Workshop on

Tag Localization in Passive UHF RFID

Outline

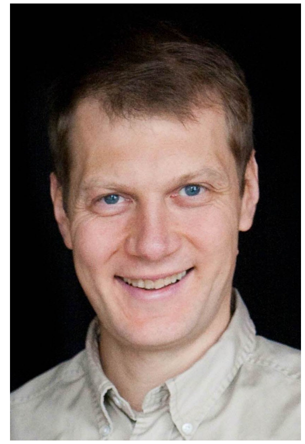
Intermec Technologies

- **Introduction / Basics**
  - Why localization? Why is it so difficult?
- **UHF RFID Channel**
  - Analysis / Simulations
- **Ranging Methods**

Coffee Break

- **Applications and Use Cases**
- **Demonstrations**
  - UHF/UWB Hybrids: The future?
  - Video demo: Circular Array
  - Live demo: ITCS

Speakers – Pavel Nikitin



Principal, Intermec Technologies and Assistant Prof., Univ. of Washington

Localization Methods

Speakers – Justin Patton

Managing director, University of Arkansas' RFID Research Center

Market Requirements, Applications, Use Cases

Speakers – Zhuo Zou

PhD student, Royal Institute of Technology, Sweden

UHF/UWB Hybrid

Speakers – Lyazid Aberbour

Research assistant, University Catholique de Louvain, Belgium

Prototype 2D AoA

Speakers – Chris Hook, Joe Leone

Chris Hook (photograph)
Executive vice president, RF Controls

Joe Leone
Director, Logistics Automation Solutions, SAIC

Live Demo: ITCS

Speakers – Daniel Arnitz

PhD student, Graz University of Technology, Austria

UHF RFID Channel

Introduction – UHF RFID

9 780552 138901 >

barcode (EAN)

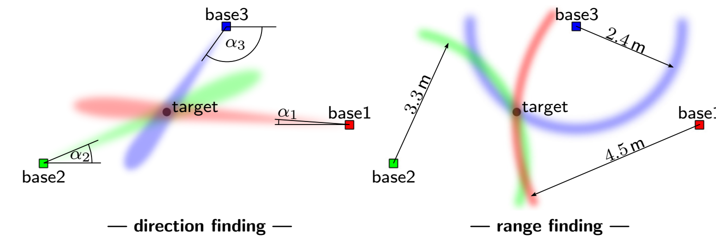
NXP Semiconductors

UHF RFID self-adhesive label

Introduction – Localization: Why/Where?

Upper images: Intermec Technologies, Lower image: Wikimedia (Kay-Uwe Rosseburg)

Introduction – How?



- **direction finding**
  - direction/angle-of-arrival (AoA)
  - beamsteering (mechanically and electrically)
- **range finding**
  - time-(difference)-of-arrival (ToA, TDoA)
  - mapped to phase: phase-of-arrival

Introduction – Why is it so difficult?

1. **Wireless Channel**
   - isolated reflection vs. dense multipath
   - clear skies vs. massive self-interference
2. **System Properties**
   - constant tracking vs. single communication
3. **Needed Accuracy**
   - 10 m error: airplane vs. tag

Images: Wikimedia (Peripitus), Intermec Technologies

UHF RFID Channel Analysis and Simulation Recommendations

Daniel Arnitz, Ulrich Muehlmann, and Klaus Witrisal

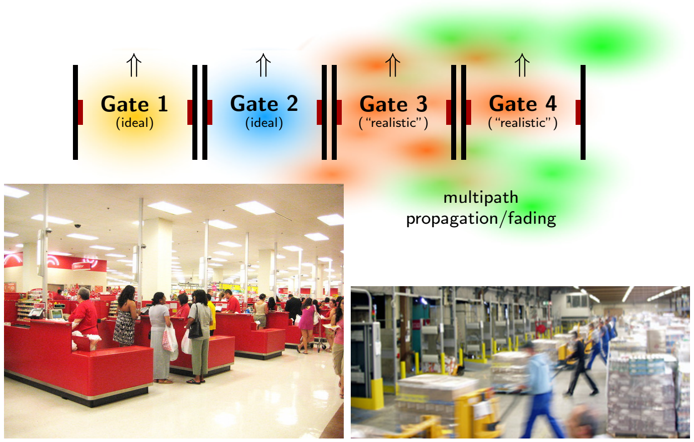
Graz University of Technology, Austria
NXP Semiconductors, Austria

This work has been funded by NXP Semiconductors and by the Austrian research promotion agency (FFG).

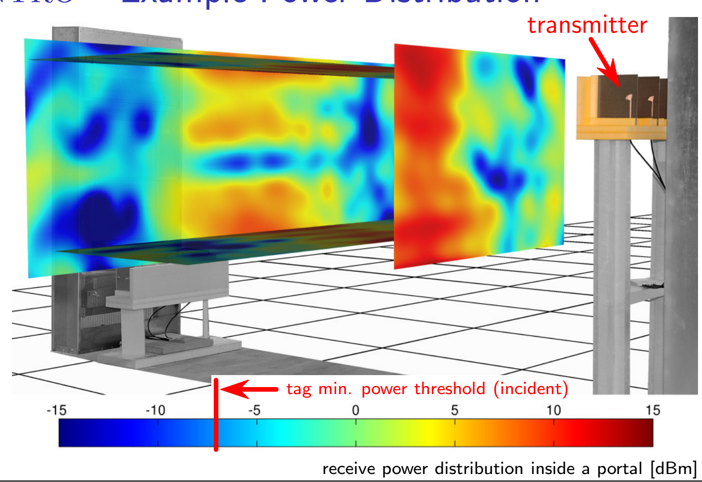
Outline

INTRO – Environments

INTRO – Readzone Management



INTRO – Example Power Distribution



Intro – Ranging/Localization

Ranging/Localization Methods

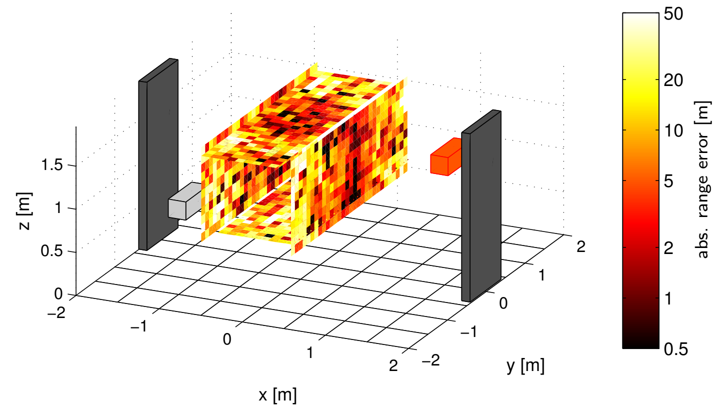
- within Gen-2 standard/spectrum: narrowband
- additional transmit signals: (ultra-)wideband

UHF RFID: Special Characteristics

- backscatter ⇒ pinhole channel
- short-range, small dimensions (enclosed space)
- attached to products ⇒ reflections close to the tag
- instable clock ($\pm 22\,\%$ drift, $\pm 2.5\,\%$ jitter)
- passive tags: nonlinear and highly variable (detuning)

Intro – Ranging Example

Phase-based ranging, $915/916$ MHz (top TX active):

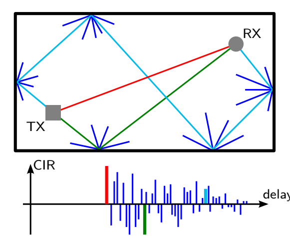


Outline

Theory – Wave Propagation Effects

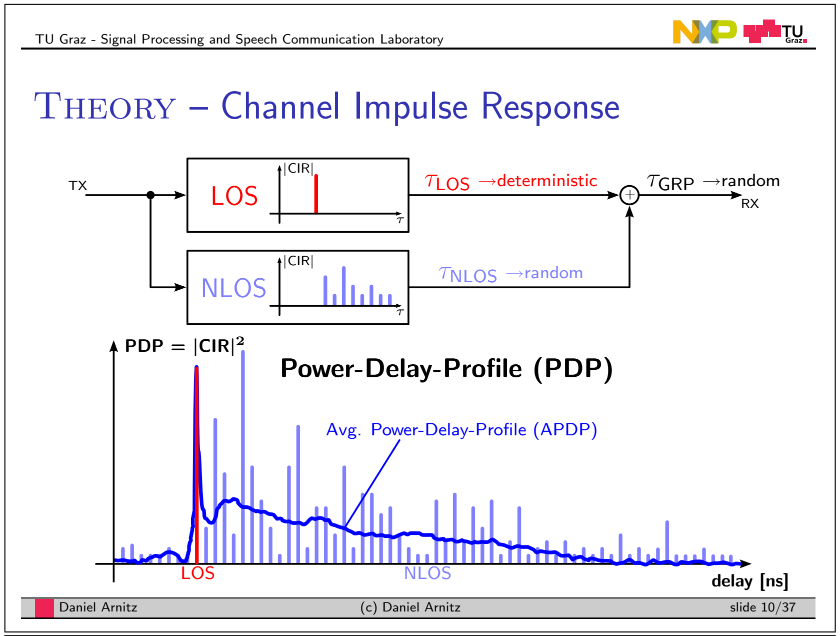
Multipath Propagation

- physical property (unavoidable)
- indoor: high number of paths
- time-variant



Physical Effects (Each Path)

1. free space path loss
2. reflection/transmission (large objects)
3. diffraction at edges
4. scattering at rough surfaces / small objects
5. waveguiding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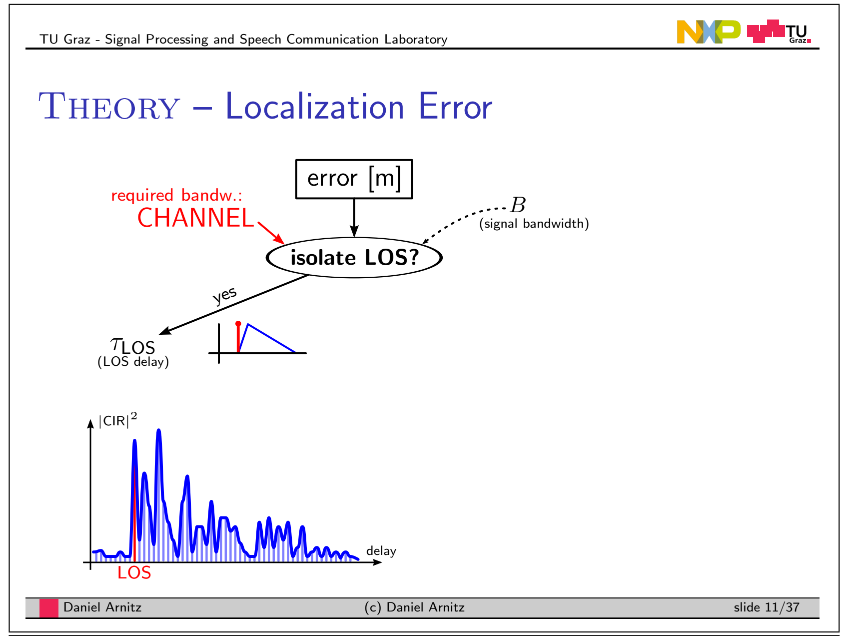
THEORY – Channel Impulse Response
TX
LOS
|CIR|
τ
τLOS →deterministic
τGRP →random
RX
NLOS
|CIR|
τ
τNLOS →random
PDP = |CIR|²
Power-Delay-Profile (PDP)
Avg. Power-Delay-Profile (APDP)
LOS
NLOS
delay [ns]
Daniel Arnitz
(c) Daniel Arnitz
slide 10/37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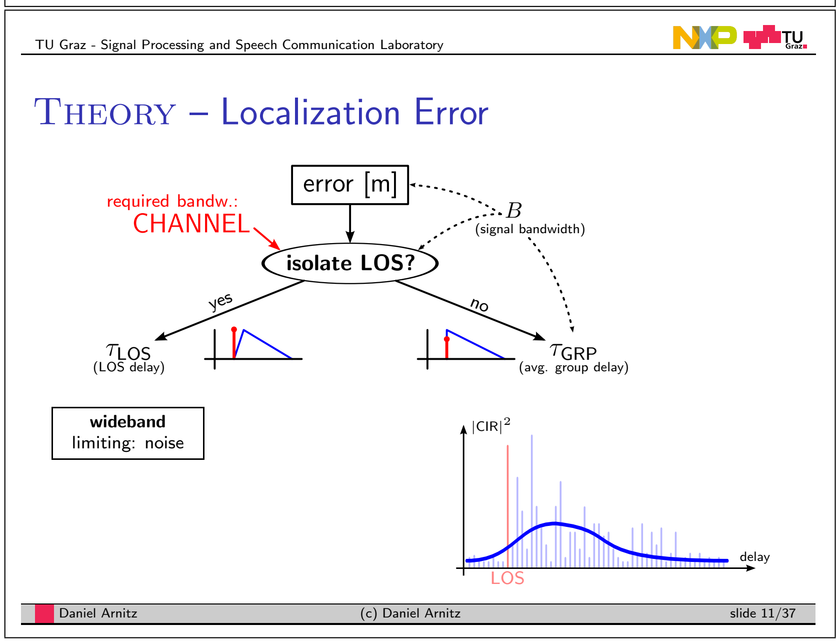
THEORY – Localization Error
error [m]
required bandw.:
CHANNEL
B
(signal bandwidth)
isolate LOS?
yes
τLOS
(LOS delay)
|CIR|²
delay
LOS
Daniel Arnitz
(c) Daniel Arnitz
slide 11/37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THEORY – Localization Error
error [m]
required bandw.:
CHANNEL
B
(signal bandwidth)
isolate LOS?
yes
no
τLOS
(LOS delay)
τGRP
(avg. group delay)
wideband
limiting: noise
|CIR|²
delay
LOS
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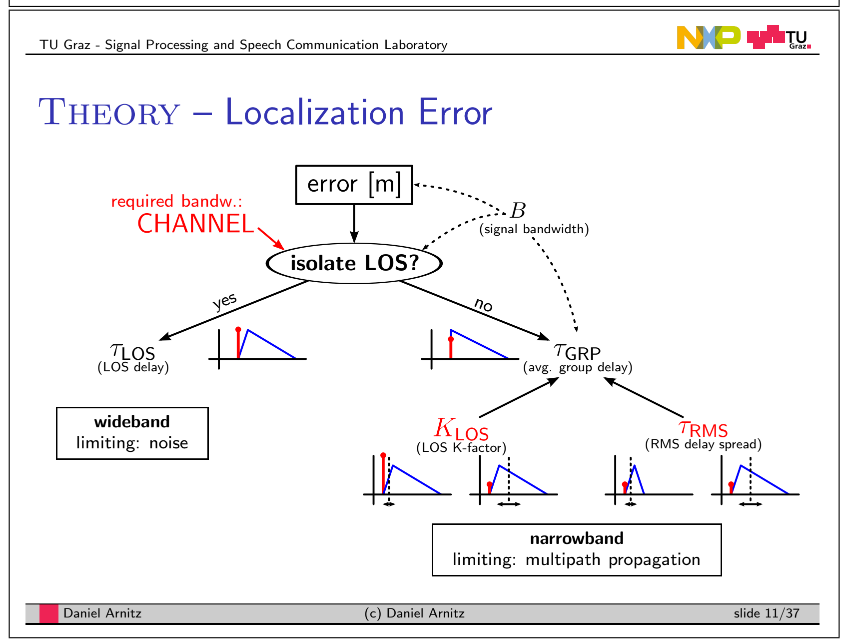
(c) Daniel Arnitz
slide 11/37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THEORY – Localization Error
error [m]
required bandw.:
CHANNEL
B
(signal bandwidth)
isolate LOS?
yes
no
τLOS
(LOS delay)
τGRP
(avg. group delay)
wideband
limiting: noise
KLOS
(LOS K-factor)
τRMS
(RMS delay spread)
narrowband
limiting: multipath propagation
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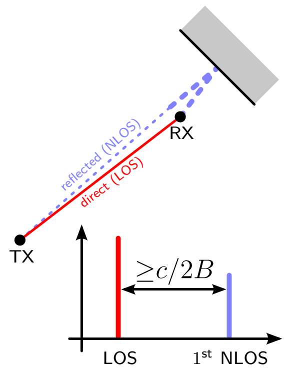
Theory – LOS Separable?



In UHF RFID?

- on the products: ≤ 1 cm
- ground/portal: ≈ 30 cm

$\Rightarrow$ **500 MHz UWB**

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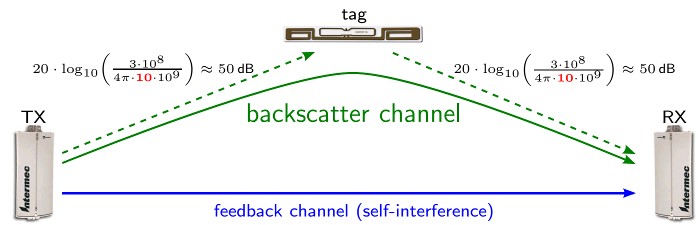
Theory – Backscatter Property



Backscatter: Two Concatenated Channels!

- high attenuation: 50 dB + 50 dB = 100 dB (10 m, 1 GHz)

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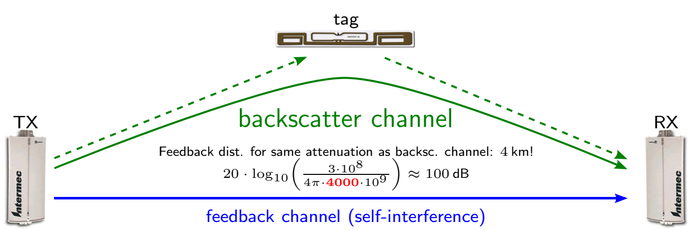
Theory – Backscatter Property



Backscatter: Two Concatenated Channels!

- high attenuation: 50 dB + 50 dB = 100 dB (10 m, 1 GHz)
- self-interference: SIR ≈ -50 dB (feedback not backscatter)

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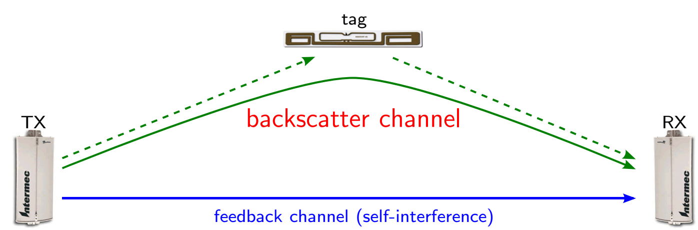
Theory – Backscatter Property



Backscatter: Two Concatenated Channels!

- high attenuation: 50 dB + 50 dB = 100 dB (10 m, 1 GHz)
- self-interference: SIR ≈ -50 dB (feedback not backscatter)
- more dispersive than worst individual (convolution)

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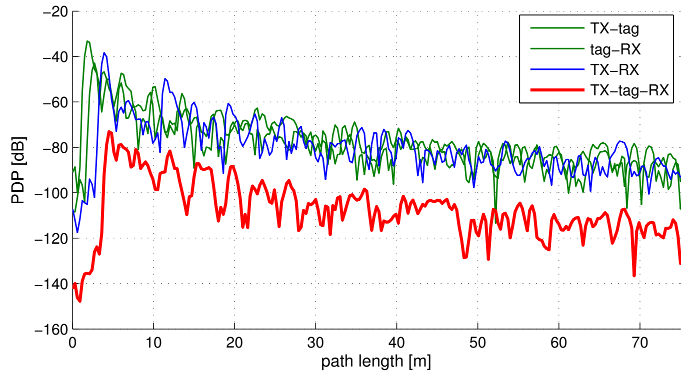
THEORY – Backscatter Property

Comparison of channels (UHF RFID portal):



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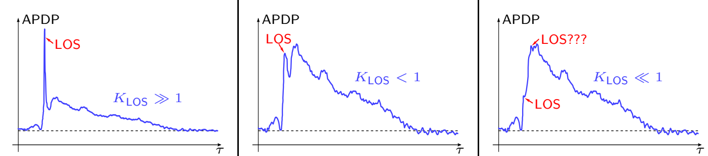
THEORY – Localization Accuracy/Precision



	LOS dom. (directive link, in air)	**NLOS dom.** — UHF RFID —	**Weak LOS** — UHF RFID —
NB LOS not isolated	$\tau_{GRP} \approx \tau_{LOS}$ unbiased some variance	$\tau_{GRP} > \tau_{LOS}$ biased high variance	$\tau_{GRP} \gg \tau_{LOS}$ biased purely random
WB LOS isolated	τ_{LOS} unbiased low variance	τ_{LOS} unbiased some variance	$> \tau_{LOS}$ biased purely random

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THEORY – Important Parameters

Basic: Shape of PDP

- shape / type of decay (exponential, ...)
- K-Factor w.r.t. LOS ("dominance of LOS") $\rightarrow K_{LOS}$
- RMS delay spread ("length of tail") $\rightarrow \tau_{RMS}$

Correlations (importance depends on method)

- frequency correlation (coherence bandwidth)
- spatial correlation (coherence distance)
- correlation in time (coherence time)

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Outline

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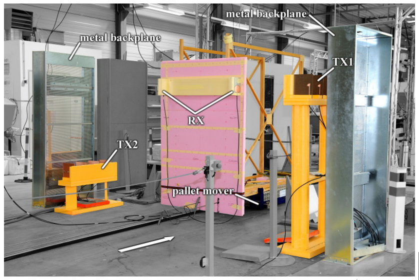
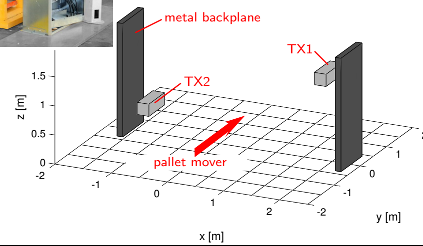
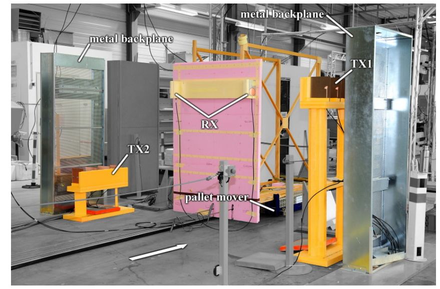
UHF Portal – Measurement Setup

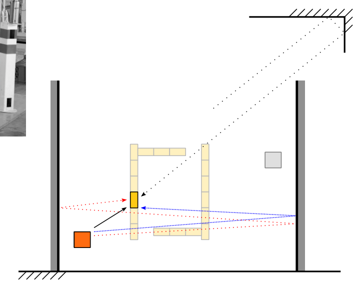




UHF Portal – Emtpy Portal

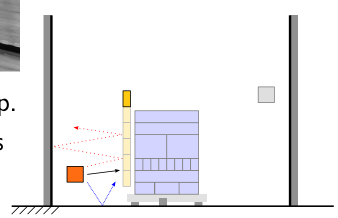


- multiple bounces
- scattered components
- "external" reflections



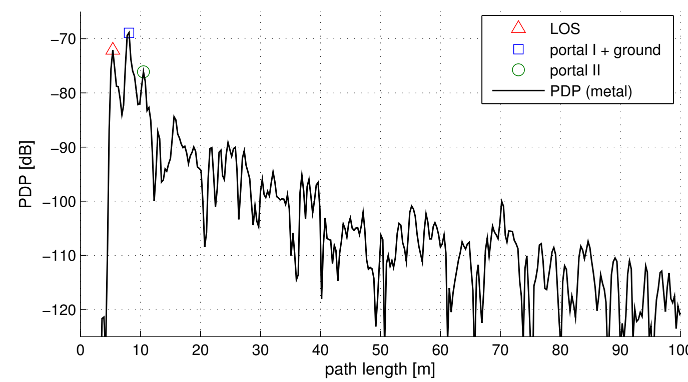
UHF Portal – Liquids Pallet

- extremely dense multipath prop.
- scattered/external components



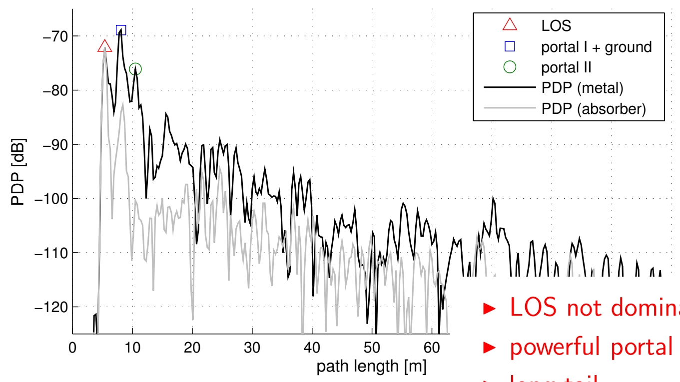
UHF Portal – Power-Delay-Profile I

Example power-delay-profile (tag inside the portal)



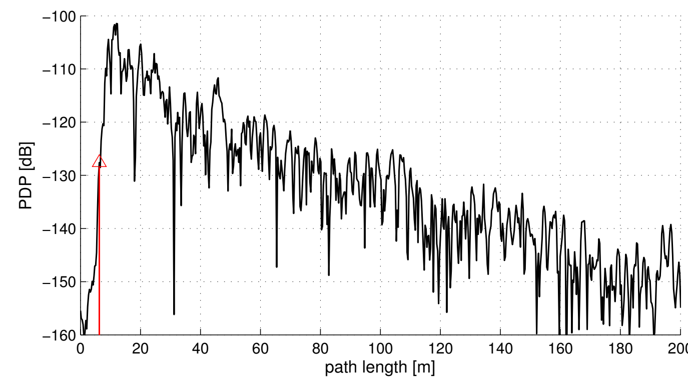
UHF Portal – Power-Delay-Profile I

Example power-delay-profile (tag inside the portal)



- LOS not dominant
- powerful portal II
- long tail

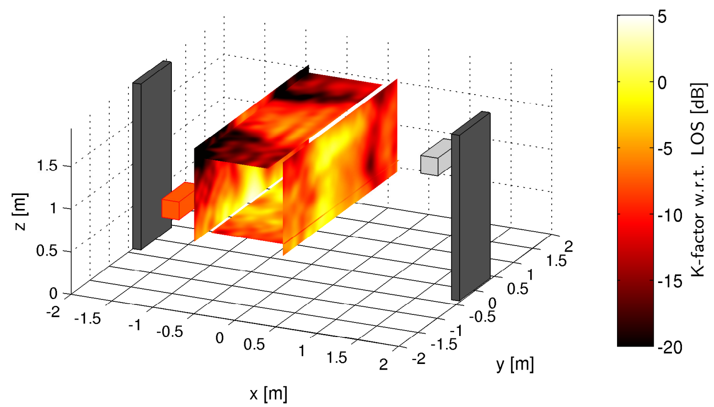
UHF Portal – Power-Delay-Profile II



... LOS attenuated + close-by reflections

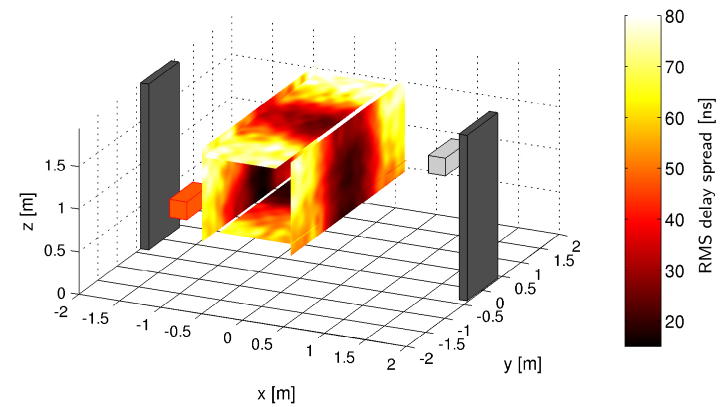
UHF Portal – Backscatter Parameters

Line-of-sight K-Factor (metal backplanes, bottom TX)



UHF Portal – Backscatter Parameters

RMS delay spread (metal backplanes, bottom TX)



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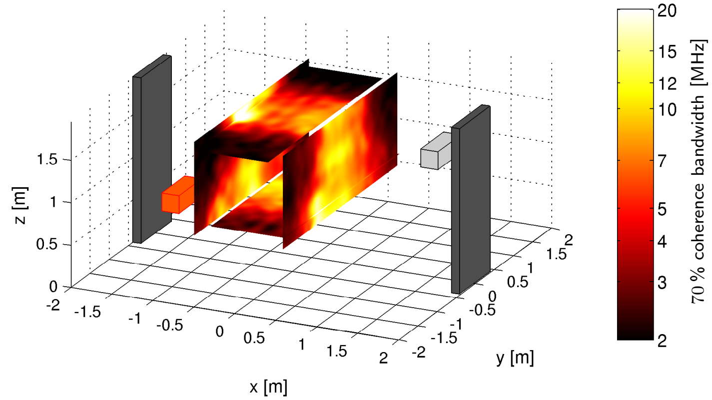
UHF PORTAL – Backscatter Parameters

70 % coherence bandwidth (metal backplanes, bottom TX)



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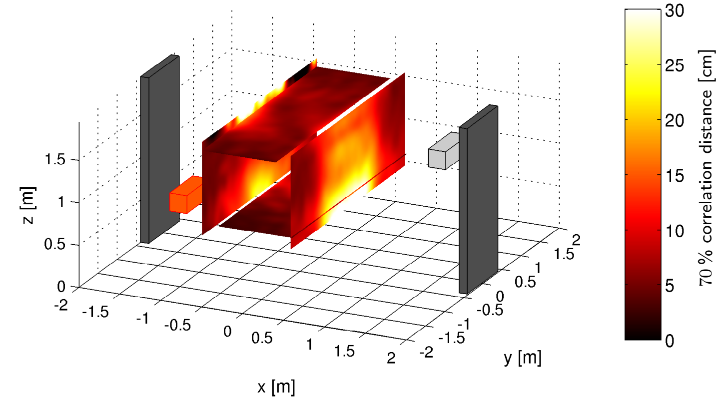
UHF PORTAL – Backscatter Parameters

70 % correlation distance (metal backplanes, bottom TX)



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Outline

Introduction and Motivation

Wireless Indoor Channel Modeling
- Multipath Propagation in a Nutshell
- Ranging/Localization: Find the LOS
- Backscatter Systems

The UHF RFID Channel in a Warehouse Portal
- Wave Propagation
- Backscatter Channel Parameters

Discussion of Channel Models
- Deterministic 3-path / Fully Stochastic / Hybrid
- Model Comparison

Conclusion

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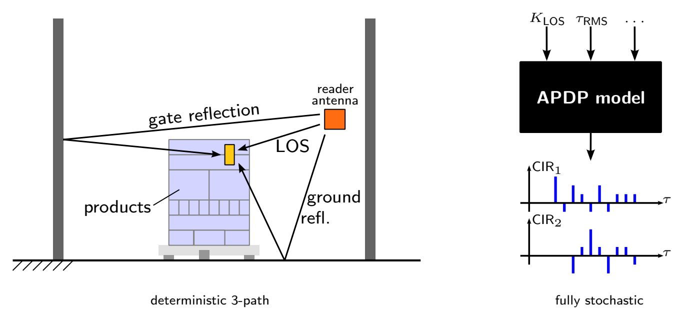
MODELS – Overview

- fully deterministic: 3-path (UHF RFID)
- fully stochastic (e.g., IEEE 802.15.4a)
- hybrid deterministic/stochastic



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Models – Overview

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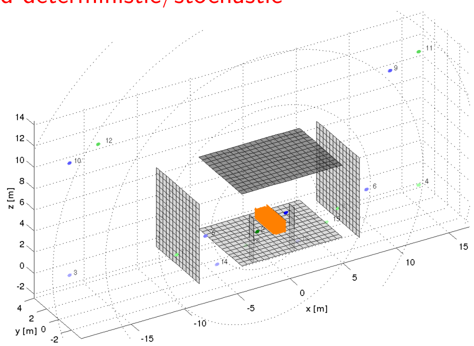
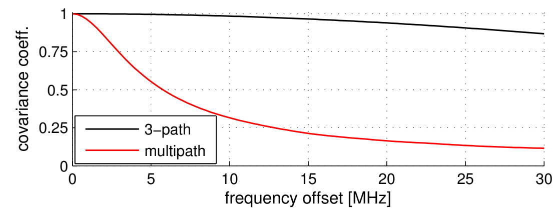
- fully stochastic (e.g., IEEE 802.15.4a)
- hybrid deterministic/stochastic



Models – Fully Deterministic: 3-path

- + works perfectly for single-carrier power/phase
- + considers specular reflections
- − frequency correlation too high ("nice channel")
- − truncated PDP: bounded error
- − sparse PDP: LOS nicely isolated (esp. for antenna-arrays)

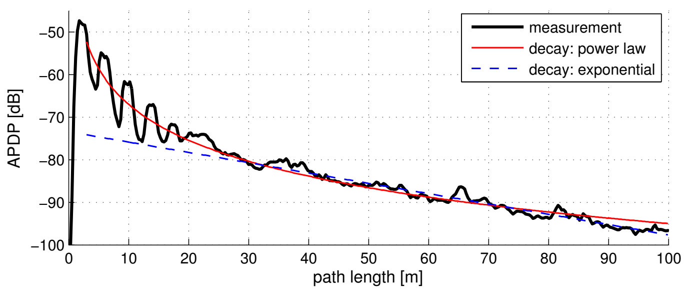
Correlation between two carriers (indirect prop. to MAE for narrowband ranging):
(for comparison: phase-based ranging, 3 MHz bandw.: mean absolute error 2.7 m (multipath) vs. 31 cm (3-path))



Models – Fully Stochastic

- + consider entire channel impulse response
- − do not consider specular reflections (freq. corr. wrong)

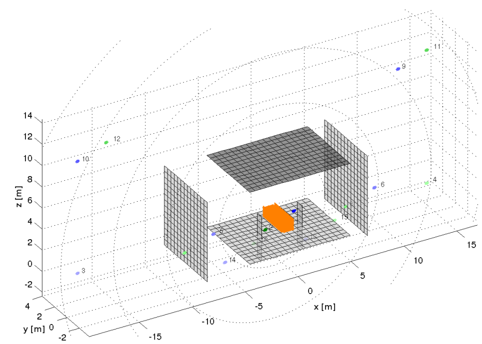
Single-channel average power-delay-profile inside the portal (metal backplanes):



Models – Hybrid (Virtual Transmitters)

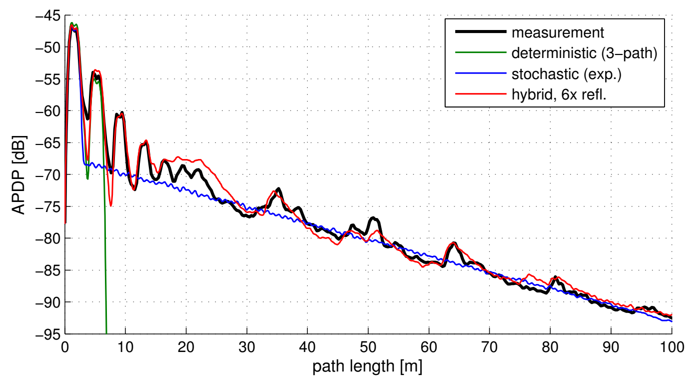
- + considers entire CIR <u>and</u> specular reflections
- − a lot of parameters (environment-dependent)

Geometric setup of the portal simulation (PARIS Framework):



MODELS – Model Comparison

Average Power-Delay-Profile, UHF portal (single-channel):



Outline

Summing Up

The UHF RFID Channel
- direct (line-of-sight) path not dominant
- small dimensions / reflections close to the tag

Parameter Summary
- LOS K-factor: always $\leq 0\,$dB
- RMS delay spread: $\geq 15\,$ns (reaches $> 100\,$ns in halls)

Modeling
- power distribution in portal: 3-path
- ranging: interreflections + scattered components

Summing Up

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Modeling
- power distribution in portal: 3-path
- ranging: interreflections + scattered components

Free as in Freedom

PARIS Simulation Framework

`www.tinyurl.com/paris-osf`

References I

- Daniel Arnitz,
  "Tag Localization in Passive UHF RFID,"
  Ph.D. thesis, Graz University of Technology, 2011 (hopefully).
- D. Arnitz, U. Muehlmann, and K. Witrisal,
  "Wideband characterization and modeling of UHF RFID channels for ranging and positioning,"
  submitted for publication.
- D. Arnitz, U. Muehlmann, and K. Witrisal,
  "Wideband characterization of backscatter channels,"
  in *Proc. Europ. Wireless Conf*, Vienna, Austria, Apr. 2011.
- D. Arnitz, U. Muehlmann, and K. Witrisal,
  "Wideband characterization of backscatter channels: Theory and theoretical background,"
  accepted for publication in *IEEE Trans. Antennas Propagat.*
- G. Li, D. Arnitz, R. Ebelt, U. Muehlmann, K. Witrisal, and M. Vossiek,
  "Bandwidth dependence of CW ranging to UHF RFID tags in severe multipath environments,"
  in *Proc. IEEE Int RFID Conf*, Orlando, FL, Apr. 2011.

... all referenced papers can be downloaded at `http://www.spsc.tugraz.at` under "Publications".

References II

- Photographs of RFID-typical environments (slide 3)
  courtesy of Intermec Technologies, `http://www.intermec.com`
- Photograph of RFID tag (slide 3, 13)
  courtesy of NXP Semiconductors, `http://www.nxp.com`
- Photograph of warehouse environment (slide 4)
  courtesy of Metro and EPCglobal GS-1, `http://www.metro.com/`, `http://www.gs1.org/epcglobal`
- Photograph of cash registers (slide 4)
  `http://en.wikipedia.org/wiki/File:Cash_Registers.JPG`
  under Creative Commons Attribution-Share Alike 3.0 Unported / GNU Free Documentation License 1.2+
- Photograph of RFID portal antenna (slide 13)
  courtesy of Intermec Technologies, `http://www.intermec.com`
- Icon for bibliography type photograph/image
  `http://www.clker.com/clipart-map-symbols-camera-white.html`
  public domain


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Ranging Methods Overview
Pavel Nikitin
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IEEE
RFID 2011
5th Annual IEEE International Conference on RFID
Orange County Convention Center
Orlando, Florida (USA)
April 12-14, 2011
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Intermec
Orlando, FL, April 12, 2011

Epigraph

"Location, location, location…"

A favorite saying of real estate agents

Intermec

Slide 2

Outline

- Wireless Localization
- How RFID is Different?
- What is Measurable in RFID?
  - Minimum Power, RSSI, Phase
- RFID Localization Methods
  - Within Gen2
  - Outside Gen2
- Simple Simulation Example
- Conclusions

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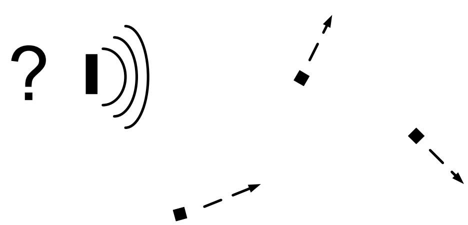
Slide 3

Localization Questions

- General question: where is the wireless node?
- Specific RADAR (Radio Detection And Ranging) questions:
  - Which direction? (bearing/altitude)
  - How far? (range/distance)
  - How fast and where does it go? (speed/velocity)



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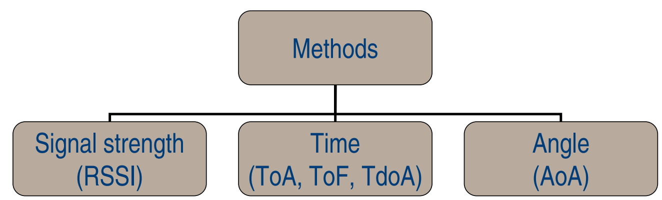
Slide 4

Wireless Localization



- Location calculations
  - Multi-lateration (from three or more known distances)
  - Multi-angulation (from three or more known angles)
  - Maximum likelihood (RSSI fingerprinting, etc.)
- Auxiliary domains
  - Acoustic (ultrasound), optical (infrared)

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Slide 5

Unlicensed Wireless Systems in US

- 902-928 MHz (UHF)
  - UHF RFID, ZigBee
- 2.4-2.483 GHz (SHF)
  - WiFi, ZigBee, Bluetooth
- 5.725-5.875 GHz (microwave)
  - WiFi
- 3.1-10.6 GHz (UWB)
  - UWB systems, PSD < 41.3 dBm/Hz, spectrum >500 MHz or 20% of center frequency)
- 24-24.25 GHz
  - Automotive radars
- 61-61.5 GHz (EHF)
  - Wireless HD

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References on Wireless Localization

- A. Savvides, C. Han, M. Strivastava, "Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors", Proceedings of MOBICOM conference, 2001
- M. Vossiek, L. Wiebking, P. Gulden, J. Weighardt, C. Hoffmann, "Wireless local positioning", IEEE Microwave Magazine, vol. 4, Issue 4, Dec. 2003, pp. 77 – 86
- G. Mao, B. Fidan, B. Anderson, "Wireless Sensor Network Localization Techniques", Computer Networks, vol. 51, no. 10, July 2007, pp. 2529-2553
- H. Liu et al., "Survey of Wireless Indoor Positioning Techniques and Systems", IEEE Transactions on Systems, Man, and Cybernetics, vol. 37, no. 6, Nov. 2007, pp. 1067 - 1080
- Presentations from RTLS session at IEEE RFID 2010: http://sites.ieee.org/rfid2010/home/presentations/

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Active Wireless System vs. Passive RFID

	Active wireless	Passive RFID
Nodes	Active	Tag is passive
Downlink power	20 dBm	30 dBm
Channel	One-way	Roundtrip
10 m path loss at 915 MHz	50 dB	100 dB
Node sensitivity	-85 dBm	-15 dBm
Uplink power	20 dBm	-20 dBm
Reader sensitivity	-85 dBm	-85 dBm
Self-interference	None	High (Tx/Rx simultaneously at the same frequency)

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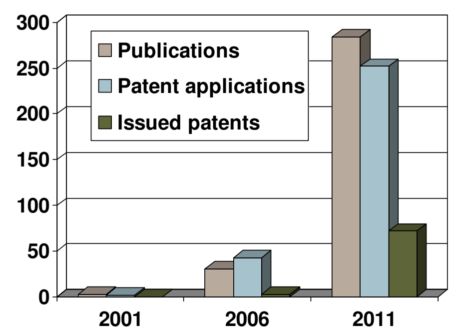
RFID Localization

- Topic of high interest in the last 10 years
- Try searching for "RFID" and "localization" in:
  - IEEEXplore
  - Google Patents



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What is Measurable in RFID?

- Tag presence (read /no read)
- Tag ID
- Minimum power to read the tag
- RSSI of the received tag signal
- Phase of the received tag signal

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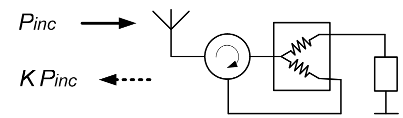
Minimum Power and Tag RSSI

- Simple microwave model of the tag



- Minimum transmit power to read the tag

$$P_{min} G_t G_{path} p = P_{tag}$$

- Tag signal power at the reader

$$RSSI = P_t G_t^2 G_{path}^2 p^2 K$$

P_{inc} – incident power
K – backscatter gain
P_{tag} – tag sensitivity
G_t – transm. antenna gain
G_{path} – path gain
p – polarization mismatch

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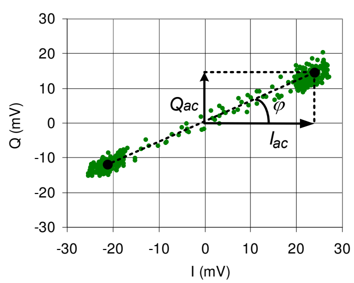
Tag Phase

- Available internally in many readers
- Depends on phases of reader, channel, and tag
- For localization, relative phase behavior is important

$$\varphi = \varphi_{path} + \varphi_{reader} + \varphi_{tag} = \arctan \frac{Q_{ac}}{I_{ac}}$$



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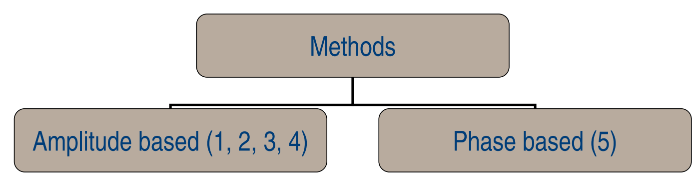
RFID Localization Methods within Gen2

1. Markers (readers or tags)
2. Transmit power control
3. Antenna beam steering
4. Tag RSSI based
5. Tag phase based (time, frequency, spatial domains)



- These methods can also be combined

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RFID Localization Methods outside Gen2

- Combination with other frequencies and technologies
  - UHF downlink, UWB uplink (Zou, 2010) - TdoA
  - Concurrent UHF and UWB interrogation (Arnitz, 2010) - ToA
  - LF, HF, NFER, etc. (yet to come)
- Combination with other domains
  - Optical, acoustic (yet to come)
- Semi-passive (BAP) tags can be used for all of the above

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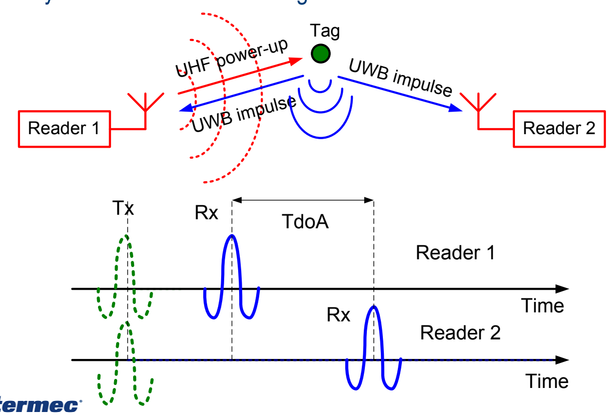
UHF RFID UWB localization: TdoA

- UHF power-up, UWB uplink (Zou, 2010)
- No synchronization between tag and readers



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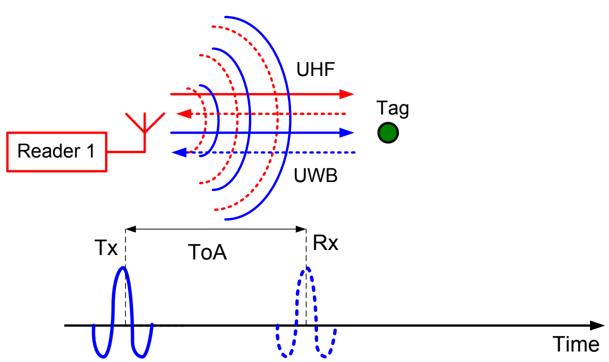
UHF RFID UWB localization: ToA

- Concurrent UHF and UWB interrogation (Arnitz, 2010)
- Coherent backscatter means reader is always synchronized with itself



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References

- M. Bouet, A. L. dos Santos, "RFID tags: Positioning principles and localization techniques", 1st IFIP Wireless Days, Nov. 2008, pp.1 – 5
- D. Arnitz, "Tag Localization in passive UHF RFID", PhD Thesis, Technical University of Graz (expected May 2011)
- Z. Zou, T. Deng. Q. Zou, M. Sarmiento, F. Jonsson, L. Zheng, "Energy detection receiver with TOA estimation enabling positioning in passive UWB-RFID system", ICUWB conference, 2010
- D. Arnitz, U. Mühlmann, K. Witrisal, "UWB Ranging in Passive UHF RFID: Proof of Concept", IET Electron. Letters, vol. 46, no. 20, pp. 1401 - 1402, Sep., 2010

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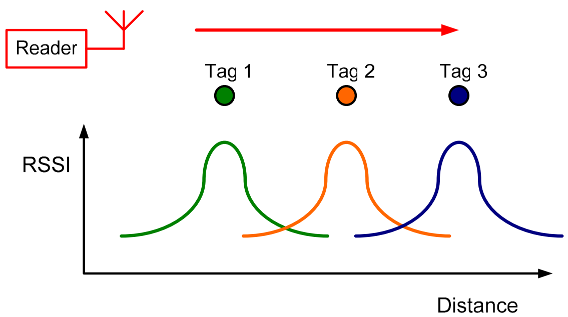
Markers Method

- Tags (or readers) can be used as fixed location markers
- Read / no read or RSSI can be used



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References

- S. Saab and S. Nakad, “A standalone RFID indoor positioning system using passive tags,” IEEE Trans. Ind. Elec., 2010
- C. Yu, R. Liu, “Application of RF Tags in Highway Reference Markers”, International IEEE Conference on Intelligent Transportation Systems, Oct. 2008, pp. 464 – 469
- M. Bouet, G. Pujolle, “L-VIRT: A 3-D Range-Free Localization Method for RFID Tags Based on Virtual Landmarks and Mobile Readers, IEEE CCNC conference, 2009
- “Object localization”, US Patent 7374103
- “Systems and methods for tracking the location of items within a controlled area”, US Pat. 7038573

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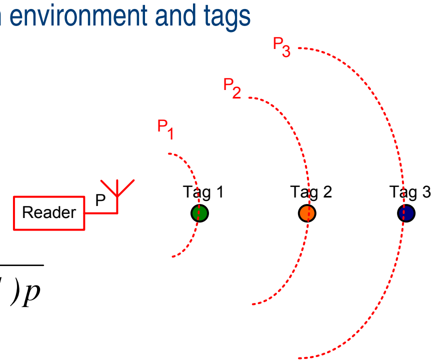
Transmit Power Control Method

- Reader varies the power to determine the minimum power to read the tag
- Path loss model can be used to calculate distance
- Strongly depends on environment and tags



$$P_{min} = \frac{P_{tag}}{G_t G_{path}(d)p}$$

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References

- C. Alippi et al., “A statistical approach to localize passive RFIDs", IEEE Int. Symposium on Circuits and Systems, pp. 843-846
- P. Wilson, D. Prashanth, and H. Aghajan, “Utilizing RFID signaling scheme for localization of stationary objects and speed estimation of mobile objects,” IEEE RFID Conference, 2007
- Reverse infrastructure location system and method, US Patent 7403120
- Object monitoring, locating, and tracking system and method employing RFID devices, US Patent 7839289

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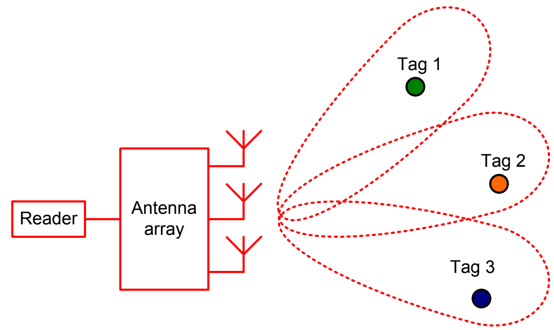
Beam Steering Method

- Can be done for either monostatic or bistatic readers
- Can be done on either transmit or receive side



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References

- RF controls http://www.rfctrls.com
- Mojix http://www.mojix.com
- RFID radar http://trolleyscan.com
- T. Hansen, M. Oristaglio, “Method for Controlling the Angular Extent of Interrogation Zones in RFID”, IEEE Antennas and Wireless Propagation Letters, vol. 5, no.1, December 2006, pp. 134 – 137
- Y. Zhang, M. G. Amin, and S. Kaushik, "Localization and tracking of passive RFID tags based on direction estimation," International Journal of Antennas and Propagation, Dec. 2007
- G. Hislop, D. Lekime, M. Drouguet, C. Craeye, “A prototype 2D direction finding system with passive RFID tags”, EuCAP conference, 2010
- “RFID beam forming system”, US Patent 7873326

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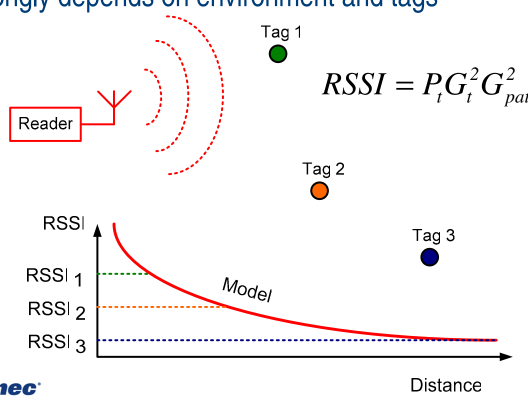
RSSI Based Method

- Path loss model can be used to calculate distance from RSSI
- Strongly depends on environment and tags

$$RSSI = P_t G_t^2 G_{path}^2 (d) p^2 K$$



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References

- M. Kim, N. Chong, “Direction Sensing RFID Reader for Mobile Robot Navigation”, IEEE Transactions on Automation Science and Engineering, vol. 6, no. 1, Jan. 2009, pp. 44 – 54
- T. Deyle, C. C. Kemp, and M. S. Reynolds, “Probabilistic UHF RFID tag pose estimation with multiple antennas and a multipath RF propagation model,” IEEE/RSJ Int. Conf. Intelligent Robots and System, 2008
- Object monitoring, locating, and tracking system and method employing RFID devices, US Patent 7839289

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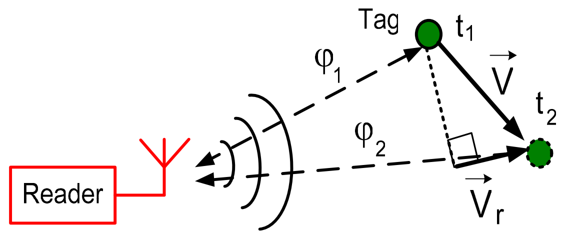
Slide 25

Phase Based Methods (Time Domain)

- Phase temporal derivative gives radial tag velocity (same as measuring the Doppler shift)



$$V_r = -\frac{c}{4\pi f}\frac{\partial \varphi}{\partial t}$$

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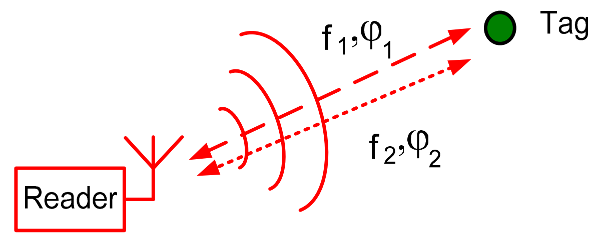
Phase Based Methods (Frequency Domain)

- Phase derivative with respect to frequency gives the distance to the tag (same principle as FM CW radar)



$$d = -\frac{c}{4\pi}\frac{\partial \varphi}{\partial f}$$

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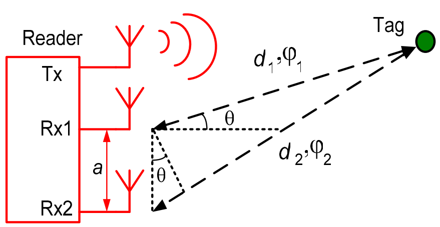
Phase Based Methods (Spatial Domain)

- Phase difference between receive antennas allows one to find the angle of arrival
- Various combinations of Tx and Rx antennas can be used



$$\theta \approx \arcsin\left[-\frac{c}{2\pi f}\frac{(\varphi_2 - \varphi_1)}{a}\right]$$

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References

- J. Heidrich et al., "Local positioning with passive UHF RFID transponders", IEEE Int. Microwave Workshop on Wireless Sensing, Local Positioning, and RFID, Sept. 2009, pp. 1 – 4
- "Method and apparatus to determine the direction to a transponder in a modulated backscatter system", US Patent 6476756
- C. Angerer, R. Langwieser, M. Rupp, "Direction of Arrival Estimation by Phased Arrays in RFID", EURASIP conference, 2010
- P. Nikitin, R. Martinez, S. Ramamurthy, H. Leland, G. Spiess, and KVS Rao, "Phase Based Spatial Identification of UHF RFID Tags", IEEE RFID Conference, 2010

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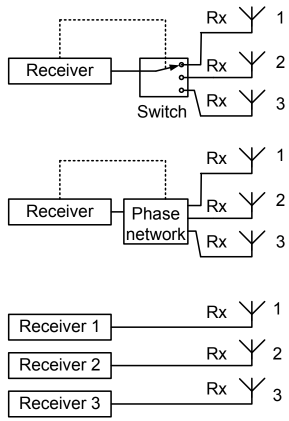
Antenna Array Configurations

- Single receiver, multiple switched antennas (cheap, slow)
- Single receiver, steerable antenna (expensive)
- Multiple receivers, multiple antennas (most expensive, fast)



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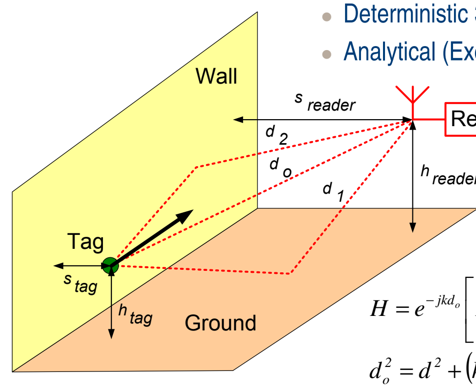
Simple Example

- Tag moves along the wall
- Deterministic 3-ray single frequency model
- Analytical (Excel spreadsheet)



$$G_{path} = \left(\frac{\lambda}{4\pi d_o}\right)^2 |H|^2$$

$$\varphi = 2\arg(H)$$

$$H = e^{-jkd_o}\left[1 + \sum_{i=1}^{2} \Gamma_i \frac{d_o}{d_i} e^{-jk(d_i - d_o)}\right]$$

$$d_o^2 = d^2 + (h_{reader} - h_{tag})^2 + (s_{reader} - s_{tag})^2$$

$$d_1^2 = d^2 + (h_{reader} + h_{tag})^2 + (s_{reader} - s_{tag})^2$$

$$d_2^2 = d^2 + (h_{reader} - h_{tag})^2 + (s_{reader} + s_{tag})^2$$

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Parameters in Simulation Example

Tag and reader antennas	Isotropic
Carrier frequency (MHz)	915
Reader antenna height (m)	1.5
Tag height (m)	1
Reader antenna space to wall (m)	3
Tag space to wall (m)	1.5
Reflection coefficients	-0.5
Tag backscatter factor (dB)	-10
Tag backscatter phase (rad)	0
Reader EIRP (dBm)	30
Reader sensitivity (dBm)	-80

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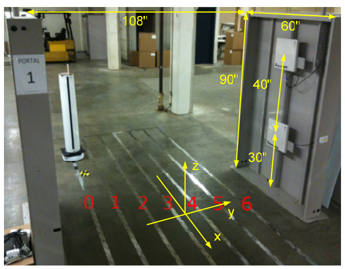
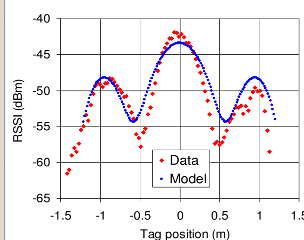
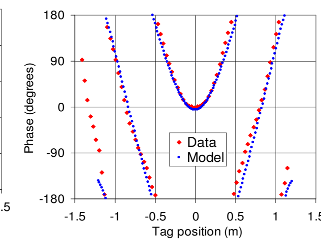
Model vs. Data

- This type of model was verified in portal
- RSSI and phase data collected on 20 tags and 4 reader antennas:
  - Intermec IF61 reader
  - Huber & Suhner CP antennas
  - AD-222 tags







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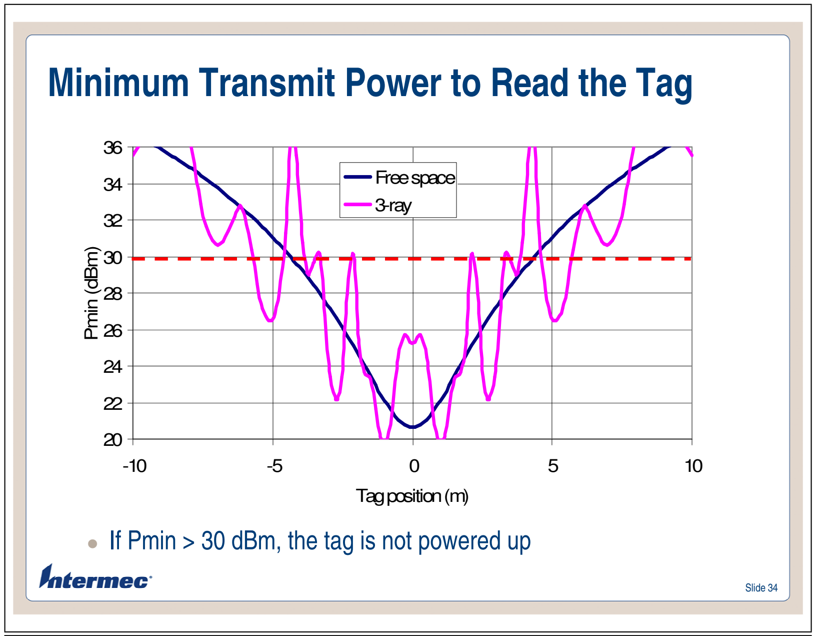
Minimum Transmit Power to Read the Tag
Pmin (dBm)
36
34
32
30
28
26
24
22
20
-10
-5
0
5
10
Tag position (m)
Free space
3-ray
If Pmin > 30 dBm, the tag is not powered up
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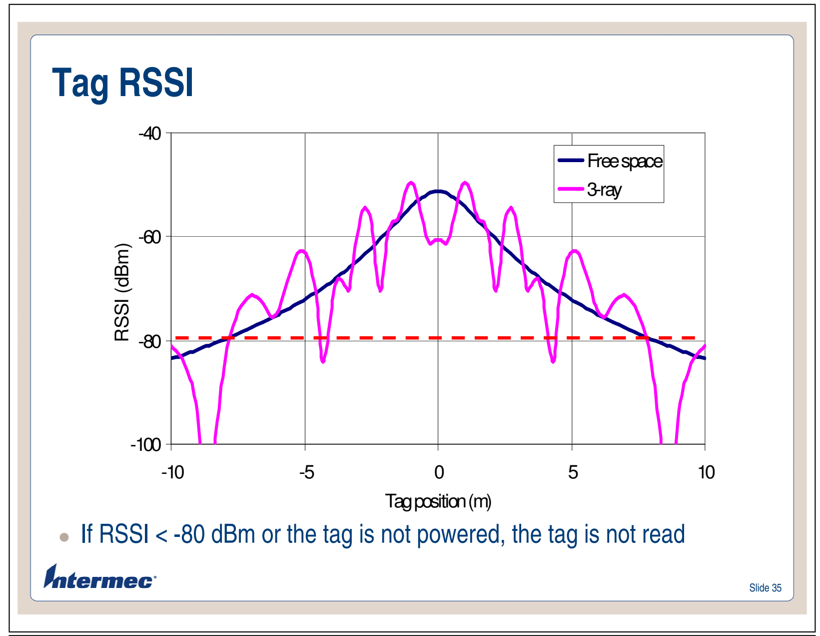
Tag RSSI
RSSI (dBm)
-40
-60
-80
-100
-10
-5
0
5
10
Tag position (m)
Free space
3-ray
If RSSI < -80 dBm or the tag is not powered, the tag is not read
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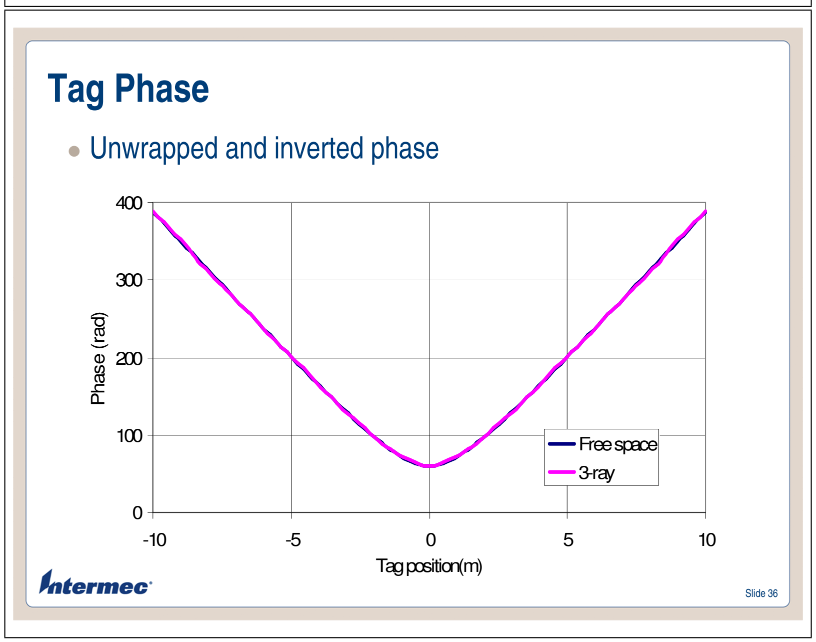
Tag Phase
Unwrapped and inverted phase
Phase (rad)
400
300
200
100
0
-10
-5
0
5
10
Tag position(m)
Free space
3-ray
Intermec
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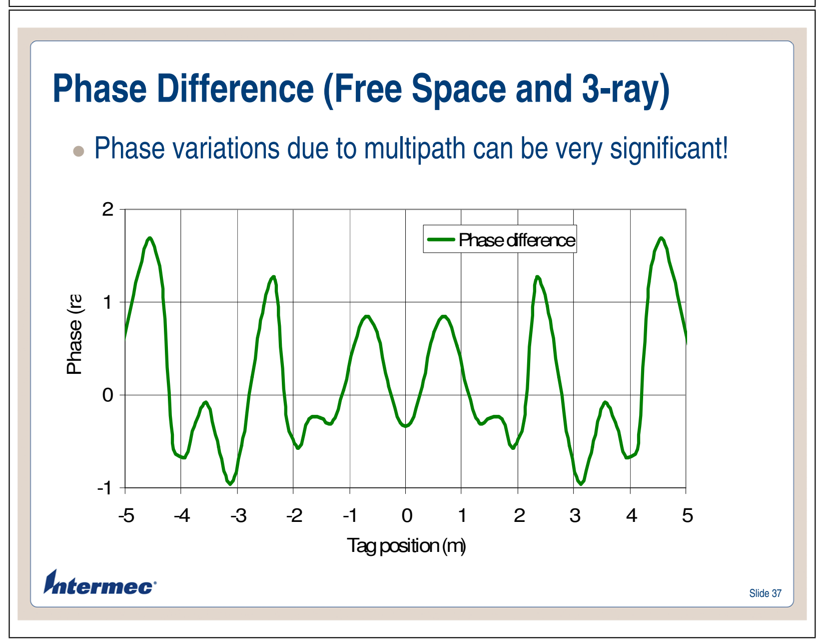
Phase Difference (Free Space and 3-ray)
Phase variations due to multipath can be very significant!
Phase (ra
2
1
0
-1
-5
-4
-3
-2
-1
0
1
2
3
4
5
Tag position (m)
Phase difference
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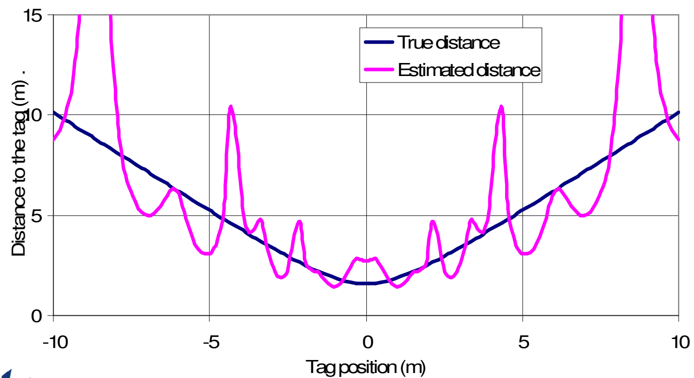
Ranging Based on Free Space RSSI Model

- Ranging error can easily exceed 100% !



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Notes on Simulation Example

- This example is a simple illustration of ranging errors
  - If you want this Excel file, send me an email
- For more realistic exploration of ranging methods one can add:
  - Directional antenna patterns
  - Antenna polarizations
  - Power-dependent tag backscatter
  - Multiple reader antennas
  - Angle-dependent reflection coefficients
- To go to more detailed simulations, download PARIS:
  - www.spsc.tugraz.at/research-topics/wireless-communications/paris-osf/

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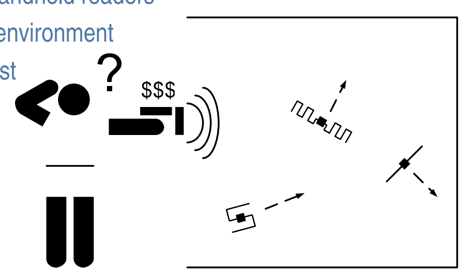
Conclusions

- Localization is one of the "Holy Grails" of UHF RFID
- Localization methods can be amplitude or phase based
- Phase based and novel (UWB) methods are promising
- Challenges to solve:
  - Tag localization from handheld readers
  - Multipath propagation environment
  - Reasonable system cost



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Thank You!

Questions or comments?

nikitin@ieee.org

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IEEE 2011 RFID Conference

April 12, 2011, Orlando, the USA

UWB as an Alternative of UHF RFID in the Era of IoT?

- From System Concept to Silicon Implementation

Zhuo Zou and Li-Rong Zheng

iPack VINN Excellence Center
School of Information and Communication Technology
KTH-Royal Institute of Technology, Sweden
zhuo@kth.se

Contributions:

Majid B.N., David S.M., Q. Zhou, J. Mao, Jonsson F., H. Tenhunen,
C. Y. Zhai, Z. Zhang, Z.B. Pang, and Q .Chen

Introduction

1. Introduction

   "Vision and mission of the Internet-of-Things"

2. System Design
3. Circuit Implementation
4. Positioning Perspective

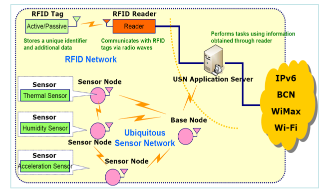
Recommended readings

[ECO_APR07] "When everything connects", The Economist; London, Apr 28, 2007; Vol.383, Iss.8526
[LRZ_Norchip09] Li-Rong Zheng and et al.; , "Future RFID and Wireless Sensors for Ubiquitous Intelligence," NORCHIP, 2008. , vol., no., pp.142-149, 16-17 Nov. 2008

2

From RFID to the Internet-of-Things

RFID tags with Sensing, Computing, Communication and Positioning capabilities reach to the Internet



convergence

Application Scenario

Who, Where, and How

RFID
Positioning
Sensing

Low power and cost systems and circuits

Technology Enabler

Constraint by limited resources (Power, Cost, Size…)
Micro-power from autonomous power scavenging (e.g. 100uW/cm^3)
ULP Design: uW/MIPS for processor and uW/Mbps for wireless link

3

A Big Picture

- From System to Silicon
  - Develop and Establish u-Power chips and radio links towards the IoT

~10m@~Mbps with ~nJ/bit energy dissipation, with sub-meter positioning accuracy

Tags
- Remote powered UHF/UWB tag
- WiFi/UWB wireless-powered tag integrating on-chip antenna (collaborated with KU-Leuven)

Links
- Air Interface
- Protocol and algorithm
- Positioning

Readers
- Multi-standard RFID Reader chipset
- Reconfigurable UWB receiver

- Semi-passive intelligent tag with multi-channel sensor interface (ongoing)

4

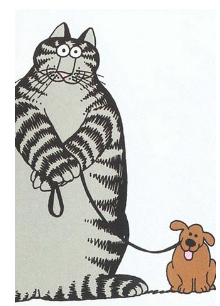
System Design

1. Introduction
2. System Design

   High time domain resolution makes UWB exclusive attractive to localization applications. Is it feasible to introduce UWB to RFID to overcome the limitations of UHF tags?

   - UHF/UWB Hybrid Solution

3. Circuit Implementation
4. Positioning Perspective



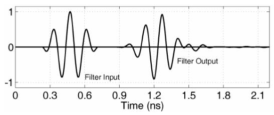
Recommended readings

[ZZ_SP07] Z. Zou and et al.; "An efficient passive RFID system for ubiquitous identification and sensing using impulse UWB radio", Springer e & i Elektrotechnik und Informationstechnik, vol. 124, pp. 397 2007.
[MW_10] Dardari, D.; D'Errico, R.; Roblin, C.; Sibille, A.; Win, M.Z.; , "Ultrawide Bandwidth RFID: The Next Generation?", Proceedings of the IEEE , vol.98, no.9, pp.1570-1582, Sept. 2010

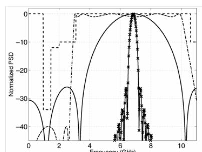
5

RFID using UWB?

- Limitations of UHF RFIDs
  - Coverage (-20 dBm)
  - Speed (~ kbps)
  - Localization accuracy
  - Multi-access (collisions)



- Impulse Radio UWB (Carrier-Less)
  - Using very short pulses instead of CW.
  - Low power TX., aggressively duty cycled radio
  - High time domain resolution for precise ranging and positioning
  - GHz-BW, large channel capacity and robust against multi-path and multi user
  - …but RX?



Is UWB feasible as an alternative of (passive) UHF RFID?

No! UWB RX. is too complex to be deployed on RFID tags

- Signal Processing: synchronization and detection
- Hardware: complexity and power consumption (~10 mW)

(Figure Source: Jha, Aand et al , "A Discrete-Time Digital-IF Interference-Robust Ultrawideband Pulse Radio Transceiver Architecture," IEEE trans. on TCAS-I, Jan 2010)

6

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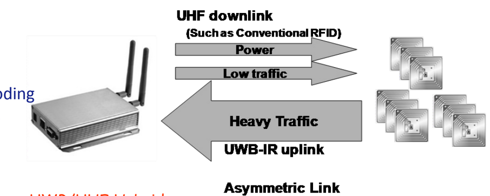
RFID using UWB?

Yes! RFID is essentially Asymmetrical.

- Large System Capacity: A large number of tags
- Asymmetrical Traffic Loads: Uplink dominated
- Asymmetrical Hardware Resources

Downlink
- UHF band
- ASK with PIE coding
- Up to 160 kbps



Uplink
- IR-UWB
- OOK Modulation
- Up to 10 Mbps

UWB/UHF Hybrid:
Benefited from UWB signaling (BW, throughput, ranging, low power, simple TX. and …), but removes the complex and power hungry RX. from tag to reader.

7

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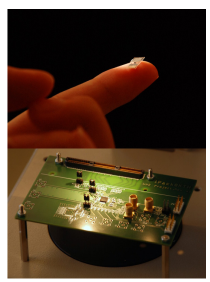
Circuit Implementation

1. Introduction
2. System Design
3. Circuit Implementation

   "needs for circuit implementation to prove the concept on silicon"
4. Positioning Perspective



Recommended readings

[Majid_ISSCC09] Baghaei-Nejad M and et al , "A remote-powered RFID tag with 10Mb/s UWB uplink and −18.5dBm sensitivity UHF downlink in 0.18μm CMOS," ISSCC 2009
[Radiom_JSSC10] Radiom M. and et al, " "Far-Field On-Chip Antennas Monolithically Integrated in a Wireless-Powered 5.8-GHz Downlink/UWB Uplink RFID Tag in 0.18um Standard CMOS," Solid-State Circuits, IEEE Journal of , vol.45, no.9, pp.1746-1758, Sept. 2010
[ZZ_TCAS11] Zhou Zou and et al., "A Low-Power and Flexible Energy Detection IR-UWB Receiver for RFID and Wireless Sensor Networks". IEEE Transactions on Circuits and Systems I-regular paper. Accepted for publishing
[WK_SPM09] Witrisal, K.and et al., "Noncoherent ultra-wideband systems," Signal Processing Magazine, IEEE , vol.26, no.4, pp.48-66, July 2009
[BS_TMTT10] Bourdel, S.and et al. , "A 9-pJ/Pulse 1.42-Vpp OOK CMOS UWB Pulse Generator for the 3.1–10.6-GHz FCC Band," Microwave Theory and Techniques, IEEE Transactions on , vol.58, no.1, pp.65-73, Jan. 2010

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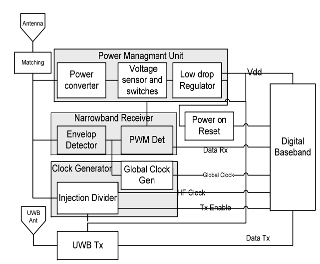
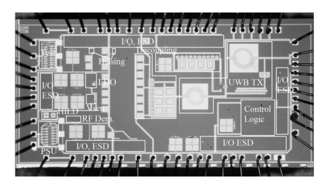
1st Tag Chip

- Remote-Powered UHF/UWB Passive Tag
  - Wireless power scavenging (battery-less)
  - 10Mb/s UWB Uplink and -18.5dBm-Sensitivity UHF (corresponding to ~<10m coverage), up to 2000 tags/second
  - Fabricated in UMC 180 nm process with 1mm² active die area





[Majid_ISSCC09]

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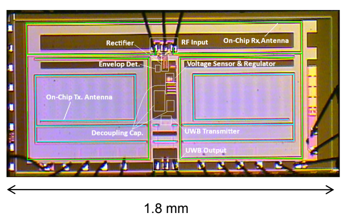
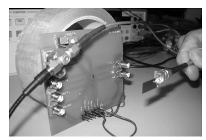
2nd Tag Chip

- Wireless-Powered WiFi(5.8 GHz)/UWB Passive Tag with On-Chip Antenna
  (collaborated with S. Radiom and G. Giele at e MICAS-ESAT, KU Leuven)
  - Aiming to reduce the process cost of RFID
  - Potential applications: animal tracking, implant, proximity card
  - 7.5 cm reading distance (4W EIRP at 5.8 GHz)





[Radiom_JSSC10]

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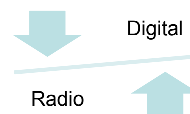
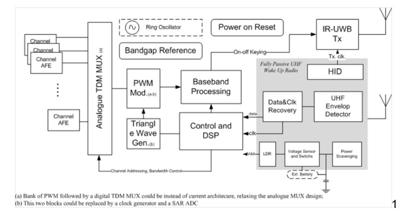
3rd Tag Concept

- Semi-Passive Multi-Channel Sensor Tag
  - Multi-channel interface for multi parameter sensing
  - TDM-CDM channel access allows scalable system capacities
  - Build-in DSP functions for distributed processing

RFID Tag → Sensor Tag → Intelligent Tag

- "Intelligence-on-Tag"
  - Leverage more digital techniques to increase the intelligence and efficiency (MCU or processor off-loads data rate and RF power)





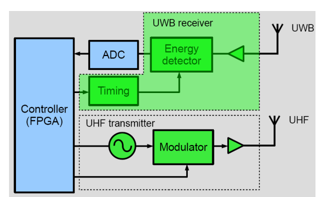
11

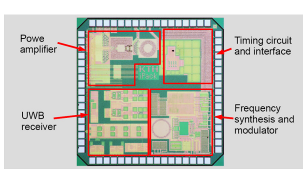
Reader Design

- Multi-standard RFID Reader Chipset in 90 nm CMOS Process

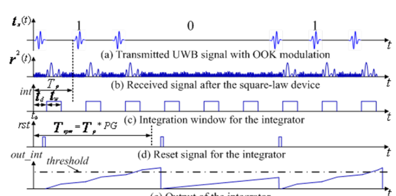
UWB Receiver is still challenging!
Coherent detection is not practical

- ADCs
- Channel estimation and timing misaligned
- Complex baseband processing
- ...





[ZZ_TCAS11]



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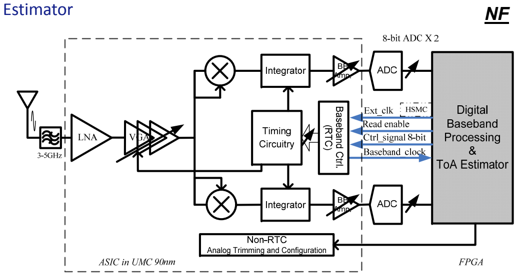
Reader Design (cont.)

- Reconfigurable Energy Detection IR-UWB Receiver with Ranging Capability
  - Simple, low power, and fast synchronization
  - Dual-channel architecture
  - Frontend and high speed baseband in 90 nm CMOS
  - Highly flexible back-end in FPGA
  - ToA Estimator

Coverage → TX. / RX. Sensitivity → RF Challenge ***NF*** / Digital Challenge ***Min SNR***



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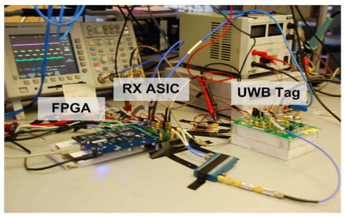
Link Evaluation

- BER Measurement
  - 10MHz pulse, uncoded OOK
  - tag+filter+ attenuator+receiver
  - -79 dBm sensitivity @ 10 Mbps
  - wireless link measurement is ongoing



[ZZ_TCAS11]

Key Figures
- 1 mm X 1 mm die area
- 16uW/23uW (single/dual channel)
- -79 dBm sensitivity @ 10 Mbps
- Multi-mode operation (synchronization, estimation, modulation…)
- Maximum data rate: 33 Mbps
- 1.1 ns phase resolution enables ToA

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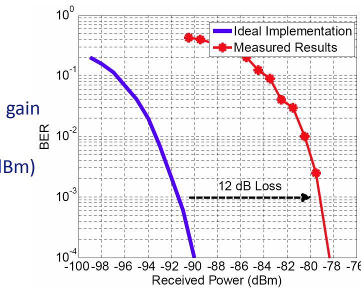
Link Evaluation (cont.)

- Discussion
  - Coverage - Lind budget
    PL=64 dB@10m LOS, 0 dB antenna gain
    Required Ptx:
    Path Loss (64dB)+Prx_sensi.(-79dBm)
    =-15dBm (~1Vpp)
    FCC allows: Ptx=-8.3 dBm
  - Even Longer?
    high gain antenna
    trade speed to coverage
    (Vpp limit on CMOS? Multi-pulse/symbol?)



"It can be achieved by the state of the art TX., which is also feasible to passive tags"

(~1Vpp@ can be achieved by state of the art TXs under the power budget of passive operations. Example [BS_TMTT10])

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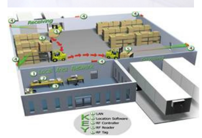
Circuit Implementation

1. Introduction
2. System Design
3. Circuit Implementation
4. Positioning Perspective
   "How it works in UWB/UHF RFID?"



Recommended readings

[GS_SP05] Gezici, S.and et al., "Localization via ultra-wideband radios: a look at positioning aspects for future sensor networks," Signal Processing Magazine, IEEE , vol.22, no.4, pp. 70- 84, July 2005
[DD_IP09] D. Dardari and et al, "Ranging with ultrawide bandwidth signals in multipath environments," Proc. IEEE, vol. 97, no. 2, pp. 404-426, Feb. 2009
[OI_TMTT06] Stoica, L., and et al "A low-complexity noncoherent IR-UWB transceiver architecture with TOA estimation," Microwave Theory and Techniques, IEEE Transactions on, June 2006
[VM_ISSCC09] Verhelst, M.; Van Helleputte, N.; Gielen, G.; Dehaene, W.; , "A reconfigurable, 0.13µm CMOS 110pJ/pulse, fully integrated IR-UWB receiver for communication and sub-cm ranging," ISSCC 2009
[DL_ISSCC09] David L. and et al., "A 1.1nJ/b 802.15.4a-Compliant Fully Integrated UWB Transceiver in 0.13µm CMOS", ISSCC 2009

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A Review

Time of Fight
1ns~30 cm

Ubiquitous Positioning, Location-based Service, Indoor Navigation

Wi-Fi, ZigBee network — UWB, RFID — Cellular

RSS, AoA, ToA, TDoA, Pattern match

Bandwidth

$$\mathrm{Var}\left(\hat{d}\right) \geq \frac{c^2}{8\,\pi^2\,\beta^2\,\mathrm{SNR}}$$

- Pioneers of UWB positioning
  - Time Domain
  - Ubisense
  - Zebra
  - DecaWave
  - Univ. Oulu [OI_TMTT06]
  - KU Lueven-IMEC [VM_ISSCC09]
  - CEA-LETI [DL_ISSCC09]
  - KTH-SPL

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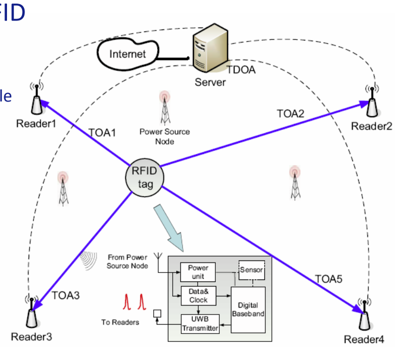
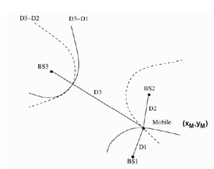
System Concept

- Locating the passive UWB-RFID
  - Passive and asymmetric
    - Tag/Reader unsynchronized
  - Two way ranging (or ToA) is not possible
  - TDoA with 4 readers
  - Energy Detector with ToA estimator
  - Backend processing
  (reader synchronization + positioning)
  (IEEE1588 Precise Time Protocol (PTP))





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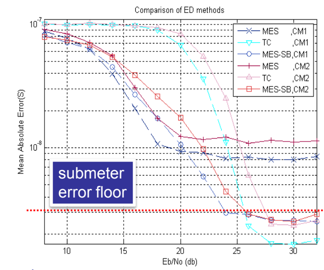
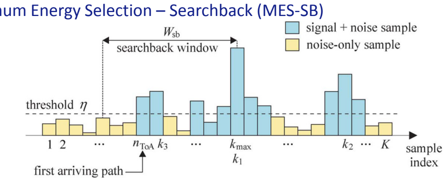
ToA using ED RX

- Challenges
  - Multi-path and NLOS
    - the strongest path is not the direct path
  - Nyquist sampling and ML estimation
    - Hardware complexity



- Energy Detection based ToA
  - Maximum Energy Selection (MES)
  - Threshold Comparison
  - Maximum Energy Selection – Searchback (MES-SB)



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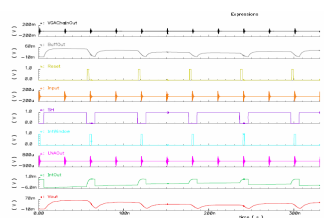
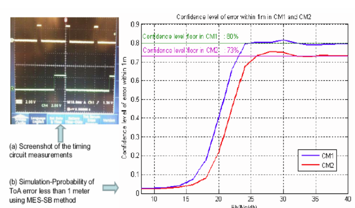
Hardware Platform

- Implemented ED Receiver
  - Up to 1GHz equivalent sampling
  - Flexible backend
  - High speed ASIC and FPGA connectors (HSMC. Altera)
  - 2 independent channels

It offers an open platform for different algorithms





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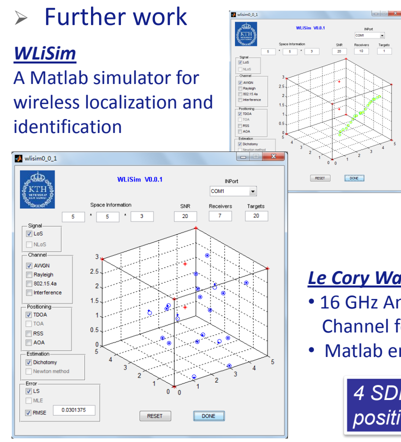
Hardware Platform

- Further work

WLiSim
A Matlab simulator for wireless localization and identification



Le Cory WaveMaster 816Zi
- 16 GHz Analog BW, 40 GS/s, 4 Independent Channel for acquisition with build-In SW
- Matlab embedded for backend processing

4 SDR or Nyquist sampling Rx. for positioning experiments

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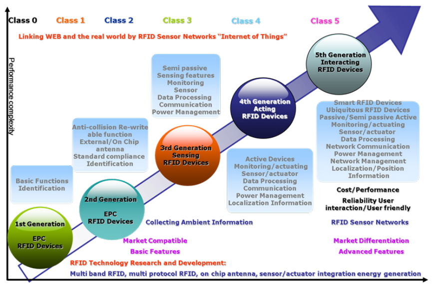
Summary

- Remarks

  Using UWB for RFID was investigated from system to silicon
  - UWB could be an alternative of passive UHF RFID
  - Also, UWB could be an alternative of HF/LF RFID (low cost and short range)
  - Still, UWB could be an alternative of 2.4GHz (semi-passive or active for WSN)

- Outlook

  More efforts are expected
  - Regulations
  - Standardizations
  - More Pionniers



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IEEE 2011 RFID Conference

April 12, 2011, Orlando, the USA

UWB as an Alternative of UHF RFID in the Era of IoT?

- From System Concept to Silicon Implementation

Q&A
Thanks!

Zhuo Zou and Li-Rong Zheng

iPack VINN Excellence Center
School of Information and Communication Technology
KTH-Royal Institute of Technology, Sweden
zhuo@kth.se

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IEEE RFID 2011

5th Annual IEEE International Conference on RFID

Workshop 2: *Working UHF RFID Localization Systems*

Direction Finding System for Locating UHF RFID Tags*

Lyazid Aberbour[1], Greg Hislop[1,2], Maxime Drouguet[1], Christophe Craeye[1], Didier Lekime[3], Joel Hancq[2,3]

[1] UCL -Université catholique de Louvain- ICTEAM ELEN, Belgium
[2]Université de Mons, Belgium,
[3]MULTITEL, Mons, Belgium

(*)RFTAG project funded by Région Wallonne

Orlando, April 12, 2011

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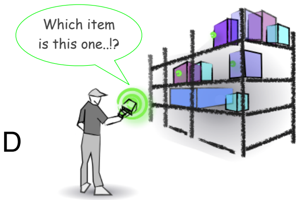
Objectives

- A system indicating to the user the location of items in a warehouse
- Develop a direction finding system capable of locating passive UHF RFID tags in a warehouse environment
- The system should be cheap, easy to install and maintain



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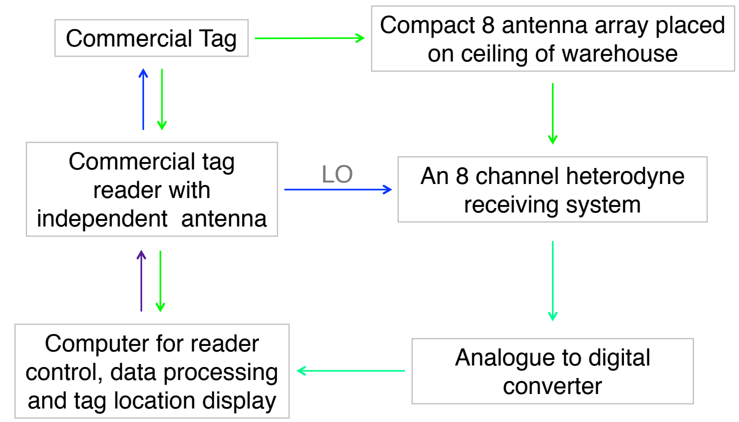
System Overview



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System Overview

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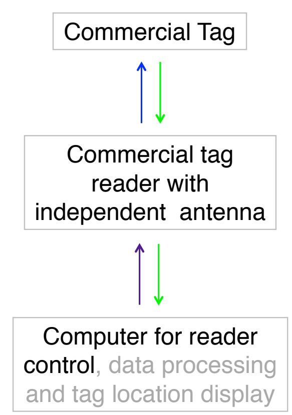
System Overview



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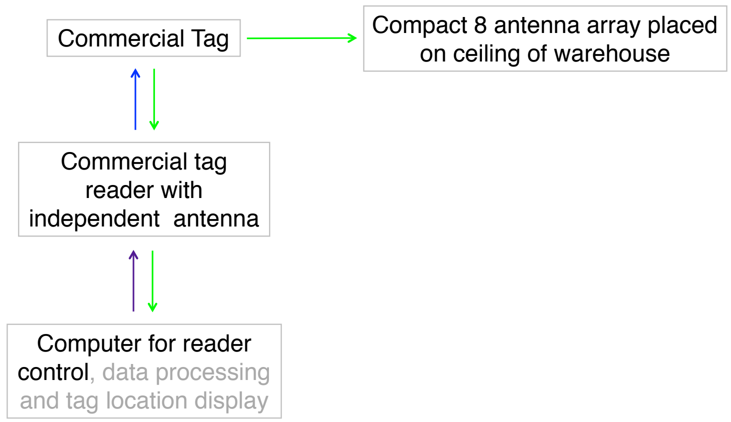
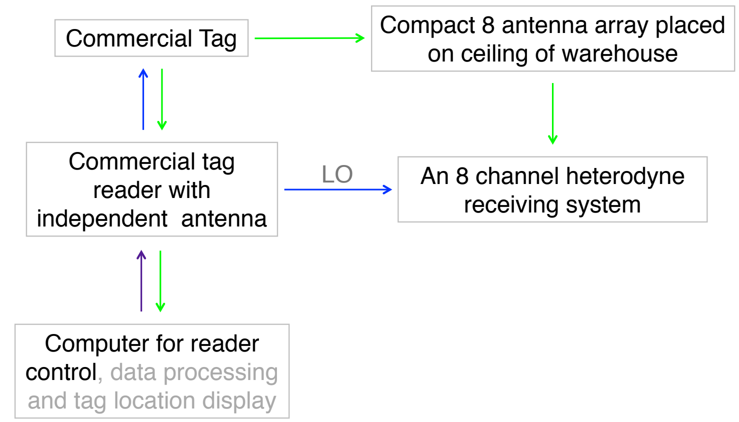
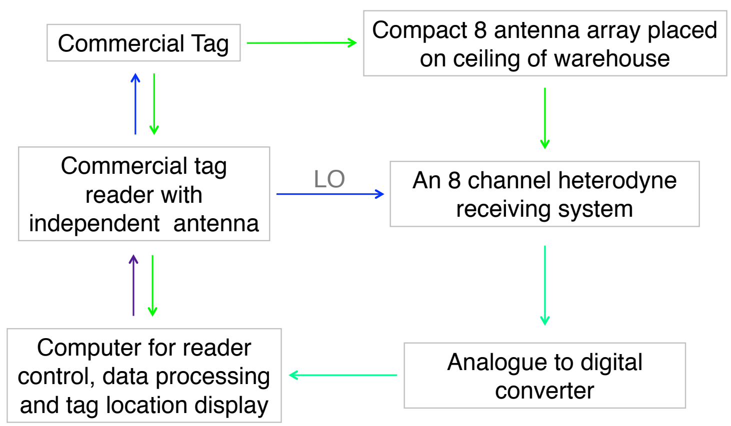
System Overview



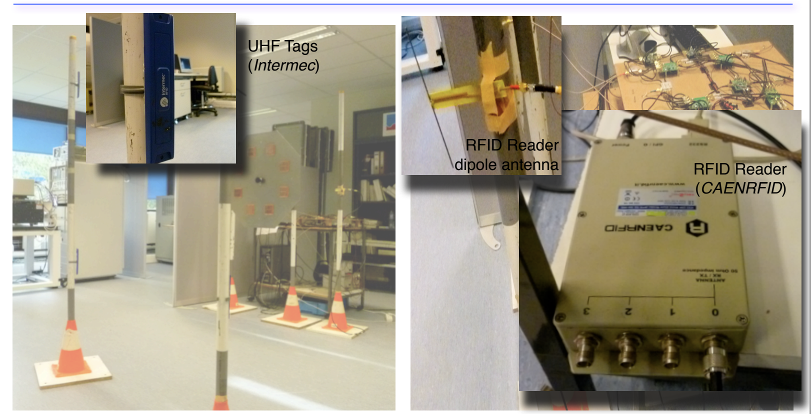
System Overview



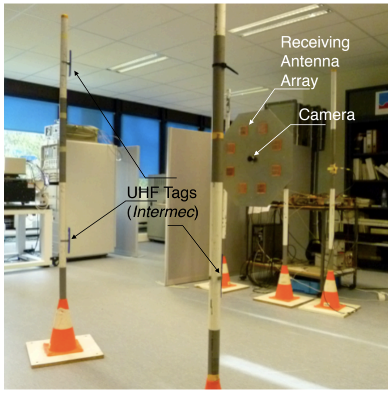
System Overview

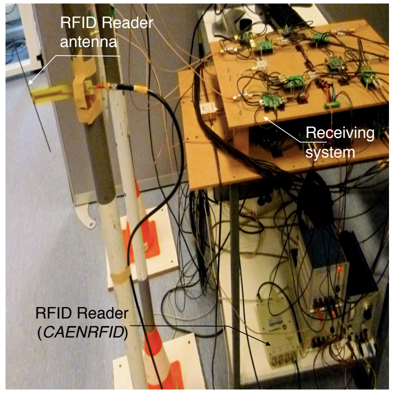


Prototype Overview



Prototype Overview





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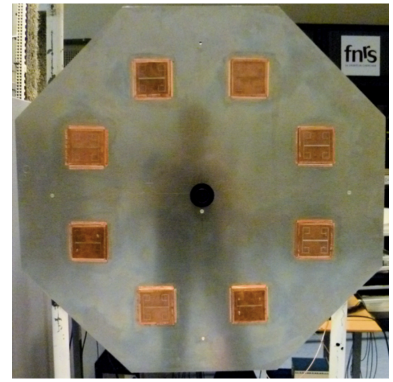
Prototype Overview

Circular Antenna Array



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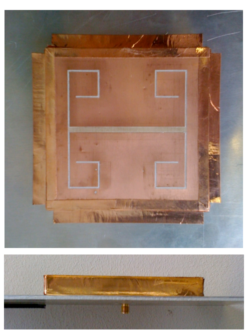
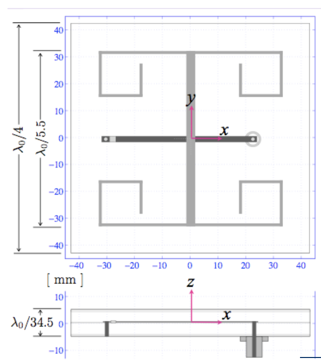
Prototype Overview

A Unidirectional Compact-Slot Antenna





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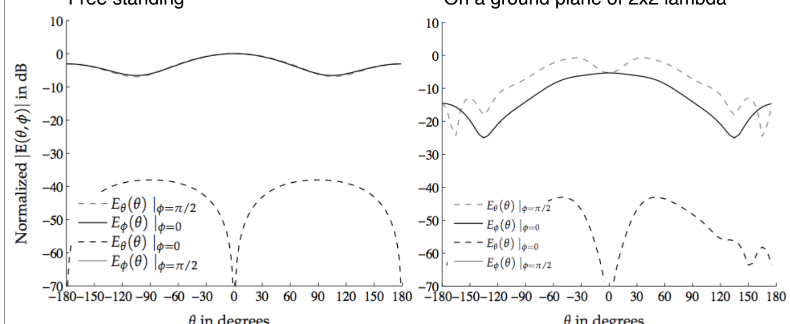
Prototype Overview

A Unidirectional Compact-Slot Antenna

- Radiation pattern of the antenna array element:

Free standing — On a ground plane of 2x2 lambda



- Matched Impedance bandwidth:
  BW = 1.2% for IS11I<-10 dB (862MHz - 877MHz)

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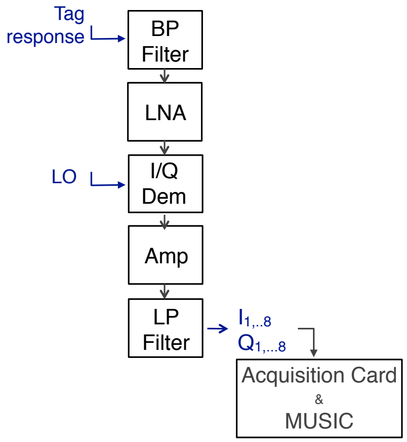
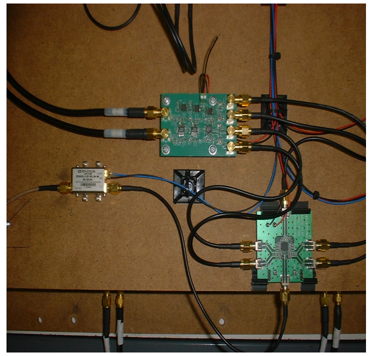
Prototype Overview

Receiving System





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Direction Finding Algorithm

MUSIC Based

- MUSIC works well when there are no reflections
  - With reflections there are multiple correlated signals coming from multiple directions
  - MUSIC works very well in warehouse and partially anechoic environments (our experience) !
- Our approach for environments with rich reflections
  - Consider all possible directions
  - Find laterally shifted correlation matrixes and average them
  - Perform MUSIC and remove low power directions from search space
  - Repeat till convergence

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IEEE RFID 2011

SAIC From Science to Solutions

RF CONTROLS IDENTIFY. LOCATE. TRACK.®

RF Controls' ITCS® with SAIC's AMS

System and Technology Overview

April 12, 2011

ITCS: Proven Technology

SAIC From Science to Solutions — RF CONTROLS IDENTIFY. LOCATE. TRACK.®

- RF Controls' Intelligent Tracking and Control System (ITCS®) is a standards-based, real-time location system which accurately locates & tracks passive UHF tags
- We have significantly enhanced field-proven technology which has been utilized in military tracking / target acquisition applications
- ITCS is unlike any technology currently used within the auto-ID industry achieving unrivaled operating range and location accuracy, taking passive UHF RFID to new heights

Footnote: visit http://www.rf-controls.com About Us to understand how...

ITCS: Headline Topics

SAIC From Science to Solutions — RF CONTROLS IDENTIFY. LOCATE. TRACK.®

- ☑ Type approved by the FCC (Part 15.247); certified CE and RoHS compliant
- ☑ Compliant with EPCglobal and ISO standards
- ☑ Identifies, locates and tracks standards compliant passive UHF RFID tags
- ☑ Superior operating range and best-in-class accuracy of tag location (in 3D)
- ☑ Provides exceptional tag reading integrity under challenging real-world conditions

ITCS Performance

SAIC From Science to Solutions — RF CONTROLS IDENTIFY. LOCATE. TRACK.®

- Operating range with Higgs-3 and Monza3 based tags 90-100'[(1)]
- ITCS can locate each tag in <u>three dimensions</u> with an accuracy of $\approx \pm 1$'
- Proven statistical signal processing methods resolve ghost images caused by multi-pathing effects
- Tracking is accomplished by time-stamping tag locations data in the system's database
- ITCS yields high fidelity, real-time data

Note: 1) Operating range is critically dependent on tag characteristics

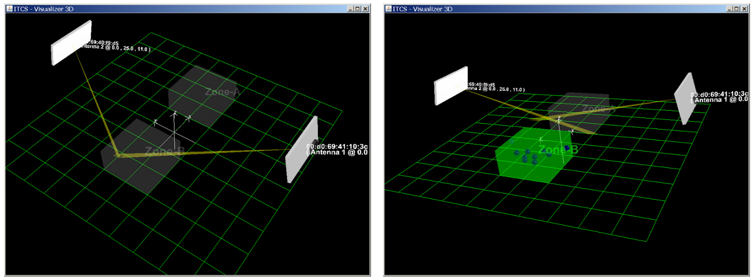
Signal Processing

SAIC From Science to Solutions — RF CONTROLS IDENTIFY. LOCATE. TRACK.®

- Advanced signal processing algorithms extract significant and valuable information from the RF link
- The angle of arrival (AoA), phase, polarity, RSSI of tag signals are all assessed
- Advanced, patented "curve fitting" algorithms are applied to ascertain the location of the "real tag" and eliminate ghost images by resolving multi-path ambiguity
- The basis for these techniques is battle proven military target acquisition and tracking technology, which RFC has enhanced and applied to pRFID/RTLS applications

How ITCS Works

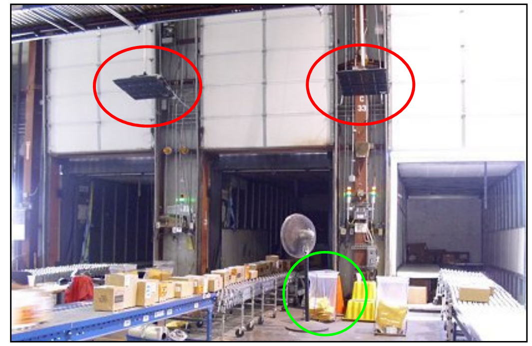
SAIC From Science to Solutions — RF CONTROLS IDENTIFY. LOCATE. TRACK.



- One of more Signal Acquisition and Source Location (SASL®) "smart antennas" scan variable areas (volumes) for tags
- The ITCS Location Processor collates multiple data points to give accurate locations of tags in 3D
- Multiple, variable size, non-contiguous scanning "zones" may be defined

ITCS "Portals"

SAIC From Science to Solutions — RF CONTROLS IDENTIFY. LOCATE. TRACK.



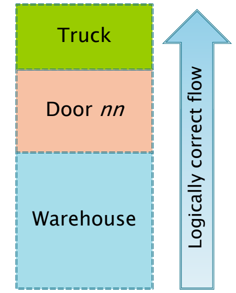


Image Courtesy of GSA and SAIC

Solution Architecture

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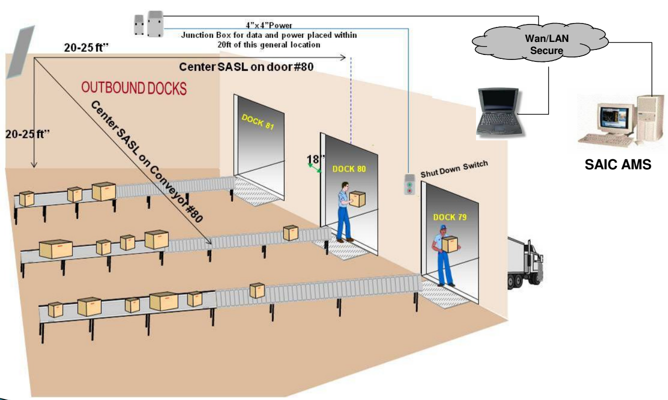

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Demonstration

ITCS – Market Feedback

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- From Reik Read at industry analysts RW Baird, referring to ITCS:
  - "We view the ability to scan specific zones as a key attribute that can help locate missing items, provide real-time out of stock information, improve pick processes and can aid in inventory transfers, all in real-time."

December 2008 RFID Journal Magazine:

RFID Journal's **Watch List**

Technologies to Watch
- Beam-Steerable Phased-Array Antennas
- Cold-Chain Sensors
- Interactive RFID Displays
- Near Field Communication
- Printed-Electronics RFID Tags
- RuBee
- Sensor Networks
- Thin-Form Batteries
- Ultra-Wideband RFID
- Zigbee

RF Controls' ITCS is unique in being the only "next generation" system to employ **bidirectional** electronically steerable phased array (BESPA™) antenna technology, to achieve zonal coverage of an area, supporting arbitrary placement of tagged items and the ability to accurately locate tags in 3D.

ITCS – Market Feedback

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- Pat Talty, Mission Engineering VP at TASC (formerly Northrop Grumman), describing the utilization of ITCS at a Navy supplies depot:
  - "The system will identify the shipment of the wrong items, or, if an item is misplaced, show you exactly where in the warehouse you can find it."
- Doug Litten, AVP at SAIC, concerning a deployment of ITCS at a large General Services Administration (GSA) distribution center:
  - "ITCS not only reads RFID tags at a greater distance and with better location accuracy than previous systems, but it also offers a RTLS capability which will help streamline operations, while reducing costs and increasing efficiencies."

ITCS – Market Feedback

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- Dr. Bill Hardgrave, Director of the RFID Research Center at the University of Arkansas:
  - "The technology is amazing. A zonal monitoring system like that is a game changer. It will not just tell you when items are in the wrong location on the retail floor, but it will also be very useful in the back room of a store, where you need to locate items that have been misplaced."
- From the CTO of one of the most respected UHF RFID companies:
  - "ITCS uniquely solves the #1 problem impeding deployment of passive UHF RFID systems today – spurious reads."
- From a global systems integration firm to a global retailer that is one of their biggest customers:
  - "In our opinion, RF Controls' ITCS is the only system that can achieve the performance you have specified for automated back of store inventory location."

SAIC Software – AMS

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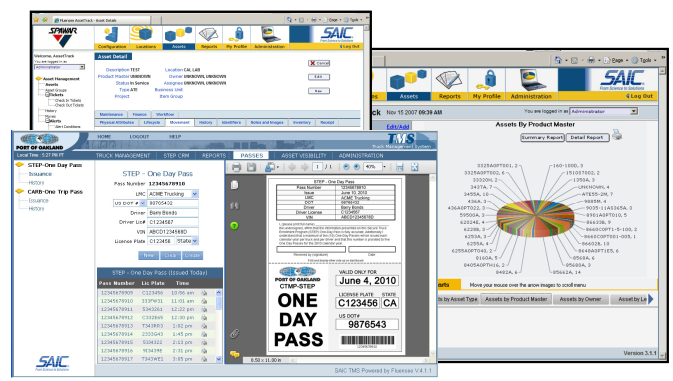

AMS is a feature-rich applications suite which provides fully customizable reports and dashboards so users can turn new, high fidelity real-time data from ITCS into actionable information

Chris Hook
VP Business Development
RF Controls, LLC
1141 S. 7th Street
St. Louis, MO 63104-3623
USA

Website: http://www.rf-controls.com
e-mail: chook@rf-controls.com
Cell phone. +1 847 274-6943

Joe Leone
Director , Logistics Automation Integration
SAIC
4640 Trindle Road
Camp Hill, PA 17011
USA

Website: http://www.saic.com
e-mail: joseph.g.leone@saic.com
Cell phone. +1 703 980-4336