A close-up photograph of a human fingerprint. The ridges and valleys of the fingerprint are clearly visible. A small, square, gold-colored RFID chip is embedded in the center of the fingerprint. The background is dark, making the fingerprint and the chip stand out.

RFID: The Next Big Little Thing

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Overview

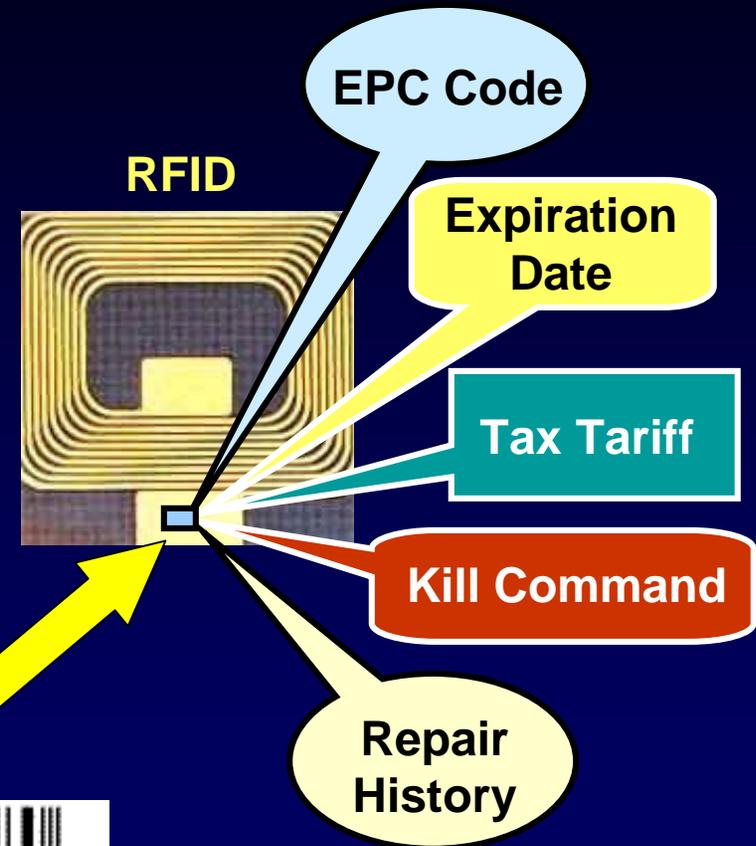
- **Motivations for RFID**
- **State of the industry**
- **Regulatory implications**
- **Comments**



Significance of RFID

Replacement for bar codes with several key advantages

- No line-of-sight required
- Harder to spoof
- Can't smudge
- Tags can be rewriteable
- Unique serial number for each tag
 - EPC replaces UPC
 - 96 bit code gives 2×10^{19} unique identifiers *for every human now alive*



RFID is Old, So What's New?

- **Previous standards**

- 125 KHz and 13.56 MHz
- Inefficient modulation (near field)
- Large antennas – credit card size
- Short range – < 3 feet

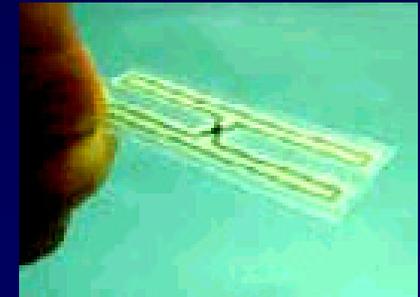
13 MHz
1 – 3 ft



- **Emerging standards**

- 900 MHz
- Efficient modulation (far field)
- Small antennas – postage stamp size possible
- Long range – ~ 20 – 30 feet
- **Made possible by deep submicron CMOS**

900 MHz
30 ft +



Myriad Applications

- **Supply chain automation**
 - Mistake-proof routing
 - Just-in-time replenishment
 - Loss prevention
- **Package tracking (UPS, FedEx)**
- **Airline tickets, luggage**
- **Pharmaceuticals**
- **Anti-counterfeiting**
- **Asset tagging, archiving**
- **Car tires**
- **Animal tagging**



RFID in Supply Chain Management



- **Albertson's distribution center in Brea, CA**
- **RFID will increase throughput and efficiency**
 - Current barcode scanning slow
 - Barcode applied manually by retailer, not supplier



RFID in Logistics



- **UPS sorting facility in Louisville, KY**
 - Handles ~5 billion parcels annually
- **RFID will increase throughput and efficiency**
 - Current barcode scanning slow and requires manual alignment



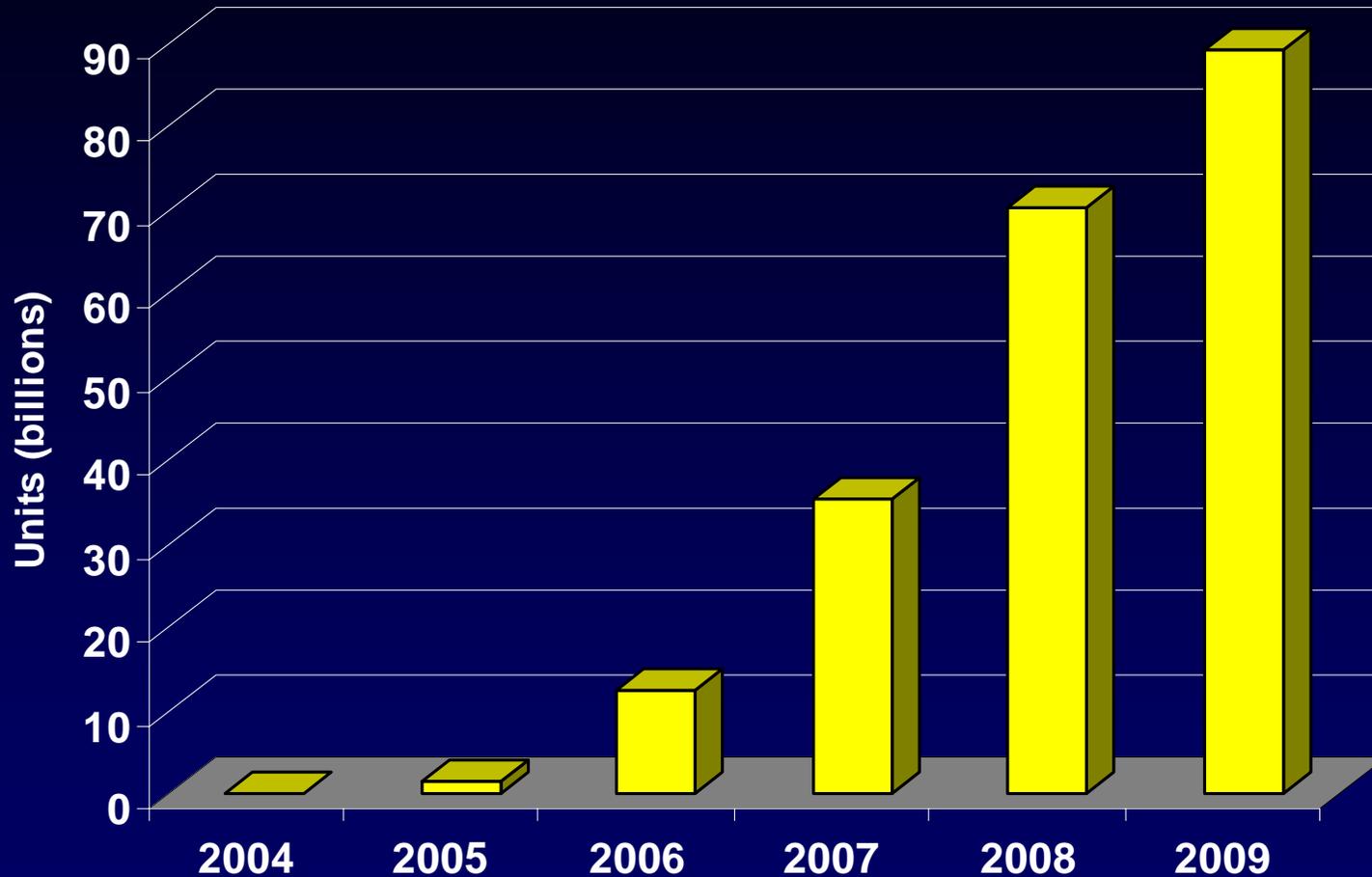
RFID Market Potential



Tag Cost	Annual Volumes	Applications
\$1.00	Millions	Reusable pallet tracking, vehicle access, access control, reusable transport cards
\$0.30	Hundreds of Millions	Anti-counterfeiting, electronic toys, securing valuable documents, baggage handling
\$0.10	Billions	Case tracking, disposable smart tickets, higher-end item level tracking
\$0.03	Tens of Billions	Item level tracking, barcode replacement
\$0.01	Trillions	Postage stamps



Astounding Volume



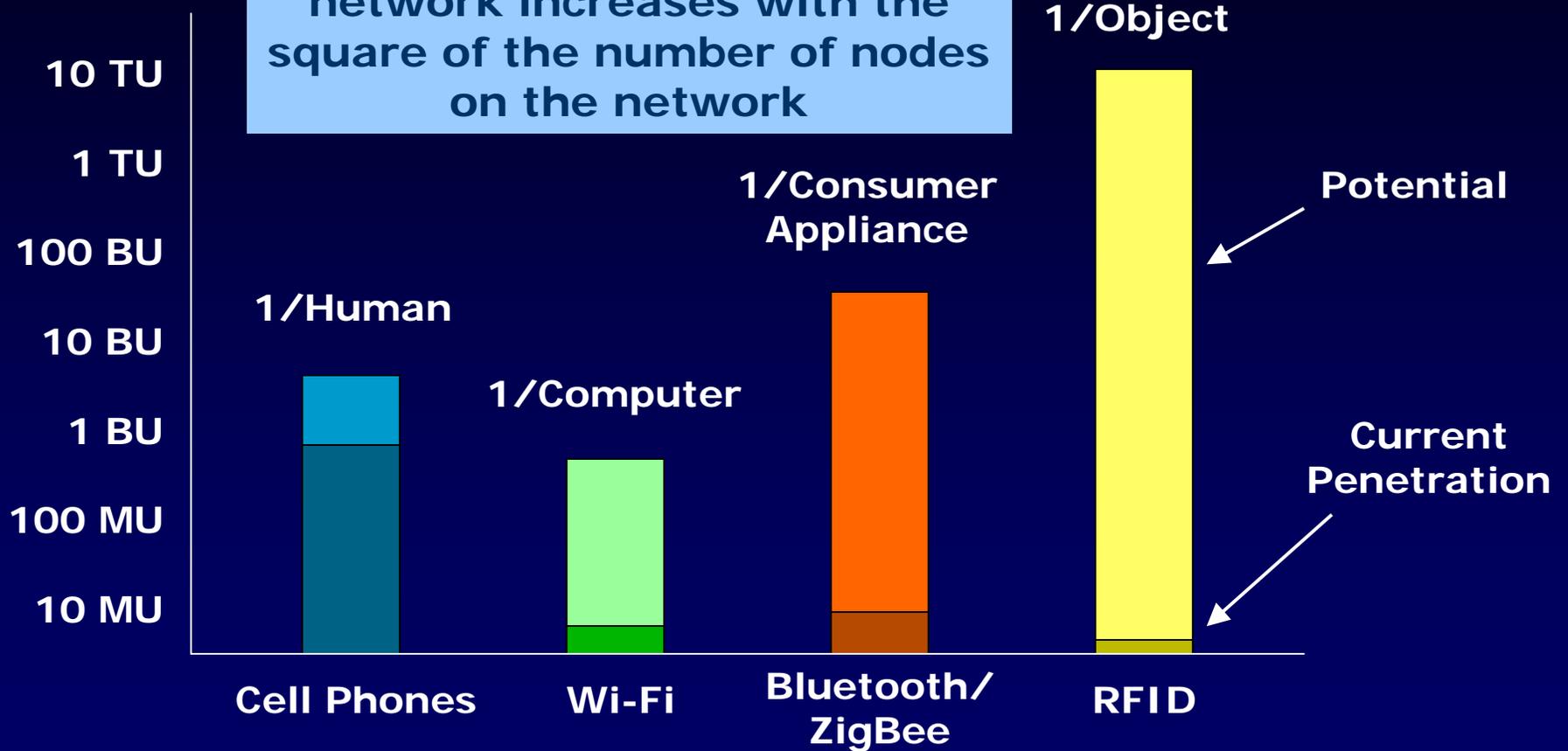
Source: Deloitte & Touche, stores.org, customer interviews.



Conservative at 100 Billion/Year?



Metcalfe's Law: The value of a network increases with the square of the number of nodes on the network



Overview

- Motivations for RFID
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RFID Standards



Bands			Standards	Comment
<135	kHz		ISO 18000-2	
6.765	6.795	MHz		
7.400	8.800	MHz		
13.55	13.57	MHz	ISO 18000-3	In common usage
26.96	27.28	MHz		Special applications only
433.0	MHz		ISO 18000-7	Active tags in Asia
868.0	870.0	MHz	ISO 18000-6 A/B	Europe
902.0	928.0	MHz	AutoID Class 0/1	North America
860.0	960.0	MHz	EPCglobal Gen2	Worldwide
2.400	2.483	GHz	ISO 18000-4	
5.725	5.875	GHz	ISO18000-5	Rarely used for RFID



UHF Standards



	EPCglobal Gen2	AutoID Class 0	AutoID Class 1	ISO 18000-6 Type A	ISO 18000-6 Type B
Air Interface	PIE-ASK BPSK FM0	PWM/FSK	PWM/PIM	PIE-ASK Biphase AM	M-ASK/ Biphase AM
EPC	96, 256b	64, 96b	64, 96b	Not defined	Not defined
Memory	128-1024b R/W	256b read only	256b RW	64kb RW	2kb RW
Data Rate	40-640 kb/s	40/80 kb/s	70/140 kb/s	33/40 kb/s	8/40 kb/s
Arbitration	Probabilistic slotted	Deterministic binary tree	Deterministic slotted	Probabilistic slotted	Probabilistic binary tree
Frequency, MHz	860-960	902-928	902-928	860-930	860-930
Security	32-bit kill, access	24-bit kill	8-bit kill	None	None

- **900 MHz UHF is the preferred band for supply-chain applications**
 - Walmart and DoD mandates
 - Rollouts in Europe, North America (and likely Asia)
- **The explosive growth in UHF RFID is the primary reason for our discussion today**



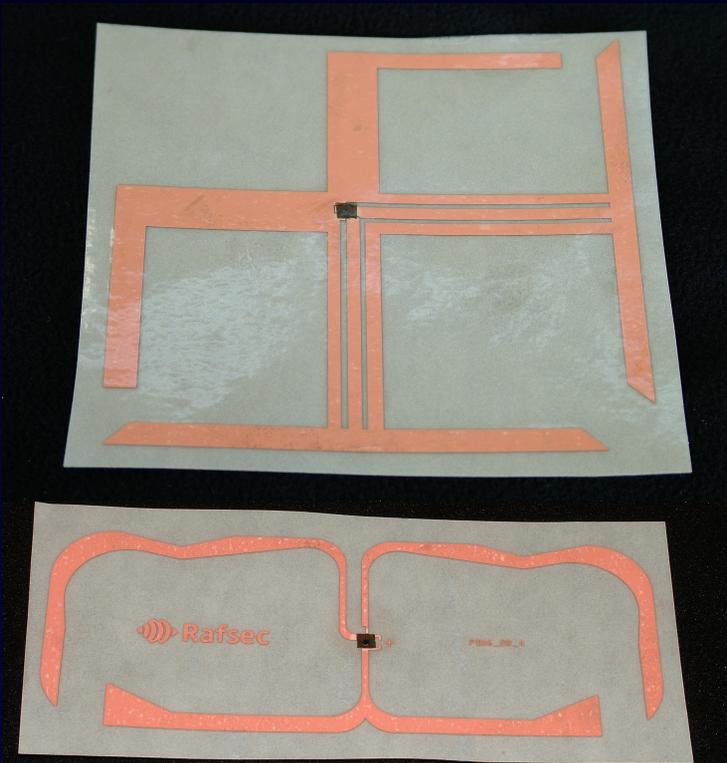
EPCglobal Gen2



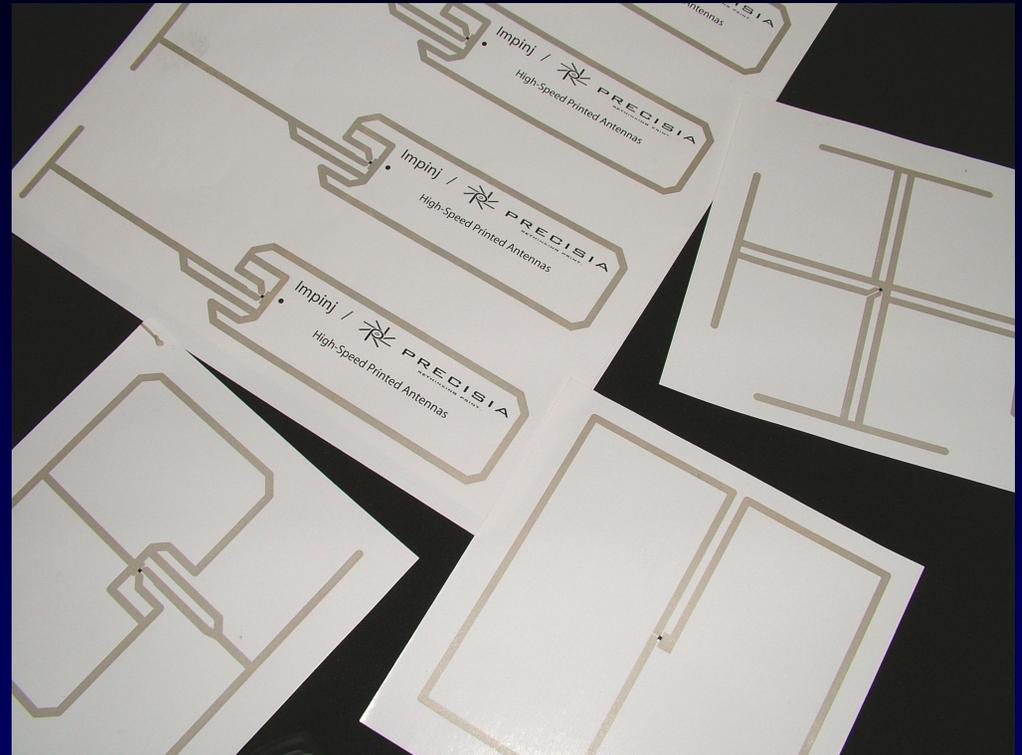
- **Single worldwide UHF standard**
 - Poised to replace existing EPCglobal Class-0/1 specs
 - Poised to supersede ISO 18000-6A/B spec
 - Gen2 will become 18000-6C in ISO
 - Candidate specification approved last week
 - Production volumes in 2Q05
- **High performance**
 - 1500 tags/sec in North America
 - 600 tags/sec in Europe
- **Access control and privacy**
 - 32-bit kill and access passwords
 - Secure R->T communications
 - Reader does not transmit EPC
- **Global regulatory compliance**



Form Factors - Tags



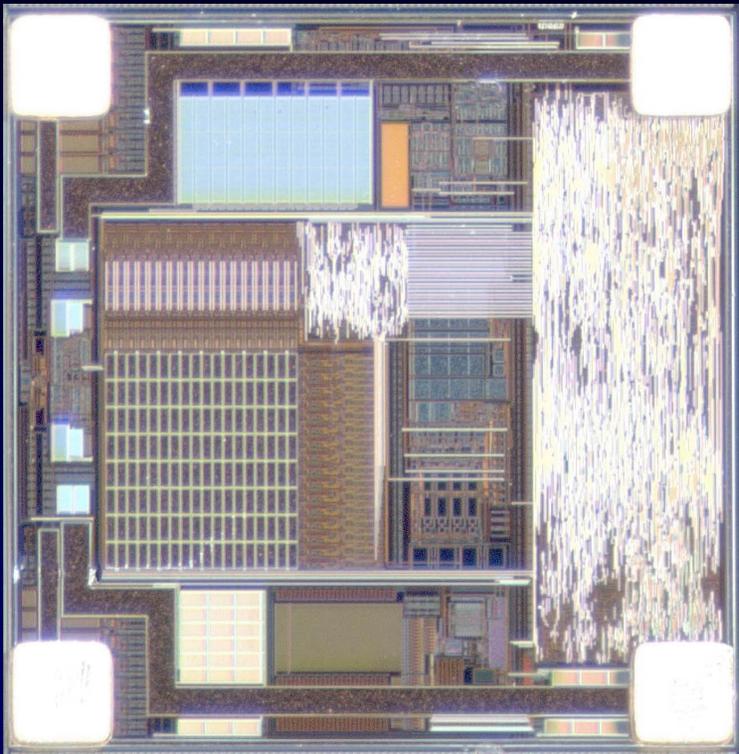
Copper on PET
(Highest Performance)



Silver Ink on Paper
(Lowest Cost)



Zuma RFID™ Chip



- Read range > 11 meters
- Write range > 8 meters
- Essentially a microprocessor with an RF interface and nonvolatile memory
- 41,798 transistors
 - Comparable in complexity to an Intel 8086
- Consumes **8 μ W** of power
- About the size of a grain of sand



Form Factors - Readers



Demo/Development Platform

Commercially-Available



Overview

- Motivations for RFID
- State of the industry
- **Regulatory implications**
- Comments



Implications of Part 15

- **Subpart 15.247 in Part 15 doesn't mention RFID**
 - Half-duplex communications
 - Passive backscatter
- **Subpart 15.247 in Part 15 doesn't preclude RFID**
 - Existing readers Class-0/1 and 18000-6A/B are certified for operation in North America
- **A tag is a passive modulator**
 - Unpowered RF reflector
 - Changes its radar cross section to convey information
- **Returns from equivalent systems (Doppler radars) are not regulated**
 - Vehicular speed sensors
 - Altimeters

... even though these returns carry target-specific information (such as distance, velocity, and acceleration)

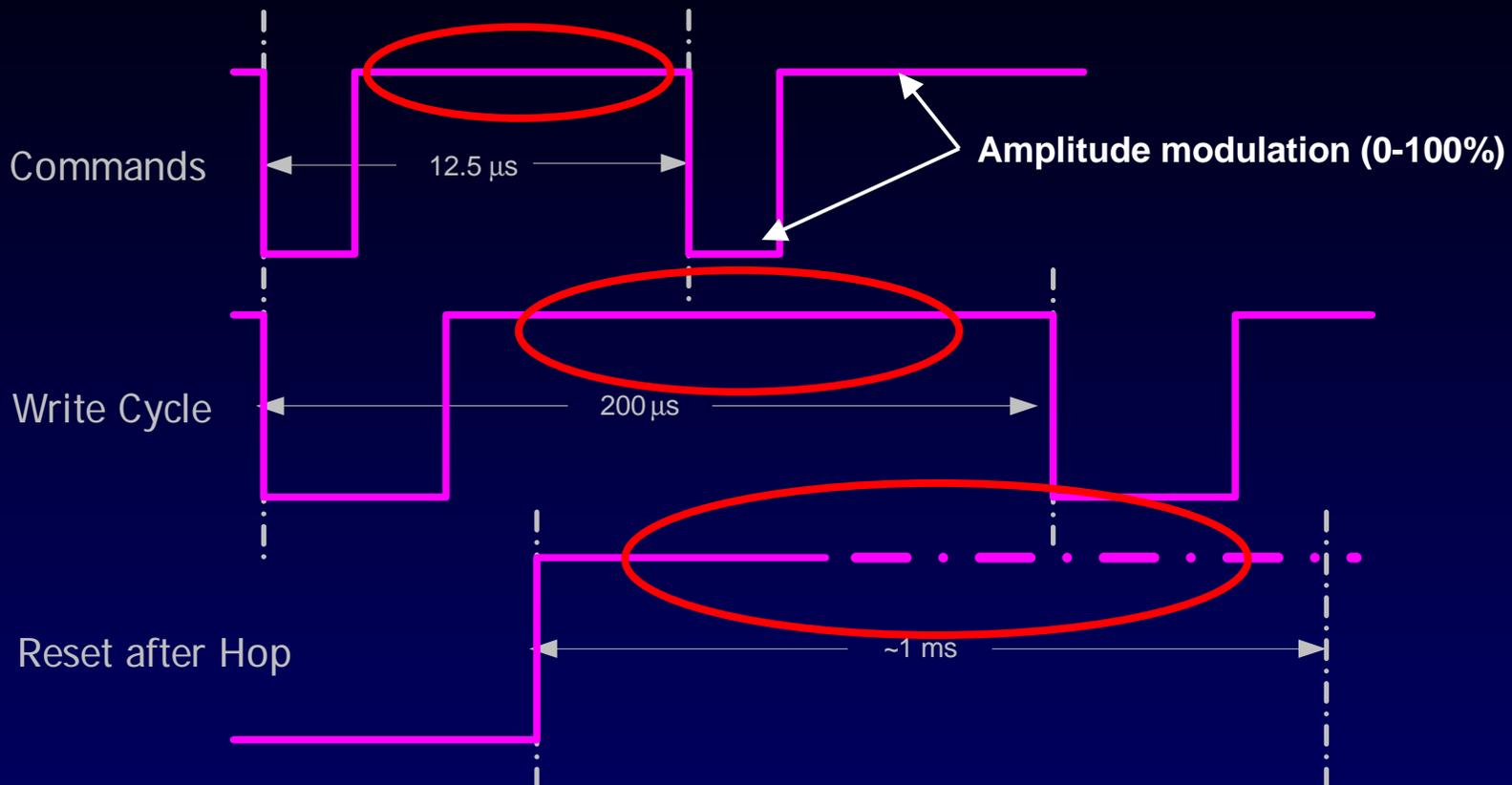


Regulatory Trip-Wires

- Part 2.1 states: "*Frequency Hopping Systems. A spread spectrum system in which the carrier is modulated with the coded information in a conventional manner causing a conventional spreading of the RF energy about the frequency carrier.*"
- Part 15.247 (a) (1) states: "The system receivers shall have input bandwidths that match the hopping channel bandwidths of their corresponding transmitters and shall shift frequencies in synchronization with the transmitted signals."



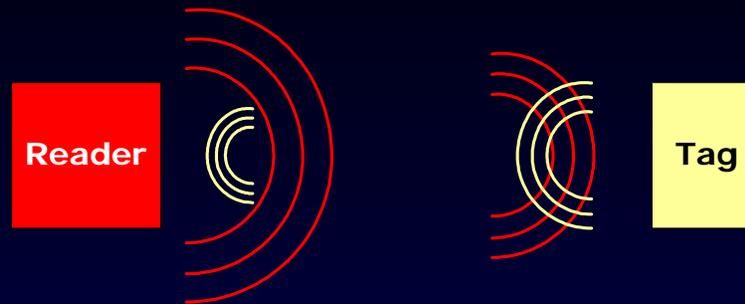
What Constitutes CW?



- **A reasonable definition: "Any useful modulation present between hop intervals does not constitute CW"**
- This could affect tag-talks-first RFID
- All current UHF standards are reader-talks-first



How is Bandwidth Defined?



- **Passive RFID tags put out no energy**
 - Not a transmitter from a *power* viewpoint
- **Passive RFID tags remodulate incident energy**
 - Are a transmitter from a *signals* viewpoint
- **Passive RFID systems do have a forward link and a return link**
 - Bandwidths are consistent within each
 - This is a characteristic of all practical, existing and proposed, UHF RFID systems
 - Side note: tags are not terribly frequency-selective, yet inherently hop frequency in sync with the reader
- **Reasonable definition: passive RFID systems have matched bandwidths in “transmitter” and “receiver”**



- **RFID will be crucial to the US economy**
 - Productivity gains in supply chain management
 - Support of global trade, with traceability at our borders
 - The industry itself
- **Regulatory issues are benign in the US**
 - But common-sense interpretations of Part 15 should be codified
- **Large (and exponentially growing) installed base of FCC-certified readers is underway**
 - New standards are fully consistent with approved practice
 - Wal-Mart requirement on its top 100 suppliers becomes operational in less than 3 months
 - Wide adoption by manufacturers and other retailers expected within 6-9 months



An Idea Whose Time Has Come



- 6 of top 7 retailers worldwide
 - > \$1 trillion revenue
- Wide support from manufacturers
- Poised to become pervasive and ubiquitous
 - Will we remember what it was like before RFID?

