PERFORMANCE OF FIVE-PORT REFLECTOMETER (FPR) IN REFLECTION MEASUREMENT

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Abstract

Five-Port Reflectometer (FPR) is a device used to measure complex reflection coefficient, Γ of dielectric material. However, the performance of the FPR need to be verified by measuring the magnitude (|Γ|) and phase (φ) of Γ using three known loads i.e. air, water, ethanol and methanol at operating frequency of 0.80 GHz, 2.82 GHz and 4.21 GHz. The comparison was conducted for comparison between FPR and Agilent E8362B PNA Network Analyzer (PNA) in terms of |Γ| and φ. It shows that the measured |Γ| and φ of all known loads using FPR has good agreement with the PNA. The absolute errors of |Γ| and φ are less than 0.0612 (6.12%) and 8.81° (2.45%), respectively.

Index terms: *Five-Port Reflectometer, Five-Port Ring Junction, Reflection Coefficient, Known Loads.*

1. Introduction

Performance network analyzer (PNA) is a detection system used for characterizing materials which provides both magnitude and phase responses of S-parameters [1]. However, the architectures embedded in PNA are complex and expensive. As the demand of material characterization by using microwave reflection techniques [2], [3] is increasing, hence, the Five-Port Reflectometer (FPR) which is using the six-port technique is developed to measure complex reflection coefficient, Γ of material under test (MUT) in terms of magnitude (|Γ|) and phase (φ). The six-port circuit theory was found by Engen [4] in the late 1970's as an alternative low cost solution to the network analyzer. Many researches on Six-Port Reflectometer (SPR) have been conducted in various applications, e.g. in biomedical [5], communication and sensing application [6], agricultural product [7]–[9] and etc. Generally, uses of additional detectors are the main element in six-port technique where it provides low cost measurement of complex Γ.

Typically, a common Six-Port Reflectometer (SPR) required six-ports i.e source port, test port and four detection port. In 2011, a modified PC-based SPR [9] has been developed where the number of detection port has been reduced to three ports and known as FPR. The Six-Port junction circuit can be designed in many patterns. Due to its simplicity, the symmetric Five-Port ring junction circuit has been proposed as in [10]. The Five-Port ring junction circuit detects three different phases shift of reflection coefficient values which can be represented by three circle radius as shown in Fig. 1. The unknown reflection coefficient is determined by the intersection of those three circles radius whose radii are determined by power measurement. On the other hands, the radii or phase should be symmetrical separated by ±120° [10]. The S-parameters of Five-Port ring junction circuit also need to agree with the Riblet and Hansson theory [10] where $|S_{11}| = |S_{22}| = |S_{33}| = |S_{44}| = S_{55}| \approx 0$ and $|S_{21}| = |S_{32}| = |S_{43}| = |S_{54}| = |S_{15}| = |S_{12}| = |S_{23}| = |S_{34}| = |S_{45}| = |S_{51}| = |S_{31}| = |S_{42}| = |S_{53}| = |S_{14}| = |S_{25}| = |S_{13}| = |S_{24}| = |S_{35}| = |S_{41}| = |S_{51}| \approx 0.5$.

In past researches, SPR has been developed and implemented in many applications. Unfortunately, most of the device system can only operate at single frequency. In literature [8], it reported that SPR was developed to measure the moisture content in oil palm fruit [8]. However, the device system can be operated at frequency of 2 GHz. Meanwhile, in 2014, SPR was used to determine dry rubber content of rubber latex [11] as well as in power device mismatch detection [12]. Similarly, the instrumentation system are also operating at single frequency i.e. 1 GHz [11] and 2.45 GHz [12] respectively. The work is in demand to explore feasibility of SPR to operate at multiple operating frequencies. The Six-Port principle which implemented in Five-Port ring junction circuit are known as Five-Port Reflectometer (FPR). The FPR can operate at frequencies of 0.80 GHz, 2.82 GHz and 4.21 GHz. In this work, the measurement was conducted to measure three known loads i.e water, ethanol and methanol, in order to justify the performance and accuracy of the developed FPR at these three frequencies.

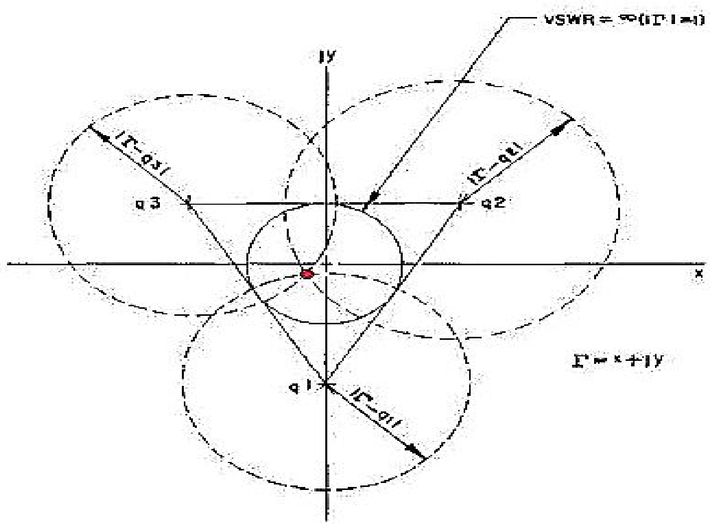

Figure 1. Optimum location of q-points in Six-Port Measurement [10].

2. Five-Port Ring Junction Circuit

Five-Port ring junction circuit using microstrip transmission line method has been designed and simulated using the AWR Microwave Office (MWO) 2002 software as in [13]. This Five-Port ring junction was designed by using the Roger 3003 (RO3003) ceramic substrate. RO3003 has dielectric constant of 3.0 with thickness of 1.52 mm and copper cladding in 35 µm. The fabricated circuit is as shown in Fig. 2. This Five-Port ring junction circuit can be operated at 0.80 GHz, 2.82 GHz and 4.21 GHz.

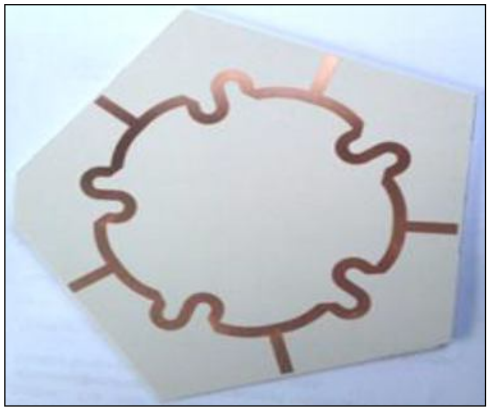

Figure 2. Fabricated SPR Circuit

3. Five-Port Reflectometer (FPR)

The Five-Port ring junction circuit need to be assembled with PICO Analogue Digital Converter (ADC), Keysight three diode detectors, Mini Circuit microwave signal source, open-ended coaxial sensor and computer tobe FPR as shown inFig. 3. Agilent Vee Pro 6.0 is used to develop a graphical user interface (GUI) as platform for interfacing. Fig. 4 shows the block diagram of FPR's configuration. Meanwhile, Fig. 5 shows the open-ended coaxial sensor. The variation of Γ due to MUT is detected by three diode detectors. The wave signal is converted from power (dBm) to voltage (V). The analog output voltages can be converted to digital signal via PICO ADC. This GUI program is also conduct computation of Six-Port and calibration algorithm using MATLAB server in Agilent VEE Pro.

4. Reflection Measurement

In aforementioned section, air, water, methanol and ethanol were used as standard load in order to ensure the accuracy of FPR. Three liquid form of standard load is preferable due to its better contact with sensor and less measurement error [9]. The reflection measurement on these loads was conducted using both Agilent E8362B PNA and FPR at 0.80 GHz, 2.82 GHz and 4.21 GHz. The measurement was carried out at room temperature.

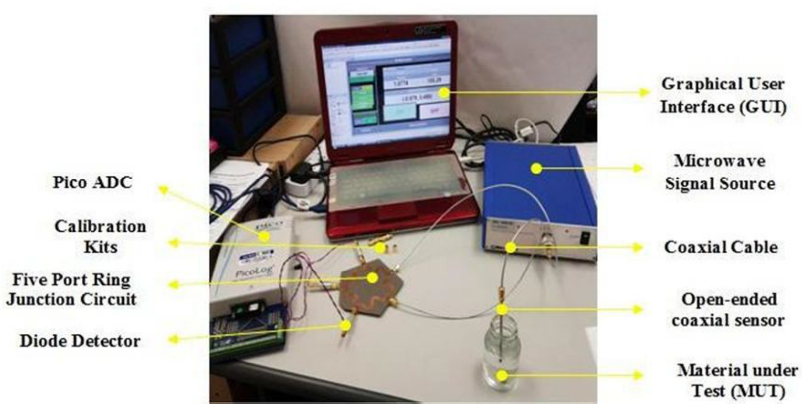

Figure 3. Assembly of FPR

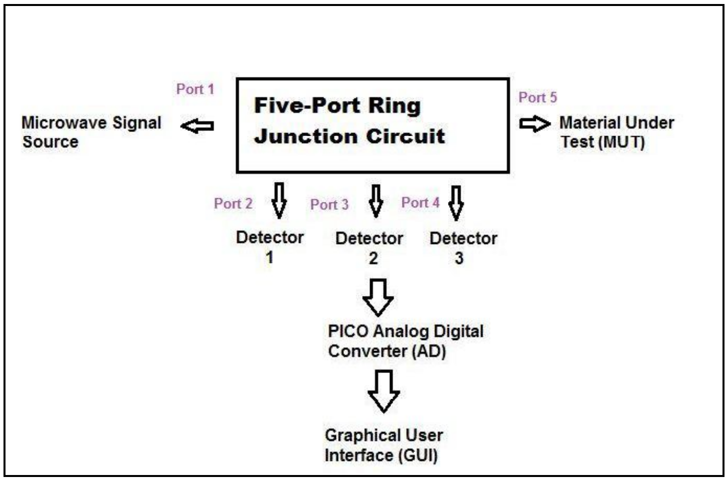

Figure 4. Configuration of FPR

Figure 5. Open-Ended Coaxial Sensor

Calibration is carried out to remove systematic error prior to the reflection measurement. Constant standard loads method use for PNA calibration is Open, Short and broadband load as shown in Fig. 6. Meanwhile, the calibration standards used for FPR are SMA termination at match, open0 (open air with phase shift 0°), open120 (open air with phase shift 120°) and open240 (open air with phase shift 240°).

Figure 6. Calibration Kits for Reflection Measurement using PNA

5. Result and Discussion

A.Comparison of Measured S-Parameter and Theoretical S-Parameter Table I. |Γ| of S-Parameter

Frequency (GHz)	S-Parameter	Measured |Γ|	Theory [10]	Absolute Error
0.80	$\|S_{11}\|$	0.0264	0.0000	0.0546
	$\|S_{21}\|$	0.5106	0.5000	0.0415
	$\|S_{31}\|$	0.4886	0.5000	0.0560
	$\|S_{41}\|$	0.4811	0.5000	0.0485
	$\|S_{51}\|$	0.5045	0.5000	0.0476
2.82	$\|S_{11}\|$	0.0219	0.0000	0.0036
	$\|S_{21}\|$	0.5068	0.5000	0.0261
	$\|S_{31}\|$	0.4418	0.5000	0.0631
	$\|S_{41}\|$	0.5084	0.5000	0.0035
	$\|S_{51}\|$	0.4991	0.5000	0.0184
4.21	$\|S_{11}\|$	0.0816	0.0000	0.0540
	$\|S_{21}\|$	0.5645	0.5000	0.0820
	$\|S_{31}\|$	0.5052	0.5000	0.0069
	$\|S_{41}\|$	0.5184	0.5000	0.0201
	$\|S_{51}\|$	0.5252	0.5000	0.0427

Table III. Φ of S-Parameter

Frequency (GHz)	S-Parameter	Measured φ Difference (°)	Theory φ Difference (°) [10]	Absolute Error
0.80	S_{21}	124	±120	4
	S_{31}			
	S_{41}	124	±120	4
	S_{51}			
2.82	S_{21}	-127	±120	7
	S_{31}			
	S_{41}	-122	±120	2
	S_{51}			
4.21	S_{21}	120	±120	0
	S_{31}			
	S_{41}	122	±120	2
	S_{51}			

In Table I and Table II, it can be observed that 0.80 GHz, 2.82 GHz and 4.21 GHz are in good agreement with the Riblet and Hansson values [10]. The absolute error between measured and theoretical S-Parameter are less than 0.09 (or 9%) and 7° (or 1.94%) for magnitude, |Γ| and phase, φ respectively. The absolute error of |Γ| and φ are generally due to the tolerance of dielectric substrate and components used in fabrication and assembly, e.g. SMA connectors, coaxial cable, microwave dielectric substrate and etc. These tolerances have not been taken into account in simulation.

B. Comparison of Complex Reflection Coefficient of Known Loads between PNA and FPR

Table IIIII. |Γ| of known loads

Load	Frequency (GHz)	Measured |Γ| (PNA)	Measured |Γ| (FPR)	Absolute error
Air	0.80	0.9916	0.9646	0.0270
	2.82	0.9876	0.9855	0.0021
	4.21	0.9827	0.9888	0.0061
Water	0.80	0.9687	0.9726	0.0039
	2.82	0.8426	0.8360	0.0066
	4.21	0.8112	0.7500	0.0612
Methanol	0.80	0.9377	0.9866	0.0489
	2.82	0.6322	0.5763	0.0559
	4.21	0.5255	0.5206	0.0049
Ethanol	0.80	0.9068	0.9629	0.0561
	2.82	0.7871	0.7311	0.0560
	4.21	0.7707	0.8277	0.0570

Table IVV. Φ of Known Loads

Load	Frequency (GHz)	Measured |Γ| (PNA)	Measured |Γ| (FPR)	Absolute error
Air	0.80	155.78	155.48	0.30
	2.82	11.59	8.66	2.93
	4.21	21.33	15.06	6.27
Water	0.80	117.14	124.78	7.64
	2.82	262.74	254.78	7.96
	4.21	252.21	243.40	8.81
Methanol	0.80	139.04	143.49	4.45
	2.82	331.06	332.71	1.65
	4.21	335.89	338.49	2.60

Ethanol	0.80	147.52	149.80	2.28
	2.82	359.34	359.88	0.54
	4.21	6.96	10.45	3.49

Table III and Table IV show the comparison between measured PNA and FPR for known loads. It can be found that the absolute error of |Γ| are less than 0.0612, while the absolute error of φ are less than 8.81° for all known loads at listed frequencies. The absolute error for both |Γ| and φ are within acceptable percentage error, i.e. it less than 6.20% and 2.45 %, respectively. On the other hand, the absolute errors produced might due to the measurement losses such as multiple reflections, instrumentation loss, systematical loss, and environmental effects.

6. Conclusion

Five-Port ring junction circuit has been successfully designed and fabricated for development of FPR. The Five-Port ring junction circuit can be operated at multiple frequencies i.e. 0.80 GHz, 2.82 GHz and 4.21 GHz with acceptable error in accordance with published literature. The S-Parameter of all operating frequencies exhibit good agreement with the theoretical values where the absolute errors are less than 0.09 and 7° in |Γ| and φ, respectively. Withal, the developed FPR was used to measure the complex reflection coefficient, Γ of air, water, methanol and ethanol. The absolute error of these known loads in |Γ| and φ is less than 0.0612 and 8.81°, respectively. These absolute errors are lies within the acceptable absolute error range compared with published values. Therefore, FPR is a reliable and accurate device in measuring complex reflection measurement.

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