Simulation of a Three Probe Reflectometer System

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Abstract- This technical paper presents the simulation of a three probe reflectometer system. Using software, it transforms the existence measurement system known as Reflectometer to Microstrip circuit. This involves design a circuit of Reflectometer using Genesys software. The simulation results and publish data from reflectometer measurement system will be compared. Thus, the output of this measurement can be used for obtaining the complex reflection coefficient of a material. The microstrip circuit will be fabricated and the Reflectometer measurement system will be smaller and portable.

1.0 Introduction

1.1 Problem Statement

The measurement systems currently available for measuring the complex reflection coefficient of a material involves hardware that are too big, heavy and are not portable. Thus, a solution to this problem is by designing a three probe reflectometer system onto a microstrip. In order to do that, the first step is to design and simulate the three probe reflectometer system in order to obtain the correct parameters and values of the circuit. The design and simulation of the circuit was done using Genesys software.

A reflection coefficient magnitude of zero is a perfect match where a value of one is perfect reflection. The reflection coefficient is a vector, so it includes an angle. Unlike VSWR, the reflection coefficient can be distinguished between short and open circuits. A short circuit has a value of -1 (1 at an angle of 180 degrees), while an open circuit is one at an angle of 0 degrees. Quite often we refer to only the magnitude of the reflection coefficient.

Reflectometer with slotted line has been one of the instruments which are used for measuring reflection coefficient on transmission line for many years. To measure water quality, three probes reflectometer has been used by Abdul Kadir Ermeey [1]. It is use an algorithm of complex coefficient measurements of water quality at microwave frequencies. Three probe reflectometer offers a simple method to measure complex reflection coefficient from three probe positions which are one eight wavelength apart.

1.2 Microstrip

A microstrip circuit uses a thin flat conductor which is parallel to a ground plane. Microstrip can be made by having a strip of copper on one side of a printed circuit board (PCB) or ceramic substrate while the other side is a continuous ground plane. The width of the strip, the thickness of the insulating layer (PCB or ceramic) and the dielectric constant of the insulating layer determine the characteristic impedance. A microstrip is a thin, flat electrical conductor separated from a ground plane by a layer of insulation or an air gap [3]

The design is integrated using a microstrip transmission lines and shunt stubs. The lumped element should be converted to distributed element to make it easier to design the layout on the microstrip since the lumped element cannot operate at high frequency. Hence the length and the width of lumped elements should be estimated by calculation to convert them into distributed elements. Firstly the width, W and effective relative permittivity ε_{reff} is determined by using "Line-Calc" in Libra. The data that have to be entered as parameters for the "Line-Calc" to perform the calculation for W and ε_{reff} are [Properties a) to d) below follows the characteristic of Rogers RT Duroid 5870 microstrip laminates] :

a) Thickness = 0.035 mm
b) Height = 0.508 mm
c) Loss tangent = 0.0001
d) Relative permittivity of substrate, ε_r = 2.33
e) Operating frequency, f = 9 GHz
f) Characteristic impedance,
    - Z_o= 50 Ω (for normal transmission line)
    - Z_h = 130 Ω (for shunt inductor)
    - Z_L = 25 Ω (for shunt capacitor)

2.0 Methodology

The slotted line is a rectangular waveguide with a longitudinal slot operating in TE_{10} mode. The slotted line detector equivalent diagram (see Figure 2) is operating at 9 GHz frequency.

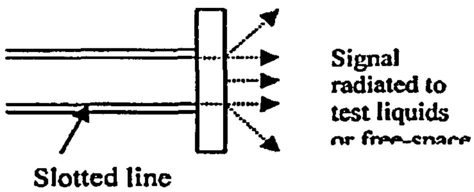

Figure 1: Arrangement for radiating liquid [1]

The arrangement of slotted line in the transmission line was then converted into a circuit design. The circuit of slotted line is being designed to measure the value of complex reflection coefficients of short circuited waveguide and open-ended waveguide.

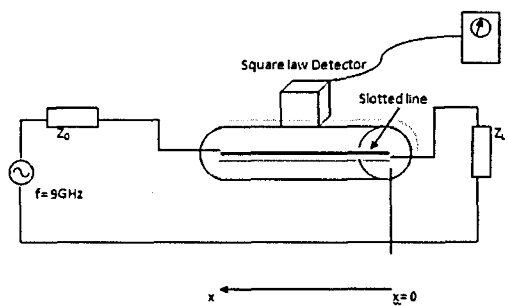

Figure 2: Arrangement of slotted line in the transmission line [7]

DC blocks and RF bypass capacitors (see Figure 3) are simple filters employing microwave capacitors. A DC block is a series capacitor that has low reactance for the RF frequency of interest (an RF short), but blocks DC because it is an open circuit at zero Hertz. An RF bypass is a shunt (parallel) element that acts like a short circuit to microwave signals, but here it is meant to reflect RF signals by shorting them out.

A capacitor often does not act as a capacitor at microwave frequencies. Microwave capacitors must be small enough to be considered lumped elements. Axial-leaded capacitors are not useful at microwave frequencies because of the need to keep small dimensions [6].

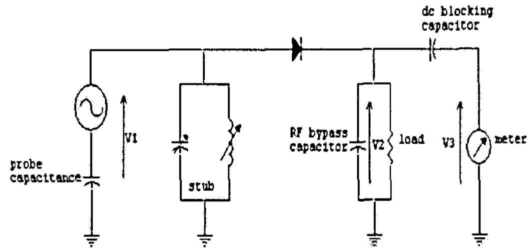

Figure 3: A slotted line detector equivalent diagrams [5]

3.0 Result and Discussion

The data for Table 1 was obtained from a paper publish by Ermeey Abdul Kadir [1]. For calculation of complex reflection coefficient which is for Table 1, a method used is using a formulation given by Ghodgaonkar [9]. A visual basic language program was developed to implement equations for calculation of complex reflection coefficient. Meanwhile, the data for Table 2 also is getting from a paper publish by Ermeey Abdul Kadir. For measured complex reflection coefficient which is for Table 2, a method is using three probe algorithm and the measurement system, complex reflection coefficient are measured for short-circuit, open ended waveguide. A method use for this Table 3 is by simulation of complex reflection coefficient. The simulation was done in Genesys. The values are then compared with the Table 1 and table 2

Table 1 Calculated Complex Reflection Coefficient [1]

Load	$\|\Gamma\|$	θ in degree
Open ended waveguide	0.2253	272.4
Short circuited waveguide	1	180

Table 2 Measured Complex Reflection Coefficient [1]

Load	$\|\Gamma\|$	θ in degree
Open ended waveguide	0.241	274.7
Short circuited waveguide	0.94	180

Table 3 Simulation Complex Reflection Coefficient

Load	$\lvert\Gamma\rvert$	θ in degree
Open ended waveguide	0.266	285.43
Short circuited waveguide	0.9	180

3.1 Simulation of an Open Circuit

The circuit is operating at a frequency of 9 GHz. The reflection coefficient and voltage standing wave ratio was simulated using the slotted line equivalent diagram. The circuit below is an open circuit of the slotted line.

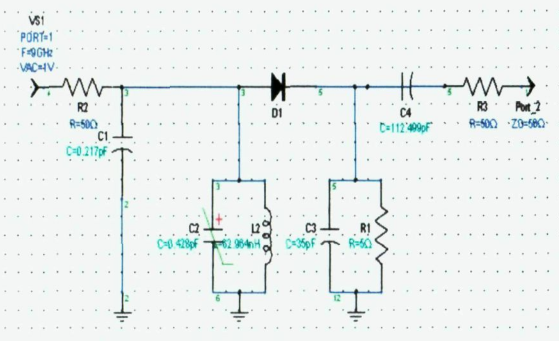

Figure 4: An open circuit of slotted line operates at 9 GHz

Figure 5 shows the reflection coefficient graph (S_{11}). The shape of the response follows the required specification. The result was obtained after making several optimizations. The theoretical magnitude of S_{11} for open circuit, 0.2253 is close to the simulated which is 0.266 (red in color), and the angle obtained is 285.43 (blue in color), close to the specifications of 272.4.

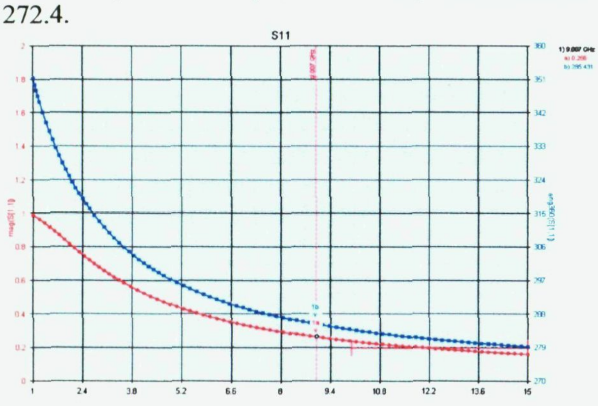

Figure 5: Graph of reflection coefficient (S_{11}) versus frequency

The requirement for the VSWR was less than 1.5 (see Figure 6). The simulated VSWR is 1.725. This value was obtained after making several optimizations made.

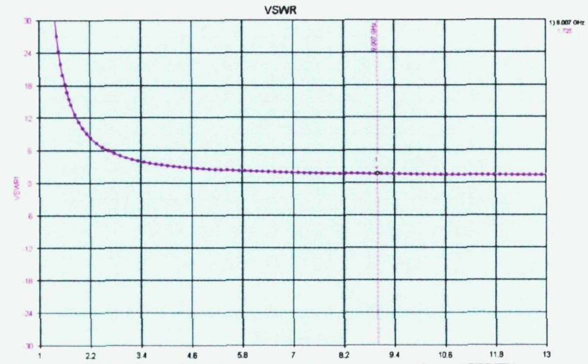

Figure 6: Graph of voltage standing wave ratio (VSWR)

3.2 Simulation of short circuit

Below is a short circuit for the slotted line. The circuit was then simulated similar to the one in open circuit.

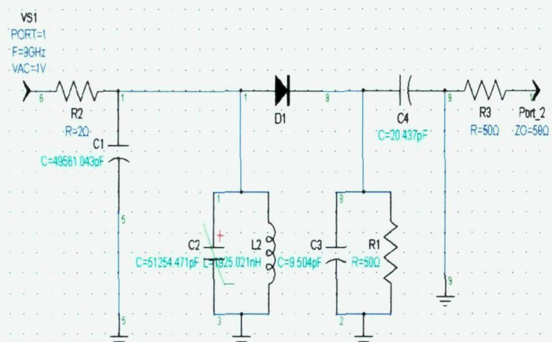

Figure 7: A short circuit of slotted line operates at 9GHz

Figure 8 is the reflection coefficient (S_{11}) graph. The shape of the response follows the required specification. The simulated magnitude for S_{11} is close to 1 which is 0.9, and the angle is 180°.

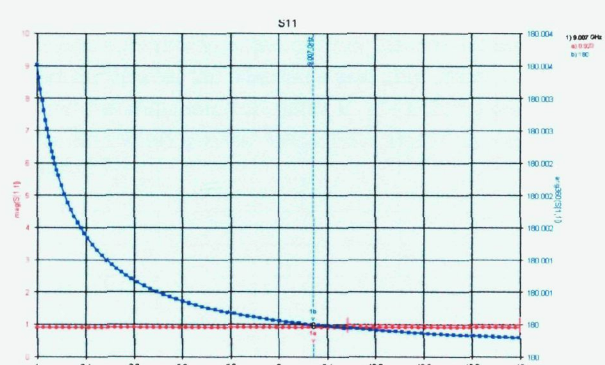

Figure 8: Graph of reflection coefficient (S_{11}) versus frequency

The simulation result of VSWR for the short circuit was not close to 1. The simulated value is 25 which are far from the expected value. Furthermore the input VSWR shown was not the value at the operating frequency which was 9.007GHz.

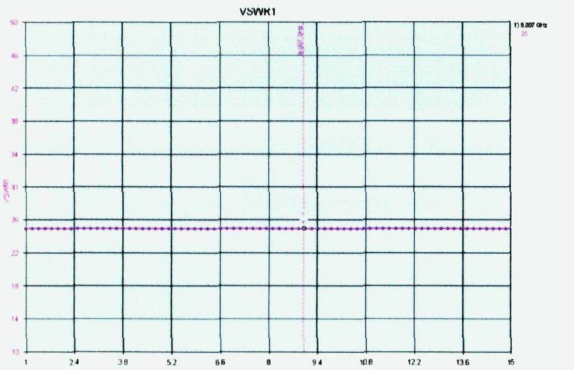

Figure 9: Graph of voltage standing wave ratio (VSWR)

3.3 Distributed Circuit for Open Circuit

The distribution process is a translation of lumped element due to the high frequency. Some calculation was done for the translation for inductor and capacitor elements.

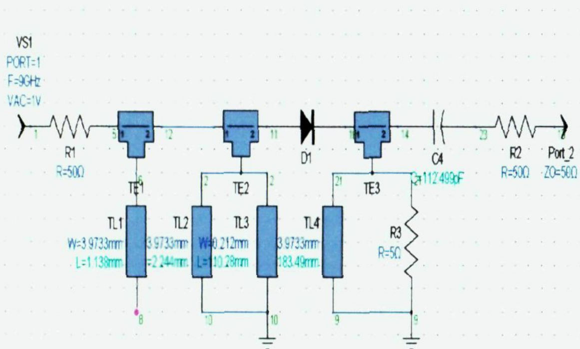

Figure 10: A distributed circuits for open circuit

Figure 11 shows the reflection coefficient after being optimized. The value of reflection coefficient (S_{11}) for magnitude is 0.2 (blue in color) meanwhile for the angle is 282.39 (green in color). The value was taken at operating frequency 9.023 GHz.

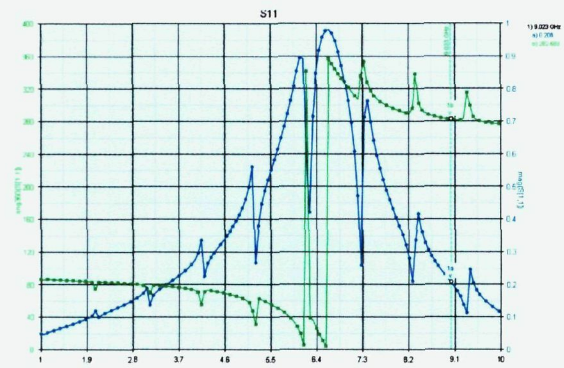

Figure 11: Graph of reflection coefficient (S_{11}) versus frequency

Figure 12 shows the voltage standing wave ratio graph. The value of VSWR is 1.525 which is greater than 1.5. The value was taken at operating frequency of 9.023 GHz.

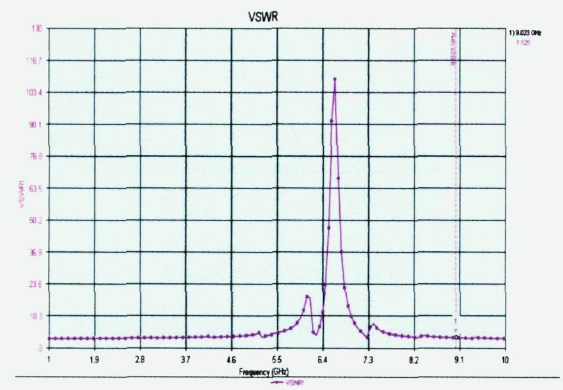

Figure 12: Input VSWR versus frequency response of distributed element after optimization

3.4 Circuit Layout for Reflectometer Design

The circuit layout produced by Genesys software was done by using the "Add Layout" option. The width and the length of the transmission line or stub were measured to produce the correct size of layout. The measurement of the transistor and chip resistor has to follow the dimension in order to get it fixed correctly with the circuit layout. The circuit layout is shown in Figure 13.

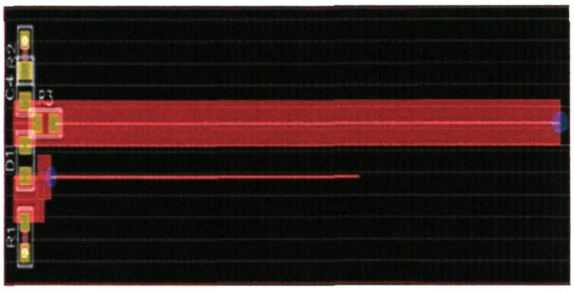

Figure 13: A circuit layout of slotted line design in Genesys

3.5 Microstrip of Reflectometer

Figure 14: Microstrip of Reflectometer

A graph below is the measurement of the microstrip reflectometer by Vector Network Analyzer (VNA). The value of complex reflection coefficient is closely similar from simulation after several measurements have been done using VNA. For short circuit the value for magnitude is 0.994 and the phase is 179.533°. Meanwhile, for open circuit the magnitude is 0.295 and the angle is 259.466°.

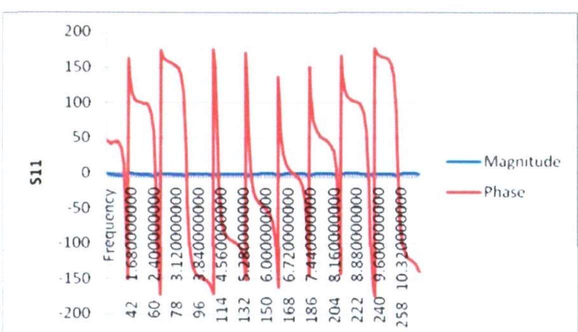

Figure 15: Graph of reflection coefficient versus frequency for short circuit

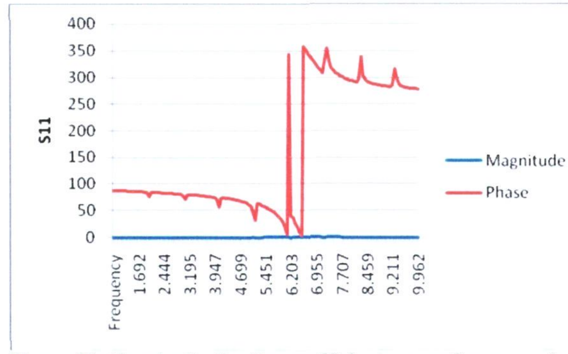

Figure 16: Graph of reflection coefficient versus frequency for open circuit

A value for the VSWR for this measurement is close to the simulation. The value of VSWR is 1.37 which is close to 1.

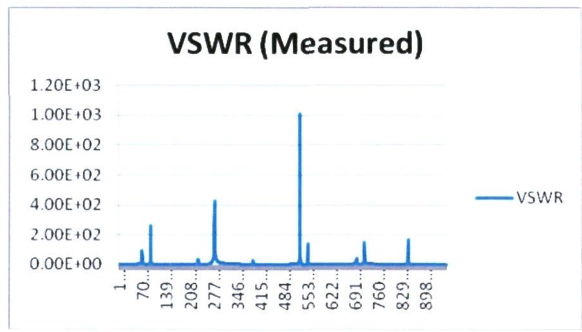

Figure 17: Graph of VSWR

There are several reasons the value for the simulation with the measurement is not same. Some of the value is not same maybe due to losses occur, dielectric losses, and radiation losses or during calibration made.

4.0 Conclusion

This technical paper has presented the design and development of reflectometer system on microstrip. A prototype of reflectometer was realized and analyzed based on simulation and measured prototype. CAD tools were used to determine the performance of the reflectometer. A prototype was fabricated on Rogers RT Duroid 5870 substrate and measured using VNA. The discrepancy result due to the conductor losses, dielectric losses and radiation losses.

From these results it shows that, the Three-probe reflectometer can be transformed into a smaller system using microstrip. Using short circuit and open circuit test, it shows a close agreement between these three systems. A conclusion can be made from the results obtained. Using Microstrip Reflectometer, it can also measure the Reflection Coefficient,Γ, similar to an expensive Vector Network Analyzer and Three-probe Reflectometer System. Using Microstrip Reflectometer, the measurement of the Reflection Coefficient for any material can be made easily and reliable.

The requirement for the value of reflection coefficient in magnitude and phase were met. The objectives for this project also have been achieved.

5.0 Recommendation

This project can be further developed by considering:

- Further studies could be done to investigate the capability of the design to measure quality of water by comparing the reflection coefficients of different types of polluted water.
- Produce reliable and accurate measurement for water quality in future.

6.0 Acknowledgment

The author would like to thank Project Supervisor, Puan Husna Abdul Rahman and Encik Ermeey Abdul Kadir for their untiring efforts in providing guidance, encouragement and invaluable advices, which have helped me tremendously in completing this project.

Last but not least, special thanks to my family and all friends who have helped and participated in this project and also gave moral support to complete this project.

7.0 References

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