Microstrip Antennas for Dielectric Property Measurement

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Abstract

The measurement of the dielectric properties of materials is of great interest in a variety of applications including measurement of the moisture, fat, salt, or sugar content of grains and food products, measurement of human tissues or artificial phantom materials used to simulate them, and many other scientific and commercial applications. Conventional methods of measuring these properties include coaxial measuring probes or cylindrical capacitive cells. The commercial equipment available for this purpose is generally too expensive to be used "in-line" and may be too fragile for many applications in harsh conditions. This paper describes microstrip antenna designs for the determination of dielectric properties. These antennas are designed for durability in extreme conditions and utilize a change of impedance when in direct or near contact to the sample to determine the dielectric properties.

Introduction

Many methods are currently employed to measure the dielectric properties of materials. These include measurement with an open-ended coaxial probe, a capacitive cells, TEM cells, monopole antennas, and others. These methods have been shown to provide accurate measurements of electrical properties in many applications, but the commercial equipment available for their use is prohibitively expensive for many applications. Each method also has its limitations. For instance, the coaxial probe has limited accuracy for granular samples due to its small sample measurement area, and the monopole antenna requires penetration of the sample, with possible damage to the sample or to the antenna in rough conditions.

The antennas designed for this paper were specifically developed for measurement of the moisture content of grain during harvesting and are therefore to be subjected to large masses of moving grain, extremes of heat or cold, and dust. Durability of these antennas was a primary objective, so a microstrip configuration was chosen.

Two possible modalities were evaluated – a single antenna with a change of impedance related to the dielectric properties of the material above the antenna or a dual antenna pair (separate receiving and transmitting antennas) with impedance and/or received power dependent on the material between the two antennas. The single antenna was chosen because of its ease of use (mounting at the bottom of a grain hopper) and the simplicity of electronics that can be used to evaluate the impedance of this antenna. The frequency of 433 MHz was chosen as being in a commercially available band, sensitive to moisture, and it was convenient to produce an antenna with approximately 1 square foot of space.

Antenna Design Method

Microstrip antenna configurations were evaluated with the HP/EESOF software "Momentum" commonly used to evaluate microstrip circuits. This program is based on the method of moments and is capable of quickly and accurately analyzing antennas up to 2 wavelengths on a side with the SUN workstations available to students at Utah State University. This was more than sufficient for this project, where the antennas were designed to be approximately ½ wavelength in dimension. Microstrip antennas are readily simulated in the momentum software as rectangular,

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circular, or even arbitrary-shaped patches. The microstrip antenna with grain on top of it was simulated by adding an additional "substrate" on top of the antenna with the electrical properties of the grain in the momentum simulation. In some cases, multiple substrates were used to represent the microstrip antenna, a plastic protective coating over it, and the grain on top of that.

Antennas needed to be resonant and well-matched to a 50-ohm feed line at 433 MHz with grain (of average moisture content) on top of the antenna. The primary factor of interest for measuring dielectric properties is the change of input impedance of the antenna as a function of the dielectric properties of the material above it. Thus, using an antenna at its resonant point was ideal, as the resonance changes significantly depending on the material above it. Several designs were examined, to find one with the largest change of input impedance over the expected range of corn of various moisture contents.

The dielectric properties of corn as a function of moisture content are given in Table 1. These properties were used to evaluate the relative impedance changes for the antennas described in the following section.

Table 1: Dielectric properties of seed corn as a function of moisture content. [1]

% Moisture	Frequency	ε_r'
8.1	1 MHz	3.1
	50 MHz	3.3
13.4	1 MHz	4.7
	50 MHz	4.0
20.3	1 MHz	7.1
	50 MHz	5.0

Antenna Designs

The first design that was examined was a simple rectangular patch, fed by a microstripline as shown in Figure 1a. This patch was resonant at about 450 to 900 MHz for the expected range of dielectric properties of corn given in Table 1. Next, to improve the sensitivity of the antenna to the material above it, a slot was cut in the patch as shown in Figure 1b. This slotted patch was fed with a 50-ohm microstripline at one corner and grounded at the other as shown. This antenna is resonant at approximately 800 MHz. To evaluate the sensitivity of the patch to its environment and determine the frequency of maximum sensitivity, the change in input impedance as a function of frequency was analyzed as the dielectric properties of the material above the antenna changed. The difference between the magnitude of the antenna impedance with $\varepsilon_r = 4.0$ and $\varepsilon_r = 3.0$ is shown in Figure 2, for the rectangular patch antenna and for the patch with the slot. Interestingly, both antennas have sizeable changes in the input impedance at both 400 and 800 MHz, and the slot has an additional region of sensitivity about 200 MHz.

Antenna Prototype

The slotted patch antenna shown in Figure 1b was prototyped on 1/8" fiberglass tile ($\varepsilon_r \cong 2.5$) with copper tape. The feed was changed from a microstripline to an SMA coaxial connector for ease of connection to the HP 8510C network analyzer. Corn of varying moisture contents was not available for initial tests, so several commercial grains were used instead. The grains were placed in a plastic box on top of the antenna to a depth of 2.5 cm. The input impedance of the antenna was measured as a function of material, and the values are given in Table 2. Although the antenna was expected to be most sensitive at 800 MHz (neglecting the 250 MHz point), the frequency where the greatest sensitivity was observed was 787.5 MHz, so these values are also given in Table 2. Reasons for this discrepancy include the fact that the simulations did not include the insulating effect of the plastic box (which as later found to be significant) and uncertainty in the dielectric properties of the fiberglass used as the antenna substrate.

Table 2 – Input impedance of the prototyped slotted patch antenna as a function of commercial grain type. Grains were placed in a plastic box on top of the antenna to a depth of 2.5 cm. The frequency is 800 or 787.5 MHz.

Grain / Product	Z(ohms) at 800 MHz	Z(ohms) at 787.5 MHz
Air (antenna alone)	31.5 – j 7.8	94 – j9
Empty plastic container	30.0 – j 7.5	91.3 – j 10.8
Tap water	2.3 + j 33.3	29 + j 34.5
Oatmeal	24.6 – j 0.15	66.5 – j 12.9
Whole Wheat Flour	24 + j 0.85	63.8 – j 11.9
White Flour	23.6 + j 1.7	61 – j 11.5
White rice	24.3 + j 0.4	65 – j 12
Hashbrown flakes	24.7 – j 1.3	69.5 – j 13.8
White sugar	21.2 + j 2.65	55.7 – j 14
Brown sugar	23.8 – j 0.4	67 – j 15

Conclusion

A simple microstrip antenna has been designed for increased sensitivity to the dielectric properties of a material placed on top of it. Initial testing indicates that this antenna does indeed perform as expected, and that a simple, durable antenna can be used to measure dielectric properties in-line for commercial or agricultural applications. Additional work is underway to try several other antenna designs that are resonant at lower frequencies, and low-cost hardware is presently being tested to electronically relate the change of input impedance to the dielectric properties of the material.

REFERENCES

[1] S.O. Nelson, "Electrical properties of agricultural products (a critical review)," Transactions of the ASAE, 1973

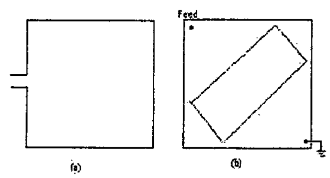

Figure 1: (a) Simple patch antenna fed by a microstripline. The antenna is 27 .39 cm wide, and 24.67 cm long. (b) Slotted patch antenna with coaxial feed and ground.

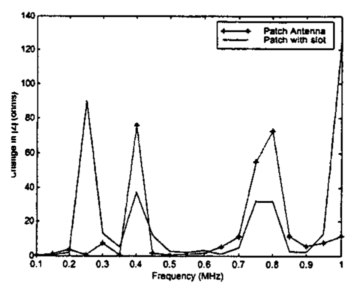

Figure 2: Difference in the |Z| (ohms) for rectangular and slotted patch antennas covered with a layer of material having $\varepsilon_r = 4$ and $\varepsilon_r = 5$.