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DUAL FREQUENCY MULTI-PURPOSE MOISTURE SENSOR BASED ON MICROSTRIP PATCH ANTENNA

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ABSTRACT

In order to device a sensor system that is capable of measuring moisture content of diverse agriculture products and crops (i.e. natural rubber latex, liquids, etc), a dual frequency sensor system has to be developed .The original idea of taking a large number of measurements (based on near field reflection method) at two different frequencies in the X-Band (8.48 and 11.65 GHz) is the driving motive for this research. The replacement of the conventional open horn antenna with microstrip radiating patches will make the sensor more versatile and compact. With the appropriate correlation, a calibration equation was found that instantly gives independent moisture content and/or dry mass content of the sample under consideration regardless of other intervening factors (i.e. measuring the moisture content of a sample independent of its bulk density). The sensor works with a laptop pc. The design and development of software using a graphical programming language (Lab View) helped analyze, manipulate and manage the huge set of data collected. The software provided error correction and incorporated the calibration of the system in order to display numerically and graphically the properties of the sample under test.

INTRODUCTION

In the last few decades, microwave dielectric-based sensors were mainly developed for sensing moisture in different materials [1]. The fact that these sensors rely on measurement of dielectric properties, which are also dependent on other physical properties of the material i.e. bulk density, moisture content, temperature etc, makes them potential multi-parameter sensors provided that appropriate correlations are established between measured dielectric and physical properties [2]. In this paper, we deviate from the open-ended coaxial line as a standard sensor for permittivity measurements. An alternative approach is introduced here based on disk patch microstrip antenna operating at two different driving frequencies in the X-Band (8.48 and 11.65 GHz). It is based on measuring reflection of the mature fields in near-field region from the sample interface. This new sensor is developed for special application of determining water content of liquids and food products easily and efficiently through the use of pre-determined calibration equation without the need for expensive VNA instruments. The sensor was tested with diluted dry milk powder.

DESIGN OF THE SENSOR

The first step was the design of each single frequency circular patch antenna and trying to optimize its parameters. Other than using full wave analysis, the circular patch antenna can be analyzed conveniently using the cavity model [3]. By using cylindrical coordinates, the cavity can be considered as two perfect electric conductors at the top and bottom to represent the patch and the ground plane. The dielectric material substrate with height *h* and dielectric constant ε_r is assumed to be truncated beyond the extent of the patch. The radius *a* does not take into account fringing. Fringing makes the patch look electrically larger [4] and for circular patch a correction introduced by using an effective radius a_e to replace the actual radius a:

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a_e}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad (1)$$

Visual basic 6 program using modified regula falsi method numerical technique was used to solve for the actual radius in equation (1). After careful consideration of separation and orientation of the disks to minimize the mutual coupling between the patches, the right configuration was chosen as shown in figure 1.

Figure 1: The top and bottom view of the patch sensor .

Two of the patches were connected to two DRO oscillators (transmitting antennas) and the other two were connected to broadband coaxial detectors with sensitivity of 500mV/1mW as shown in the schematic figure 2.

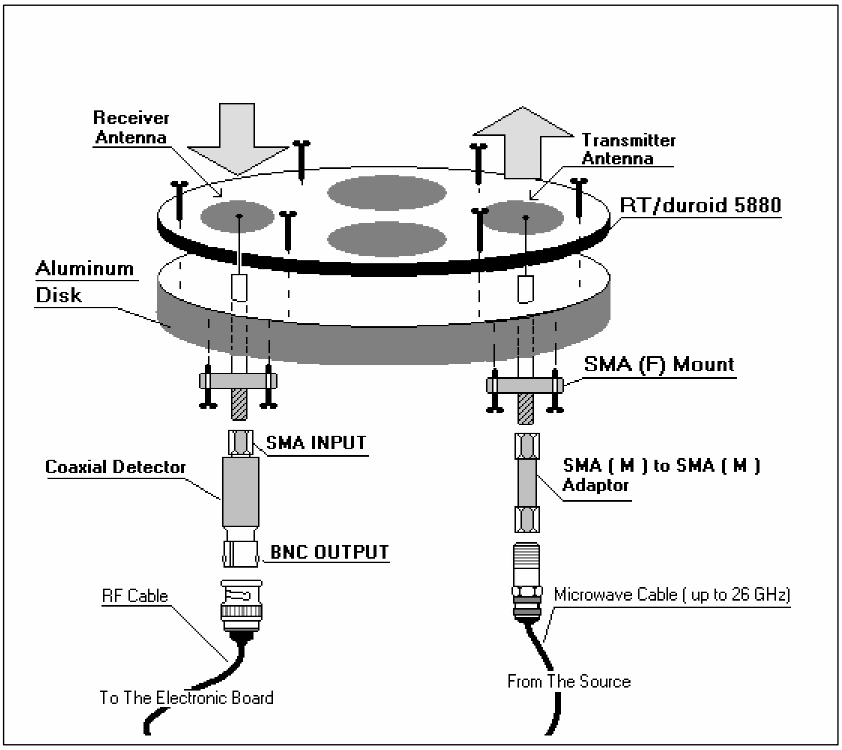

Figure 2: The schematic diagram for the sensor patch part with its connectors.

INTERFACING

In order to interface the sensor to a laptop PC through the use of data acquisition card there is a need to design two electronic boards. One will serve some functions like supplying a stable 7.0 volts to the two DRO sources and protecting the oscillators from voltage over surge. The second will be used for filtering, amplifying and conditioning the output signal in order to be fed to a data acquisition card, DAQ 6024E National Instruments card via. 68-bin connector.

SAMPLES AND PROCEDURE

The sensor was tested on samples of ordinary dried milk powder bought from a retail store. The samples were divided into two groups. The first group was used to calibrate the sensor system. This group consists of 150 diluted solution samples with moisture content ranging from 50 % to 90 %.
The steps of calibration are as follows:

- Turning on the Oscillators by two relays for 3 minutes warm up time.
- Calibrating the sensor with two standards open air (empty cup), and distilled water.
- Measuring the reflected power from the sample interface for each diluted solution sample.
- Normalization of the measured signals to that of distilled water Γ_i / Γ_w.
- Finding appropriate weighing functions φ_1 and φ_2 to incorporate signals from both detectors such that:

$$\Gamma_i = \varphi_1 \Gamma_{1,i} + \phi_2 \Gamma_{2,i} \quad ; \quad i = 1, \;\; 15 \qquad (2)$$

Where

$$\varphi_1 + \varphi_2 = 1 \quad (3)$$

- Fitting the results into a 4-th order polynomial, equation (4) and calculating the correlation factor.

$$MC = \alpha_0 + \alpha_1\Gamma^1 + \alpha_2\Gamma^2 + \alpha_3\Gamma^3 + \alpha_4\Gamma^4 \quad (4)$$

The second group is used to test the sensor and the fitting. This group consists of four sample solutions with random moisture content percentage. The measuring procedure consists of:

- Turning on the oscillators by two relays for a warm up time.
- Measuring again the two standards as instructed by the program, air and pure water.
- Filling the cup to the specified level with the sample solution and taking the reflected signal measurements. Leveling the liquid sample in the cup is important as demonstrated in [5] and [6].

The program will instantly display the moisture content based on the two standards measurements and the sample.

RESULTS AND DISSCUSSION

For good reproducible measurements, enough time (3 minutes or more) should be allowed for warming up of the driving DRO oscillators as shown in figure3. Failing to do so will result in error readings and the accuracy is significantly reduced.

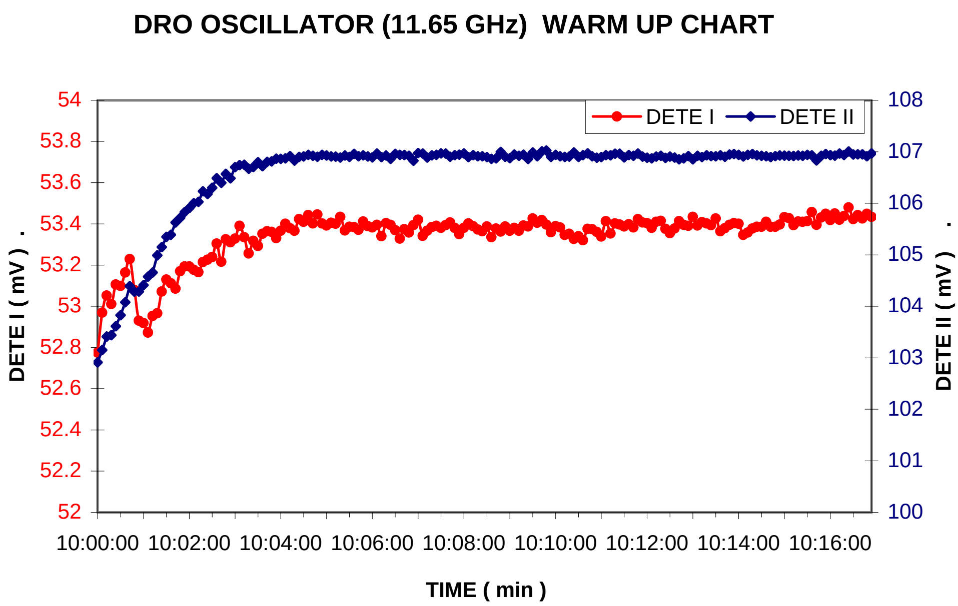

Figure3: The detected voltage at both receiving patches as the oscillator warms up.

The distance from the sample interface i.e. the bottom of the cup to the patch of radiating antennas should be optimized for maximum reflected power as shown in figure 4.

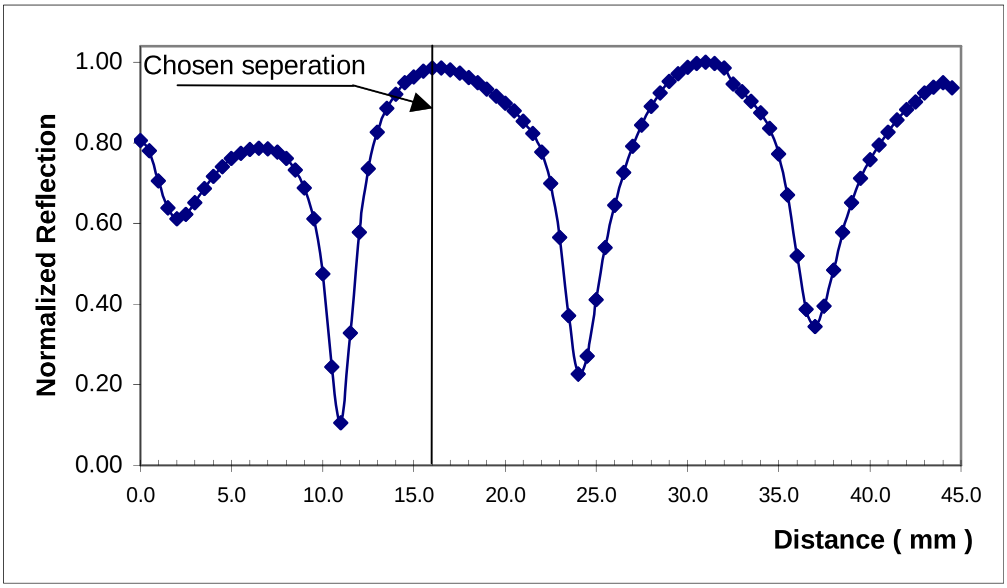

Figure 4: Optimization the distances to the sample interface from the sensor.

The position of first maximum corresponding to constructive interference the standing wave was chosen as the distance of the solution holder to the sensor patch.

CALIBRATION AND SAMPLES

The values of moisture content for the 15 calibration sample solutions were obtained using the formula:

$$MC = \frac{m_w - m_d}{m_w} \qquad (5)$$

where,
m_w is the mass of wet material and m_d is the mass of dry material.
By weighing of the samples before and after dilution helped calculating values of moisture content, which are listed as first column in table 1. They were used to evaluate the five constants of equation (4) using fourth order polynomial regression analysis. Normalized measured signals $\Gamma_{1,i} / \Gamma_w$ and $\Gamma_{2,i} / \Gamma_w$ at 8.48 and 11.65GHz are listed in the fourth and fifth columns of table 1 respectively.
The normalized weighted values obtained from equation (2) were used to calculate the four unknown constants in equation (4) by polynomial regression and found to be:

$$MC\% = -337009.73\,\Gamma^4 + 1293047.38\,\Gamma^3 - 855970.24\,\Gamma^2 + 1181511.42\,\Gamma - 281484.47 \qquad (6)$$

With coefficient of determination, R^2 of 0.9880 and standard error of calibration (SEC) was 2.1% moisture content.

Table 1: Predicated moisture content from both detectors along with percentage errors.

MC %	Γ1 (mV)	Γ2 (mV)	Γ1/ Γw	Γ2/ Γw	Γ	Pred. *MC*	Abs Error
50.0	105.37	211.69	0.831003	0.9133455	0.8721743	51.3	1.261
53.7	105.94	211.31	0.8355088	0.9116814	0.8735951	52.0	-1.768
56.4	108.83	213.47	0.8583064	0.9209928	0.8896496	57.4	1.028
58.8	110.72	214.45	0.8732487	0.9252482	0.8992485	59.3	0.443
61.9	112.89	215.47	0.8903465	0.9296299	0.9099882	60.7	-1.267
64.6	117.20	219.31	0.9243505	0.9462095	0.93528	64.4	-0.252
67.0	119.05	220.97	0.938908	0.9533513	0.9461296	67.0	0.058
70.2	121.23	223.67	0.9561217	0.9650011	0.9605614	72.1	1.812
72.9	122.01	224.47	0.9622443	0.9684773	0.9653608	74.1	1.209
75.6	122.56	224.71	0.9666349	0.9694882	0.9680615	75.4	-0.213
78.1	122.50	225.36	0.9661727	0.97229	0.9692313	76.0	-2.139
80.5	124.03	227.71	0.9781875	0.9824445	0.980316	81.9	1.415
84.2	124.78	226.42	0.9840797	0.9768827	0.9804812	82.0	-2.196
85.7	125.10	228.61	0.9866216	0.9863417	0.9864817	85.6	-0.117
86.9	125.62	229.20	0.9907417	0.9888907	0.9898162	87.7	0.727

Using these constants in equation (6), column 7 lists predicted moisture content of all the 15 samples in the calibration group and their absolute error is calculated in column 8.
For the validation group, using the normalized detected signals in equation (6) the predicted values of moisture content were found and shown in table 2, column 7. These values were compared with the values obtained from weighing method, equation (5) and the results are summarized in Table 2 along with percentage error deviations.

Table 2: Predicted moisture content for the validation group.

MC %	Γ1 (mV)	Γ2 (mV)	Γ1/ Γw	Γ2/ Γw	Γ	Pred. *MC*	Error %
59.1	106.99	218.72	0.8847617	0.9398448	0.9123033	61.0	-3.091
64.7	109.75	219.59	0.9075754	0.9436215	0.9255985	62.7	3.097
68.9	114.46	224.37	0.9464994	0.9641419	0.9553207	70.0	-1.600
74.9	117.51	226.68	0.971736	0.9740665	0.9729013	77.8	-3.871

Figure 5 shows that the predicted moisture content values averaged over all moisture level were compared well with the corresponding real calculated values, shown as circular dots in the figure.

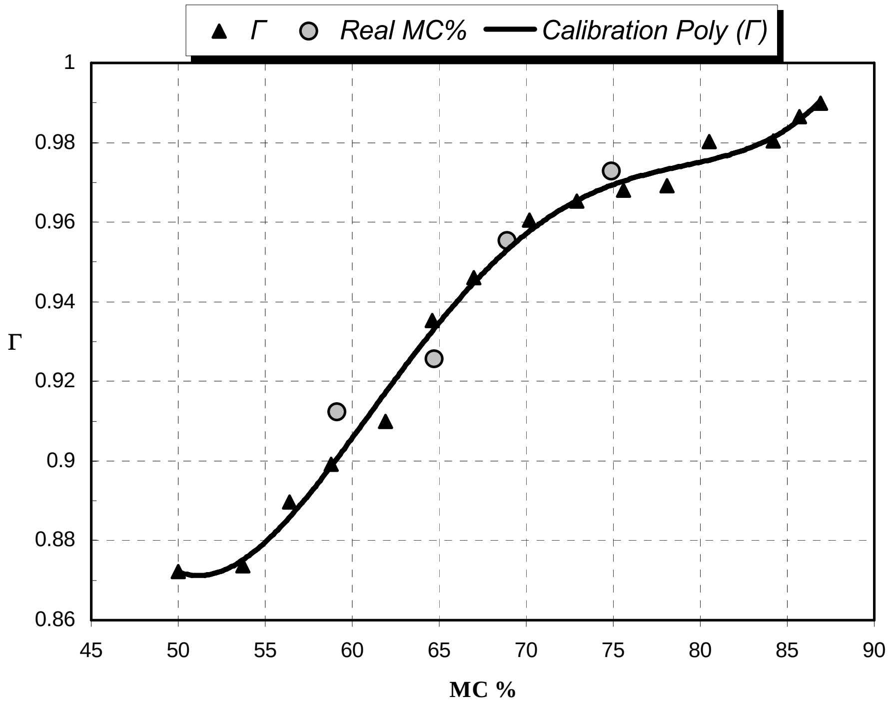

Figure 5: Calibration curve for moisture content of milk solutions.

Although the predictability has slightly decreased in the higher moisture level, the values obtained by the sensor were close to the calculated weight method. Improvements in the predicted values in high moisture range can be accomplished, by adjusting the weights of equation (2). In other words, recalculating the predicted values using adaptive polynomial regression is done by adjusting the weights depending on the range of moisture content values of the first run.

CONCLUSION

Reflection coefficients measurements at two frequencies, 8.48 and 11.65 GHz, using milk powder solution placed at special distance from radiating microstrip patches could be used to determine the moisture content of the samples nondestructively and rapidly to an accuracy within 3.2% of their real moisture values for over 85% of the samples tested in the moisture range from 50% to 90%.

Using this method, it might be possible to develop more accurate and rapid nondestructive moisture sensors of other similar products i.e. honey, latex, palm oil…etc.

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