

Design & Implementation of Dual Band Power Dividers

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Abstract— This paper presents design and analysis of Dual Band 2-way Equal/Unequal power dividers at frequency 325 & 650 MHz using ArlonTC350 substrate. The proposed power divider can operate at two frequencies without reactive components. There is structure of the power divider and the formulas used to determine the design parameters have been given. A scheme is proposed for the dual-band operation of the power divider/combiner, which has simple structure and is suitable for distributed circuit implementation. The dual band operation is achieved by attaching two central transmission line stubs to the conventional Wilkinson divider and an isolation resistor. For verification, dual band power dividers operating at 325 and 650 MHz are fabricated; the experimental results show that the designed equal/unequal power divider fulfills all the features of a conventional Wilkinson power divider. Finally, the EM simulated results are validated with the characterization of microstrip power dividers at 325 & 650 MHz. After that optimization has also done using AWR to improve the return loss and isolation. The measurements carried out on the fabricated PCB comply with the simulation results. The measurement results of this design provide an insertion loss, return loss (or VSWR) and isolation with the good result.

Index Terms— AWRDE, Advanced Wireless Revolution Design Environment, PDC, Power Divider/Combiner

1. INTRODUCTION

Wilkinson power divider can be classified as the equal power divider and the unequal power divider. Many efforts have been done on the equal Wilkinson power dividers with size reduction and harmonics suppression, and similarly on the unequal ones with high dividing ratio. However, these equal/unequal Wilkinson power dividers operate only in single-band applications as given in Pozar M. David (2011). Recently, many topologies of dual-band equal/unequal Wilkinson power dividers have been reported in applications of dual-band wireless communication systems.

Design of dual band components such as antennas, filters, and transformers is the research focus. As the key components, PDCs are widely used in microwave and millimeter-wave systems. In usual, the conventional power dividers are designed at a single band. Many researchers like Wu Lei *et al* (2006) and Dib Nihad, Khodie Majid (2007) have been made Wilkinson power dividers for dual-frequency application. Wu Y. *et al* (2009) discuss a design i.e. transmission lines in conventional WPD are replaced by the two impedance transformer and at the output parallel connection of a capacitor (C), a resistor (R), and an inductor (L) with parallel connection are shunted. Sakagami Iwata *et al* (2013) present a planar Dual-band 3-Way Wilkinson Power Dividers, 2 sections of transmission lines with two open circuited stubs are used for all 3 outputs. Maktoomi Mohammad A. and Hashmi Mohammad S. (2014) have present a dual band power divider using coupled line sections and stub. Park Myun-Joo & Lee Byungje (2008) have been proposed a new scheme in which dual band operation is achieved by attaching two central transmission line stubs to the conventional WPDC. Design of a novel dual-band unequal Wilkinson power divider with power division ratio of K has discussed by Li X. *et al* (2010).

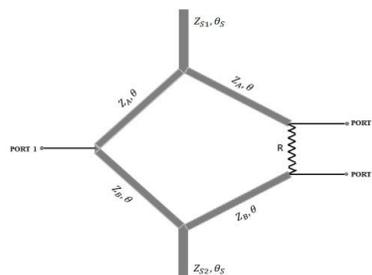


Fig. 1: Dual-band power divider using stubs

The dual mode operation is achieved simply by adding a transmission line stub in the middle of the conventional Wilkinson divider structure as you can see. These transmission line stubs are used to provide matching at both of the frequencies. There are no additional reactive components are needed, only a single resistor is required exactly the same as that in the conventional Wilkinson structure.

Figure 1 shows the schematic representation of the proposed Wilkinson power divider/combiner structure for the dual-band operation.

1. EXPERIMENTAL VERIFICATION OF DUAL BAND EQUAL PDC IN AWRDE

In the following, the dual band mechanism of the proposed scheme is clarified through the detailed analysis of the structure and the design equations are derived from it, as discussed in Park Myun-Joo & Lee Byungje (2008). The proposed divider is symmetric in structure and can be analyzed by the even-odd decomposition method. The result can be summarized into the following equations.

$$\theta = \frac{\pi}{1 + f_2/f_1} = 60^\circ$$

$$Z_A = Z_B = \left[\sqrt{2} / \tan \theta \right] \cdot Z_0 = 40.8\Omega$$

In the above, f_1 and $f_2(f_1 < f_2)$ designates the two band frequencies of the divider.

The open or the short stub design by the following equations

Open stub design $\theta_s = 2\theta = 120^\circ$

$$Z_{S1} = Z_{S2} = [\tan^2 2\theta / \sqrt{2} \tan \theta] \cdot Z_0 = 61\Omega$$

Short stub design $\theta_s = \theta = 60^\circ$

$$Z_{S1} = Z_{S2} = [\sqrt{2} / \tan \theta (\tan^2 \theta - 1)] \cdot Z_0 = 20.5\Omega$$

The value of resistor R can be obtained as

$$R = 2 \cdot Z_0 = 100 \Omega$$

Length and width have been calculated using these impedances at lowest frequency. An interesting special case occurs when the band ratio f_2/f_1 is set equal to 3. In this case, the above design formulas yield $\theta_1 = \pi/4$, $Z_1 = \sqrt{2}$ & $Z_s = \infty$ Therefore, the stubs vanish and the conventional Wilkinson divider structure is reproduced exactly. In this respect, the proposed scheme can be regarded as just generalization of the conventional Wilkinson power divider.

As an example, a Dual band Wilkinson Power Divider at frequencies 325 MHz and 650 MHz is to be designed using open circuit stubs. The target specification is a better than -20 dB isolation and return loss at these frequencies. Fig. 2(b) shows the layout of the studied divider with equal power division. After performing full-wave electromagnetic simulations (AWDE MWO) by taking the bend and junction effects into consideration, the power divider with a power division ratio of 1:1 is designed optimally, and its physical parameters are determined. Fig. 2(c) shows a photograph of the fabricated circuit.

There are optimization has been done to get the best results at both of the frequencies, so here the line impedances are different from the calculated values, these are:

$$z_1 = 41.49\Omega \quad z_s = 62.85\Omega$$

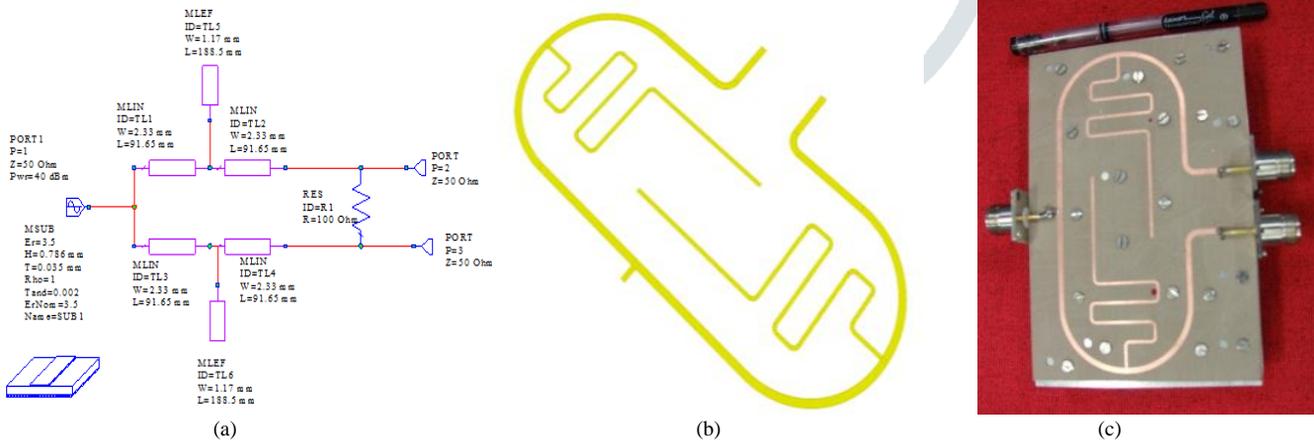


Fig. 2: (a) Schematic of the proposed dual-band equal power divider (b) Layout of the studied dual band power divider with equal power division, where $Z_A=Z_B= 41.49-\Omega$, $Z_S=62.85 \Omega$, $\theta=60$, $\theta_s = 120$, and $R=2 \cdot Z_0$ (Z_0 Referred to a 50 Ω system) (c) Photograph of the fabricated circuit.

The open stub design as presented above is implemented in microstrip circuit. The detailed circuit layout fabricated on Arlon TC350, The dielectric substrate used is TMM4, dielectric constant stability ($\epsilon=3.5$) and loss tangent 0.002 which is less/very low at high frequency. The height of the conductor used is 0.786 mm, thickness of the conductor is 0.035 mm and Copper is used as a conductor.

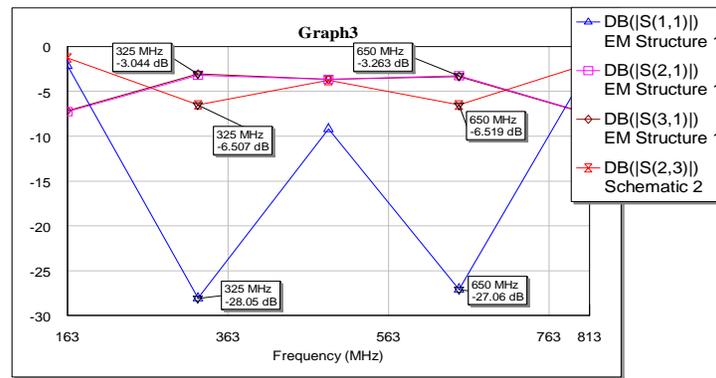


Fig. 3: Dual-band Wilkinson power divider performance (simulated) with band ratio $f_2/f_1=2$ using open stubs

EM simulation doesn't consider the resistor. So simulation results are shown here without resistor.

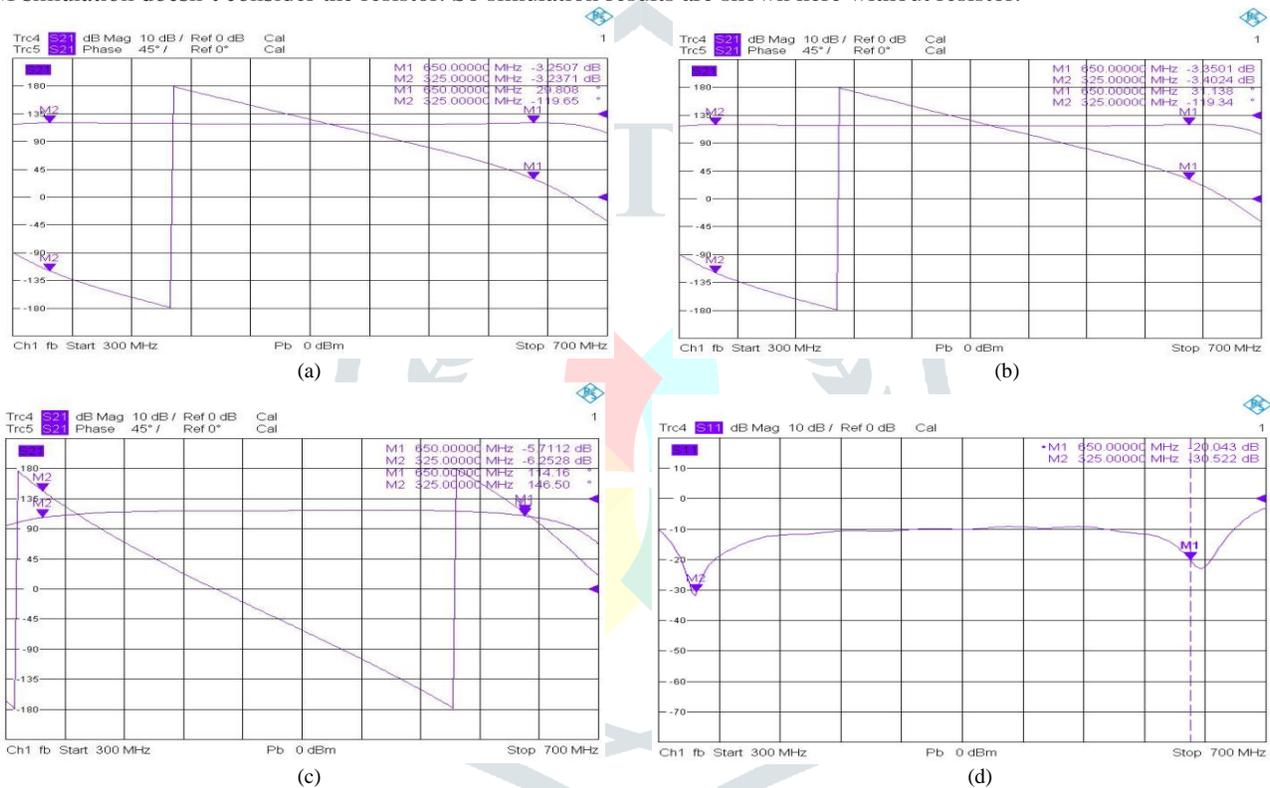


Fig. 4: Performance of the studied dual band power divider with equal power division (a) & (b) Transmission (c) isolation response (d) Reflection response

Table 1: Measurement Results after fabrication of dual band equal power divider

S-PARAMETERS	@ 325MHz	@ 650MHz
Return Loss	-30.5 dB	-20.04 dB
Coupling at port 2 & 3	-3.2 dB & -3.4 dB	-3.2 dB & -3.3 dB
Isolation without Resistor	-6.2 dB	-5.7 dB

After the fabrication, the two-way dual band equal power divider PCB is tested on the RF measurement device, i.e., Vector Network Analyzer and if required. The practical S-Parameters are measured and matched with the theoretical circuit simulation results obtained.

All simulated and measured results are shown in Fig. 3 & 4, where the power division and isolation responses are described in Fig. 4(a), (b), & (c) and reflection responses are recorded in Fig. 4(d). Manufacturing tolerances on the dielectric constant of the laminate and track width imperfections as part of the PCB milling process resulted in the return loss and isolation not being as same as simulated. Also the extra losses are due to the SMA connectors (i.e., nonideal coaxial/microstrip line transitions). Part of this loss could be due to the thin protective coating used to prevent the copper tracks from oxidising. The losses in the the

insertion loss of the coupled path is also 0.2 dB more than circuit due to the resistance of the tracks, dielectric losses of the substrate and radiation losses of the microstrip lines, vary with frequency, as can be seen in figure.

2. EXPERIMENTAL VERIFICATION OF DUAL BAND UNEQUAL PDC IN AWRDE

The schematic of the designed unequal dual-band Wilkinson power divider with an output power dividing ratio of K ($P_3/P_2=2$) is presented in Figure 5(a). It basically consists of two section of transmission line of different characteristic impedance (Z_A and Z_B) and two stubs as well as an isolation resistor. Even and odd mode analysis is not applicable in this case because power dividing ratio is unequal. To achieve impedance matching, the following resistance relationships must be satisfied:

$$Z_0 = \frac{Z_{in2}Z_{in3}}{Z_{in2} + Z_{in3}}$$

The solutions are assigned to the two frequencies f_1 and f_2 ($f_1 < f_2$), and calculation is done at the lower frequency.

$$\theta = \frac{\pi}{1 + f_2/f_1}$$

After some algebraic manipulation as given in Li X. *et al* (2010), the following equations can be obtained to design the characteristic impedances of two transmission line sections:

$$Z_A = \frac{\sqrt{(1+K)\sqrt{K}}}{\tan \theta} Z_0 = 59.46 \Omega \qquad Z_B = \frac{\sqrt{(1+K)}}{K^{3/4} \tan \theta} Z_0 = 29.73 \Omega$$

For open stubs, $\theta_S = 2\theta$

$$Z_{S1} = \frac{\tan^2 2\theta \sqrt{(1+K)\sqrt{K}}}{2 \tan \theta} Z_0 = 89.19 \Omega \qquad Z_{S2} = \frac{\tan^2 2\theta \sqrt{(1+K)}}{2K^{3/4} \tan \theta} Z_0 = 44.45 \Omega$$

For short stubs, $\theta_S = \theta$

$$Z_{S1} = \frac{\sqrt{(1+K)\sqrt{K}}}{\tan \theta (\tan^2 \theta - 1)} Z_0 \qquad Z_{S2} = \frac{\sqrt{(1+K)}}{K^{3/4} \tan \theta (\tan^2 \theta - 1)} Z_0$$

The value of resistor R can be obtained as

$$R = \frac{1+K}{\sqrt{K}}$$

As an example, a Dual band Wilkinson Power Divider with power division ratio 2:1 at frequencies 325 MHz and 650 MHz is to be designed using open circuit stubs. Figure 5 shows the impedance lines and stubs calculated as a function of frequency ratio ($f_2 > f_1$) when $k = 2$.

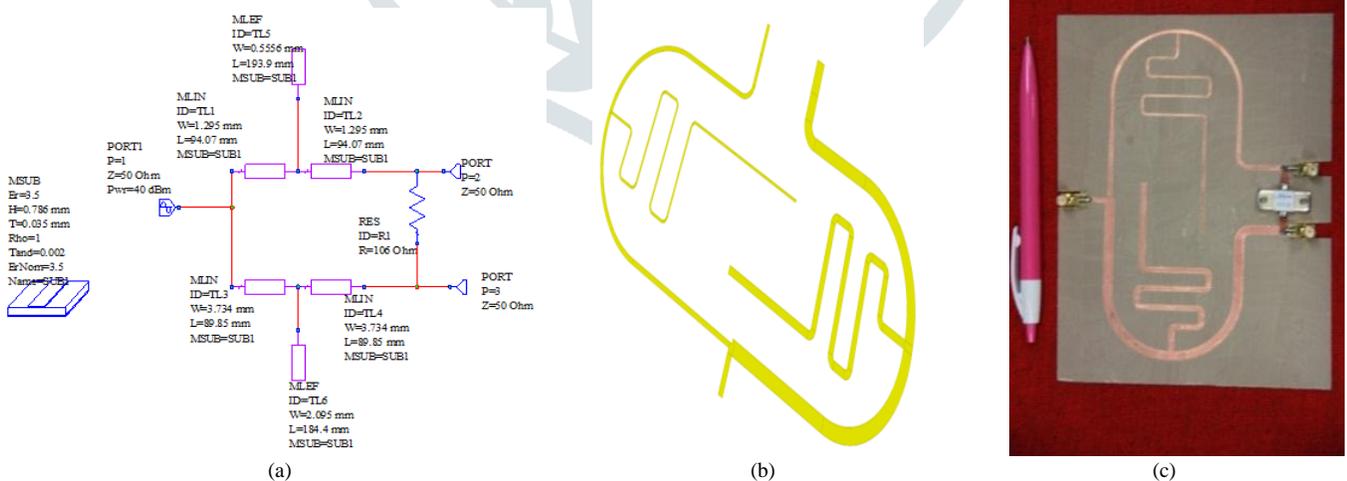


Fig. 5. (a) Schematic of the proposed dual-band unequal power divider (b) Layout of the studied dual band power divider with power division ratio $K=2$, where $Z_A=59.46\text{-}\Omega$, $Z_B= 29.73 \Omega$, $Z_{S1}=89.19 \Omega$, $Z_{S2}=44.45 \Omega$, $\theta=60$, $\theta_s=120$, and $R=106 \Omega$ (c) Photograph of the fabricated circuit

Layout of the unequal dual band PDC is shown above. Three 10mm long tracks are used, to allow connections to be made to the circuit. These short lines will have some effect on the performance of the divider. There is improvement in return loss at both of the frequencies. We can see in the simulation result.

Here EM Simulation results of the proposed divider are not shown, because EM simulation does not consider the resistor. Due to this, coupling and Isolation will be affected. After the fabrication, the two-way dual band equal power divider PCB is tested on the RF measurement device, i.e., Vector Network Analyzer. The practical S-Parameters are measured and matched with the theoretical circuit simulation results obtained.

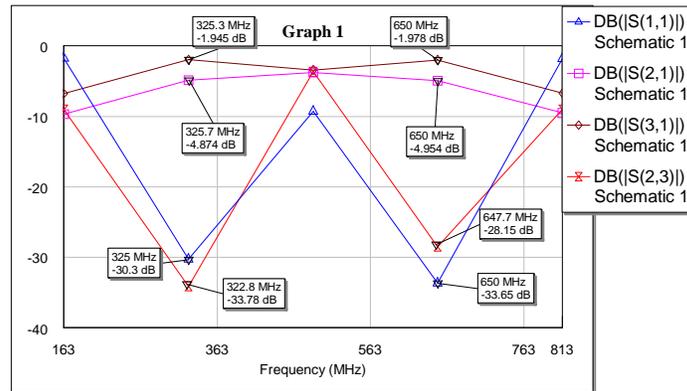


Fig.6. Dual-band unequal power divider performance (simulated) with band ratio $f_2/f_1=2$ using open stubs

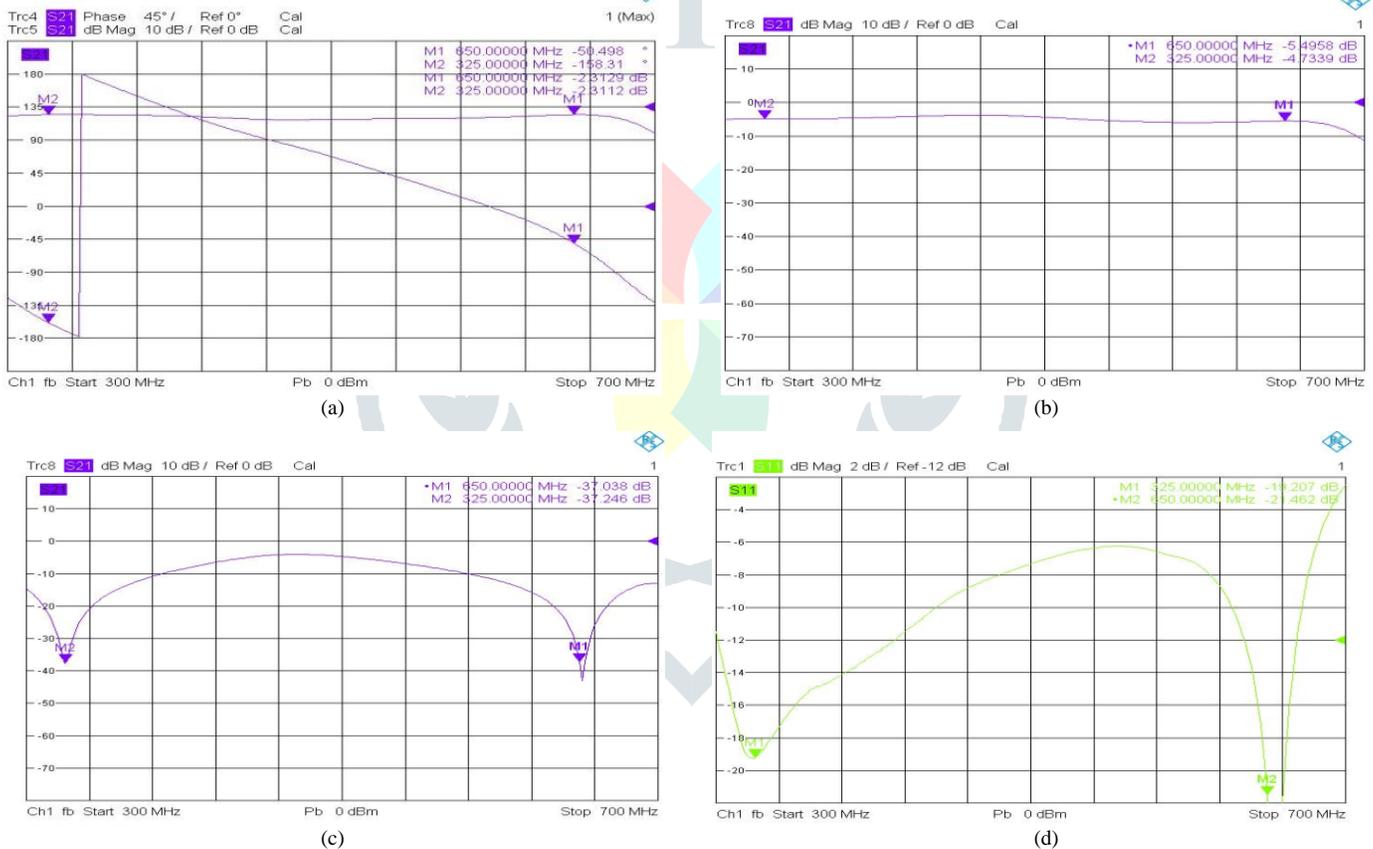


Fig. 7. Performance of the studied dual band power divider with unequal power division (a) & (b) Transmission (c) isolation responses (d) Reflection response

Table 1: Measurement Results after fabrication of dual band unequal power divider

S-PARAMETERS	@ 325MHz	@ 650MHz
Return Loss	-19.2dB	-21.46 dB
Coupling at port 2 & 3	-2.3 dB & -4.7 dB	-2.3 dB & -5.2 dB
Isolation with Resistor	-37.2 dB	-37 dB

Manufacturing tolerances on the dielectric constant of the laminate and track width imperfections as part of the PCB milling process resulted in the return loss and isolation not being as good as simulated. The insertion loss of the coupled path is also 0.5 dB more than obtained by the simulation. Part of this loss could be due to the thin protective coating used to prevent the copper tracks from oxidizing. The losses in the circuit due to the resistance of the tracks, dielectric losses of the substrate and radiation losses of the micro strip lines, vary with frequency, as can be seen in figure.

3. CONCLUSION

Analysis and design of power dividers and combiners were carried out. If Resistor will be connected to the fabricated circuit then Isolation is better than -25 dB, S-parameters of the PDC were measured by terminating its different ports with open/short condition and the measurement results were compared with the simulated results of Wilkinson power dividers/combiners in Microwave Office (MWO) software of AWRDE.

ACKNOWLEDGMENT

The pre-requisites for a task to be successfully completed are constant inspiration, guidance and good working environment. Fortunately all the above requirements were satisfied at Radio Frequency System Division Lab, RRCAT Indore (M.P.), where I carried out my project work. I feel privileged to express my heartiest thanks and gratitude to guide Dr. Akhilesh Jain, Scientific Officer/G & Head, Solid-State RF Amplifier Lab, RRCAT, Ms. Kriti Pathak, Scientific Officer/C, RRCAT, Mr. M.R. Lad, Division Head, RFSD, RRCAT, Ms. Garima Tiwari, Asst. Professor, GGITS, Jabalpur and Dr. Vinod Kapse (HOD ECE, GGITS, Jabalpur) for providing me the time, resources and invaluable guidance and encouragement throughout the whole work. I sincerely wish to express my gratefulness to all the staff members of RFSD Lab, RRCAT, Indore and GGITS, Jabalpur.

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