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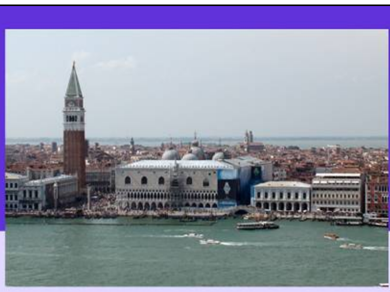

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Microwave Detection of Soil Moisture Using C-Band Rectangular Waveguide

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Abstract: Microwave propagation inside a waveguide is known to be dependent on dielectric filled inside the guide. The soil can be thought of as dielectric material and filled in the rectangular waveguide to modify wave propagation. This paper describes different approach of detection of water mixed in the soil using C-band microwave waveguide, after filling dirty soil inside it. The results of detection parameter from 5 to 6 GHz have been shown in agreement with the expected and % of water content in the soil can be known using such approach, which may be extended for applications on future planetary missions. *Copyright © 2010 IFSA.*

Keywords: Microwave, Soil, Waveguide, Moisture

1. Motivation

Planetary bodies like Moon or Mars are known for their either no atmosphere or very light atmosphere, where no water can survive in free form. The possibility of the existence of water/ice on the Moon, for example, could be due to cometary bombardment on the lunar surface and water molecules might be trapped inside the permanently dark regions near the pole. This may create water in the form of ice or water/ice mixed with the soil (Rogolith). However, detection of the water/ice on Moon is not easy and requires special techniques which can work in hostile environment. Before actually designing a device for detection of water in soil, for planetary applications, a laboratory exercise is needed to establish and verify the technique. This is a motivating factor for us to show one of the possible techniques for detection of soil moisture.

2. Introduction

There has been a controversy about the presence of water/ice on the lunar surface. Clementine orbiter data showed that the water might be present from the radar based experiment, while earth based Arecibo Observatory have shown that water might not be present on the Moon as given by Spudis, P., 2006 [1]. Recent mission to the Moon has detected presence of water on the Moon as given by Pieters et al. [2]. However, all such techniques are based on remote observation and for confirming presence of water ice in a given region on the Moon, in situ measurements may be carried out. Many experiments have been carried out for determination of soil parameters, e.g., dielectric study of soil with moisture as given by Chaudhari, H. C. and Shinde, V. J., 2008 and Curtis, J. O., 2001 [3, 4] and Baker-Javis, J. et al, 1990, Janezic, M. D. and Jargon, Jeffrey A., 1998, Logsdon, S. D., 2005 and Srivastava, S. K. and Mishra, G. P., 2004 [5-8] show work carried out on the soil properties. Stein. J. and Kane, D. L., 1983 [9] shows the technique of water content monitoring using time domain reflectometry. In our application, the objective is to find out the water content in a soil sample and the device may be made compact to use for planetary applications. Before really designing the device for the planet, one needs to carry out the experiment in laboratory environment. As a part of this exercise, one approach has been shown in this paper. This is based on microwave detection of soil moisture using C-band microwave waveguide. Efforts have been made to show that the technique can prove the presence of water/ice mixed in the soil. Moisture content of the order 0.5 % can easily be detected by this method and sensitivity of the method depends on the sensitivity of the instrument as well as measuring accuracy.

It is known that microwave absorption is higher in the dielectric waveguide as compared to free space propagation. When such waveguide is filled with soil having water/ice mixed, this attenuation increases further. In order to carry out the experiment, a C-band microwave waveguide has been designed and developed in house. Also, coax-to-waveguide adapter as well as antenna have been designed and developed. These are given in the next section. Different types of soils have been collected and samples were prepared with known amount of water content (by weight percentage). This and experimental set up for testing are described in Section IV and V. Systematic testing of soil moisture was carried out and a set of library was generated. The results of detection parameters from 5 to 6 GHz have been measured using microwave Vector Network Analyzer (VNA). This provides a calibration curve for detection of unknown soil sample. Using available calibration curve and designed C-band waveguide, unknown sample was tested again using VNA. From the measurements and calibration curve, amount of water in the given sample was found. Practical results are described in Section VI. Dielectric constant of the dirty soil and water may be obtained using S-parameters as given by Sudheendran, K. et al [10] and compared with known values to provide a way to decide if the water is present in the soil. The results show that the technique can be applied to detect the presence of water/ice mixed with soil and can be extended for future planetary missions. This possibility is described at the end of the paper.

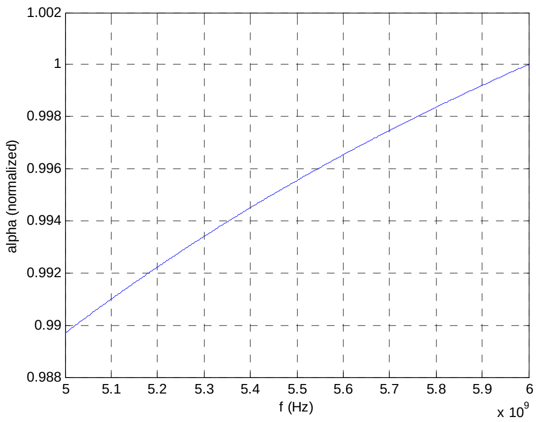
3. Design and Development of Waveguide and Adapter

It is known that C-band extends from 4 to 8 GHz and in order to test the device, VNA should also be in the same frequency range, which is our case is Rohde & Schwarz ZVB-8 capable of working from 300 kHz to 8 GHz. Choice remained as to make circular or rectangular waveguide for the testing and later was selected for easy manufacturing including polishing on the inner walls of the waveguide. Main specifications of the rectangular waveguide are frequency of operation, cut-off frequency, cross-sectional dimensions, length of the guide, material of walls, wall thickness, polishing of the walls and flanges at the ends to couple it with adapters. Important specifications are shown in Table 1.

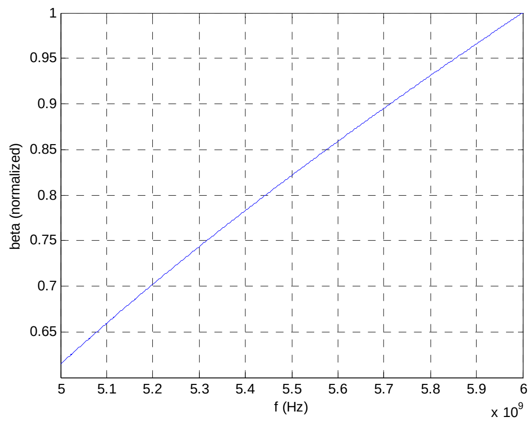
Normalized attenuation constant and phase constant of wave inside the waveguide have been found using standard waveguide equations from literature and plotted in Fig. 1.

Table 1. Important parameters of waveguide (and adapters)

Parameter	Value
Useful Frequency Range	4.28 to 9.37 GHz
Cut-off Frequency	4.28279482 GHz
Cross-sectional Dimension	35 mm x 16 mm
Length	300 mm
Material	Aluminum
Wall Thickness	5 mm
Flange Dimension	40 mm x 21 mm



(a)



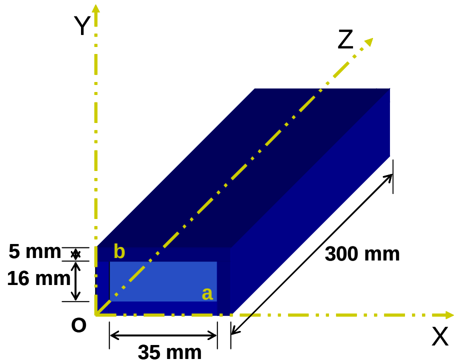
(b)

Fig. 1. Normalized attenuation and phase constant of C-band rectangular waveguide for frequency range of 5 to 6 GHz.

In order to couple coaxial input and output to rectangular waveguide, coax-to-waveguide adapters have been designed and developed. Antenna diameter, back short distance of the antenna from the end of flange, antenna length, antenna material and appropriate connector need to be considered; over and above those parameters which are required for waveguide design. Parameters for adapters are given in Table 2. The photographs of the waveguides and adapters are shown in Fig. 2.

Table 2. Important specifications of adapters.

Parameter	Value
Probe Diameter	1.27 mm
Back Short Distance	11.7 mm
Probe Length	10.5 mm
Probe Material	Aluminum
Wall Thickness	5 mm
Flange Dimension	40 mm x 21 mm
Connector	N (F)



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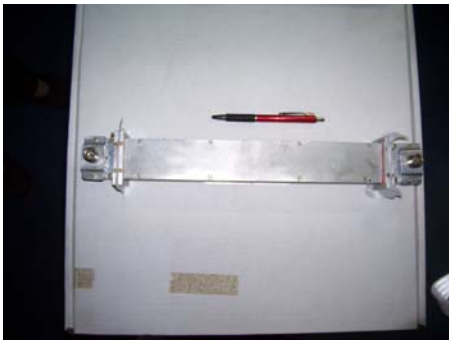

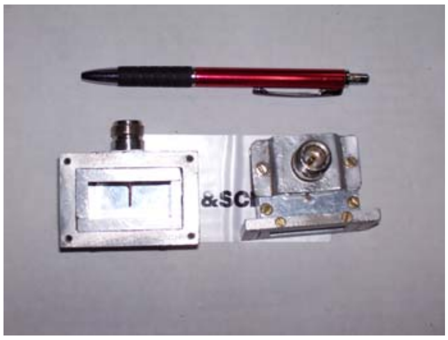

(b) (c)

Fig. 2. (a) C-band rectangular waveguide; (b) photograph of waveguide; and (c) photograph of coax-to-waveguide adapter with probe inside.

4. Sample Collection and Preparation

Electromagnetic wave propagation inside an empty waveguide is through air acting as a dielectric material. When it is filled with soil, it adds in the dielectric behaviour of the medium and wave propagation through it, is affected. There are three types of soils in general, i.e., sand, clay and loam, found in literature. These samples are available from construction site, garden site and agricultural site respectively. Few samples are collected from various locations and then they are first dried in an oven at 120^{o} C for 48 hours to make sure that no moisture is present in them. Dry soil sample is one of the test samples for the experiment. Known amount of water is added (by weight percentage) in such dry soil, it is mixed thoroughly and allowed to settle for 20 minutes. Samples as dry soil and dry soil with 0.5 %, 1 %, 1.5 %, 2 %, 2.5% and 3 % are taken for the measurements. Weight of sample in each case is taken as 250 grams plus the amount of water.

5. Experimental Set up

Samples prepared were filled in C-band waveguide and connected to microwave Vector Network.

Analyzer, to measure various S-parameters of the waveguide. The instrument was calibrated using standard 'Through-Open-Short-Match (TOSM)' two port calibration technique before connecting device under test, having plane of calibration taken up to connectors initially; which may be shifted to sample surface, if needed, as given by Sudheendran, K. et al [10]. The experimental set up is shown in Fig. 3. One of the ports of VNA is connected to the adapter through co-axial cable and the other adapter is connected to another port of VNA. Various soil samples are filled inside the guide to alter the attenuation caused by the presence of water. Once all samples are measured, a calibration curve is drawn for S21 parameter versus weight % of water in the sample. Later on, unknown samples are taken and its attenuation is measured. The data is fitted in the calibration curve which can then indicate the % of water in the sample. This technique gives directly the % of water present and need not use the Topp's equation given by Topp, G. C. et al [11].

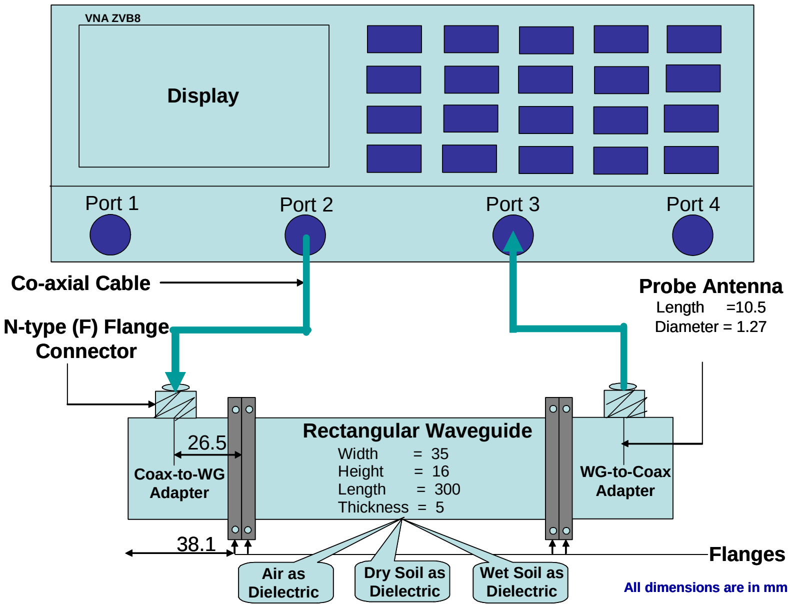

Fig. 3. Experimental set up for soil moisture testing.

6. Practical Results

Various plots of attenuation of microwave signal due to presence of moisture (S21) for frequency range from 5 GHz to 6 GHz are shown in Fig. 4 and 5. Fig. 4 gives comparison for sample1 (with texture as sand) for 0 % (dry soil), 1 %, 2 % and 3 % of water in the soil, while Fig. 5 shows comparison for samples (with texture as clay) for 0 % (dry soil), 1 %, 2 % and 3 % of water in the soil. For testing an unknown sample, calibration curve for various frequencies were obtained, which are plotted in Figs. 6 and 7 for sample1 and sample 2, respectively.

7. Conclusion and Future Work

Various S-parameters have been measured during the testing. Following conclusions are made from the results:
(1) Attenuation of the wave increases in dry soil as compared to air as a dielectric.
(2) Attenuation of the wave increases in wet soil as compared to dry soil as a dielectric.
(3) Attenuation is more in clay type of soil as compared to sandy soil.
(4) Plot of S21 vs. % of water in soil samples is almost linear.

Since it is ongoing project, the aim of the project is to make an autonomous and compact device which may be used for future planetary applications. For achieving this goal, microwave source, microwave detector and a processor along with decision algorithm capable of analyzing the results can be added. Better sensitivity of the device and detection of unknown soil sample independent of soil texture are planned.

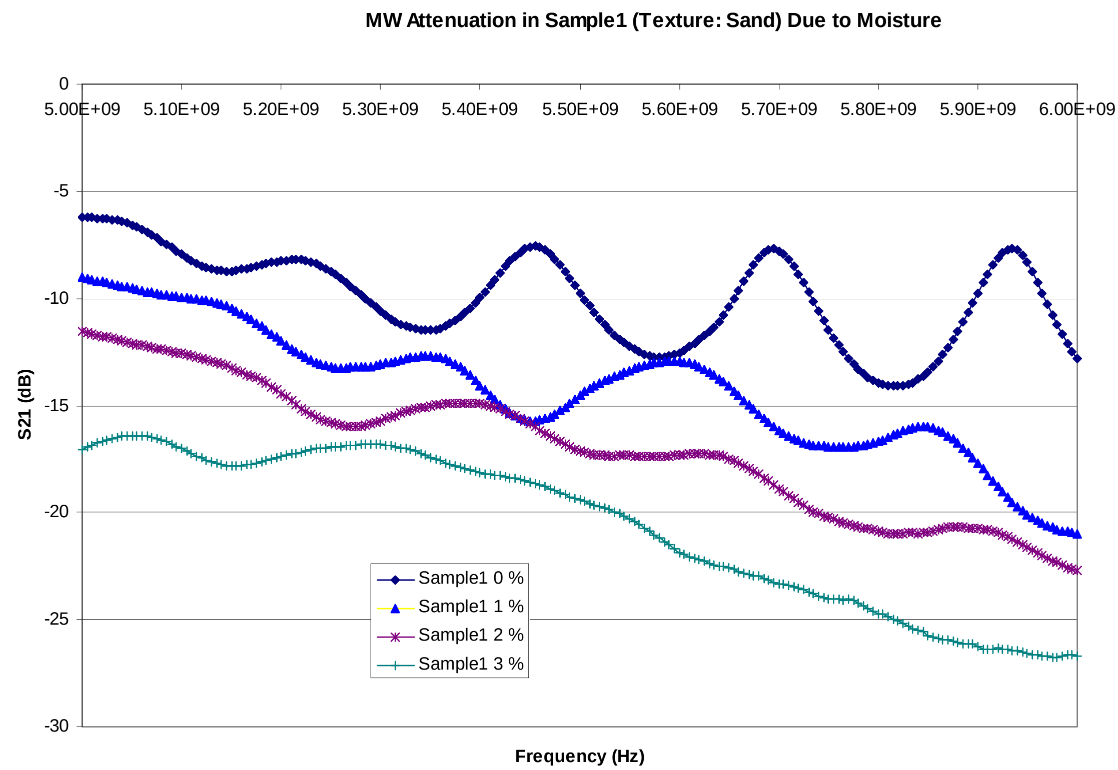

Fig. 4. Signal attenuation in soil sample1 (texture: sand) due to moisture.

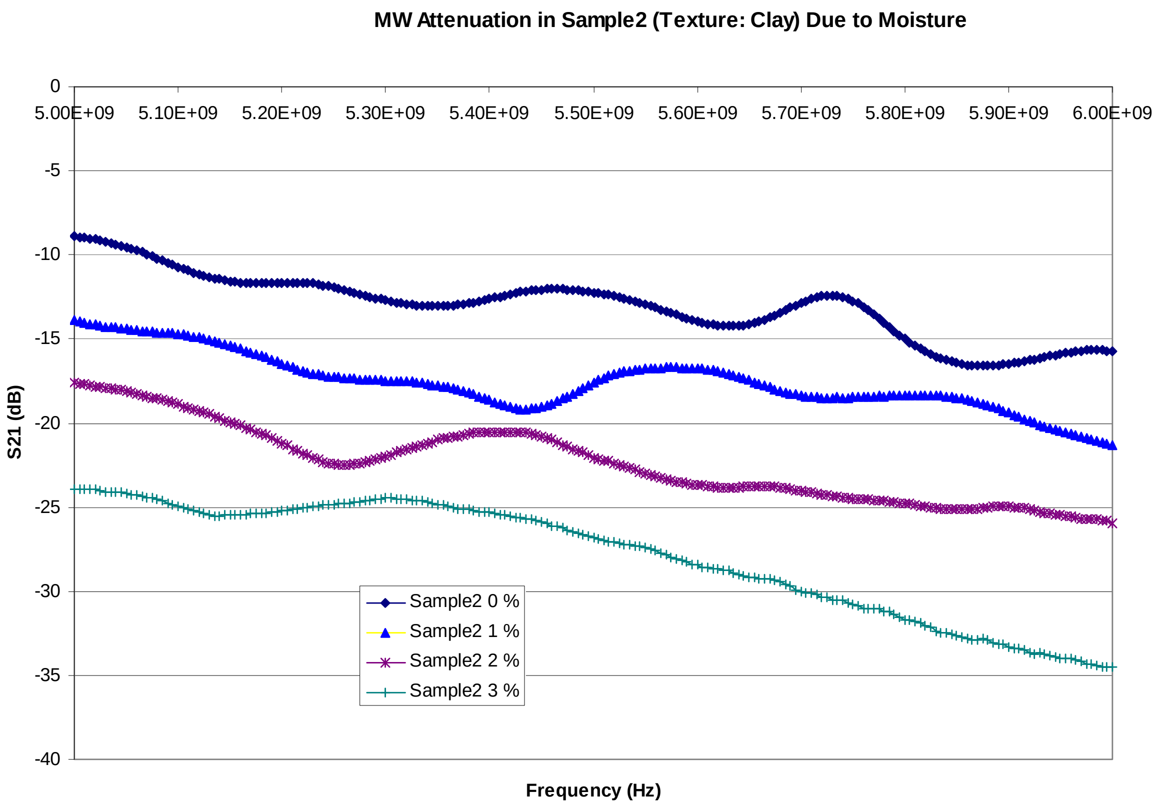

Fig. 5. Signal attenuation in soil sample2 (texture: clay) due to moisture.

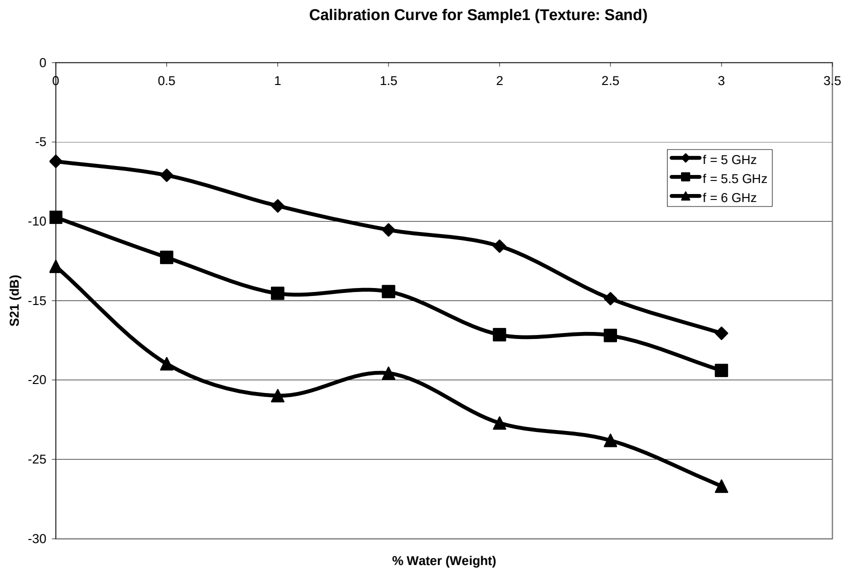

Fig. 6. Calibration curve for detection of water in soil sample1 (texture: clay).

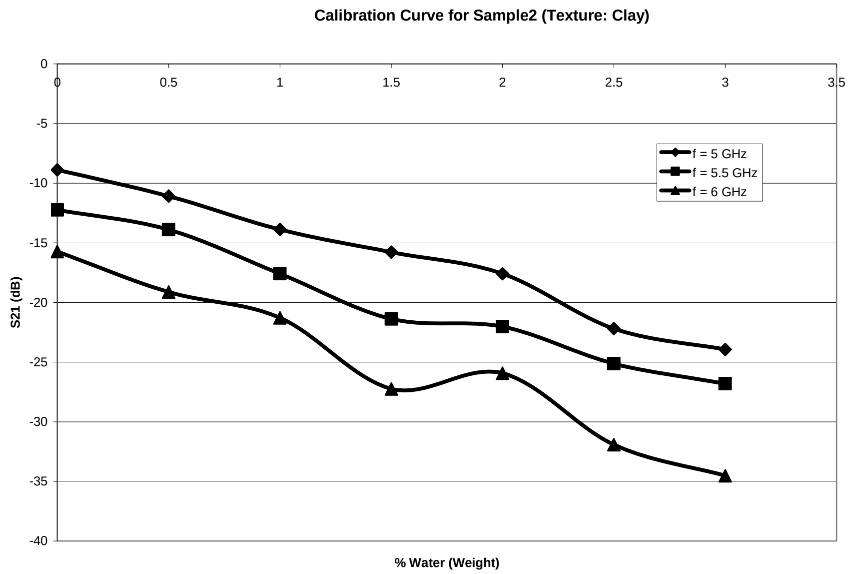

Fig. 7. Calibration curve for detection of water in soil sample2 (texture: clay).

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