Design of Power Divider for C-Band Operation Using High Frequency Defected Ground Structure (DGS) Technique

S.Gopalakrishnan [1], D.Vijayakumar [2], G.Sasi [3]

[1, 2] *Department of ECE*, CMR College of Engineering & Technology, Hyderabad, Telangana-501401, India.
Email: [1] drgopalakrishna@cmrcet.org, [2] drdvijayakumar@cmrcet.org

[3] *Department of ECE*, PSNA College of Engineering and Technology, Dindigul, Tamilnadu-624622, India.
[3] Email: Shasiece14@psnacet.edu.in

Abstract **- Power dividers and directional couplers are passive devices used frequently in the field of radio technology. In the field of microwave engineering and circuit design, Power Divider is a specific class of power divider circuit that can accomplish isolation between the output ports while maintaining a coordinated condition on all ports. In this paper, the Triangular shaped Micro strip Power Divider is designed for C-band operation using Defected Ground Structure (DGS). The triangular structure of the power divider is introduced to have collinearly output. The passive power divider is used extensively at microwave and millimeter wave frequencies. It supports frequency ranges from 2 to 4.5GHz for better return loss. Phase and amplitude equalizations are used at the output ports to achieve better performance. Calculations are carried out using different simulation tools based on different numerical techniques.**

Keywords - Power divider, Directional coupler, Strip line, micro strip, Triangular Shaped Wilkinson Power Divider,

I. INTRODUCTION

Power entering the output port is coupled to the isolated port but not to the coupled port. A directional coupler designed to split power equally between two ports is called a hybrid coupler. Directional couplers are most frequently constructed from two coupled transmission lines set close enough together such that energy passing through one is coupled to the other [1] [2]. This technique is favored at the microwave frequencies where transmission line designs are commonly used to implement many circuit elements. Directional couplers and power dividers have many applications. These include providing a signal sample for measurement or monitoring, feedback, combining feeds to and from antennae, antenna beam forming, providing taps for cable distributed systems such as cable TV, and separating transmitted and received signals on telephone lines.

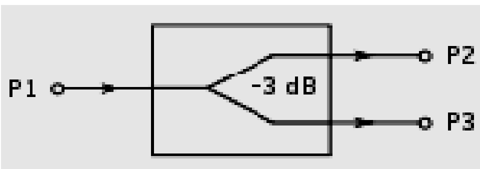

Figure 1. Symbol for power divider

Common properties desired for all directional couplers are wide operational bandwidth, high directivity, and a good impedance match at all ports when the other ports are terminated in matched loads [3].

A. Directional Couplers

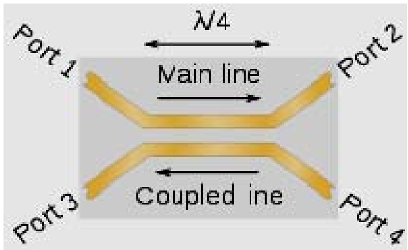

Figure 2. Single section λ/4 directional coupler

The most common form of directional coupler is a pair of coupled transmission lines. They can be realized in a number of technologies including coaxial and the planar technologies (Stripline and Microstrip). An implementation in strip line is shown in figure 2 of a quarter-wavelength (λ/4) directional coupler [4]. The power on the coupled line flows in the opposite direction to the power on the main line, hence the port arrangement is not the same as shown in figure 2, but the numbering remains the same. For this reason it is sometimes called a backward coupler. The main line is the section between ports 1 and 2 and the coupled line is the section between ports 3 and 4. Since the directional coupler is a linear device, the notations on figure 1.2 are arbitrary. Any port can be the input, which will result in the directly connected port being the transmitted port, the adjacent port being the coupled port, and the diagonal port being the isolated port.

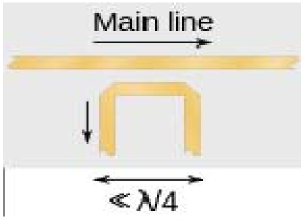

Figure 3 Short section directional coupler

Accuracy of coupling factor depends on the dimensional tolerances for the spacing of the two coupled lines. For planar printed technologies this comes down to the resolution of the printing process which determines the minimum track width that can be produced and also puts a limit on how close the lines can be placed to each other. This becomes a problem when very tight coupling is required and 3 dB couplers often use a different design.

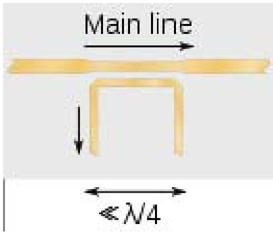

Figure 4 Short section directional coupler with 50 Ω main line and 100 Ω coupled line

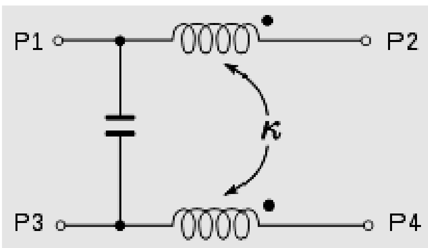

Figure 5-a. Lumped element equivalent circuit of the couplers

The λ/4 coupled line design is good for coaxial and strip line implementations but does not work so well in the now popular micro strip format, although designs do exist. The reason for this is that micro strip is not a homogeneous medium – there are two different mediums above and below the transmission strip. This leads to transmission modes other than the usual TEM mode found in conductive circuits [7]. The propagation velocities of even and odd modes are different leading to signal dispersion. A better solution for micro strip a coupled line much shorter than λ/4, shown in figure .4, but this has the disadvantage of a coupling factor which rises noticeably with frequency. A variation of this design sometimes encountered has the coupled line a higher impedance than the main line such as shown in figure 5. This design is advantageous where the coupler is being fed to a detector for power monitoring. The higher impedance line results in a higher RF voltage for a given main line power making the work of the detector diode easier. The frequency range specified by manufacturers is that of the coupled line [5] [6]. The main line response is much wider: for instance a coupler specified as 2– 4 GHz might have a main line which could operate at 1–5 GHz. As with all distributed element circuits, the coupled response is periodic with frequency. For example, a λ/4 coupled line coupler will have responses at nλ/4 where n is an odd integer.

B. Power Dividers

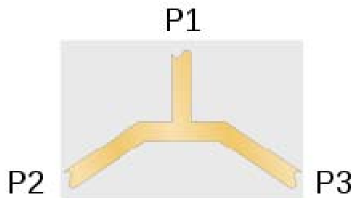

Figure. 5-b Simple T-junction power division in planar format

The earliest transmission line power dividers were simple T-junctions. These suffer from very poor isolation between the output ports – a large part of the power reflected back from port 2 finds its way into port 3. It can be shown that it is not theoretically possible to simultaneously match all three ports of a passive, lossless three-port and poor isolation is unavoidable. It is, however, possible with four- ports and this is the fundamental reason why four-port devices are used to implement three-port power dividers: four-port devices can be designed so that power arriving at port 2 is split between port 1 and port 4 (which is terminated with a matching load) and none (in the ideal case) goes to port 3.

The term hybrid coupler originally applied to 3 dB coupled line directional couplers, that is, directional couplers in which the two outputs are each half the input power. This synonymously meant a quadrature 3 dB coupler with outputs 90° out of phase. Now any matched 4-port with isolated arms and equal power division is called a hybrid or hybrid coupler. Other types can have different phase relationships. If 90°, it is a 90° hybrid, if 180°, a 180° hybrid and so on. In this article hybrid coupler without qualification means a coupled line hybrid.

DOI 10.5013/IJSSST.a.19.06.21

ISSN: 1473-804x online, 1473-8031 print

II. CURRENT SYSTEMS

A. Wilkinson Power Divider Splitter Combiner

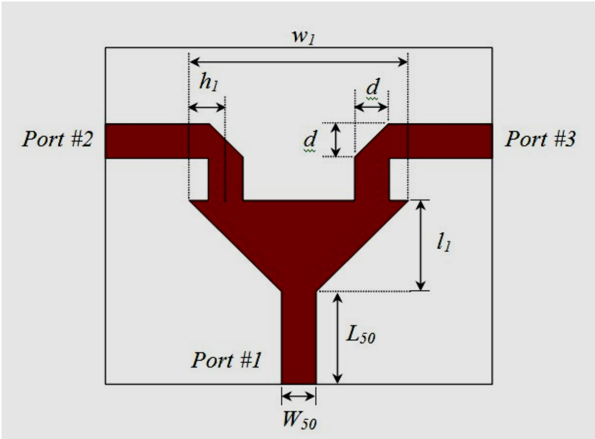

Figure 6.Triangular Shaped Wilkinson Power Divider

In the field of microwave engineering and circuit design, the Wilkinson Power Divider is a specific class of power divider circuit that can achieve isolation between the output ports while maintaining a matched condition on all ports. The Wilkinson design can also be used as a power combiner because it is made up of passive components and hence reciprocal. First published by Ernest J. Wilkinson in 1960, this circuit finds wide use in radio frequency communication systems utilizing multiple channels since the high degree of isolation between the output ports prevents crosstalk between the individual channels. It uses quarter wave transformers, which can be easily fabricated as quarter wave lines on printed circuit boards. It is also possible to use other forms of transmission line (e.g. coaxial cable) or lumped circuit elements (inductors and capacitors).The Wilkinson divider splitter / Wilkinson combiner is a form of power splitter / power combiner that is often used in microwave applications. It uses quarter wave transformers, which are easily fabricated as quarter wave lines on printed circuit boards and as a result it offers the possibility of proving a very cheap and simple splitter / divider / combiner while still providing high levels of performance. While the printed circuit board transmission line approach is widely used for the Wilkinson divider / splitter combiner, it is also possible to use other forms of transmission line (e.g. coaxial cable) or lumped circuit elements (inductors and capacitors).The Wilkinson power divider or Wilkinson splitter as it is also known takes its name from Ernest Wilkinson, the electronics engineer who initially developed it in the 1960s. Wilkinson published his idea in IRE Trans. on Microwave Theory and Techniques, in January 1960 under the title: “An N-way Power Divider”. It can be seen from the title of the paper that the idea for what is now known as the Wilkinson power splitter is for a multiple port device, although the most common implementation seen in practice these days is for a two way divider [8].

B. Two Way Wilkinson Power Divider Basics

Although the Wilkinson power divider concept can be used for an N-way system, it is easiest to see how it operates as a two way system, and later expand it out to see how the Wilkinson power splitter can be used as an n-way device. The Wilkinson power divider / Wilkinson combiner uses quarter wave transformers to split the input signal to provide two output signals that are in phase with each other [9].

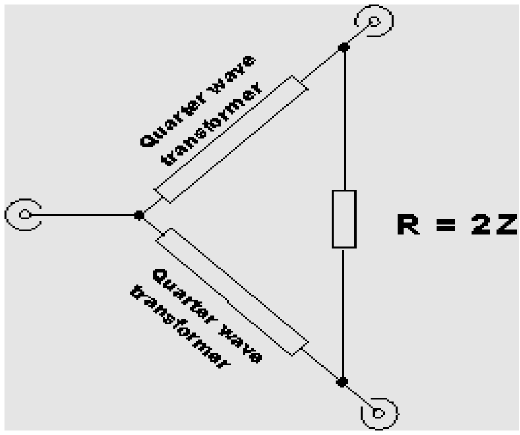

Figure.7 A 2-way Wilkinson Power Divider

C. A Two Way Wilkinson Power Splitter/Divider and Wilkinson Combiner

The resistor between the two output ports enables the two outputs to matched while also providing isolation. The resistor does not dissipate any power, and as a result the Wilkinson power divider can theoretically be lossless [10]. In practice there are some losses, but these are generally low.

The values within the two way Wilkinson divider / combiner can be calculated:

$$R = 2 \times Zo \quad (1)$$

$$Zmatch = 1.414 \times Zo \quad (2)$$

Where:
R = the value of the terminating resistor connected between the two ports
Zo = the characteristic impedance of the overall system
Zmatch = the impedance of the quarter wave transformers in the legs of the power divider combiner.

DOI 10.5013/IJSSST.a.19.06.21

ISSN: 1473-804x online, 1473-8031 print

III. NEW PROPOSED POWER DIVIDER DESIGN

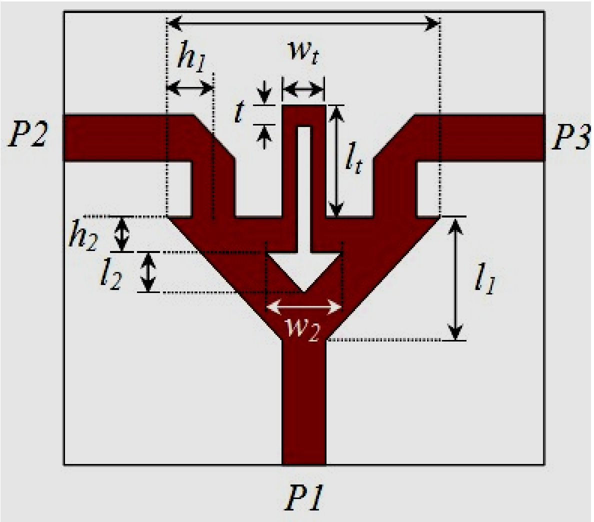

Figure 8.Geometry of proposed TPD Design-top view.

It is a triangular shaped microstrip power divider for C-band operation, i.e. 4.0-8. 0GHz using Defected Ground Structure (DGS) technique. Calculations are carried out using different simulation tools based on different numerical techniques.

The geometry of the conventional triangular shaped power divider (TPD) circuit layout is illustrated in Fig. 11. The substrate used in our design is Rogers RT5880 with a thickness of 1.575 mm, a relative permittivity εr = 2.2, and a loss tangent tanδ = 0.0009. The impedance of the input and output ports are chosen to be 50Ω.

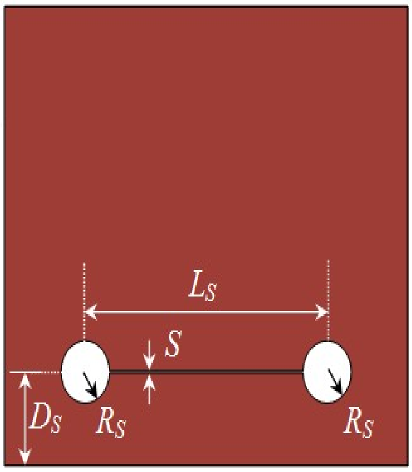

Figure 9. Geometry of proposed TPD Design-bottom view.

The simulated input reflection coefficient (S11) and transmission coefficients (S21 & S31) responses between input and output ports are shown in Fig. 4.2. It can be seen that the operating frequency is 8.5GHz with operating bandwidth of 1.5GHz (18%). The calculated results show a good input return loss of -13dB (HFSS [6]) and -16dB (CST MWS [7]) and insertion losses of -4dB (HFSS) and -3.4dB (CST MWS), respectively. In this paper, we present a triangular shaped microstrip power divider for C-band operation, i.e. 4.0-8.0GHz using Defected Ground Structure (DGS) technique. Calculations are carried out using different simulation tools based on different numerical techniques.

To improve the TPD performance and to broaden the bandwidth, a defected ground structure (DGS) has been proposed to the conventional TPD. Fig.12 Shows the proposed TPD circuit layout for C-band operation. The bottom view shows the ground plane with two circular cuts of radius RS separated by distance LS and they are connected together by an arrow line with thickness S. The DGS is located at a distance DS from the substrate edge. The triangular shaped patch has been modified using a tuning stub of width wt , length lt and thickness t. A cut in the tuning stub has been added with widthw2, length l2 and located at h2 from the edge of the triangular patch. It is used for matching purposes and to enhance the impedance bandwidth. The parameters of the proposed TPD were optimized to attain good return loss at all ports and good isolation over the whole C-band frequency range. The optimized parameters dimensions for the proposed TPD are tabulated in Table1.

TABLE 1: OPTIMIZED PARAMETERS DIMENSIONS FOR THE PROPOSED TPD

Input/output lines (50Ω)	W_{50}	L_{50}	Units: mm		
	4.5	10			
Power divider dimensions	w_1	l_1	w_2	l_2	w_t
	28.4	11.95	8.0	4.0	4.5
	l_t	t	h_1	h_2	
	10.9	2.0	4.73	3.4	

A. High Frequency Structure Simulator (Hfss)

HFSS is a high-performance full-wave Electro Magnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S Parameters, Resonant Frequency, and Fields.

B. Typical Uses Include

- Package Modeling – BGA, QFP, Flip-Chip
- PCB Board Modeling – Power/Ground planes, Mesh Grid Grounds, Backplanes
- Silicon/GaAs - Spiral Inductors, Transformers EMC/EMI – Shield
- Enclosures, Coupling, Near- or Far-Field Radiation
- Antennas/Mobile Communications – Patches, Dipoles, Horns, Conformal Cell Phone Antennas, Quadrafilar Helix, Specific Absorption Rate(SAR), Infinite Arrays, Radar Cross Section(RCS), Frequency Selective Surfaces(FSS)
- Connectors – Coax, SFP/XFP, Backplane, Transitions
- Waveguide – Filters, Resonators, Transitions, Couplers
- Filters – Cavity Filters, Micro strip, Dielectric

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques. Ansoft pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep (ALPS). Today, HFSS continues to lead the industry with innovations such as Modes-to-Nodes and Full-WaveSpice™.Ansoft HFSS has evolved over a period of years with input from many users and industries. In industry, Ansoft HFSS is the tool of choice for high-productivity research, development, and virtual prototyping.

C. System Requirements

Microsoft Windows XP (32/64), Windows 2000, or Windows 2003 Server. For upto-date information, refer to the HFSS Release Notes.

- Pentium –based computer.
- 128MB RAM minimum.
- 8MB Video Card minimum.
- Mouse or other pointing device.
- CD-ROM drive.

IV. RESULTS AND DISCUSSION

A. Simulation Results

A parametric study has been carried out to address the effect of DGS parameters (RS, S, LS, and DS) on the performance of the proposed TPD. It is found that the TPD performance is very sensitive to the DGS parameters. Fig. 4 (a) & (b) presents the simulated reflection and transmission coefficients for different RS values with fixed S, LS, and DS to 0.2 mm, 30 mm and 9 mm, respectively. The optimum RS value is found to be 3mm. The variation of reflection and transmission coefficients with S for fixed RS = 3 mm, LS = 30mm, and DS = 9mm are introduced. The optimum value for S is found to be 0.2 mm.The simulated reflection and transmission coefficients for different LS values with fixed RS, S, and DS to 3 mm, 0.2 mm and 9 mm, respectively. The optimum LS value is found to be 30 mm. The variation of reflection and transmission coefficients with DS for fixed RS = 3 mm, LS = 30 mm, and S = 0.2 mm. The optimum value for DS is found to be 9 mm. From calculated S-parameters for the proposed TPD. The power is split equally between the output ports from -0.7dB to -1.5dB (using HFSS) or from -0.3dB to -2.5dB (using CST MWS). The input reflection coefficient S11 is lower than -13dB through the whole C-band range. The phase difference between the two outputs ports and group delay for the proposed TPD. It has been shown that the two output signals are in phase with good phase linearity across the whole frequency band. The group delay of the proposed TPD is almost constant and less than 2ns which shows good linearity within the UWB frequency spectrum.

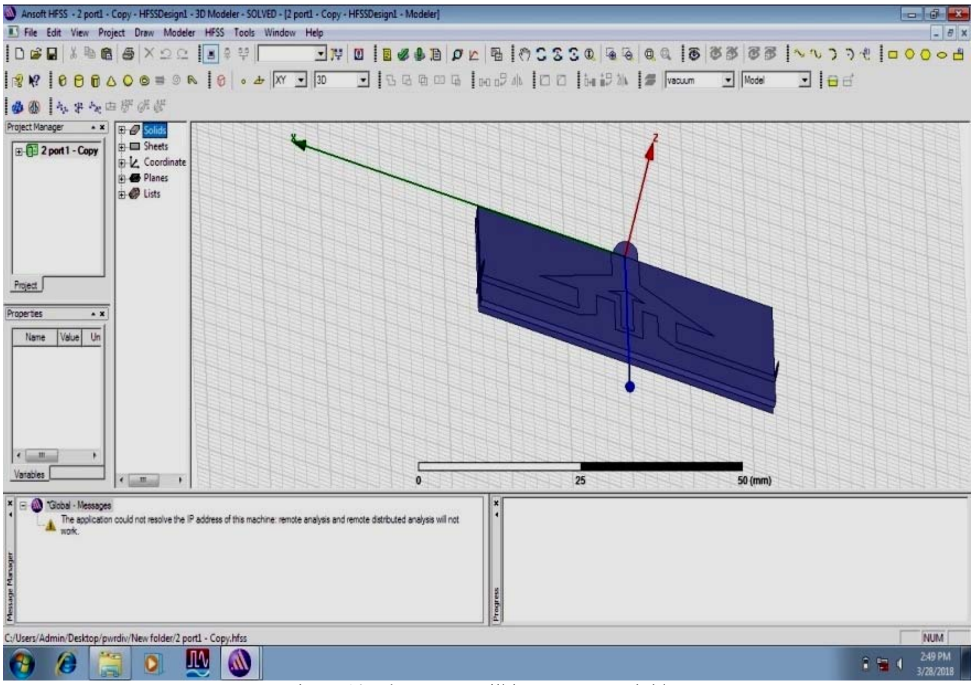

Figure 10. Three way Wilkinson Power Divider.

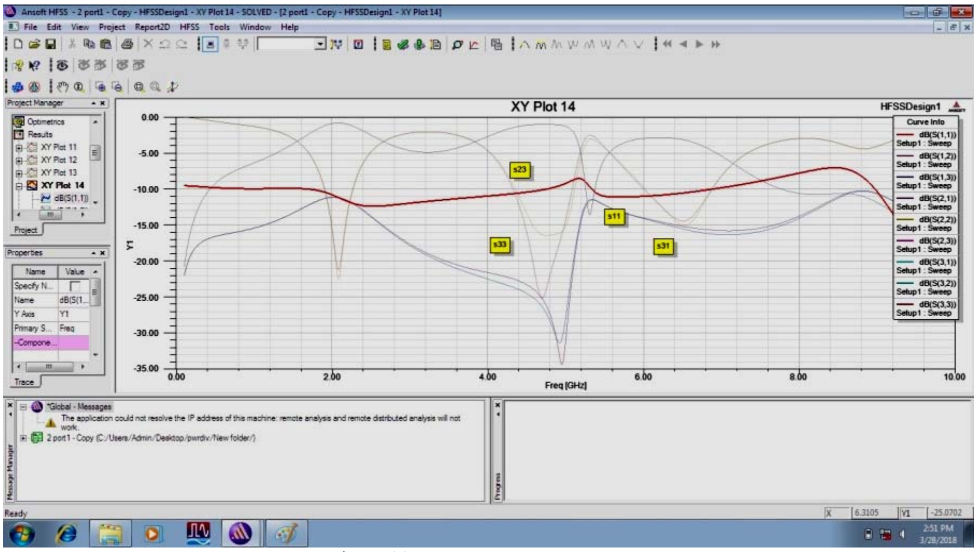

Figure 11. Return Loss Vs Frequency.

The characteristics between return loss and frequency are as shown in the figure 14. In this graph, the output is obtained for s11 parameter. Bandwidth is obtained between the range 2GHz - 4.7GHz. Return loss (-22dB) is simulated for this frequency range.

V. CONCLUSION

The modified Triangular shaped Wilkinson Power Divider with good return loss and reduced number of amplifiers is designed for C-band operation using Defected Ground Structure (DGS). In the Triangular Power Divider, return loss (-22dB) is obtained in the required frequency ranges from 2 to 4.5GHz .Collinear output and increased bandwidth are achieved for better performance.

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