Master's Thesis

A Dual-Resonant Microstrip Antenna for UHF RFID in the Cold Chain Using Corrugated Fiberboard as a Substrate

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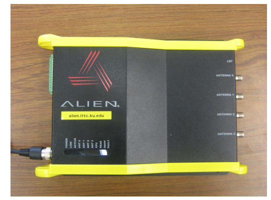
Food Safety

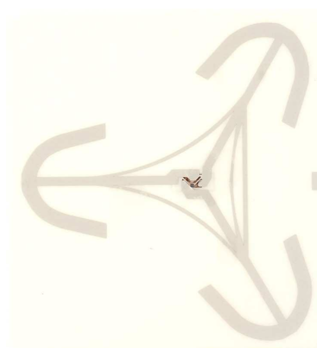
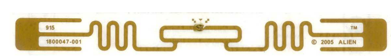
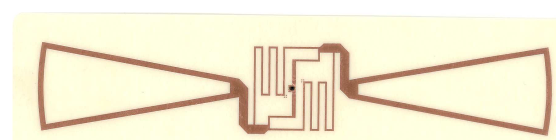
- US GAO 2007 report on food safety [1]
  - 76 million people contract food-borne illness
  - 325,000 require hospitalization
  - 5000 die
- Caused by consumption of contaminated food
- Efficient recall of contaminated food is necessary
- State of recall efficiency in 2004 – 36% to 38% of contaminated food recalled
- Passive UHF RFID has been identified as a technology that increases visibility in the cold chain [2]

Introduction to Passive UHF RFID

- Why?
  - No line of sight
  - No proximity required
  - Cheap
  - Authentication
- How?
  - Reader
  - Tag
  - Backscatter



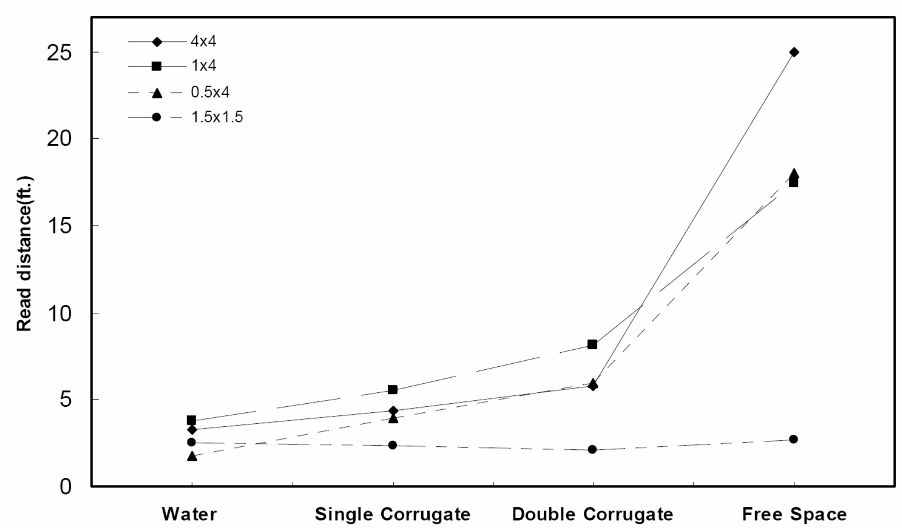


Limitations of passive UHF RFID in Cold Chain

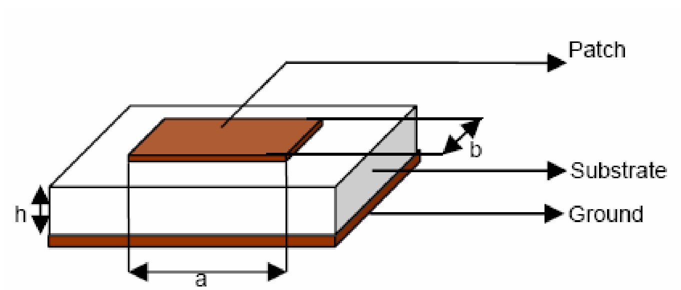
- Products in cold chain have high water content
- Corrugated fiberboard is hygroscopic
- Water content varies with change in temperature and humidity
- Tag antenna performance degrades in proximity to water
- It is desirable to have consistent performance to avoid near-far problem

Tag performance degradation in proximity to water [3]



Microstrip Antenna

- Microstrip antenna is a potential solution



- Inherent ground plane provides isolation
- Use in supply chain limited by thickness and cost
- Using corrugated fiberboard as the antenna substrate solves thickness limitations
- Using a completely planar antenna solves cost limitations

Microstrip Antenna Challenges

- Corrugated cardboard is hygroscopic
- Water content changes with temperature and humidity variations

Water content in corrugated fiberboard [4]

Temp.	40% RH	90% RH
1° C	8 g/100g (Sorption) 10 g/100g (Desorption)	16 g/100g (Sorption) 18 g/100g (Desorption)
40° C	6 g/100g (Sorption) 10 g/100g (Desorption)	14 g/100g (Sorption) 18 g/100g (Desorption)

Measured dielectric properties

Water content (g/100g)	ε_r	tan δ
~0	1.22	0.005
6.5	1.28	0.007
10	1.35	0.016
18	1.4	0.027
25	1.5	0.038

- Change in water content affects dielectric properties
- Microstrip antennas are usually built using materials that have stable dielectric properties

Thesis Statement

"To build a feasible UHF RFID tag antenna for the Cold Chain that has a good consistent level of performance irrespective of change in contents of the corrugated fiberboard container and change in water content of the corrugated fiberboard"

Microstrip Antenna Facts

- Radiation efficiency is directly proportional to width of the microstrip antenna

$$\frac{1}{\eta} = Q_r\left(\frac{1}{Q_r} + \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_{sw}}\right)$$

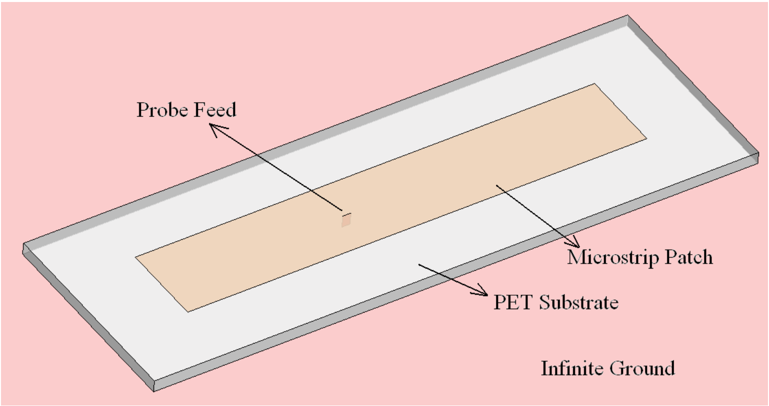
$$Q_r = \frac{2\pi f W_{es}}{P_r}$$

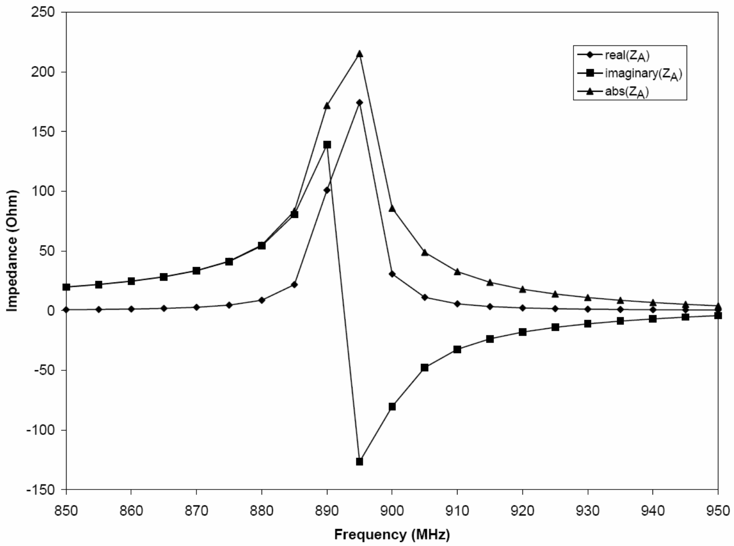
$$W_{es} \propto width, \qquad P_r \propto width^2$$

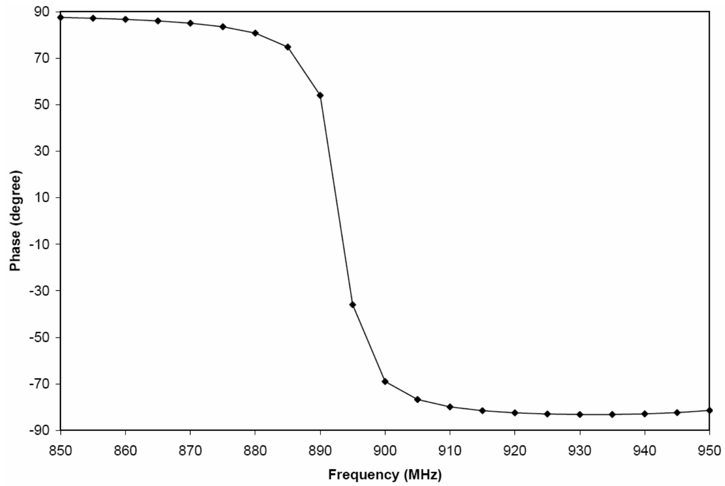
- Resonant frequency is inversely proportional to square root of the relative permittivity

$$f_o \propto \frac{1}{\sqrt{\varepsilon_r}}$$

Microstrip Antenna Facts



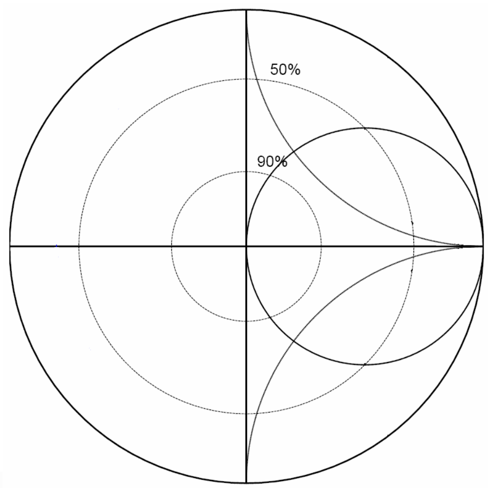




- Patch dimensions 114mmX20mm
- Substrate dimensions 150mmX50mmX1.62mm
- Probe fed 10mm from center
- Polyethylene substrate

Power Transfer Efficiency

- Chip has a complex input impedance
- Power transfer efficiency τ is the measure of impedance mismatch loss [5]
- τ is plotted in a power wave smith chart



$$\tau = \frac{4R_c R_a}{\left|Z_c + Z_a\right|^2}, \quad 0 \le \tau \le 1.$$

$$s = \frac{Z_a - Z_c^*}{Z_a + Z_c}, \quad 0 \le |s|^2 \le 1.$$

$$\tau + |s|^2 = 1$$

$$\hat{z}_a = \frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c}$$

$$\hat{z}_a = \frac{1+s}{1-s}$$

Design Constraint

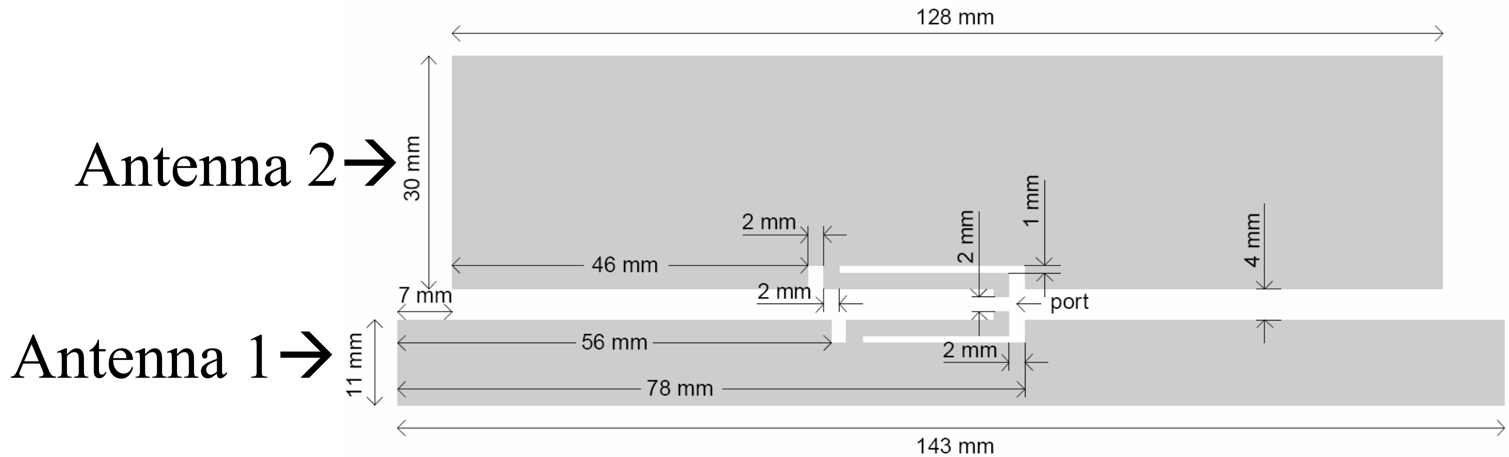
- Performance of a tag limited by realized gain G_R

$$G_R = D\eta\tau$$

- Directivity is fairly constant with variations in dielectric properties
- Radiation efficiency and power transfer efficiency change with variations in dielectric properties
- Design constraint formally defined as

$$\eta(w)\tau(w) \geq 0.9\eta(25g/100g), \quad 0g/100g \leq w \leq 25g/100g$$

Proposed Antenna Design

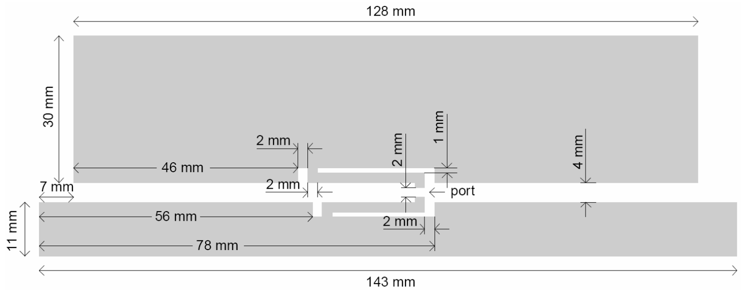


$$f_o \propto \frac{1}{\sqrt{\varepsilon_r}}$$

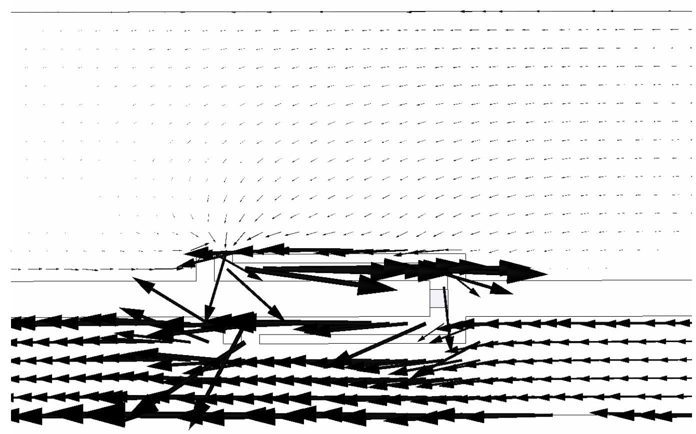
$$\eta \propto width$$

Region 1	$f < f_1$	$\angle Z_{A1} \approx 90^\circ$	$\angle Z_{A2} \approx 90^\circ$
Region 2	$f = f_1$	$\angle Z_{A1} = 0^\circ$	$\angle Z_{A2} \approx 90^\circ$
Region 3	$f_1 < f < f_2$	$\angle Z_{A1} \approx -90^\circ$	$\angle Z_{A2} \approx 90^\circ$
Region 4	$f = f_2$	$\angle Z_{A1} \approx -90^\circ$	$\angle Z_{A2} = 0^\circ$
Region 5	$f > f_2$	$\angle Z_{A1} \approx -90^\circ$	$\angle Z_{A2} \approx -90^\circ$

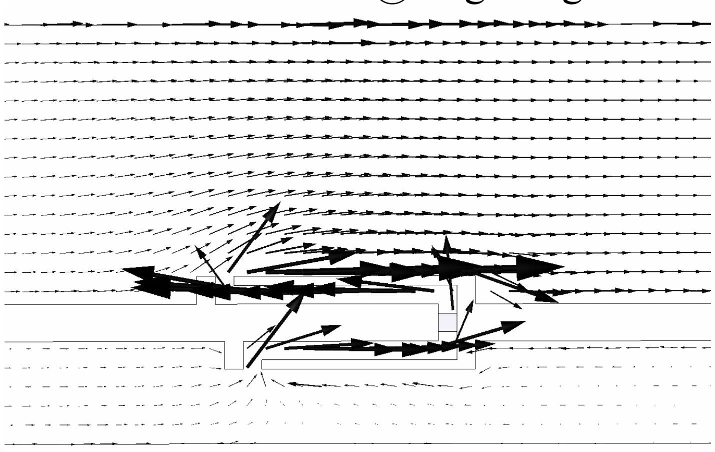
Surface Currents



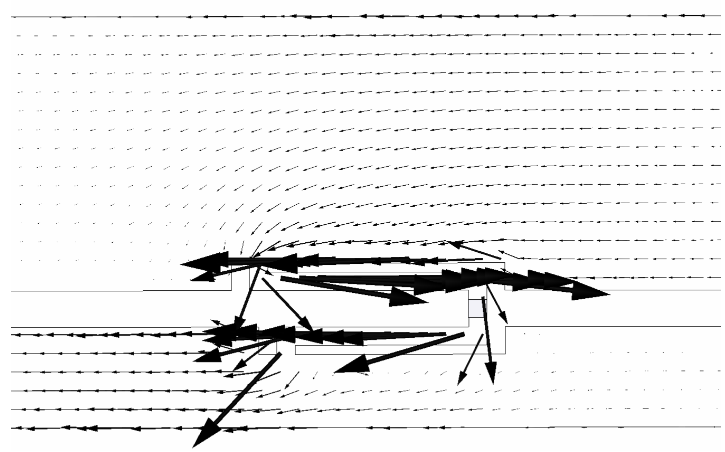
Surface Currents @ 0g/100g



Surface Currents @ 18g/100g

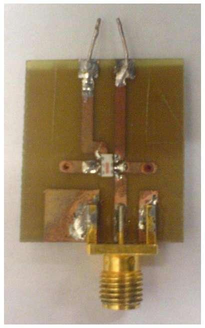


Surface Currents @ 10g/100g



Validation

- Simulated
  - Finite element tool Ansoft HFSS v 10.1
  - Obtained impedance and realized gain
- Measured impedance
  - In a network analyzer
  - Used a chip balun mounted on a PCB to probe the antenna
- Measured realized gain
  - In-direct method
  - Used Samsys MP9320 UHF RFID reader



$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \tau\rho$$

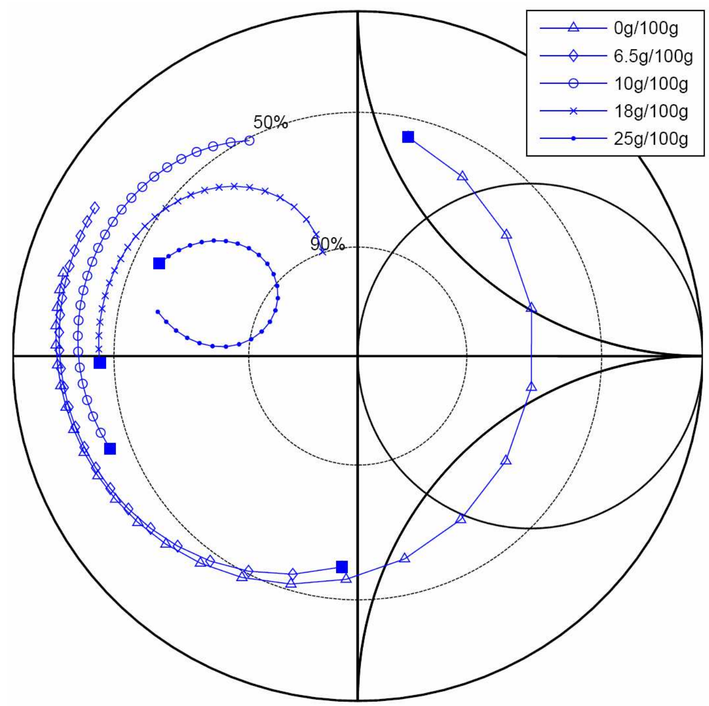
$$G_R = D\eta\tau$$

$$G_r = D\eta$$

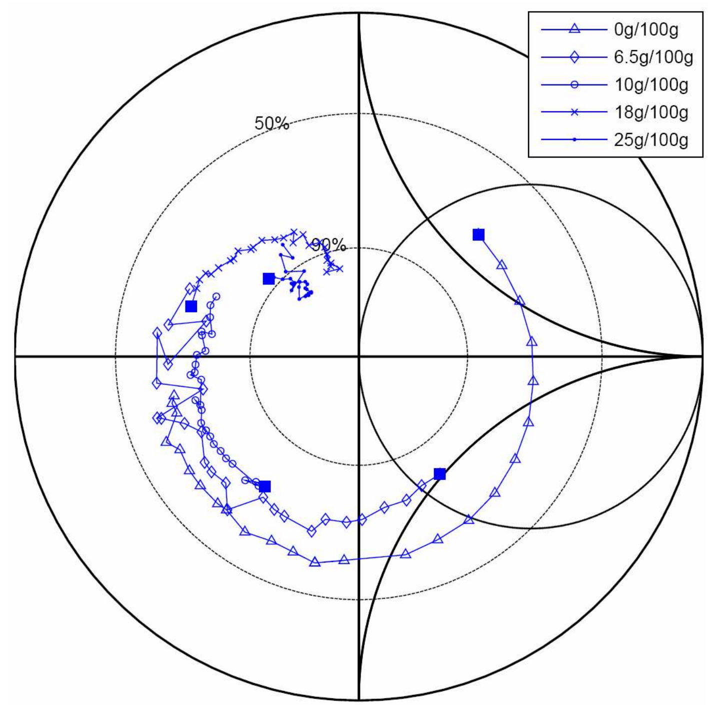
$$G_R = \frac{P_r}{P_t G_t}\left(\frac{4\pi R}{\lambda}\right)^2 \frac{1}{\rho}$$

Simulated and Measured Impedance

Simulated Impedance



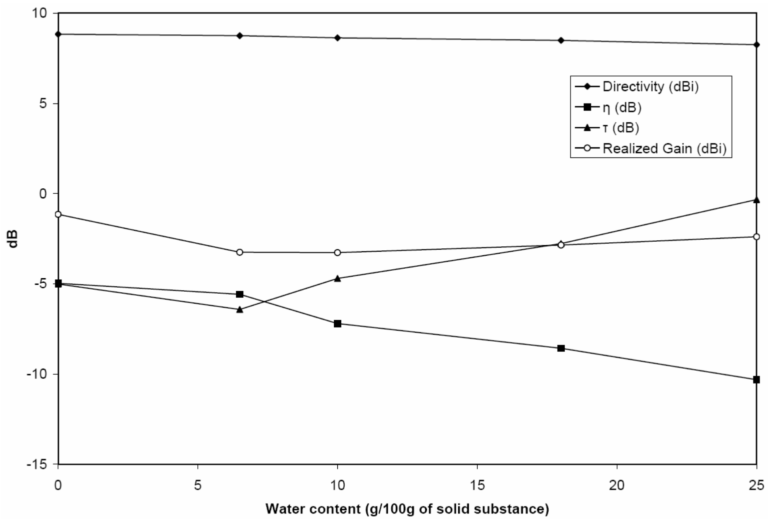
Measured Impedance



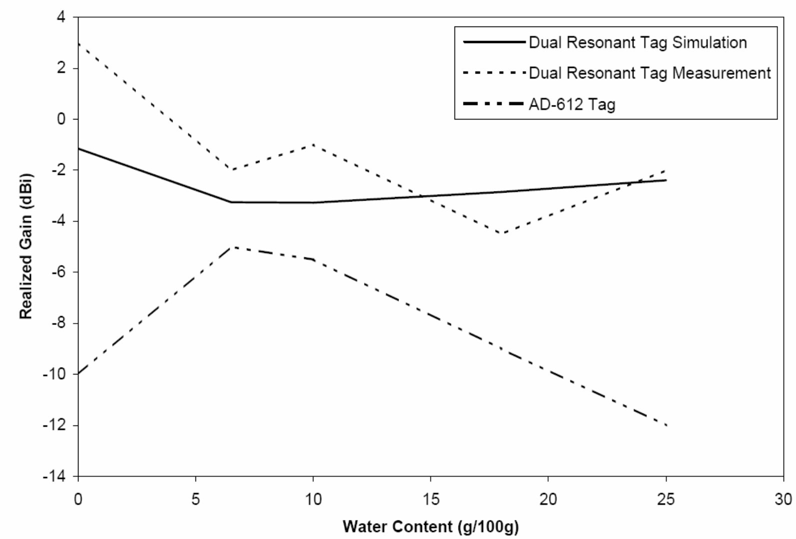
- Center of the smith chart represents a complex impedance of 35+j110

Simulated and Measured Performance

Simulated antenna parameters



Measured Realized Gain

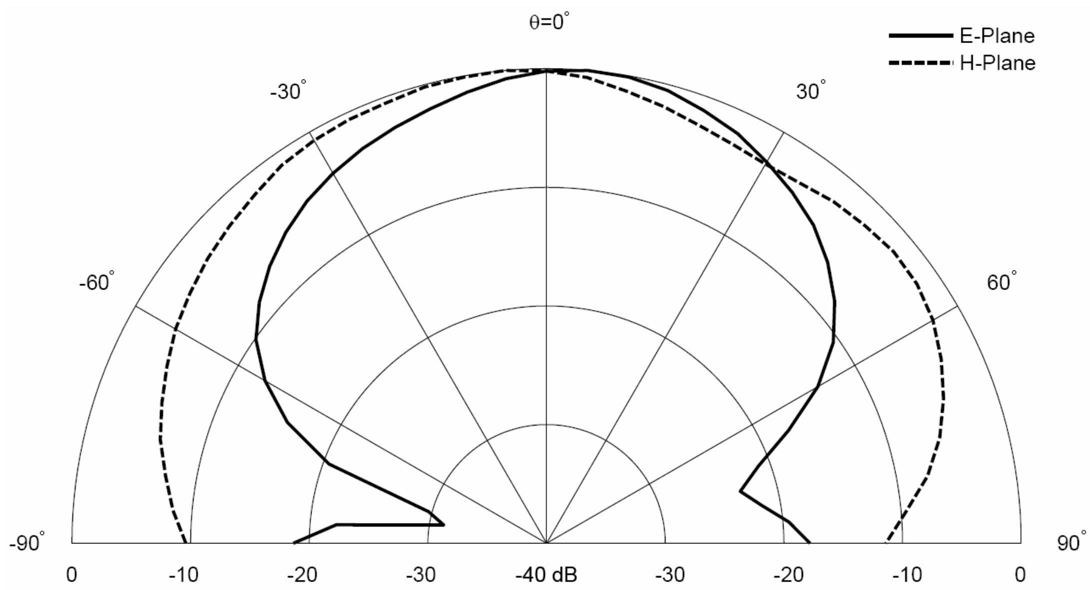


- Simulated gain follows our design constraint

$$\eta(w)\tau(w) \geq 0.9\eta(25g/100g), \qquad 0g/100g \leq w \leq 25g/100g$$

- Good agreement between measured and simulated realized gain
- Gain of AD-612 Tag was measured and is plotted for comparison

Measured Radiation Pattern



- Radiation pattern of the proposed antenna was measured in room temperature conditions at 915 MHz
- Figure shows directivity pattern with peak directivity normalized to 0 dB

Conclusion

- The proposed antenna design was simulated and validated using impedance and realized gain measurements
- The proposed antenna design meets the performance requirements of an ideal tag for cold chain applications
- The proposed antenna design meets the thickness and cost constraints for cold chain applications

Future Work

- Efficiency at the higher water contents can be increased further by compromising width
- Smaller form factor can be achieved by compromising performance equally over various water content
- More rigorous dielectric measurement of corrugated fiberboard at various temperature conditions
- More rigorous dielectric measurement of corrugated fiberboard from various manufacturers

References

1. Federal Oversight of Food Safety: High-Risk Designation Can Bring Attention to Limitations in the Government's Food Recall Programs http://www.gao.gov/new.items/d07785t.pdf April 24, 2007.
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3. Supreetha Rao Aroor and Daniel D. Deavours. Evaluation of the State of Passive UHF RFID: An Experimental Approach. *IEEE Systems Journal*, to appear.
4. Marcondes J., "Corrugated fibreboard in modified atmospheres: moisture sorption/desorption and shock conditioning," Packaging Technology and Science, vol.9, no.2, pp.87-98, Dec. 1996.
5. K. Kurokawa, "Power waves and the scattering matrix," IEEE Transactions on Microwave Theory and Techiques, vol. MTT-13, no. 3, pp. 194–202, Mar. 1965.

Thank you!

Questions?