2 are the characteristics impedances of the two different transmission lines.
β_1 and β_2 are the constants corresponding to first and second operating frequencies.

The output ports of the dual frequency Wilkinson Power Divider are isolated from one another by the parallel combination of the lumped elements (i.e. Resistor, Capacitor and Inductor). Ideally no current flows through the resistor as the ports are of the same potential, but if non-identical signals which are out of phase are combined a voltage differential is formed between the ports causing current to flow through the resistor, reducing the isolation. Isolation is a critical factor when determining interference or "crosstalk" between the ports.

Isolation i.e. S_{23}, input reflection coefficient $S_{11,}$ output reflection coefficients S_{22}, S_{33} and transmission coefficients $S_{21,}$ S_{31} are used to measure the dual frequency Wilkinson Power Divider characteristics.

Forward transmission and input reflection of the dual frequency Wilkinson Power Divider depends only on the transmission lines while isolation and output reflection coefficients depends on the structure of transmission lines and the parallel combination of lumped elements.

III. RESEARCH WORKS

The very first dual frequency Wilkinson Power Divider was proposed for an operating frequency (f_0) and with its first even harmonic ($2f_0$). That power divider consists of two sections of λ/6 wave transmission line with different characteristic impedances as shown in Fig.3.Simulation done by Agilent ADS software with operating frequencies of 1 GHz and 2 GHz for a substrate material RO 4003 is reported in [2]. Power is equally divided and transmitted at both operating frequencies while the isolation is 20 dB at 1 GHz and 18 dB at 2 GHz. Input return loss is 30dB at 1GHz and 28 dB at 2GHz, output return loss at 1 & 2 GHz is 18dB & 22dB respectively.

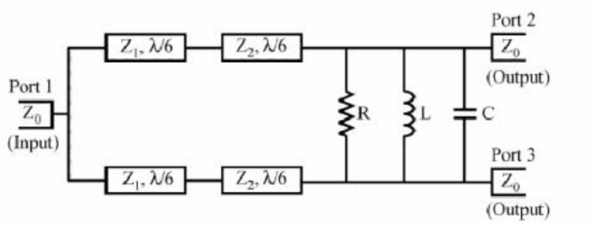

Fig 3. Dual frequency Wilkinson Power Divider for a Frequency and Its First Harmonic

The dual frequency Wilkinson Power Divider operating at different frequency ratios is proposed and the design fabricated is as shown in Fig.4 below. Simulation done by Agilent ADS software with operating frequencies of 1 GHz and 4 GHz for a substrate material RO 4003 is reported in [1]. Input return loss is 30dB at 1GHz and 35 dB at 4 GHz, output return loss at 1 & 4 GHz is 18dB & 36dB respectively. Power is equally divided and transmitted at both operating frequencies while the isolation is 20 dB at 1 GHz and 18 dB at 4 GHz.

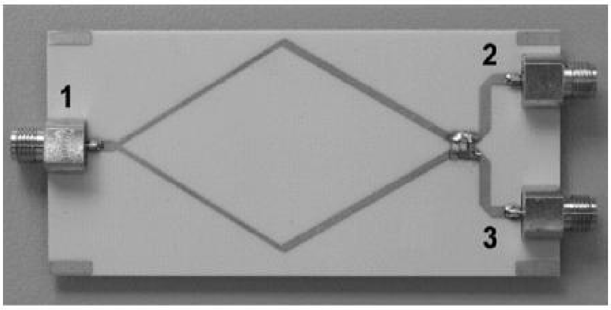

Fig 4. Dual frequency Wilkinson Power Divider

The Dual Frequency Wilkinson Power Divider operating at a single frequency and its first harmonic with unequal power divider ratio was proposed. As shown in Fig.5, four groups of λ /6 wavelength transmission lines with different characteristic impedances are used to match all port. Since the power dividing ratio is variable, the traditional even-mode and odd-mode analysis is not suitable. Using conventional transmission line theory, design as shown in fig 5 .is reported [3], which consists of four different transmission lines having different characteristic impedances to give unequal power division. The impedance Z as shown in Fig.5 consists of parallel combination of lumped components i.e. resistor, inductor, capacitor. The combination of lumped components is used to improve the isolation of output ports of dual frequency Wilkinson unequal power divider. Practically the unequal power divider was fabricated on a FR4 substrate. The power dividing ratio is 3.9 at 1 GHz and 3.4 at 2 GHz. The insertion loss S_{21} is 5.8 dB at 1GHz and 6.2 dB at 2GHz while S_{31} is 2.3 dB at 1GHz and 2.4 dB at 2 GHz. The match parameters i.e. $S_{11,}$ S_{22}, S_{33} are below 14 dB at 1 GHz and 2 GHz. The isolation parameters are 20 dB at 1 GHz and 18 dB at 2 GHz.

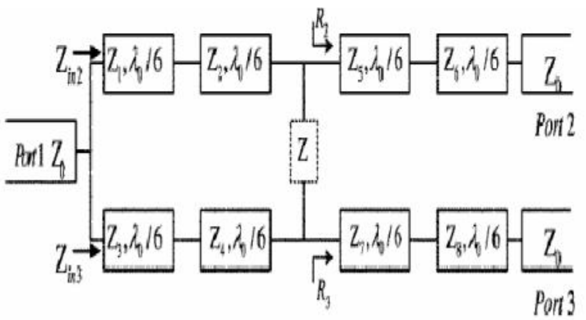

Fig 5. Dual frequency Wilkinson Unequal Power Divider for a Frequency and Its First Harmonic

A generalized dual-band Wilkinson Power Divider with a parallel *LC* circuit at the middle of constituent transmission lines is shown in Fig.6. The structure for the purpose of improvement in bandwidth is reported in [4]. Due to common even-mode circuits the input return losses and power division characteristics of proposed and conventional dual frequency Wilkinson Power Dividers are identical. The sum of reflected power at an output port and transmitted power to an isolation port in the proposed divider is always smaller than that in the case of a conventional dual frequency power divider. Therefore, wide band frequency characteristics are obtained in the proposed divider.

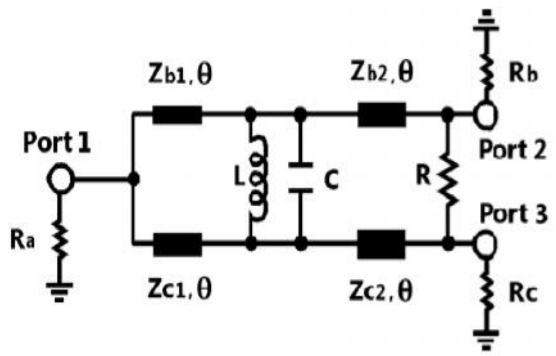

Fig 6. Parallel LC circuit at middle of dual frequency Wilkinson Power Divider

Dual frequency Wilkinson Power Divider has the main application in mobile devices. To make the mobile handsets more and more compact, reduction in the size of power divider has become a prime concern. By using defected ground structure and electronic band gap elements, the miniaturization of dual frequency Wilkinson Power Divider can be done. As shown in Fig.7 is the dumb-bell shaped DGS which is applied for microstrip line where a, b, g are the dimensions of DGS.

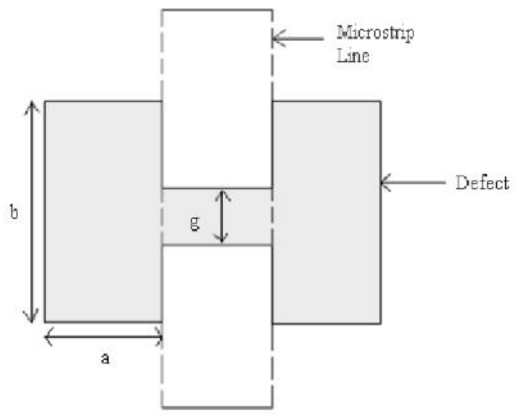

Fig 7. Dumb-bell Shaped DGS

Substrate plays a vital role in the fabrication processes. FR4, Rogers, poly tetrafluorethylene (PTFE) substrates are widely available in the market. Out of that Rogers RO 4000 is the widely used one. The main advantage of this is superior high frequency performance and low cost circuit fabrication. Low dielectric loss allow RO 4000 series material to be used in many applications where higher operating frequencies limits the conventional circuit board laminates [6]. Another option for substrate is FR4 i.e. glass epoxy.

Softwares available for EM simulation are AWR Microwave Office, Zeland IE3D, Agilent ADS.

Microwave Office design suite provides solutions for all types of RF and microwave circuits, from integrated microwave assemblies to monolithic microwave integrated circuits (MMICs). By using this software one can do schematic, layout design, simulation of linear and nonlinear circuits, EM analysis, synthesis, optimization and yield analysis. Microwave Office software seamlessly integrates AWR's powerful, innovative tools and technologies with application-specific tools from partner companies to bring their high-frequency designs to life quickly and easily. [7].

Advanced Design System (ADS) is a computer aided design tool (CAD) from Agilent Technologies. It allows for design of circuits in both the RF and microwave range. ADS are in common use in universities around the world, making it a well known tool for a large number of electronics graduates. This, along with being a marked leader in a number of fields, has made ADS the industry leader in high-frequency design. Among the innovative functions of ADS is the Harmonic Balance function which was the first commercially available simulator of its kind when it was introduced in the early 1980's. It also has the only commercially available timed synchronous data flow simulator for system level simulation. The key components when designing a circuit in ADS is a schematic window where the circuit is drawn and simulated, a data display window where the simulation results can be displayed in various forms, and a layout window where the physical components are laid out and simulated using electromagnetic simulators [8].

IE3D is an integrated full-wave electromagnetic simulation and optimization package for the analysis and design of 3-D microstrip antennas, microwave and millimeter-wave integrated circuits, and high-speed printed circuit board. Maxwell Equations of E-field and H-field involves many unknowns. Instead, the IE3D solves the Maxwell's Equations in an integral form with Green's functions. For most practical circuit and antenna structures, the metallic domain is limited and the solution domain of the IE3D is also very limited. A typical example is a microstrip circuit. The solution domain is the just the surface of the printed strip only. Its solution domain is significantly smaller than that of the original Maxwell's Equations [9].

IV. CONCLUSION

In this paper we have taken the review of various techniques for the design of dual frequency Wilkinson Power Divider. Also a discussion of different frequency and power ratios for a dual frequency Wilkinson Power Divider are discussed. And we have observed that as dual frequency Wilkinson Power Divider consists of two different transmission lines, its size also get increased if compared with conventional Wilkinson Power Divider, hence main challenge is miniaturization of the divider. Using Defected Ground Structures (DGS) and Electromagnetic Band Gap (EBG) cells size reduction, harmonic suppression and S-parameters improvement can be achieved [5].

Dual frequency Wilkinson equal power divider operating at two cellular frequencies in GSM band can be designed with lumped components using the FR4 substrate. Since it consists of two different transmission lines with two different frequencies, it has considerable size increment in comparison with conventional single frequency Wilkinson Power Divider. Hence the size reduction of the same can be done by using slow wave effects of defected ground structure. This can be designed in Agilent ADS software.

REFERENCES

[1]. Lei Wu, Zengguang Sun, Hayattin Yilmaz, and Manfred Berroth, "A Dual-Frequency Wilkinson Power Divider", IEEE Transactions and Microwave Theroy, Techniques , Vol. 54, No. 1, January 2006.
[2]. Wu, L., Yilmaz, H., Bitzer, T., Berroth, A.Pascht.M. , "A dual-frequency Wilkinson Power Divider: for a frequency and its first harmonic", IEEE, Microwave and Wireless Components Letters, Volume: 15, Issue: 2, 2005.
[3]. Wu, Yong-le, Zhou, Hui , Zhang, Ya-Xing, Liu, Yuan'an , "An Unequal Wilkinson Power Divider for a Frequency and Its First Harmonic", IEEE, Volume :18,Issue:11,Microwave and Wireless Components Letters, 2008
[4]. Xiaolong Wang, IwataSakagami, Kensaku Takahashi, Shingo Okamura, "A Generalized Dual-Band Wilkinson Power Divider With Parallel L,C and R Components" ,IEEE TRANSACTIONS on microwave theory and Techniques, vol. 60, no. 4, April 2012
[5]. Chou, I-Tung ; Peng, Chia-Mei M. ; I-Fong Chen, "A dual-band Wilkinson Power Divider with microstrip slow-wave structures", Page(s): 723 – 726,Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC)Publication Year: 2010
[6]. www.rogerscorp.com
[7]. www.awrcorp.com
[8]. www.agilent.com
[9]. IE3D elctromagnetic simulator.,www.zeland.com
[10]. D.M.Pozar, *Microwave Engineering*, 3rd ed. Hoboken, NJ: Wiley,2005.