Physics of RFID

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Agenda

- Radio Waves
- Active vs. Passive
- Near Field vs. Far Field
- Behavior of HF Fields
- Behavior of UHF Fields
- Addressing UHF Physics Issues
What are radio waves?

• Radio waves are an invisible form of electromagnetic radiation with wavelengths that vary from one millimeter to 100,000 km
• Radio waves behave differently depending on their frequency
What is frequency?

- Number of radio waves that pass a fixed point per unit time
- Usually expressed in hertz
- 1 hertz is equal to one cycle per second
- 1 kilohertz (kHz) is 1,000 Hz
- 1 megahertz (MHz) is 1,000,000 Hz
Electromagnetic Spectrum
Basic RFID System
RFID Tag

- Integrated circuit
- Interconnect
- Antenna
- Substrate
Active Tags

- Broadcast a signal
- Performance not usually an issue
  - Think of your cell phone
- Distances can vary depending on frequency of broadcast
With Passive Tags, Frequency greatly affects performance

- Low frequency is like your FM radio
  - Waves pass through walls easily
- As the frequency increases...
  - the amount of data that can be transferred per second increases
  - radio waves behave more like light
  - ability to penetrate materials diminishes
Passive Tags

• Use energy from the reader
• Radio waves from the reader are on the same frequency as waves being reflected by the tag
  – Reader emissions 1,000 times as strong as the tag reflecting back
  – Depending on environmental conditions reading tags can be difficult
Read range of passive RFID

- The range that can be achieved in an RFID system is determined by
  - The power emitted by the reader antenna
  - The power available within the tag
  - The environmental conditions and structures
  - Material on which the tag is placed or in which it is embedded
## Effect of materials on RF

<table>
<thead>
<tr>
<th>Material Composition</th>
<th>Effect on RF Signal</th>
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</thead>
<tbody>
<tr>
<td>Corrugated Cardboard</td>
<td>Absorption from moisture</td>
</tr>
<tr>
<td>Conductive Liquids</td>
<td>Absorption</td>
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<tr>
<td>Glass</td>
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<tr>
<td>Groups of Cans</td>
<td>Multiple propagation effects; reflection</td>
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<tr>
<td>Humans/Animals</td>
<td>Absorption; detuning; reflection</td>
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<tr>
<td>Metals</td>
<td>Reflection</td>
</tr>
<tr>
<td>Plastics</td>
<td>Detuning (dielectric effect)</td>
</tr>
</tbody>
</table>
Performance of different passive RFID tags

Low-frequency (LF) tags

- 125 kHz or 134 kHz
- Short read range (1 mm to 3 feet)
- Works well around water
- Can be used near metal
- Used for access control, animal tracking, asset tracking
Performance of different passive RFID tags

High-frequency (HF) 13.56 MHz
- Short read range (around 1-3 feet)
- Works well around water and near metal
- Well-defined read field
- Well-established standards
- Used where medium data rate and read ranges are acceptable, mainly access control and financial transactions
Performance of different passive RFID tags

Ultrahigh-frequency (UHF)
- 860 MHz to 960 MHz
- Longer read range (up to 30 feet) and faster data transmission
- Signal bounces off metal and is absorbed by water
- No defined read field, null spots
- Global standard (ISO 18000-6C)
Near Field vs. Far Field

- Near field is within one wave length
- Far field is beyond one wave length
- These are very different types of communication
- Near field is magnetic
- Far field is electromagnetic
Near Field Communication

• LF and HF systems work with near-field communication
• A coil in the reader emits energy that creates a magnetic field with the coil in the tag
• The tag modulates and demodulates its antenna, changing the field
• The reader picks up changes in the field and turns them into binary data
Near Field Communication

Reader

Magnetic field

Power source (temporary storage)

Transponder

Load modulator

BP

DEMOD

f_{rd}+f_{H}

Chip

C1

C2
Near Field Communications

• Characteristics of near-field RFID systems
  – Short read range
  – Well-defined read zone
  – Consistent reads
  – Good penetration through materials
  – Not highly affected by water
Far Field Communications

- UHF systems work with far-field communication
- A plate or patch antenna radiates energy
- An antenna attached to the chip receives the radio waves and converts them to energy to power the chip
- Antenna is designed to capture most energy
Behavior of UHF Tags

- UHF tags usually have large antennas
- The tag converts energy from the reader into energy to run the chip
- The reader antenna can be circular-polarized
  - Energy emitted in a circular pattern to reduce orientation sensitivity
- The reader antenna can be linear-polarized
  - Energy is channeled into a specific spatial orientation to increase read range
UHF Tag Examples
Behavior of UHF Tags

• The chip uses the energy to modulate the antenna, changing the wave reflected back

• Modulation is the process of altering the signal parameters of a high frequency carrier in relation to the signal to be transmitted (the data)

• Different ways to modulate the antenna
  – Analog: AM, FM
  – Digital: ASK, FSK, PSK
Analog Modulation
Digital Modulation
Signal Coding

• It takes the message to be transmitted and codes it in a way that will be optimal for the transmission channel
• It provides protection against interference or/and collisions
• Examples: NRZ code, RZ code, Differential coding, pulse-pause coding, … etc
Signal Coding

NRZ

RZ

Manchester (Ethernet)

Differential Manchester (Token Ring)

Bipolar
UHF Near Field Tags

- Some companies are developing UHF tags that work in the near field
  - Short read range
  - More defined read zone
  - More consistent reads
  - Good penetration through materials
  - Less affected by water
Conclusion

• LF, HF and UHF perform differently because of the physics of different radio waves
• RFID users must choose the RFID system that works best for their application(s)
• RFID suppliers must overcome the limitations of UHF tags to achieve consistent reads
RFID Regulations

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Presentation Overview

• The electromagnetic spectrum
• EM spectrum issues
• Wireless devices using the EM spectrum
• Licensed and unlicensed bands
• The ISM bands
• Spectrum allocation
• Standards
• Regulation
The electromagnetic (EM) spectrum

• The spectrum is a resource that governments divide up for different uses
  – FM radio - 148.5 - 283.5 kHz
  – Paging systems — 169.4 to 169.8125 MHz
  – Medical implants — 402 MHz - 405 MHz
  – Citizens-band radio — 446 MHz range
  – Alarm systems — 869.25 MHz – 869.3 MHz
  – GSM — 880-890 MHz/925-935 MHz
  – Broadcast TV — 11.7 to 12.5 GHz
The electromagnetic (EM) spectrum

• Governments carefully control the spectrum
  • Federal Communications Commission (FCC)
  • European Telecommunication Standards Institute (ETSI)
  • International Telecommunication Union (ITU) manages the spectrum globally
• Global management of the spectrum is done via three ‘regions’
The electromagnetic (EM) spectrum
EM spectrum issues

- Once spectrum bands areas are allocated, it is difficult to change them
- Many devices competing for bands
- Governments must avoid having one device interfere with another
Common wireless devices

- Garage-door openers (26.9 to 40.0 MHz)
- Baby monitors (30 to 46 MHz)
- Radio-controlled aircraft (35 MHz)
- Radio-controlled surface vehicles (40 MHz)
- Wireless switches (433.6 MHz)
- GSM mobile phones (890 to 960 MHz)
- Pet tracking systems (900 MHz and 1800 MHz)
- Cordless DECT phones (1880-1900 MHz)
Licensed and unlicensed bands

• Some bands are licensed
  – Television
  – Radio
  – Cellular phones

• RFID uses unlicensed bands

• 13.56 MHz is used in most countries around the world for high-frequency RFID systems

• 125 kHz used by many countries for LF
The ISM bands

• UHF uses the unlicensed industrial, scientific and medical (ISM) radio bands
• Originally reserved internationally for non-commercial use of RF (electromagnetic) fields for industrial, scientific and medical purposes
• Now used by RFID, Wi-Fi and other devices
RFID regulations

• Regulatory agencies also control
  – Power output
  – Use of channels
  – Duty cycle and other aspects of operation

• Readers must be certified by the FCC (Federal Communications Commission) in the US, ETSI (European Telecommunications Standards Institute) in Europe, etc., to meet these requirements
Spectrum allocation

• ETSI has recommended 865.6 to 867.6 MHz
  – 10x 200Khz channels
  – Power up to 2 watts

• The FCC has allocated 902 MHz to 928 MHz for UHF RFID systems
  – 50x 500Khz channels
  – 4 watts of power output
Spectrum allocation worldwide

- Australia and New Zealand: 918 - 926 MHz
- Japan: 952-954 MHz
- China: No allocation for UHF
- India: 865-867 MHz
- Argentina: 902-928 MHz
- Brazil: 902-907.5 MHz
- South Africa: 915.2-915.4 MHz
Standards bodies

- International Organization for Standardization (ISO)
  - Air-interface standards (how tags and readers communicate)
  - Data-protocol standards (structure of data on tag)
  - Animal identification standards
  - Gas-cylinder standards
Standards bodies

• EPCglobal
  – Air-interface standards
  – Tag-data standards
  – Reader-interface standard
  – Data-sharing standards
  – Network-protocol standards
  – New classes of tags
Standards bodies

• Standards for using RFID within specific industries
  – International Air Transport Association (IATA)
    • Baggage-tag standard
    • Supply-chain standard (Spec 2000)
  – Auto Industry Action Group (AIAG)
  – Chemical industry standards (CIDX)
Legislation

• Most bills have been introduced at the state level in the United States
• Most have focused on
  – Restricting some uses of RFID
  – Requiring disclosure of use of RFID systems
  – Requiring removal or deactivation of tags
  – Requiring the study of RFID’s impact on privacy
Legislation

No laws proposed in Europe yet

• In 2005, the European Commission tapped its advisory body on data protection and privacy—the Article 29 Working Party—to conduct its first assessment of data protection issues related to RFID

• Workshops held periodically since then

• Web site set up to gather opinions
Legislation

• On Oct. 18, 2006 the EC issued its report on RFID
• On Nov 23, 2006 EC Decision published on harmonization of the radio spectrum for RFID devices operating in the UHF band
• On May 12, 2009, EC issued a recommendation on the implementation of privacy and data protection principles in applications supported by RFID
The EPCglobal Vision

“The Internet of Things”

• Use EPC-standard tags to track items in real time as they move through the supply chain

• Use open-standard networking protocols to share data among supply chain partners

• Automate many business processes

• Transform the global supply-chain from a push model to a pull model
THANK YOU
Real World Considerations

Understanding the factors that will affect RFID deployments

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Factors

• Cost, cost, cost
• Deployment issues
• System performance
  – Materials tagged
  – Quality of tags/readers
  – Noise/interference
• Privacy/social issues
Costs

RFID Readers
$$

RFID Tags
$

Organizational Strategy Development
$$..$$$

System Costs
$$$ 

Edgeware Devices
$$

System Integration
$$$$

Hardware Deployment
$$$ 

Ongoing Maintenance
$$..$$$

Project Management
$$$

Change Management
$$$

System Costs
$$$ 

Edgeware Devices
$$

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$$$$

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$$$ 

Ongoing Maintenance
$$..$$$

Project Management
$$$

Change Management
$$$

TENTH ANNUAL CONFERENCE AND EXHIBITION
APR. 3-5, 2012 | WALT DISNEY WORLD SWAN AND DOLPHIN RESORT, ORLANDO, FLA
Cost of Tags

• Tags
  – ~5 cents for UHF inlays
  – ~10 cents and up for UHF
  – ~20 cents and up for UHF smart labels
  – ~50 cents and up for HF smart labels
  – ~Semi-active tags are $10 and up
  – ~Active tags $15 and up
Bringing down cost of Tags

• Research and development focused on
  – More efficient ways to assemble tags
  – Conductive inks for printing antennas
  – Improved converting processes for labels
  – Recyclable tags
  – Embedding techniques
Cost of Readers

- A typical UHF standalone reader: $1,000 to $3,000
- Handheld readers:
  - Small UHF readers: $200 and up
  - HF readers: $200 and up
- Label printers: $3,000 and up
- Active RFID Readers: Depends on type of system!
Bringing down cost of Readers

• Research and development is being done on a system and component level

• Goal is to shrink the components on a reader’s printed circuit board down to a few chips

• UHF readers could come down to less than $100

• Investments won’t be made until volumes increase
Middleware, Apps, Installation

• Cost depends on your project size
• World Kitchen spent $400,000 to become Wal-Mart-compliant
• That includes
  – Readers
  – Initial lot of tags
  – SAP’s All middleware
  – Integration with SAP back-end systems
  – Installation
Deployment Issues

- Limited number of people/systems integrators with RFID experience
- Readers aren’t plug-and-play
  - Antennas need to be properly positioned and tuned
  - Appropriate technology needs to be used
- Limited number of reader form factors
- Limited testing and deployment tools
- Not many best practices
Systems Performance Issues

- Materials can be “RF friendly” or “RF unfriendly”
- Water is unfriendly (absorbs UHF energy)
- Metal reflects radio waves
- Different types of materials detune tag antennas
- Anti-static containers absorb RF
- Behavior of RF is unpredictable
Deployment Issues

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• Limited number of reader form factors
• Limited testing and deployment tools
• Not many best practices
Tagging Liquid Products

• Look for air gaps in packaging to keep tag away from water-based products
• Use a tag with a foam spacer to keep tags off water products
• Use tags designed to work well around water
Tagging Metal Products

- Use metal-mount tags that have spacers to keep tags away from the metal
- Use tags designed to couple with the metal product
- Find air gap in packaging that keeps tag away from the metal
Quality of Tags

• Few companies deliver 100% readable tags
• Tag yields continue to improve
• 2% failure is not uncommon
Quality of Readers

- Reader performance does vary
- Generally, readers work well
- Read scenarios in your application will determine appropriate reader format to choose
- Interoperability will improve over time
Challenging RF Environments

• Electromagnetic energy will affect your ability to read tags consistently
• Any device operating in the UHF spectrum can interfere with UHF RFID systems:
  – Cordless phones
  – Older wireless networks
  – Some alarm systems
Challenging RF Environments

• Other devices give off electromagnetic energy:
  – Electric motors
  – Forklift trucks
  – Some conveyors
  – Florescent lights
Work-arounds for RF issues

• Have a site survey done to see where problems might occur
• Shield electric motors
• Upgrade older wireless LANs
• Deploy in areas with less metal, if possible
• Attenuate reader signal to avoid false reads
• Get antennas as close to tags as possible
Privacy Issues

• Tagging individual items or cases consumers might buy could raise problems:
  – Bad press
  – Angry customers

• Take concerns seriously

• Be open with customers:
  – What data you are collecting
  – Where RFID is used

• Use “RFID inside” labels
Environmental Issues

- Metal antennas can’t be recycled
- Metallic ink antennas can’t be put in some landfills
- New readers will need to comply with recycling laws for electronic components
THANK YOU
Building an RFID Business Case
Understanding how RFID can deliver a return on investment

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Outline

• Closed loop vs. Open loop
• RFID as infrastructure
• Building business case
• Evaluate & prioritize
• Pilot phase
• ROI models
Open Loop vs Closed Loop

• Closed Loop Solutions
  – Applications span single organizations
  – Information retained within organization

• Open Loop Solutions
  – Applications span multiple organizations and or locations
  – Information shared to benefit all trading partners
Closed Loop Solutions

• Closed Loop solutions solve a specific problem
  – Lost, stolen, misplaced assets
  – Manufacturing errors
  – Slow warehousing throughput
  – Time wasted searching for documents
Business Case – Closed Loop

- Business Case easier to develop
- Identify pain points within the organization
- Quantify loss (assets, productivity)
- Evaluate potential benefits
- Organization paying for deployment experiences the benefits!
P&G Facility finds ROI in floor

- A P&G facility in Spain needed to increase throughput
- Warehouse was a bottle neck
- Needed to go to direct loading, no staging on the dock
- Needed a system that was 100% accurate & fast
- RFID was the answer
P&G Facility finds ROI in floor

• Installed tags in floor, readers under the forklift
• Associated the pallet with the location
• System cost ~$150,000
• Benefits
  – Increased throughput (40% faster)
  – Improved order accuracy
  – Reduced forklift drivers by one per shift
• ROI achieved within one year
Open Loop Solutions

• **Definition:** “the RFID transponder remains on the object and leaves the process or production site for a long period of time or without reuse for the same process” *

• Open loop solutions tend to benefit multiple organizations
  – Item Tracking in Retail
  – Pharmaceutical Tracking
  – Traceability initiatives

Business Case – Open Loop

• Business Case complex to develop
• Identify pain points within the entire supply chain
• Quantify value of information at various points and for various stakeholders
• Evaluate potential benefits
• Determine an appropriate mechanism for sharing deployment costs!
RFID as Infrastructure

- Multiple applications can be supported using the same infrastructure.
- Initial investment justified for one application can provide additional benefits for a fraction of investment.
- Support costs shared over multiple applications.
- Ex. Premise access solution deployed to identify vehicles can be used to enable better records keeping for vehicle maintenance.
Building a Business Case for RFID as Infrastructure

• Identify the pain points
• Examine how internal benefits can be achieved within multiple functional areas
  – Leverage the same tags
  – Leverage the same reader infrastructure
• Bring in stakeholders from a variety of areas of the business: operations, finance, IT, security
Business Case Challenges for RFID as Infrastructure

• No one application delivers complete ROI
• Infrastructure costs are high
• Infrastructure depends on how it’s used
• New funding models need to be explored
• However: Long-term benefits can be great
Building Business Case

• Pay attention to business processes
• Draft a clear understanding of the business requirements
• Identify appropriate technologies that will help address identified requirements
• Deploy pilot project
  – Observe performance of selected technologies
  – Uncover challenges that might have been unaccounted during initial planning stages
Building Business Case

- Communicate, communicate, communicate...
- Revisit initial assumptions and update based on current information
- Spend time and effort on data management

*Proactively acting on real time information will enable operational benefits*
Evaluate & Prioritize

• What are the quantifiable costs/benefits?
• Will the initiative be critical in enabling bottom-line benefits?
• Will the initiative create a strategic point of difference or enable better quality of service?
Evaluate Potential Challenges

• What processes will be impacted in one or multiple businesses and/or functions?
• Are new processes being created, and/or current processes being significantly retooled?
• How many people are affected?
• Are reporting relationships and performance measures affected?
• Are there dependencies on long-term integrated solutions and/or significant data conversions?
Analyze Current Processes

• Break down the way you are doing things today
• Analyze gaps or weaknesses in those processes
• Examine how they might be addressed, given the ability to gather RFID data at key points in those processes
Pilot Phase

• Limit the scope
• Run the pilot—then run it again
• Examine assumptions
• Examine other changes going on to confirm benefits came from RFID and not other factors
• Determine the return on investment
Pilot Phase

- Confirm the benefits can be achieved
- Make sure the hardware and software perform the way they did in the field test
- Make sure people are trained properly
- Prepare for the roll out
ROI Models

• Measurable enhancements should be determined based on functional area:
  – Operational enhancements
    • Cost savings due to more efficient processes
  – Security enhancements
    • Increased Security; Cost savings might not be an objective

• Need flexible ROI models based on maturity of project
ROI Models – Innovative Projects

• Realistic cost savings might be hard to predict

• Lack of experiential knowledge; *Lots of assumptions to build initial ROI*

• Track project success based on defined deliverables
  – Freeze requirements to avoid scope creep
  – Tangible deliverables based on requirements
ROI Models – Mature Projects

• Ability to predict cost savings based on experiential knowledge
• Well defined requirements & deliverables
• Project success measured based on initial calculations
• $\text{ROI} = \frac{\text{Earnings or Cost Savings}}{\text{Cost}}$
THANK YOU