Use of Microstrip Patch Antennas in Grain and Pulverized Materials Permittivity Measurement

Mahmoud A. El Sabbagh *[1,4], Omar M. Ramahi [2,3,4], Samir Trabelsi [1], Stuart O. Nelson [1] and Latif Khan [5]
[1] USDA-ARS, Richard B. Russell Agricultural Research Center, Athens, Georgia 30604
[2] Mechanical Engineering Department, [3] Electrical and Computer Engineering Department and [4] Calce Electronic Products and Systems Center, University of Maryland, College Park, MD 20742
[5] Illinois State Geological Survey, 615 E. Peabody Dr. Champaign, IL 61820

I. INTRODUCTION

Real-time sensing of moisture content and other physical properties of wet granular and pulverized materials is crucial in many industries where these properties are used as quality control factors for the optimization of a given process, especially when large quantities are involved. The transmission method is commonly used to measure the complex permittivity of dielectric materials [1]-[3]. A common feature in the previously built systems is the use of horn antennas at the transmitting and receiving ends, and a microwave network analyzer for the scattering parameters measurement. The purpose and motivation in this work is to build an inexpensive and light weight microwave sensor.

In this paper, we report on a free-space microwave system developed for the measurement of the relative complex permittivity of granular materials (wheat, soybeans and corn) and of pulverized materials (coal). The system, as shown in Fig. 1, consists of a transmitting antenna and a receiving antenna separated by a space filled by the sample to be characterized and a network analyzer for transmission measurement. The receiving antenna is mounted on a movable plate, which gives the flexibility of having different sample thicknesses.

The system is considered a two-port device. The testing procedure developed is nondestructive and easy for implementation. At a fixed moisture level, the dielectric constant and loss factor of the test materials are determined and compared with other published data.

II. ANTENNA DESIGN AND CHARACTERIZATION

Patch antennas were designed on a substrate with a dielectric constant of 3.38, height of 1.5 mm, the width and the length are 220 and 150 mm, respectively. The patch length and width are 15.25 and 26 mm respectively. The feed point was placed at coordinates of 4.332 and 13 mm. Two antennas with these dimensions were built and used as transmitter and receiver. Fifty-ohm SMA female connectors were used as the feeding port at the transmitting antenna and as the

0-7803-7846-6/03/$17.00 ©2003 IEEE

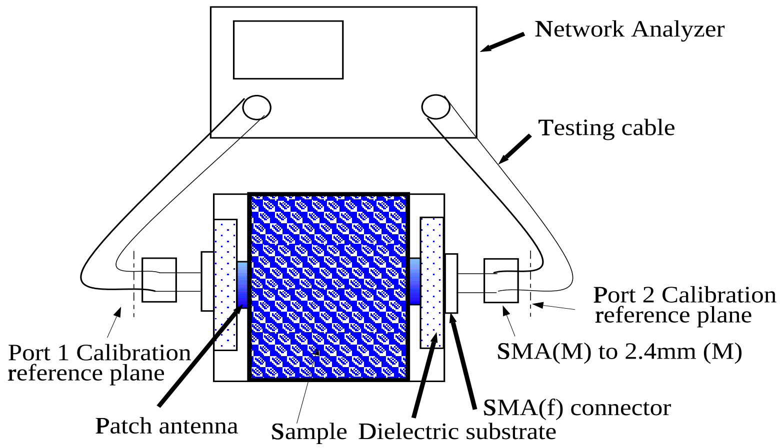

Fig. 1. Schematic diagram of the setup used for complex permittivity measurements.

output port at the receiving antenna.

The designed antennas were characterized by measuring the scattering parameters of the transmitting and receiving antennas for different separations between the two antennas as shown in Fig. 2. The resonant frequency is between 4.3 GHz and 4.4 GHz and the 20-dB return loss bandwidth is about 200 MHz. Fig. 2 shows that as the separation between the two antennas (with empty space between the antenna) increases, the frequency at which the antenna has minimum input reflection and maximum transmission decreases. This is due to the loading effect that varies with the spacing between the antennas.

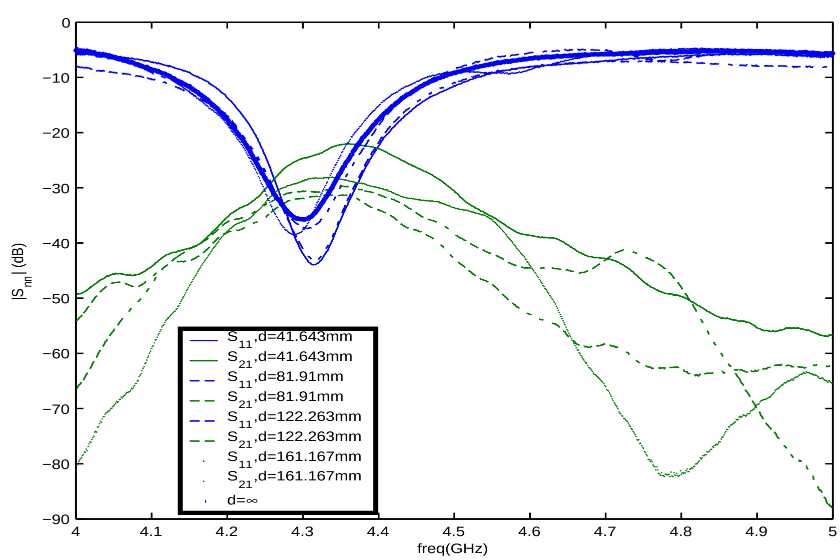

Fig. 2. Effect of the air gap separation between the transmitting and receiving antennas on the scattering parameters magnitude.

III. MEASUREMENTS ON MATERIALS

A microwave network analyzer, of the type PNA Agilent series E8364A with the capability of performing measurements between 45 MHz and 50 GHz, was used. The network analyzer was connected to the two ports of the device through 50 Ω coaxial cables (2.4 mm) with no sample between the antennas. Then, a calibration procedure was performed as follows: choose mechanical calibration, and select thru response. After the calibration was done, the scattering transmission coefficient (S_{21}) was set to zero (both magnitude and phase). This calibration can be done in another way by saving the data (for both magnitude and phase, with the sample holder empty) in the memory and then displaying the results by using the function Data/Memory. After the calibration is done, the sample is placed between the two antennas (in the sample holder). The Short-Open-Load-Thru (SOLT) calibration was also used, and it was found to give results very close (within 1%) to those obtained from the Thru calibration. The transmission was read, the magnitude representing the attenuation due to the dielectric sample and the phase representing the delay due to wave propagation in the dielectric medium. The two readings of magnitude and phase were used to calculate the real and imaginary parts of the relative complex permittivity as follows [1]:

$$\epsilon' \approx \left(1 + \frac{|\Delta\phi|\lambda_0}{360d}\right)^2 \tag{1}$$

$$\epsilon'' \approx \frac{|\Delta A|\lambda_0\sqrt{\epsilon'}}{8.686\pi d} \tag{2}$$

where $\Delta\phi$ is the phase shift in degrees, ΔA is the attenuation in decibels and λ_0 is the free-space wavelength. When computing the free-space wavelength, the frequency taken is the one at which the antenna has maximum radiation (the reflection coefficient is minimum). In this experiment, the frequency was $\approx$ 4.45 GHz.

IV. EXPERIMENTAL RESULTS

Fig. 3 shows that with a sample between the two antennas, the frequency at which the antenna has minimum input reflection and maximum transmission increases as sample thickness increases.

The relative complex permittivity of wheat and coal are shown in tables I, II. The measurement temperature was 23°C and the measurement frequency was 4.45 GHz. The moisture level for wheat, was: 10.9%. For samples with thicknesses smaller than 10 cm, the requirement of 10-dB one-way attenuation was not met. Therefore values of the complex permittivity are not accurate because of multiple-reflection effects. For sample thicknesses greater than 10 cm, the 10-dB one-way attenuation requirement was met, and these values for complex permittivity should be more reliable. The latter values compare favorably with data reported in the literature for commodities of similar moisture contents when differences in frequency and bulk density are taken into account [4].

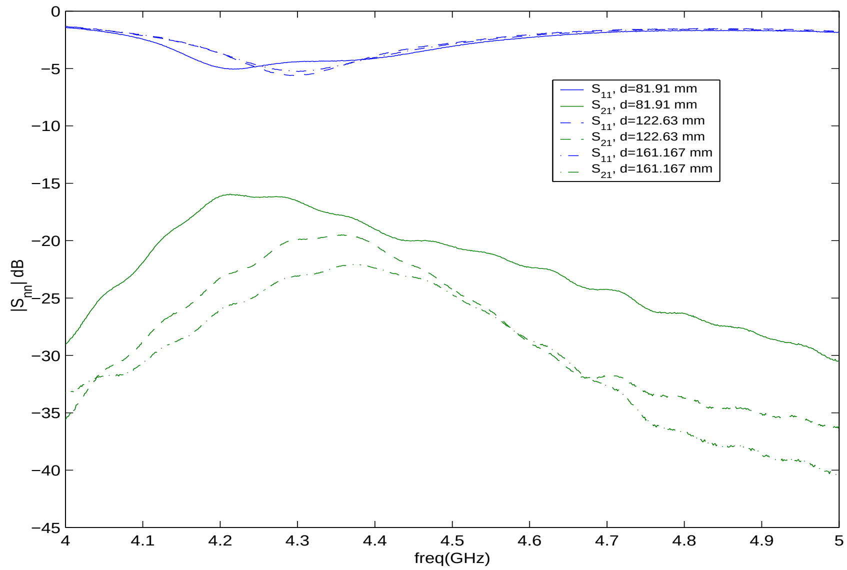

Fig. 3. Effect of the separation between the transmitting and receiving antennas on the scattering parameters, with soybeans between the antennas.

TABLE I

RELATIVE COMPLEX PERMITTIVITY FOR WHEAT

d(mm)	Density(kg/m^3)	ϵ'	ϵ''
41.6	740.9	2.55	0.09
161.2	803.6	2.72	0.35

REFERENCES

[1] S. Trabelsi, A. W. Kraszewski, S. O. Nelson, "Nondestructive microwave characterization for determining the bulk density and moisture content of shelled corn", *Measurement Science and Technology*, pp. 1548-1556, 1998.

[2] Stuart O. Nelson, "Measurement and calculation of powdered mixture permittivities", *IEEE Transactions on Instrumentation and Measurement*, vol. 50, pp. 1066-1070, Oct. 2001.

[3] Ki-Bok Kim, Jong-Heon Kim, Seung Seok Lee, and Sang Ha Noh, "Measurement of grain moisture content using microwave attenuation at 10.5 GHz and moisture density", *IEEE Transactions on Instrumentation and Measurement*, vol. 51, pp. 72-77, Feb. 2002.

[4] Stuart O. Nelson, "Dielectric properties of agricultural products - measurements and applications", *IEEE Transaction on Electrical Insulation*, vol. 26, pp. 845-869, Oct. 1991.

TABLE II

RELATIVE COMPLEX PERMITTIVITY FOR PULVERIZED COAL

d(mm)	f(GHz)	Density(kg/m^3)	ϵ'	ϵ''
3.1	4.44	555.4	5.57	0.84
10.5	4.42	638.9	4.35	1.36