Orientation Determination of a Scatterer Based on Polarimetric Radar Measurements

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Chipless RFID Technology

- Linear time-invariant systems
- Fully printable using ink-jet technology and conductive ink

Consequently, chipless tags do not have:

- battery
- emitting system
- memory
- back-scattering modulation
- media access control

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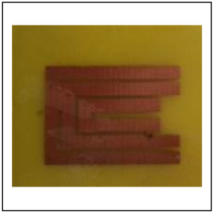

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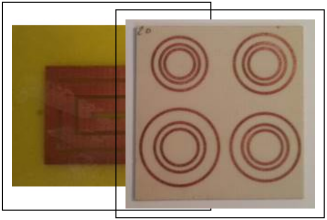

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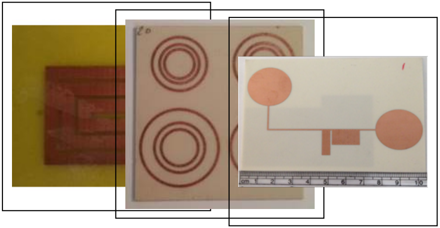

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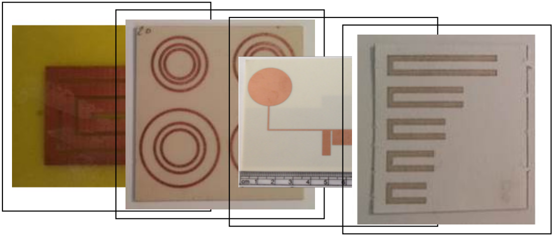

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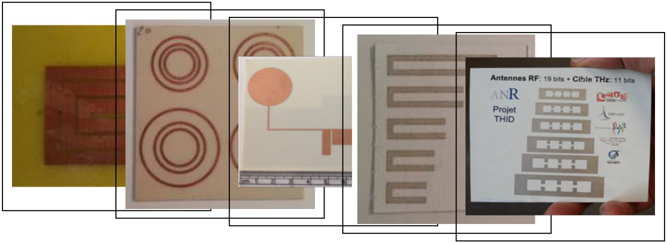
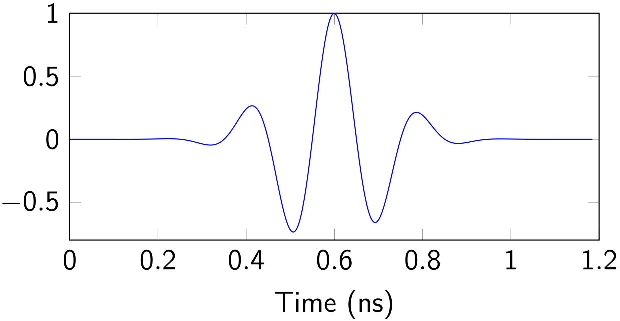


Principle



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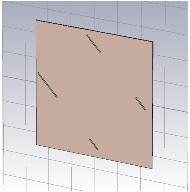

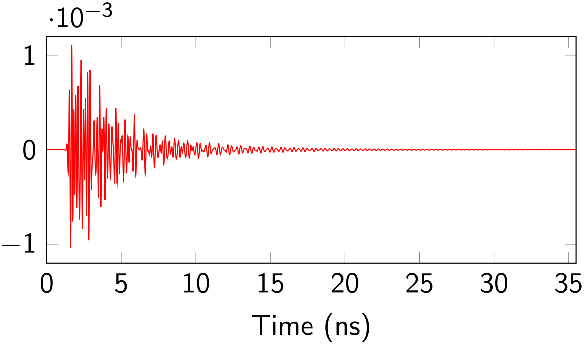

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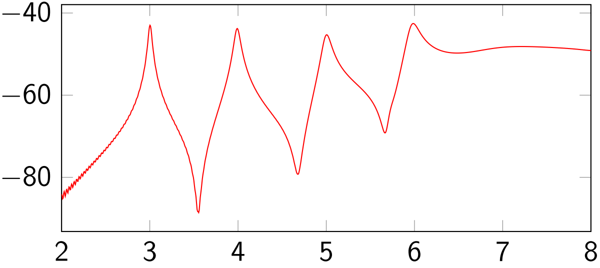
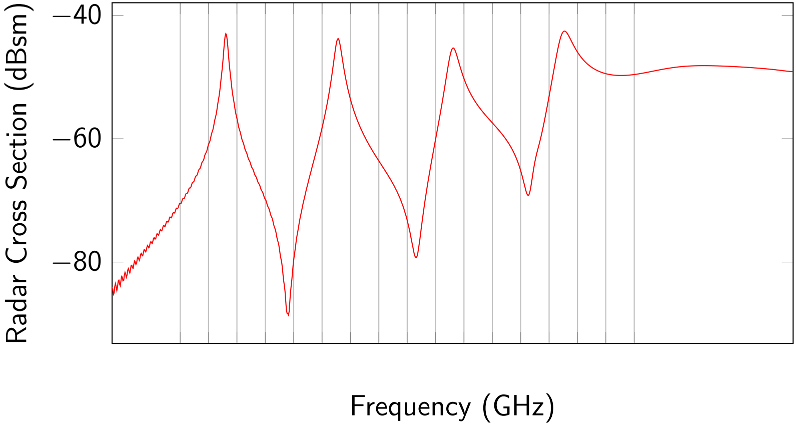
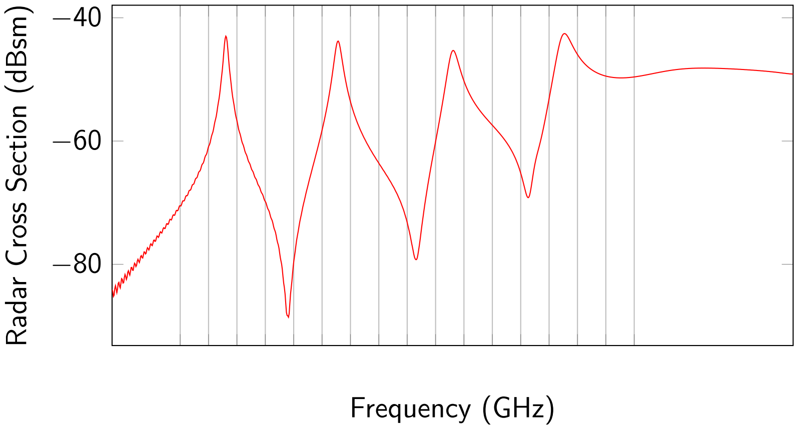


Data Encoding





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Comparison

	Barcode	Chipless RFID	RFID
Discretion	-	+++	++
Writing	-	+	+++
Multiple reading	-	-	+++
Coding density	++	-	+++
Read range	+	-	+++
Sensing	-	+++	+
Cost	+++	++	-

Objectives

Design a procedure (on the reader) side which can estimate the orientation of a chipless tag. Proposed method has the following advantages:

- valid for any scatterers
- based on an analytical model (without lookup table)
- can be used for different distances
- sensing and identification can be combined (without reducing the coding capacity)

Polarization Scattering Matrix

The description of the interaction of a wave with a chipless tag is described by its polarization scattering matrix **S** which links the scattered electric field vector E^r, to the incident field vector E^i in vertical v and horizontal h polarizations:

$$\begin{bmatrix} E_v^r \\ E_h^r \end{bmatrix} = \begin{bmatrix} S_{vv} & S_{vh} \\ S_{hv} & S_{hh} \end{bmatrix} \cdot \begin{bmatrix} E_v^i \\ E_h^i \end{bmatrix} \tag{1}$$

- $S_{xy} \in C$ and is a function of the frequency
- $S_{vh} = S_{hv}$ since chipless tags are passive and reciprocal
- (1) is valid for any scatterer.

Rotation of a Scatterer

If we consider a rotation of the tag by an angle θ under normal incidence, we can show that the parameters of the **S** matrix at θ are linked to the initial ones by the following expression:

$$\mathbf{S}(\theta) = \mathbf{\Omega}^T \cdot \mathbf{S} \cdot \mathbf{\Omega} \tag{2}$$

where ^{T} is the transpose operator and $\mathbf{\Omega}$ is a rotation matrix defined by:

$$\mathbf{\Omega} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \tag{3}$$

Analytical Expression

From (2), expression of $S_{vv}(\theta)$ can be written as:

$$S_{vv}(\theta) = S_{vv}\cos^2\theta + S_{vh}\sin 2\theta + S_{hh}\sin^2\theta \qquad (4)$$

By reducing the power of $\cos^2$ and $\sin^2$:

$$S_{vv}(\theta) = S_{vv}\frac{1+\cos 2\theta}{2} + S_{vh}\sin 2\theta + S_{hh}\frac{1-\cos 2\theta}{2} \qquad (5)$$

By regrouping constant terms and $\cos 2\theta$ terms, we have:

$$S_{vv}(\theta) - \frac{S_{vv}+S_{hh}}{2} = \frac{S_{vv}-S_{hh}}{2}\cos 2\theta + S_{vh}\sin 2\theta \qquad (6)$$

Analytical Expression

Setting $\tan\theta = t$ (with $\sin 2\theta = \frac{2t}{1+t^2}$ and $\cos 2\theta = \frac{1-t^2}{1+t^2}$) and rearranging leads to:

$$S_{vv}(\theta) - \frac{S_{vv} + S_{hh}}{2} = \frac{S_{vv} - S_{hh}}{2}\frac{1-t^2}{1+t^2} + S_{vh}\frac{2t}{1+t^2} \tag{7}$$

After developing:

$$(S_{vv}(\theta) - S_{hh})t^2 + 2S_{vh}t + (S_{vv}(\theta) - S_{vv}) = 0 \tag{8}$$

where we can recognize a classical second order polynomial of real variable t with complex coefficients.

Solutions of this polynomial can be expressed as:

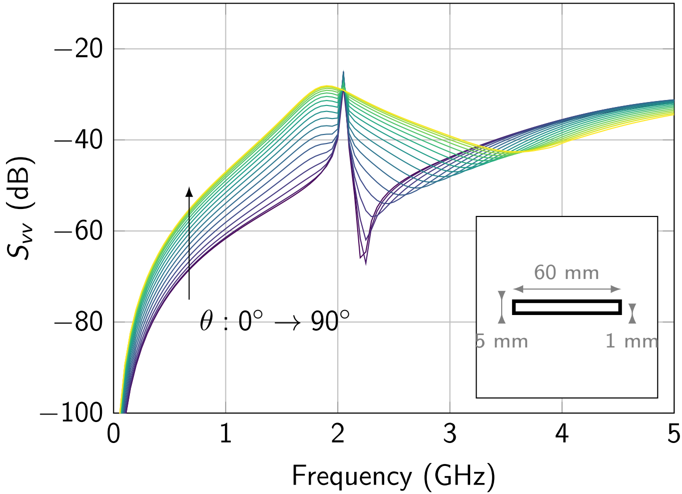
$$t_{1,2} = \frac{-2S_{vh} \pm \sqrt{\Delta}}{2(S_{vv}(\theta) - S_{hh})} \quad (9)$$

where $\Delta = (2S_{vh})^2 - 4(S_{vv}(\theta) - S_{hh})(S_{vv}(\theta) - S_{vv})$. Finally, θ can be extracted from $t_{1,2}$:

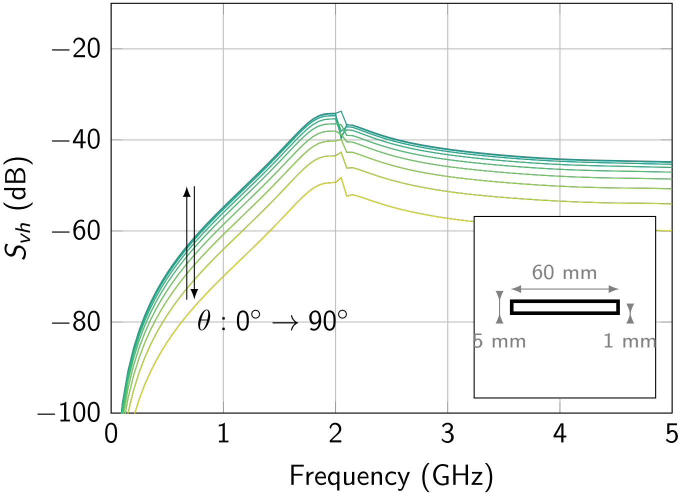
$$\hat{\theta} = \arctan(t_{1,2}) \quad (10)$$

- Need 3 reference measurements: S_{vv}, S_{vh}, and S_{hh}
- 1 measurement in co-polarization $S_{vv}(\theta)$
- This determination is valid for any scatterer
- Note that $t_{1,2}$ is real (without considering noise)

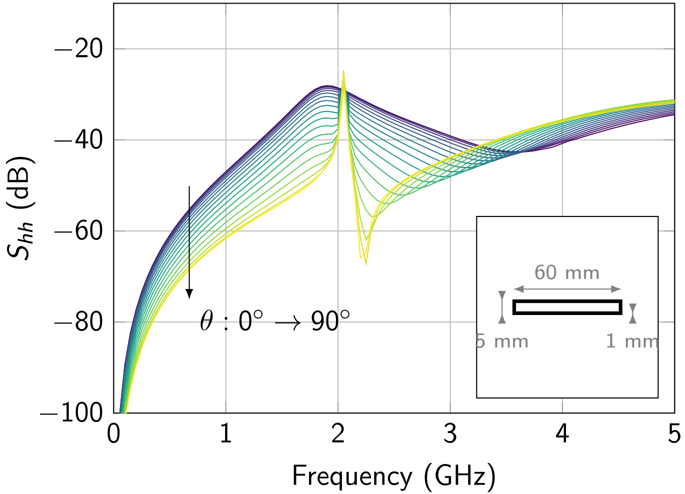
Vertical Co-polarization



Cross-polarization



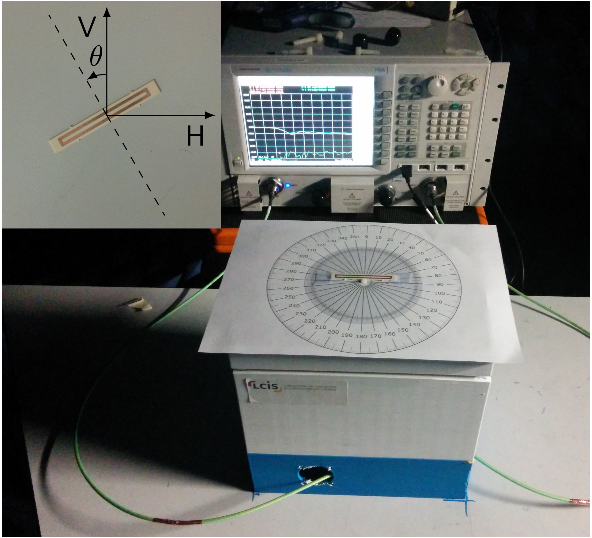
Horizontal Co-polarization



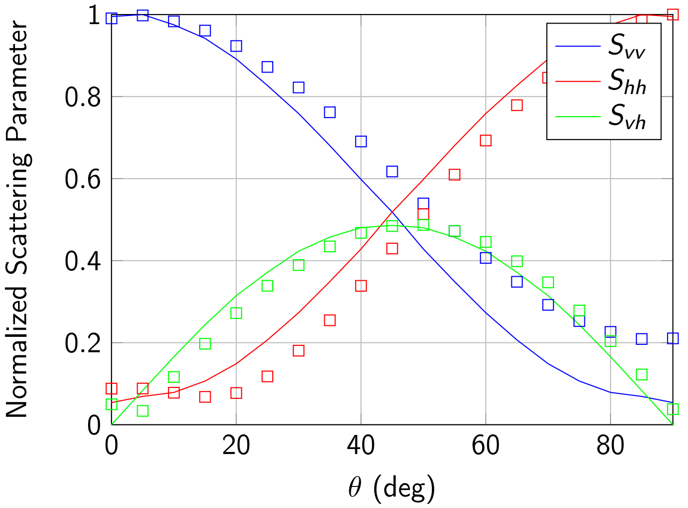
Comments

- For horizontal loop, information is encoded into S_{vv} (sharp peak)
- S_{hh} cannot encode information
- S_{vv} and S_{hh} do not present a zero response for general scatterer
- S_{vh} presents 2 zero response at $\theta = 0^\circ$ and $\theta = 90^\circ$ due to the symmetry of the loop
- $S_{vv}(\theta) = S_{hh}(\theta + \pi/2)$

Measurement Bench

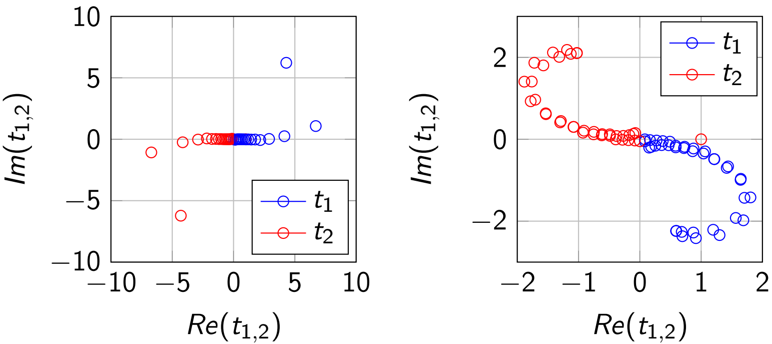


Results



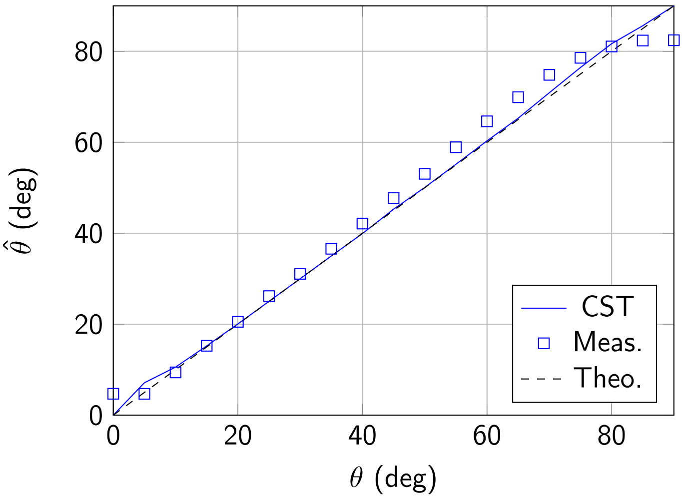
Normalized Scattering Parameter
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
θ (deg)
S_{vv}
S_{hh}
S_{vh}

Results



- Comparison of $t_{1,2}$ in simulation and measurement
- $t_{1,2}$ should lie on the real axis
- Imaginary parts seems to be opposite...

Results



Comments

- Reference measurement has been chosen at $\theta = 0^\circ$
- Range of the sensor is $\hat{\theta} \in [0^\circ; 90^\circ]$
- Average value of the absolute orientation error is 0.53° in simulation
- Average value of the absolute orientation error is 2.70° in anechoic chamber

Conclusion

In this paper, we have presented a method which allows to extract the orientation of any chipless tag based on the knowledge of its polarization scattering matrix and a measurement of its co-polarization response in an unknown orientation.

- 3 reference measurements in known orientation
- a single measurement in co-polarization in unknown orientation
- Error in anechoic chamber is less than 3° over a 90° interval
- Sensing is based in on amplitude and phase variation
- Identification can still be realized without reducing the coding capacity
- Method can be easily extended to cross-polariation case

Thank you for your kind attention

Feel free to send your questions/remarks to:

`nicolas.barbot@lcis.grenoble-inp.fr`