RFID's: Supply Chain and Future Prospects in a Globalized Port Environment

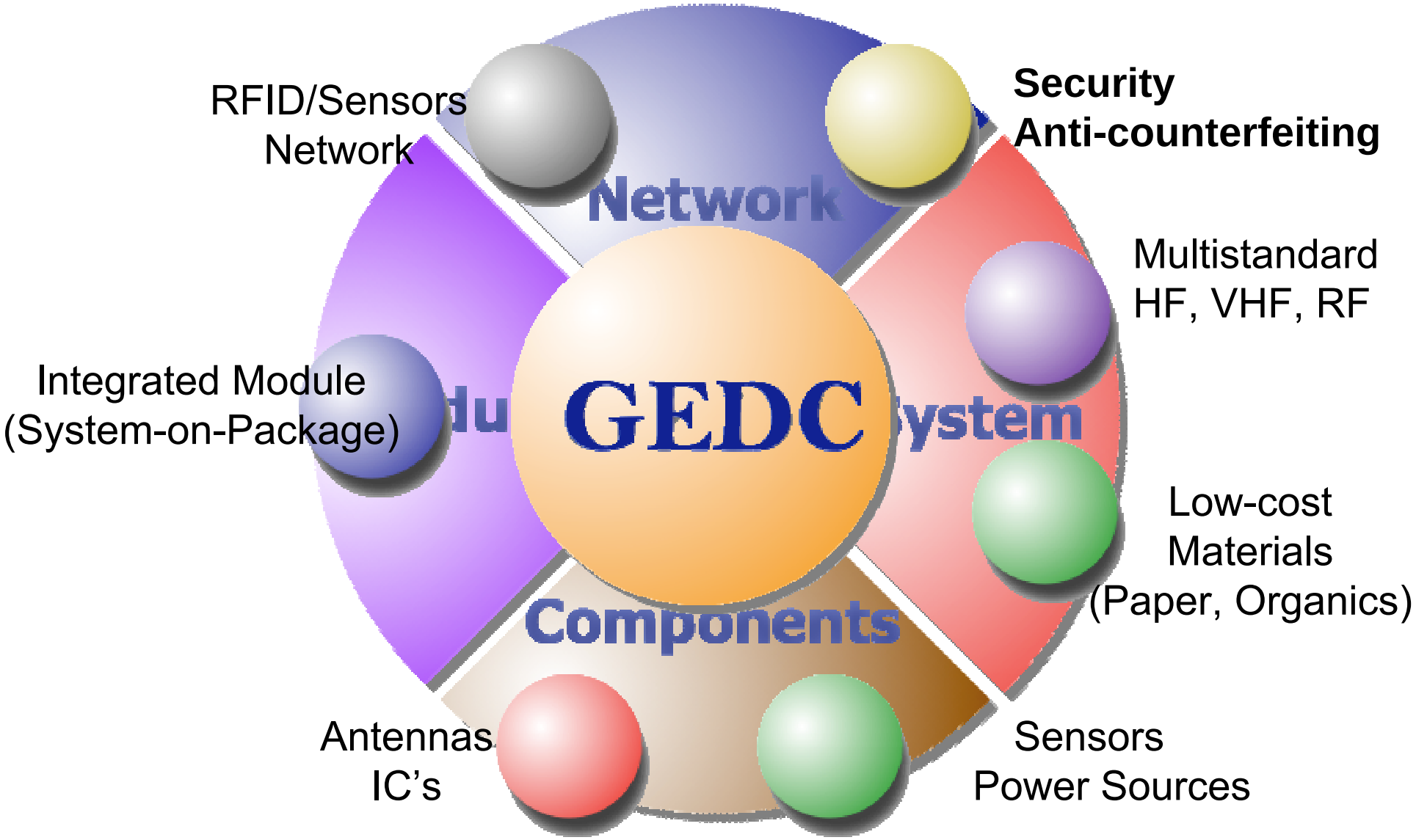
GEDC/Georgia Tech

"Port RF Electronics" GROUP

Prof. Manos M. Tentzeris

(etentze@ece.gatech.edu)

GEDC *P.I.R.E.A.S. Testbed*
(Port Integrated RF-Enabled Agile Systems)

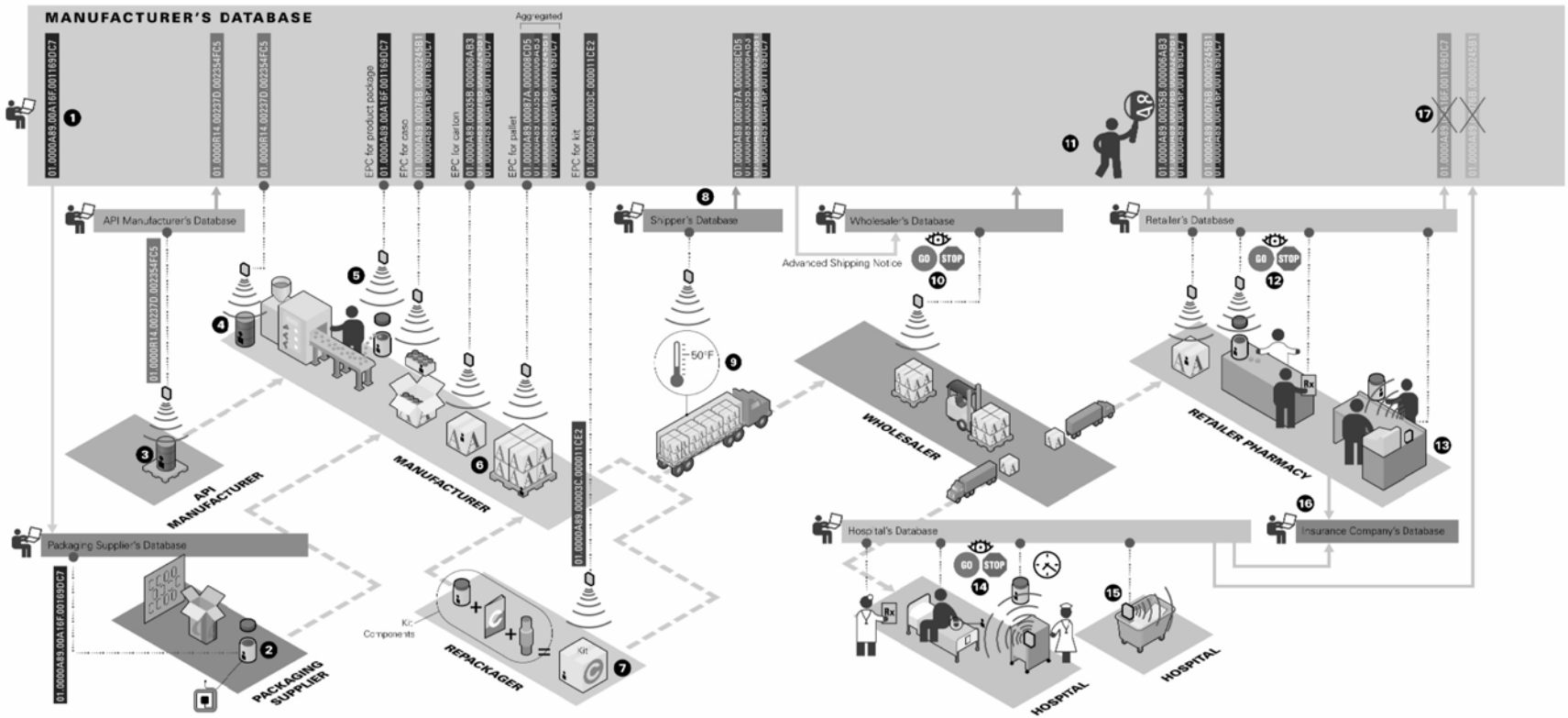


PIREAS RFID/Sensors Lab

- **Building designs using ink-jet metal printing on/embedded in low-cost paper for various thicknesses and sizes (hydrophobic paper)**

- Test Bed facility for various RFID applications:
  - Aeronautical industry
  - Pharmaceutical industry
  - Port security
  - Airport security and baggage tracking
  - Automotive industry (tire pressure monitoring sensor system)
  - Inventory control
  - Wearable electronics

How RFID Technology Protects Pharmaceutical Supply Chain



1
Manufacturer assigns a unique EPC number to each product to allow track and trace throughout the supply chain.

2
Packaging supplier "writes" to the tag the EPC number assigned by the manufacturer and embeds the tag in empty packaging materials.

3
Raw materials are tagged to allow the product's pedigree to extend back as far as needed.

4
Manufacturer receives raw materials and records their EPC numbers in the manufacturer's database, linking raw material data to final product EPC and building pedigree.

5
EPC number and product information are recorded in the manufacturer's database at the end of the manufacturing process. Only products with valid EPC numbers can move through the supply chain.

6
Additional EPC numbers are assigned to cases, cartons, and pallets as products are aggregated. The aggregation information is recorded in the manufacturer's database.

7
Kits can be assembled with both tagged and untagged products. If needed, a kit can have its own unique EPC number.

8
Sharing data among trading partners removes the burden of collecting and storing every detail. The EPC number serves as a key to ensure a perfect match between products and their data. Security rules prevent unauthorized parties from accessing sensitive data.

9
Sensors can record conditions throughout the supply chain and add this information to the product's history.

10
Advance Shipping Notices (ASN) give the wholesaler detailed EPC data about shipments before products arrive. Radio frequency scans of incoming shipments can reveal mismatches before products come off the truck.

11
Virtual agents continually monitor EPC numbers throughout the supply chain and instantly highlight any EPC numbers that are odd, duplicated, or out of place.

12
Prescription errors can be reduced by automatically comparing the data associated with a product's EPC number to customer's records.

13
POS system detects when a product is purchased at a pharmacy and leaves the supply chain.

14
Administering errors can be reduced by scanning patient ID and drug EPC number and automatically comparing the associated information to check for expiration date and pedigree and to ensure a match to the physician's prescription.

15
RFID readers on recycling bins can detect the tags of discarded products and deduce that they have reached the end of the supply chain.

16
Insurance companies can collect a wealth of accurate and useful information when the EPC number of a drug is linked to a specific patient at the point when a drug is actually administered.

17
EPC numbers become inactive when the product reaches the end of the supply chain, but product information remains in the database.

BearingPoint

RFID tag/sensor on organic Material

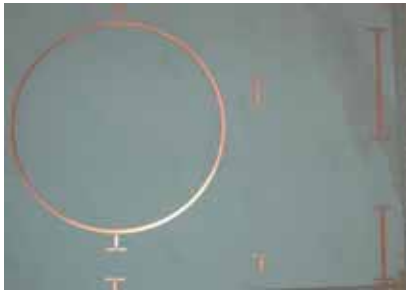
Why consider LCP as a substrate?

- Liquid Crystal Polymer (LCP) can be used as a high performance multilayer substrate
- Excellent electrical properties ($\varepsilon_r \sim 3.10$ and $\tan\delta=0.002$)
- Flexible (Sensors can be rolled or molded into desired shape)
- Good performance: mechanical integration compatibility and economic viability

High-bandwidth S-Antenna

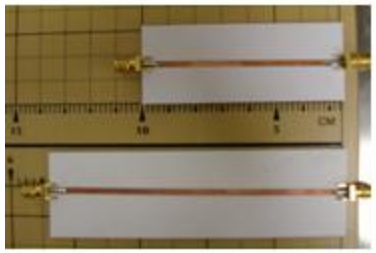
Antennas fabricated on 12”x12” in LCP Film

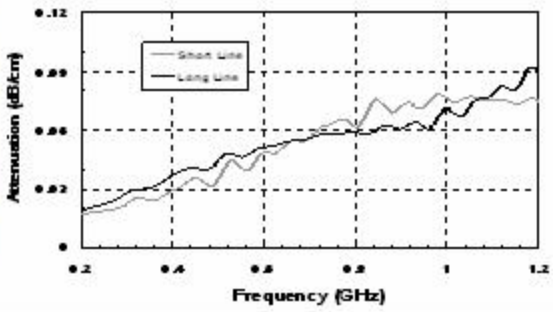
Electrical characterization using Various Methods



Ring Resonator Method

Cavity Resonator Method





Transmission Line Method

RFID printed on paper: conductive ink

PAPER:

• Environmental Friendly and low cost

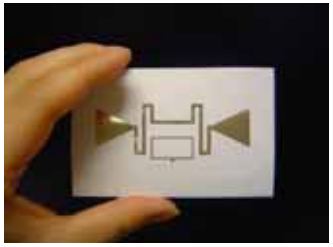
(LOWEST COST MATERIAL MADE BY HUMANKIND)

• Large Reel to Reel Processing

• Compatible for printing circuitry by direct write methodologies

• Can be made hydrophobic and can host nano-scale additives (e.g. fire retardant textiles)

• Dielectric constant εr (~2) close to air's

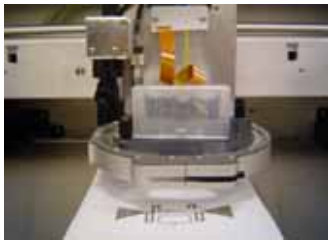


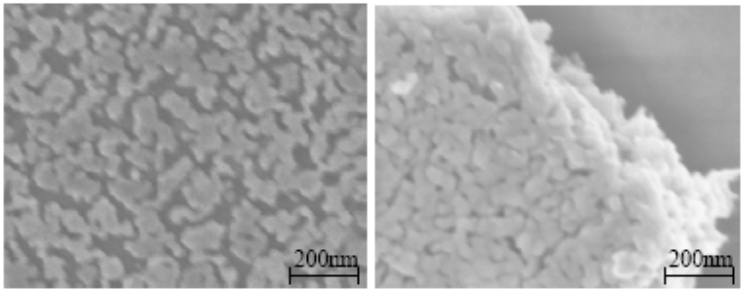
INK:

• Consisting of nano-spheres melting and sintering at low temperatures (100 °C)

• After melting a good percolation channel is created for electrons flow.

• Provides a better result than traditional polymer thick film material approach.

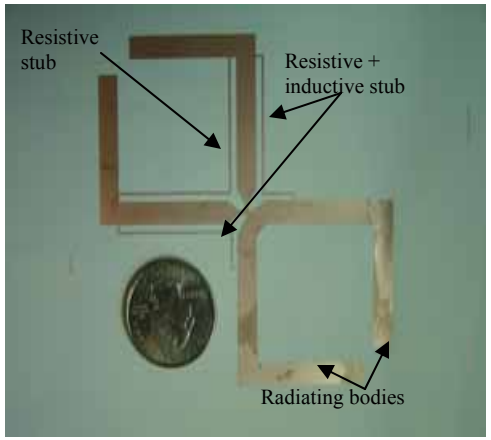


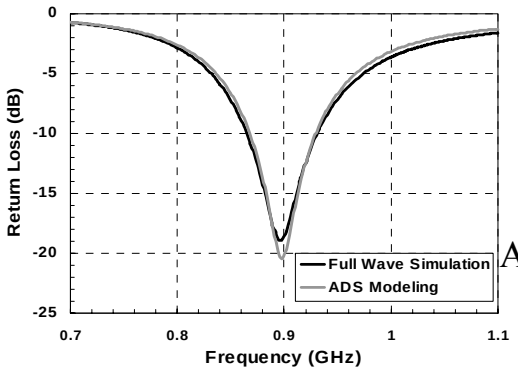


SEM images of printed silver nano-particle ink, after 15 minutes of curing at 100°C and 150°C

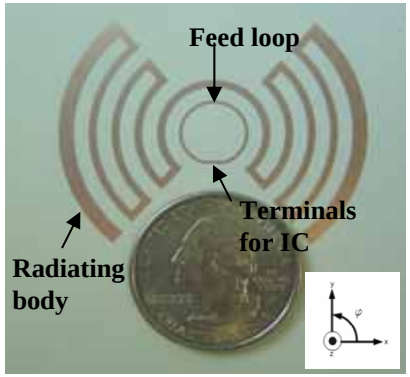
UHF RFID Antenna Design

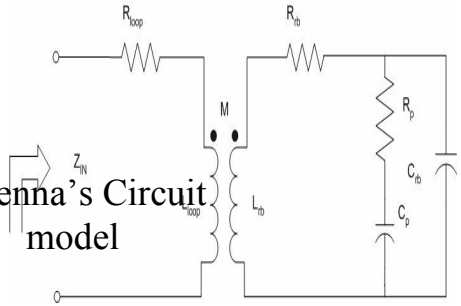
Dual Polarized for harsh environments



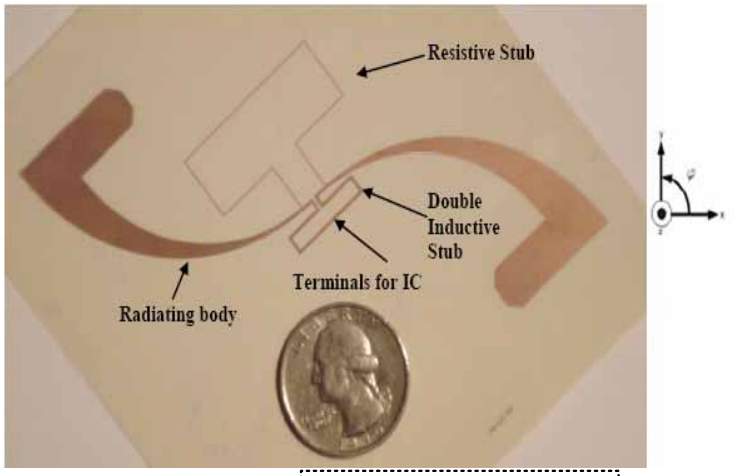


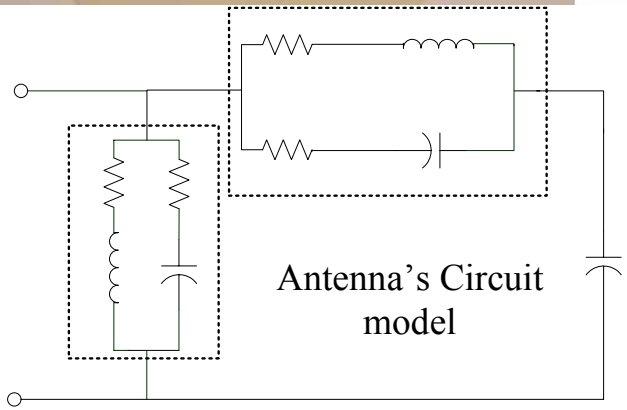
Ultra-compact





High-bandwidth

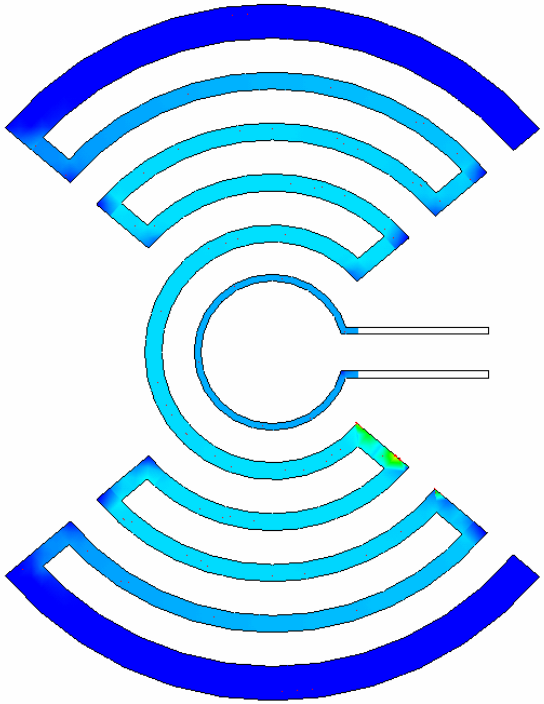


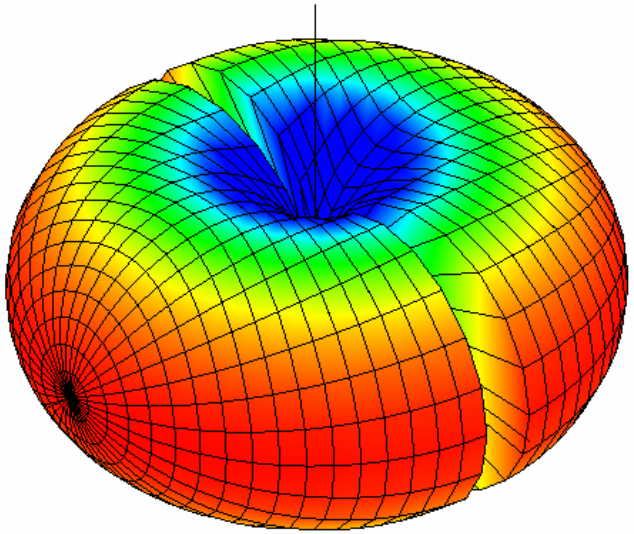


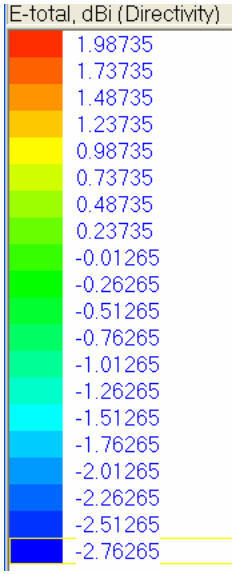
Frequency of operation UHF RFID band (860 → 930 MHz)

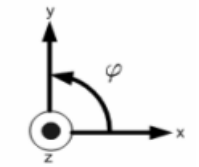
Design variables can be chosen to have any center frequency

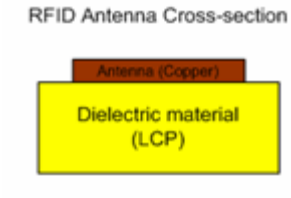
Arc-shape antenna









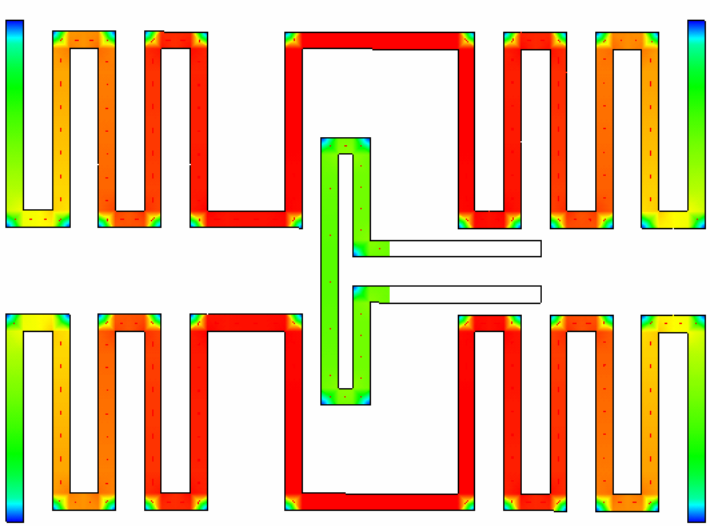


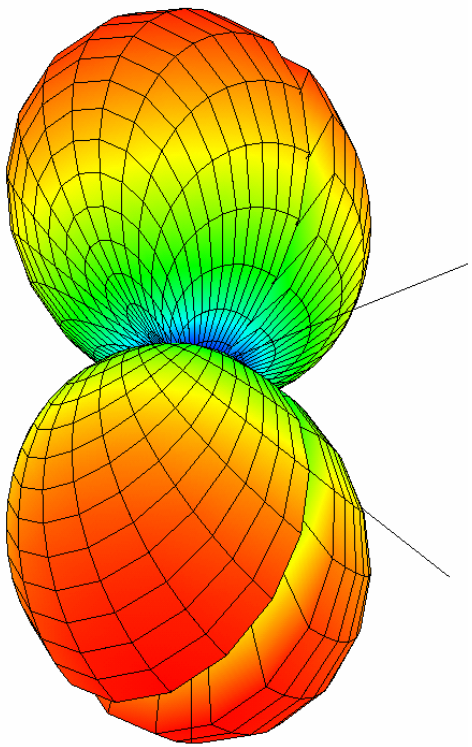
- Directivity = 1.99dBi
- Radiation Efficiency = 89.7%

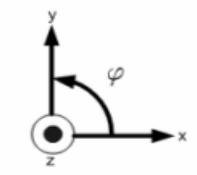
Copper thickness: 18 um

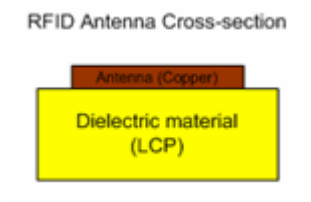
LCP thickness: 50.8 um (2 mil)

Dual radiating type antennas







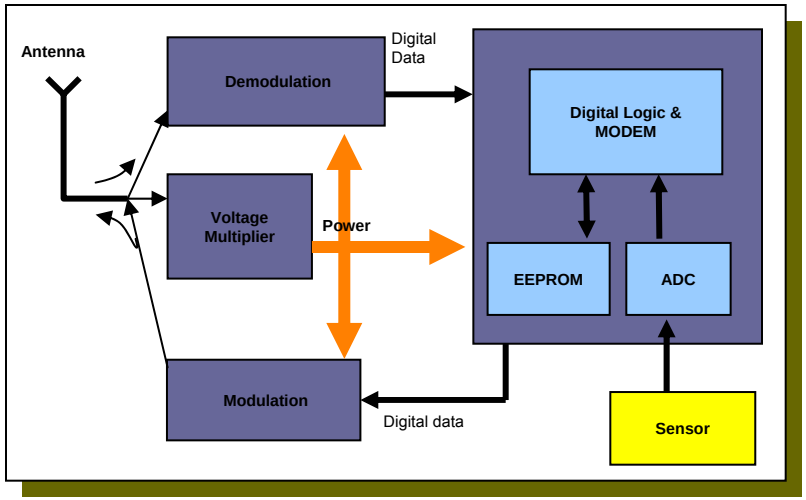


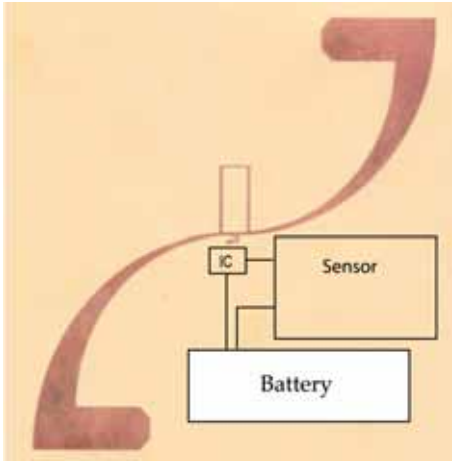
- Directivity = 5.62dBi
- Radiation Efficiency = 79.9%

Copper thickness: 18 um

LCP thickness: 50.8 um (2 mil)

RFID/Sensor Module Integration





- **Ultimate goal**: All printed RFID tag (antenna, IC, battery, and sensor) on paper
- Operating frequency: UHF (900 MHz), RF (2.45 GHz), potentially up to 60 GHz
- Suggested Module integration:
  - Printed battery on surface
  - Printable sensor technology on surface
  - Surface mounted IC

Operation modes

Passive Tags:

- Antenna uses EM power from reader.

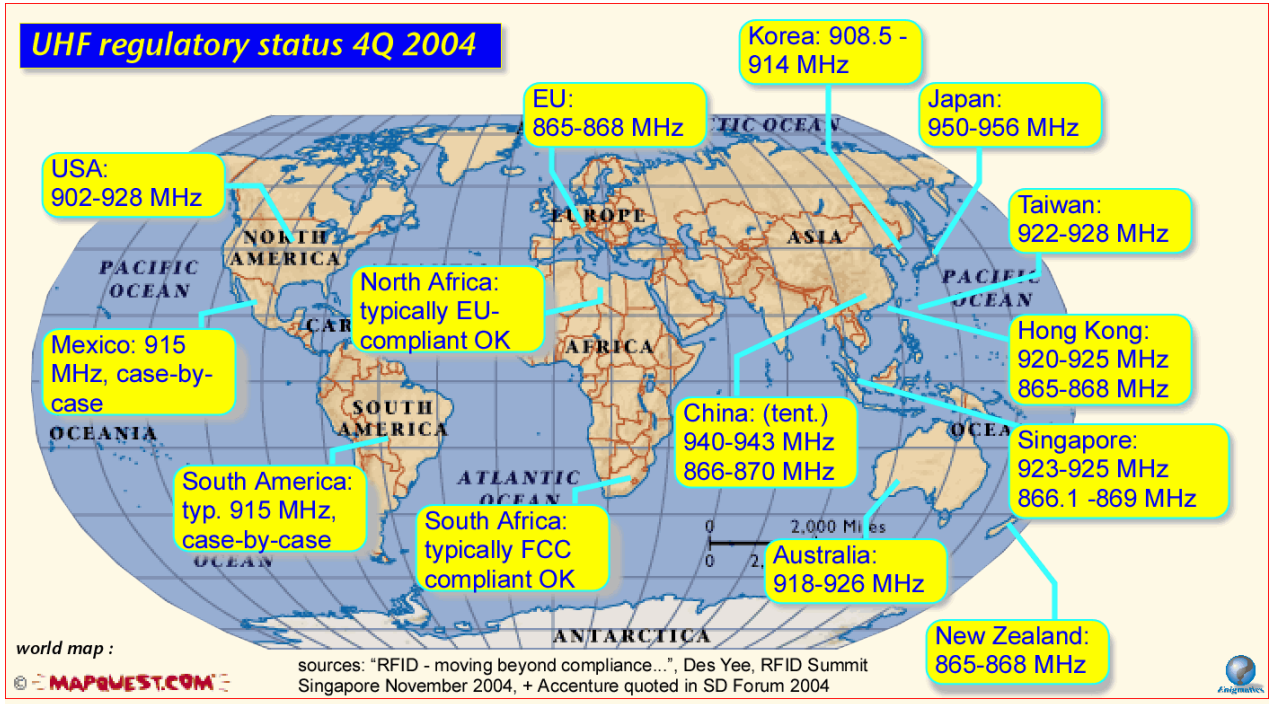
Semi-Passive Tags:

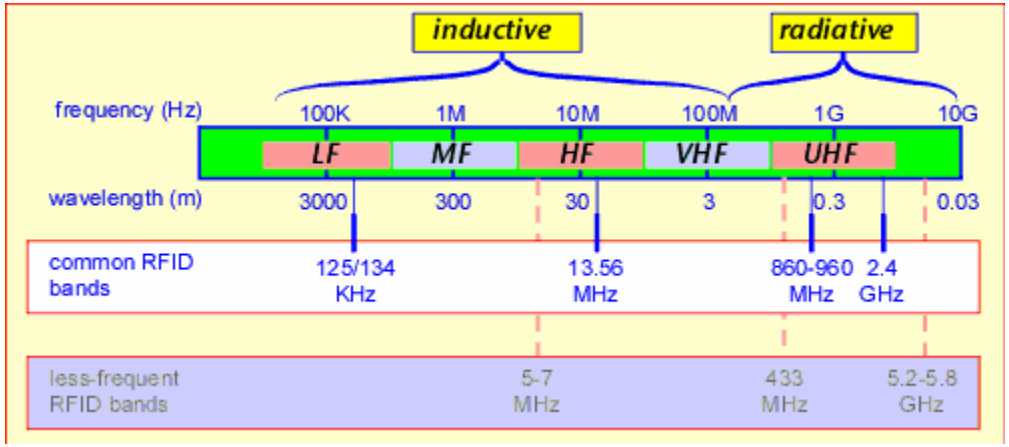
- IC uses EM power distribution
- Sensor uses battery
- Increased node's lifetime

Active tag:

- IC and sensor utilize battery
- Increased data range (>100 ft compared to 30 ft in semi-passive)
- Excellent for harsh environments for their improved S/N

RFID Frequency Bands

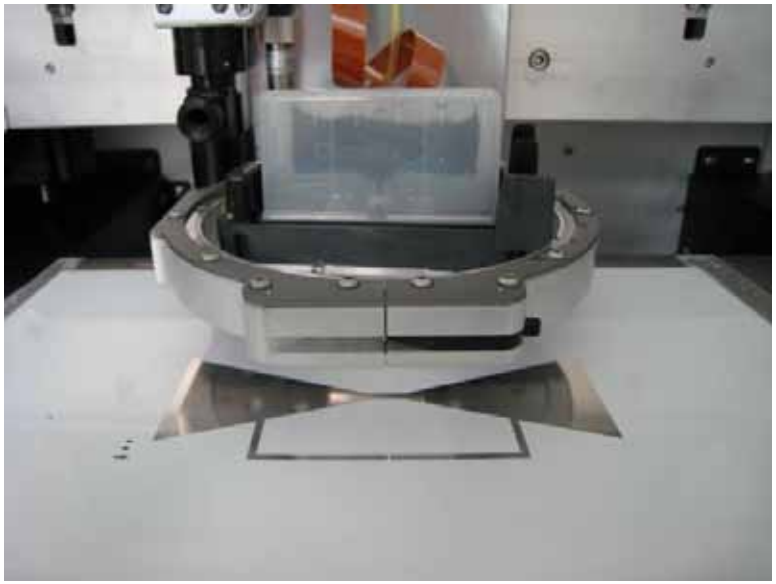


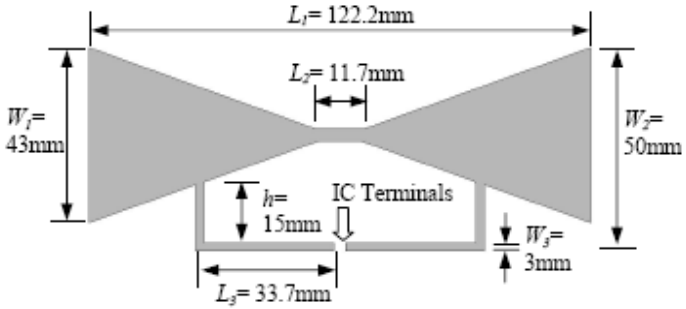


UHF RFID Antenna- Global Operability

Tracking boxes, pallets, and containers imported imposes a challenge namely frequency of operation and bandwidth.

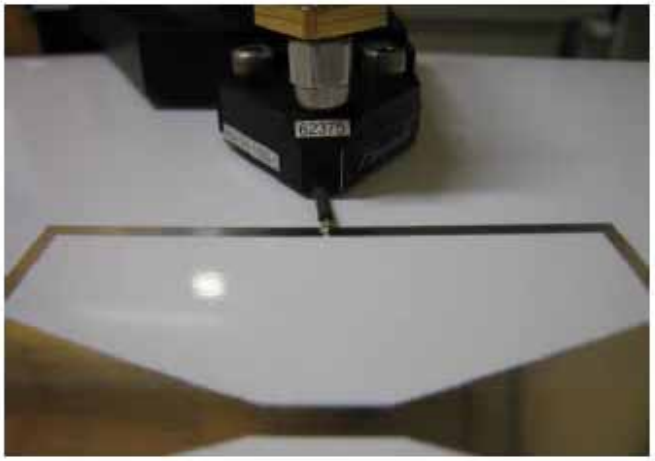
- In order to tackle this challenge a universal RFID tag needs to be designed (frequency 860MHz → 960 MHz) with a certain added tolerance.

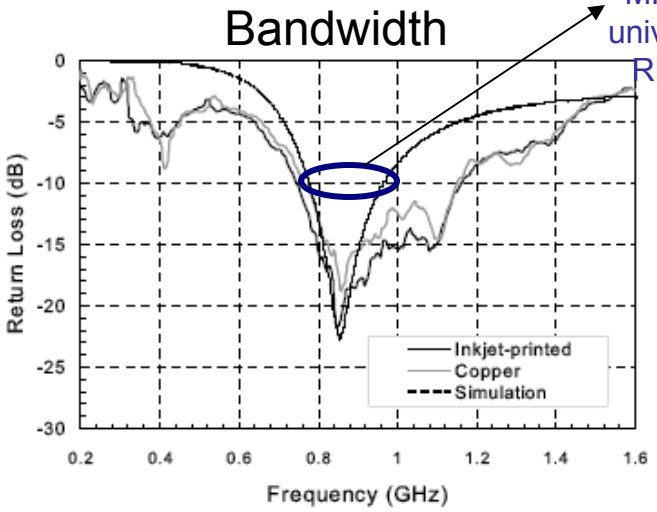


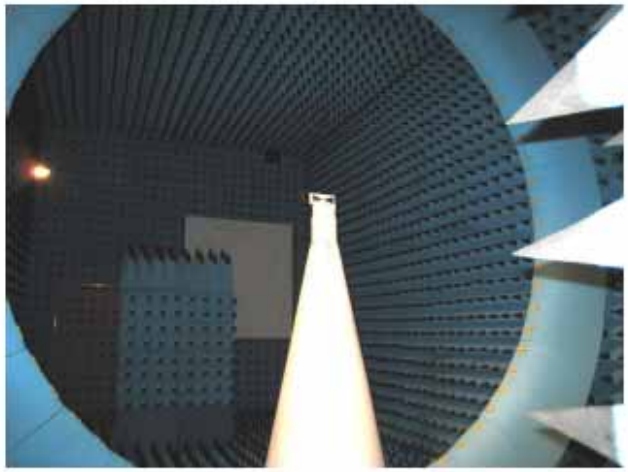


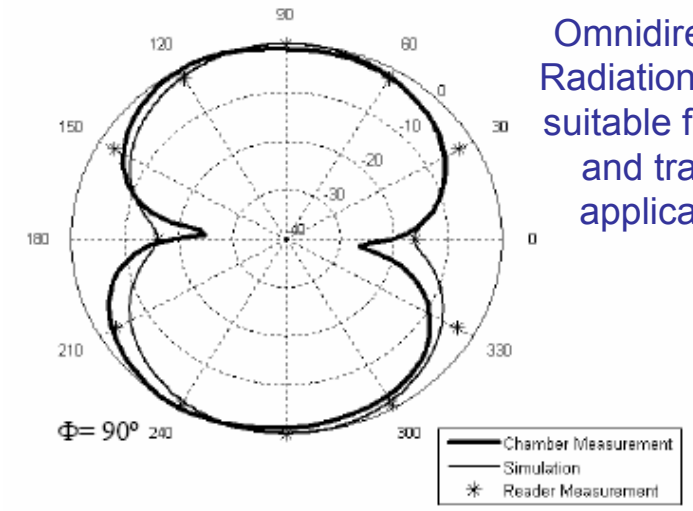
T-match folded bow-tie RFID tag module

UHF Global RFID Antenna-measurement results



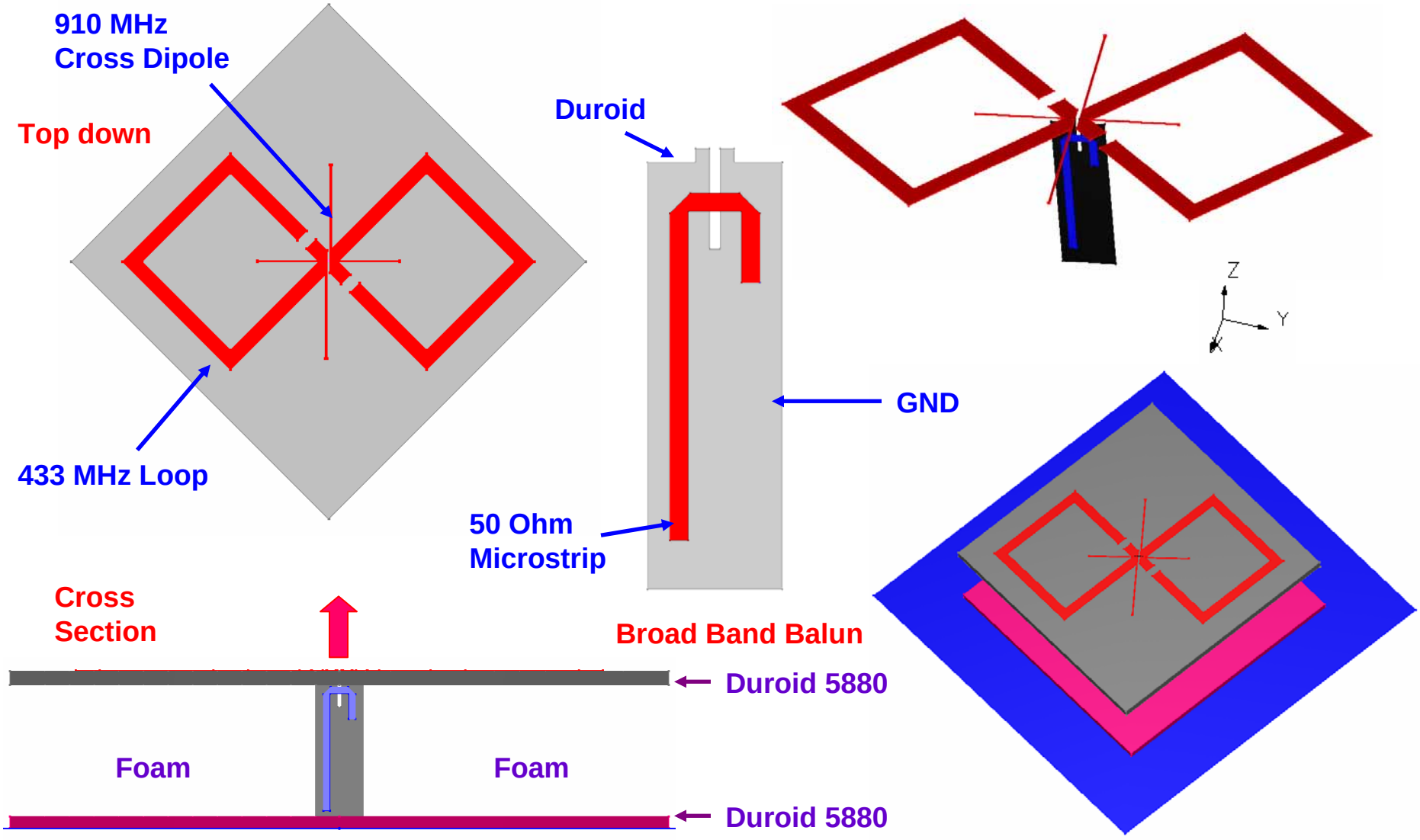




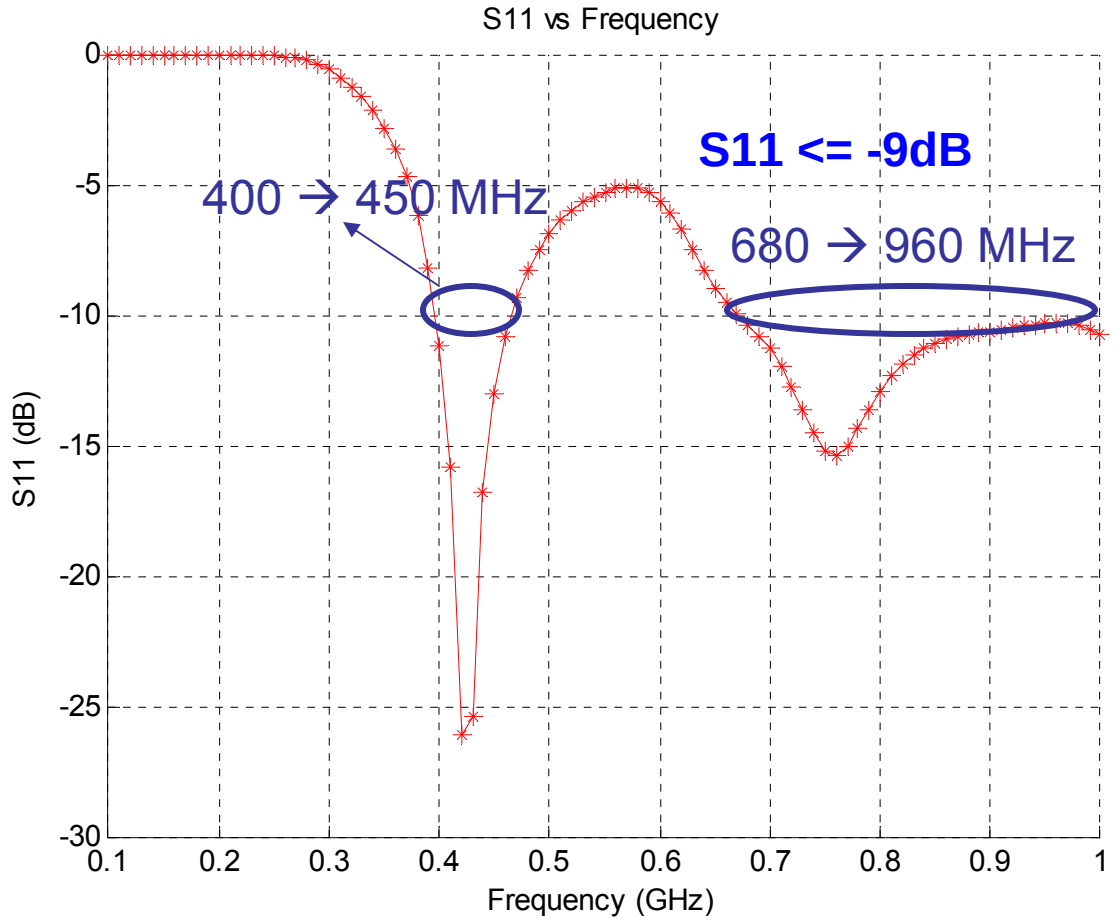


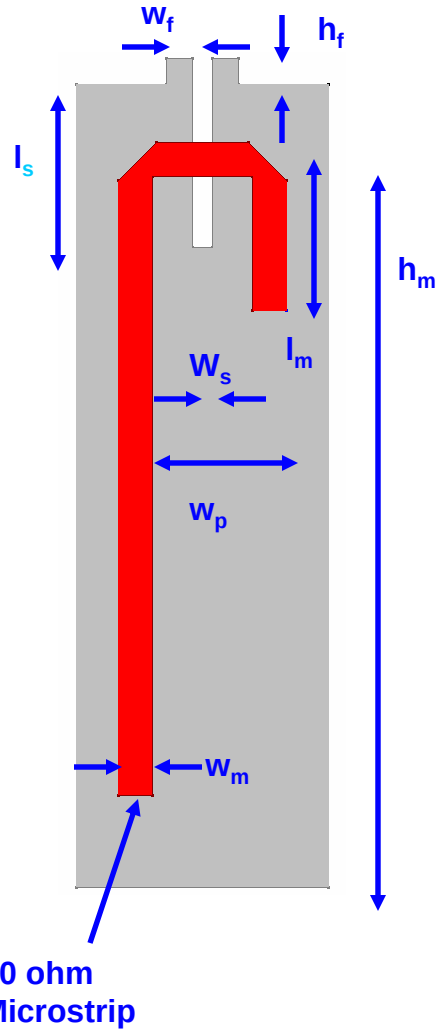
Omnidirectional Radiation Pattern suitable for RFID and tracking applications!

“Universal” 433/900MHz Reader with CP “Smart” Diversity



Dual Band Impedance Matching

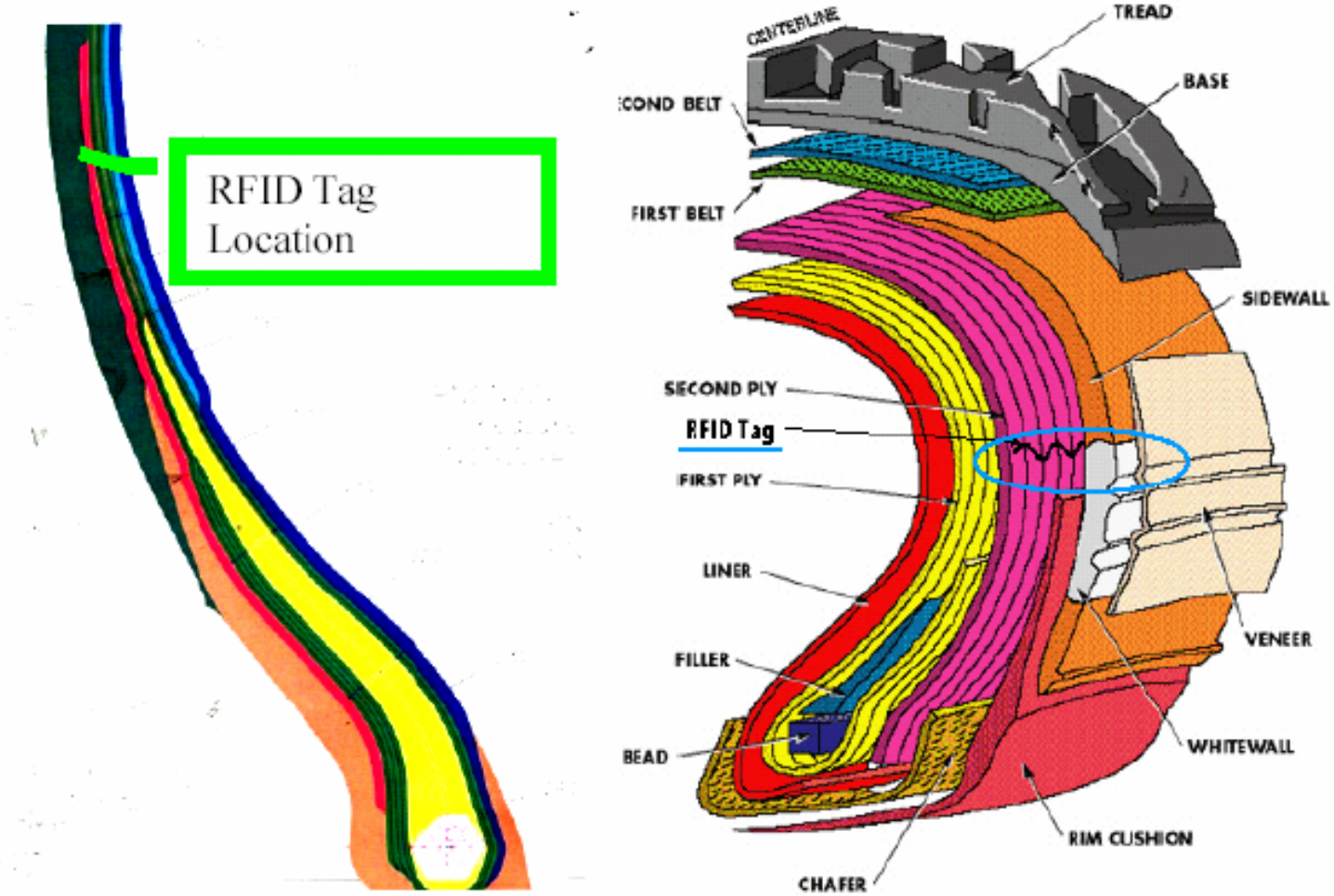




Matching can be achieved by adjusting the slot length (ls) and height (hm) and length of microstrip line (lm)

RF Tag for Tire

Placement of the transponder in the tire:



Thin Film Batteries

Main Characteristics:

•High temperature capability (-55°C ~ 300°C)

•Tested life cycle (45,000 cycles)

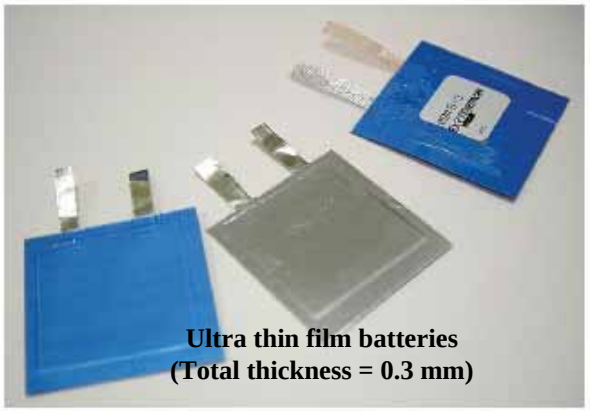
•High capacity anode: 2,250mAh/g

•Full charged voltage = 4.2 V

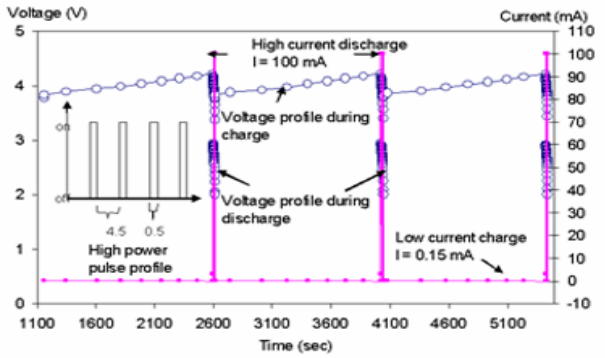
•Energy density 200 ~ 400 μW/cm2

•Life Cycle ~ 40,000

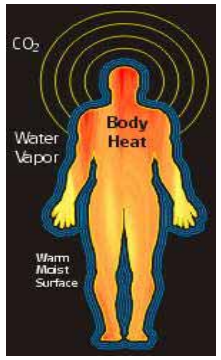
•Price < 50 cents per battery



Ultra thin film batteries (Total thickness = 0.3 mm)



Battery (0.1 mAh) discharged by a 100 mA pulse at 80°



Sources of energy in a human body

Recharging mechanisms:

Carnot system

Solar cell

RF charging trough energy collected at RFID tag

Power scavenging

Pressure →
Using a piezoelectric printed collector

Light → Printed solar cells

Temperature (human body heat) → Using a modified Carnot cycle *(projected efficiency of 50%)*

Recent Breakthroughs in Thin Film Battery

NEC

300 micron thin
No heavy metals
Environment friendly
Polymer electrolyte

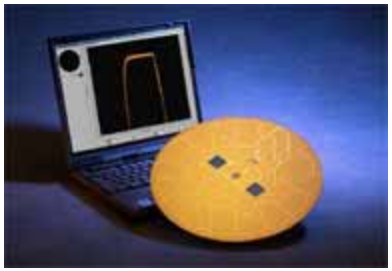
Carrier film -
Plastics

Press Release
Jan 29, 2006

Philips
Lithylene™ battery

Free form factor
Porous lithium
Polymer electrolyte

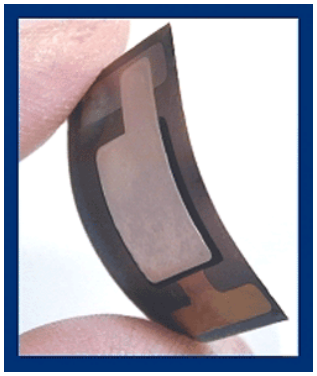
Licensed to
Stone Battery, Taiwan
March 2006

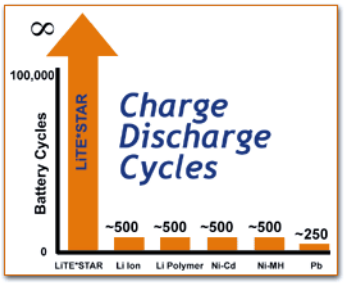


ORNL

Thin film Li battery
Flexible
Smaller
Lighter
Rechargeable
Manufacturable

Press release
Dec 21, 2005

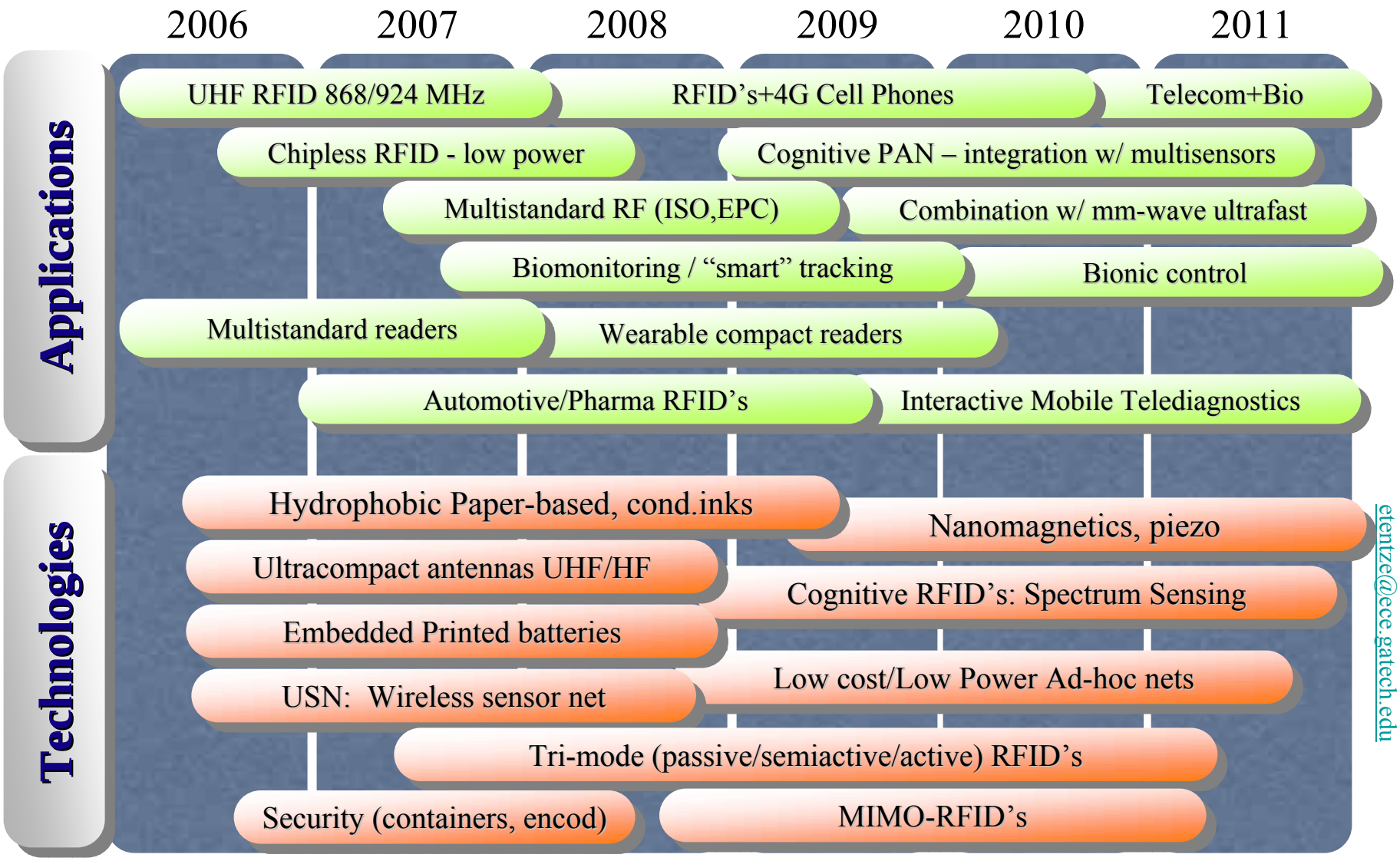




Infinite Power
Solutions
LITE*STAR

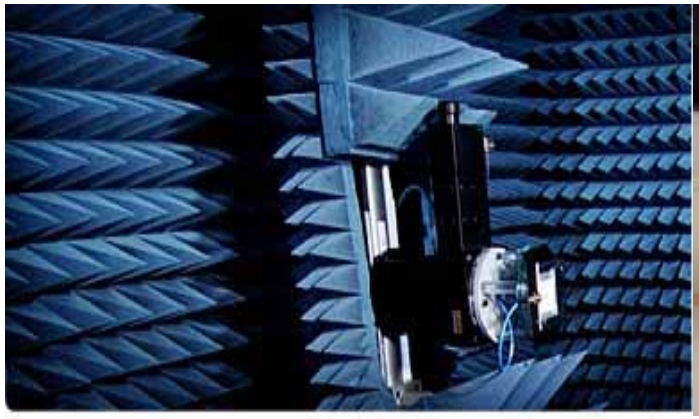
50 Micron battery
LiPON electrolyte,
Lithium anode,
LiCoO cathode
Voltage of up to 4.0 V

GEDC Roadmap: PIREAS

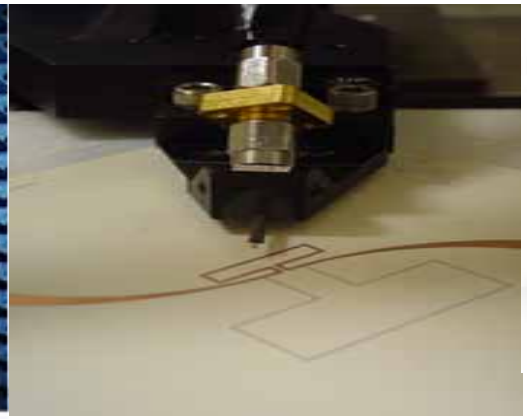


April 26, 2007 by M.Tentzeris,
etentze@ece.gatech.edu

Measurement capabilities and Testbed

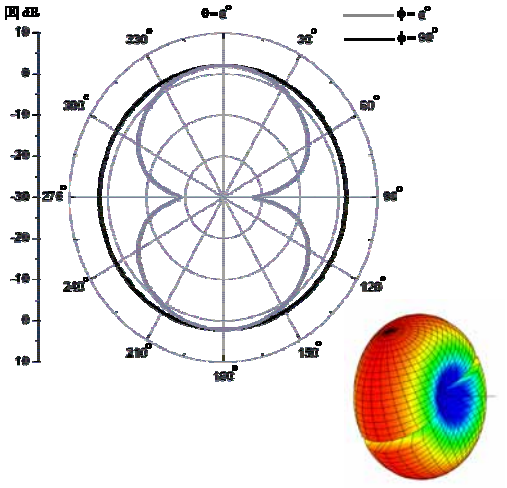


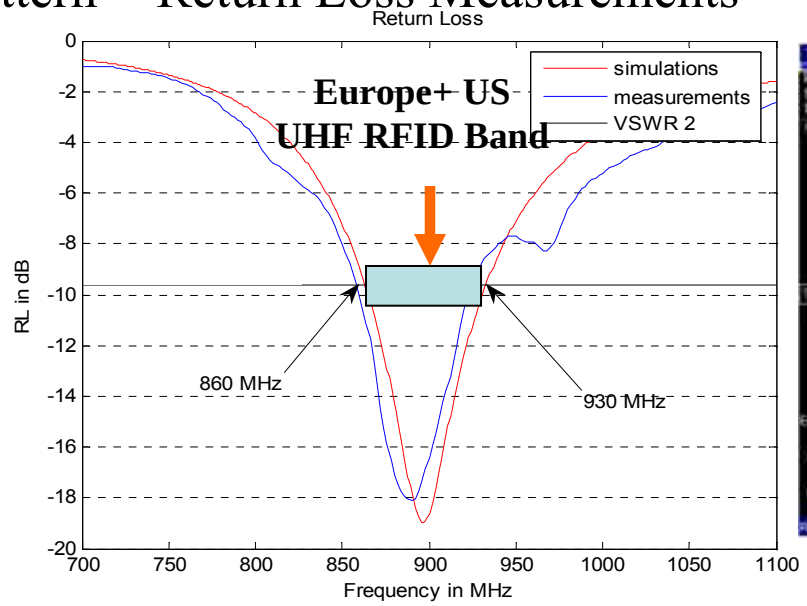
Antenna Radiation Pattern

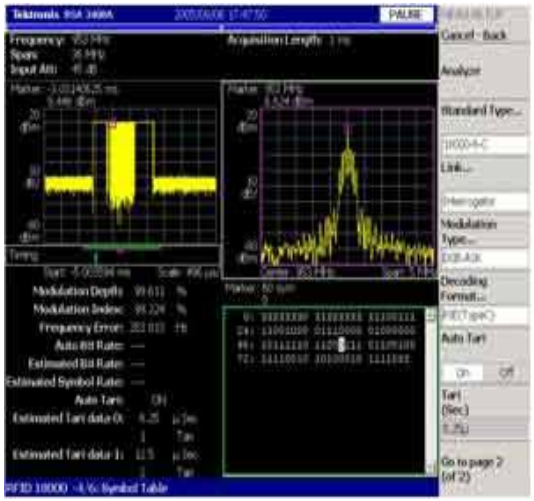


Return Loss Measurements

power/freq/time RTSA measurements







PIREAS RFID TESTBED

Active Reader (Mantis II)

XR 400 UHF Reader Kit

agile reader
(Infinity 510w)

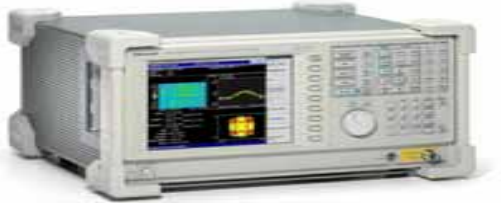
NIST standards

ZVA Vector Network Analyzer

Materials Inkjet Printer

R&S SMJ100A

HP Vector Network Analyzer



RSA3408A

Selected Operating Frequencies (1)

- **< 135 kHz (LF)**
  - Short range
  - Low data (read-) rates
  - Penetrate non-metallic materials (e.g. water)
  - Do not penetrate / transmit around metals
  - E.g. for animal identification
- **13,56 MHz (HF)**
  - ISM Band
  - Higher data rates and range (than <135 kHz-systems)
  - Penetrate non-metallic materials (e.g. water)
  - Do not penetrate / transmit around metals
  - E.g. for contactless smart cards

Selected Operating Frequencies (2)

- **860-930 MHz (UHF)**
  - High data rate / long range
  - Effective around metals
  - Do not penetrate water
  - Differences in frequency (Europe, USA, Japan)
  - E.g. for logistics
- **2,45 GHz (UHF)**
  - ISM Band (same as Bluetooth, WLAN)
  - High data rate, long range
  - Effective around metals
  - Do not penetrate water
  - E.g. for logistics

System Ranges - Classification

- **Close Coupling Systems**
  - Range: < 1cm
  - Frequencies: DC ... 30 MHz
  - Based on *inductive* or *capacitive coupling*
  - E.g. for door locking systems
- **Remote Coupling Systems**
  - Range: < 1m
  - Frequencies: 135 kHz or 13,56 MHz
  - Mostly based on *inductive coupling*
  - E.g. for contactless smart cards
- **Long Range Systems**
  - Range: > 1m
  - Also known as *backscatter systems*
  - Frequencies: 860-930 MHz or 2,45 GHz
  - E.g. for logistics

GEDC RFID

Applications

-Healthcare and pharmaceutical applications
-access control
-sensor and metering applications
-payment systems
-communication and transportation
-parcel and document tracking
-distribution logistics
-automotive systems
-livestock or pet tracking

PIREAS RFID/Sensors Lab

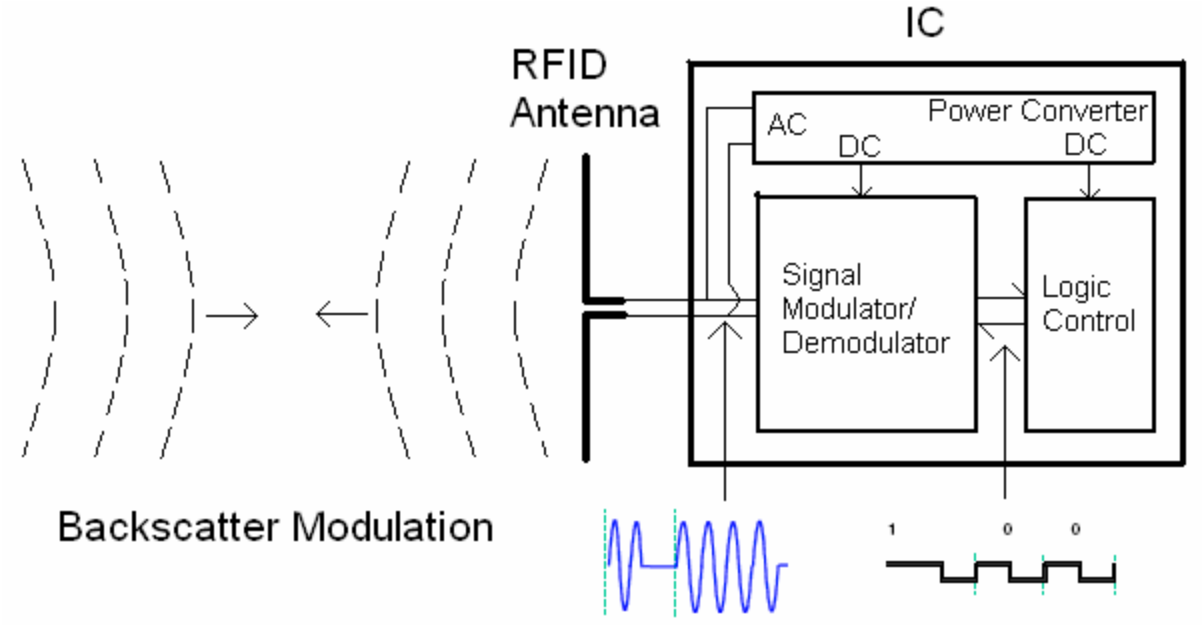
❖**Sensor applications:**

- Temperature (such as ambient temperature)
- Pressure (such as environmental, objects such as tires)
- Chemical/Biological detection
- Monitoring environmental conditions
- Tracking movement (e.g. livestock)
- Flood and fire detection

Military:

- Battlefield surveillance (wearable electronics)
- Gravitational and inclination (such as helicopter altitude detection, measuring inclination for parachute drops)
- Remote sensing (such as passive miniature unattended ground sensors)
- Biological and chemical attack detection

RFID Transponder

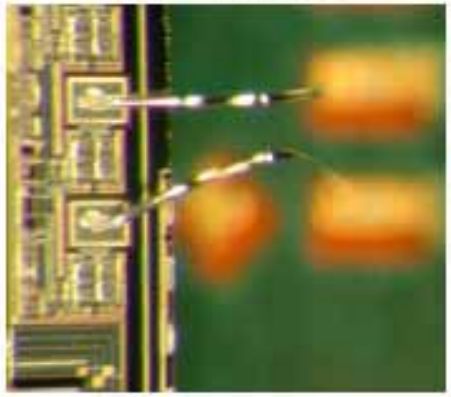


- Antenna Bandwidth = ~ 860-960 MHz (Universal Comm. regulations)
- IC Communicates using UHF Gen-2 Protocol
- Communication data rate from 4 to 640 kbps (Depends on bit encoding used)

RFID IC Integration Techniques

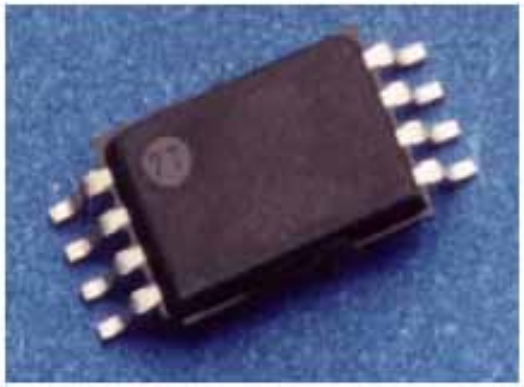
(Source: Ansoft, TI)

Bondwires

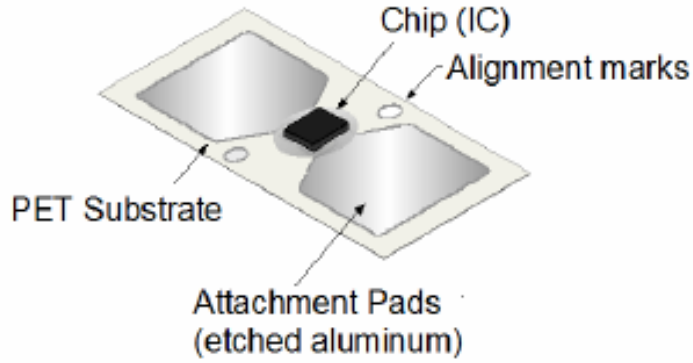


Flip Chip

TSSOP

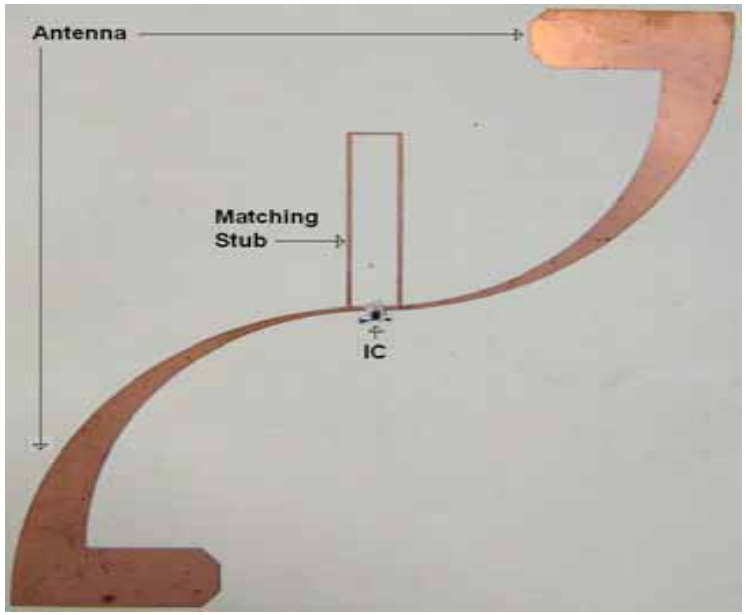


IC Strap

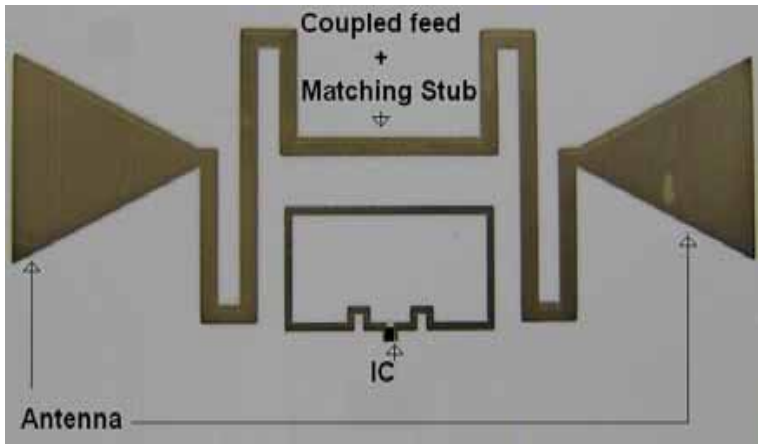


More RFID Tag Prototypes

- S-Shaped Dipole
  - IC Assembly: solder bump flip chip
  - Omni directional radiation pattern



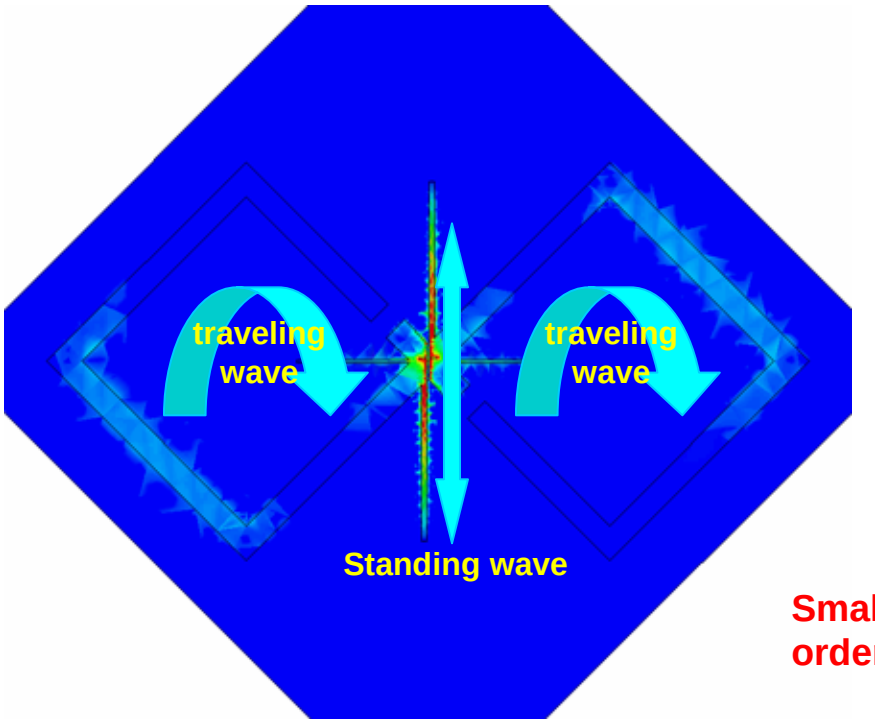
- Coupled Feed Dipole
  - IC Assembly: Surface mount soldering technique
  - IC Package: TSSOP



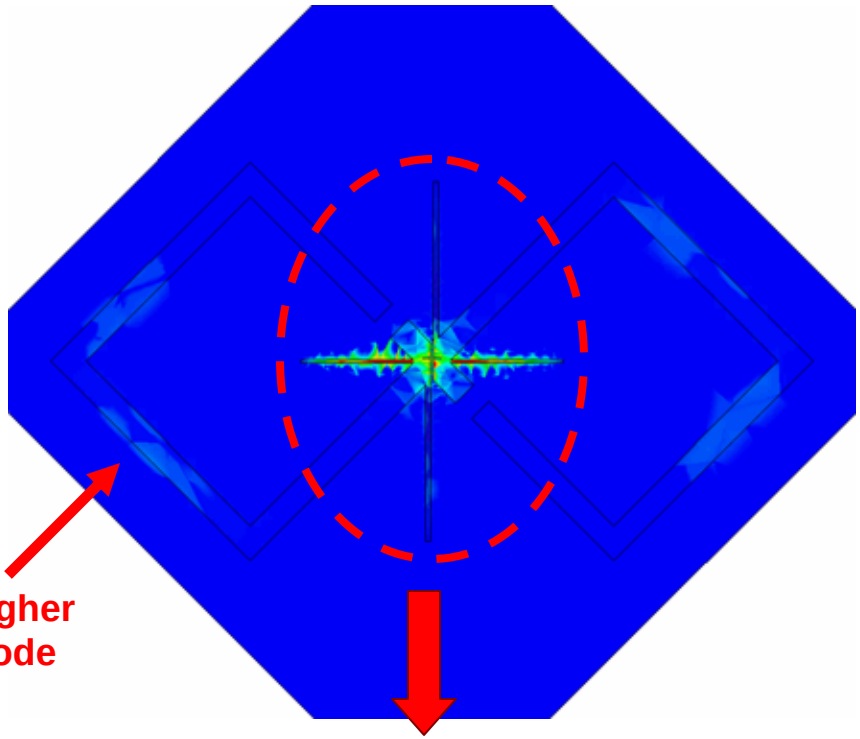
Current Distribution

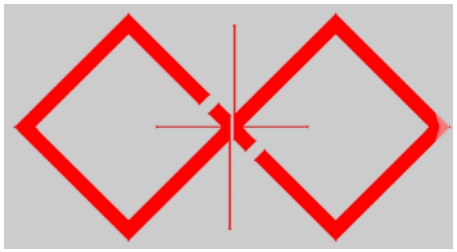
Surface Current Magnitude

At 433 MHz

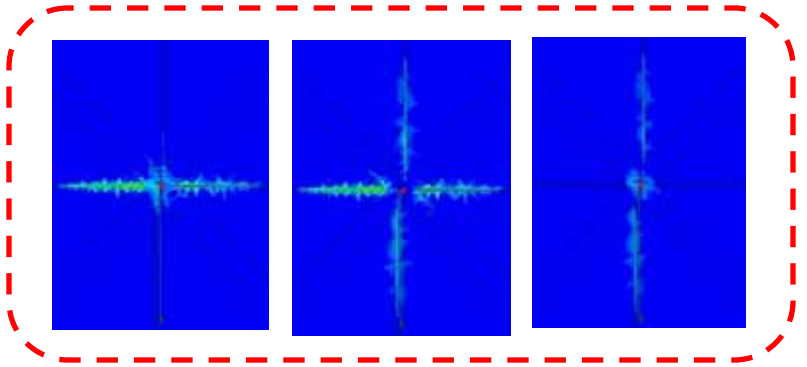


At 910 MHz





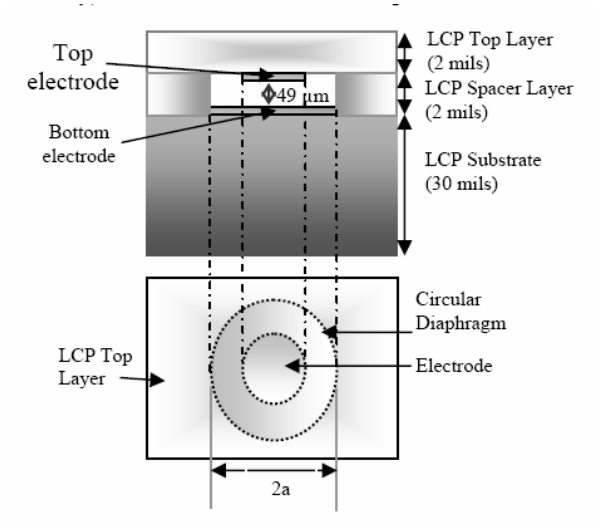
With the cross dipole, there is less cross talk as opposed to using a parasitic loop to cover the 910 MHz band



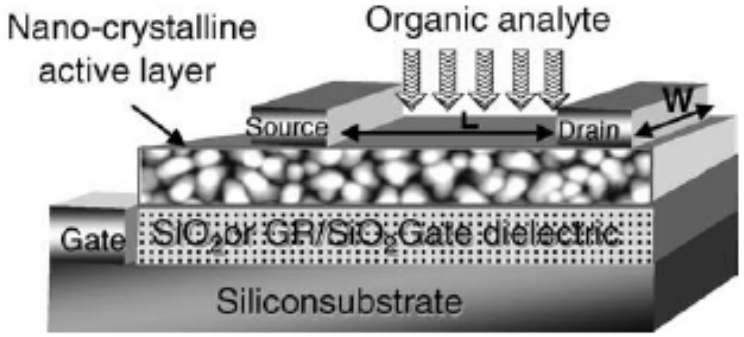
Integrated Sensors in RFID tags

Possibilities:

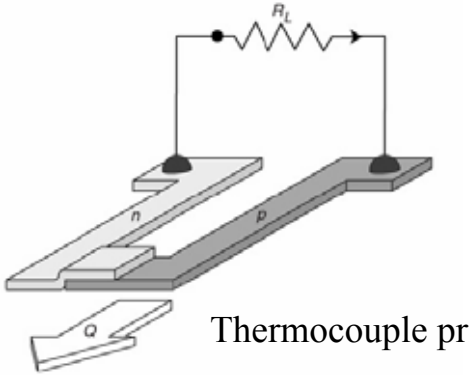
- **Pressure sensors** on organic material (Liquid Crystal Polymer)
- **Temperature sensors** using printed thermocouple pairs
- **Chemical sensors** using organic thin-film transistors (OTFT)



Pressure sensor on LCP principle



Chemical sensor OTFT principle



Thermocouple principle