Chipless RFID and Sensors
An Unconventional Approach

Somnath Mukherjee

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- Background Information
- State of the Art
- Fundamentals of Proposed Technique
- Tag Design Considerations
- Challenges and Future Work
- Conclusion

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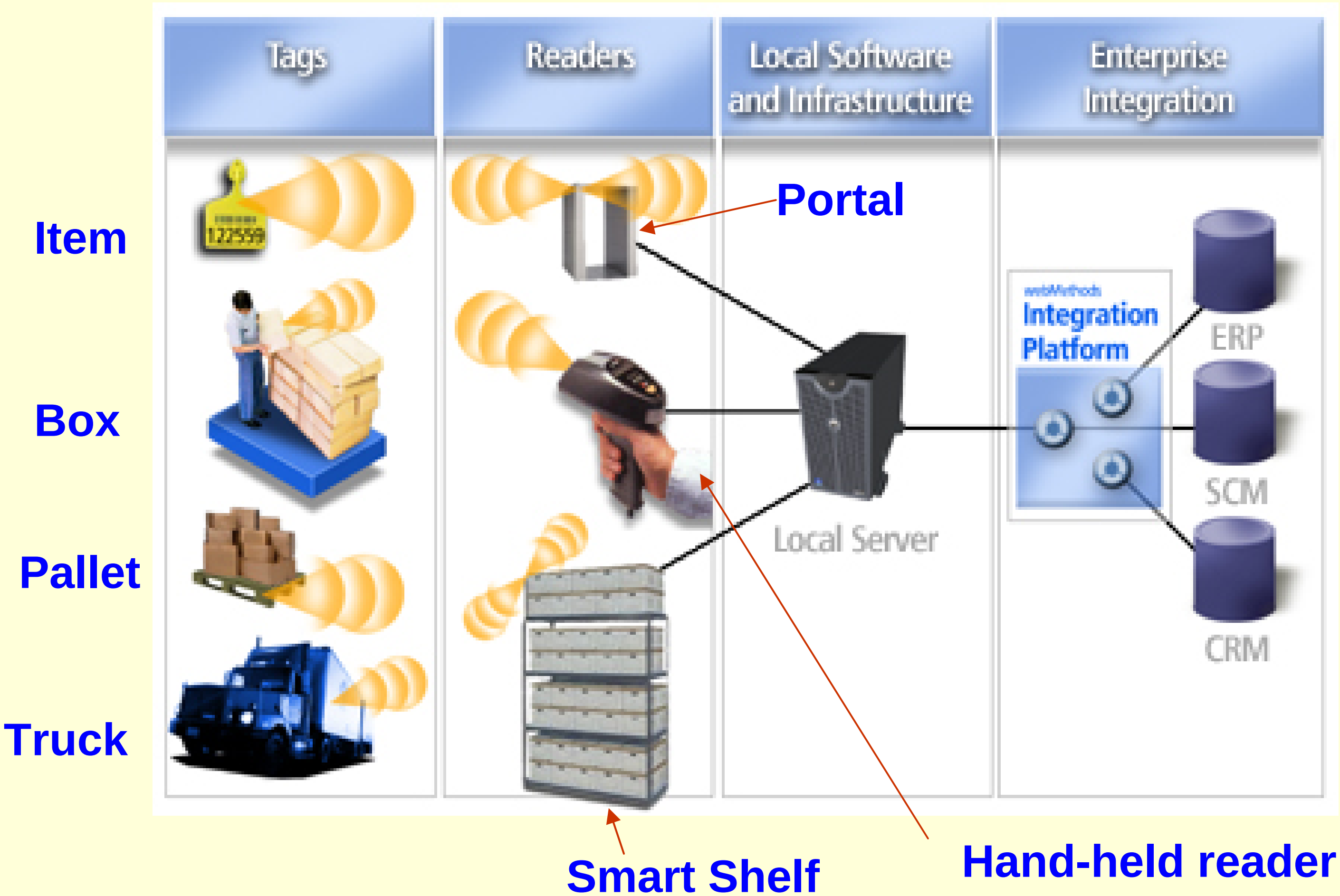
RFID in Supply Chain Management



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RFID in Retail

Automatic Check out

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Conveyer based Monitoring

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RFID Tracking of Assets

Complement Bar Codes

RFID has the potential for certain attractive properties not available with Bar Codes

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RF Bar Code vs. Optical Bar Codes

Wish List for Item Level Tagging

- *Price* of RF Bar Codes comparable with Optical Bar Codes
- *Printing* at users' premises or on packaging material

- *Advantages of RF Bar Codes:*
  - Longer range
  - No Line-of-Sight required
  - Co-ordinate information
  - Automatic readout with real time tracking and visibility
    - Without human intervention
    - Scanning at conveyer speeds
    - Perpetual inventory – simultaneous multiple readouts ("Smart shelves")

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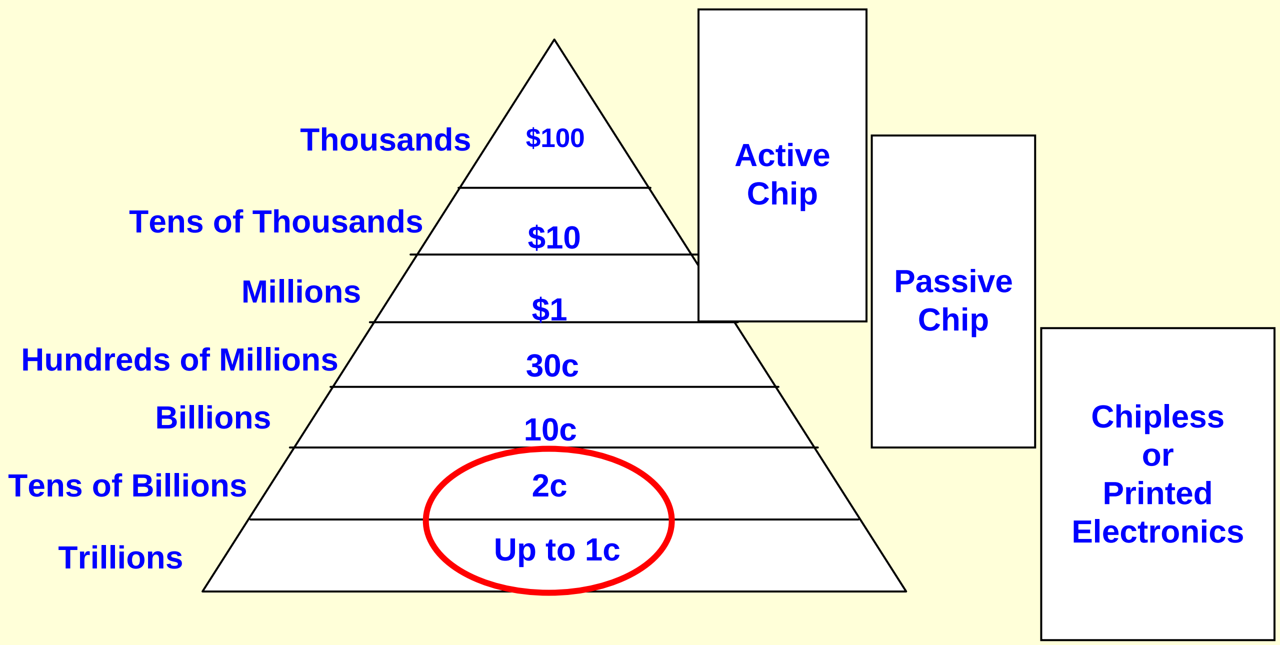
Market - RFID



Source: IDTechEx

Use low cost printing technique with conducting ink?

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Chip based RFID

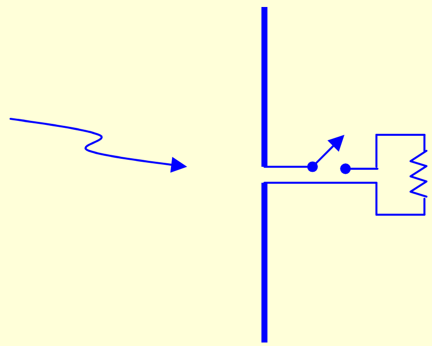
Active Tags – contains battery. Expensive.

Passive Backscatter Tags – contains no battery

Chip

Chip

Passive Backscatter Tag



Amplitude Modulation of RCS

Rectenna

Roughly half of RF power received is used to operate the chip

Memory (Information) created as a time sequence

Read and Write Operations

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Chipless State of Art

- **Resonance based**
  - LC (Electronic Article Surveillance – 1 bit)
  - Metal fibers (mm wave)
  - SAW
  - Others…
- **Imaging based (mm wave)**
- **Chemical based**
- **Printed Electronics (not chipless)**

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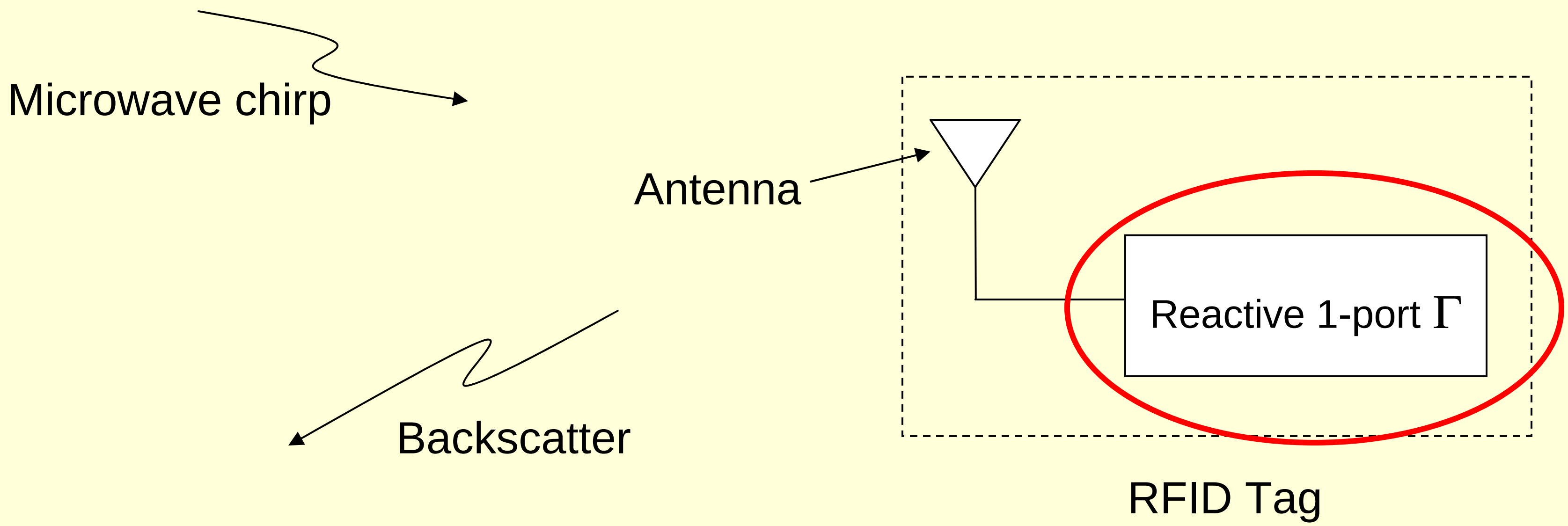
Basic Principle – Chipless RFID



Print the antenna and the reactance on the item to be tagged

No rectenna

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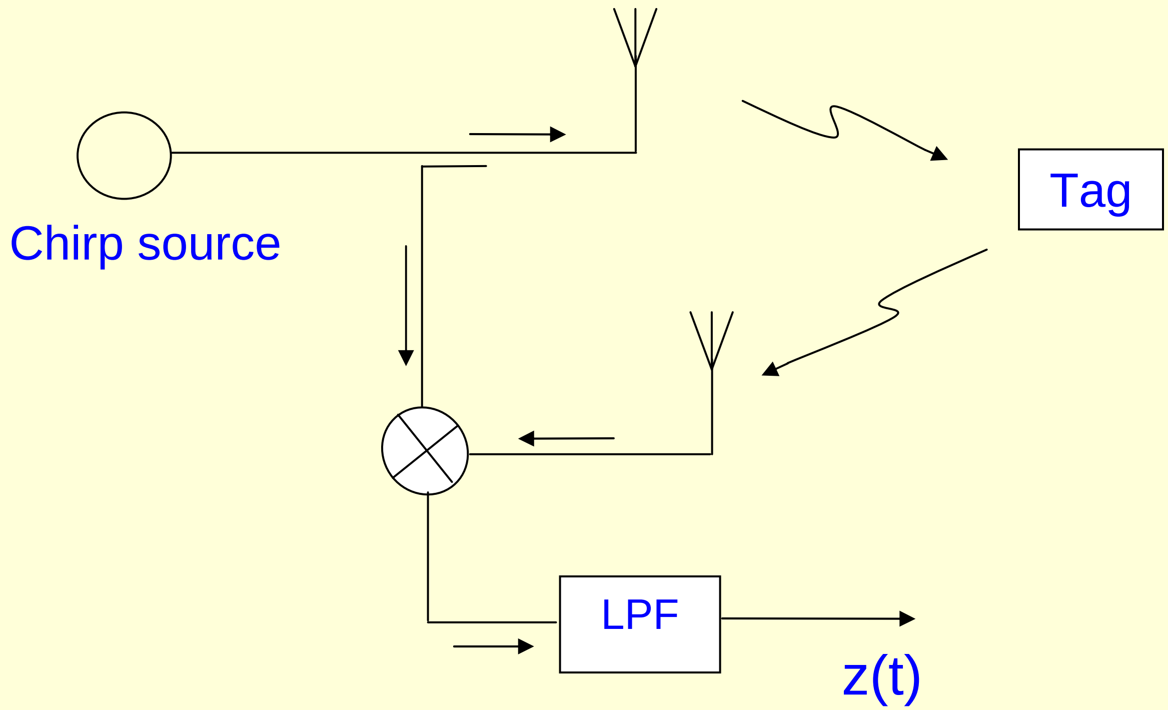
RFID Reader - FMCW radar



For wideband point target, z(t) is a sinewave with frequency $K\tau/2\pi$

Linear chirp with chirp rate $K/2\pi$

τ = roundtrip time delay

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Scattering from Reactive 1-port

- Backscatter signal will be ***constant envelope***

  $|\Gamma| = 1$

- Objective:

  Characterize the ***phase ripple/delay*** of the Reactance remotely

- Processing similar to FMCW radar technique *but recovers phase information*

- Fundamentally a *frequency domain* measurement

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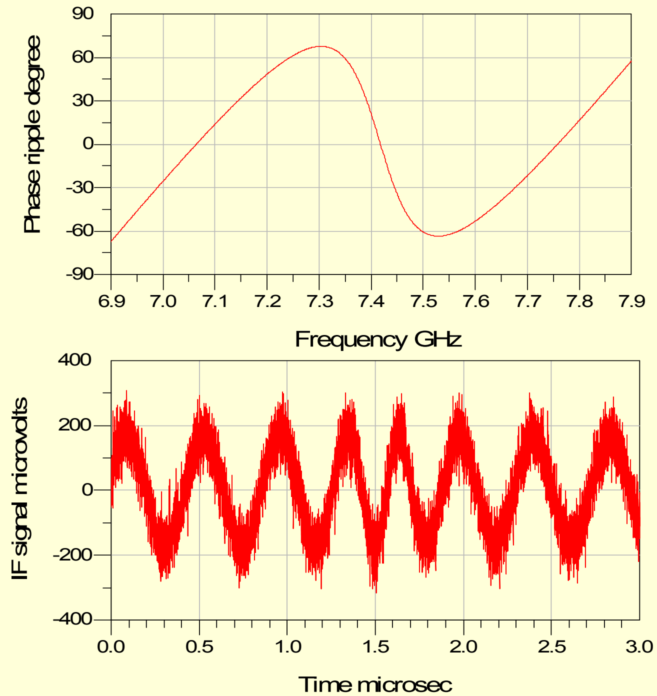
Illustration of Phase Mapping

$\arg(\Gamma(f))$

$z(t)$



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arg(Γ(f)) mapped to IF

- z(t) ~ $\Gamma(f(t)).\cos[2\pi f_0\tau + K\tau.t + \psi(f(t))]$
  - Assumption:
    - Impulse response of Γ(f) << chirp duration
    - $\Gamma(f) = |\Gamma(f)|$, $\psi(f) = \arg(\Gamma(f))$
    - start frequency f_0, chirp rate = $K/2\pi$
- Phase-frequency profile is mapped on the IF
  - Constant envelope IF signal with resonances in Γ(f) manifested as phase modulation

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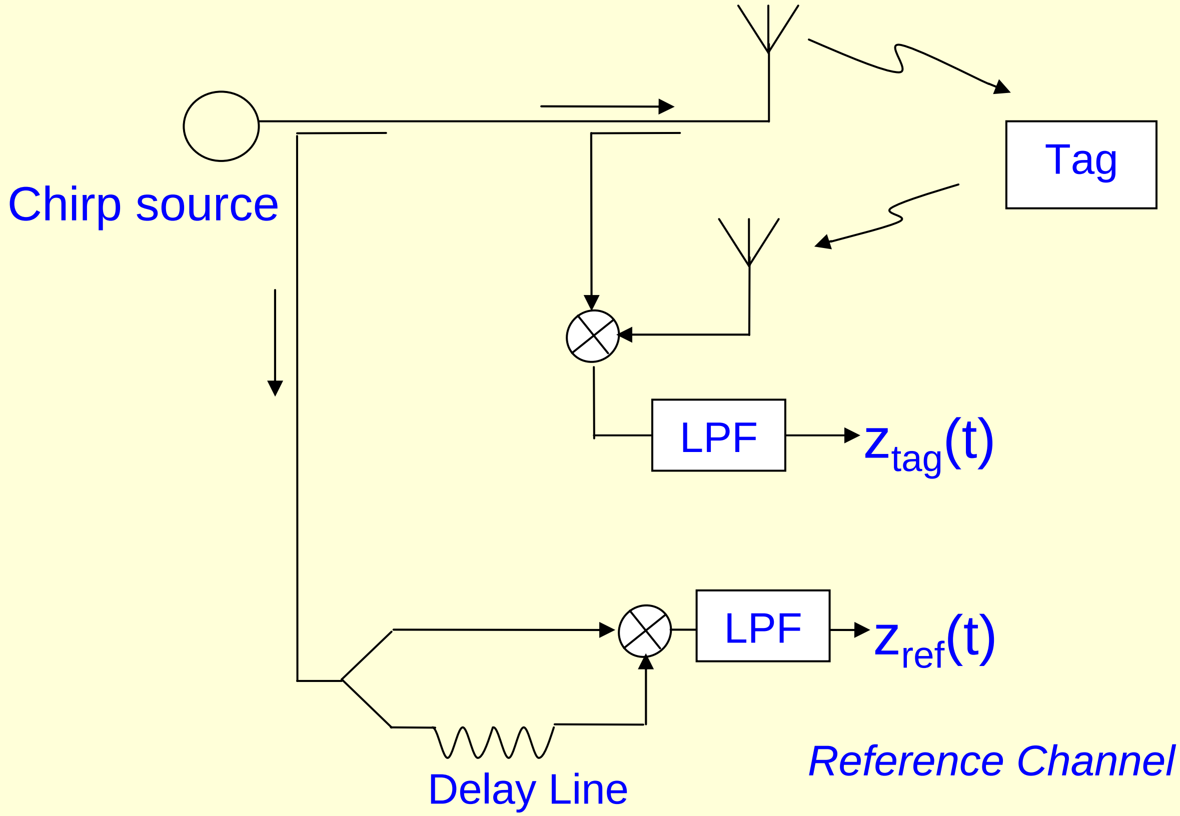
Adding Reference Channel



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Reference channel in Reader

- Reference channel in reader generates a benchmark signal based on a fixed delay

- Also could be used to correct amplitude imperfections and deviation from linearity in the chirp

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Recovery of Phase-Frequency Profile

$z_{tag}(t)$ Hilbert Transform → $\zeta_{\mathbf{tag}}(t)$

$z_{ref}(t)$ Hilbert Transform → $\zeta_{\mathbf{ref}}(t)$

$\arg(\zeta_{tag}(t)/\ \zeta_{ref}(t))$

$= 2\pi f_0.(\tau-\tau_{ref}) + K.(\tau-\ \tau_{ref}).t + \psi(f(t)) + \psi_{ref}$

There may be alternative methods!

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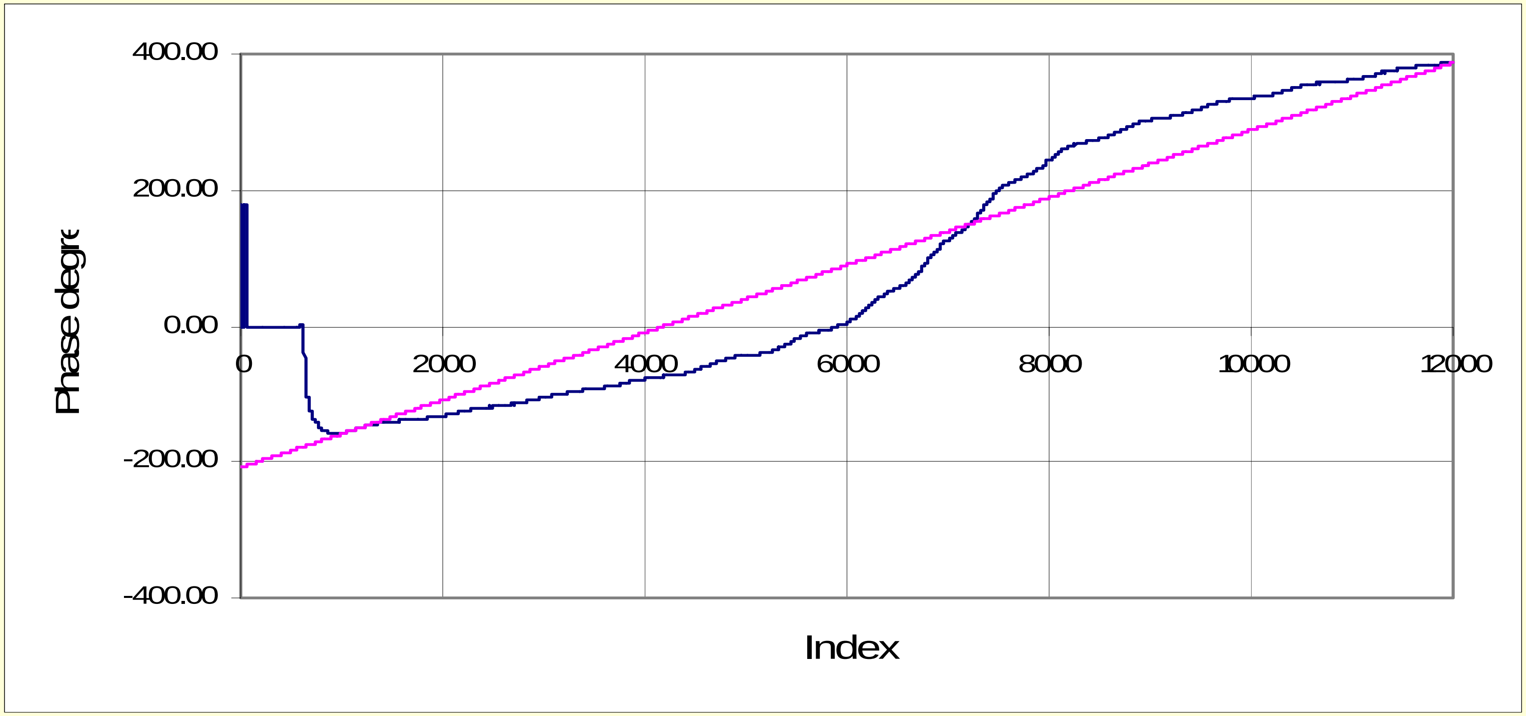
Unwrapped Phase



Chirp duration: 3 ms
Chirp bandwidth: 1 GHz
Reference channel delay: 6 ns
τ: 6.6.ns

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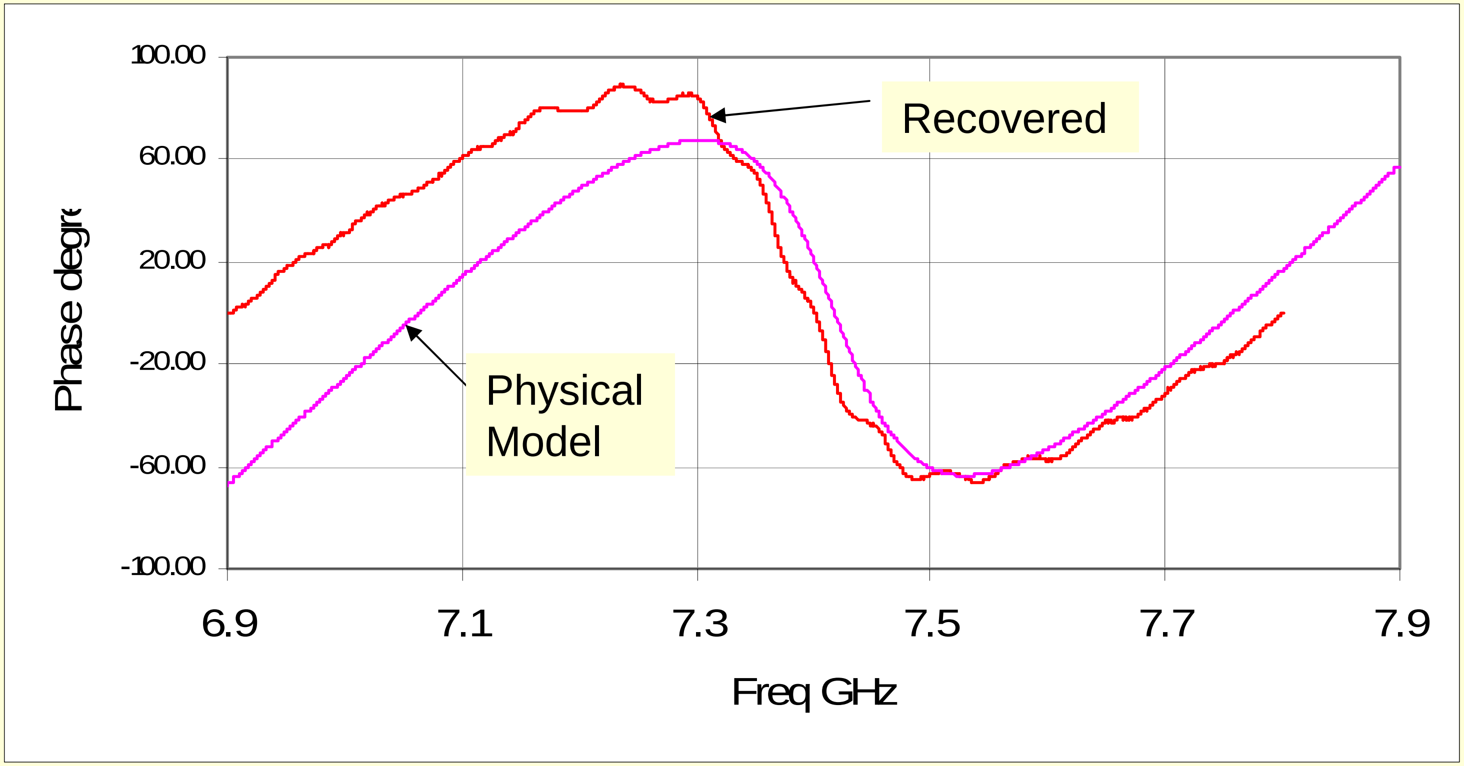
Recovered Phase



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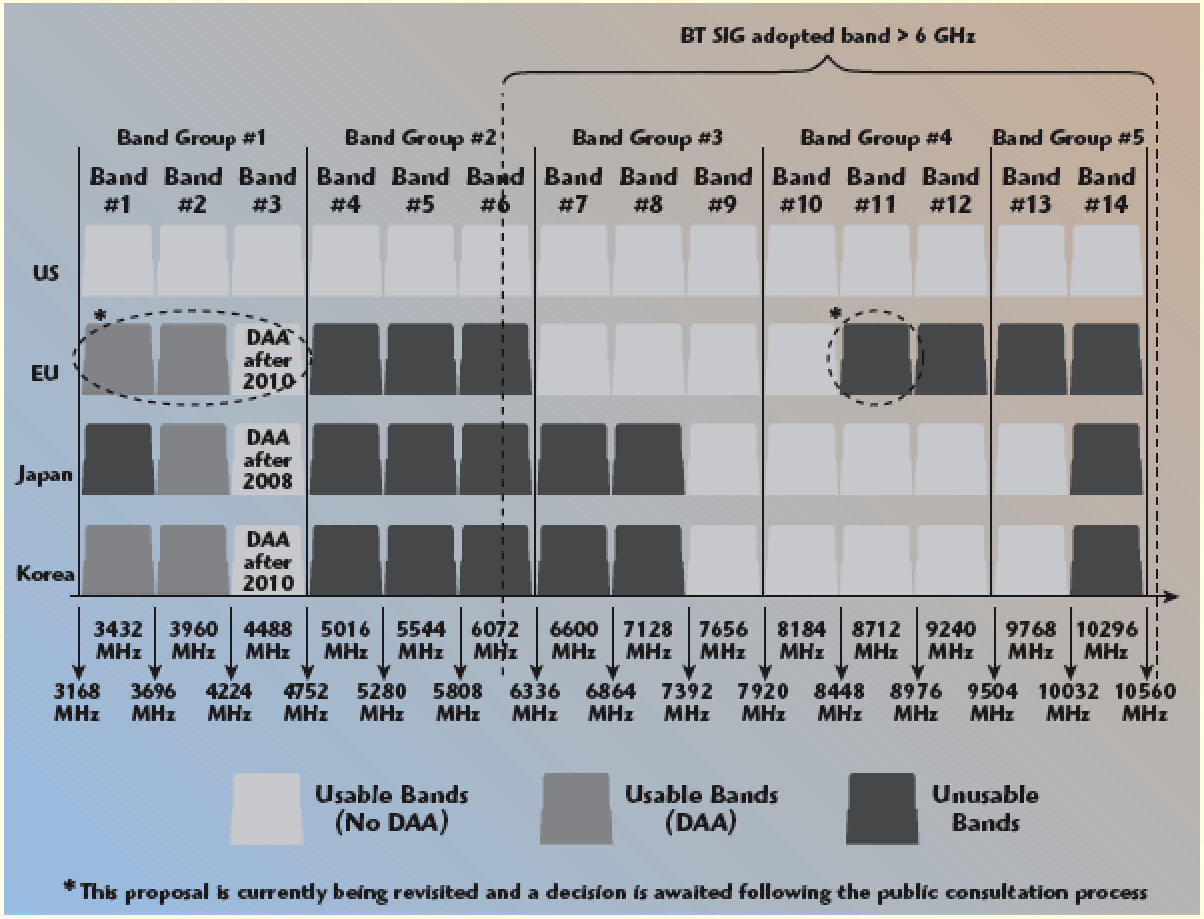
Frequency Spectrum



Source: Microwave Journal

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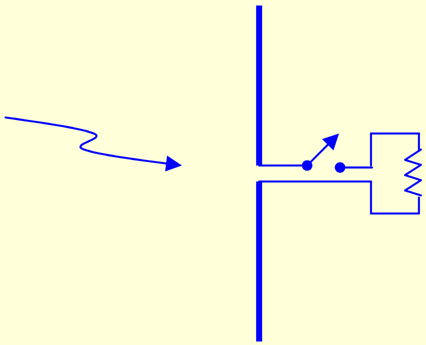
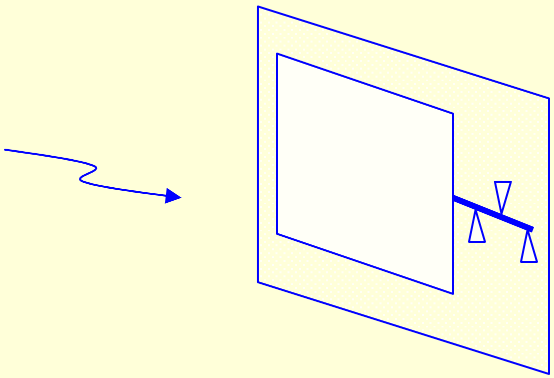
Chip vs. Chipless



Chip-based Tag

- Processing – time-domain
- Amplitude modulation of RCS
- Typically a dipole (or variation)
- Minimum scatter



Chipless Tag

- Processing – frequency-domain
- Amp/Phase Modulation of RCS
- Typically a patch (variation?)
- Not a minimum scatter device

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Antenna Categories

- **Minimum Scatter Antenna**
  - Negligible back-scatter under open circuit condition
  - When terminated, as much is dissipated as is re-radiated
  - Amplitude modulation of RCS
- **Non Minimum Scatter Antenna**
  - Magnitude of back-scatter independent of reactive load (ideal condition)
  - Negligible back-scatter when terminated (Low Structural Scattering)
  - Amplitude/Phase modulation of Complex RCS

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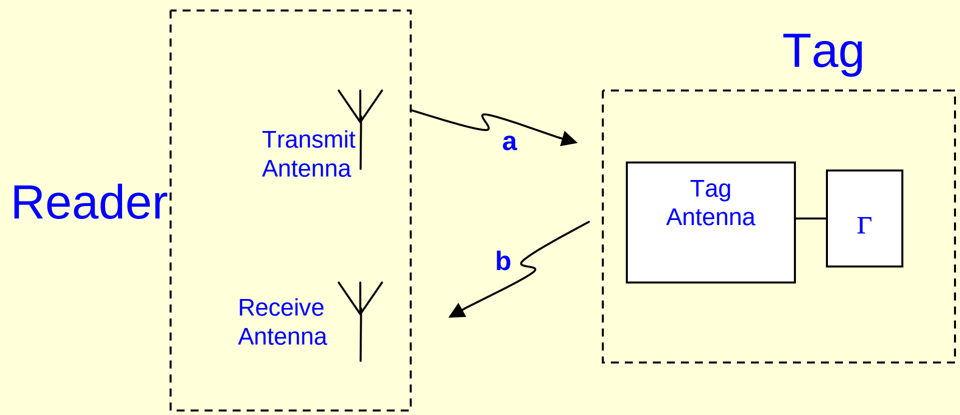
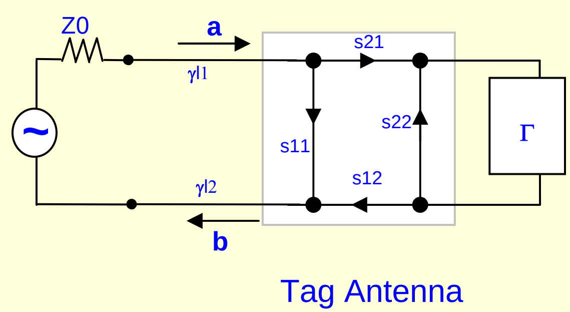
Two-port Equivalent Circuit

Motivation:

Determine Γ remotely (tag information is encoded there) by de-embedding effect of Tag antenna





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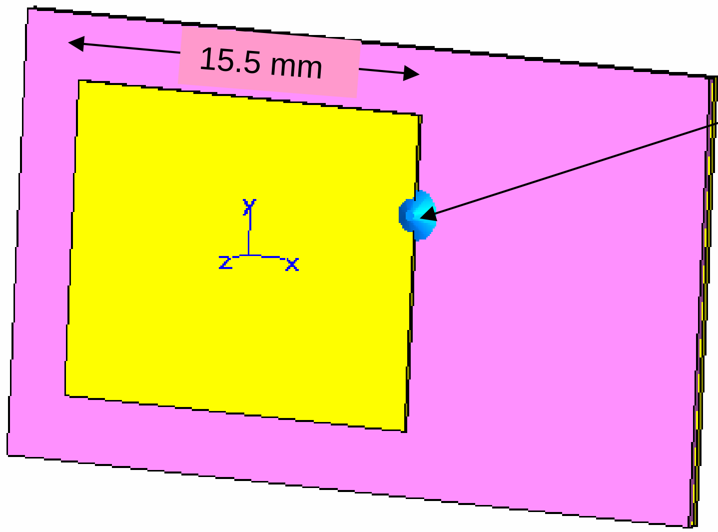
Example: Rectangular Patch on Ground Plane

Patch and Ground:

Copper 5.8.10^7 S/m

Substrate:

εr =4.5 tanδ = 0.0



Lumped Terminations applied here

Patch on a large ground plane

Intentional structural scattering

Vector Network Analyzer calibration

Open, short and load standards for characterizing unknown two-port

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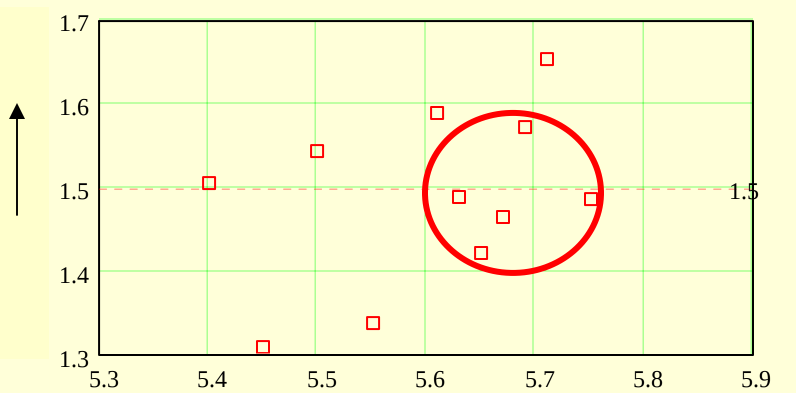
De-embedding ‘DUT’

DUT: 1.5 nH
lumped inductor

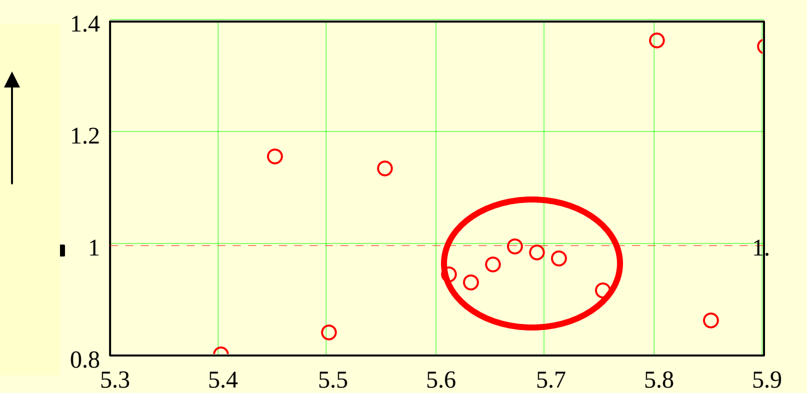
De-embedded
Value nH



Frequency GHz

DUT: 1.0 pF
lumped capacitor

De-embedded
Value pF



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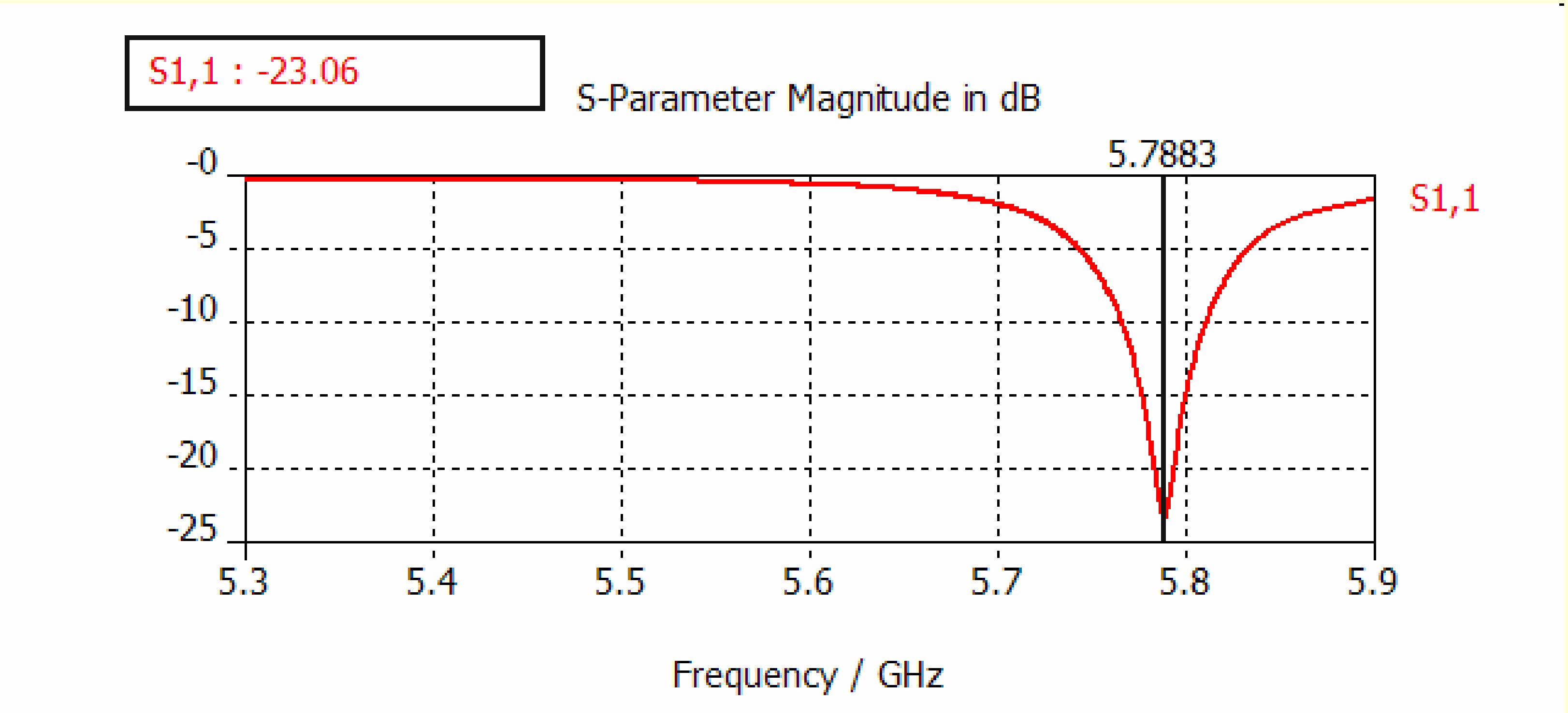
Return Loss of Patch in Transmit Mode



Accuracy is expected to be higher when resonant mode scatter is large compared to structural scatter

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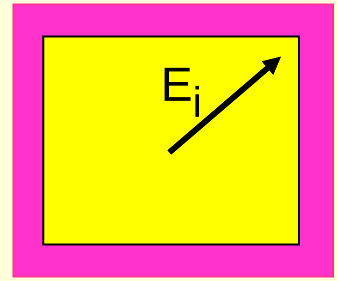
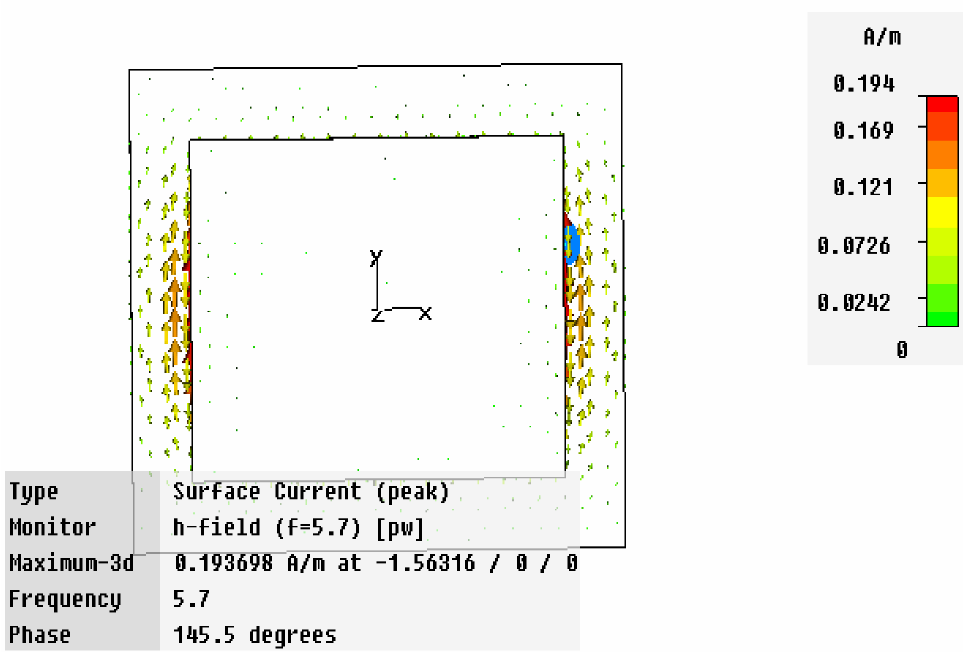
Surface Current

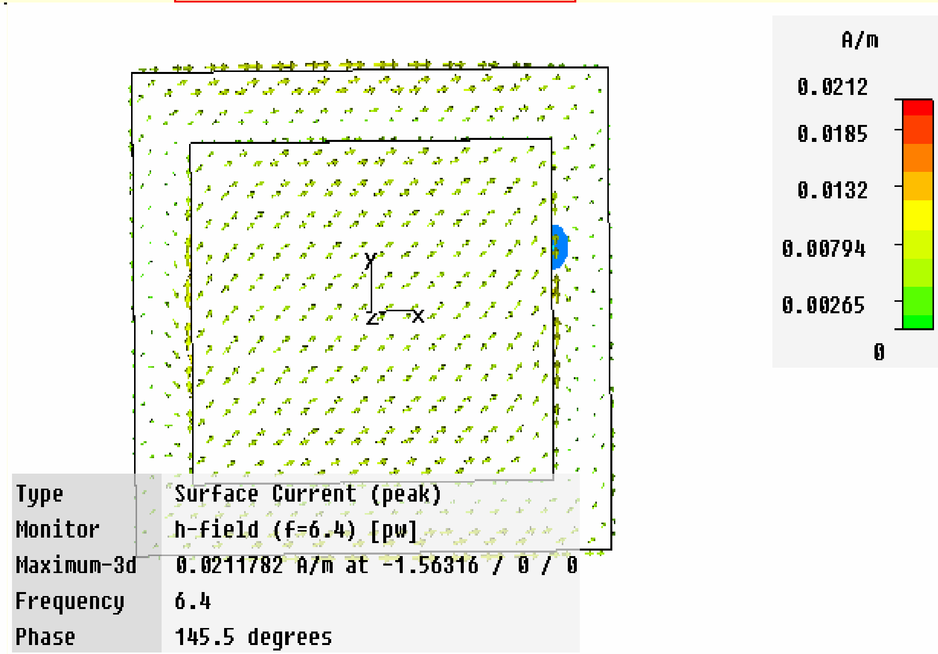
No reactive termination (Open)
Excitation: Linear polarized plane wave 45° to patch edge



Resonant Scattering

Structural Scattering





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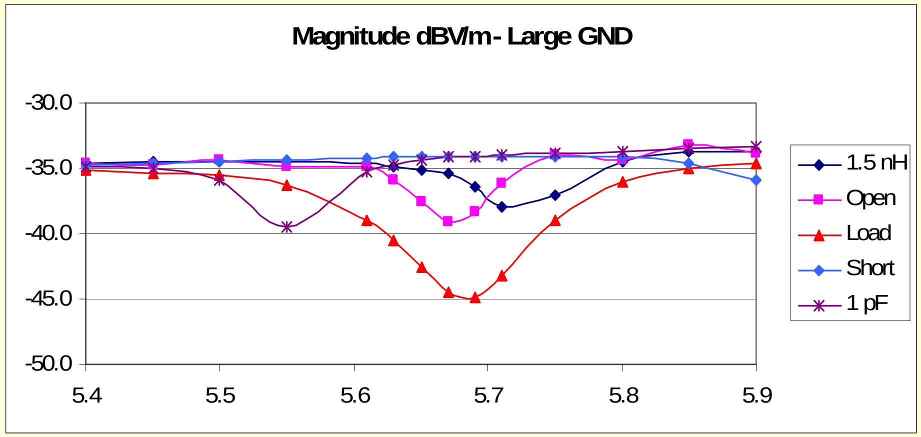
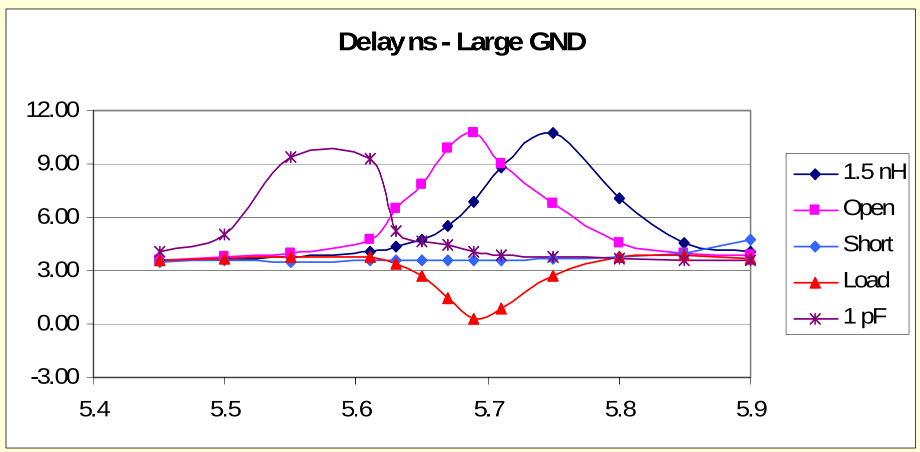
Some Reactive Terminations

Farfield Magnitude dBV/m



Frequency GHz

Farfield Delay ns



Patch and Ground:

Copper 5.8.10^7 S/m

Substrate:

εr =4.5 tanδ = 0.025

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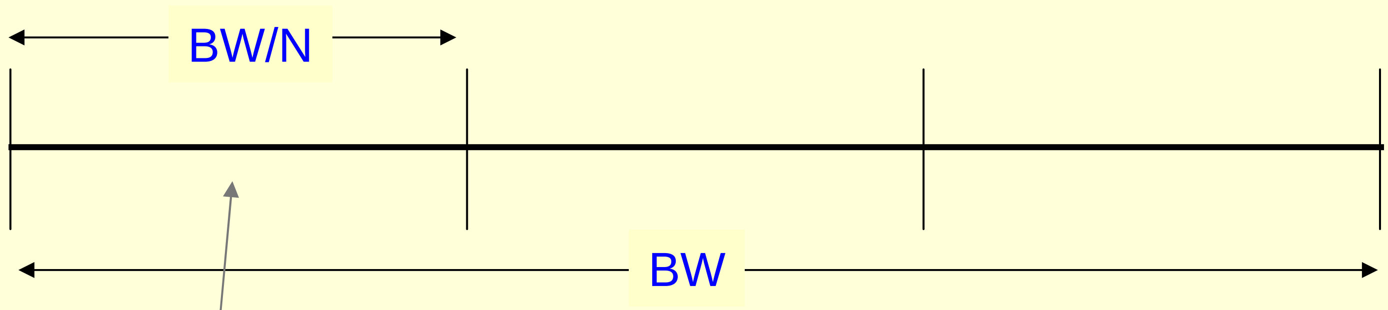
Multiple Resonances For Encoding Information



N segments. Each contains one resonance

Δf: Resolution for resonances .

Number of encoded bits = $N.\log_2[BW/N.\Delta f]$

Example: BW = 3 GHz, N = 6, Δf = 0.1 GHz => Number of bits = 14

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Generation of Multiple Resonances

- One broadband antenna terminated by a reactance with multiple resonances
    - Single layer implementation
    - Design of low structural scatter antenna with adequate bandwidth may be a challenge

- Multiple narrowband scattering elements
    - Multiple layer implementation => Compact
    - Cost?
    - Low structural scattering
    - Higher Order modes

- Combination of above

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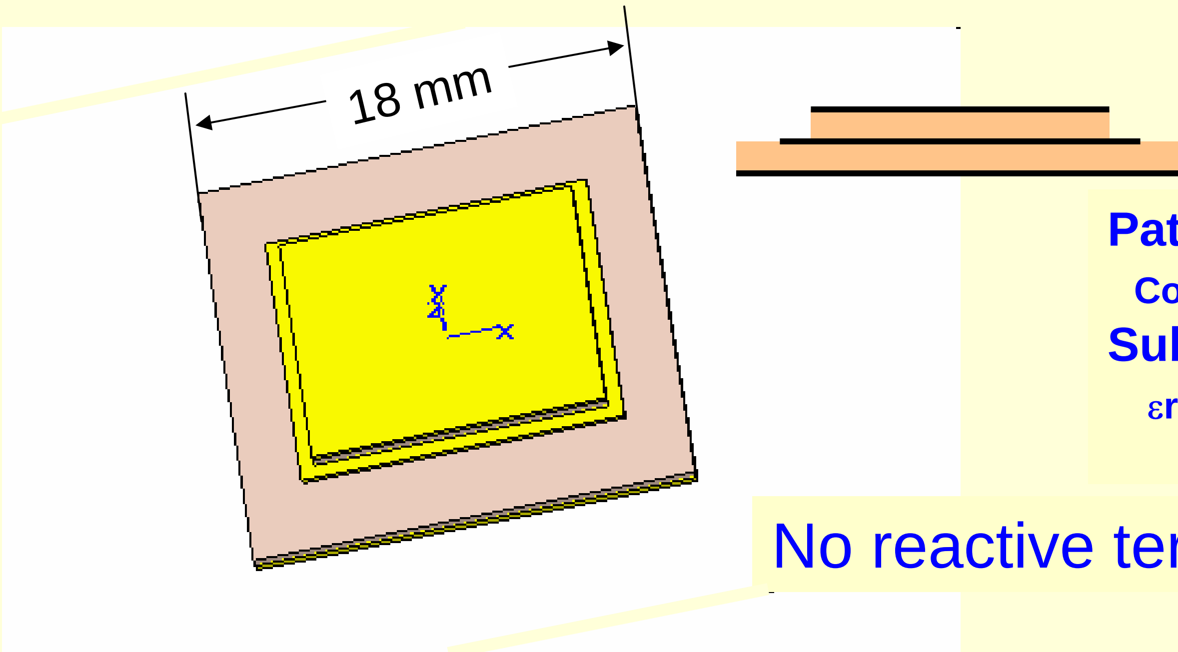
Stacked Two Layer Tag



Patches and Ground:

Copper 5.8.10^7 S/m

Substrates:

εr =4.5 tanδ = 0.002

No reactive termination

- Only one patch is resonant at a time
- Upper patch uses inner patch as ground plane when resonant
- Need to reconcile with higher order mode issue

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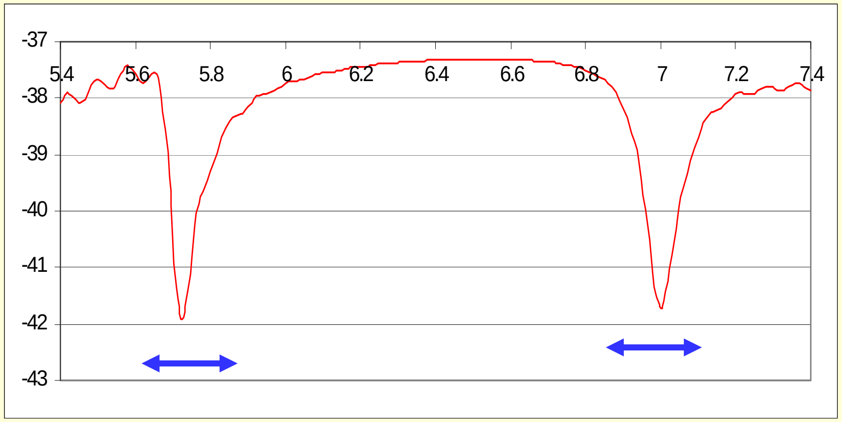
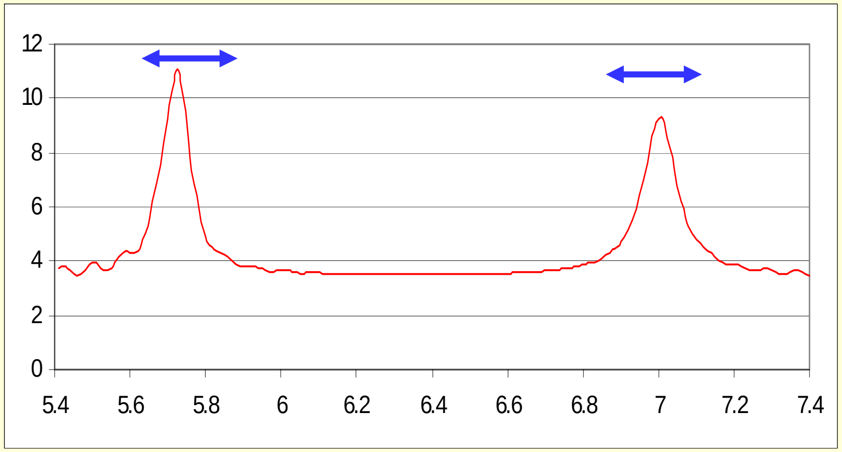
Stacked Two Layer Tag

Farfield
Magnitude
dBV/m



Frequency GHz

Farfield
Delay ns



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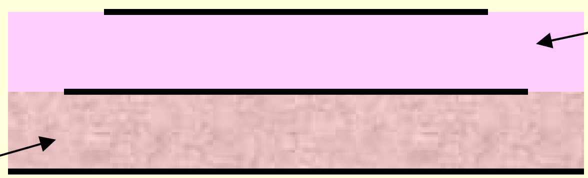
Sensor Example: Using Stacked Patches



Physical parameter
(e.g. temperature)
sensitive dielectric

Stable dielectric material
Provides reference

Disposable Sensors

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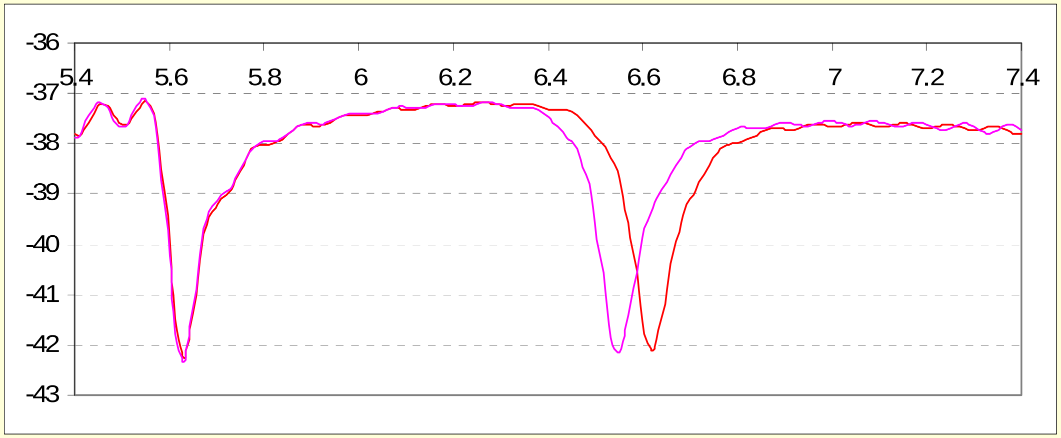
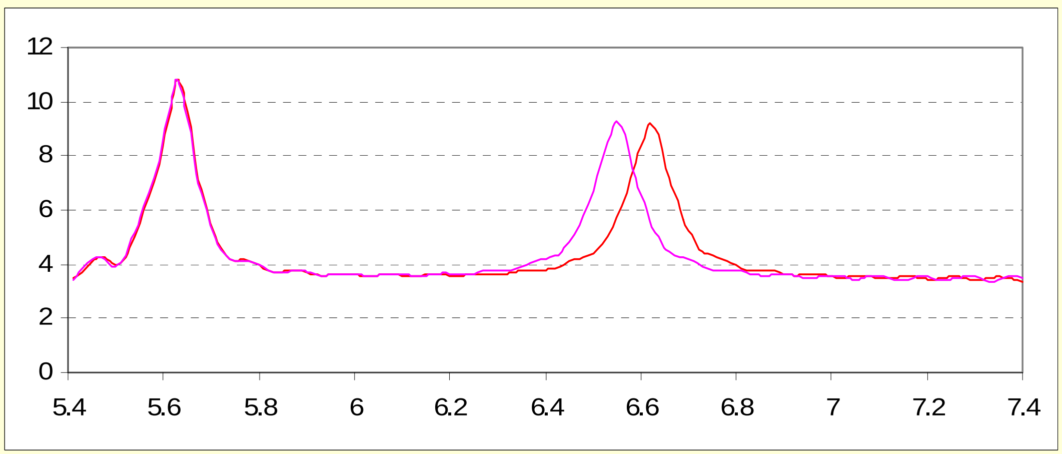
Sensor Example: Using Stacked Patches

Farfield
Magnitude
dBV/m



Frequency GHz

Farfield
Delay ns



Patches and Ground:

Copper 5.8.10^7 S/m

Substrates:

εr =4.5 tanδ= 0.002

εr =**4.4** and **4.5**, tanδ= 0.002

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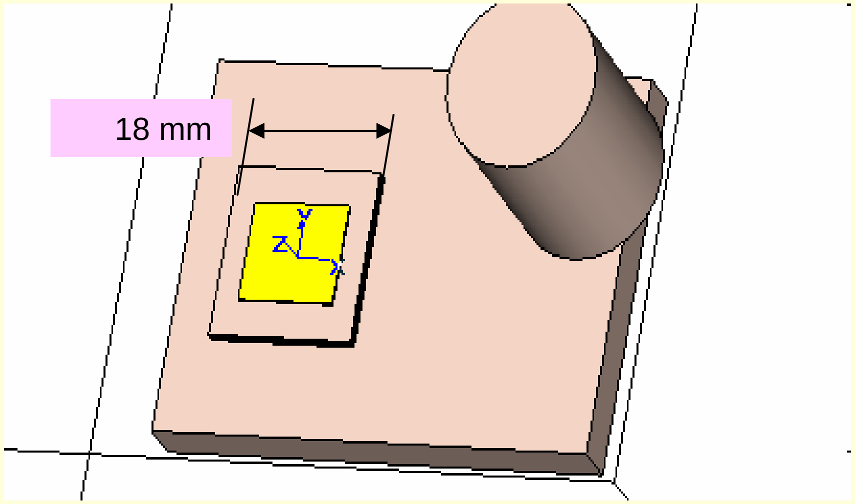
Stacked Patch with Clutter



Patches and Ground:
Copper 5.8.10^{7} S/m
Substrate:
εr =4.5 tanδ = 0.002
Clutter:
εr =3.0 tanδ = 0.003

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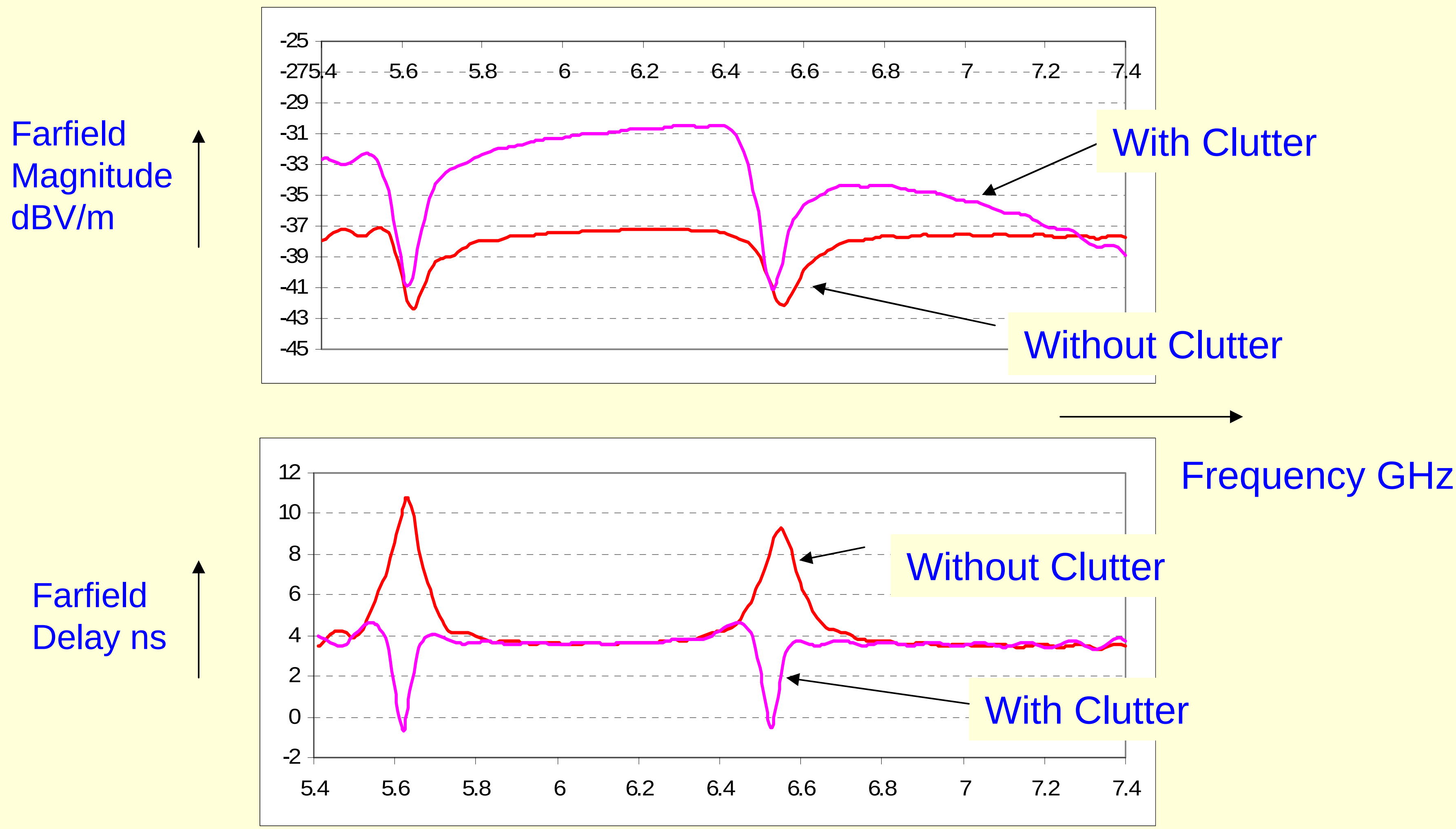
Stacked Patch with Clutter



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Clutter Mitigation

Potential Candidates

- Time Gating
- Polarization
- Inverse Filtering
- Filtering to separate fast changing tag response from slow changing clutter
- Coherent Focusing
- Others?...

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Future Investigation

- **Impairments**
  - Aging
  - Temperature variation
  - Noise
  - Measurement accuracy
  - Antenna feedthrough
  - Chirp non-linearity
  - Others….
- **Intentional and non-intentional interference**
  - Narrow-band interference

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Challenges

- **Single layer printable tag**
  - General synthesis procedure for RCS of flat frequency response and controlled phase fluctuations
  - 40+ bits of information

- **Mitigation of Clutter**
  - Multi-static Coherent Processing to improve resolution
  - Selective fades reduced by inverse filtering?

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Disposable Sensors

- **Measurement of Physical Parameters:**
  - Temperature
  - Pressure
  - Magnetic field (current)
  - Others….
- **Applications**
  - Asset tagging with temperature monitoring
  - Remote measurement of tire pressure
  - Remote weighing
  - Remote measurement of power in electrical power grids

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Conclusion

- **Novel approach to RF Bar Codes and Sensors**
  - **FMCW variant for Reader**
  - **Remote Frequency Domain *Vector* Measurement**

- **Non minimum scatter antenna for Tag**
  - **Reduction of structural scattering**
  - **Generation of multiple resonances to encode information**

- **Disruptive yet simple Technology**

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Conclusion (contd.)

- **Meets criterion for:**
  - Low cost
  - Simple printing technique
  - Lossless tag => longer range
  - Constant envelope signal
    - No compromise in CNR over amplitude resonances
    - Combat Selective Fade
  - Low detection bandwidth
    - CNR
  - Resolution between tags
  - Distance information

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Conclusion (contd.)

- **Future work**
  - **Single layer Tag**
    - Large bandwidth, low structural scatter antenna
    - 40+ bits
- **Disposable sensors**
- **Mitigation of Clutter**
    - Improve spatial resolution
    - Multi-static processing

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Thank You

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