Mobile and Ubiquitous Computing

RFID Basics

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Overview

- RFID principle(s) of operation
- Components of a tag and a reader
- Coupling effects
  - Near and far field coupling
- Air interfaces and modulation
- Characteristics of each type

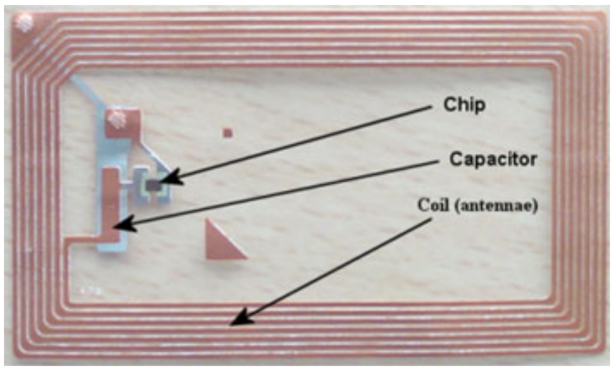
RFID Basics

- From now on we consider **passive** RFID only
- RFID uses wireless to
  - transmit energy and
  - for communication
- RFID systems are asymmetric
  - Reader or interrogator: provides energy and controls communication
  - Tag: draws energy and responds to reader

RFID Basics

- AC oscillation at the end-points of an antenna creates magnetic and electric fields
- RFID uses these fields to transmit energy and for communication
- Depending on which field is used and how the transmitted energy is used we get different types of RFID systems
  - HF and UHF the main focus in this module

Tag components

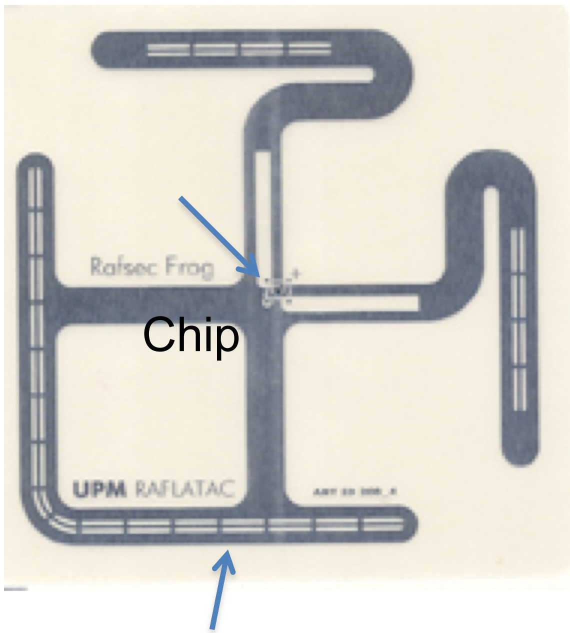


Tag internals

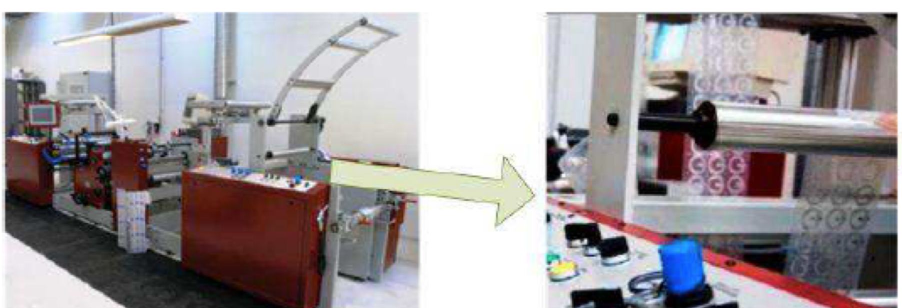
Typical polymer enclosure

- Antenna (different types according to coupling method used)
- Chip (for passive tags this is a simple state machine)
- Capacitor (to store transmitted power)
- Enclosure

Printable RFID tag



Printed antenna



- Antenna printed by ink-jet type printer (screen or rotarry printing)
- Mixture of silver and carbon
- Far more cost efficient to welding

Tag composition

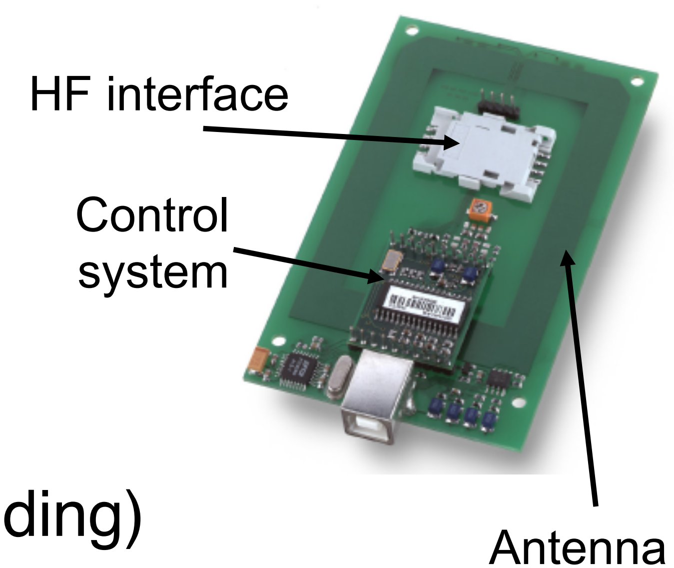
Material stack-up

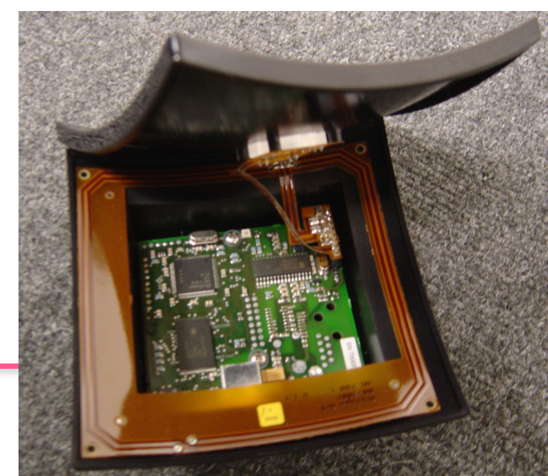
Layer	Name	Material	Comment
	Face stock		ISO9706 compliant
	Adhesive		pH neutral, permanent
	Chip		
	Antenna	Aluminum	
	Substrate	PET	
	Adhesive		pH neutral, permanent
	Liner	White Glassine paper or equivalent	

Source: Tagsys AK tag product specifications

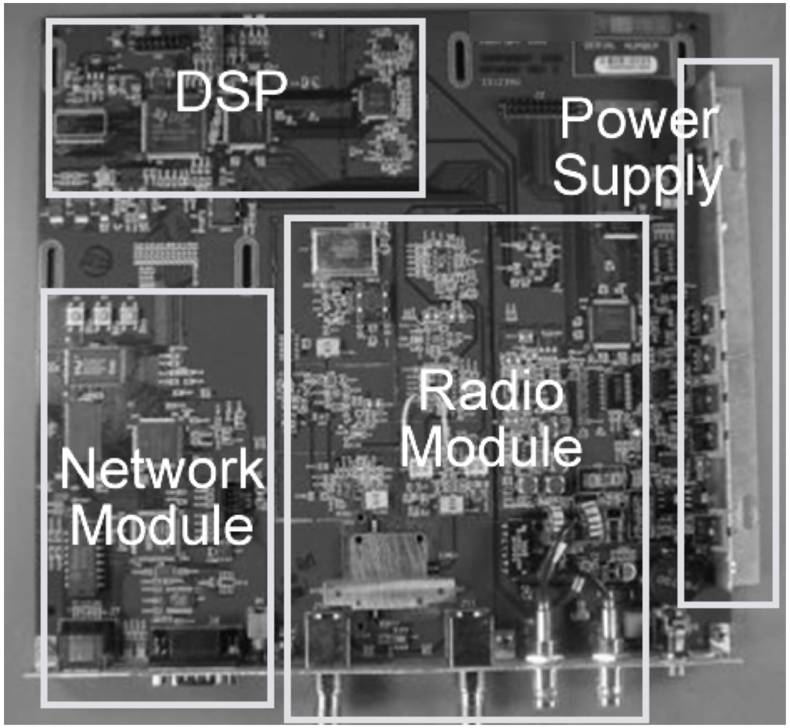
Reader components

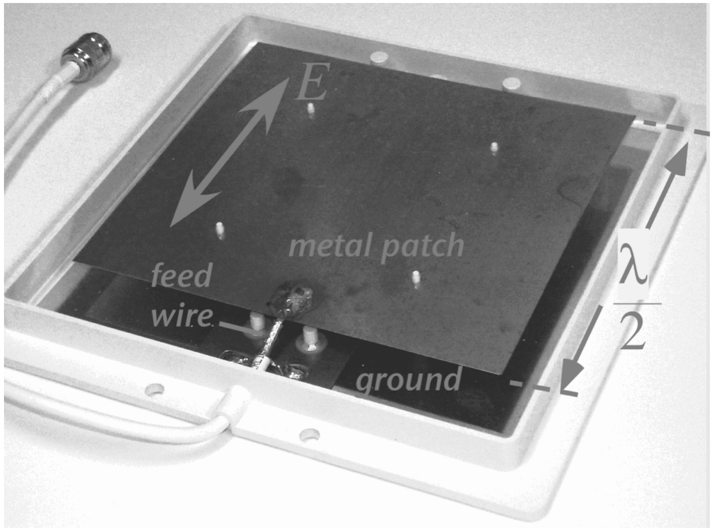
- HF interface
  - transmitter/receiver
  - separate pathways
- Control system
  - microcontroller
  - ASIC module (crypto, signal coding)
  - network module
- Antenna
  - integrated/external
  - one or many

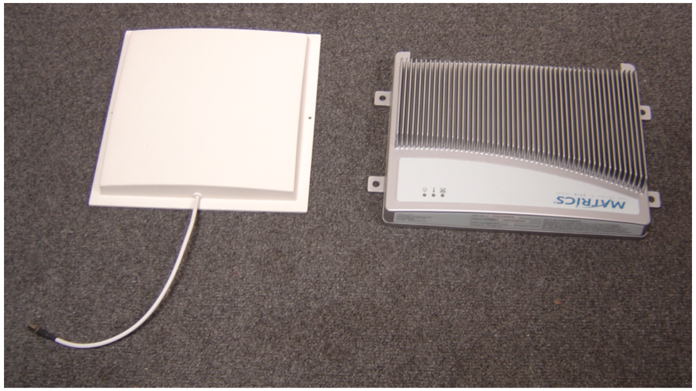




UHF Reader and antenna







Component roles

- High-frequency interface
  - generates transmission power to activate tag
  - modulates transmission/demodulates tag signal
- Control system
  - control communication with tags
    - anti-collision, data crypto, authentication
  - signal coding and decoding
  - interact with network services
- Multiple antennas are seen as one (cf. tag orientation issues later)

Near and Far Field

- <100Mhz magnetic, inductive or near-field coupling
  - Near field means that the wavelength is several times greater than the distance between the reader and tag
  - Examples: 128 kHz and 13.56 MHz
  - Same principles as the transformer
  - Electric component is not involved
- >100Mhz capacitively or far-field coupling
  - Examples: 915MHz and 2.45 GHz
  - Same principle as the Radar
  - Magnetic field is not involved

Active versus Passive

- Power to operate the chip
- Active tags:
  - Use battery to power up the chip
- Passive tags:
  - Power up using the coupling effect
  - Essentially the reader transmits power used by the tag
- Semi-passive tags
  - Use battery to operate the chip
  - Antenna optimized for data transmission

Active Tags

- Advantages
  - Transmit at higher power levels
  - Longer range
  - More reliable communication
  - Can operate in challenging environments (e.g. around water)
  - Can have additional sensing capability (e.g. temperature)
  - Can initiate transmissions
- Limitations
  - Stop when their battery expires (10 years at best)
  - More expensive
  - Larger size (to accommodate the battery)

Passive Tags

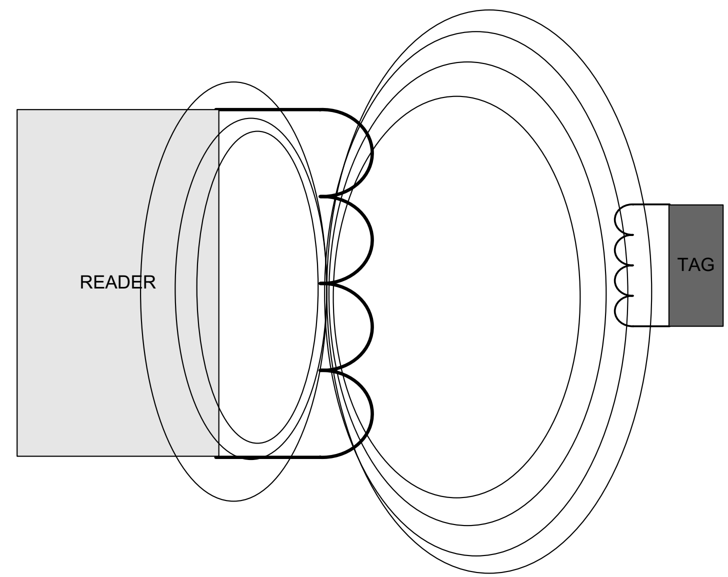
- Advantages
  - Low cost
  - No battery, so they do not expire (unless damaged)
  - Small size
  - Increasingly printable
- Limitations
  - Restricted processor, memory and communications
    - Functionality has to be offloaded to the network
    - Limited capability to protect themselves
  - Only operate in the vicinity of readers
  - Harder to operate in harsh environments

Passive Tag Implications

- Manufacture at less than 5 cents per tag by 2010
  - not counting royalties and other IPR!
- Major interest in logistics
  - industry backing
- Massive investment by semiconductor industry
  - rapid progress on many fronts
- Key idea:
  - store only a Universally Unique Identifier in the tag
  - carry out all related processing on the network

Near Field Coupling

- Employs magnetic induction
  - Same idea as the transformer
  - Coil-shaped antenna
- AC at coil->current at antenna
- Charge stored in tag capacitor
- Powers up chip
- Tag changes impendence at coil affecting current drawn by coil
- Reader decodes change via the potential variation in its resistance
- Process called load modulation



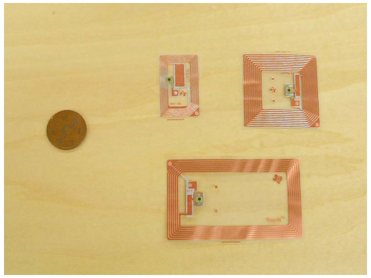
Near Field Coupling

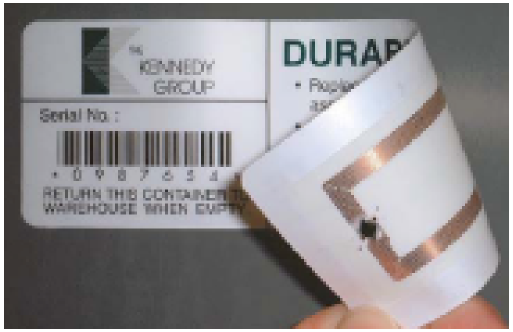
- Coils of reader and tag separated in space
- Coupling requires that magnetic field of reader intersects the tag coil
- This is the near field of the EM field created by AC oscillation
- Strength of field falls proportionally to $1/d^3$
  – center of reader coil to tag

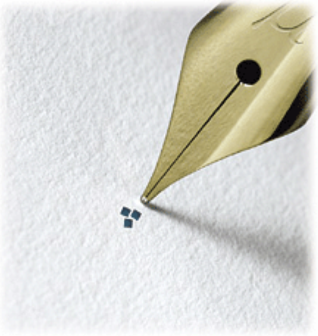
Near Field Coupling

- Size of field depends on frequency of current and limited within $2D^2/\lambda$
  – after this, the far field starts
- Examples:
  – ISO 14443 operates at 13.56MHz, NF is 3.6 meters
  – UHF 915Mhz NF is 6cm
- Larger antennas can help
- In practice most systems work in 1-30cm range

NF Tag examples

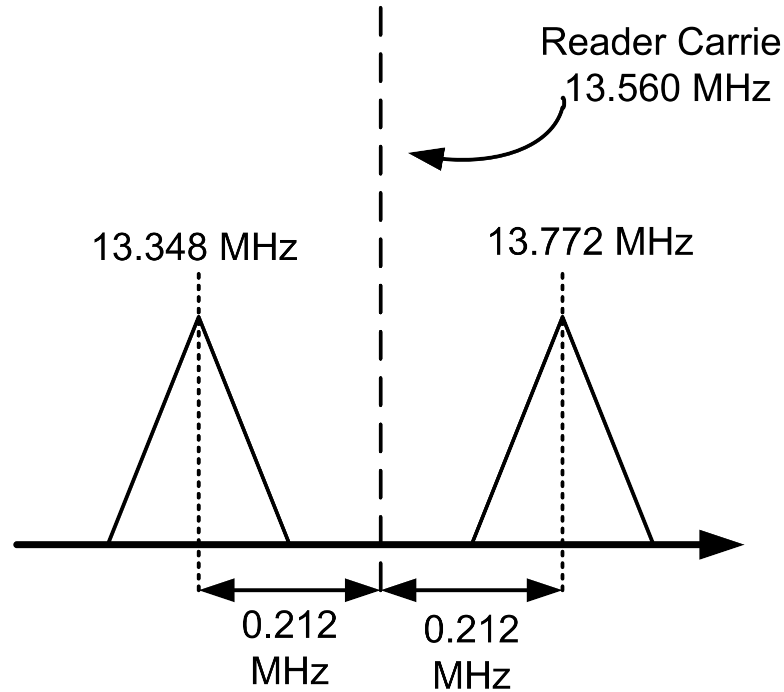






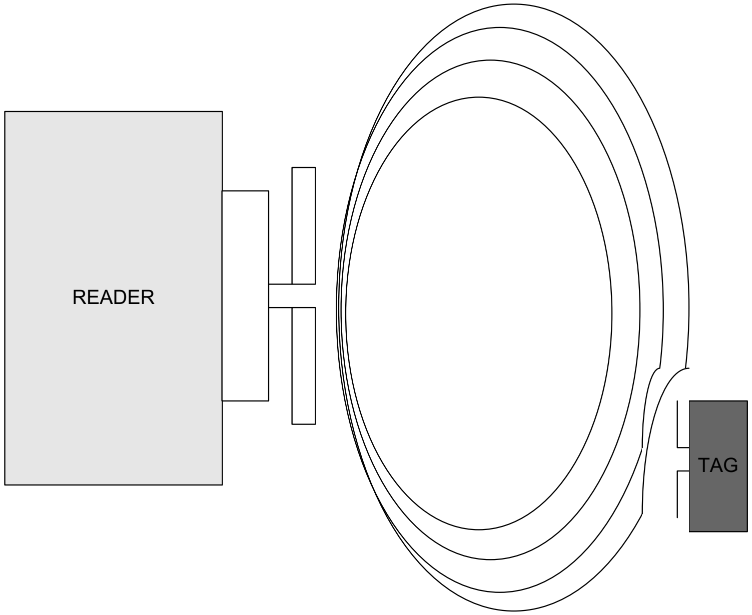
Communication with load modulation

- Voltage fluctuation at reader antenna as result of tag resistor change is tiny
  - e.g. 100V reader to 10mV signal
- Detecting this signal is a problem
- Load modulation using the subcarriers is one solution
- Load resistor of transponder switched on/off at frequency f_s then two spectral lines at $f_r \pm f_s$
- Data transmitted using this frequency



Far Field Coupling

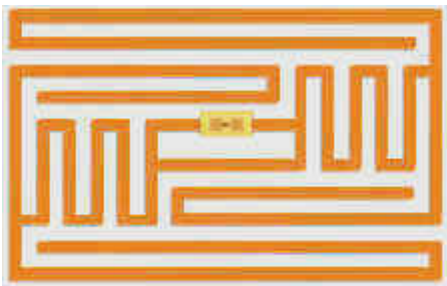
- Antenna is a dipole
- RF backscatter rather than induction
- Backscatter: reflect back some part of reader RF signal
- Reader decodes reflections as variation in amplitude
- Reader must have very sensitive receiver:
  - energy attenuation reduces by $1/d^2$
  - so reflections $1/d^4$ of original power
  - d separation of tag and reader

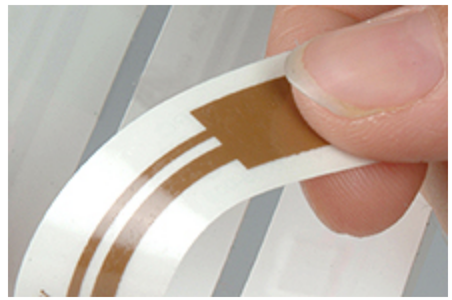


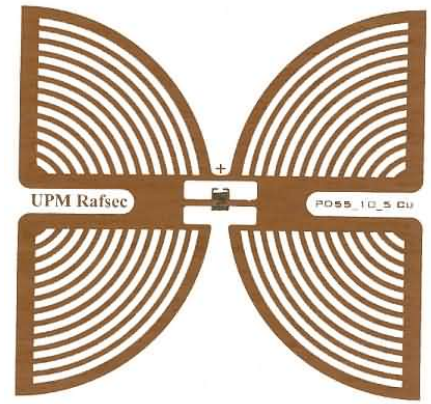
Far Field Coupling

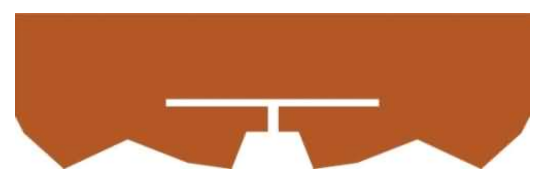
- Backscatter is the radar principle
  - electromagnetic waves are reflected by objects greater than ½ of the wavelength
- *The reflection cross section (*the signature of the object) can be modified by altering the load connected to the antenna of the tag
  - switching the tag resistor on and off creates the data stream
- Effective range of reading is typically 3-4 meters
- Reader sensitivity one microwatt
- Tags benefit from Moore's law
  - less energy needed to power up the tag

FF Tag examples









Tag orientation effects

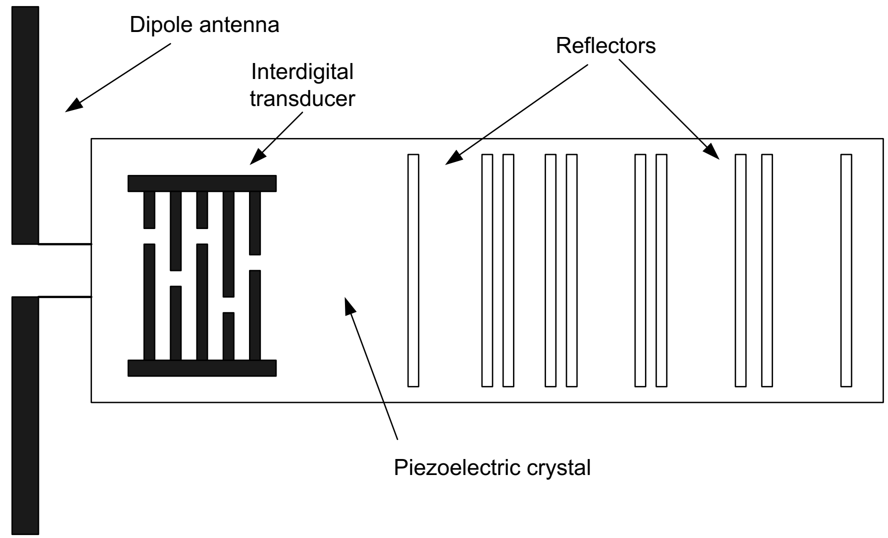
- Alignment of tag antenna is second most important factor in effectiveness (after distance)
- In either near field or far field systems tag must NOT be perpendicular to reader antenna
  - Tag fails to be read
- (Partial) solution to this problem:
  - Antenna design or many antennas with different alignments
  - Multiple readers (but beware of reader collisions)

Influence of Objects and Environment

- Inductive systems
  - Unaffected by dielectric or insulator materials e.g. paper, plastics, masonry, ceramics
  - Metals weaken the field (depending how ferrous they are)
  - May also detune tags if they work at a resonant frequency
- Electric
  - Can penetrate dielectric material
  - Water molecules absorb energy
  - Metals reflect or scatter and can completely cloak tag
  - Tag on tag effect are also very strong in higher densities

SAW Tags

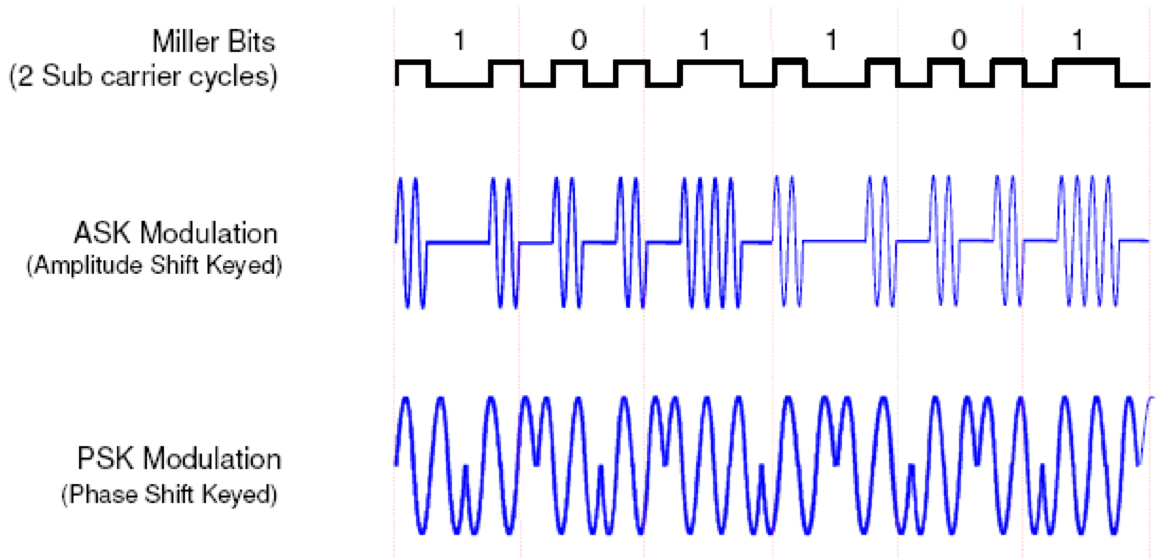
- Surface acoustic wave
- Reader scanning pulse (2.45 GHz) into IT and converted into acoustic wave
- Reflectors bounce back creating unique signature due to their arrangement
- IT converts back to pulse (one pulse per reflector)
- Transmitted to reader



UHF Gen 2 Tags

- 860-960 MHz UHF
  - Europe 865.6-867.6 MHz
  - N. America 902-928 MHz
  - Japan 952-954
- Listen before you talk
- Dense reader installations
- 2-3.28W (effective)
- 500-1500reads/s

Modulation and encoding



- Reader to tag:
  - Modulation: ASK
  - Encoding: Pulse Interval
  - Bit Rate: 26.7 to 128 Kbits/s
- Tag to reader:
  - Modulation: ASK or PSK BACKSCATTER
  - Encoding: FM0 Baseband (40 to 640 Kbits/s)
  - Miller Sub-carrier (5 to 320 Kbits/s)

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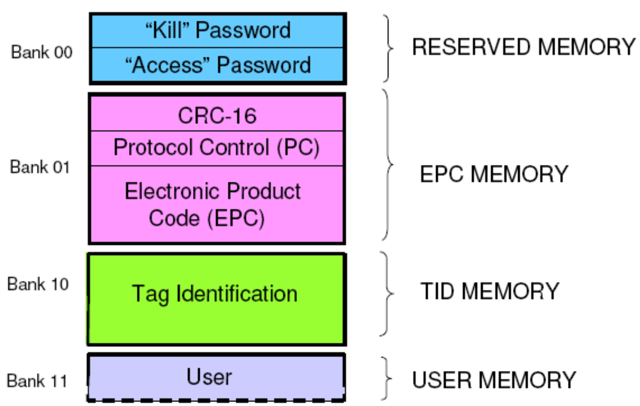
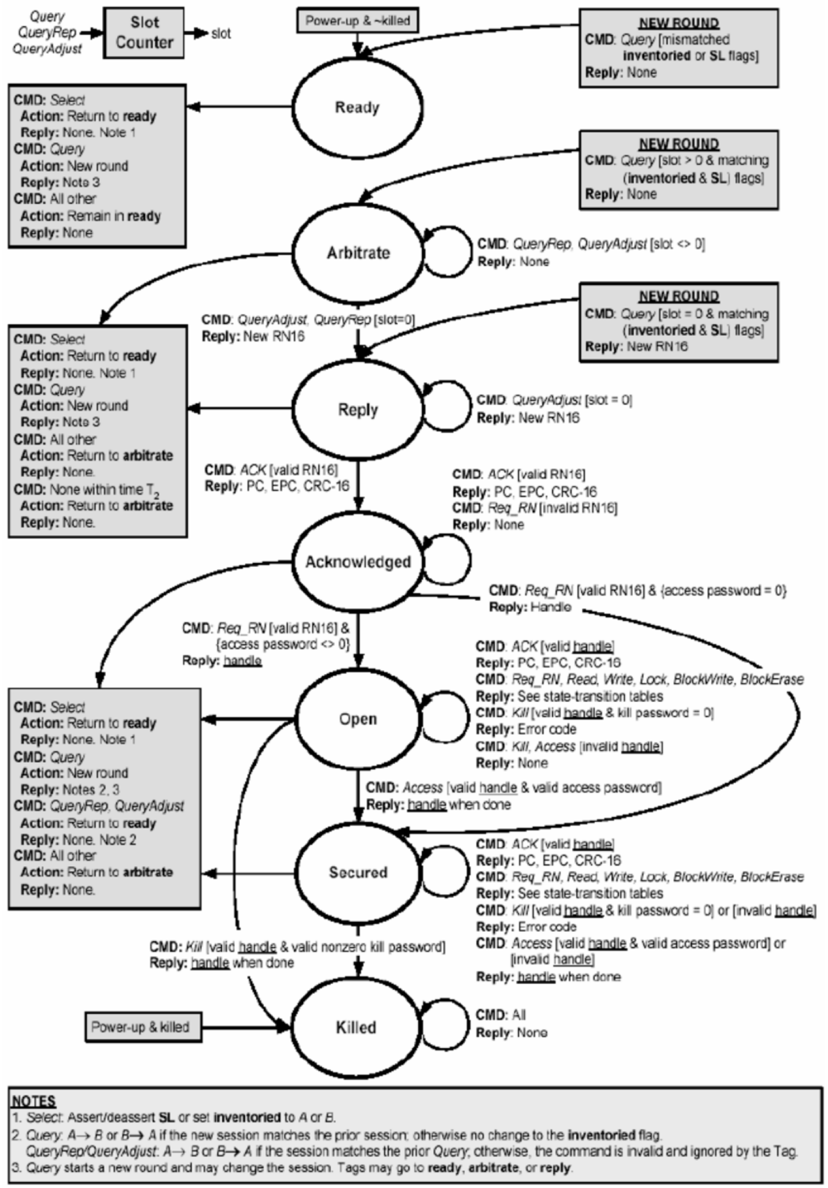
Memory structure

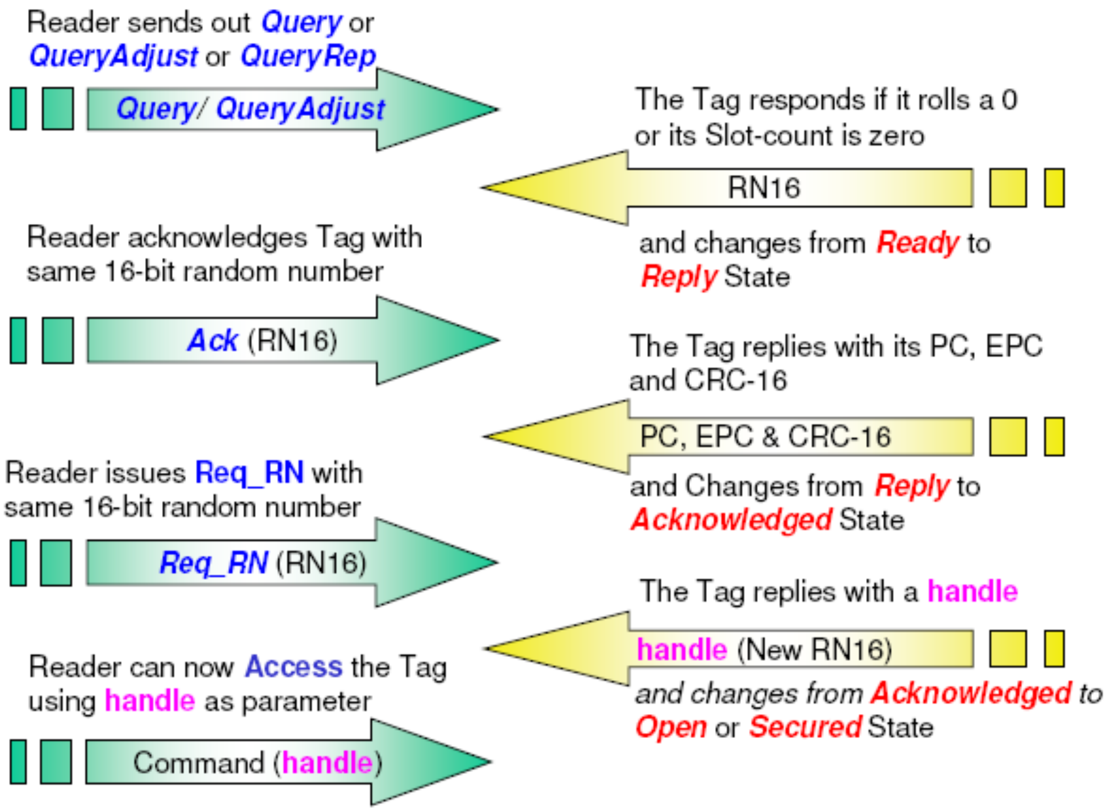


- Reserved: kill and secure passwords,
- EPC: CRC(16), PC and EPC
  - 5-bits giving the length of the PC + EPC
  - 2-bits RFU (always zero)
  - 9-bits for a Numbering System Id (NSI)
    - Which may contain an EPCglobal™ header
    - or an AFI as defined in ISO 15961
- TID and USER covered

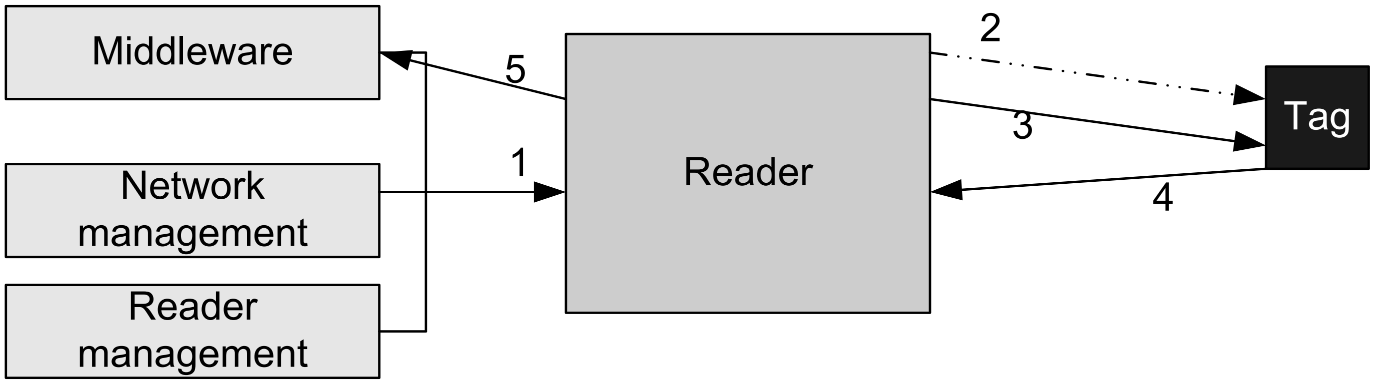


From: EPCTM Radio-Frequency Identity Protocols Generation-2 UHF RFID

Tag states


Reader sends out Query or QueryAdjust or QueryRep
Query/ QueryAdjust
The Tag responds if it rolls a 0 or its Slot-count is zero
RN16
and changes from Ready to Reply State
Reader acknowledges Tag with same 16-bit random number
Ack (RN16)
The Tag replies with its PC, EPC and CRC-16
PC, EPC & CRC-16
and Changes from Reply to Acknowledged State
Reader issues Req_RN with same 16-bit random number
Req_RN (RN16)
The Tag replies with a handle
handle (New RN16)
and changes from Acknowledged to Open or Secured State
Reader can now Access the Tag using handle as parameter
Command (handle)

Sequence of events



1. reader configured with operational parameters
2. reader creates field that powers up the tag
3. reader initiates communication
4. tag responds
5. information returned to middleware/applications after possible additional processing step

Types of tags (by frequency)

Band	Frequency	Use
Low Frequency (LF)	120-135 kHz	Short range applications
High Frequency (HF)	13.56 kHz	Worldwide frequency available to smart cards and labels
Ultra High Frequency (UHF)	433 MHz 860-950 MHz	Active low power tags Supply chain
Microwave	2.45 GHz	Active tag technology gives range and fast data rates.

LF Tags

Data capacity	Low to High	64-bit read-only up to 2kbit read/write
Read-write	RO/RW	Both types available
Data transfer	Slow	Typical less than 1 kbits/s and may be as low as 200 bits/s (e.g. 0.5 second per tag of 96-bits at 200 bits/s)
Range	Low	Up to 0.5m for passive tag systems Up to 2m for active tag systems
Readability	Low	Single read and anti-collision systems available.
Form	Varied	Operating temperature typically -40 to +85^{O}C 5-10 cm^3 active and 2-5 cm^2 passive
Costs	Varied	Best suited to ratios of 30 tags per reader
Applications		Manufacturing support, large vehicle and container identification, access control, animal identification, proprietary

HF Tags

Data capacity	High	Passive RW from 512 bits (often with a 64-bit factory set UID) to 8kbit (in addressable sectors)
Read-write	RO/RW	Both types available
Data transfer	Medium	Typically 25 kbits/s but commonly in excess of 100 kbits/s (e.g. 40 tags in 0.1 sec for 512 bit tags) Error checking built into protocols in some cases (lower effective)
Range	Low	Up to 1.2m for passive tag systems Up to 1.5m for EAS applications
Readability	Low	Anti-collision systems for about 40 tags per reader
Form	Varied	Operating temperature typically -25 to +70^{O}C Typical 10 cm^3 active and 10 cm^2 passive Flexible or rigid substrates, industrial hardened
Costs	Varied	Depends on form factor, but currently about 75 cent
Applications		Parcel tracking and services, airline baggage management and reconciliation, library systems and rental services, laundry services and logistics

UHF Tags

Data capacity	High	Active-passive between 32 bits to 4 kbits
Read-write	RO/RW	Both types available
Data transfer	Fast	Typically 40 kbits/s but can be in excess of 256 kbits/s (downlink up to 160)
Range	High	Up to 7m for read (or 6.5 in Europe) Up to 5m for write
Readability	Low	Anti-collision systems for about 100 tags per reader (reported 1000)
Form	Varied	Operating temperature typically -40 to +65^{O}C Typical 1-2 cm^3 active and 10 cm^2 passive Flexible or rigid substrates, industrial hardened
Costs	Medium	Depends on form factor (target is 5 cents but currently about 25)
Applications		Asset tracking, supply chain

Microwave Tags

Data capacity	High	Active-passive between 128 bits to 32 kbits (partitioned)
Read-write	RO/RW	Both types available
Data transfer	Fast	Typically 100 kbits/s but can be in excess of 1 Mbits/s
Range	High	Up to 30m for read (typical 5m) About 1m for writes
Readability	Low	Advanced anti-collision systems
Form	Varied	Operating temperature typically -25 to +70^{O}C Typical 1 cm^2 passive
Costs	High	Depends on form factor (relatively high)
Applications		Fast moving vehicles, factory automation, access control, road tolling and supply chain and military logistics.

Summary

- RFID principle of operation
- Passive and active tags
- Components of a tag and a reader
- Coupling effects
  - Near and far field coupling
- Air interfaces and modulation
- Characteristics of each type
- Trade-offs