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Packaging and RFID: Incorporating RFID in the Real World

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Abstract

Radio frequency identification (RFID) mandates by the U.S. Department of Defense (DoD) and many of the top world-wide retailers, including Wal-Mart, Target, Tesco, and Metro, have created new challenges for packaging. For optimum performance, RFID tags require minimal interference from liquids, metals, and other RF absorbant and reflective materials. Product packaging must be designed from the beginning to enable optimum RFID performance. The Packaging and RFID Research Program within the Auto-ID Labs of MIT is leading the design and development of tools, knowledge, and packaging design principles for the application and use of RFID systems. This paper highlights the 2004 research achievements of the Packaging and RFID Program and describes the challenges of incorporating RFID into product packaging that will be addressed in 2005.

1. Introduction

Radio frequency identification (RFID) mandates by the U.S. Department of Defense (DoD) and many of the worlds largest retailers, including Wal-Mart, Target, Tesco, and Metro, have launched the first large-scale use of passive RFID for item-level object identification. While passive RFID is an old technology, its use for object identification is not well understood and many challenges must be overcome before the expected performance and benefits of RFID will be realized. The Packaging and RFID Research Program within the Auto-ID Labs of the Massachusetts Institute of Technology is the leading research program turning the art of RFID into the science of RFID.

The primary research goals of the MIT Packaging Research Program are to develop tools to enable users of RFID systems to better understand and utilize the technologies, to develop a broad knowledge on the impacts of materials and packaging design on the performance of RFID systems, and to develop a set of basic principles for the design of packaging and the use of materials in conjunction with the RFID systems. The Packaging Research Program aims to accelerate the implementation of passive RFID technologies within its sponsoring organizations and to advance the state of the art in packaging design for RFID systems.

In this article, we examine the primary research projects of the Packaging Research Program and summarize the challenges that its future projects will address.

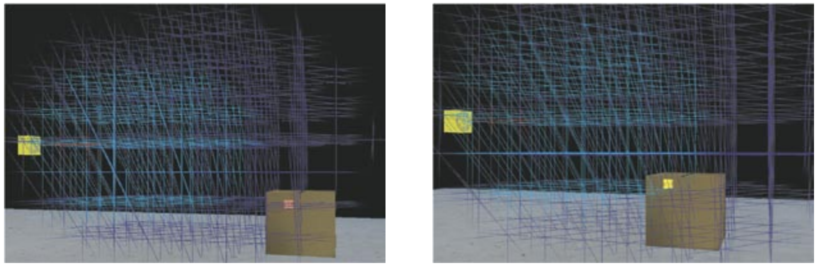
2. Radio Frequency Idenification Challenges

RFID is an automated identification technology that is not simply a bar code replacement. The greater identification capabilities of RFID systems (line-of-sight not required) and the greater functional capabilities of RFID systems (dynamic data) as compared to bar codes makes RFID systems a great enabling technology. However, RFID is not a silver bullet to all of your identification problems. RFID is simply a powerful copper bullet with limitations due to physics and cost.

The relative immaturity of passive RFID technologies and, particularly, the use of these technologies for item identification means that there are few experts, no large scale deployment experience, and little understanding of the performance limits of this technology. The result is that many implementations attempt to operate beyond the reliable performance limits of the technology; yielding unexpectedly poor results. Fortunately, the performance of passive RFID systems will improve over time, particularly given its relative immaturity today.

Even with these performance improvements, the processes within which RFID systems operate must be designed for RFID. The process reengineering that was necessary to achieve maximal benefit from bar codes is similarly required to achieve maximal benefits from RFID systems. Processes that have been engineered to work with bar codes will need to be reengineered to work even better with RFID systems. Before the process reengineering that will achieve maximal benefits from RFID systems are implemented, there are several deployment challenges that must be met to achieve immediate benefits with existing processes. These deployment challenges range from upgrading the information systems to handle the item level serialization enabled by RFID systems, determining an appropriate frequency for the operation of the RFID systems, identifying necessary reader antenna locations and configurations, integration of the tags into the packaging, tag antenna design for the package and its contents, and the best feasible packaging design that enables the highest read probability.

The Packaging Research Program is initially addressing the tag integration, tag antenna design, and packaging design challenges. The three primary ongoing projects are described in the following.



(a) Tag Powered Off (b) Tag Powered On

Fig 1: Real-Time EM Simulator: a real-time tool to explore the system capabilities

3. RFID Simulator Project

The objective of the RFID Simulator Project is to develop a real-time RFID environment Graphical Simulation Tool that graphically represents the environment and simulation results to enable laymen to easily understand the results. The Graphical Simulation Tool is used to increase user understanding of RFID by simulating certain aspects of an RFID environment and displaying the resultant data visually to the user. To quickly develop intuition, the simulation tool has a few key features. First, the simulation tool has an intuitive user interface that allows users to create environments quickly and easily. Menu driven actions create different items such as antennae, tags, and boxes of products. The interface allows users to create pallet-like environments in which the properties of different boxes are quickly alterable to show the effects that different materials have on the electromagnetic power radiated by the antennae.

The simulation tool also has a unique electromagnetics engine that allows for the user to select between different electromagnetic approximation algorithms. Having multiple algorithms to select from allows users to control the speed and accuracy of the results that are produced by the Tool.

The default algorithm used by the electromagnetics engine is designed to produce real-time results. If an object is moved in the simulation environment, that object can drastically change the electromagnetic power in a given area. Therefore, when an object is moved, the electromagnetics engine defaults to using a first order real-time algorithm. Longer running, more accurate algorithms may be used to simulate static environments. By defaulting to a real-time algorithm, the simulation tool makes it easy to move objects around a scene quickly while still computing results to give the user some feedback as to the effects on the environment the changes are causing. Once objects are set in place, the user has the option of running more accurate algorithms.

The Graphical Simulation Tool provides data in an easy to understand and three-dimensional manner. Other commercial software packages calculate a large amount of data and require a radio frequency expert to operate, but the data most pertinent to RFID users is the electromagnetic power. So the simulation tool provides the possibly non-expert user with only the electromagnetic power, allowing for faster calculations. The power over a volume of space is drawn to the screen as a complete volume as shown in Figure 2. This allows for fast prototyping. Instead of needing to view many two dimensional graphs or only being able to view two-dimensional contours over a volume of space, the user now has access to see an entire volume of data. The simulation tool allows the user to fully explore this volume of data at any angle without needing to rerun any simulations. The net result being that the simulation tool is easy to use and produces results quickly which leads the users to develop intuition about UHF RFID more quickly than other software packages.

4. Semi-Passive Tag/Field Probe Project

The objective of the Semi-Passive Tag/Field Probe Project is to develop a Field Probe Tool that can be utilized to evaluate the actual field strengths and communication signal quality. With the increased use of RFID systems in commercial product tracking comes a critical need for the ability to evaluate these systems in their warehouse environments. While the tag and reader manufacturers continue to improve their particular products, the user is left with the daunting task of integrating these individual parts into a reliable and predictable system. Moreover, due to the complicated nature of the interactions between the readers electromagnetic field and the objects in the environment, it is exceedingly difficult, even with the assistance of the Graphical Simulation Tool, to develop an intuitive sense for optimizing the setup of an RFID portal. Currently, this process of reader and tag optimization is a tedious and slow trial and error process.

As humans, one thing that hinders our ability to optimize these systems is the fact that we cannot actually see the electromagnetic fields that are so vital to the operation of an RFID portal. If these fields were like light, we could easily visualize where the shadows (no-read zones) are, and consequently how changing the environment changes where these shadows appear. Such instantaneous feedback would allow us to better judge, for example, how to place the tags on the boxes such that they are in the brightest sections of the field. What is needed is a measurement tool that can translate the strength of the electromagnetic field at various points in space into a value that we can understand, such as a simple light bar display, or a computer generated 3-D image of the actual power levels. The Field Probe, shown in Figure 3, is the tool that translates the strength of the electromagnetic field into a human understandable value.

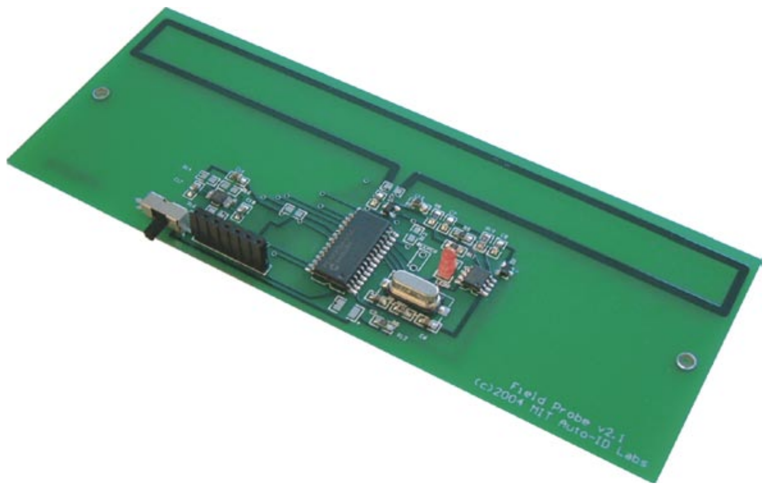


Fig. 2: Field Probe: a semi-passive emulation tool

The Field Probe is a battery-powered, semi-passive RFID tag implemented using discrete components affixed to a printed circuit board. Not much larger than a pure passive UHF RFID tag, the Field Probes most basic operation is to measure the relative strength of an electromagnetic field and present that information to the user in an intuitive manner. An LED light bar is used to visually alert the user to the relative field strength. However, this is of limited use when the tag is embedded within a pallet of products. An audible beacon, whose pitch and volume increase with field strength, is used to audibly alert the user of the field strength. However, this is of limited use in noisy environments. Therefore, a third method of communicating the field strength to the user is provided: the tag communicates its field strength to the reader.

The Field Probe is more than a simple power meter. The Field Probe is a general purpose UHF tag emulator that has the ability to sample sensor data (such as field strength) and transmit that data back to the reader. More generally, the field probe is a research platform where other sensors or metrics can be added in order to quantify both the strength of the field as well as the quality of the communication it is receiving. Through the use of multiple field probes (each with a unique identifier) an approximate three-dimensional image of the field strength can be constructed. Thus, real-time, in situ visualization of the electromagnetic performance of a real world RFID system may be constructed.

The Field Probe is one of the principle tools utilized to evaluate the packaging impact on the performance of RFID systems.

5. Packaging Impact on RFID Project

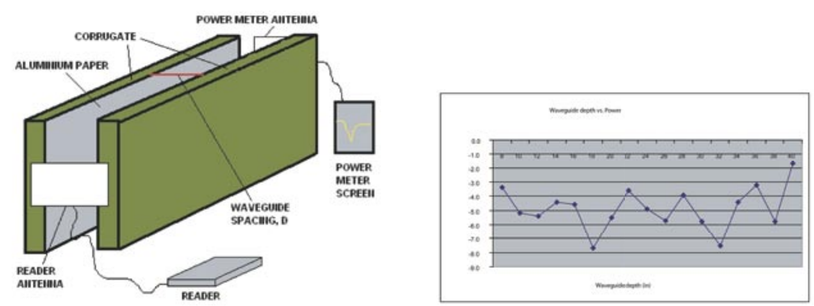
The objective of the Packaging Impact on RFID Project is to evaluate the impact of different materials and packaging designs on the performance of a passive RFID system. The ultimate goal in an RFID system is to maximize the communication link between the reader and the tags while at the same time, minimizing the effect of the local environment (materials, geometry, orientation, etc.).

While reader-tag communication has improved significantly over the past five years, tags continue to be extremely sensitive to their surroundings.

Microwave frequencies present unique problems in transmission, generation and circuit design that are not encountered at lower frequencies. This project studies electromagnetic penetration through materials and suggests possible means to improve this penetration through pallets given the fundamental electromagnetic challenges in reader-tag communication. In investigating fundamental electromagnetic challenges in reader-tag communication it was discovered that the amount of power that will reach a given tag is dependent on the dielectric and conductive properties of the material of propagation. Using water as a sample medium, our experiment studied how the transmitted power varies with material thickness.

When calculated theoretically, it was found that the transmission coefficient using three different conductivities (0.01, 0.03, 0.1) exhibited similar periodic shapes. The points at which the transmission through these materials peaked and troughed were periodic every quarter of a wavelength. The theory showed that propagation through a material varies with the thickness of the material and is dependent on the electromagnetic properties of the material. The results obtained using water as a sample medium demonstrated similar shapes to the theoretical transmission coefficient calculations. These results showed that the attenuation loss is not significant, even when using a lossy material such as water. The experiment also illustrated that reflection loss is far more significant than loss due to attenuation or spreading loss. The data showed that the thickness of a specific material influences where the power reaching the tag is a maximum or minimum. In addition, these specific depths are dependent on the wavelength of propagation of the specific material. Using the results of the experiments, it was established that variables such as permeability, permittivity, frequency and wavelength of propagation determine the power that reaches a tagged object. Given the constraints in RF propagation through materials, how can tagreader communication be improved? Auto-ID Labs is currently exploring a potential universal standard for pallet and case design. While the solution that is being developed may not be the absolute approach, it is one that should be considered.

The ideal properties of a general solution should be able to reduce or avoid reflection loss, be independent of the case dimensions and be independent of the material of the product. Auto-ID Labs consider conductive spacer layers, or waveguides, as a potential solution to low readability and fundamental electromagnetic challenges in reader-tag communication. Studies are being conducted to investigate how spacing between layers in a pallet can be used to improve the penetration of the electromagnetic field into the pallet as illustrated in Figure 4.



(a) Experimental Setup (b) Measured Power

Figure 3: Waveguide: a packaging feature to improve tag readability

The results show a periodic behavior of the guided wave along the conductive spacers. It was also found that the size of the gap greatly influences the penetration to the center of the pallet. With this improved identification, however, there is a tradeoff; with greater penetration into the pallet there is a slight loss of pallet space. Depending on the depth to the center of the pallet needed, the size of the gap can vary, i.e. the threshold gap is also dependent on the depth of the pallet.

6. Summary

The Packaging and RFID Research Program is leading the world in turning the art of RFID into the science of RFID. The Graphical Simulation Tool being developed will be used by non-expert users to develop intuition about the environmental impacts on RFID systems and to quickly investigate different packaging and environment configurations. These simulation results can be experimentally verified by using the Field Probe. In addition, the Field Probe can be used to investigate difficult to model and simulate environments and to track down the causes of unusual behaviors in the system. Both the Simulation Tool and the Field Probe are being used within the Packaging Impact on RFID Project to evaluate the impact of different materials and different packaging features on the performance of RFID systems.

The final work product from the Impact Project will be the first version of an Implementation Guide. The Implementation Guide will document the key packaging and material features that impact RFID system performance and provide stepby-step recipes for how to evaluate different scenarios and products. The Implementation Guide is a living document that will be continually updated as more knowledge is gained.

The continuation of the Impact Project and the commencement of a Tag Antenna Design Project and Reader Antenna Design Project will provide the cornerstone of the new learnings to be gained in the coming year. As the Packaging Program moves forward with its research and tool development, its sponsors will be able to immediately apply that knowledge to their benefits.