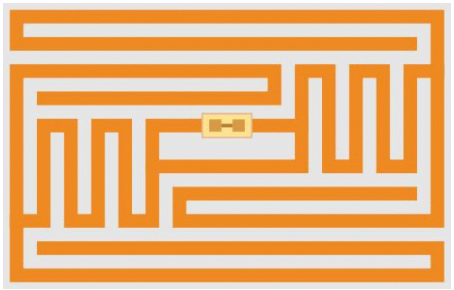
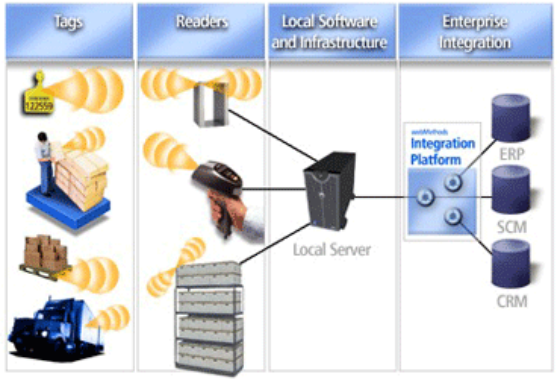
ECE 5990





Note 2

Technical Overview of RFID Operations

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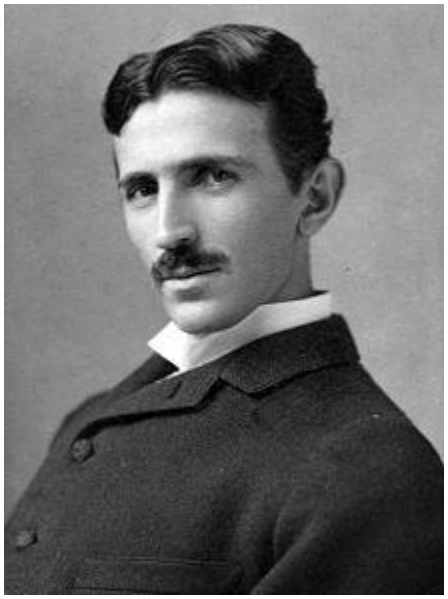
Outline

- Ideal RFID systems
- Practical considerations and constraints of RFID
  - Sensitivity
  - Ambient interference
  - Antenna orientation
  - Multiplexing and inter-tag interference
  - Multi-reader, multi-tag interference
- Other desirable RFID functions
  - Security and privacy
  - Locating and real-time tracking
  - Last leaf in femtocells of network

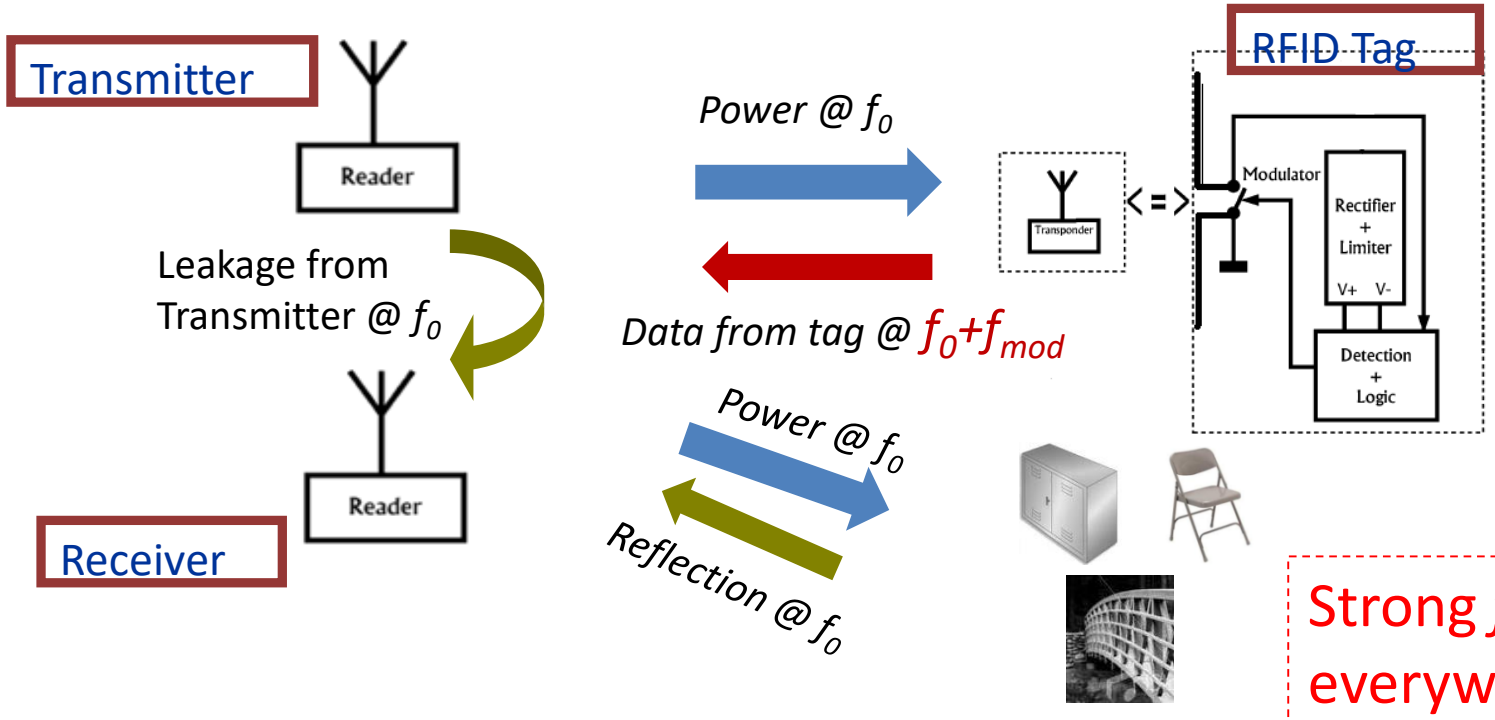
Quotable Quotes

“Today's scientists have substituted mathematics for experiments, and they wander off through equation after equation, and eventually build a structure which has no relation to reality.”

— Nikola Tesla (1856 – 1943)



Conventional Backscattered Passive RFID



Strong f_0 everywhere for indoors, even near resonance

Conventional Passive RFID System

Backscattering Modulation

- Biggest Challenge: Self and multi-path interference

Ideal RFID System (ID Acquisition) 1

1. A well-defined read zone for each reader. The reader has a 100% read rate for tags within its read zone, and a 0% read rate for tags outside its read zone.

   (Readers and tags interfere with one another in overlapped read zones)

   (Tag-tag interference; other-reader-tag interference; reader-reader interference, etc.)

2. Performance is insensitive to the physical orientation of tags.

   (No isotropic radiation from any one physical antenna possible. Always a nearly blind spot)

3. Performance is insensitive to the nature of the object on which the tag is placed.

   (Metal, water, body, and large radar-cross-section objects all change radiation and backscattering significantly)

4. Performance is insensitive to the environment.

   (Human body movement, large walls, package of water, etc., can all affect)

Ideal RFID System (ID Acquisition) 2

5. Multiple tags communicate with the reader in a collision-free manner and the time for reading a fixed number of tags can be known a priori.

   (Tag antennas, collide, interfere and detune each other. For some logistic applications, the number of tags in the read zone cannot be known beforehand, and sometime even an upper bound is difficult to predict.)

6. Performance is unaffected by multiple readers with overlapping read zones, or by multiple tags within a read zone.

   (A polling process to count and sequence tags, and readers, often due to bandwidth constraint, will reduce performance with increasing numbers of tags and readers)

7. Performance is unaffected by relative motion between the readers and the tags as long as the read zone is maintained.

   (Tag velocity can affect signal strength, and often is limited in a protocol).

Ideal RFID System (Extra Features)

1. High level of **security** and privacy.

   (Limited security in present protocol of IPX and EPC)

2. **Locating** of each tag within the read zone with high level of precision and fast refresh rate.

   (Very immature)

3. **Low cost** of RFID components and high return of investment.

   (Tags are around 20 cents; readers are still about $500)

4. **Easy integration** of RFID software into existing application software.

   (NFC in Linux, but IPX/EPC are still uncertain)

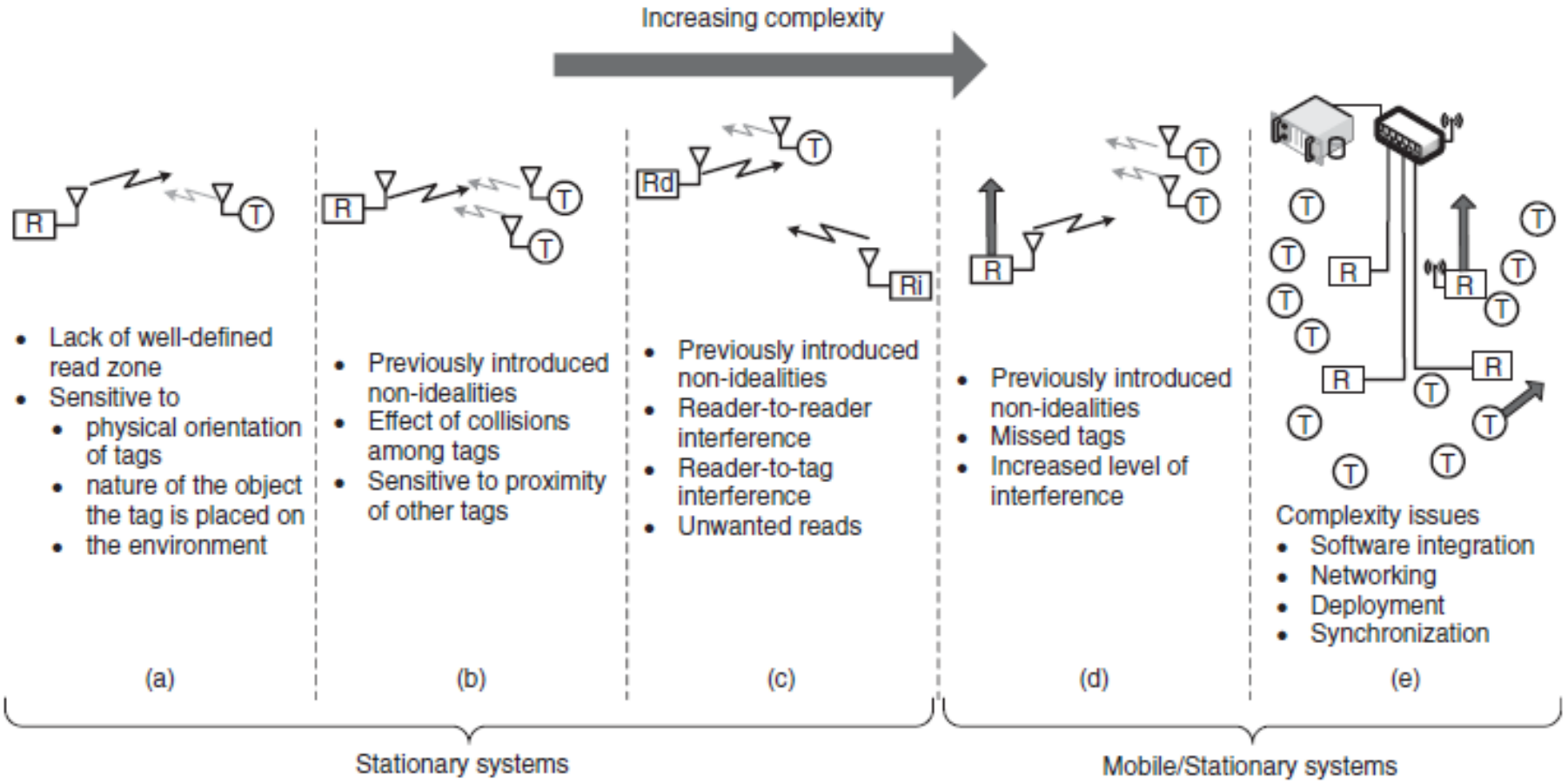
5. **Simple deployment** of multiple tags.

   (Only true for passive tags. Batteries in tags are costly and hard to deploy)

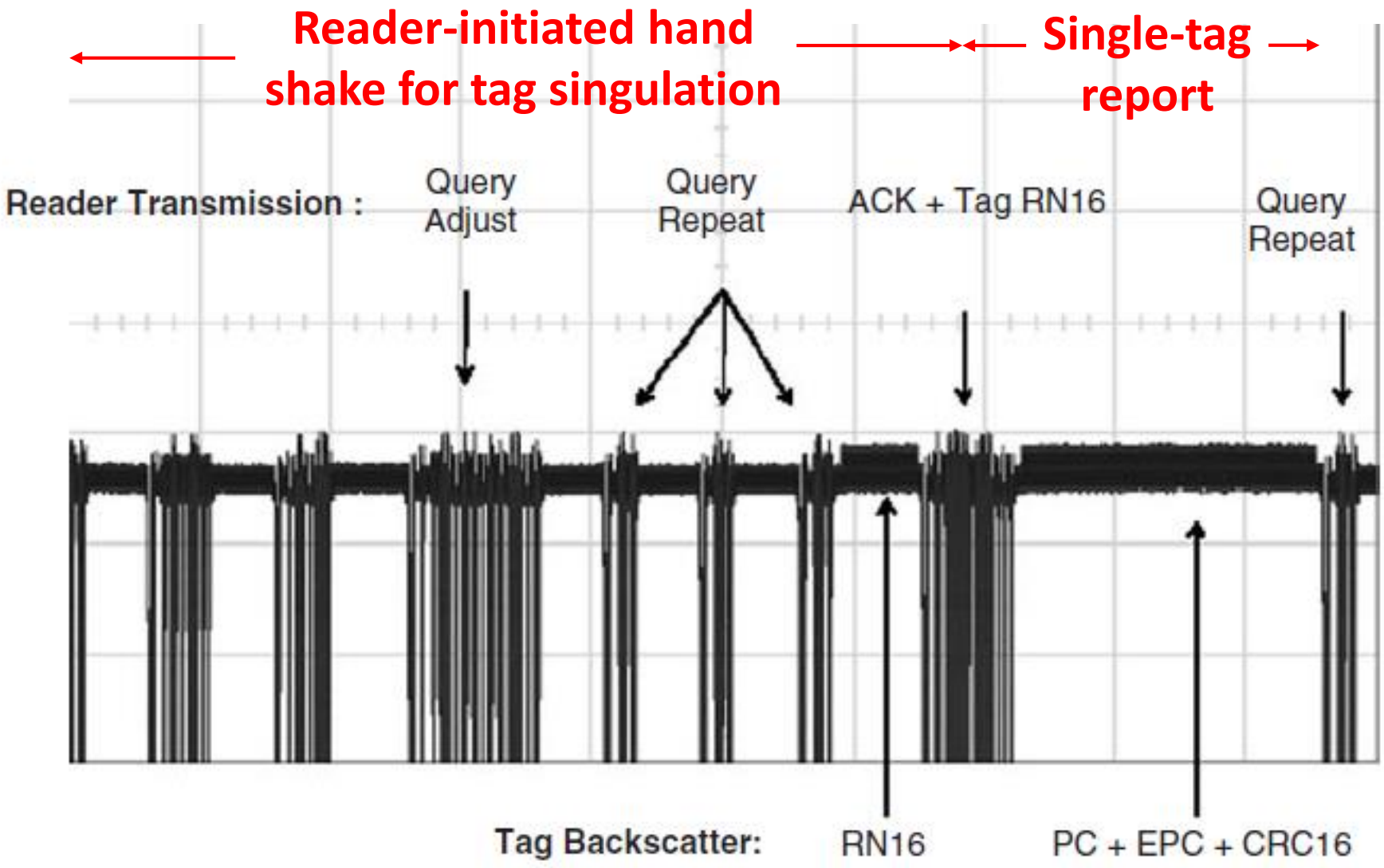
6. Simple deployment and easy **synchronization** of multiple readers.

RFID System Complexity

a) One reader, one tag
b) One reader, multiple tags
c) Multiple readers, multiple tags
d) Multiple reader/tag in motion
e) Complex active/passive wireless and wired networks



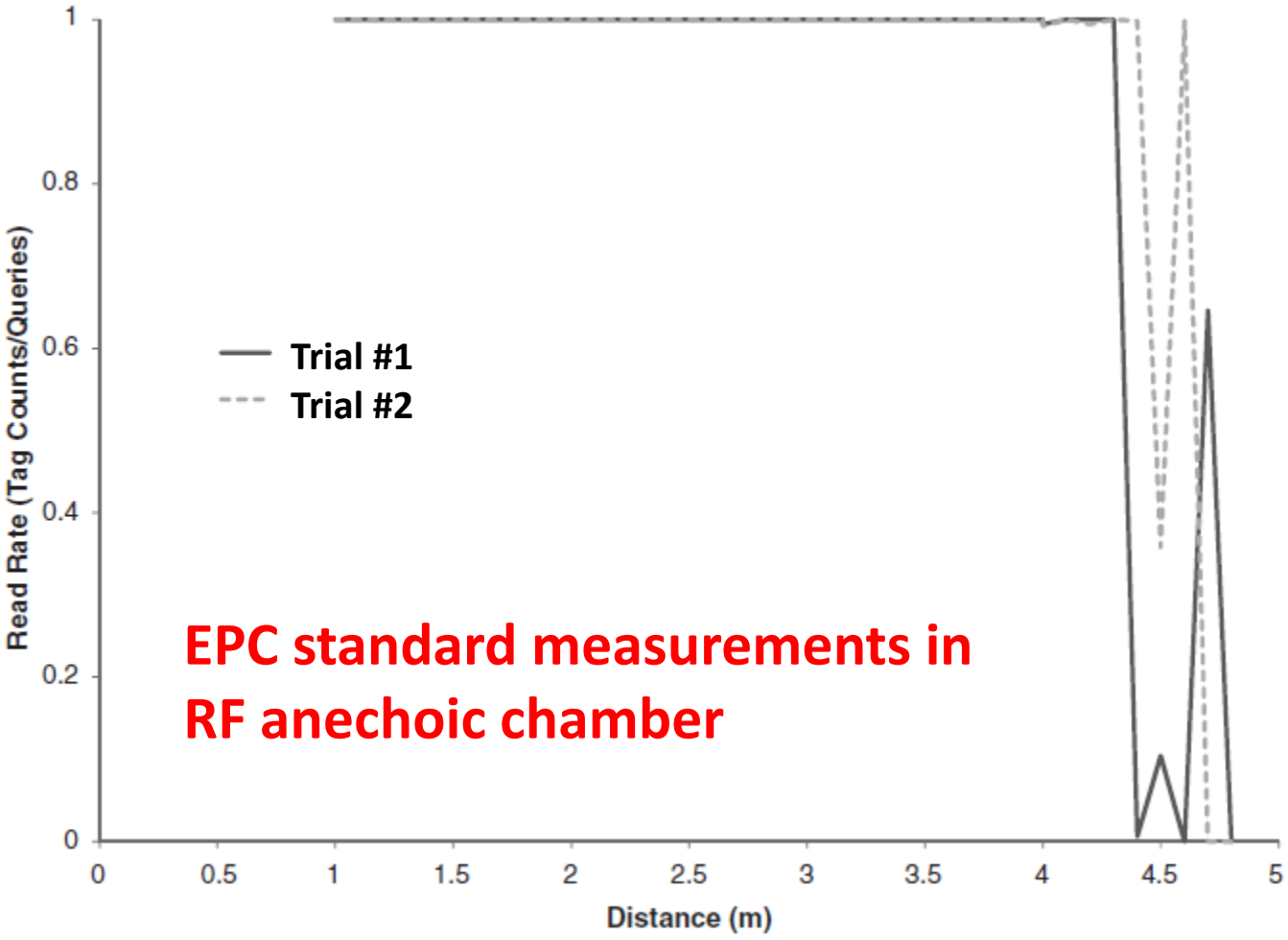
Reader Quires and Tag Handshake



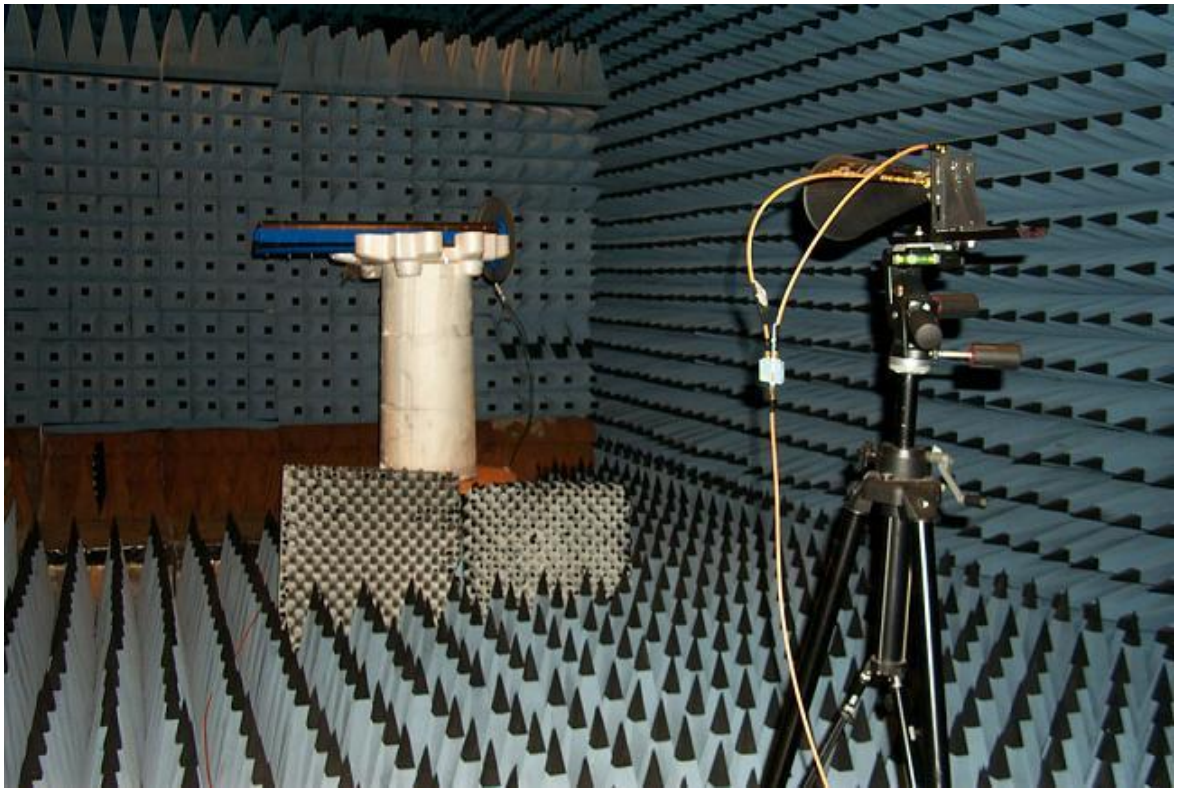
More details in air protocol and EPC Gen 2 standards

Lack of Well-Defined Read Zone

- Read rate depends on distance and ambient
- Measurement in RF anechoic chamber.



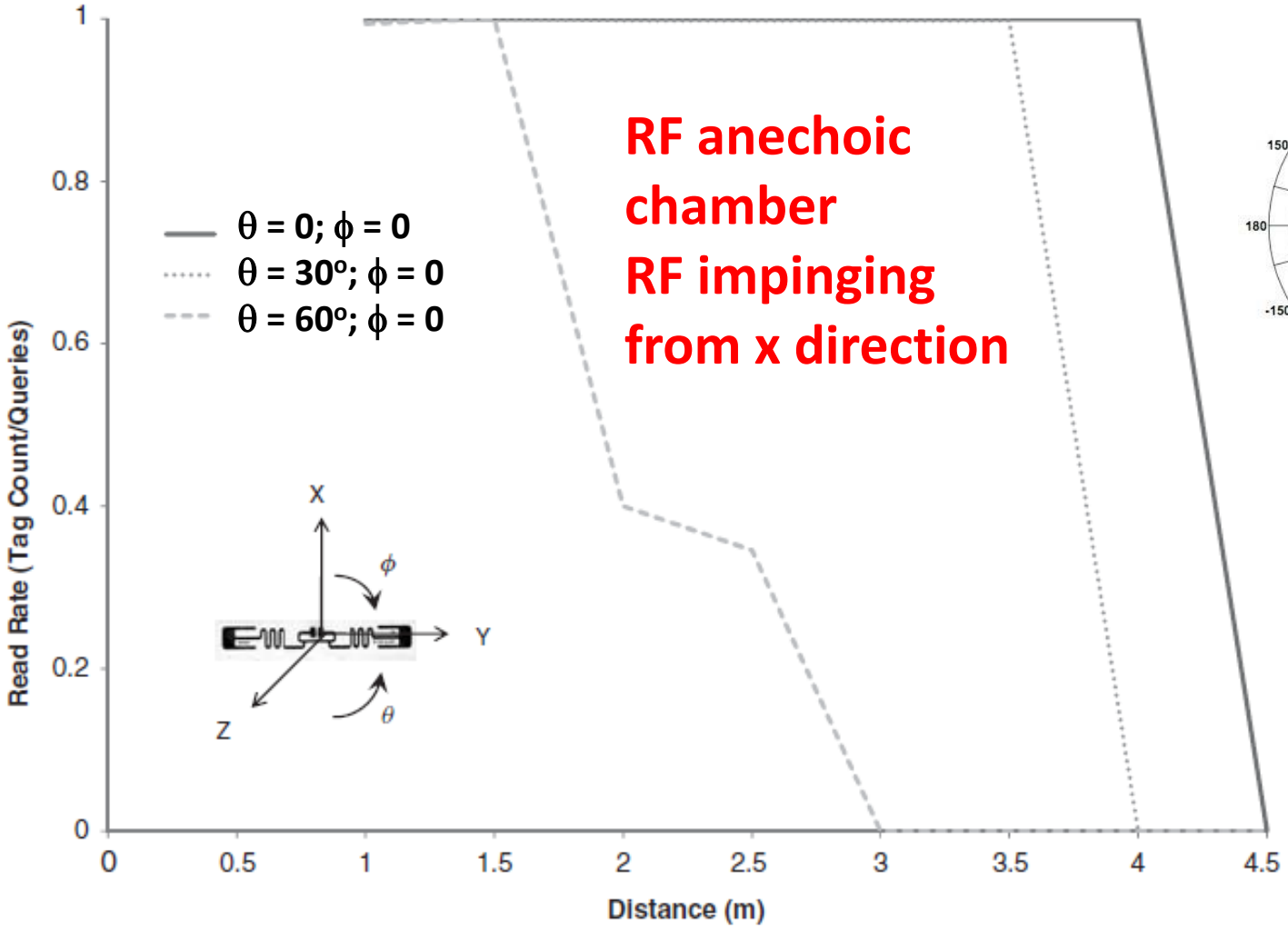
Anechoic RF Characterization

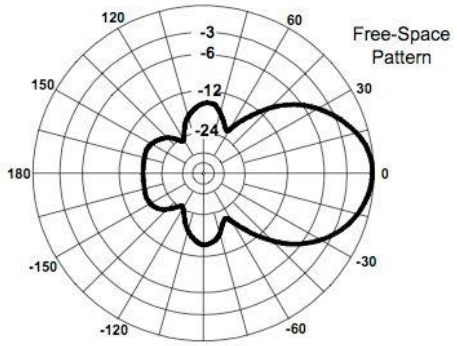


- Removal of RF echoing helps characterization of various interference sources: self, ground, stationary/moving objects, etc.
- Required for FCC (Federal Communications Commission) RF radiation and ISO (International Standard Office) SAR (Specific absorption rate) regulations.

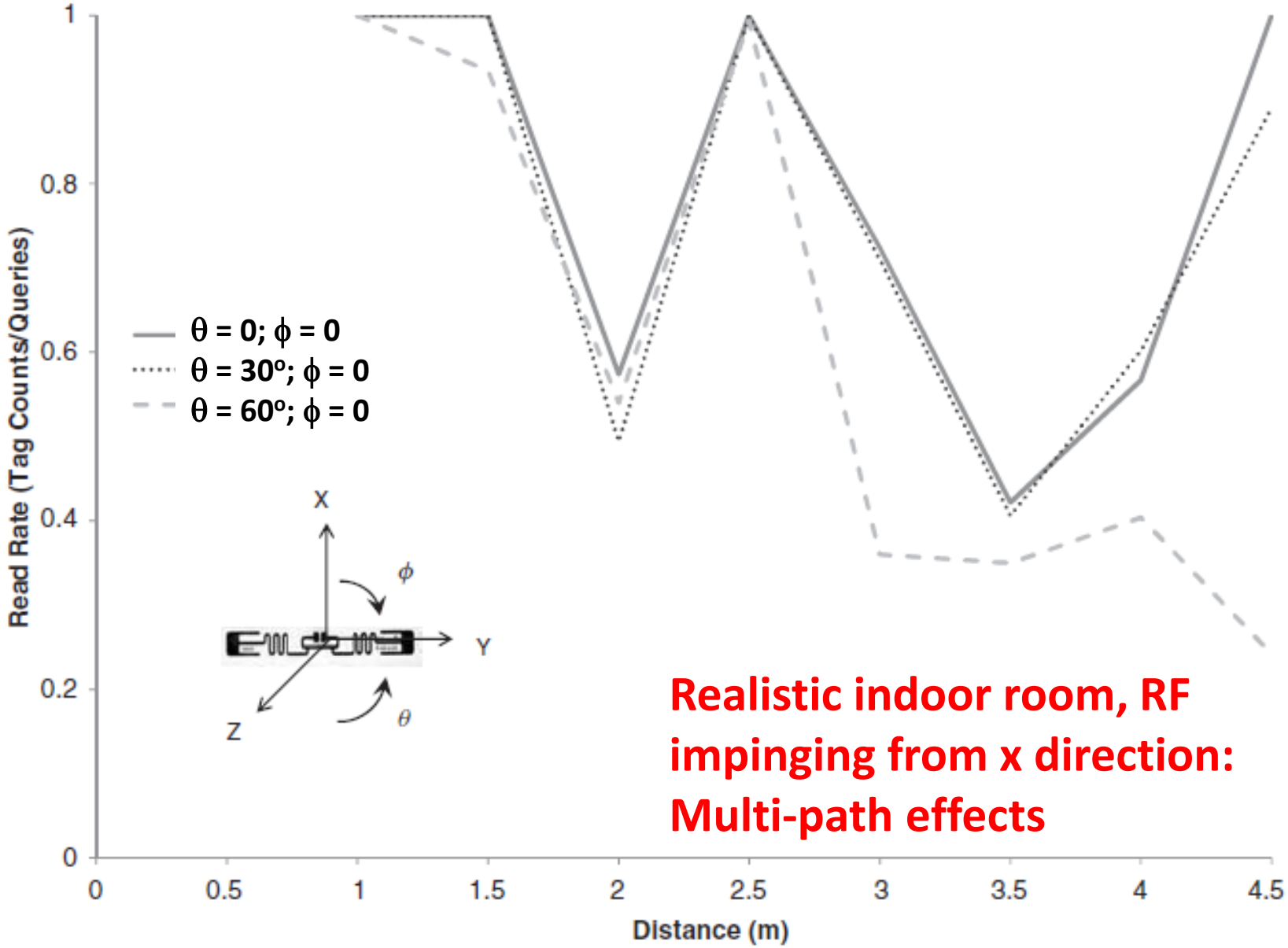
Tag Orientation Dependence

- No single antenna can achieve isotropic radiation
- Printed antenna has a plane of literally no radar cross section





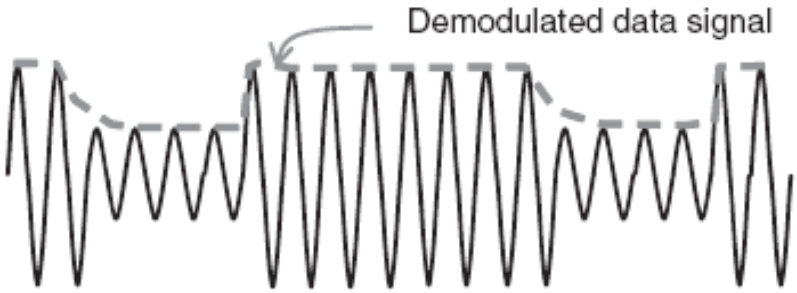
Tag Orientation Dependence



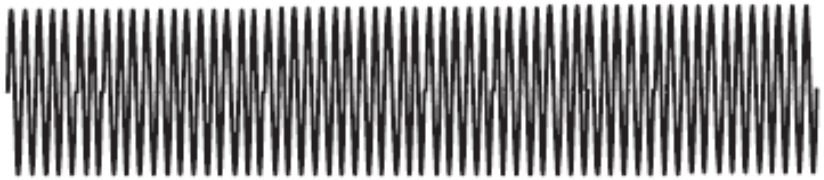
Multi-path Scattering for Indoors

- Ground
- Ceiling
- Power grid
- Wall
- Metal cabinet
- Desk
- Furniture
- Computer
- People
- Moving objects

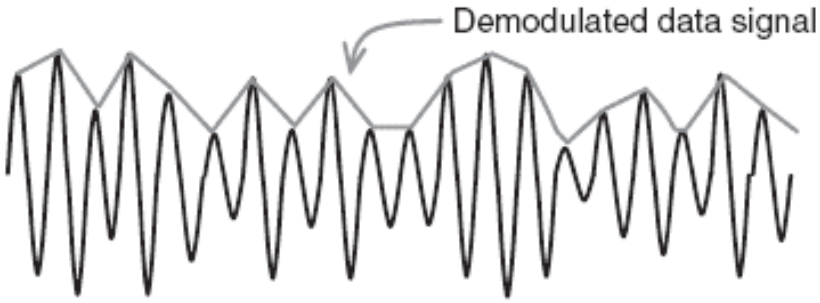
Collision Between Tags



(a) Carrier modulated signal received without interferer



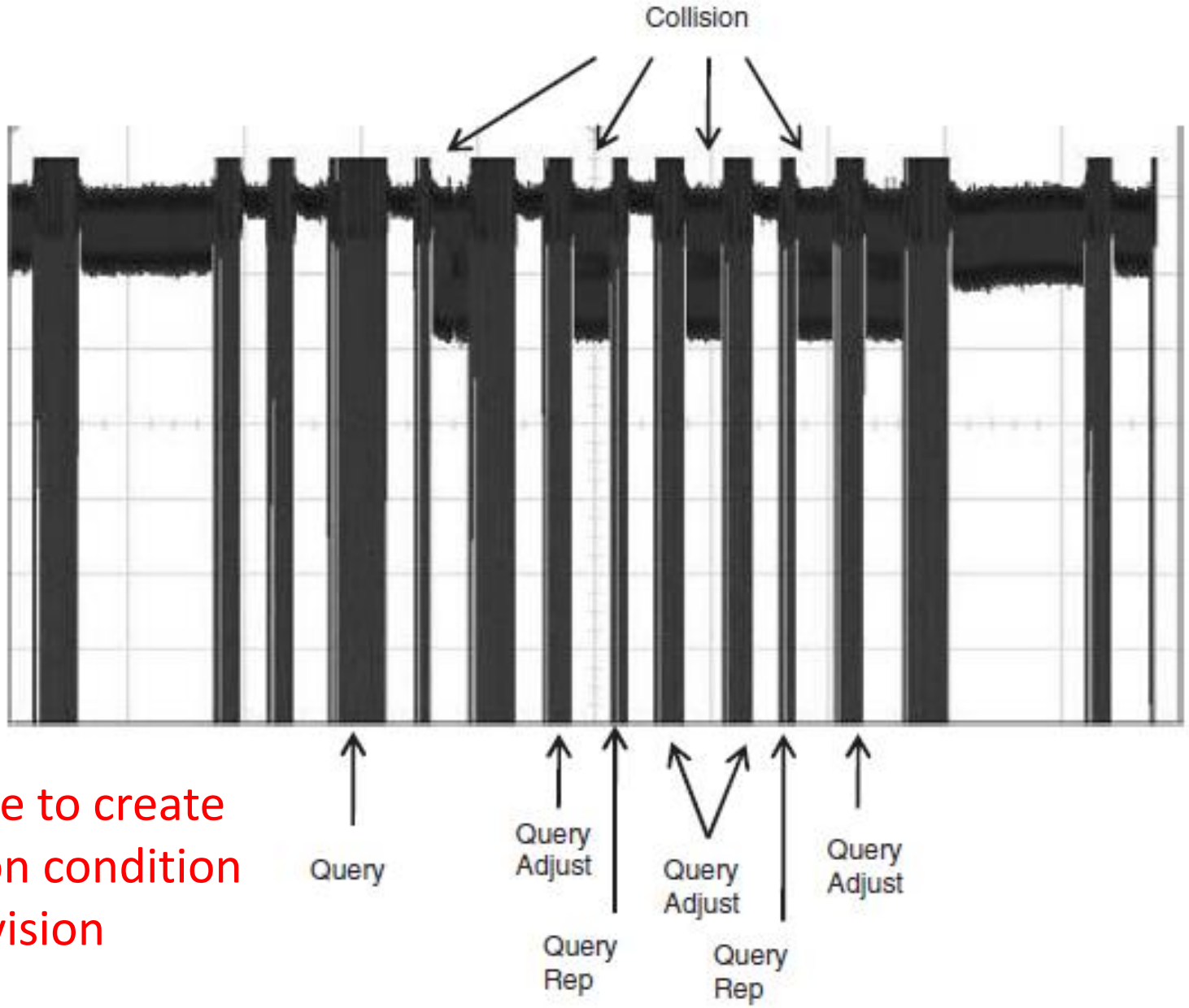
(b) Interfering carrier in another channel



(c) Corrupted data signal

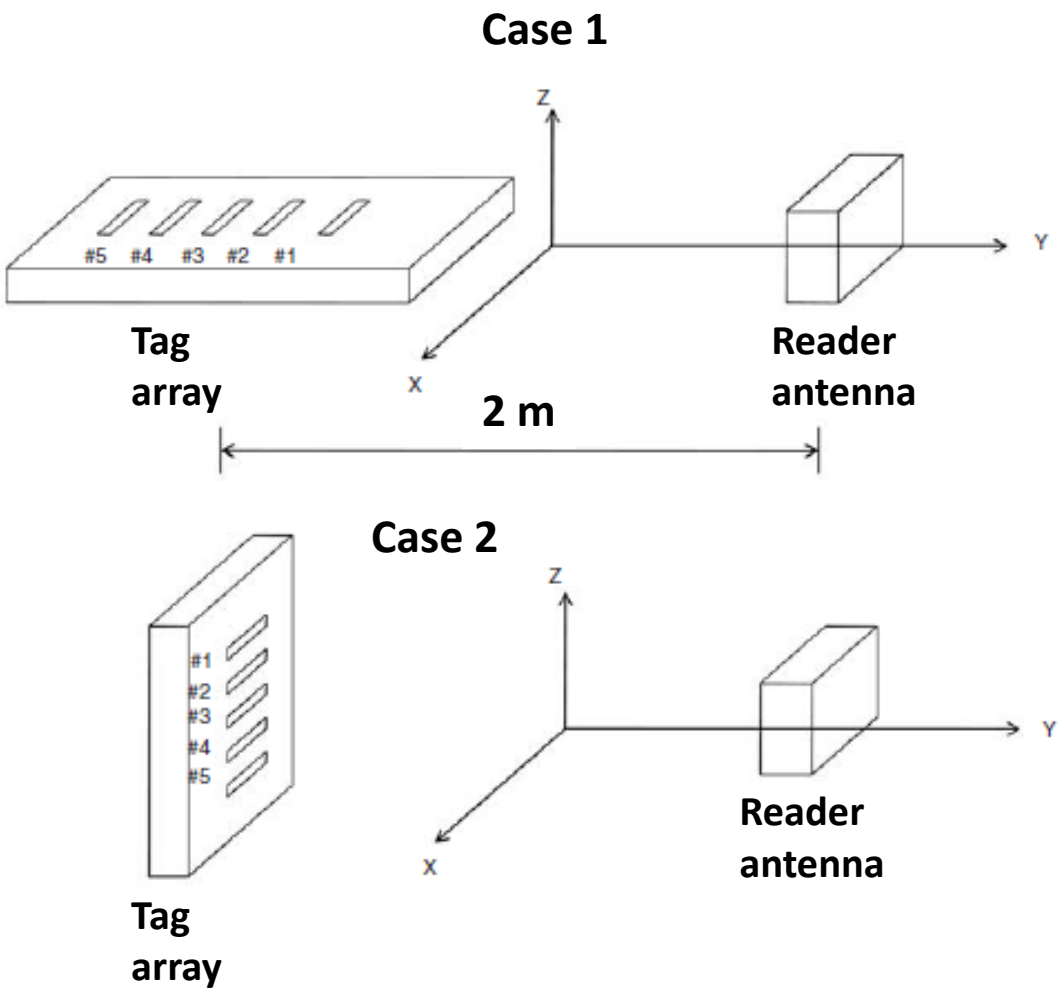
- In-channel or out-channel collision
- Inter-tag collision degrades read speed greatly.
- Anti-collision air protocol is needed for tag singulation using time division.
- If the number of tags is known *a priori*, resolution is much easier.

Collision at Query Mode (In Channel)



Query mode to create non-collision condition by time division

Tag Antenna Detuning in Proximity



The tag singulation has been performed: only one tag responds at a given time interval, but there are still near-field antenna detuning for intertag interference.

Read Rate	Case 1	Case 2	Well separated
Tag 1	0.98	0.45	0.98
Tag 2	0.98	0.01	0.98
Tag 3	0.56	0.02	0.97
Tag 4	0.38	0.18	0.98
Tag 5	0.11	0.87	0.98

Intertag Interference: Fundamental Issues

?DMA: ? division multiple access

- Why time division is the most popular way to resolve intertag interference in the RFID system with one reader and multiple tags??

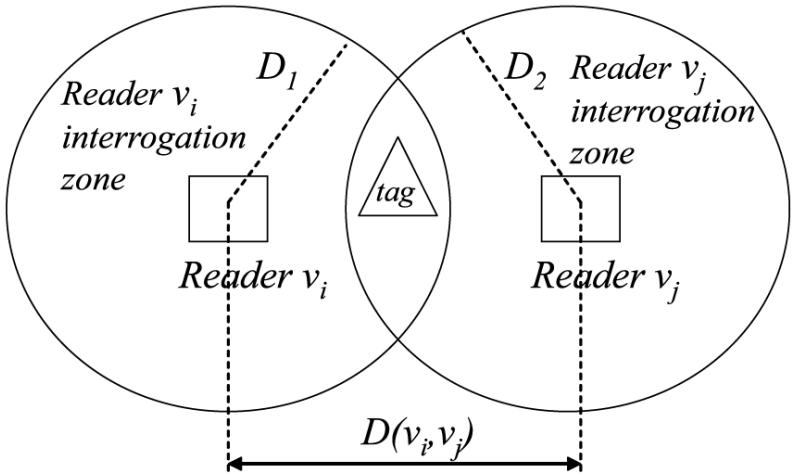
- Spatial division (radiation has beam forming so that different tags are in different “zones”)?
- Frequency division (each tag responds in a different subband)?
- Code division (each tag has an orthogonal code to modulate the backscattering wave)?

Reader-Reader Interference

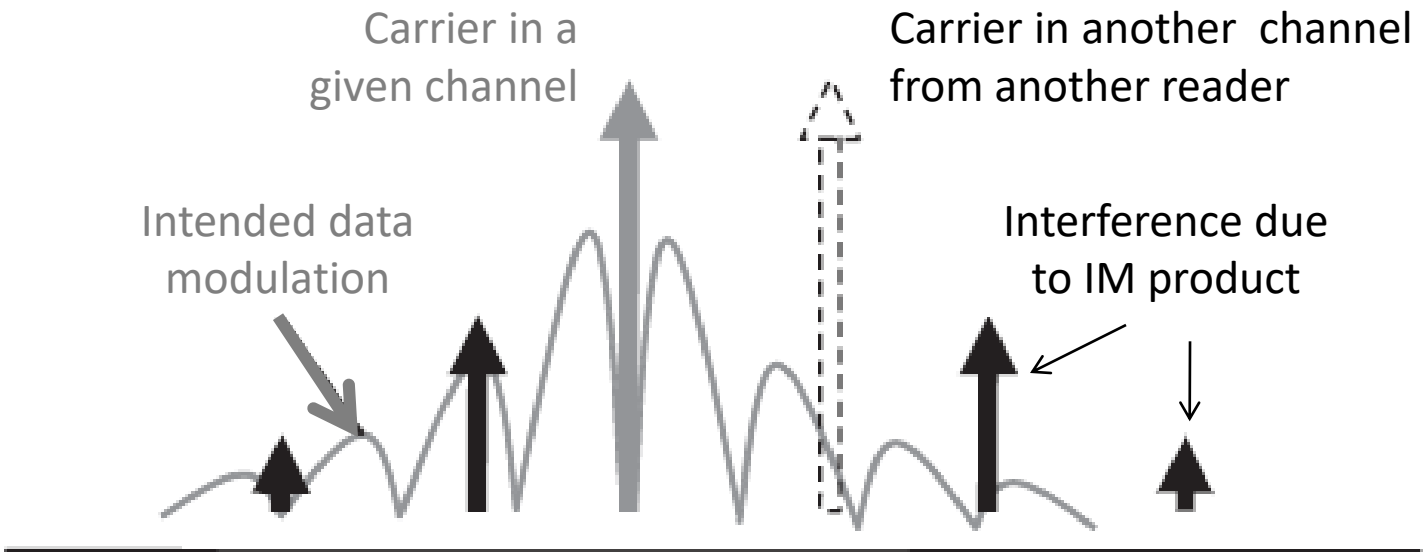
Reader 1 Mode	Reader 2 Mode	Reader 1 read rate	Reader 2 read rate
BLF = 256kHz	OFF	0.98	-
OFF	BLF = 200kHz	-	0.98
BLF = 256kHz	BLF = 200kHz	0.35	0.39

BLF: backscattering link frequency

- Reading the same tag 2 meters away with the same EPC query and singulation steps
- No synchronization between readers
- Signals from another reader at the receiver is often much stronger in strength off band and in band: has to rely on modulation or timing
- Additional reader-tag interference.



Reader Out-of-Channel Interference

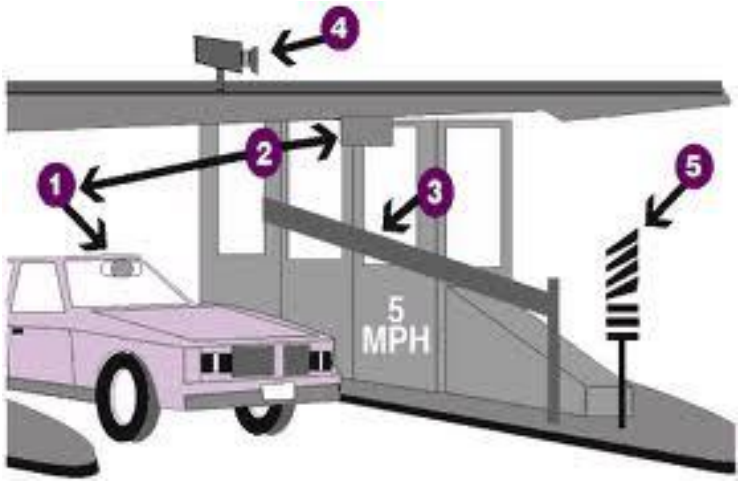


Intermodulation (IM) product due to another reader in another channel can interfere the intended data demodulation.

Mobile Readers and Tags

- Motion may be purposely introduced to improve read rate, as antennas have “blind spots”.
- Stationary “landmark” tags are often added for calibration.
- 15 km/h or 0.5m/s is considered sufficiently slow, and can be adopted by most RFID systems
- Tag-talk-first (TTF) protocol allows faster tag speed than reader-talk-first (RTF)
- Important applications in conveyer belts and “Easy Pass”.

1. E-Z pass tag
2. Tag reader
3. Car restraining device
4. Monitoring camera
5. Information display

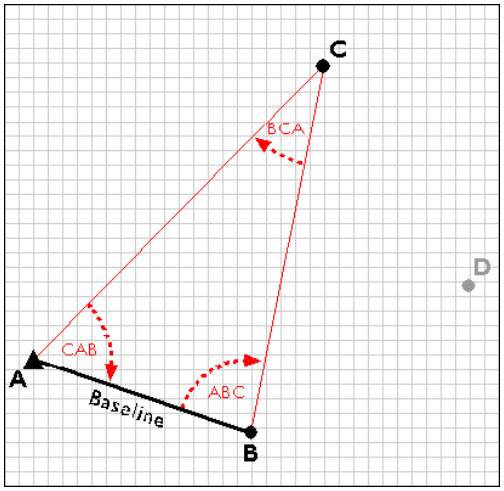


Security and Privacy in Passive RFID Tags

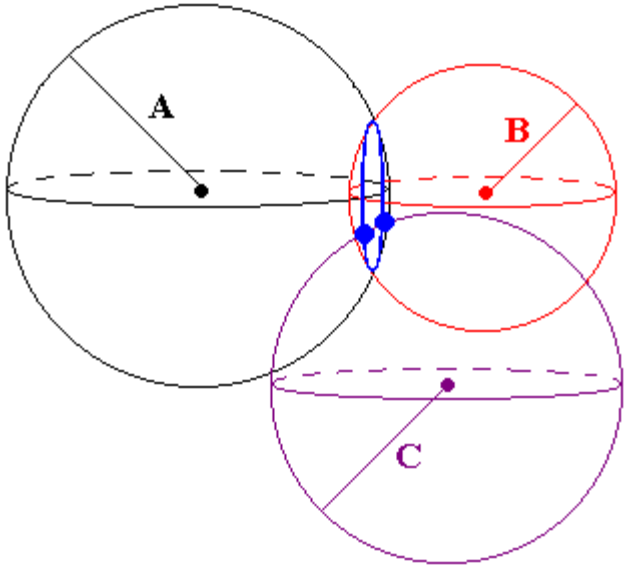
- Backscattering is difficult to achieve security and privacy without heavy air protocols and complex tag circuits
- Prevention of eavesdropping can be readily achived for readers, not for passive tags
- Ability to modify and kill the tag responses is included in EPC
- Security and error correction are related in cost and reliability
- NFC has less multiplexing and privacy issues.

Real-Time Ranging and Locating of RFID Tags

- Real-time locating system (RTLS) is yet to be realized for indoors
- Received signal strength (RSS)
- Center of origin (COO)
- Time of arrival/flight (ToA or ToF)
- Time difference of arrival (TDoA)
- Continuous wave (CW) phase-based:
  - Dual frequency continuous wave (DFCW)
  - Multi-frequency continuous wave (MFCW)



Triangulation



Trilateration

What Did You Learn

- Ideal RFID system expectations
- Tag antenna orientation
- Multi-path backscattering
- Multi-tag collision and detuning
- Reader interference
- Additional desirable RFID capabilities