Comparative Performance Analysis of Various Micro-strip Power Dividers

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Abstract — **In this paper, a 2-way equal Wilkinson Power Divider (WPD), 3-way equal and unequal Wilkinson power divider and 2-way Gysel Power Divider (GPD) is proposed, implemented and analyzed. The proposed Power Dividers are based on micro-strip line with 50 ohm characteristic impedance. The dividers are composed of multi-section micro-strip line and isolation resistors. They provide high isolation and very good input/output ports matching simultaneously at arbitrary design frequencies. The power divider geometry is analyzed using AWR simulator and the performance metrics such as insertion loss, return loss and isolation loss are computed. This study reports the successful implementation of micro-strip line based Wilkinson power divider and Gysel Power Divider with low losses for a frequency range of 0 to 3 GHz with 1.030 GHz centre frequency (IFF Frequency band).**

Keywords: Wilkinson power divider; Gysel power divider; Micro-strip line; Identification friend or foe.

I. INTRODUCTION

POWER dividers are called as power splitters. When used in reverse it acts as the power-combiner, a vital role in various RF and communication applications [1, 2].

It is a passive device which is used in the field of radio technology which requires power to be distributed among different paths. The easiest way to approach this method can be done by using a power splitter/divider.

The areas of applications are TV analyzer, hand-held spectrum analyzer, antenna arrays, and microwave applications, WLAN such as 802.11b, 802.11g, and 802.11n over a frequency range of 2.4GHz band.

Power dividers are used especially for antenna array systems that utilize power-splitting network, such as a corporate or parallel feed system. The two main categories of power dividers are reactive and resistive and each can be suited for its own specific applications.

Wilkinson Power Divider (WPD) belongs to reactive power divider in which it has some special properties such as lossless network, high isolation between output ports and low insertion and isolation loss [1 - 3]. It has a single input port and more than one output port. But the main advantage of divider is that all ports are theoretically matched and output ports are isolated from one another [4].

It is usual, but not mandatory, for the transmission from the input port to be identical to all output ports. It can be designed with different transmission line sections such as strip-line coaxial, micro-strip, airstrip and lumped element circuit topographies to realize its designs. The desirable properties of a power divider are low insertion loss, low isolation loss, high isolation between outputs ports and high return loss. The additional desirable property of a power divider is wider bandwidth leading to number of

The additional desirable property of a power divider is wider bandwidth leading to number of sections and is helpful for *N*-way power division [1, 2].

In this paper, 2-way Wilkinson Power Divider, 2-way Gysel Power Divider, 3-way equal and Unequal Wilkinson Power Divider are proposed. The design of Power Dividers is deployed on glass-reinforced epoxy (FR-4) dielectric substrate with relative permittivity of 4.4, height 1.6 mm and thickness of 0.05 mm. Simulation of the proposed structure in AWR Software shows acceptable values of reflection coefficient, insertion loss and isolation at centre frequency of 1.030 GHz. The proposed power divider has potential application in radar and defense systems, especially in phased-array systems.

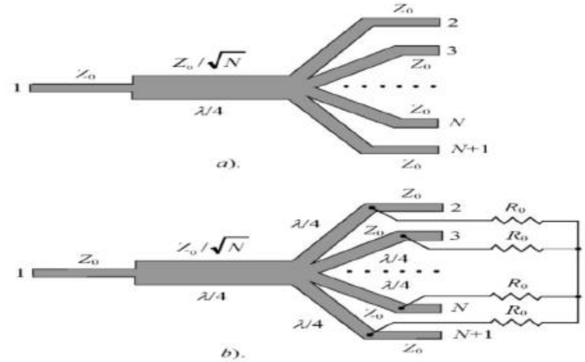


Figure 1. Circuit topologies of N-way in-phase combiners/dividers (a) Without terminating resistors (b) with terminating resistors.

Figure 1 shows circuit topologies of *N*-way in-phase combiners/dividers without terminating resistors and with terminating resistors.

II. PREVIOUS WORK

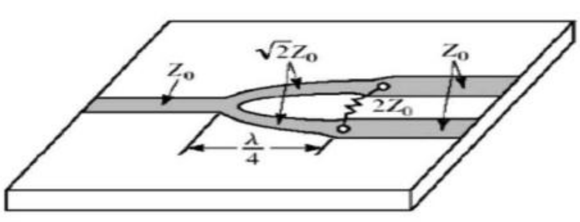
In 1960, a theoretical approach of power divider with *N*-output port (*N* >2) was developed by Wilkinson [5]. Since the related work is one of the fundamental theories in hybrid power divider, then it has been becoming most reference for next researchers that work related to the power divider/splitter and its application. Some development to utilize a power-splitting network, such a corporate or parallel feed system has been applied for antenna array systems by use of 3-port power dividers [6].

In this work, the use of corporate feeding network is applied to split signal power between *N* outputs ports with a certain distribution while maintaining equal path lengths from input to output ports. Unfortunately, all the related works are usually for a normal condition of application.

Whilst for a specific application, such as lower power surveillance radar, a power divider with an unusual number of output ports still needs to be further investigated to be developable. In addition to the Wilkinson topology, the main problem for *N* output port more than 2 is the non planarity of the circuit due to the presence of a floating node connecting all isolation resistors together [7]. Nevertheless, the Wilkinson *N*-way divider or combiner topology still remains attractive up to now, at least, for some reasons such as the possibility of designing an odd number of outputs, the capability to have a compact size (only a quarter wavelength) and a theoretical ideal performance.

III. WILKINSON POWER DIVIDER

The Wilkinson power divider is a three-port network which is lossless when the output ports are matched; where only reflected power is dissipated. Input power can be split into two or more in-phase signals with the same amplitude. For a two-way Wilkinson power divider with λ/4 impedance transformers (characteristic impedance $2\sqrt{Z_0}$) and a lumped isolation resistor of 2, high isolation between the output ports can be obtained [5]. The design of an equal-split (3 dB) Wilkinson power divider is often made in strip-line or micro-strip form. The basic topology and its equivalent transmission line model are shown in Fig.2.



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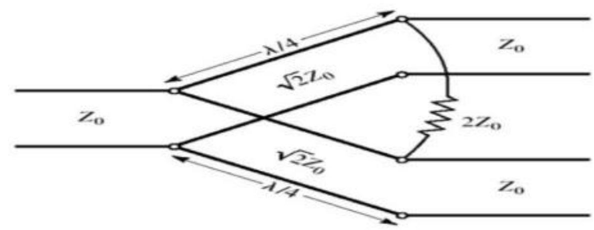


(*b*)

Figure 2. the Wilkinson power divider (*a*) an equal-split Wilkinson Power divider in micro-strip form and (*b*) Equivalent Transmission line circuit.

IV. GYSEL POWER DIVIDER

The Gysel power divider overcomes the high power-handling problem by introducing two short-ended resistors that can transfer the heat to the ground plane effectively. For this specialty, much attention has recently been paid to the Gysel power divider. Figure 3 shows Gysel high-power in-phase planar combiner/divider**.**

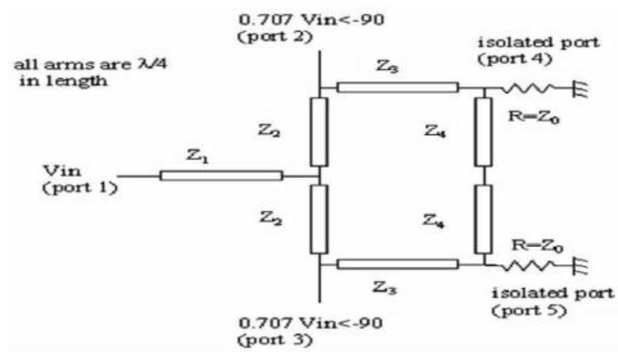


Figure 3. Gysel high-power in-phase planar combiner/divider**.**

V. DETERMINATION OF PARAMETERS

Isolation, VSWR, Input power, Amplitude balance, return loss, and insertion losses are the common measurable parameters for the WPD. Return loss is the loss of signal power resulting from the reflected power caused at a discontinuity in a transmission line or optical fibre which may lead to a mismatch with the terminating load or with a device inserted in the line:

$$RL\ (dB) = -20 \log_{10} |S_{11}| \qquad (1)$$

Insertion loss is the loss of the signal power resulting from the insertion of a device in a transmission line. In case the two measurement ports use the same reference impedance, the insertion loss in can be expressed as below:

$$IL\ (dB) = -20 \log_{10} |S_{21}| \qquad (2)$$

For *N*-Port WPD,

$$IL = -10 \log_{N} (dB) \qquad (3)$$

Isolation is when splitting a signal the voltage present on each side of the isolation resistor is of equal potential and therefore no current flows through the resistor and no power dissipated. The isolation in can be expressed as below:

Isolation (dB) = -20 $\log_{10} |S_{32}|$ (4)

Voltage Standing Wave Ratio is a measure of the deviation of impedance from the characteristic impedance of the power divider and is given by

$$VSWR= 1 + |\tau| / 1- |\tau| \quad (5)$$

$$|\tau|= 10^{-RL(dB)/ 20} \quad (6)$$

VI. DESIGN OF 2-WAY WILKINSON POWER DIVIDER

The Micro-strip realization of 2-Way WPD is show in Figure 4.

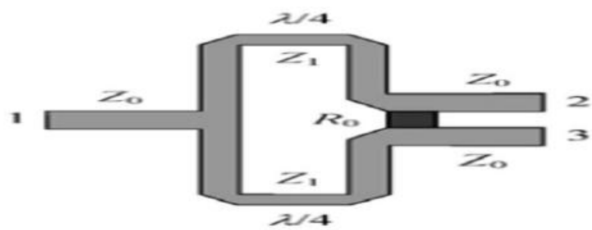


Figure 4. Micro-strip realization of 2-Way WPD.

The design values are Z_0= 50 Ω, Z_1= $Z_0\sqrt{2}$= 70.71 Ω, R_0= $2Z_0$= 100 Ω. The circuit diagram is shown in Fig. 5.

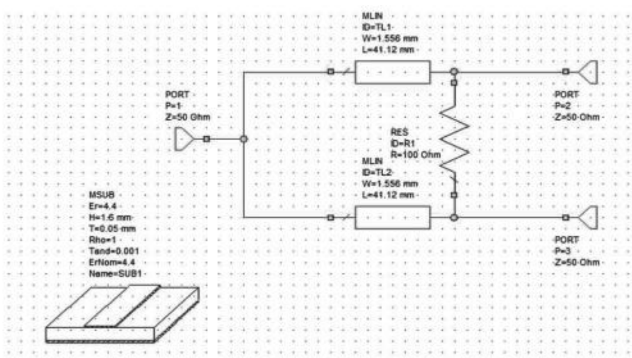


Figure 5. Circuit Diagram of 2-Way WPD.

In figure 5, the length and width of transmission lines are L = 41.12 mm and W = 1.556 mm.

VII. DESIGN OF 2-WAY GYSEL POWER DIVIDER

The circuit topology of 2-Way Gysel Power Divider is shown in figure 6.

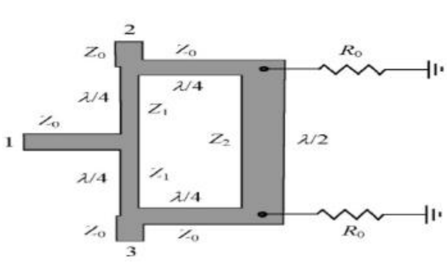


Figure 6. Gysel high-power in-phase planar combiner divider.

For a two-way Gysel planar power combiner/divider, the circuit topology of which is shown in Fig.6, the balanced 100Ω ballast resistor is replaced by a transmission-line network and two 50Ω resistors are connected to ground acting as the out-of phase load [8].

The design values are Z_0= 50 Ω, Z_1= $Z_0\sqrt{2}$= 70.71 Ω, Z_2= $Z_0\sqrt{2}$ = 70.71 Ω, R_0=Z_0= 50 Ω. The circuit diagram implemented on AWR is shown in Fig. 7.

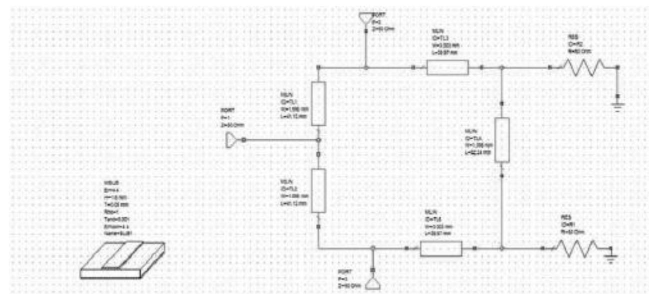


Figure 7. Circuit Diagram of 2-Way GPD.

From figures 6 and 7, the length and width of transmission line Z_1 are L = 41.12 mm and W = 1.556 mm respectively, the length and width of transmission line Z_0 are L = 39.97 mm and W = 3.003 mm respectively and the length and width of transmission line Z_2 are L = 82.24 mm and W = 1.556 mm respectively.

VIII. DESIGN OF 3-WAY EQUAL WILKINSON POWER DIVIDER

The circuit topology of 3-Way Equal WPD is shown in Fig. 8 [9].

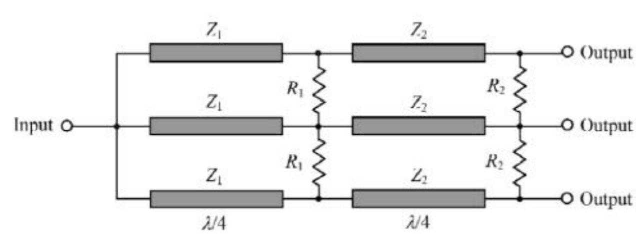


Figure 8. Micro-Strip 3-Way WPD with improved isolation.

Assuming all the impedances of the input and three output ports be 50Ω, the characteristic impedances of the quarter-wave transmission lines are selected for a maximally flat performance as Z_1 = 114Ω and Z_2= 65.8Ω. To match circuit at the centre frequency, the values of the ballast planar resistors should be chosen as R_1 = 64.95Ω and R_2 = 200Ω. In this case, the isolation between output ports of such a three way divider demonstrates more than 20 dB in an octave frequency bandwidth. The circuit diagram of 3-Way Equal WPD is shown in Fig. 9.

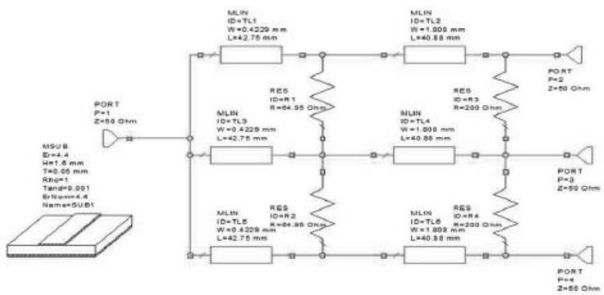


Figure 9. Realization of 3-way equal WPD on AWR software.

From figures 8 and 9, the length and width of transmission line Z_1 are $L = 42.74$ mm and $W = 0.4229$ mm respectively and the length and width of transmission line Z_2 are $L = 40.88$ mm and $W = 1.808$ mm respectively.

IX. DESIGN OF 3-WAY UNEQUAL WILKINSON POWER DIVIDER

The circuit topology of 3-Way Unequal WPD is shown in Fig. 10.

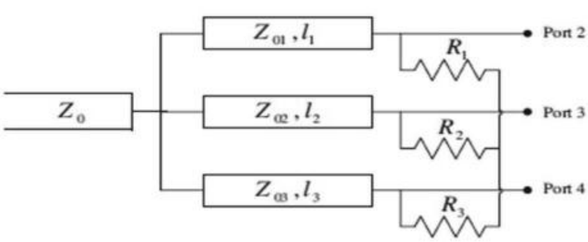


Figure 10. 3-Way unequal WPD.

Here $Z_0 = 50\ \Omega$. The input power is divided as follows: 50% goes to port 2, 25% goes to port 3, and 25% goes to port 4. The parameters of branch 1 (Z_{01} and l_1) are found by combining ports 3 and 4 (branch 2 and branch 3). The equivalent 2-way model is shown in Fig. 11. This 2-way model is equal-split, *i.e.*, $K^2 = 1$, (P% branch 2 + P% branch 3 = 50%). Using the analysis, branch 1 parameters are as follows: $Z_{01} = Z_0\sqrt{K}(1+K^2)$, $R_1 = K\,(Z_0)$ and $l_1 = \lambda/4$.

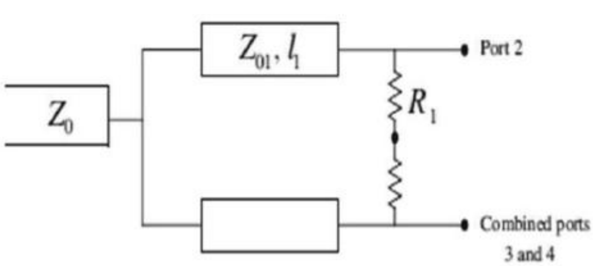


Figure 11. Equivalent model to derive the parameters of branch 1.

Parameters of branch 2 (Z_{02} and l_2) are found by combining ports 2 and 4 (branch 1 and branch 3). Since ports 3 and 4 have the same power ratio, the same results are achieved by combining ports 2 and 3 to find the parameters of branch 3 (Z_{03} and l_3). In this case, the equivalent 2-way model is shown in figure 12.The power split ratio in this divider is $k^2 = 3$, since the combined ports take 75% of the input power.

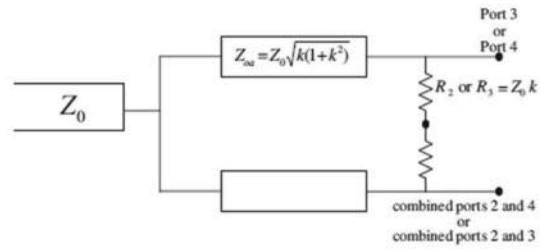


Figure 12. Equivalent model to derive the parameters of branch 2 (or branch 3).

Thus, the parameters of branches 2 and 3 are given as follows: $Z_{02} = Z_{03} = Z_0\sqrt{K}(1+K^2)$; $R_2 = R_3 = Z_0\,(K)$, $l_2 = l_3 = \lambda/4$. Using the above formulae, we get $Z_{01} = 70.7\Omega$; $Z_{02} = Z_{03} = 131.61\ \Omega$; $R_1 = 50\ \Omega$; $R_2 = R_3 = 86.60\ \Omega$ [10].

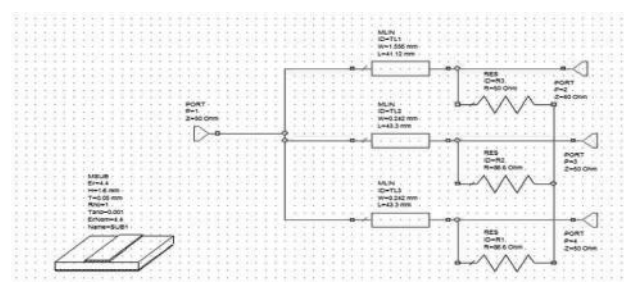


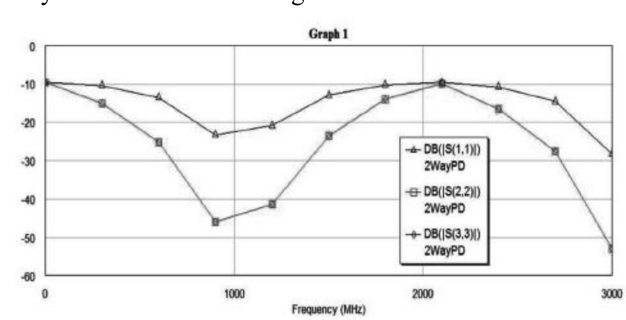
Figure 13. Circuit diagram of 3-way unequal WPD.

From the figures 10 and 13, the length and width of transmission line Z_{01} are L = 41.12 mm and W = 1.556 mm respectively, the length and width of transmission line Z_{02} are L= 43.3 mm and W = 0.242 mm respectively and the length and width of transmission line Z_2 are L= 43.3 mm and W = 0.242 mm respectively.

X. RESULTS AND DISCUSSION

Following sections show simulation results of various performance parameters of 2-way WPD, 2-way GPD, 3-way equal WPD and 3-way unequal WPD.

2-Way Wilkinson Power Divider: Performance parameters of 2-Way WPD are shown in Fig. 14.



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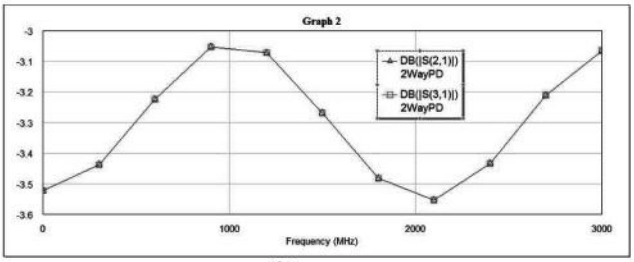

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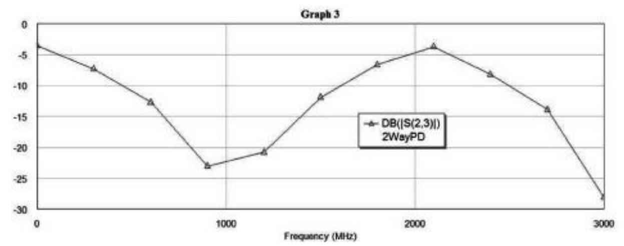
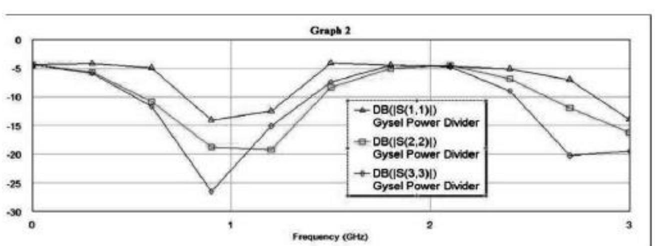


(*c*)

Figure 14. (*a*) 2 -way WPD matching *S*-parameters
(*b*) 2 -way WPD transmission *S*-parameters
(*c*) 2 -way WPD isolation *S*-parameters.

Figure 14(*a*) shows 2-way WPD matching *S*-parameters. From the figure, we obtain the value of return loss as -22.22 dB. Figure 14(*b*) shows 2-way WPD transmission *S*-Parameters. From the figure we obtain the value of insertion loss as -3.0611 dB. The figure 14(*c*) shows 2-way WPD isolation S-Parameters. From the figure, we obtain the value of isolation between port 2 and 3 as -22.08 dB.

2-Way Gysel Power Divider: The performance parameters of 2-Way GPD are shown in Fig. 15.



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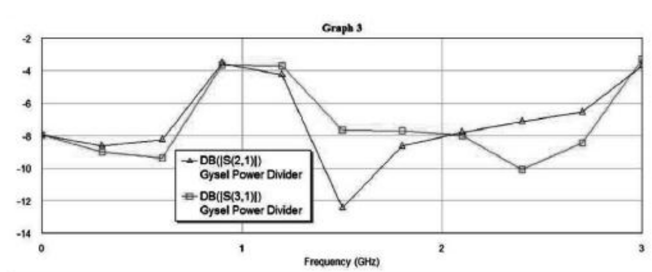

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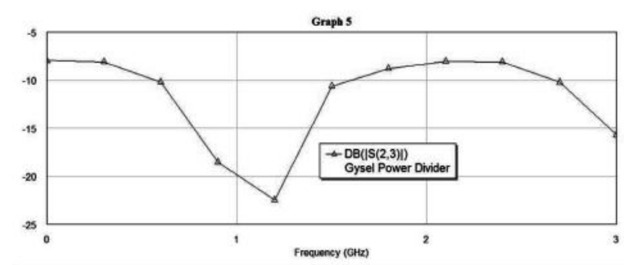

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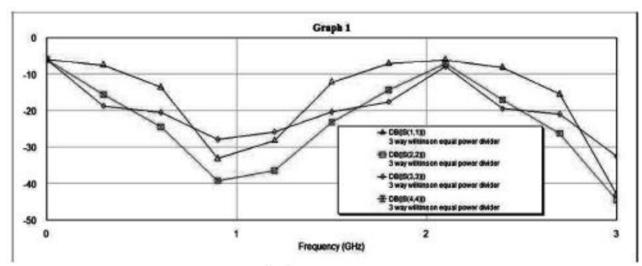
Figure 15: (*a*) 2 -way GPD matching *S*-parameters
(*b*) 2 -way GPD transmission *S*-parameters
(*c*) 2 -way GPD isolation *S*-parameters.

Figure 15(*a*) shows 2-way GPD matching *S*-parameters. From the figure, we obtain the value of return loss as -13.75 dB. Figure 15(*b*) shows 2-way GPD transmission *S*-parameters. From the figure, we obtain the value of insertion loss as -3.7426 dB. Figure 15(*c*) shows 2-way GPD isolation *S*-parameters. From the figure, we obtain the value of isolation between port 2 and 3 as -20.06 dB.

3-Way Equal Wilkinson Power Divider: Performance parameters of 3-way equal WPD are shown in Fig. 16.



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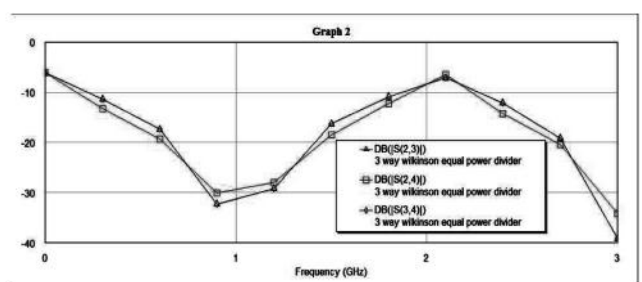

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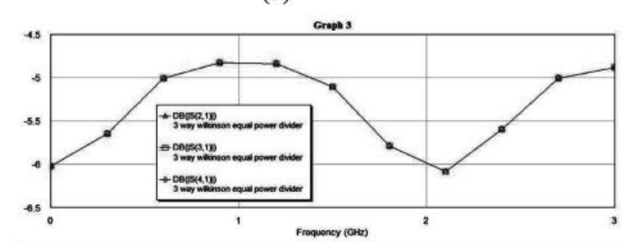

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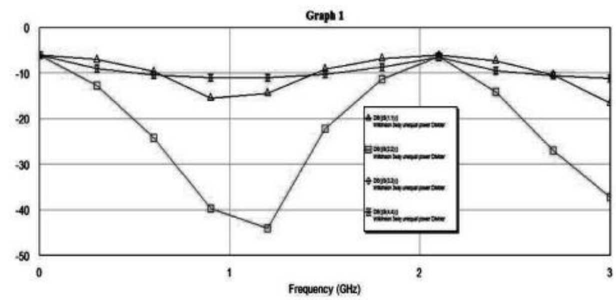
Figure 16 (*a*) 3 -way equal WPD matching *S*-parameters
(*b*) 3 -way equal WPD isolation *S*-parameters
(*c*) 3 -way equal WPD transmission *S*-parameters.

Figure 16(*a*) shows the 3-way equal WPD matching *S*-parameters. From the figure, we obtain the value of return loss as -31.09 dB. Figure 16(*b*) shows the 3-way WPD isolation *S*-parameters. From the figure, we obtain the isolation between port 2 and 3 as -30.97 dB, the isolation between port 3 and 4 as -30.97 dB and the isolation between port 2 and 4 as -29.20 dB. Figure 16(*c*) shows the 3-way WPD transmission *S*-parameters. From the figure, we obtain the value of insertion loss as -4.8333 dB.

3-Way Unequal Wilkinson Power Divider: Performance parameters of 3-way unequal WPD are shown in Fig. 17.



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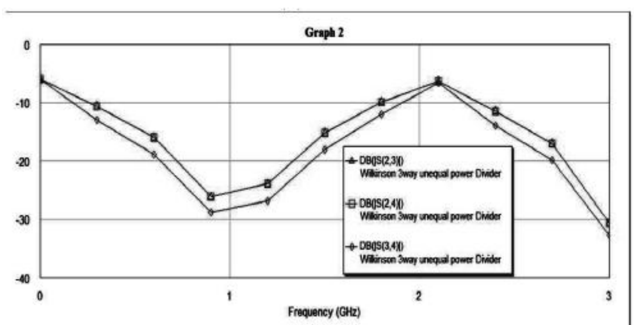

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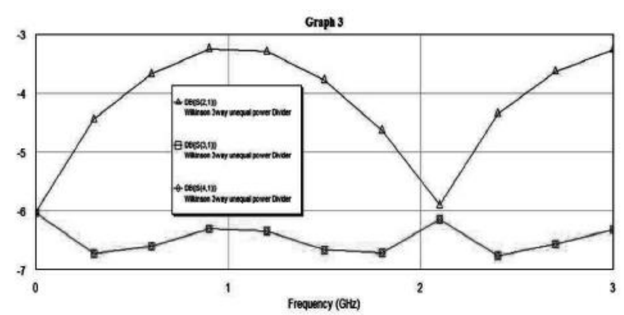

(*c*)

Figure 17 (*a*) 3 -way unequal WPD matching *S*-parameters
(*b*) 3 -way unequal WPD isolation *S*-parameters
(*c*) 3 -way unequal WPD transmission *S*-parameters.

Figure 17(*a*) shows the 3-way unequal WPD matching *S*-parameters. From the figure, we obtain the value of return loss as -15.05 dB. Figure 17(*b*) shows the 3-way WPD isolation *S*-parameters. From the figure, we obtain the isolation between port 2 and 3 as -25.19 dB, the isolation between port 3 and 4 as -27.92 dB and the isolation between port 2 and 4 as -25.19 dB. Figure 17(*c*) shows the 3-way WPD transmission *S*-parameters. From the figure we obtain the value of insertion loss as -3.268 dB. Important results are tabulated in Table 1.

TABLE1 -- PERFORMANCE ANALYSIS OF VARIOUS POWER DIVIDERS

Power Dividers	Return Loss (S_{11} in dB)	Insertion Loss (S_{211} in dB)
2-way WPD	-22.22	-3.0611
2-way GPD	-13.75	-3.7426
3-way Equal WPD	-31.079	-4.833
3-way Unequal WPD	-15.05	-3.268

XI. CONCLUSION

This paper presented a detailed analysis of Power Dividers using AWR Software on FR-4 substrate with dielectric constant 4.4, height 1.6 mm, characteristic impedance 50 ohm, electrical length 90 deg and thickness 0.05 mm at centre frequency of 1030 MHz (IFF Frequency Band). The analysis has taken important parameters like isolation loss, insertion loss and return loss. Comparison between 2-way Wilkinson Power Divider and 2-way Gysel Power Divider is done and also between 3-way Wilkinson Equal Power Divider and 3-way Unequal Wilkinson Power Divider.

The analysis shows that 2-way WPD outperforms 2-way GPD with high return loss of 22.22 dB, low insertion loss of 3.0611 dB and high isolation loss of 22.08 dB as compared to GPD with return loss of 13.75 dB, insertion loss 3.7426 dB and isolation loss of 20.06 dB.

The analysis shows that 3-way equal WPD outperforms 3-way unequal WPD with high return loss of 31.079 dB, insertion loss of 4.833 dB (3-port WPD should have at least 4.77 dB insertion loss) and high isolation loss as compared to 3-way unequal WPD with return loss of 15.05 dB, insertion loss 3.268 dB and low isolation loss.

REFERENCES

[1] F. Hosseini, M. Khalaj-Amir Hosseini and M. Yazdani, "A miniaturized Wilkinson power divider using non-uniform transmission line," *Journal of Electromagnetics Waves and Applications*, vol. 23, no. 7, pp. 917-924, 2009.

[2] B. Li, X. Wu and W. Wu, "A 10:1 unequal Wilkinson power divider using coupled lines with two shorts," *IEEE Microwave and Wireless Components Letters*, vol. 19, no. 12, pp.789-791, 2009.

[3] D. M. Pozar, *Microwave Engineering*, John Wiley & Sons, Inc., 2005, third ed., pp. 318-324.

[4] Y. Wu, Y. Liu, S. Li and C. Yu, "Extremely unequal Wilkinson power divider with dual transmission lines," *Electronics Letters*, vol. 46, no. 1, 90-91, 2010

[5] E.J. Wilkinson, "An *N*-way hybrid power divider," *IRE Trans. Microwave Theory and Techniques*, vol. MTT-8, pp. 116-118, Jan.1960

[6] D. D. Harty, *Novel design of a wideband Ribcage-dipole array*

and its feeding network, Thesis, Electrical and Computer Engineering

[7] D. Maurin and K. Wu, "A compact 1.7-2.1 GHz three-way power combiner using micro-strip technology with better than 93,8% combining efficiency," *IEEE Microwave and Guided Wave Letter*s, vol. 6, no. 2, Feb. 1996.

[8] R. Knochel and B. Mayer, "Broadband Printed Circuit 0°/180° Couplers and High Power In phase Power Dividers," *1990 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 471.

[9] N. Nagai, E. Maekawa and K.Ono, "New *N*-way Hybrid Power Dividers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp. 1008-1012, Dec. 1977.

[10] J.J. Taub and G. P. Kurpis, A more general *N*-way hybrid power divider," *Ibid.*, vol. 17, no. 7, 406-408, July 1969.

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He has been honoured as IETE Sh. Devi Singh Tyagi Award 2018. He received various awards for innovative efforts, six sigma, technical symposiums etc.