UHF Gen2 RFID
Where do we go from here?

April 27, 2009
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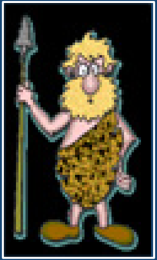
A Brief History of UHF Gen2

I have omitted innumerable milestones and key events…

< 2003



Ancient history (ISO 18000-6 A/B & Auto-ID C0/C1)

2003

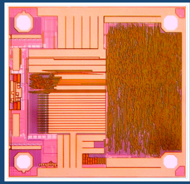
Walmart

Key RFID mandates

2004

Gen2 ratified (Dec 2004)

2005



First Gen2 chip

2006

First DRM reader

2007

First fielded NF UHF

2008

First prod'n reader chip

2009

Privacy & security

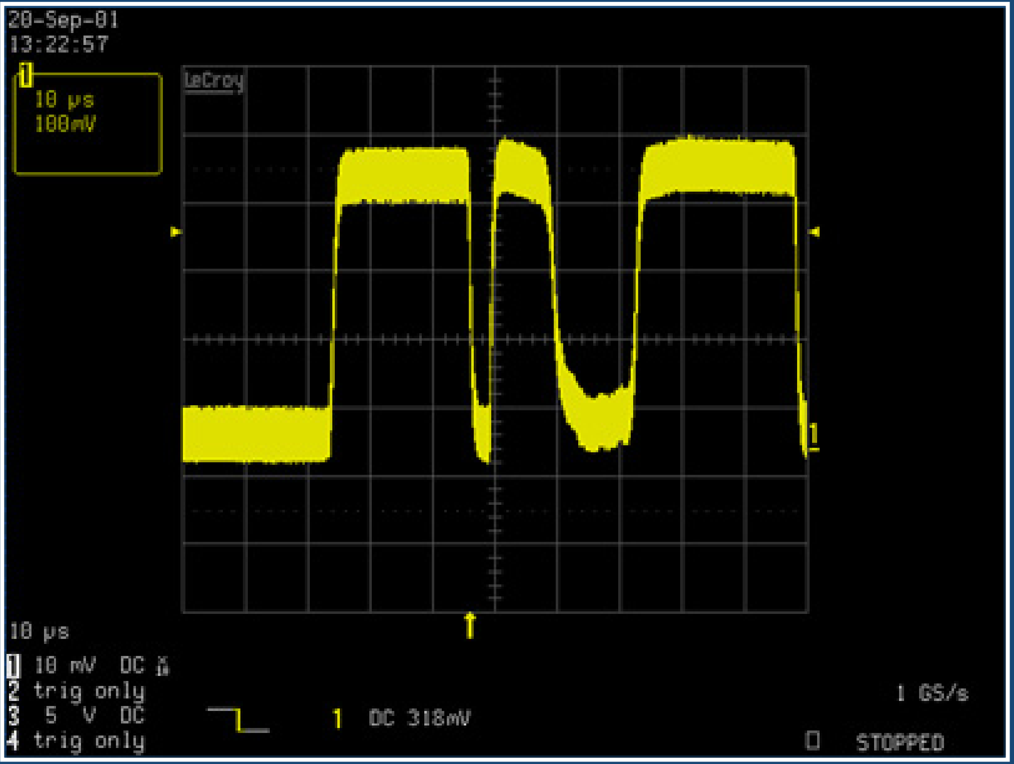
Step Back to 2003…

- **These entities (and many others) joined EPCglobal**
  - They created user requirements
  - They wanted a worldwide standard
  - They wanted RFID products that worked

2003: RFID Issues

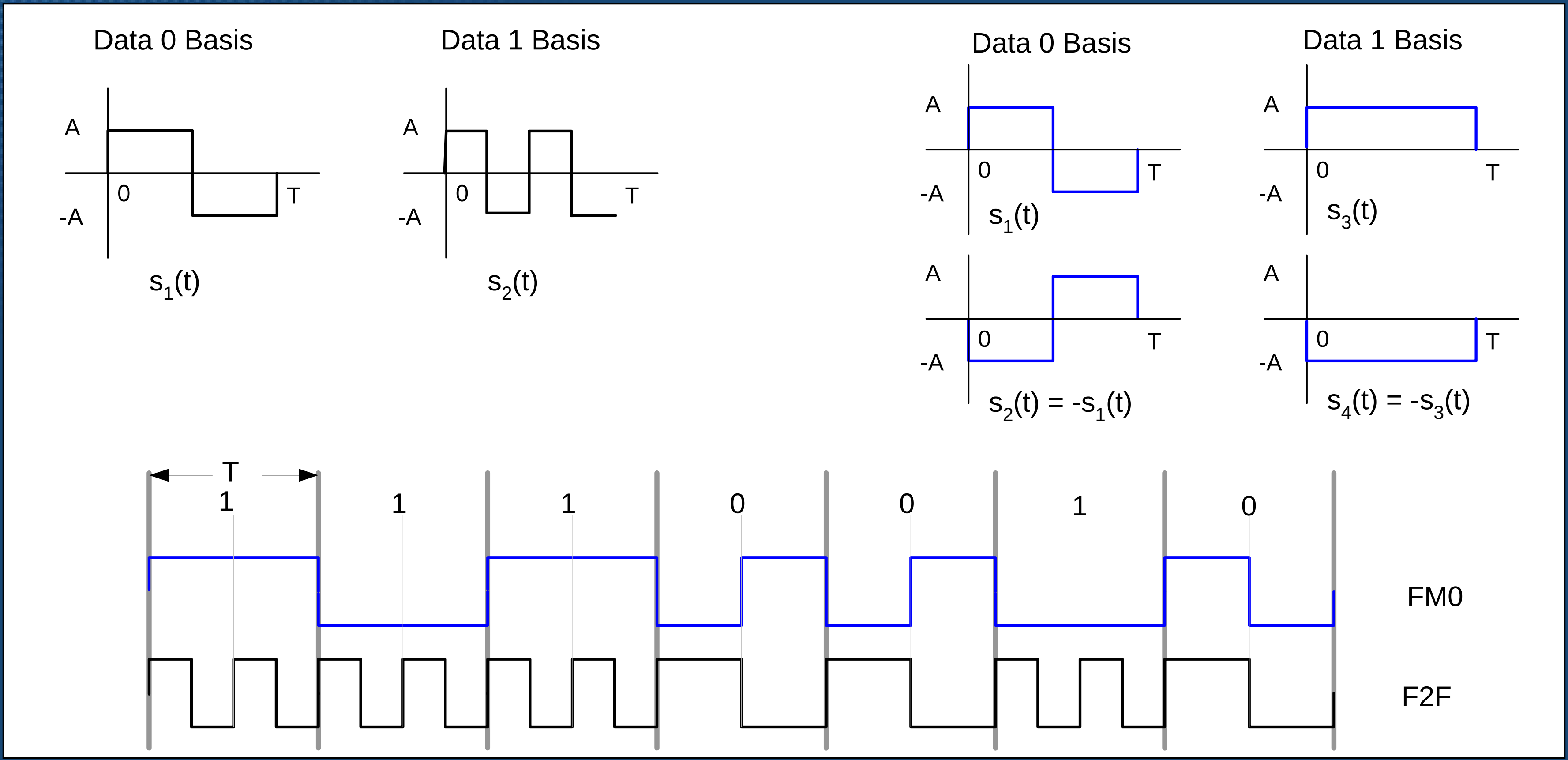
- **Existing UHF RFID simply didn't perform**
  - No dense-reader capability
  - No worldwide operation
  - Poor spectral efficiency
  - Ghost reads
  - Low speed
  - Lots more
- **UHF RFID technology was ancient**

Example: A "difficult-to-detect" response from an RFID tag

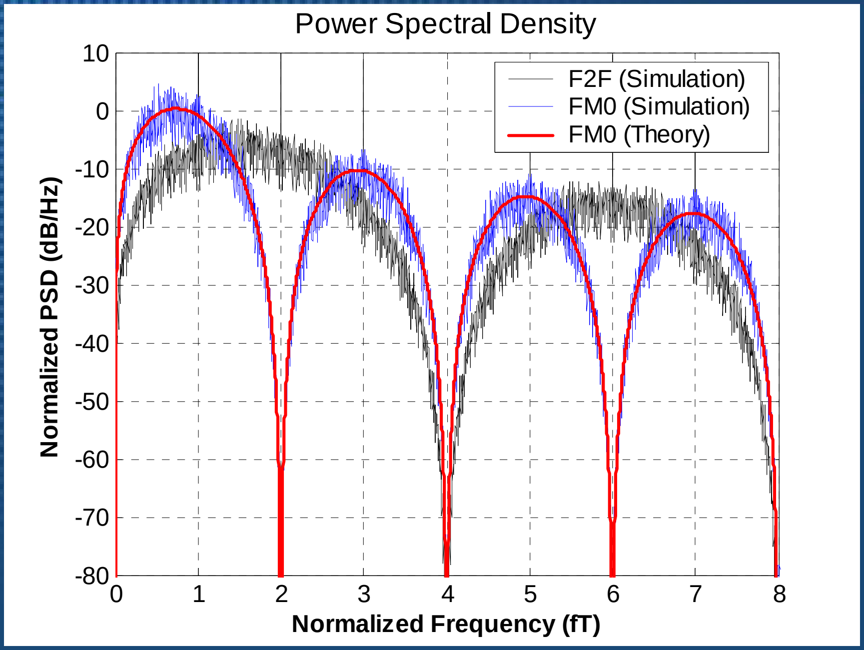


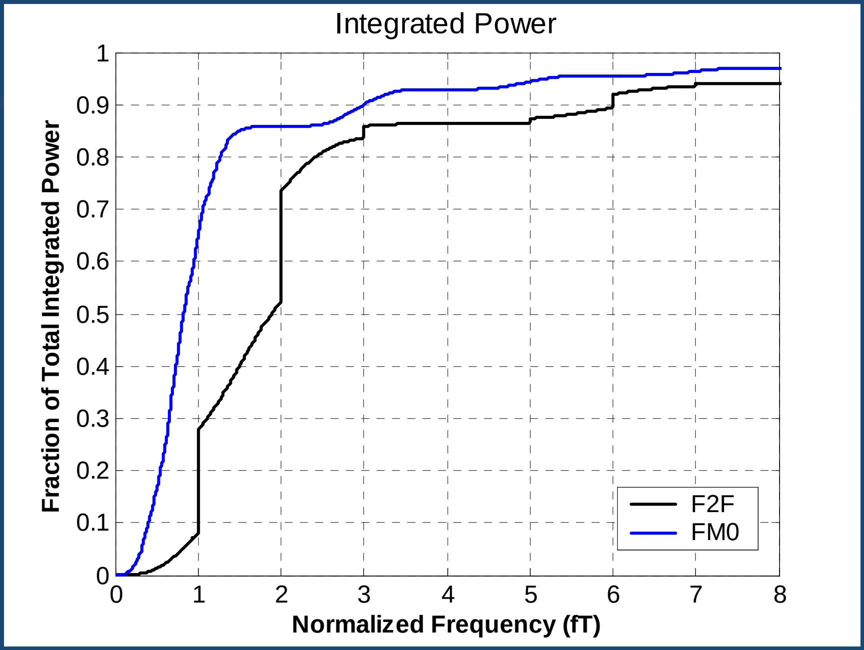
2003 Tradeoff: T->R Signaling

- **Class-1 F2F Encoding**
  - Linear modulation w/o memory
  - Orthogonal basis functions
- **Proposed Gen2 FM0 Encoding**
  - Linear modulation with memory
  - Biorthogonal basis functions



T->R Bandwidth Efficiency

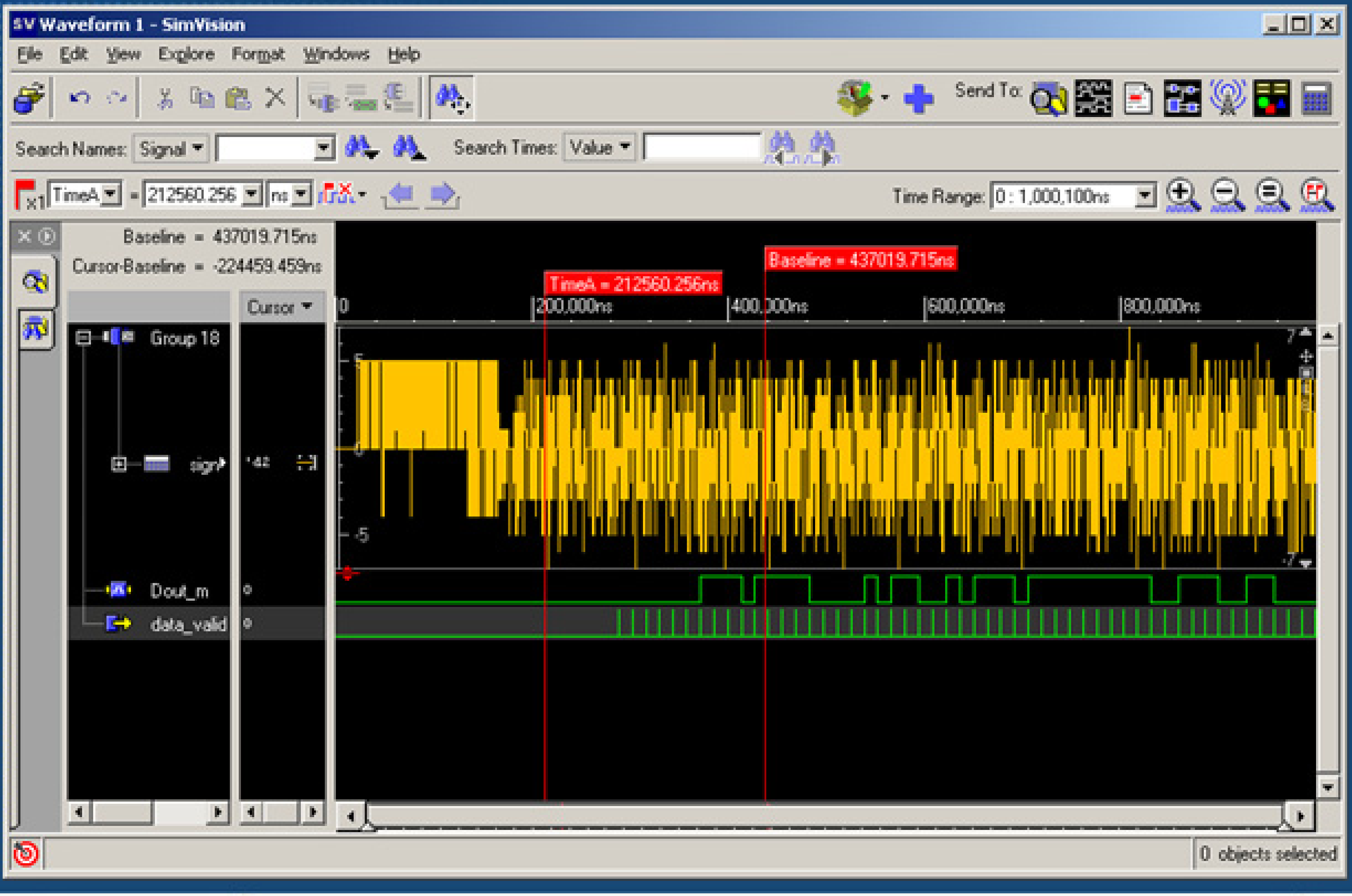




- **FM0 requires approximately 0.5× the bandwidth of F2F**
  - FM0 : 80% power bandwidth ≅ 1.25/T
  - F2F : 80% power bandwidth ≅ 2.45/T
- **FM0 has a lower symbol BER than F2F at a given Eb/No**
  - Exploit memory within FM0 waveform (MLSE)

Introduce Modern Radio Techniques

A recoverable signal for a properly designed Gen2 reader

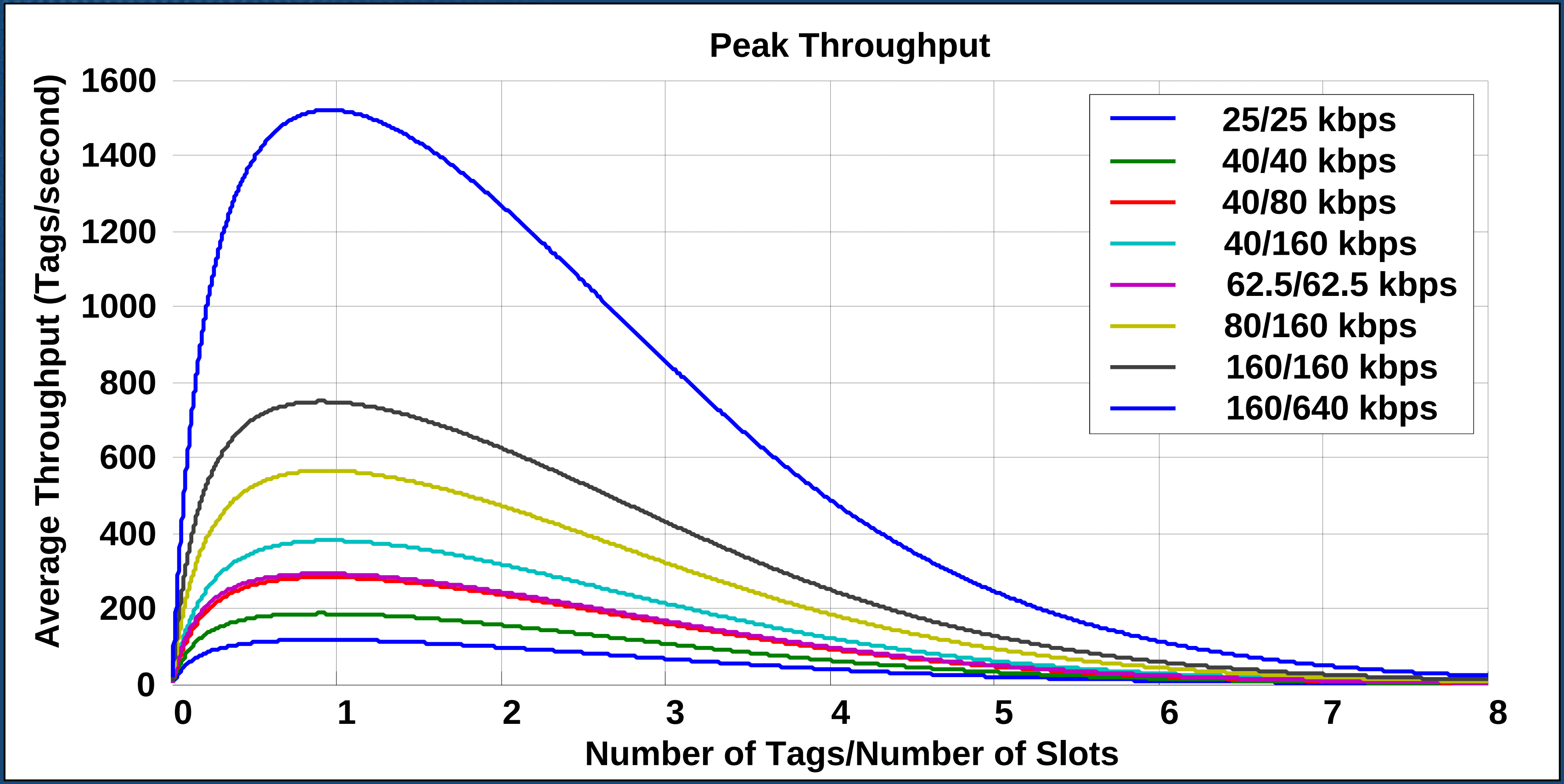


2004: UHF Gen2 Ratified

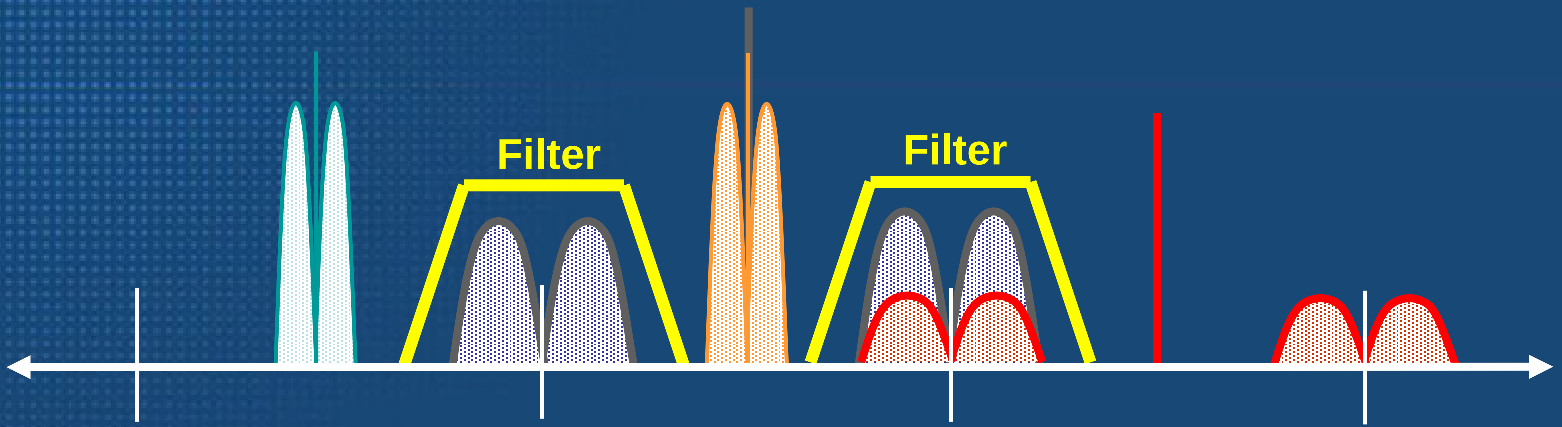
User Requirement	Gen2 Capability
Global regulatory compliance	Europe, North America, others ✓
Memory access control	32-bit access password, memory locking ✓
Fast read speed	> 1000 tags/sec peak ✓
Dense-reader operation	Dense-reader operating mode ✓
Kill security	32-bit kill password ✓
Memory write capability	> 400 tags/minute write rate ✓
Bit masked filtering	Flexible *Select* command ✓
Optional user memory	Vendor option ✓
Low cost	Multi-vendor availability ✓
Industry certification plan	EPCglobal™ certification ✓

Simulated Gen2 Throughput

- **Absolute peak performance**
  - Assumes 100% detection of tag collisions and empty slots
  - Assumes tags do not lose power during an inventory round



Dense-Reader Mode



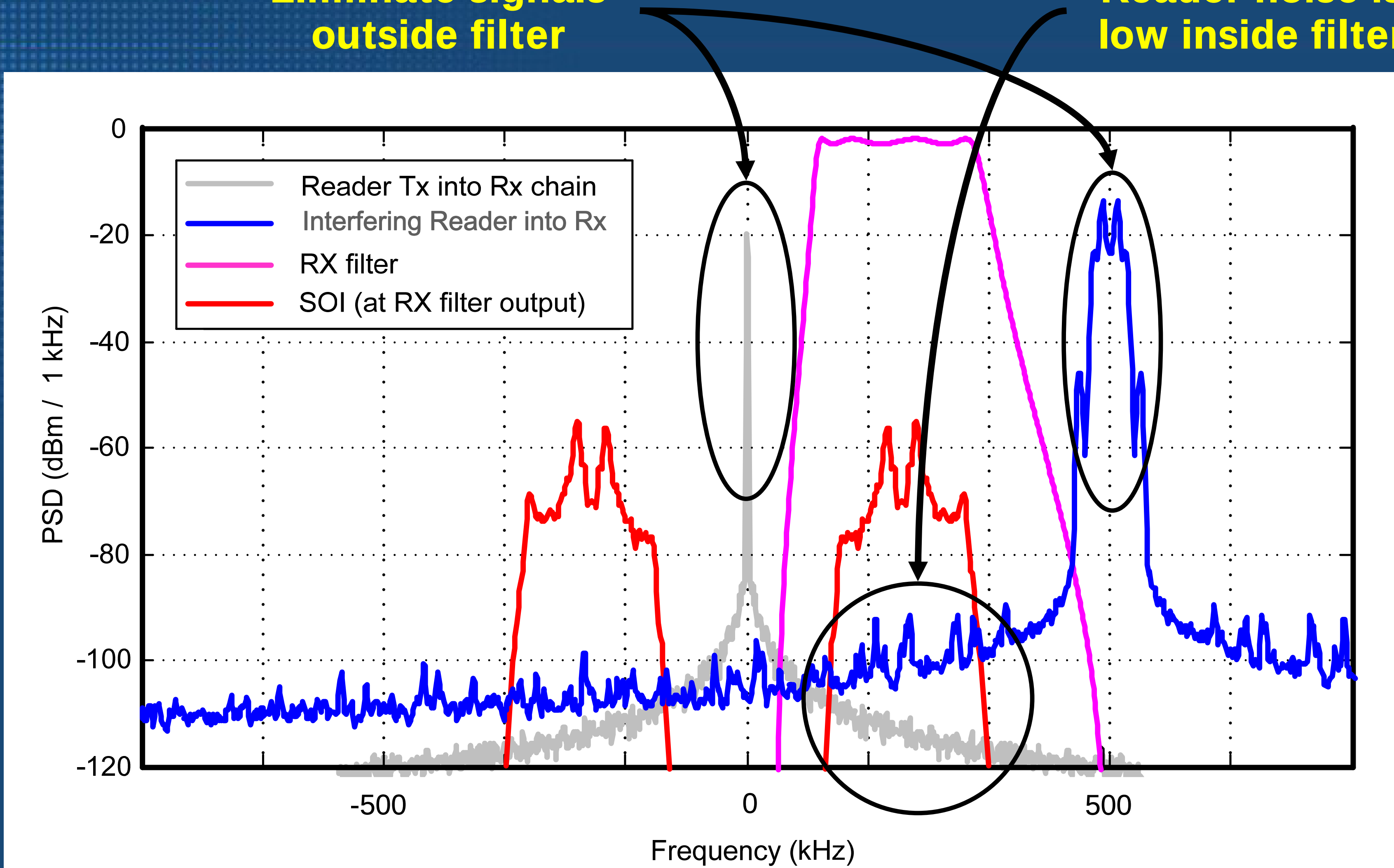
Readers collide with readers but not tags
Readers filter interfering readers from their tag responses

- **Goal: 10's or 100's of readers operating simultaneously**
  - Using only a few MHz of bandwidth
- **Solution: Dense-reader mode using Miller backscatter**
  - Separates tags and readers in frequency
  - Prevents reader—tag interference
  - Eliminates need for LBT

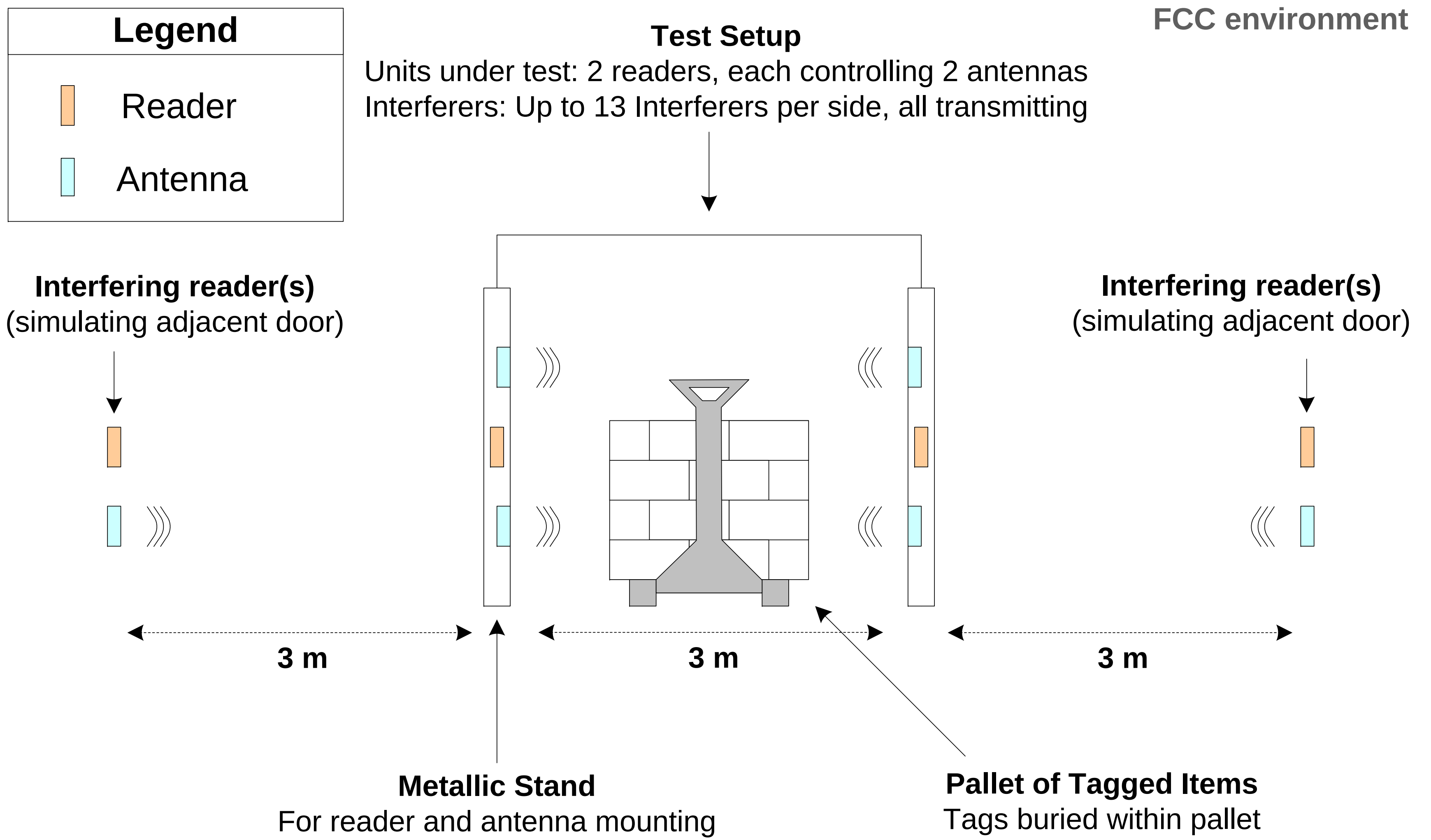
Dense-Reader Operation

Eliminate signals outside filter

Reader noise is low inside filter

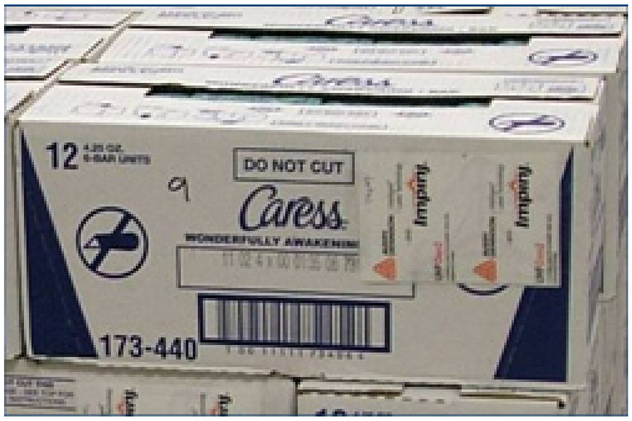


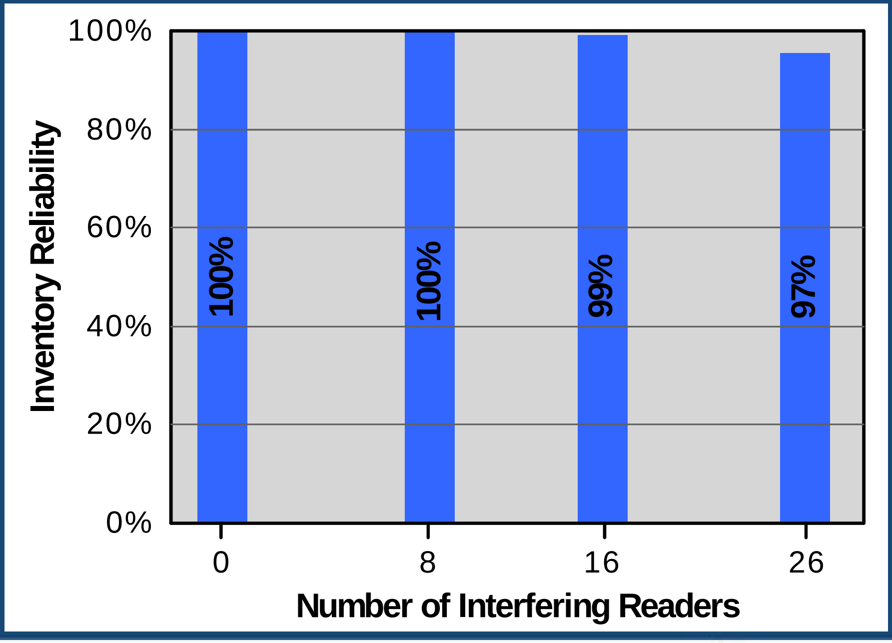
2005 Gen2 Testing



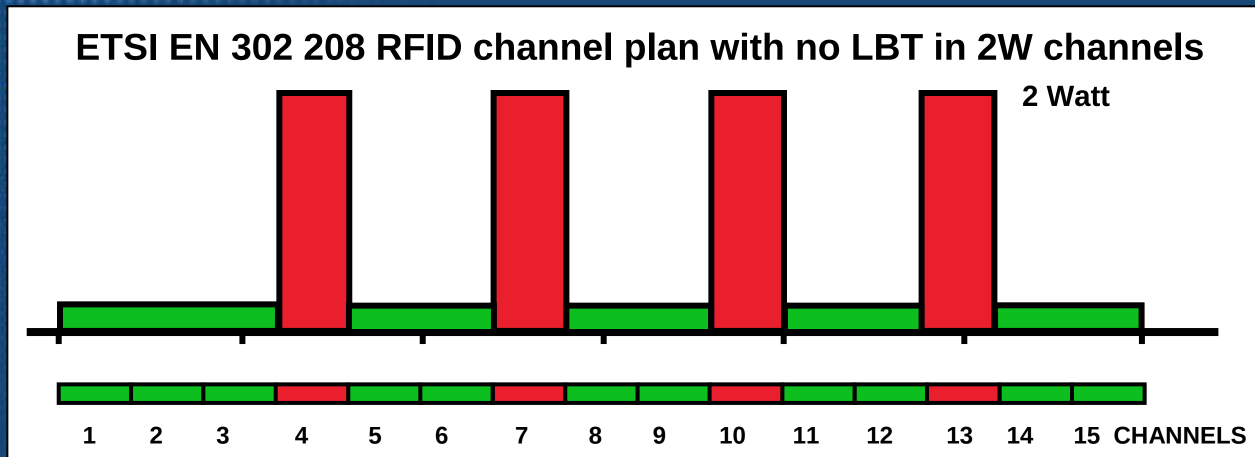
2005 Test Results – It Works!!

- Reader on either side of dock door
- Tags on each of 40 boxes of Caress® soap
- All readers transmitting simultaneously
- There is a co-channel or adjacent channel reader 80% of the time





2006: EU Regulatory Issues Solved



<u>THE TEST</u>

36 dock doors

62 items/pallet

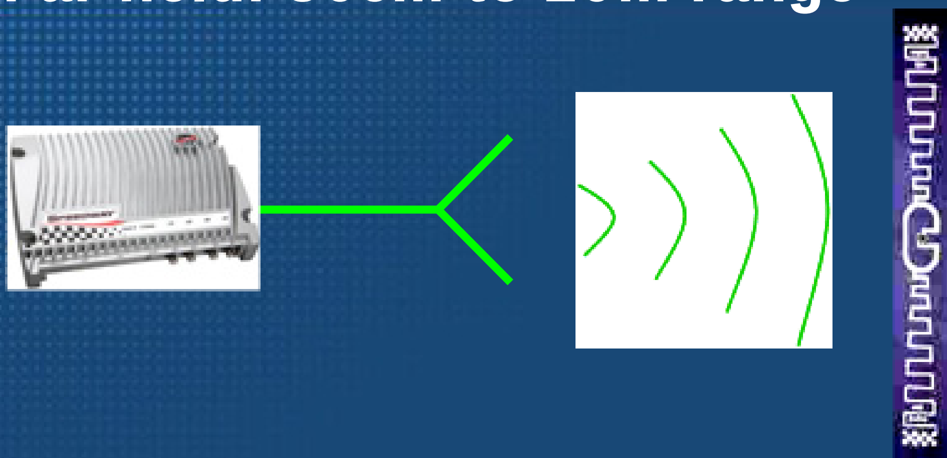
36 pallet pulls (simultaneous)

36 readers transmitting simultaneously

98.2% accuracy

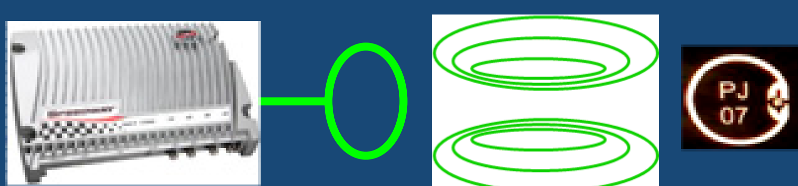
2007: Near-Field UHF for Item Tagging

- **Far field: 30cm to 10m range**



Far-Field UHF RFID
Electromagnetic waves
Long range: 30cm to 10m
Attenuated by dielectrics

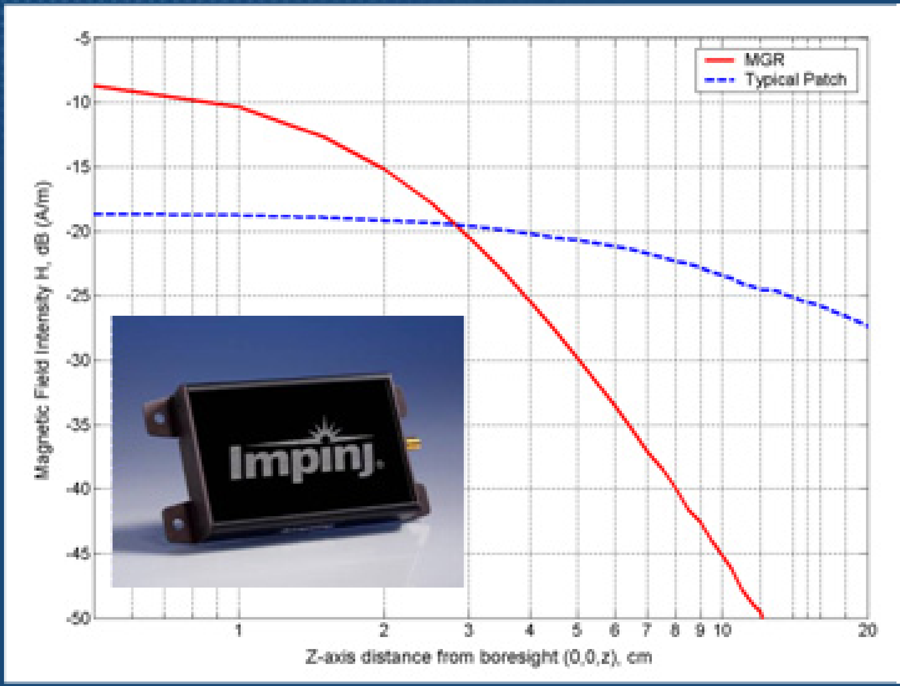
- **Near field: 0 to 60cm range**
  - Reads on liquids and metals
  - The only difference is the antennas

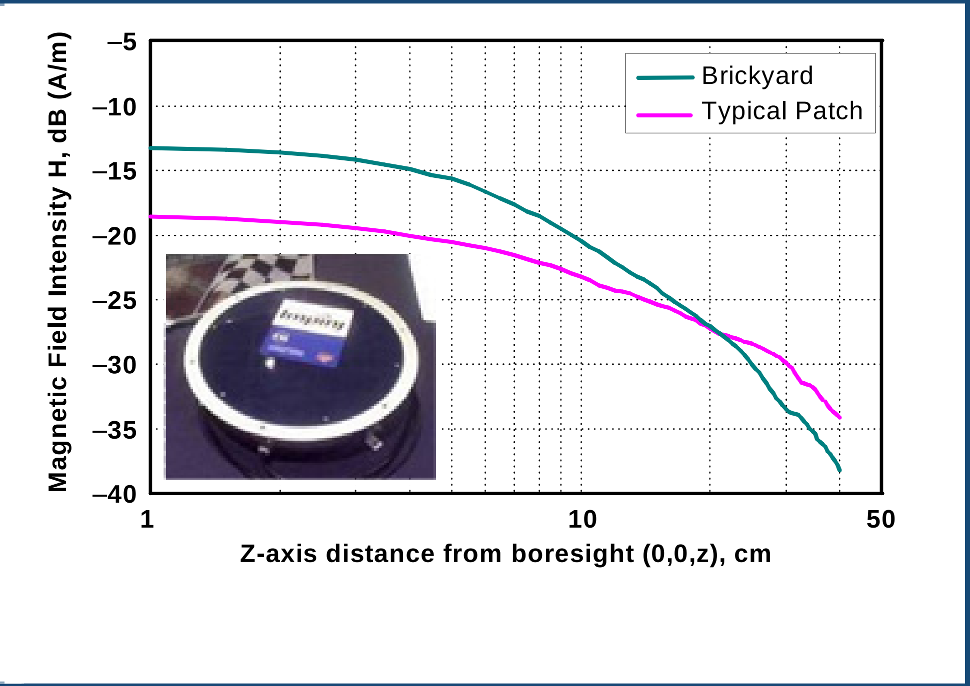


Near-Field UHF RFID
Magnetic or electric fields
Short range: 0 to 60cm
Unaffected by dielectrics

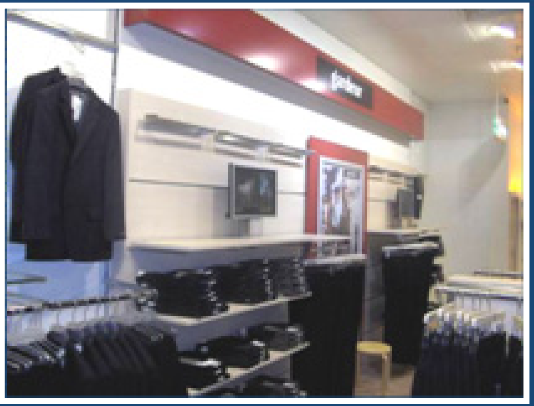
Antenna Characteristics

Antenna Type	Typical Read Range
Near field	~10 cm
Transitional near field	~ 60 cm
Far field	10+ m





Item Tagging @ Metro Galeria Kaufhof

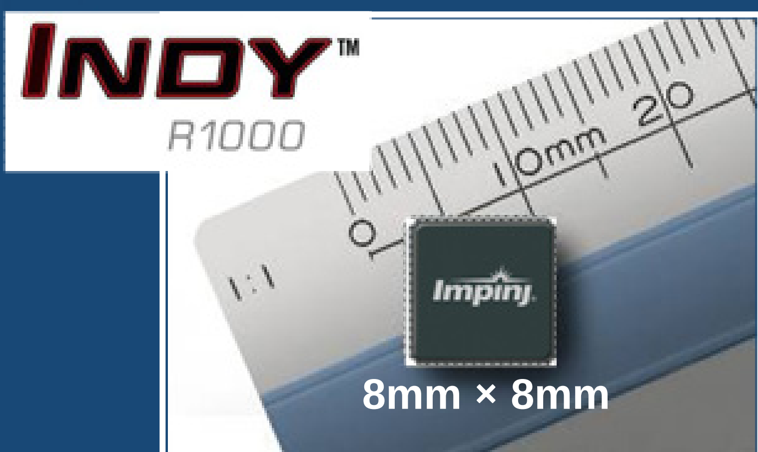


2008: Reader Silicon => Many Products





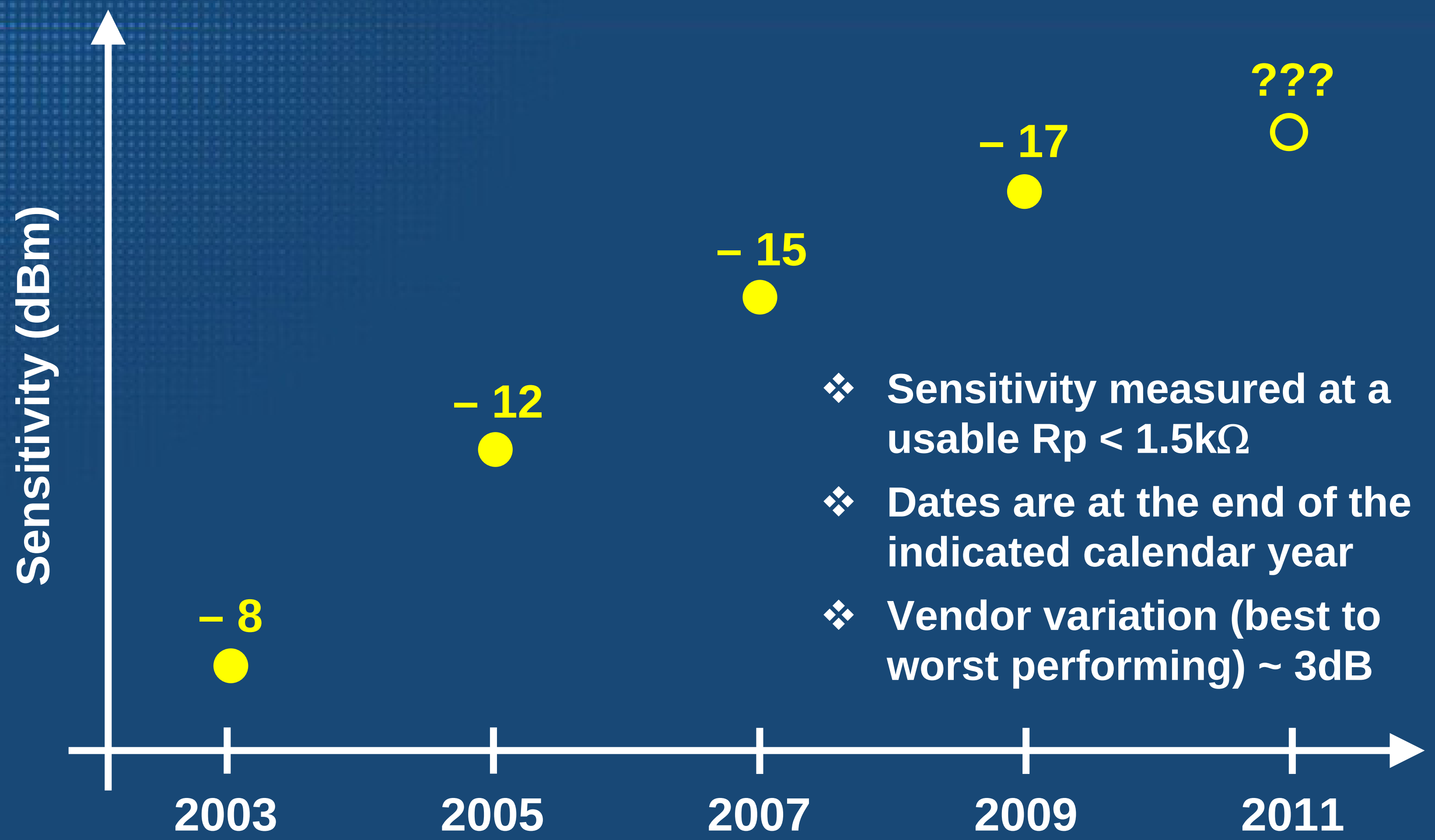




Enter 2009…

- **We have a handle on many hard problems**
  - Die sensitivity
  - Broadband inlay tuning
  - Inlay orientation insensitivity
  - Tag interference rejection
  - Reader sensitivity, selectivity, speed

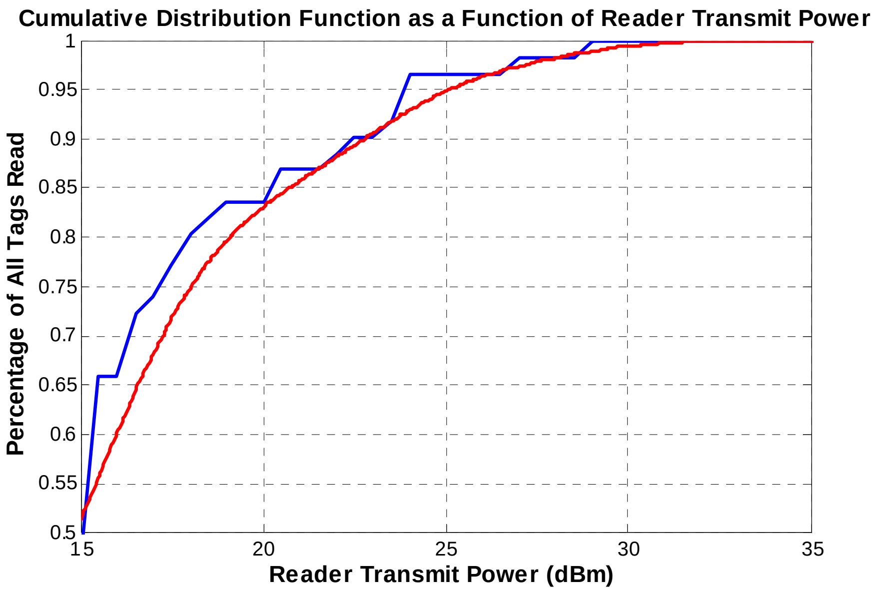
Best Die Sensitivity

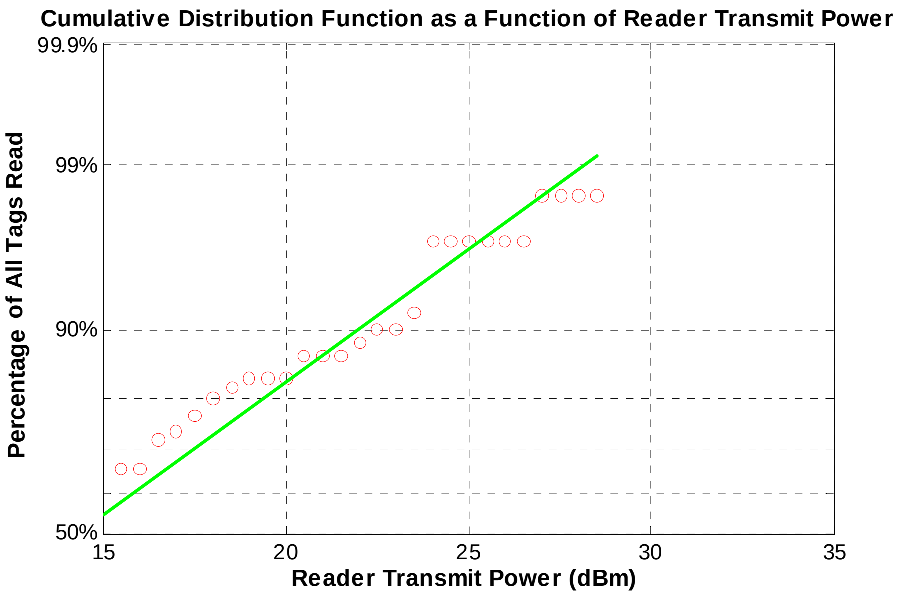


- Sensitivity measured at a usable Rp < 1.5kΩ
- Dates are at the end of the indicated calendar year
- Vendor variation (best to worst performing) ~ 3dB

Why Sensitivity Matters

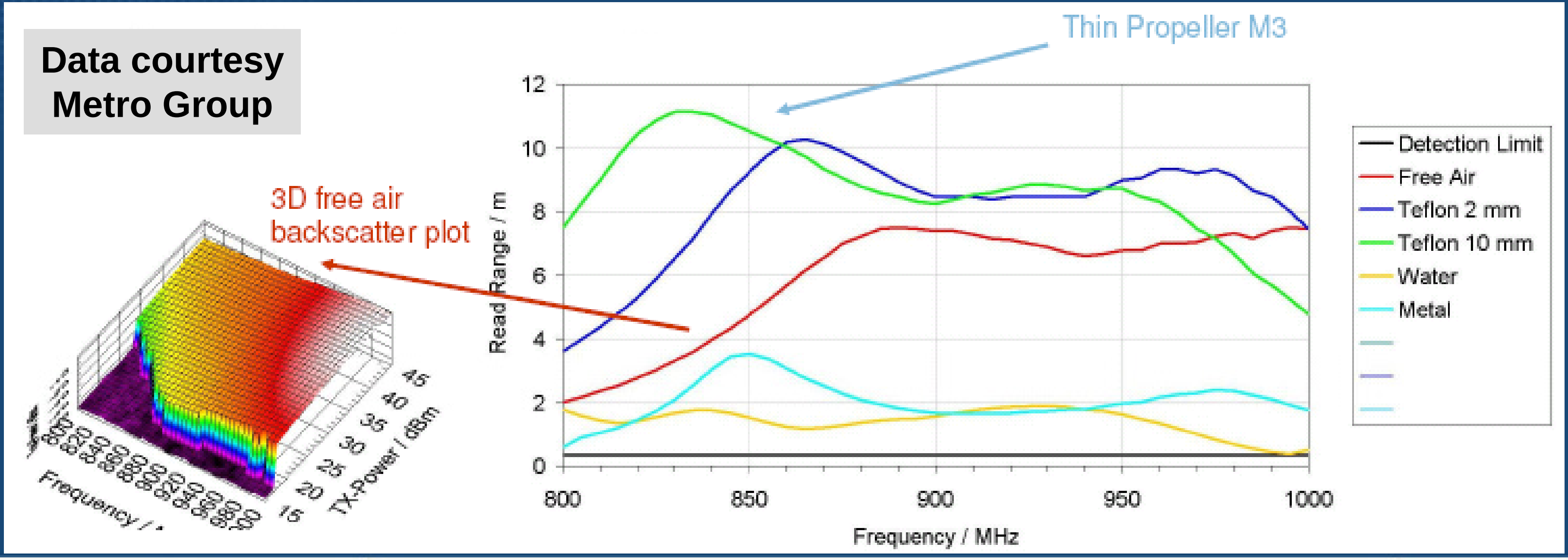
- **A cart containing 30 difficult-to-read items**
  - 36-pack soft-drink cans
  - 32-pack bottled water
  - Two large roasts
  - Aluminum foil
  - Multiple foil-lined bags
  - Lots more...





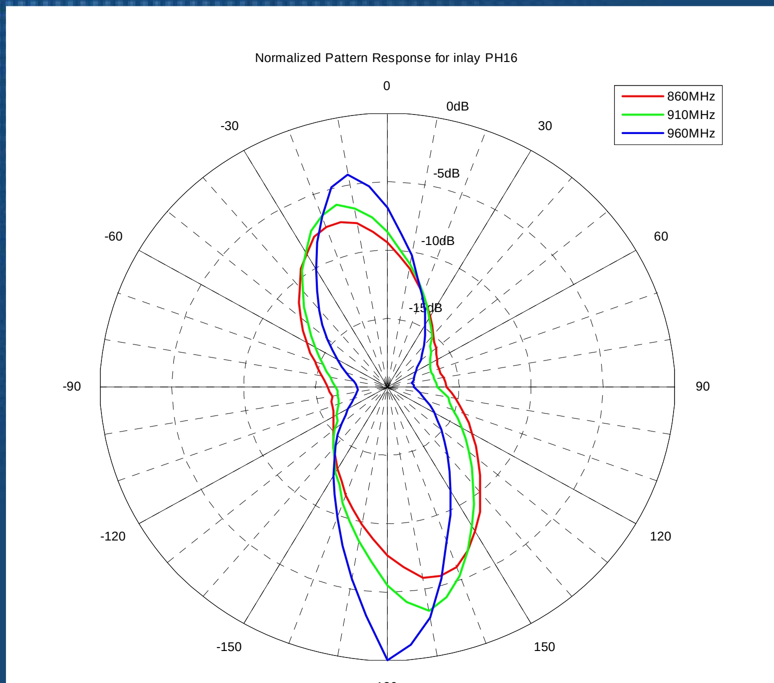
Broadband Inlay Tuning

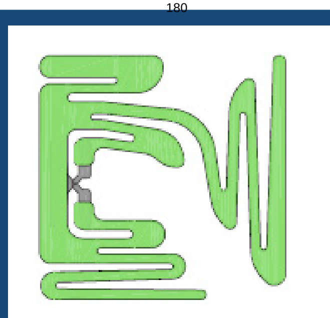
- **Notice that the free-space tuning is high**
  - Tuning "pulls in" to 860 – 960 MHz for typical objects
- **Other tags achieve similar range on metal / liquids**
  - May require a 1 – 2 mm spacer
- **The Propeller is a single-dipole tag**
  - Dual-dipole designs add orientation insensitivity



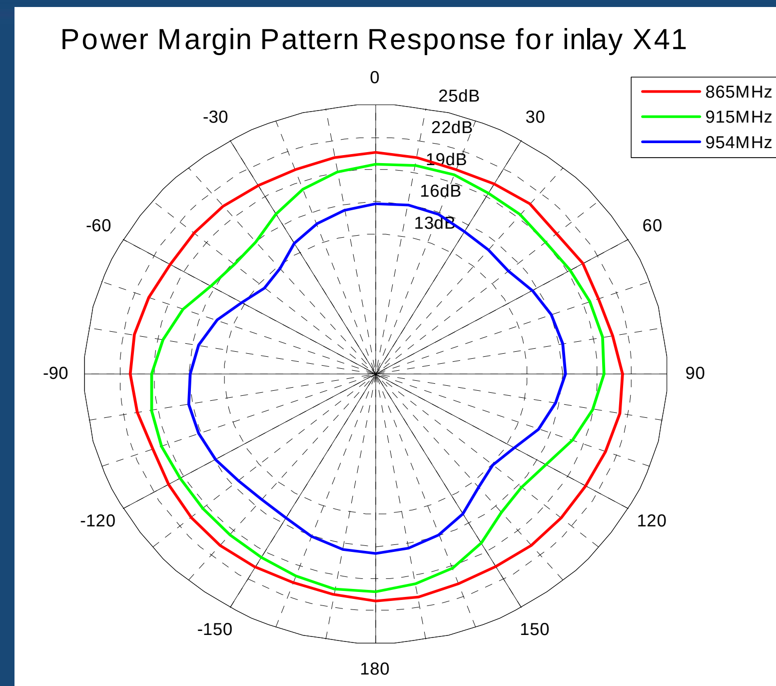
Orientation Insensitivity

2007

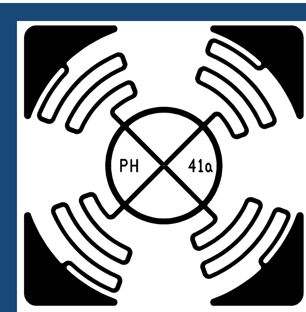




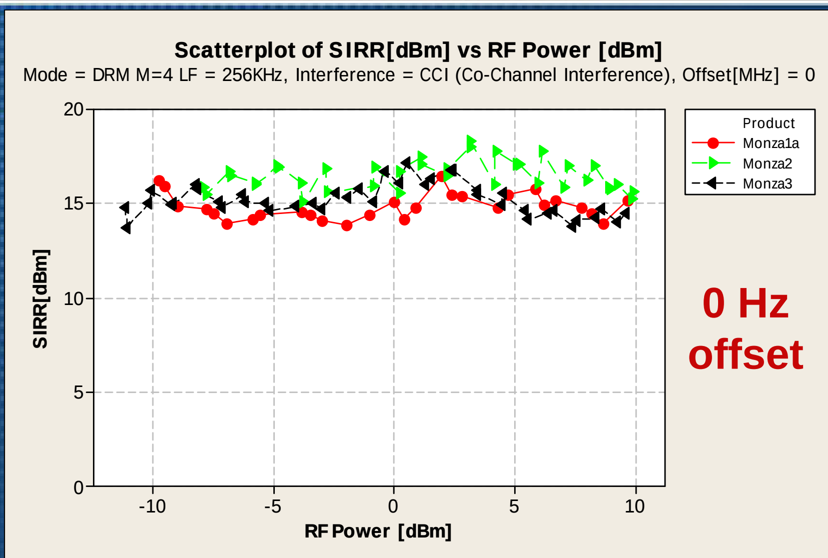
2009

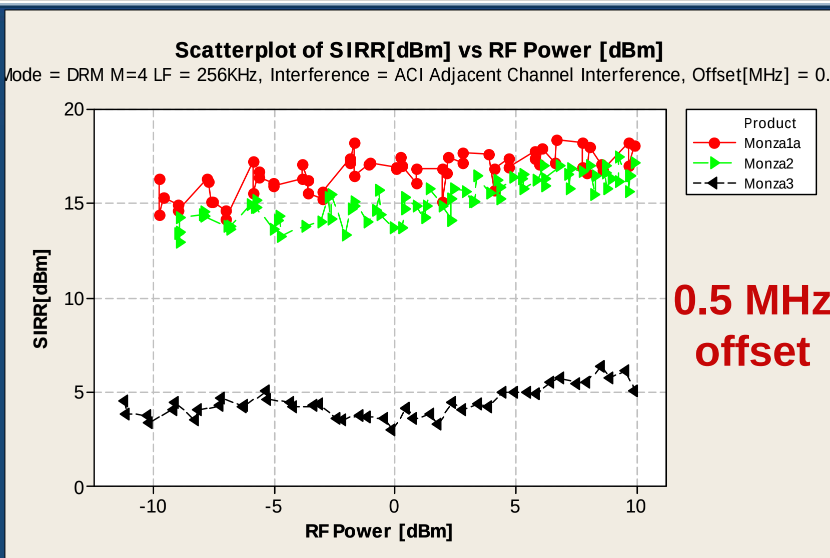


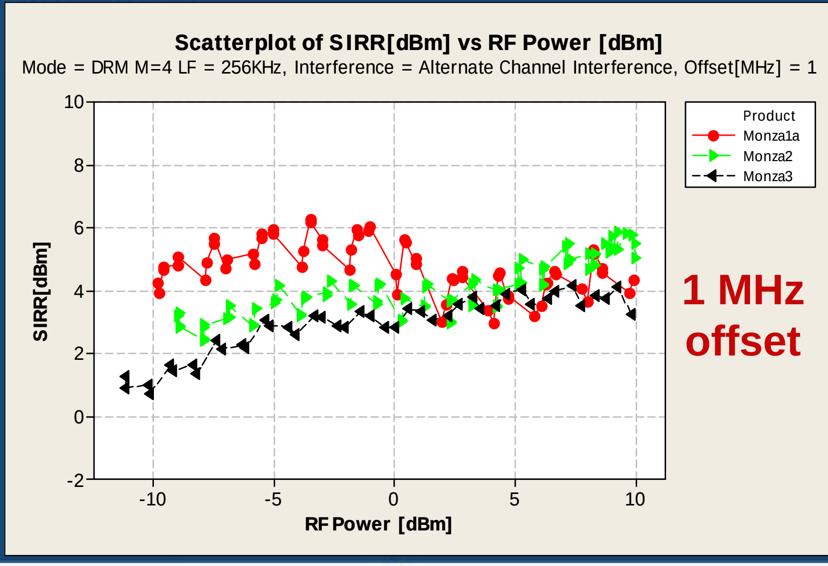
Small inlay (4×4 cm)

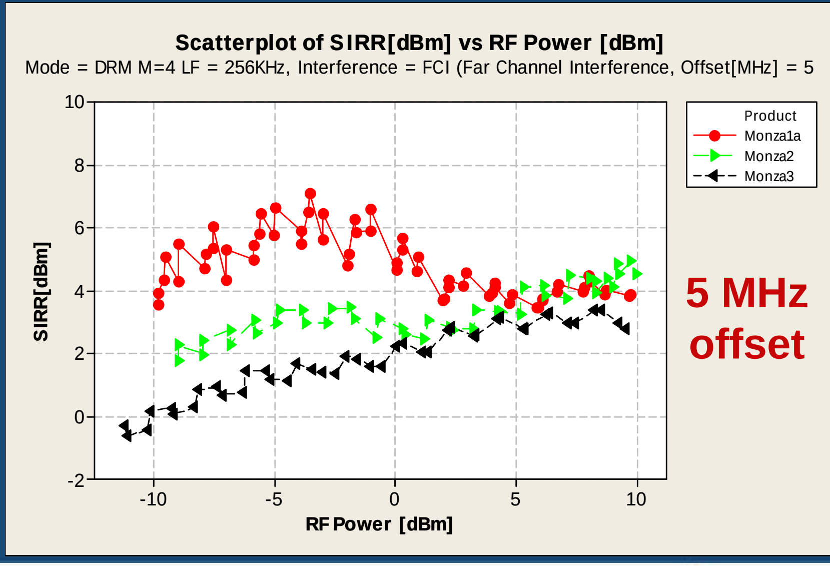


Interference Rejection

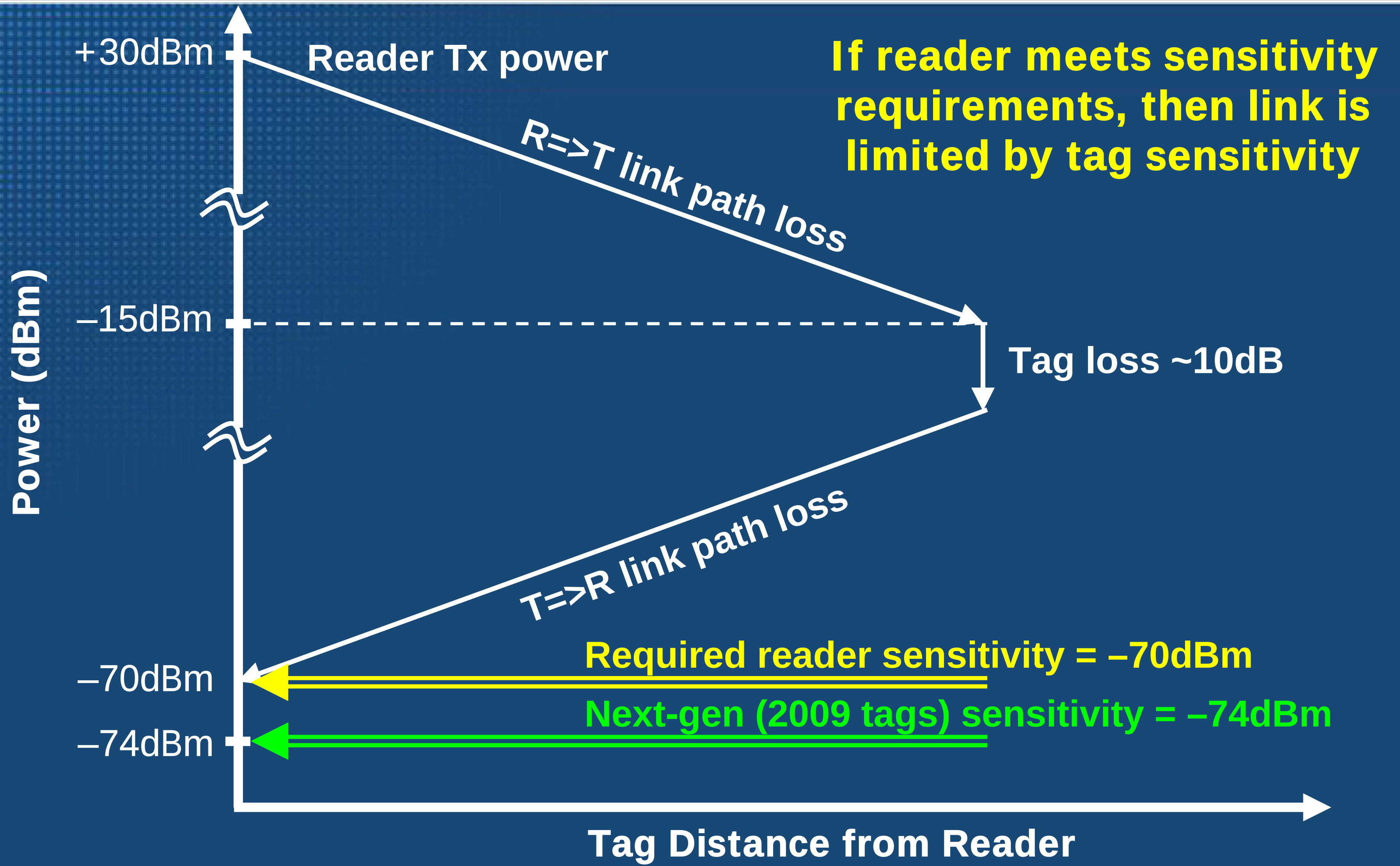








Reader Sensitivity Requirements



2009: Best Reader Performance

Parameter	Performance	Conditions
Receive Sensitivity	–80 dBm	30dBm Tx, 8dB return loss, M=4
Interference rejection	74 dB	CW interferer, adjacent channel
	66 dB	Mod interferer, adjacent channel
	80 dB	CW interferer, 2nd adjacent channel
Max. throughput	1000 tags/sec	FCC, quiet environment
Typ. throughput	380 tags/sec	FCC, 5 nearby readers

Speedway reader today can achieve >99% inventory accuracy on these pallets

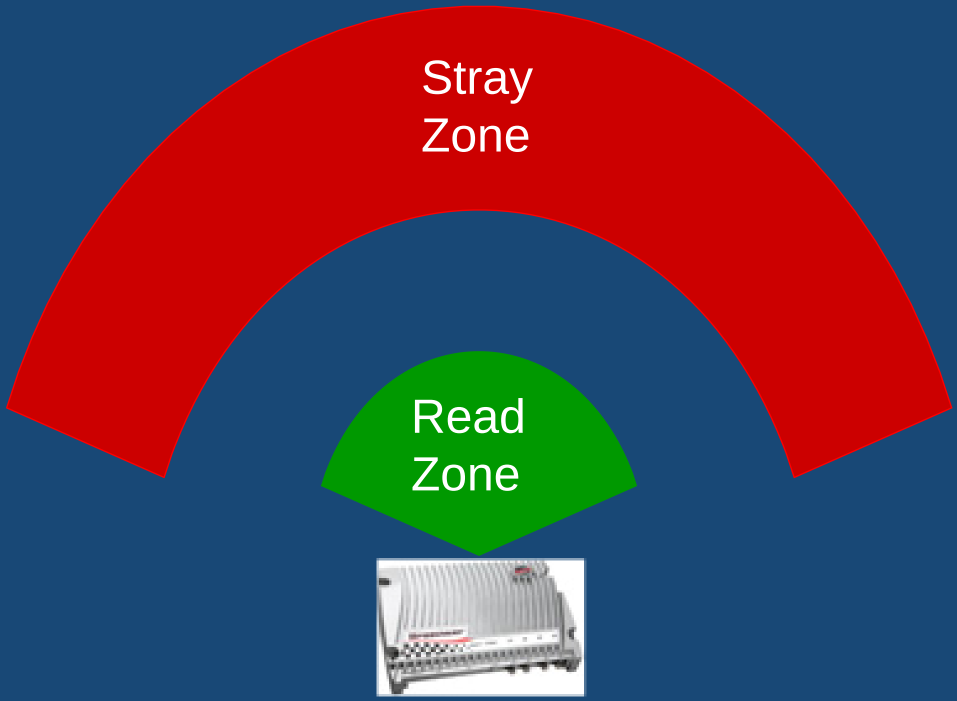
700 items moving at 1.5m/s

Looking Forward

- **Two biggest unsolved problems**
  - Read-zone confinement
  - Consumer privacy
- **Two solvable but open problems**
  - Tag security and authentication
  - Inlay antenna design methodology
- **Two problems being solved now**
  - Battery, sensor, and I/O enabled tags
  - Combining RFID and EAS functionality on a tag

Read-Zone Confinement

- **Stray reads have caused some retailers to abandon RFID**
- **How do we contain the RF field?**
  - Antenna design?
  - RF phase?
  - Tag RSSI?
  - Statistical techniques?
  - Other?
- **Even tag ranging is not good enough**
  - Customers want to confine the RF field in near-arbitrary shapes and sizes



Consumer Privacy

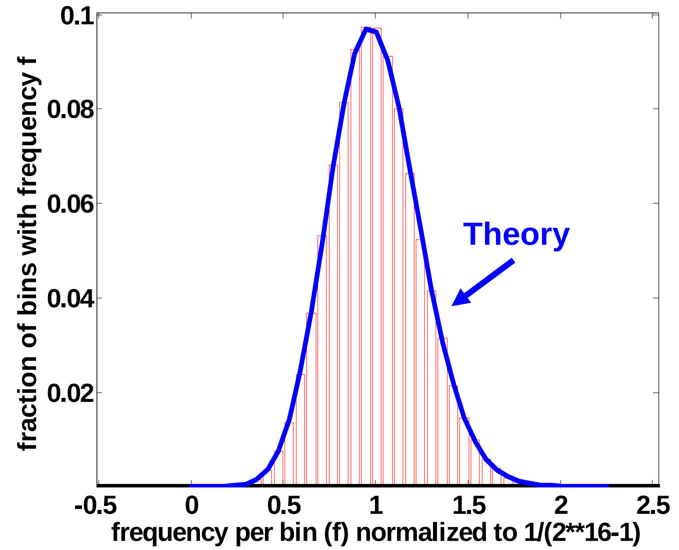
- **An erroneous privacy example: “Police… [will be] able to walk around with RFID readers and collect the serial numbers from people’s clothing…”**
    - IEEE Spectrum, July 2004

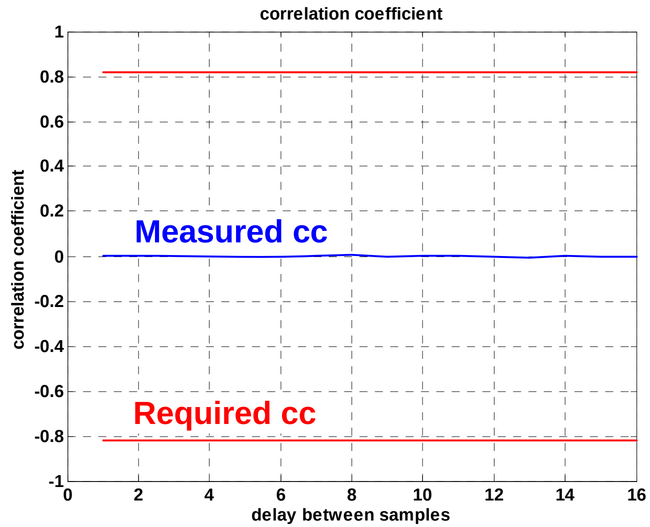
A cartoon from 2004

Educating consumers in 2008

Security and Authentication

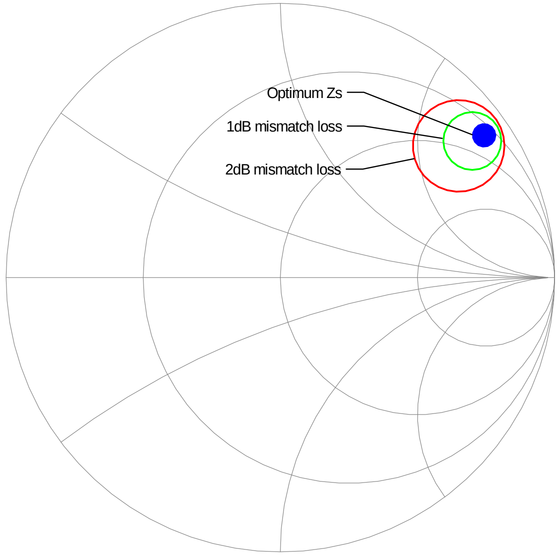
- **Not hard to implement a security algorithm on a Gen2 chip**
  - Early versions of the Gen2 spec (from 2004) proposed security!
- **Plus, Gen2 tags have good RNGs**
  - Rqmn't: An RN16 drawn from a Tag's RNG 10 ms after powerup shall not be predictable with a probability greater than 0.025%
- **Test data from 1 million RN16s**
  - Predictability: Follows binomial distb'n
  - Correlation coefficient <0.006
    - >100× better than needed to meet 0.025% prediction rqmn't

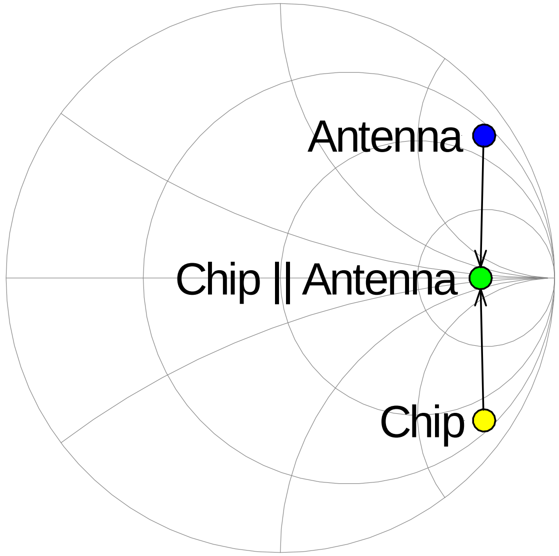




Inlay Design

- **Many antenna designers try to apply their linear RF training to inlay design**
  – But an RFID chip is not a linear system
- **The proper methodology isn't difficult**
  1. Find optimum antenna impedance
  2. Design inductive loop
  3. Design radiating element
  4. Couple radiating element to loop
  5. Verify experimentally
  6. Iterate
- **A well-designed inlay maintains a good impedance match with changes in**
  – Frequency
  – Host materials
  – Nearby tags





Predictions

Problem	Observations	Prediction	Requires research?
Read-zone confinement	• Unlikely to find a "silver bullet"	• A layered solution that combines physical and statistical techniques	Yes
Privacy	• The problem is not nearly as bad as the hype suggests	• Password-free tag anony-mization & range reduction will be "good enough"	No
Security & authentication	• Need to evaluate the trade space of security vs cost	• Add challenge-response security for those who need it	Yes
Inlay-design methodology	• A black art today…	• Will remain an art until the academic community teaches inlay design	Yes (education)


Questions?
April 27, 2009
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