DESIGN A POWER DIVIDER FOR A RADAR ANTENNA RECEIVER SYSTEM
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ABSTRACT

Limitation in the current Radar system is incomplete measurement and incomplete sampling, due to the quality of the receiving signal. The Radar system is a very expensive set-up, therefore there is a crucial need for a backup system to enhance the system capabilities. The proposed backup system can be used for monitoring and surveillance purposes. Accurate data can be determined based on the quality of pickup or receiving signal, thus one of the important area is to maintain the quality of receiving signal by designing a power divider.

1.0 INTRODUCTION

1.2 Antenna For Receiving Systems

Antenna for receiving system requires robust components in order to fully utilize the radar functional. One such essential component is the power divider and its complementary power combining circuitry. Conventional power divider operates at a fundamental frequency and odd harmonics. This project focuses on the design of a microwave power divider with the capability of operating at multi frequencies. The design made use of the odd and even-mode approaches to determine the power divider circuit parameters for suitable power division. The design starts with the conventional power divider which was simulated using AWR Microwave Office 2004. Further modifications have been performed on the basic power divider. The circuit performances are investigated using Scattering parameters related to a multi-port network. These include the return loss, isolation, forward and transmission coefficients. The simulation results are then analyzed and compared.

1.3 AWR Microwave Office

The AWR Design Environment comprises two powerful tools that can be used together to create an integrated system and RF design environment, Visual System Simulator (VSS) and Microwave Office (MWO). These powerful tools are fully integrated in the AWR Design Environment and allow you to incorporate circuit designs into system designs without leaving the AWR Design Environment.

Microwave Office enables you to design circuits composed of schematics and electromagnetic (EM) structures from an extensive electrical model database, and then generate layout representations of these designs. It can perform simulations using one of Microwave Office's simulation engines; a linear simulator, an advanced harmonic balance simulator, a 3D-planar EM simulator (EM Sight), or an optional HSPICE simulator and display the output in a wide variety of graphical forms based on your analysis needs. It also can then tune or optimize the designs and your changes are automatically and immediately reflected in the layout.

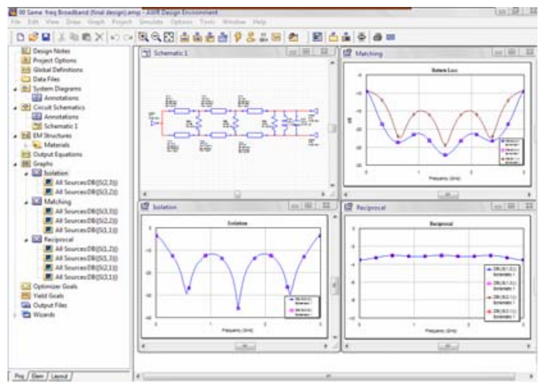


Figure 1.1 An Example of AWR Microwave Office sheet.

MWO has many function and main tools, for this thesis not all function are being used. Only related tools are being used, the frequently tools being used in simulation are:

1.4 Working with Schematics and Netlists in MWO

A schematic is a graphical representation of a circuit while a netlist is a text-based description. A Microwave Office project can include multiple linear and nonlinear schematics and netlists.

1.5 Using the Element Browser

The Element Browser gives user access to a comprehensive database of hierarchical groups of circuit elements for schematics and system blocks for system diagrams. The XML Libraries folders in the Element Browser provide a wide range of electrical models and S-parameter files from manufacturers. Circuit elements include models, sources, ports, probes, measurement devices, data libraries, and model libraries that can be placed in a circuit schematic for linear and non-linear simulations.

1.6 Using the Linear Simulator

Linear simulators use nodal analysis to simulate the characteristics of a circuit. Linear simulations are used for circuits such as low noise amplifiers, filters, and couplers whose elements can be characterized by an admittance matrix. Linear simulators typically generate measurements such as gain, stability, noise figure, reflection coefficient, noise circles, and gain circles.

1.7 Creating Output Graphs and Measurements

MWO can view the results of your circuit and system simulations in various graphical forms. Before perform a simulation, user can create a graph and specify the data, or measurements, that want to plot. Measurements can include for example, gain, noise or scattering coefficients.

2.0 THEORY

2.1 Power Divider Theory

Basically n+1 ports power divider and combiner consist of 1 input and n outputs for divider case, and vice versa for combiner as described schematically in Figure 2.1

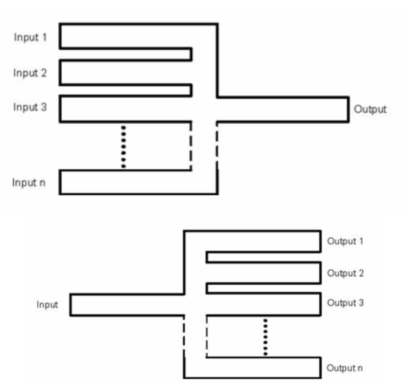


Figure 2.1 *Schematic block diagram of n+1 ports power combiner and power divider*

Minimal type of power divider and combiner is three ports network, which is composed of single input and double outputs (for divider) or double inputs and single output (for combiner). To simplify complexity, discussion in this sub chapter is focused on three ports power divider. Other types of power divider can be carried out in similar way. To have further understanding of power divider and combiner properties, network scattering matrix is frequently used. Scattering matrix of three ports power divider and combiner is composed of nine components, as shown below.

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

2.2 Wilkinson Power Combiner and Divider Theory

It is shown previously that a simple power divider could not fulfill properties of lossless, reciprocal, and matched at the same time. That is the reason why Wilkinson power divider was developed. In Wilkinson power divider isolation resistor between output ports is employed to achieve those properties. Dissipation of energy occurs only in isolation resistor when signal enters the network from any output port, but it should not affect Wilkinson network efficiency. Besides, this isolation resistor provides perfect isolation to protect output ports at the working frequency. Generally, Wilkinson power divider can be provided in any number of output ports, either arbitrary even or odd number. Basic three ports Wilkinson power divider is described schematically in Figure 2.2.

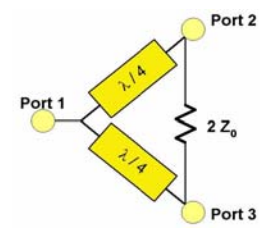
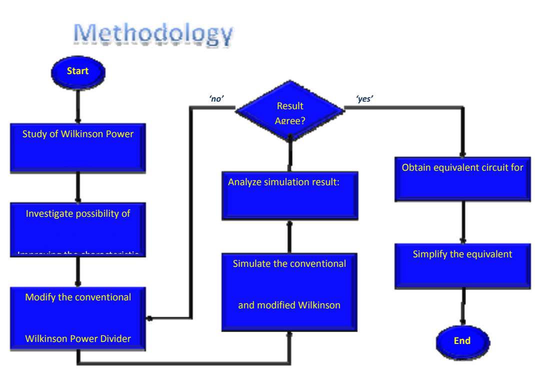


Figure 2.2 Schematic diagram of Wilkinson Power Divider

3.0 METHODOLOGY



4.0 DESIGN PROCESS

4.1 Basic Conventional Wilkinson Power Divider Using Microwave Office

The design has been started with basic conventional WPD with various single operating frequencies (0.9 GHz, 1.8 GHz and 2.7 GHz). This circuit has one input port and two ports, to give a good isolation the resistor, R has been used to separate the output ports. The prototype values for the design are obtained and tabulated in Table 4.1.

Parameter	Operating Frequency		
	0.9 GHz	1.8 GHz	2.7 GHz
Z_1	70.711 Ω	70.711 Ω	70.711 Ω
Z_0	50 Ω	50 Ω	50 Ω
R	100 Ω	100 Ω	100 Ω

Table 4.1 Prototype values for conventional design.

The basic schematic circuit layout for designs of conventional WPD is shown in Figure 4.1.

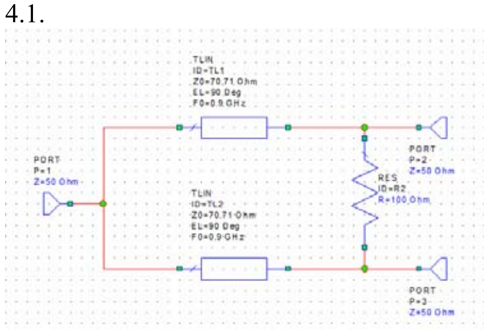


Figure 4.1 Basic Conventional WPD Circuit.

The results of simulation for basic conventional WPD at different range of single operating as bellow:

(i) **Operating Frequency 0.9 GHz**

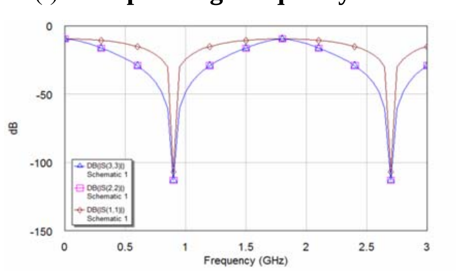


Figure 4.2 Simulated return loss of basic WPD at 0.9 GHz.

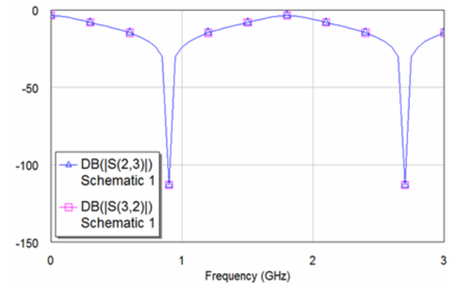


Figure 4.3 Simulated isolation of basic WPD at 0.9 GHz.

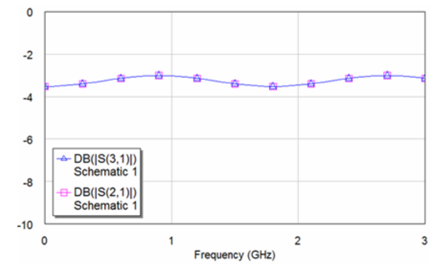


Figure 4.4 Simulated power division of basic WPD at 0.9 GHz.

(ii) **Operating Frequency 1.8 GHz**

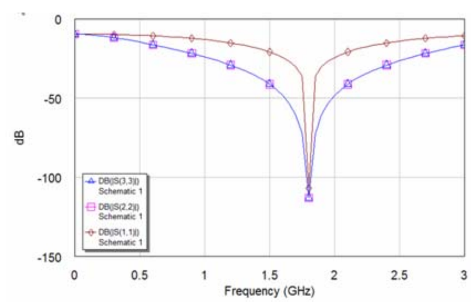


Figure 4.5 Simulated return loss of basic WPD at 1.8 GHz.

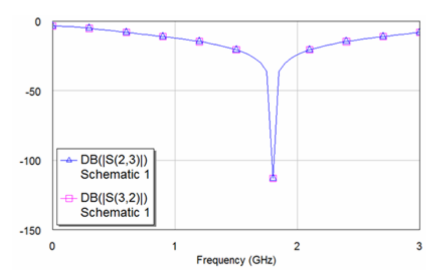


Figure 4.6 Simulated isolation of basic WPD at 1.8 GHz.

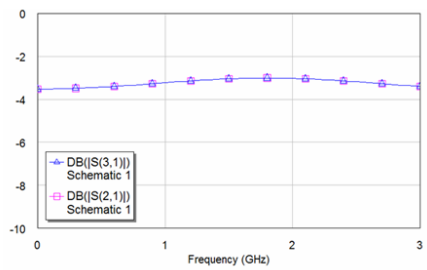


Figure 4.7 Simulated power division of basic WPD at 1.8 GHz.

(iii) **Operating Frequency 2.7 GHz**

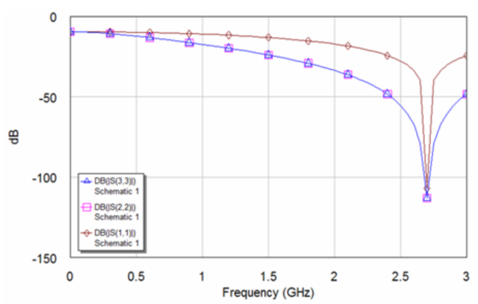


Figure 4.8 Simulated return loss of basic WPD at 2.7 GHz.

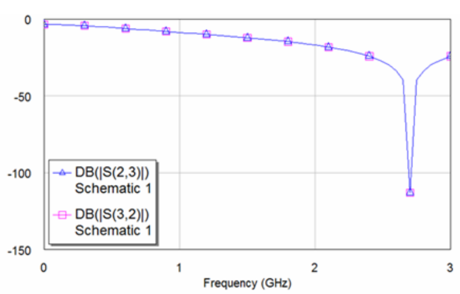


Figure 4.9 Simulated isolation of basic WPD at 2.7 GHz.

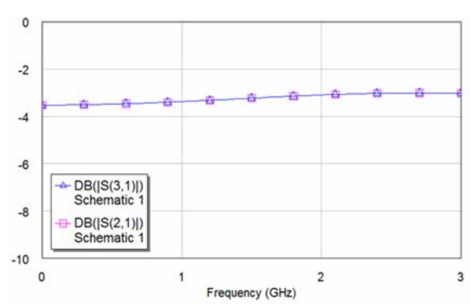


Figure 4.10 Simulated power division of basic WPD at 2.7 GHz.

There are three single operating frequency have been chosen for the simulation process. From the simulation result, it was observed that at 0.9 GHz, it has an excellent return loss of -120 dB at all ports with the bandwidth (BW) of -10 dB. By the way, it shows a narrowband response by looking the S_{11}, S_{22} and S_{33}. Isolation between ports was eexcellent with -120 dB between port 2 and 3, and vice-versa. Equal power division from Port 1 to Port 2 and 3 was also achieved by looking at S_{21} and S_{31}. A Very small loss of 0.4 dB observed. It agrees with theory.

With 1.8 GHz, the simulated result shows an excellent return losses of -120 dB at all ports with the BW of -10 dB from the input of 1.2 GHz and 2.5 GHz output which is narrowband. An excellent isolation of -120 dB can be seen between port 2 and 3, and vice-versa. The equal power division from Port 1 to Ports 2 and 3, S_{21} and S_{31}, achieved and agree with theory.

At 2.7 GHz, the excellent return losses of -120 dB achieved at all ports and have an excellent isolation of -120 dB between ports 2 and 3, and vice-versa. A equal power division from Port 1 to Port 2 and 3; S_{21} and S_{31}, and it also agree with theory.

Form the simulation result observed, with some references, there are some area which can be improved especially on the response for the broadband characteristics. In order to achieve this specification, few modifications to the conventional circuit of WPD and fine tuning process have to be done. Therefore, the first modification is the **"Tri Section Modified WPD"** which is introducing the lumped element into the circuit design.

4.2 Tri Section Modified Wilkinson Power Divider with Lumped Element

The configuration of this circuit is using a three section of quarter wave transformer with the combination of three operating frequency (0.9 GHz, 1.8 GHz and 2.7 GHz) together with the resistor, R as an isolator between the ports. This configuration has been design by changing various configuration and values of lumped element RL, RC and RLC. However, from the simulation result, this type of configuration still giving the narrowband result and the desired specification still cannot be achieved.

The design than proceed with the same structure but using single operating frequency for tri section configuration. By using a single operating frequency, the desired response was observed and it shows that the structure can be improved. The design than proceed with the operating frequency of 0.9 GHz. The schematic circuit layout for designs of Tri Section Modified WPD is shown in Figure 4.11.

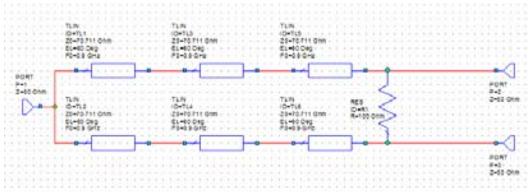


Figure 4.11 The schematic layout for basic Tri Section Modified WPD

From the simulation result of Tri Section Modified WPD, with the isolation of resistance (R), an excellent return losses of -120 dB at all ports at first 3 frequencies and at -10 dB BW for input is 0.6 GHz and output is 0.8 GHz. However, it stills a narrowband. The excellent isolation of -120 dB was observed between port 2 and 3, and vice-versa. The equal power division from Port 1 to Port 2 and 3; S_{21} and S_{31}, at 0.5 GHz, 1.5 GHz and 2.5 GHz was shown.

By studying and doing some analysis from the simulation results, few improvement of the response with tri operational frequencies, f_o, $2f_o$ and $3f_o$ was observed. However, it still narrowband and the desired specification still not achieved.. Therefore, some elements have been introduced (R, L and C) to the circuit.

(i) Tri Section Modified WPD with RL Element

The configuration of this circuit is using three sections of quarter wave transformer with operating frequency 0.9 GHz and resistor, R as isolation between the ports. A value of R is 100 Ω and value of L for this simulation is setting as variable, it will help for observing the effects of this element.

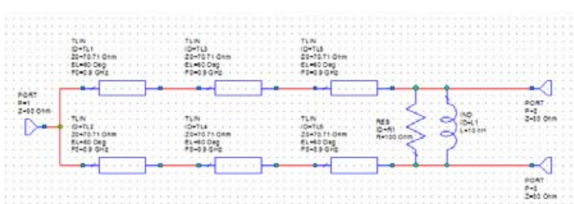


Figure 4.12 The schematic layout for Tri Section Modified WPD with RL Element.

From the simulation result of RL combination, the excellent input return loss of -120 dB at 3 lower frequencies was observed. Reasonably good output return loss at output ports at higher 3 frequencies. Inconsistent response observed due to RL loading. The simulation shows reasonably good isolation of <-15dB between port 2 and 3, and vice-versa, at 3 higher frequencies, but equal power division of -3 dB at output ports at the three lower frequencies.

(ii) Tri Section Modified WPD with RC Element

The configuration of this circuit is using three sections of quarter wave transformer with the operating frequency of 0.9 GHz and the resistor, R as an isolator between the ports. A value of R is 100 Ω and the value of C for this simulation was set as variable, in order to observed the effect of this element and to find the desired optimum output.

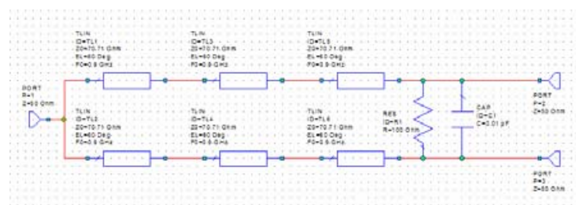


Figure 4.13 The schematic layout for Tri Section Modified WPD with RC Element.

From the simulation result with the RC combinations, the excellent return losses at the 3 lower frequencies observed at all ports. The BW of -10 dB observed at the input of 0.6 GHz and 0.85 GHz output. However, it still narrowband but have some improvement compared with R and RL design.

(iii) Tri Section Modified WPD with RLC Element

This configuration is having same structure as the circuit before, with the RLC element at the isolation part in output port. A value of R is 2Zo = 100 Ω and the value of L and C were set to variable for observing the effect on those elements in the circuit and for the purpose of finding the optimum desired output.

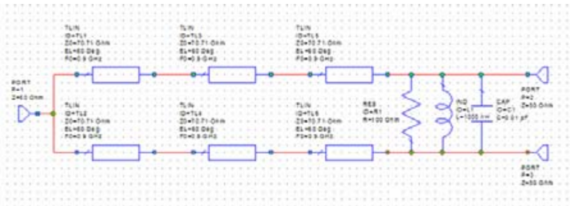


Figure 4.14 The schematic layout for Tri Section Modified WPD with RLC Element.

From the simulation performed, the excellent return losses were observed at the 3 lower frequencies, at all ports with RLC loading. The BW becomes broader at -10 dB BW, for input BW = 0.6 GHz and output BW = 0.9 GHz. It shows some improvement in term of broader but still narrowband. The excellent isolation observed (<-42 dB) between port 2 and 3, and vice-versa, at the lower 3 frequencies. The result shows the greatest isolation at 1.4 GHz and has an equal power division of -3 dB at output ports at the 3 frequencies with minor loss of 0.4 dB. It still can be accepted.

4.3 Tri Section Modified Wilkinson Power Divider with R Segment in Cascade

In this configuration, Tri Section Modified WPD with R segment cascaded was maintained as the circuit before, but additional isolator was added as a cascade segment.

(i) Tri Section Modified WPD with 2nd Segment in Cascade

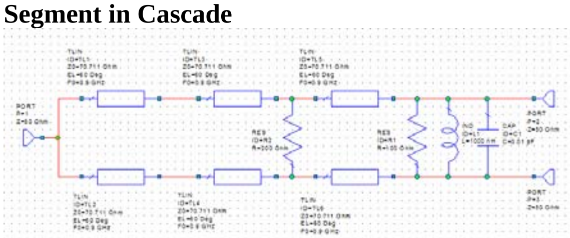


Figure 4.15 The schematic layout for Tri Section Modified WPD with 2nd Segment in Cascade.

From the simulation results, by referring to S_{22} and S_{33}, it shows excellent return losses for output ports. Behaviour at input remains and narrow bandwidth was observed. However, the output ports exhibit broadband characteristic to 2.5 GHz. Optimum output return losses was observed at 1.3 GHz with excellent isolation between port 2 and port 3, and vice versa at 3 frequencies with broader characteristic. The optimum isolation is at 1.3 GHz. Equal power division of -3 dB at output ports, at the 3 frequencies.

(ii) Tri Section Modified WPD with at 1st Segment in Cascade

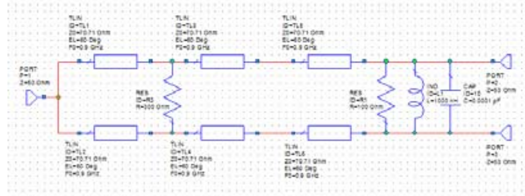


Figure 4.16 The schematic layout for Tri Section Modified WPD with 1st Segment in Cascade.

From the simulation result, it shows an excellent return loss with the behaviour at input port remains with the narrow bandwidth. However, output ports exhibit better broadband characteristic to 2.5 GHz. Optimum output return losses observed at 0.6 GHz and 2.2 GHz. Excellent improvement of isolation between ports 2 and 3, and vice versa with broader characteristic.

(iii) Tri Section Modified WPD with Full Segment in Cascade

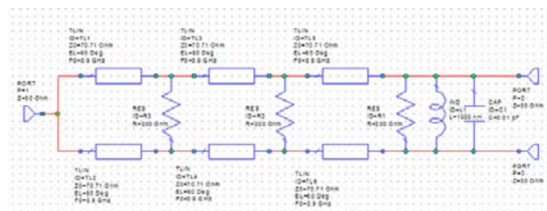


Figure 4.17 The schematic layout for Tri Section Modified WPD with Full Segment in Cascade.

From the simulation result, it shows the excellent return losses and the behaviour at input remains with a narrow bandwidth. Output ports exhibit broadband characteristic to 2.5 GHz. The result shows excellent isolation between the output ports with broadband characteristic from 0.2 GHz to 2.5 GHz. Optimum isolations at 0.4 GHz and 2.2 GHz and the equal power division of -3 dB at the output ports.

From the simulations process of segment cascading, we can see that the broadband for the output ports has been improved by few modifications of the segment cascading and also through several tuning process of the tuning circuit (RLC). However, the modification was only affecting the output ports. Therefore, the tuning process has to be carried out with the impedance of the transmission line for the final circuit design.

4.4 Final Design Of The Modified Wilkinson Power Divider

From the result of Tri Section Modified WPD with full segment in cascade, several modifications and tuning process has been carried out in order to get the desired specification. Broadband characteristic has been identified by observing the response of this simulated result for input (S_{11}) and output ports (S_{22} and S_{33}). After several tuning process, the specifications of circuit where operating frequency and the bandwidth were observed to improve was identified.

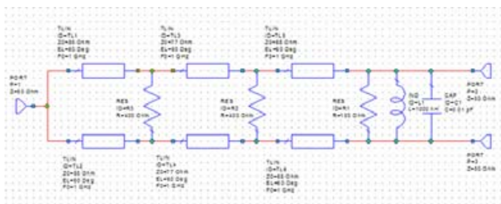


Figure 4.18 The schematic layout for Final Design of Tri Section Modified WPD with Full Segment in Cascade.

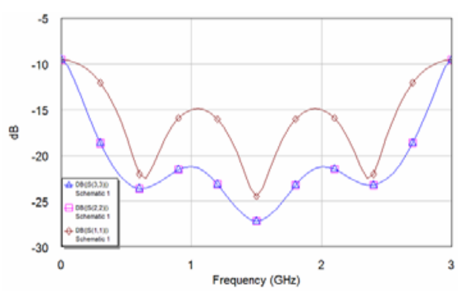


Figure 4.19 Simulated return loss for Final Design of Tri Section Modified WPD with Full Segment in Cascade.

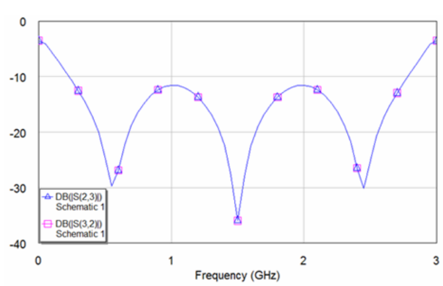


Figure 4.20 Simulated isolation for Final Design of Tri Section Modified WPD with Full Segment in Cascade.

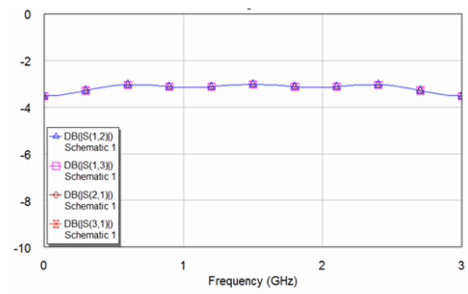


Figure 4.21 Simulated power division for Final Design of Tri Section Modified WPD with Full Segment in Cascade.

From the simulation result, the excellent broadband return losses over 3 GHz range achieved. The output ports equally better matched with the optimum frequency at 1.5 GHz and specifications achieved. The improvement circuit, give an excellent isolation between output ports from 0.2 GHz to 2.8 GHz. The equal power division of -3 dB at output ports, over 3 GHz range also meet the desired specification.

5.0 CONCLUSION

The modified WPD has been improved the broadband characteristic by introducing a 1^{st} segment, 2^{nd} segment and full segment cascading. The desired specification achieved by tuning the RLC elements. The output ports become a broadband by adding the cascading segment. The design allows flexibility as each output port has an identical output up to 2.7 GHz. The isolation and return lost still gives a good reading and the power division is almost stable for all simulation results around -3 dB.

6.0 DISCUSSION

(i) The modified Wilkinson has 3 sections of quarter wavelength transmission lines. The first 2 are loaded with R, the third is loaded with RLC.

(ii) The proposed configuration has broadband characteristic, compared to conventional Wilkinson

(iii) The design allows flexibility as each output port has identical output to 3 GHz.

(iv) The extra output provides cost saving due to low maintenance cost.

(v) Additional cost saving on the storage and installation.

7.0 FUTURE DEVELOPMENT

The simulation results obtained from the design can be improved in many different ways. Suggestions for further research are as follow:

(i) Adapt the proposed design for other sections of receiving radar antenna (from 3 GHz to 10 GHz and 10 GHz to 18 GHz).

(ii) Design the combiner component for combining all designed sections of radar system.

(iii) Physical implementation and test to the real radar system.

REFERENCES

1. David M. Pozar, ***Microwave Engineering***, Addison Wesley Publishing Company Inc. USA, 2005..

2. David M. Pozar, ***Microwave and RF Wireless System***, John Wiley & Sons, Inc. USA, 2001.

3. Kai Chang, Inder Bahl, Vijay Nair, ***RF and Microwave Circuit and Component Design for Wireless Systems***, Wiley Interscience, John Wiley & Sons, Inc. USA, 2002.

4. James Bao-Yen Tsui, ***Microwave Receiver with Electronic Warfare Application***, John Wiley & Sons, Inc, USA, 1986.

5. David L. Adamy, ***Introduction to Electronic Warfare Modeling and Simulation***, Artech House, Inc, 2003.

6. ***Electronic Warfare and Radar System Engineering Handbook***, Naval Air Warfare Center, NAWCWPNS TP 8347, rev 2 of 1 April 1999.

7. Kun-Hui Yi and Bongkoo Kang, ***Modified Wilkinson Power Divider for nth Harmonic Suppression***, IEEE Microwave And Wireless Components Letters, Vol. 13, No. 5, May 2003

8. L. Wu, H. Yilmaz, T. Bitzer, and A. Pascht. M. Berroth, ***A Dual-Frequency Wilkinson Power Divider,*** IEEE Microwave And Wireless Components Letters, Vol. 15, No. 2, February 2005

9. Lei Wu, Zengguang Sun, Hayattin Yilmaz, and Manfred Berroth, ***A Dual-Frequency Wilkinson Power Divider: For a Frequency and Its First Harmonic***, IEEE Transactions On Microwave Theory And Techniques, Vol. 54, No. 1, January 2006

10. B. Piernus, M. Hirata, ***Enhanced Miniaturized Wilkinson Power Divider,*** IEEE MlT-S Digest, 2003.

11. Dongke Zh, Yewen Zhang, ***Codirectional Coupler and Power Divider Mixed Microstrip and Metamaterials with Lumped-Elements L-C,*** Intemational Conference on Microwave and Millimeter Wave Technology Proceedings, 2004.