RFID Technology Evolution, Applications, and Trends

TRB Research Initiatives in RFID
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Washington DC
• RFID Technologies & Evolution
• Current Application Areas
• Trends
RFID Typical Practical Goals

- No battery or long battery life – years
  - Aftermarket Automotive or other uses
- Secure ID number storage & reading
  - Factory programmed and locked
  - Vs. Authentication of tag and/or reader
- Small scratch-pad read-write memory for systems where back end communications cannot be assured. Read-only is often viable.
- Tag Communications correlated to item/vehicle
  - Unagged item/vehicle identification
- FCC Regulatory Approval & Frequency Rules
Typical Transportation Requirements

- Accurately Read vehicle Toll Tag
  - <5 in 10,000 misses = >99.95% success rate
  - <1 incorrect number in 10,000,000 transactions
  - Avoid shadowing, cross-lane reads, out of sequence reads, duplicate transactions
  - Handle bumper-to-bumper traffic and open road

- Lane Controller verifies Tag Status and lights Traffic Signal or tag light – Account OK or Low?

- Do not stop! Safety First.

- Replenish tag/account elsewhere/automatically
History of RFID – See Shrouds of Time by Dr Jeremy Landt, AIM Pub

- IFF Radar 1939
- Article Surveillance 1 bit 1960’s
- Lab & Commercial interest 1970’s
- Animal ID 1970’s
- Automatic Vehicle ID – AVI
  - Golden Gate Bridge 420 KHz 1972
  - Lincoln Tunnel 1973 three other technologies
- Rail 1980’s-Long Island RR & AAR Test Track
- Trucking – Arizona & HELP project late 1980’s
Recent Timeline

1987
- Basic BackScatter Protocol for transportation applications

1988
- First ETC System in North America goes live

1990-1992
- Read-write Backscatter and Active RFID technologies

1991
- First large Scale Transportation Asset management system using RFID - AAR

1994

1996
- Development of Single Chip backscatter solutions for general applications

1997
- First Open Road Electronic Toll Collection System

1999
- First Fully Automated mCommerce System

2000

2002

2003- Present
- Multi-protocol reader and High Speed passive read-write tags for Transportation Applications
Technologies used for RFID communication

- Radar – Modulated Backscatter - CW
  - Unsynchronized Tag Response
- Pulse/Field Trigger – LF or UHF RF or IR
- Addressed Data Modulation - Commands
  - Subgroup Requests & Sorting
- Tag response – MB, FSK, AM, OFDM, BPSK, QPSK, QAM
  - Some Frequency Doubling Systems LF & UHF
- Swept Frequency or Frequency Hopping
  - Often for Higher Power Unlicensed Operation
- UWB Ultra Wideband 5.8 to 7.2 GHz
- Horizontal or Circular Polarization
Technologies used for RFID Circuits

- **SAW – Surface Acoustic Wave**
  - Reflector Positions form ID
- **CMOS UHF RF powered - IF only**
  - Passive or semi-active battery assist – Single Chip
- **Low Frequency Inductive powered**
  - With UHF communication
- **Full active receiver and transmitter**
  - Sleep cycles and wakeup
  - TDMA
- **Complex integrated circuits for 802.11a-like OFDM – powered by vehicle**
MB technique is the basis of many toll & supply chain systems in US and Europe (5.8 DSRC).

- CW transmitter
- Tag often operates over many frequencies
- Transponder (tag) provides identification via modulation of backscatter reflection
  - RF interrogation field powers the microwatts needed for tag operation
- Antenna Keyed In and Out of Circuit at data rate
- Homodyne Receiver in Reader—Transmitted signal mixed with reflected signal to immediately convert to base band IF signal
Typical Technology Development

- Basic Techniques demonstrated
- Commercialized early application
- Standards – de-facto or Standards Org
- Higher Data Communication Speed
  - Multi-protocol readers
- More memory
- Read-Write on the fly
- Display or Lights Feedback
- Authentication
Radio Frequency ID Systems Diagram:

- HOST (Tag ID Communication)
- Antenna
- Tag
- Reader
- RF Module

(lane controller)
RFID Challenges

- Antenna Coverage Volume
- Polarization / Orientation of tag
- Minimizing metal / conductive shielding
- Poor Mounting causing Failed Writes or Reads
- Minimal Time in Antenna Pattern
- Achieving useful Data Rates in error-prone RF
- RF Interference
- Null Zones or Long Range Reflections
- RF Power Levels – sufficient but not too high to properly locate tag, match to sensed vehicle
- Tag power consumption – Battery Life
RFID Applications

- Item ID: Retail, Conveyor line, Process Control
  - Tag carrying item characteristics / contents
- Item Location and Surveillance
- Container Door Security, Alarm, Temp. and ID
- Building or Border Access Control
- Vehicle Access Control or Toll Collection
- Smart Card Payment
- Location Signposts – Rail or Buses, AVL
- Traffic Management – Weigh Station Bypass
- Safety Communications
- Information Download or Upload
Harold the Tagged Animal  ~1976
Toll and Traffic Management

- Cash free, card-free, and hands-free operation for patrons
- High accuracy - Revenue collection transactions
- High reliability, Traffic throughput and congestion avoidance
- Harsh environments - External and extremes
Tag Capabilities – Generalized

◆ **Read-Only Rail Standard**
  - 120 bit, 13 ms.+read, 20/40 KHz, Sub-bit encoding for effective data rate ~9600 baud
  - Band: 902-904, 909.75 to 921.75MHz
  - Read Range 5 - 25 feet
  - 80 mph

◆ **Read-Write Toll**
  - 128 to 256 bits, Triggered Read 500 Kbaud
  - 100+ mph
  - Reader or Controller determines what to write to specific tag before it exits antenna zone
AEM Automatic Equipment Monitoring

- Rolling Stock/Container Readers
Single Chip Sticker Tag – Used in Supply Chain and Toll Collection

- Single Integrated Circuit
- High Performance
- UHF Frequency
- Beam Powered – No Battery
- Read/Write capable
  - Extended memory
- Beam powered – No Battery
- Requires proper commands to cause tag to respond via backscatter
Unusual Tags & Applications

- Waterproof External / License Plate / Pavement
- High Temperature - Thaw Shed
- Bullet Proof – slot antenna
- Modem Tag
- Tire ID
- Sensor Tag
- Tamper Resistant Tag
- Display Tag
- Smart Card
- Runner ID & Timing
- Multi-band operation around World
American DSRC WAVE 5.9 GHz

- Digital Short Range Communication
  - Wireless Access for Vehicular Environment
- FCC Allocation & Regulations 90.379
  - 7 each 10 MHz channels (combine some to 20 MHz)
  - OFDM-Orthogonal Freq. Division Multiplexing
  - 802.11a – at twice the symbol length/half bandwidth
    - Needed for multi-path ISI (inter symbol interference) minimization
  - ASTM E-2213 Physical/MAC Layer Standard
- IEEE standards for higher layers 802.11p
- Auto Manufacturers researching incorporating into vehicles for Safety Communication
ACCESS CONTROL
PROBE DATA COLLECTION
TRAFFIC INFORMATION
TOLL COLLECTION
GAS (FUEL) PAYMENT
DRIVE-THRU PAYMENT
  PARKING PAYMENT
  FAST FOOD PAYMENT
  PHARMACY PAYMENT
IDB DATA TRANSFER
  DIAGNOSTIC DATA
  REPAIR-SERVICE RECORD
  VEHICLE COMPUTER PROGRAM UPDATES
  MAP and MUSIC DATA UPDATES
RENTAL CAR PROCESSING
IN-VEHICLE SIGNING
  WORK ZONE WARNING
  HIGHWAY/RAIL INTERSECTION WARNING
  ROAD CONDITION WARNING
ROLLOVER WARNING
MAINLINE SCREENING (WEIGH-STATION CLEARANCE)
BORDER CLEARANCE
UNIQUE CVO FLEET MANAGEMENT
ON-BOARD SAFETY DATA TRANSFER
TRUCK TRACTOR-TRAILER SAE DATA BUS INTERFACE
DRIVER’S DAILY LOG
VEHICLE SAFETY INSPECTION
EMERGENCY VEHICLE SIGNAL PREEMPTION
TRANSIT VEHICLE SIGNAL PRIORITY
TRANSIT VEHICLE DATA TRANSFER
LOCOMOTIVE DATA TRANSFER
LOCOMOTIVE FUEL MONITORING
INTERSECTION COLLISION AVOIDANCE
VEHICLE to VEHICLE DATA TRANSFER
  VEHICLE STOPPED or SLOWING WARNING
Ad Hoc Networks

- Peer to Peer Network – Tag to Tag
- MANET- Mobile Ad Hoc Networking
- Mesh Communication Network
- Resolve the Hidden Transmitter Problem
  - 5.9 GHz OFDM Range about 600 to 1000 feet typically from roadside to vehicle
- Packet Network relaying
  - Data more important than location and ID
Reader & Antenna Technology

- High speed applications 100 mph
  - Read only or Read-Write
- 2W synthesized – FCC 30 Watts ERP
- High gain antenna
- Internal electronic attenuator
- Overhead antenna mounting
- Open Road – Multiple Lanes with no barriers and lane changing
  - Lane Center and Lane Edge Antennas
Overhead Antenna Design

- Match object presence with identification
- Minimize Null Zones in pattern e.g. from Yagi
  - Panel Antenna preferred
- Broad Area Coverage Low Gain Antennas
- 4X distance or 10 db power “rule”
- Typical Panel Antenna Focused zone 13 dBi
  Gain – Horizontal Pattern
  - Front to Side >15 dB rejection
  - Beam width ~ 35 degree E & H plane
  - Overhead mounting to control range
- Match Windshield Angle – 15 degree angle towards oncoming traffic
Frequencies and Power Levels

- Typically licensed 912.5 to 919.0 MHz
  - Synthesized 500 KHz steps
  - FCC ITS Radio Service – 90.351
  - Band Shared with Federal Government - IRAC
- 30-500 Kbits/second data rate, Manchester encoding in reader interrogation commands
- Panel gain antenna pointed down in toll lane
- Feed line, internal and external attenuation results in less than 30 watts ERP
  - Typically < 1 w ERP at Horizon
RF Spectrum for RFID Readers

- Country Dependent
- FCC Equipment Authorization & ID #
- Some Equipment requires Site Licenses
- Bands – Often shared – Most used:
  - LF – 66 & 132 KHz
  - HF – 13.56 MHz
  - VHF – 49 MHz
  - UHF – 315, 433, 902-928 MHz, or 2.45 GHz
  - Microwave – 5.8 GHz (Europe) 5.9 GHz US
- Data Bandwidth, Latency, and Number of Readers at site influences Frequency selection
Marketplace Trends

- GPS Location and ID Determination
- Cellular Network for communication
- DSRC 5.9 GHz
- Fuel Tax Replacement
- More highly integrated applications with Vehicle Navigation system
- Satellite Tracking – Continuous Visibility
- Simple, Low Cost & Completely separate RFID
- No Display on Tags
Trends in Technology

- Single Chip Tags with Read-Write Operation at Highway Speeds, and multi-mode operation
- Increased Security
- Mutual Authentication for High Value Parking
- Registration Stickers/Plates with RFID- EVR
- Multiple Readers for different bands or Multi-Protocol Readers in same band
- Time Difference of Arrival or Angle of Arrival for Tag/Object Location
Additional Trends in Technology

- Multiple Application integration of processors and GPS receivers
- Higher circuit integration & Lower current
- Integrated with vehicle data bus & Power
- DSRC 802.11p transponders also use 802.11a
- Communication Handoff between Roadside Units
Conclusion

A Variety of Technologies and System Designs Contribute to Fertile Environment for R & D