Material Characterization using Microwave Signal Properties at 2.4 GHz and 5.2 GHz

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***Abstract*— This paper presents a material characterization method by using microwave signals at the frequency of 2.4 GHz and 5.2 GHz. Two types of circular loop FSS are used to filter the transmission waves at both selected frequency bands. The chosen materials for characterization are distilled water, bicarbonate water, rock and black soil. The measurement is conducted in an indoor environment with the distance of 30 mm. The materials are characterized based on reflection and transmission signals extracted from measured S-parameters. The results showed that black soil has the highest reflection loss at the frequency of 2.4 GHz while distilled water has the highest reflection at the frequency of 5.2 GHz. Meanwhile, rock showed minimum transmission losses of -18 dB and -26 dB at 2.4 GHz and 5.2 GHz respectively. This characterization method can be used to identify different materials such as liquid or solid structure.**

Keywords—frequency selective surface (FSS); reflection (S11); transmission (S21); ism band

I. Introduction

In 1968, metamaterial had been proposed by V.G Veselago. These metamaterials possess characteristics of subwavelength with particles smaller than the wavelength of light and it also has properties that may not be available in nature. Normally these metamaterials gain their properties from their design structures instead of composition. Therefore, antennas, filters, FSS and etc., are some of the potential applications of metamaterials in the design of radio-frequency components [1-5].

FSS is a type of periodic structure that functions as a filter in space [6]. This Frequency Selective Surface (FSS) usually consists of two surfaces which are metallic patch element and aperture elements (slot) [6-7]. Each element in the design has its own specific purpose and function. For example, the patch element produces band stop signal while the aperture element will produce band-pass signal. These surfaces periodically exhibit nearly total reflection (patches) or nearly total transmission (apertures) at the resonance frequency [6]. An FSS can be etched on FR4 in order to provide transmission improvements for WLAN applications at 2.4 GHz and 5.2 GHz. This paper proposed the characteristics of the FSS that were based on different materials to observe the performance of the FSS.

II. FSS Design Process

The proposed physical design structure of the FSS is as shown in Figure 1. This structure has been designed using FR4 material where the thickness of substrate is 1.6mm, the dielectric constant is 4.4 and loss tangent is 0.019. Meanwhile, the surface of FSS has been designed using copper material. This design was analyzed using Computer Simulation Technology (CST) Microwave Studio (MWS) software.

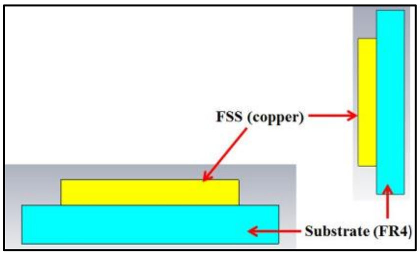
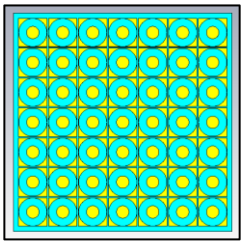
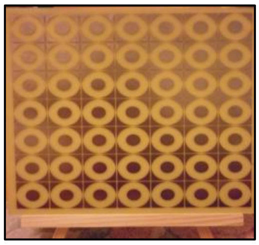


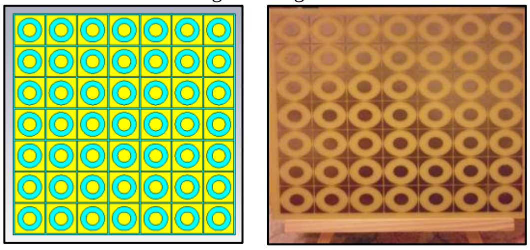
Fig. 1. Design structure of FSS

In this paper, two types of circular loop with different sizes will be investigated. The first design is Design A that can produce 2.4 GHz while the second design is Design B that can produce 5.2 GHz as shown in Figure 2 (a) and 3 (a). The design parameter that has been set for Design A is length of (***a***) 13.8mm, radius of circle FSS (***b***) 13.6mm and radius of circle loop (***c***) 4.2mm. Meanwhile, the physical parameters that have been set for Design B are the length of (***a***), radius of circle FSS (***b***) and radius circle loop (***c***) are 13.8mm, 11mm, 6mm respectively.





a. Design in CST software b. Prototype
Fig. 2. Design A



a. Design in CST software b. Prototype
Fig. 3. Design B

Figure 2 (b) and 3 (b) shows the designed FSS after completing fabrication. This design has been fabricated using chemical etching to remove unwanted copper. The measurement process for those designs will be described in the measurement setup.

III. Measurement Setup

Figure 4 shows the measurement setup to test the FSS design by using a pair of horn antenna (for transmitter and receiver) and network analyzer. Both of the horn antennas are connected to the network analyzer. Port 1 of the Network Analyzer is connected to the transmitter horn antenna while the receiver horn antenna is connected to port 2. The distance between transmitter horn antenna and receiver is fixed at 60mm. The measurement results of reflection and transmission was measured to observe the performance of FSS.

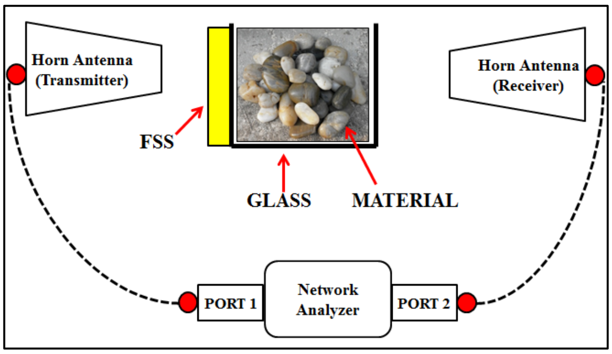


Fig. 4. Equipment setup

Figure 5 shows the materials that have been tested by using an aquarium filled with rock, black soil, distilled water and bicarbonate water. The measurement and analysis process of the FSS performance has been done for each target material. The result and analysis for the measurement process will be described in the next section.

a. Rock b. Black soil
c. Distilled water d. Bicarbonate water
Fig. 5. Materials for testing application.

IV. Results and Discussion

Figure 6 and Figure 7 show the measurement result without FSS for the reflection and transmission respectively. From Table 1, it can be illustrated that at frequency 2.4 GHz and 5.2 GHz, the reflection and transmission for distilled water are -24.89 dB and -27.5 dB. Distilled water shows minimum reflection compared with other materials. However, the transmission result for distilled water is -38.42 dB and -28.44 dB. Distilled water did not produce a minimum performance when compared with bicarbonate water, black soil and rock at frequencies of 2.4 GHz and 5.2 GHz.

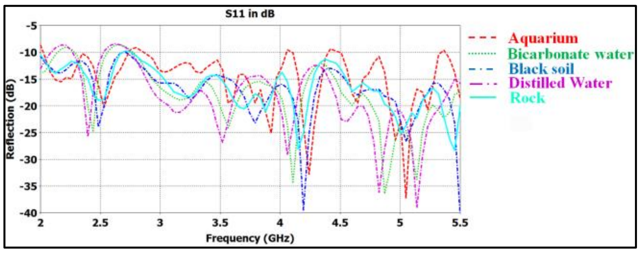


Fig. 6. Measurement Reflection, S_{11}

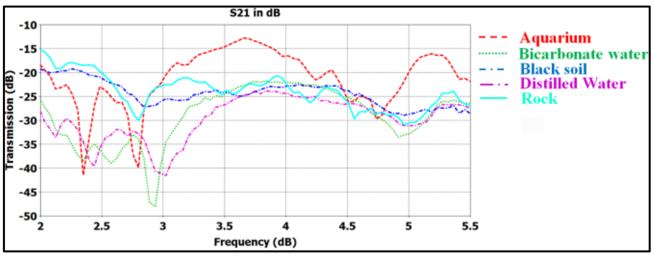


Fig. 7. Measurement Transmission, S_{21}

TABLE 1: MEASUREMENT WITHOUT FSS

Material	Reflection, S_{11} (dB)		Transmission, S_{21} (dB)	
	2.4GHz	5.2GHz	2.4GHz	5.2GHz
Aquarium	-11.07	-18.54	-33.04	-16.13

Bicarbonate water	-20.68	-23.58	-36.04	-27.91
Black soil	-12.84	-18.47	-20.47	-27.94
Distilled water	-24.89	-27.59	-38.42	-28.44
Rock	-15.24	-18.62	-18.39	-26.67

Figure 8 and Figure 9 show the measurement results of reflection with FSS. In Table 1 and Table 2, it can be observed that the reflection and transmission effect are not similar when FSS is used in the measurement setup. The range of reflection at both frequencies is from -15 dB to -19 dB. In this case, the minimum reflection is -19.81 dB as found at the frequency of 5.2 GHz. Meanwhile, rock produces the minimum reflection of -18.53 dB at the frequency of 2.4 GHz.

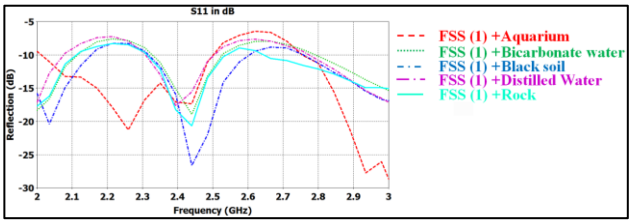


Fig. 8. Measurement S_{11} for configuration 1 with other material.

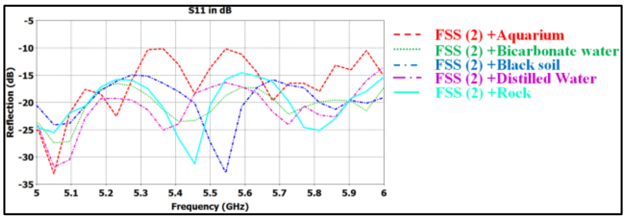


Fig. 9. Measurement S_{11} for configuration 2 with other material

The transmission wave result with FSS is shown in Figure 10 and Figure 11. The result showed that the materials with FSS and without FSS were not much affected by the transmission of microwave signal. Reflection is measured from -16.13 dB to -16.22 dB when the FSS was used. However, bicarbonate water, black soil, distilled water and rock show an increment in the transmission signal from -27.91dB to -25.47dB, -27.94 dB to -26.41 dB, -28.44 dB to -26.41 dB and -26.67 dB to -25.07dB respectively.

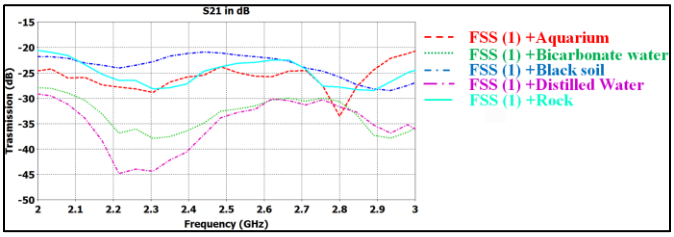


Fig. 10. Measurement S_{21} for configuration 1 with other material

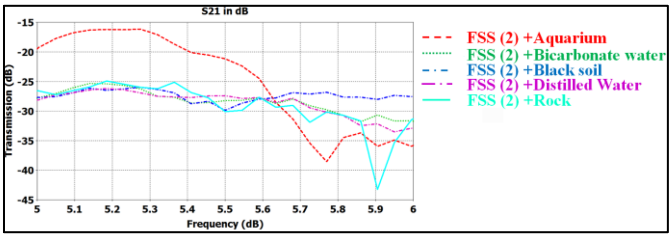


Fig. 11. Measurement S_{21} for configuration 2 with other material

TABLE 2: MEASUREMENT RESULT WITH FSS

Material	Reflection, S_{11} (dB)		Transmission, S_{21} (dB)	
	2.4GHz	5.2GHz	2.4GHz	5.2GHz
Aquarium	-17.12	-19.81	-25.77	-16.22
Bicarbonate water	-15.57	-17.22	-36.29	-25.47
Black soil	-17.13	-17.23	-21.18	-26.41
Distilled water	-17.42	-19.26	-40.17	-26.26
Rock	-18.53	-16.68	-26.92	-25.07

V. CONCLUSION

In this paper, the method to characterize different materials using a microwave signal is presented. Two types of circular loop FSS were used as the microwave filter to filter the radiated signals which propagated through the materials. The proposed measurement technique showed that different materials can be characterized by using microwave signal reflection and transmission properties.

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