2228 Microwave Imaging of Cotton Bales

Mathew G. Pelletier
Agricultural Engineer
USDA, ARS
Cotton Production and Processing Research Unit
Lubbock, TX

Edward M. Barnes
Director, Agricultural Research
Cotton Incorporated.
Cary, NC

Abstract

New moisture restoration systems are increasingly capable of adding excess moisture to cotton bales. Further investigation into these systems has revealed large variations of the bales internal moisture that is not readily monitored from the outside of the bale. This research examines a new microwave imaging technique to view the internal moisture variations of cotton bale lint. Tests on the developed imaging sensor showed the ability to resolve small structures of high permittivity, against a low permittivity background, that were less than 1 cm in width. The accuracy of the sensing structure was also shown to provide the ability to accurately determine the permittivity of known permittivity standards to an r^2>0.99. A preliminary test of the imaging capabilities on a wet commercial UD bale showed the technique was able to accurately image and determine the location of the pre-placed wet layer within the bale.

Introduction

The final stage in the cotton processing stream is the cotton bale packaging system. Recent innovations have shown that the use of cotton moisture restoration systems both reduce stress on the pale packaging system as well as add additional weight to the bales. As cotton is sold on a wet basis, these systems were beginning to proliferate through the ginning industry. This trend was tempered as recent research has shown that excess moisture in the bales will cause fiber degradation and color-grade changes, (Baker et al. 2005, Hughs et al., 2004; Anthony, 2003a, 2003b). This issue has become so important that it prompted the U.S. National Cotton Council to make a recommendation for bales to be limited to less than 7.5% moisture. More importantly, this need has recently led to the Mississippi Cotton Exchange to place a new ruling on acceptable bales for trade, the requirement to have less than 7.5% moisture and within the last year has prompted the U.S. Farm Service Agency to issue a new ruling for bales placed into the CC loan program, that dictates that the moisture content inside the bale shall not exceed 7.5% *anywhere* in the bale. Thus, there is now a contractual obligation to produce bales that do not exceed 7.5% moisture with real legal implications in the advent of bales found with moisture in excess of 7.5%.

In addition the moisture level issue, there have been several recent studies that have indicated that the moisture within the bales is also highly variable in moisture restored bales. This variability is further being magnified as the moisture content increases (Byler and Anthony, 2003; Pelletier 2003, Valco et al. 2004). To further illustrate this variability, a wet bale that was manufactured in normal course of business from a commercial gin was split open and sampled for gravimetric moisture, from the oven moistures a volumetric distribution of the moisture is presented in figure 1 to show just how variable the internal moisture can become.

Given the overwhelming push to mandate that bales stay below 7.5% moisture, it is clear there is a need to be able to monitor the internal moisture throughout the bale as it is prohibitively expensive to exhaustively sample a bale for moisture on a whole-bale basis. As there is currently no available systems that can provide this internal bale moisture information, research was conducted in an effort to develop a technique by which to image the internal moisture of a bale.

Methods, Procedures and Results

Building on the earlier success of this laboratory's microwave moisture sensors, (Pelletier, 2004, 2005a,b, 2007), this work was extended to determine if a method could be developed to provide the ability to image the internal bale moisture.

The current microwave horns in use by our system utilize a very large aperture, required for reduction of multipath interference as well as to provide the necessary transmission gain; resulting in a large an aperture determined to be detrimental to determination of small local moisture variability. Therefore, alternatives were investigated and it was discovered that an existing ultra-wide-band antenna had the unique property of providing the very narrow beam width required for an imaging application.

To quantify the imaging antenna's beam-width, a vial of water was slowly scanned from left to right across the transmission line of two opposing transmit/receive pair of the imaging antennas, while the effect of the vial upon the signal was monitored on a microwave impedance analyzer for the through transmission complex scattering parameters, S21. Post analysis conversion of the scattering parameters was performed to convert from complex S21 data to propagation delay that is the normal measurement for bale moisture. Figure 2 shows the results of the test, which reveals the imaging sensors can resolve high permittivity objects to within ½ to 1 cm.

Given the successful identification of a small beam-width sensor, Pelletier (2006b) previously noted the sensors had been subjected to testing using known permittivity solutions as well as mini-cotton bales, for determination of the sensors ability to accurately determine permittivity of materials.. Results are repeated here for convenience for the reader.

The previous test that was performed on the sensors consisted of utilizing two liquids of known permittivity, triacylglycerol (TAG) with published e_r=2.60, and the second, Dimethyl Ketone (DK) with e_r=21.4 at 20C. Each liquid was combined into a binary solution that was mixed in various concentrations for testing. Figure 3 details the success the sensors showed in their ability to perform quantitative analysis of the chemical concentrations. A further check was done by theoretically calculating the true permittivity directly from the chemical concentration, as determined gravimetrically during mixing of the solution, in conjunction with the known permittivity of each of the constituents. The results of the calculated permittivity from known literature references against the obtained permittivity as measured by the sensors are detailed in figure 4. We note the significance of these results, as it shows the sensors have the ability to predict the propagation delay of a material ***without the need for a calibration***. All that's needed is apriori knowledge of the relation between the material's moisture content with respect the electrical permittivity.

Using apriori knowledge of the relation between cotton moisture and permittivity, the permittivity values in figure 4 were converted to lint moisture contents associated and presented as figure 5. To verify such accuracy was possible, tests were conducted with mini-bales, where a known amount of water was added to the oven dry lint. The estimated sensor-based moisture contents of these minibales are reported in figure 6.

With the identification and establishment of a sensor suitable for microwave imaging of cotton bales, a test of the imaging capabilities was performed on a typical commercial UD bale. The bale was placed into a bale press to remove the bale ties and then a layer, approximately 20-30 cm deep, was then removed and set aside and subsequently followed by an additional layer of cotton, approximately 15 cm deep, that was removed and treated with the addition of water to bring the cotton moisture of this layer to above 10% moisture. The layer was then replaced back into the bale, followed by the replacement of the dry cap layer and then the bale was re-tied.

With the UD bale now configured with a wet layer, the imaging sensors were utilized to obtain a series a scans across the flat of the bale as detailed in figure 7. Through a series of scans, a two-dimensional cross-section of the bale moisture was obtained and is shown in figure 8. The wet layer is very obvious, represented as the blue streak in the figure.

Conclusions

This research examined a new microwave imaging technique developed to view the internal moisture variations cotton bales. Tests on the developed imaging sensor showed the ability to resolve small structures of high permittivity, against a low permittivity background, that were less than 1 cm in width. At this resolution, the technique shows promise in providing the ability to accurately identify internal high moisture areas within the bale. The accuracy of the sensing antennas were also shown to provide the ability to accurately determine the permittivity of known permittivity standards to an $r^2 > 0.99$. A preliminary test of the imaging capabilities on a wet commercial UD bale showed the technique was able to accurately image and determine the location of the pre-placed wet layer within the bale.

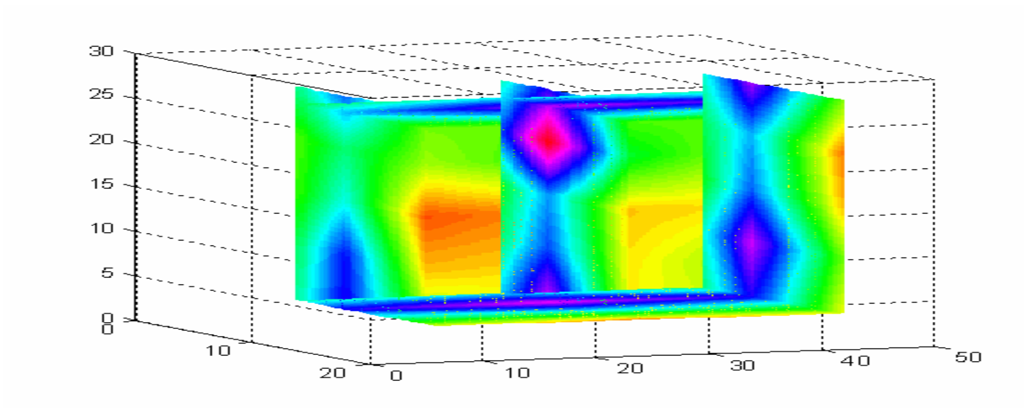

Figure 1: High variability of commercially produced bale, exhibiting variations in moisture from below 7% (yellow-brown) to well in excess of 13% (blue-pink).

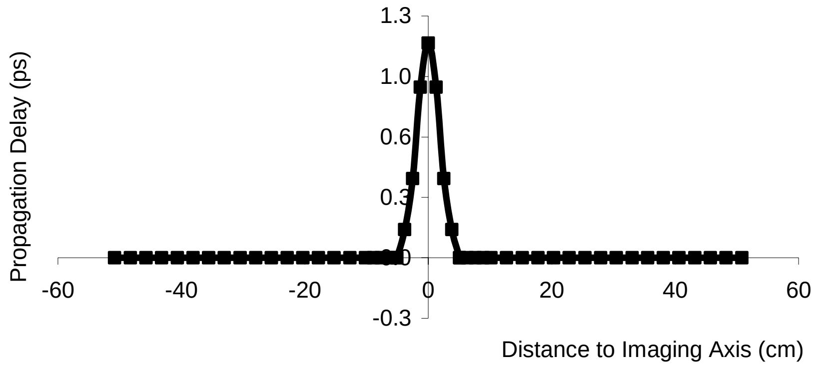

Figure 2: Impulse response of imaging antennas.

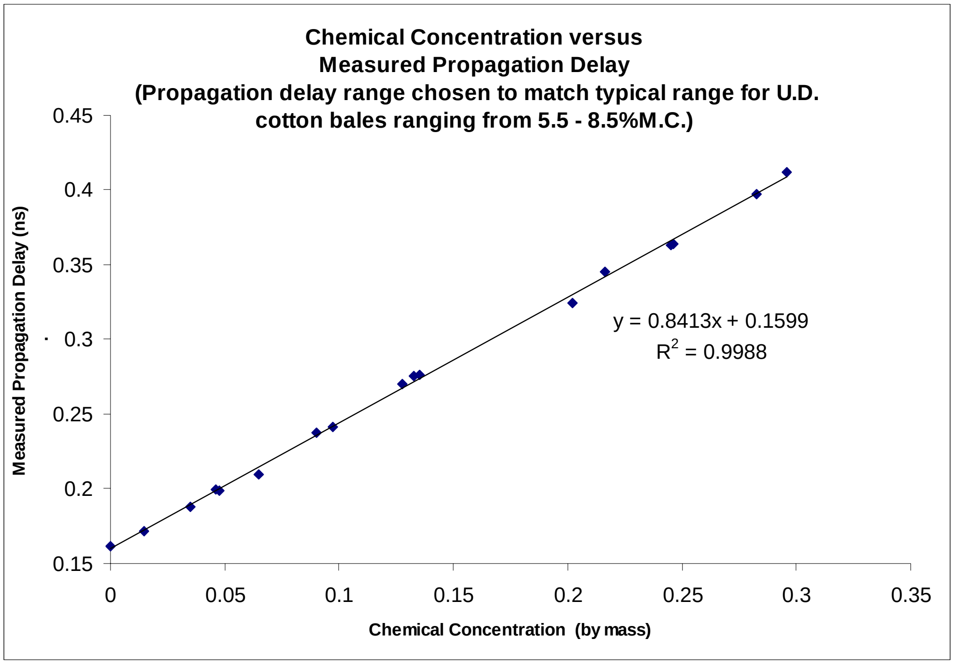

Figure 3: Imaging antennas tested against known dielectrics to determine accuracy of system in measurement of permittivity.

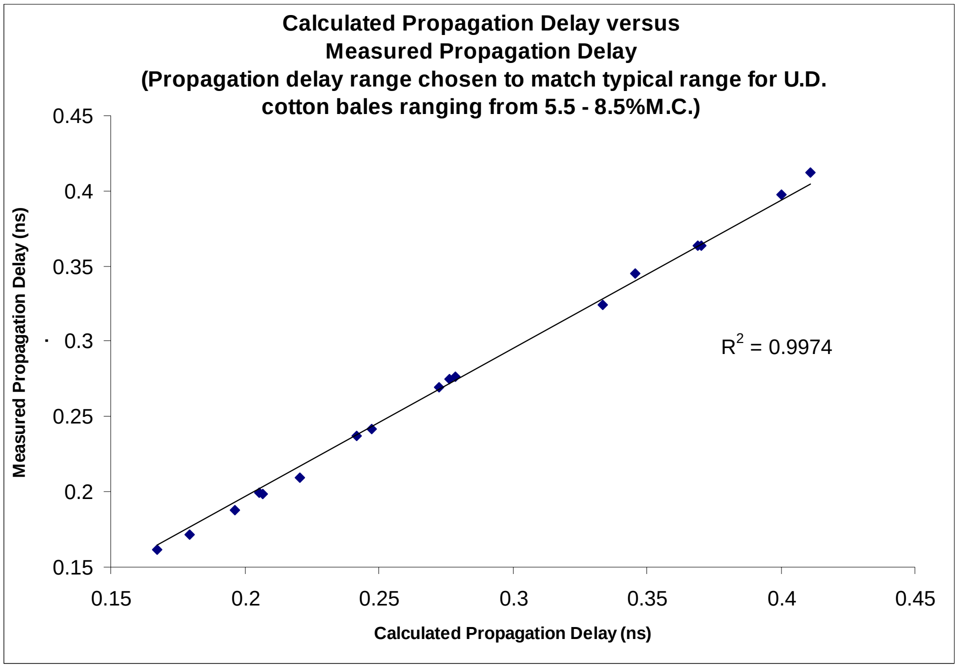

Figure 4: Comparison between permittivity as calculated from the known values versus imaging antenna's measured permittivity.

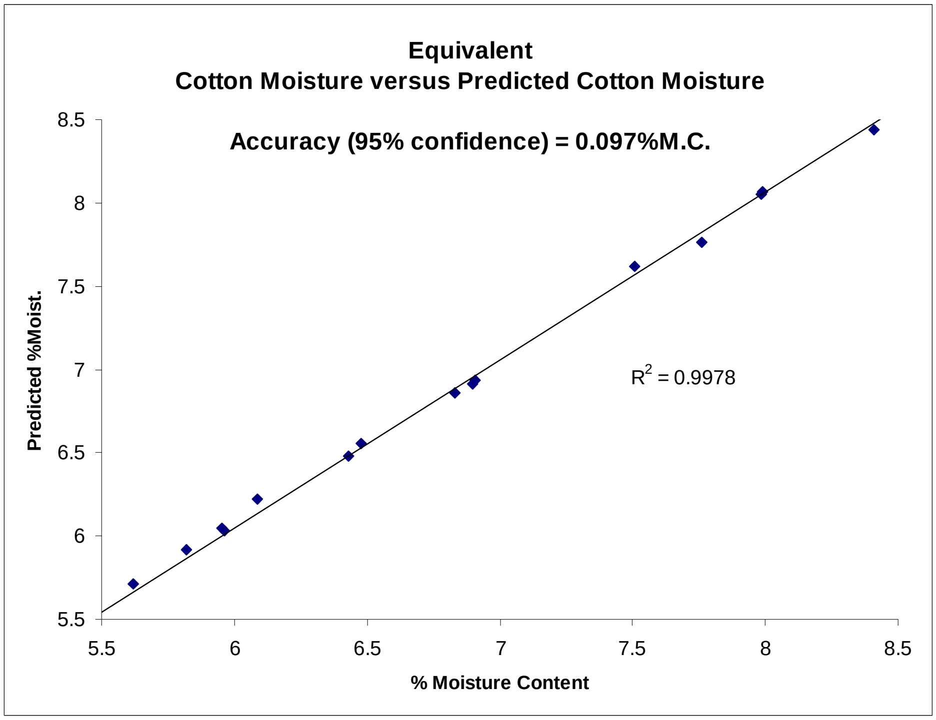

Figure 5: Transformation of the permittivity test of imaging antennas to equivalent permittivity of cotton bale at various moisture contents at U.D. bale density.

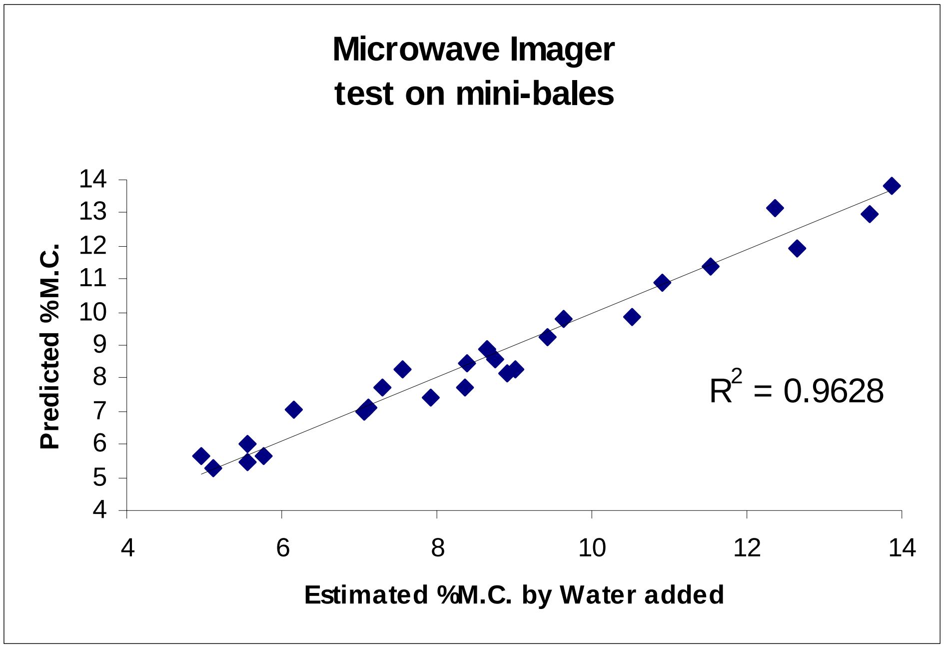

Figure 6: Test on mini-bales with imaging antennas

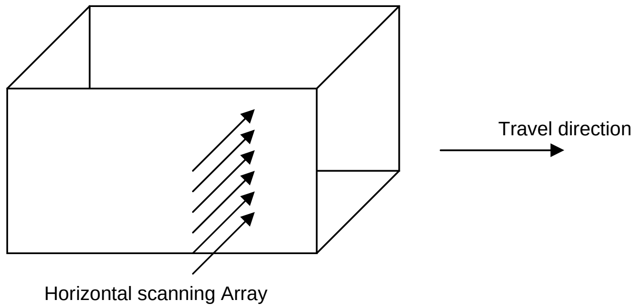

Figure 7: Schematic of the configuration of the position of scanning antenna with respect to the bale travel.

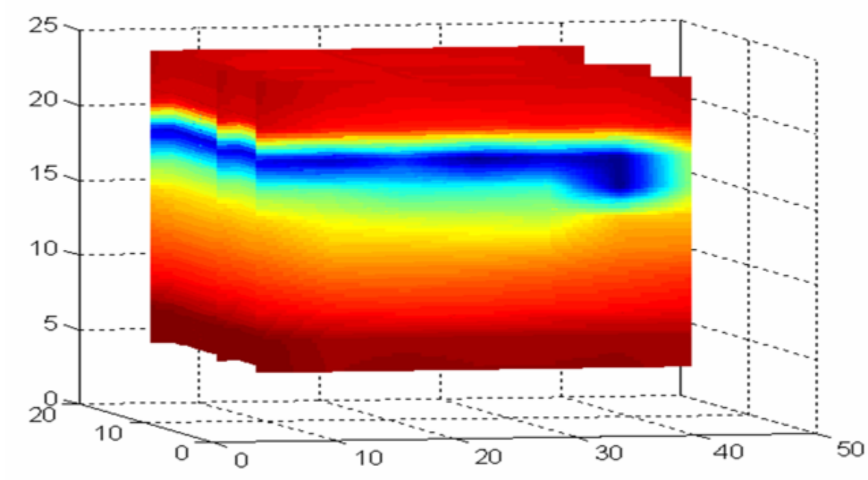

Figure 8: Test on partially wet UD bale with imaging antennas; red-dry (6% M.C.) to dark blue-wet (>10%M.C.).

References

Anthony, W.S. 2003a. Impact of Moisture on Baled Cotton. American Society Of Agricultural Engineers Meetings Papers. Paper No. 031167, 37pp.

Anthony, W.S. 2003b. The Impact of Excess Moisture In The Bale On Fiber Quality. National Cotton Council Beltwide Cotton Conference.

Baker, K.D., Hughs, S.E., Mcalister, D.D. 2005. Bale moisture addition with a rotor spray system. In: Proceedings of the Beltwide Cotton Conference, January 4-7, 2005, New Orleans, Louisiana. p. 808-812. 2005

R.K. Byler and W.S. Anthony, 1995. Development of a moisture sensor for gin use. Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

R.K. Byler and W.S. Anthony, 1997. Measurement Concepts in a gin process control system, Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis, TN.

Byler, R.K., Anthony, W.S. 2003. Measurement Of Bale Moisture Content Based On Bale Compression Pressure. 2003 Beltwide Cotton Conference.

Hughs, E., D. McAlister, C. Armijo, and K. Baker, 2004. Bale Moisture Addition-A Case Study. Proceedings of the Beltwide Conference.

Pelletier, M.G. 2004. Multi-Path Interference Investigation for Cotton Bale Microwave Moisture Sensing. J. Cotton Sci. 8:170-178.

Pelletier, M.G. 2005a. Multi-path Interference Mitigation for Cotton Bale Microwave Moisture Sensing. J. Cotton Sci. 9:135-144.

Pelletier, M.G. 2005b. Bale moisture sensing: Field Trial. 2005 Beltwide Cotton Conference.

Pelletier, M. G. 2006a. Multi-path resistant microwave moisture sensor. U.S. Patent No. 7,078,913.

Pelletier, M.G. 2006b. Absolute Moisture Sensing. 2006 Beltwide Cotton Conference.

Valco, T.D., Anthony, W.S., Byler, R.K., Pelletier, M.G., Hughs, S.E., Norman, W.M. Moisture Restoration Of Cotton. Cotton Gin And Oil Mill Press, September 4, 2004 Pp5-8.