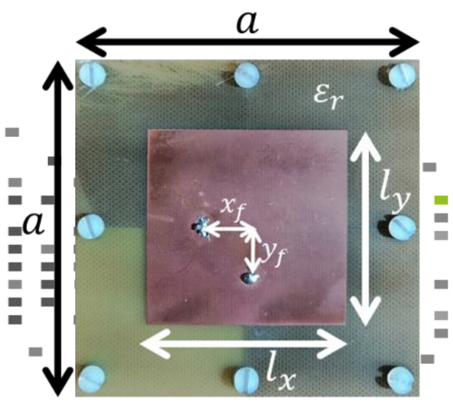
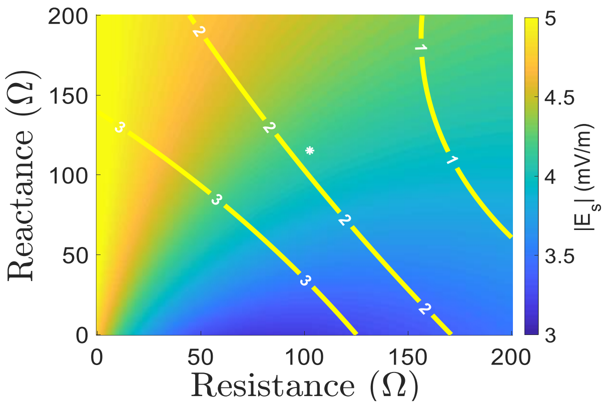
CONTRÔLE DE LA POLARISATION DU CHAMP ÉLECTROMAGNÉTIQUE : DE LA RÉTRODIFFUSION POLARIMÉTRIQUE AU CAPTEUR SANS FIL

Luis Felipe FONSECA DIAS, Camille JOUVAUD, Christophe DELAVEAUD, Hervé AUBERT





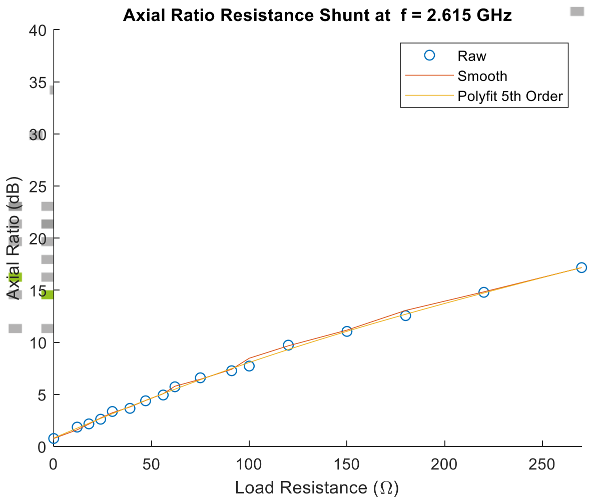
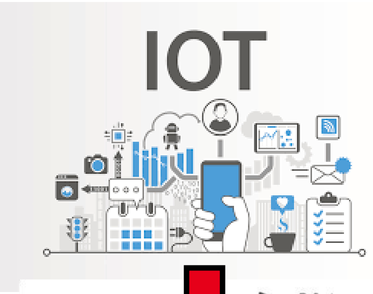
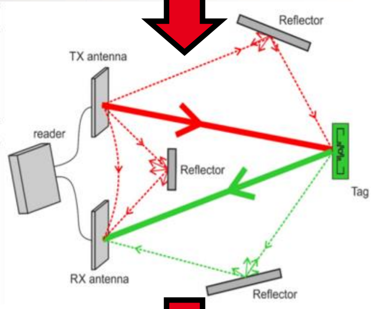
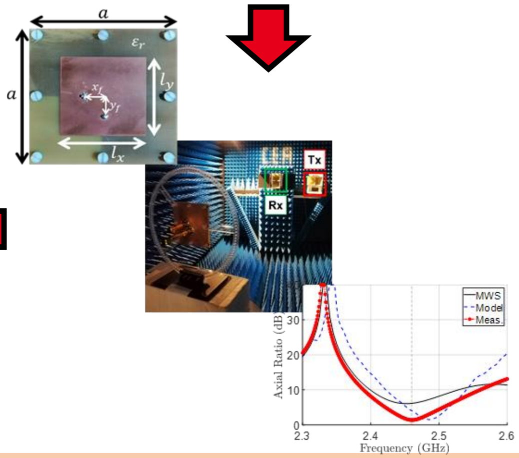


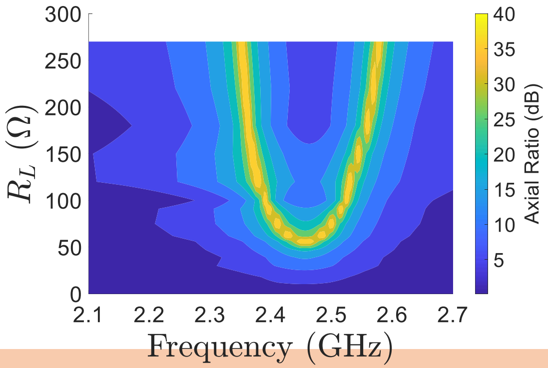
TABLE DES MATIÈRES





$$[d^s] = \left([S^0] - \frac{1}{2}[S^a][K][I^0]\right)[\rho_i]$$





MOTIVATIONS

How to make the outdoor and indoor passive sensor more visible??

Physical Value

Temperature, Humidity, Gas, Pressure …

Antenna Design

Optimal impedance to transducer

Directive radiation, Polarization fixed

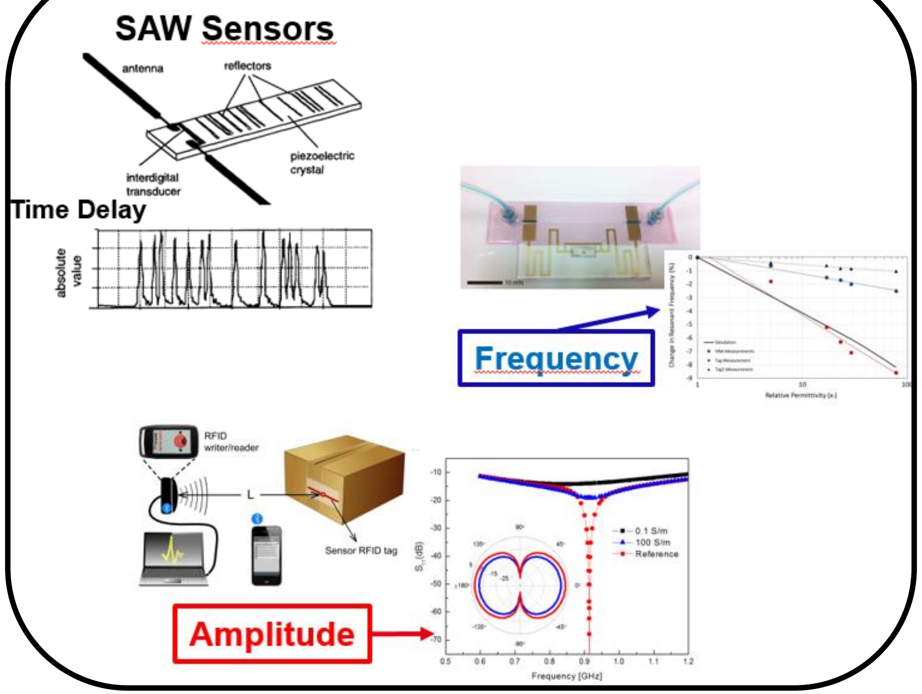
Interrogation Principle

Frequency or Amplitude Modulation

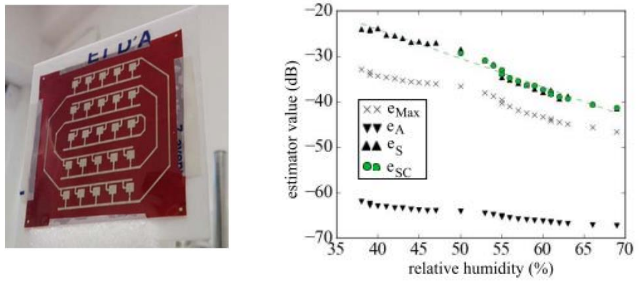
Clutter reduction techniques

Polarization Control

This work focus on the Interrogation Principle based on the polarization control
Especially on antenna with ground plane or in front of a metallic plane



Cross-Polarization



D. Henry, J. G. D. Hester, H. Aubert, P. Pons and M. M. Tentzeris, "Long-Range Wireless Interrogation of Passive Humidity Sensors Using Van-Atta Cross-Polarization Effect and Different Beam Scanning Techniques", *IEEE Transactions on Microw. Theory & Techn.*, pp. 5345-5354, Vol. 65, Issue 12, Dec. 2017

ETAT DE L'ART → POLARISATION

Interrogation Principle

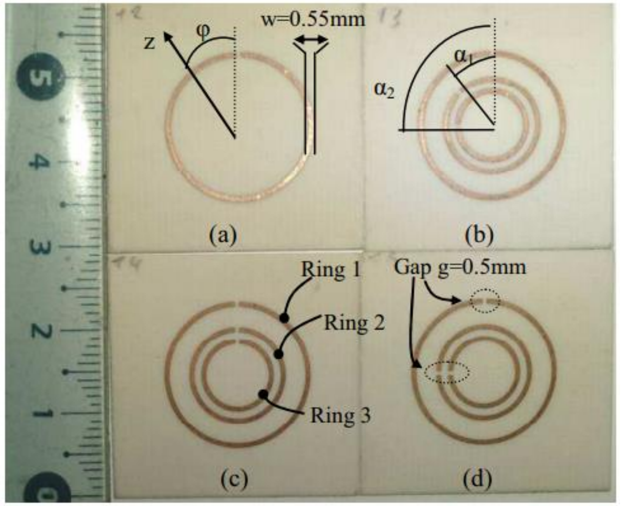
Frequency or Amplitude Modulation

Clutter reduction techniques

Polarization Control

Compact Chipless RFID Tag using polarisation diversity [1]

Mesures réalisées à deux fréquence → 6 bits sur 3x3 cm^3



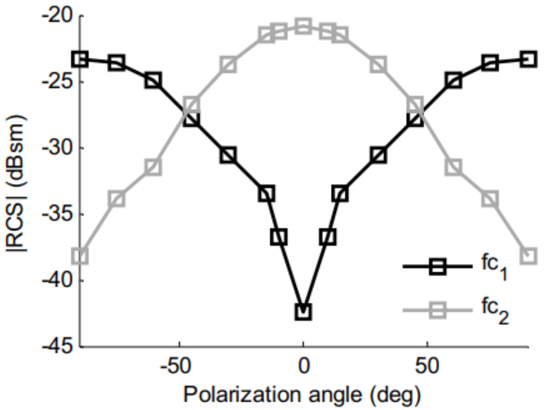


Fig. 5. |RCS| simulation results for a single split ring resonator (Fig. 2 (a)) as a function of the incident wave polarization angle for the two resonant modes fc_1=3.1 GHz and fc_2=4.6 GHz.

[1] A. Vena, E. Perret and S. Tedjini, **"A Compact Chipless RFID Tag Using Polarization Diversity for Encoding and Sensing"**, *2012 IEEE International Conference on RFID (RFID)*, Orlando, USA, April 2012

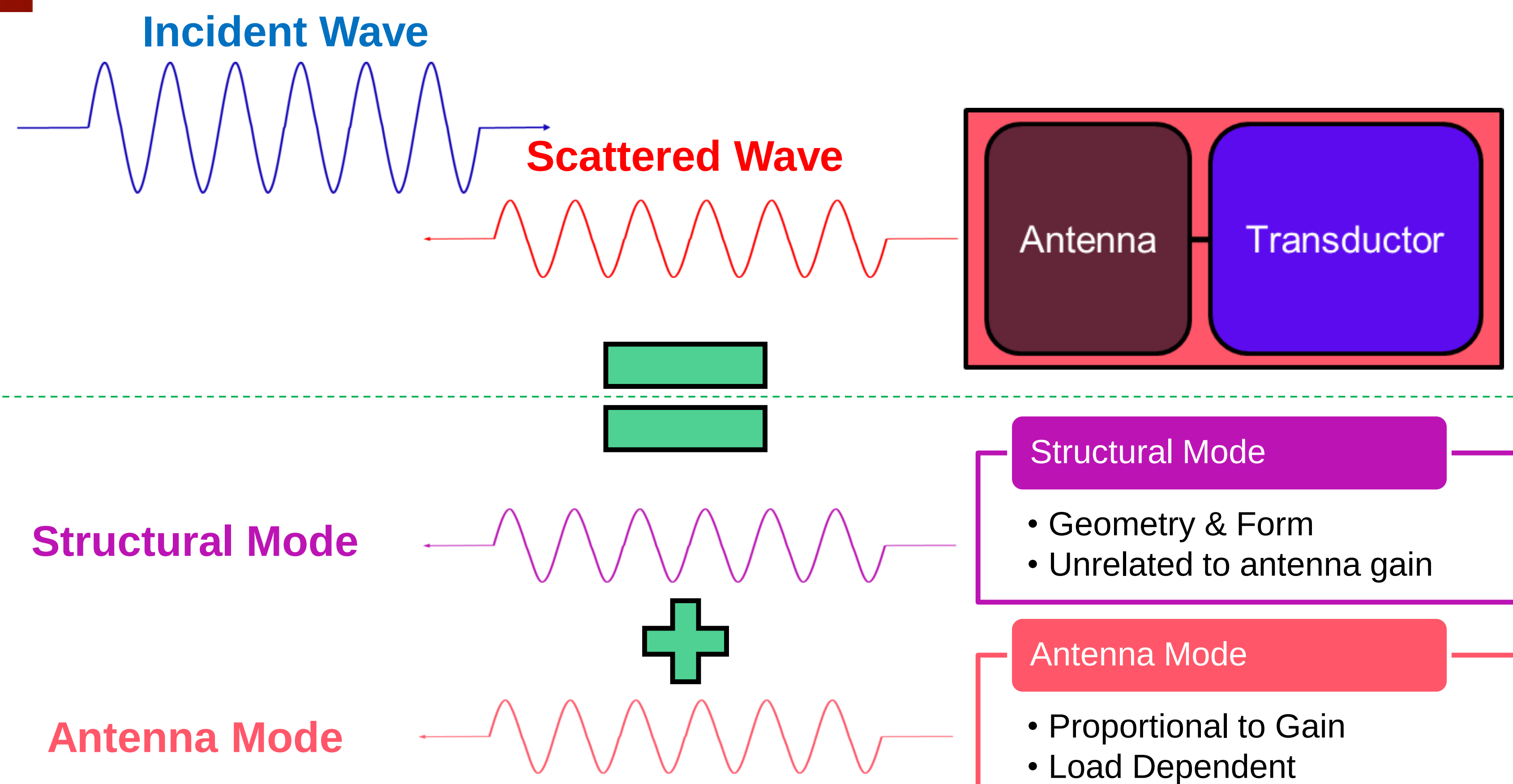
HISTOIRE DES MODÈLES DE RÉTRODIFFUSIONS

1963	1989	1994	2022
Green	Hansen	Heidrich	This work
Simple physical definition	Clear SWE Development	Not SWE, Polarization based	Not SWE, Polarization based
Circuit Analysis	Sum up Linear Analysis	Two-port	N-port (Two-port Validation)
Single port	Single port and no polarization	Characterization Considerations	Characterization Considerations
Lack of Characterization	Lack of Measurement	Limiting Conditions	More General

Mettre en place un modèle multiports qui caractérise toutes les interactions entre

- Onde incidente
- Onde réfléchie
- Champ absorbé
- Champ re-réfléchi

DEFINITIONS



Structural Mode

- Geometry & Form
- Unrelated to antenna gain

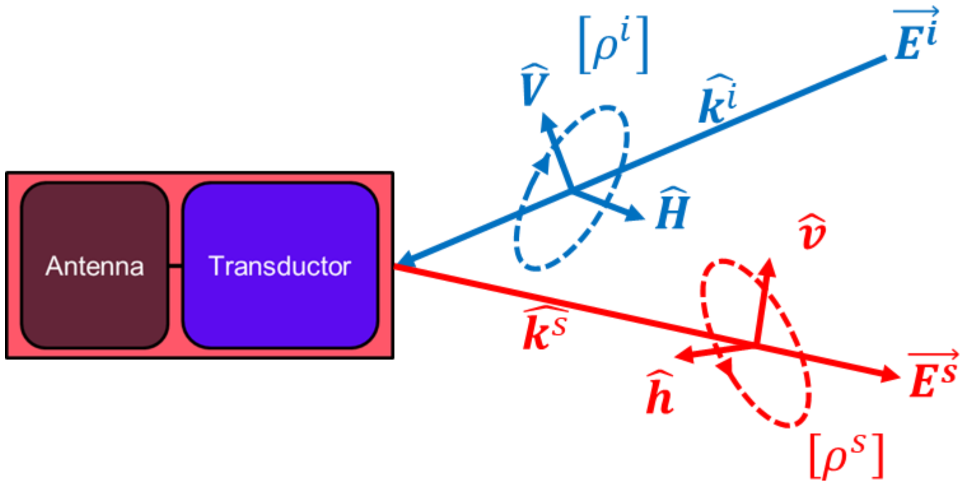
→ Ground plane

Antenna Mode

- Proportional to Gain
- Load Dependent

Different Authors, different definitions

MODÈLE POLARIMÉTRIQUE – DÉFINITIONS



Polarization

$$\vec{E} = [\hat{v} \quad \hat{h}] \begin{bmatrix} E_v \\ E_h \end{bmatrix}$$

$$\begin{bmatrix} E_v \\ E_h \end{bmatrix} = \begin{bmatrix} S_{vV} & S_{vH} \\ S_{hV} & S_{hH} \end{bmatrix} \begin{bmatrix} \sin\alpha \, e^{j\delta} \\ \cos\alpha \end{bmatrix}$$

$$[\rho] \equiv \begin{bmatrix} \sin\alpha \, e^{j\delta} \\ \cos\alpha \end{bmatrix}$$

Backscattering

$$\sigma = 4\pi \left(\frac{|E^s|}{|E^i|} \right)^2$$

$$\begin{bmatrix} E_v^S \\ E_h^S \end{bmatrix} = E^i \begin{bmatrix} S_{vV}^s & S_{vH}^s \\ S_{hV}^s & S_{hH}^s \end{bmatrix} [\rho_i]$$

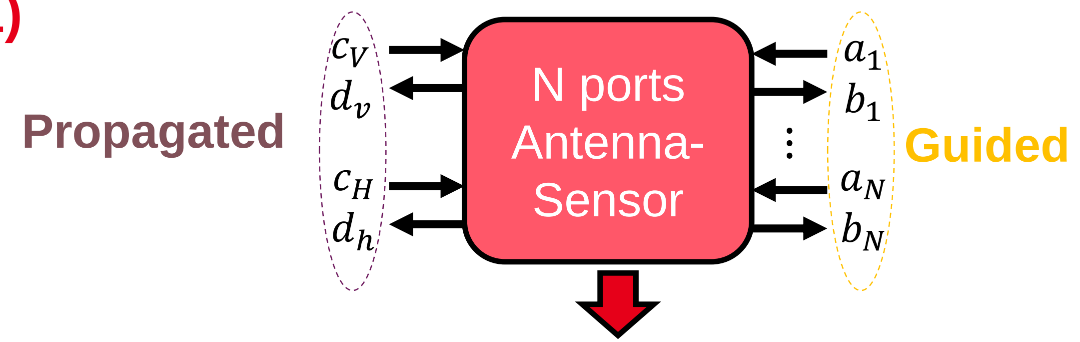
$$[\rho_i] \equiv \begin{bmatrix} \sin\alpha_i \, e^{j\delta_i} \\ \cos\alpha_i \end{bmatrix}$$

→ Mise en place d'un modèle compatible avec des mesures et une caractérisation bistatique

MODÈLE GÉNÉRAL (1)

Conditions

- Given frequency
- Far field
- Incident Propagation (θ_i, ϕ_i)
- Scattering Propagation (θ_s, ϕ_s)



C_V et C_H : incident wave
d_v et d_h : scattered wave
V : vertical
H: Horizontal

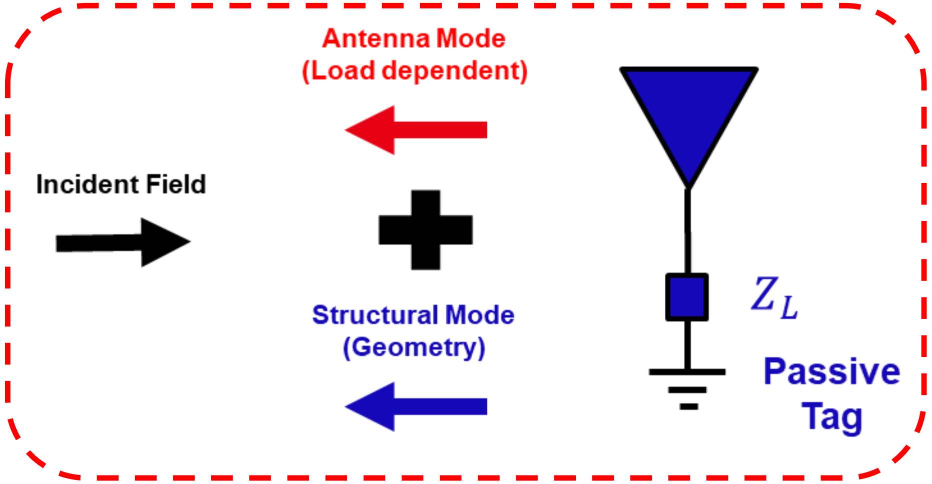
$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \\ d_v \\ d_h \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} & S_{1V} & S_{1H} \\ S_{21} & S_{22} & & S_{2N} & S_{2V} & S_{2H} \\ \vdots & & \ddots & & \vdots & \\ S_{N1} & S_{n2} & & S_{NN} & S_{NV} & S_{NH} \\ S_{v1} & S_{v2} & \cdots & S_{vN} & S_{vV} & S_{vH} \\ S_{h1} & S_{h2} & & S_{hN} & S_{hV} & S_{hH} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \\ c_V \\ c_H \end{bmatrix}$$

[S] [R] [T] [P]

- $[S]$ - NxN S-parameters from Antenna
- $[R]$ - Nx2 Receiving Matrix (Transceiver to Sensor)
- $[T]$ - 2xN Transmitting Matrix (Sensor to Transceiver)
- $[P]$ - 2x2 Depolarizing Matrix (Sensor & Environment)

MODÈLE GENERAL (3)

- Développement de la matrice de rétrodiffusion complète



Radiated field, normalized by ports currents

$$[S^a] = \begin{bmatrix} S^a_{v1} & \cdots & S^a_{vN} \\ S^a_{h1} & \cdots & S^a_{hN} \end{bmatrix}$$

$[I^0]$ Short circuit matrix current NxN matrix

Structural mode — Antenna mode

$$[\hat{v}_s \quad \hat{h}_s]\begin{bmatrix} E_v^s \\ E_h^s \end{bmatrix} = [\hat{v}_s \quad \hat{h}_s]\left([S^0] - \frac{1}{2}[S^a][K][I^0]\right)\begin{bmatrix} \sin\alpha_i \, e^{j\delta_i} \\ \cos\alpha_i \end{bmatrix}$$

Antenna-load interface matrix
$K_{ij}(Z_L, Z_a)$

$$[\boldsymbol{K}] = ([\boldsymbol{1}] - [\boldsymbol{S}])([\boldsymbol{1}] + [\boldsymbol{S}])^{-1}([\boldsymbol{1}] + [\hat{\boldsymbol{S}}])([\boldsymbol{1}] - [\boldsymbol{S}][\hat{\boldsymbol{S}}])^{-1}([\boldsymbol{1}] + [\boldsymbol{S}])$$

$$[K] = 2[z_a]^{-1}[z_L]([z_L] + [z_a])^{-1}[z_a]$$

Two-Port

$$\frac{Z_L}{Z_L + Z_a}$$

Single-Port

The Polarization State is function of the load $[Z_L]$

R.C. Hansen, "Relationships between antennas as scatterers and as radiators", *Proceedings of IEEE*, pp. 659-662, Vol. 77, Issue 5, May 1989

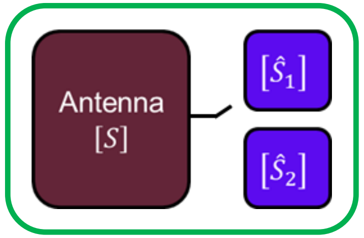
L. F. Fonseca Dias, C. Jouvaud, C. Delaveaud and H. Aubert, "Linear-to-Circular Polarization Conversion from Impedance Loading of Single-Port Patch Antennas," *2020 IEEE APS-URSI*, Montréal, Canada, July 2020

MODÈLE GENERAL (4)

Theory Model ⟷ $$[d^s] = \left([S^0] - \frac{1}{2}[S^a][K][I^0]\right)[\rho_i]$$

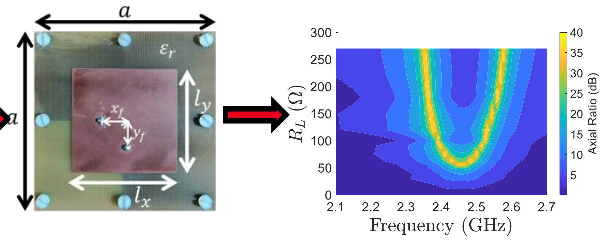
Define parameters $[S^0]$, $[I^0]$ and $[S^a]$

Characterization ⟷



Apply the model to a solution!

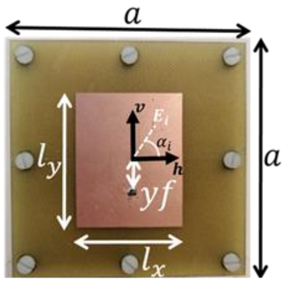
Application ⟷



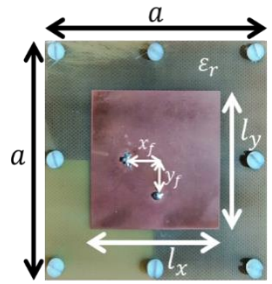
Validation expérimentale

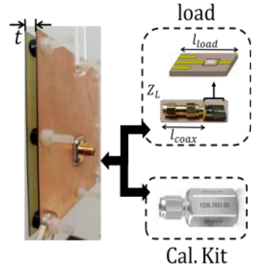
Antenne microruban (avec plan de masse)

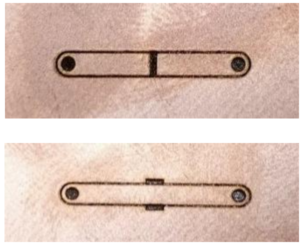
1 port

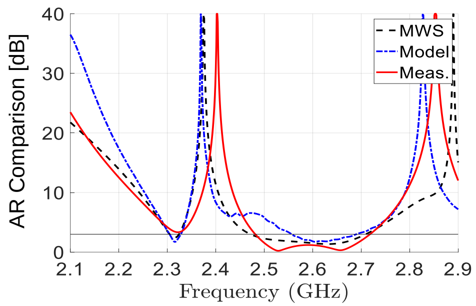


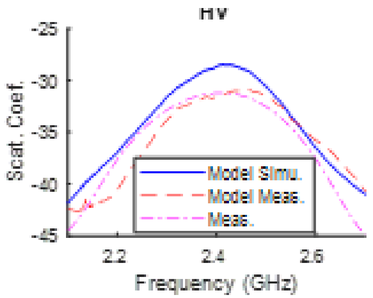
2 ports





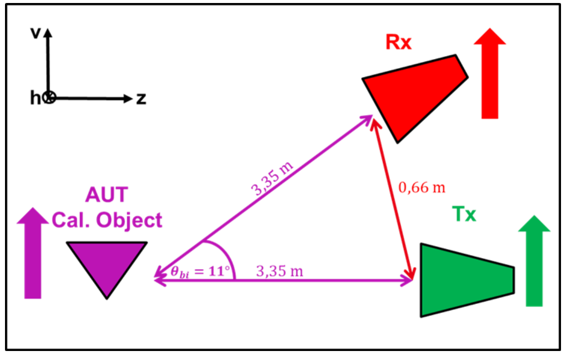


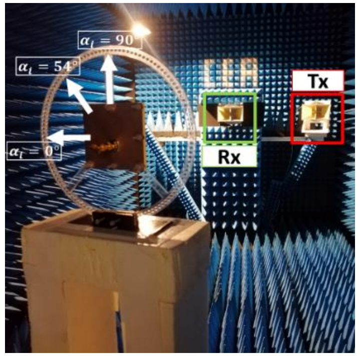




VALIDATION – RCS SETUP & CALIBRATION

- Setup de mesure:





Measurement Process

(for a given direction)

1st	**Local Excitation**	$[S^a]$	$[S]$ or $[Z_a]$
2nd	**Characterize Model**	$[I^0]$ and $[S^0]$	
3rd	**Identify for R_L Pol. Diversity**	$R_1^{ser}, R_2^{ser}, R_1^{shu}, R_2^{shu}$	
4th	**Measure Polarization**	**Axial Ratios**	

Isolation → Metal Sphere → Corner Reflector → Rotated CR

Isolation: Empty Chamber Once a day

Metal Sphere: $[S^{c1}] = \begin{bmatrix} a & 0 \\ 0 & a \end{bmatrix}$

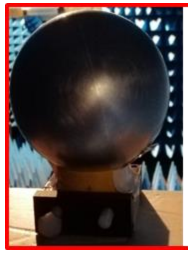
Corner Reflector: $[S^{c2}] = \begin{bmatrix} b & 0 \\ 0 & c \end{bmatrix}$

Rotated CR: $[S^{c3}] = [Rot]^{-1} \begin{bmatrix} b & 0 \\ 0 & c \end{bmatrix} [Rot] = \begin{bmatrix} d & e \\ e & f \end{bmatrix}$

Where:

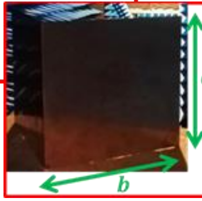
$[Rot] = \begin{bmatrix} \cos\rho & \sin\rho \\ -\sin\rho & \cos\rho \end{bmatrix}$

If $\rho = 45°$, $d = f$



$r = 50$ mm

sphere



$a = 150$ mm

$b = 150$ mm

Metal plate

$a = 150$ mm

$b = 150$ mm

Corner reflector

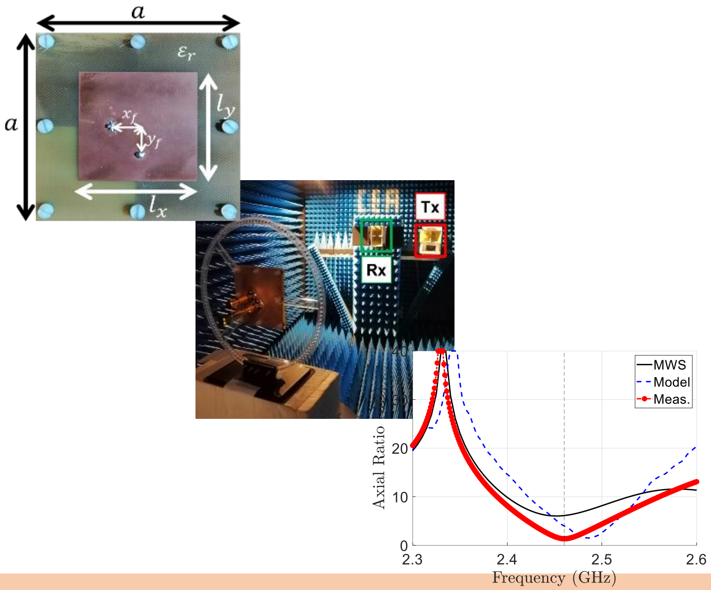
RÉTRODIFFUSION POLARIMÉTRIQUE

- Mise en place d'un nouveau modèle polarimétrique pour la rétrodiffusion d'antennes à N ports

- Grâce au modèle → contrôle de la polarisation de la rétrodiffusion

$$[\boldsymbol{d^s}] = \left([\boldsymbol{S^0}] - \frac{\mathbf{1}}{\mathbf{2}}[\boldsymbol{S^a}][\boldsymbol{K}][\boldsymbol{I^0}]\right)[\boldsymbol{\rho_i}]$$

- Quelles applications?



VALIDATION – 1-PORT ANTENNA (1)

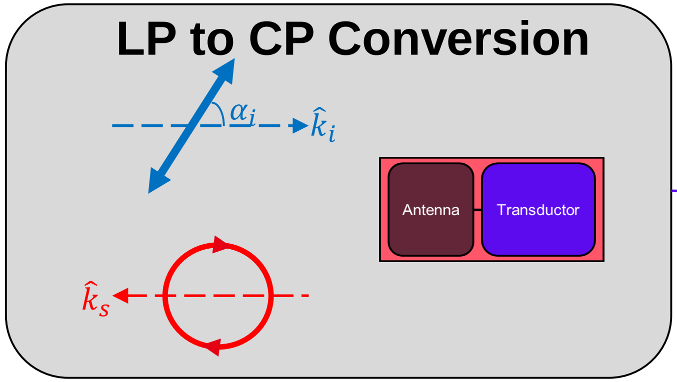
- Conversion de Polarisation Linéaire à Circulaire à l'aide d'un Tag Chargé par une Impédance Passive

$$[\boldsymbol{d}^s] = \left([\boldsymbol{S}^0] - \frac{1}{2}[\boldsymbol{S}^a][\boldsymbol{K}][\boldsymbol{I}^0]\right)[\boldsymbol{\rho}_i]$$

→ 1-Port Antenna →

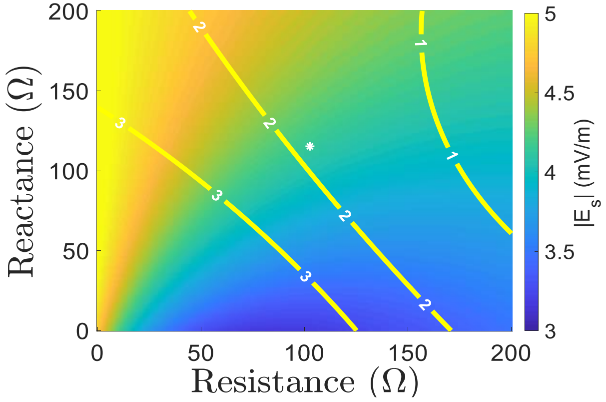
$$\begin{cases} E_v^s = E_v^0(\alpha_i,\delta_i) - \dfrac{Z_L}{Z_L + Z_a} A_v(\alpha_i,\delta_i) \\ E_h^s = E_h^0(\alpha_i) \end{cases}$$

$$A_v = S_{v1}^a I_{1V}^0 \sin\alpha_i \, e^{j\delta_i}$$



$$Z_L^{\pm} = \frac{Z_a}{\dfrac{A_v(\alpha_i,\delta_i)}{E_v^0(\alpha_i,\delta_i) \pm jE_h^0(\alpha_i)} - 1}$$

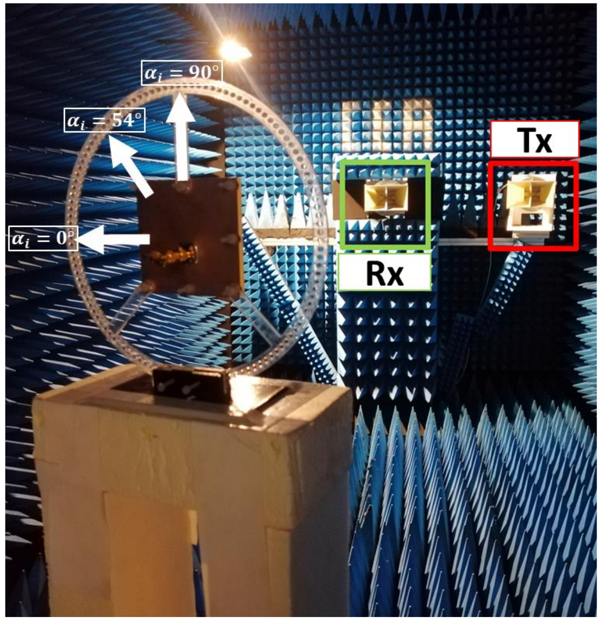
$\alpha_i = 54°$
$\delta_i = 0$



AR versus complex load

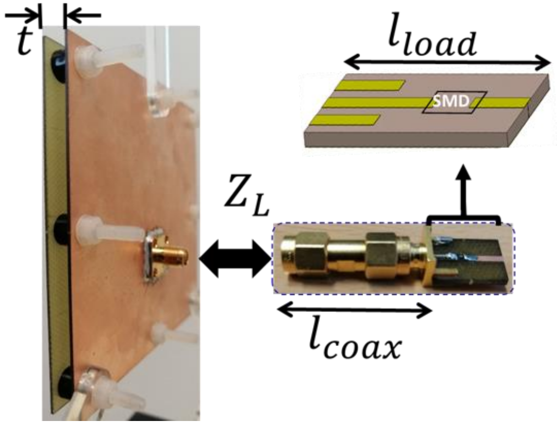
VALIDATION – 1-PORT ANTENNA (2)

- Conversion de Polarisation Linéaire à Circulaire à l'aide d'un Tag Chargé par une Impédance Passive

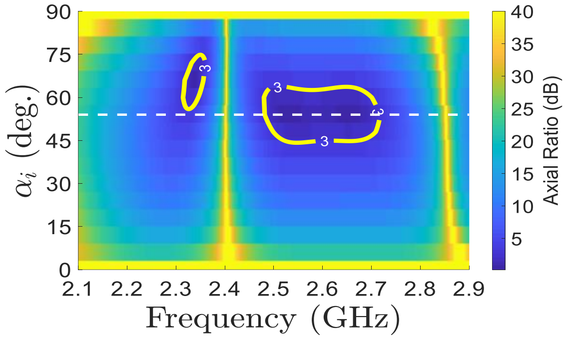


$Z_L^{+/-}$ at 2,6 GHz from Model

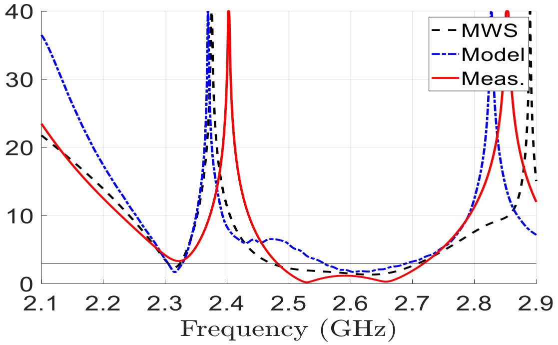
$$Z_L^{+} = 93{,}6 + j114{,}5\ \Omega$$



AR from Measurements

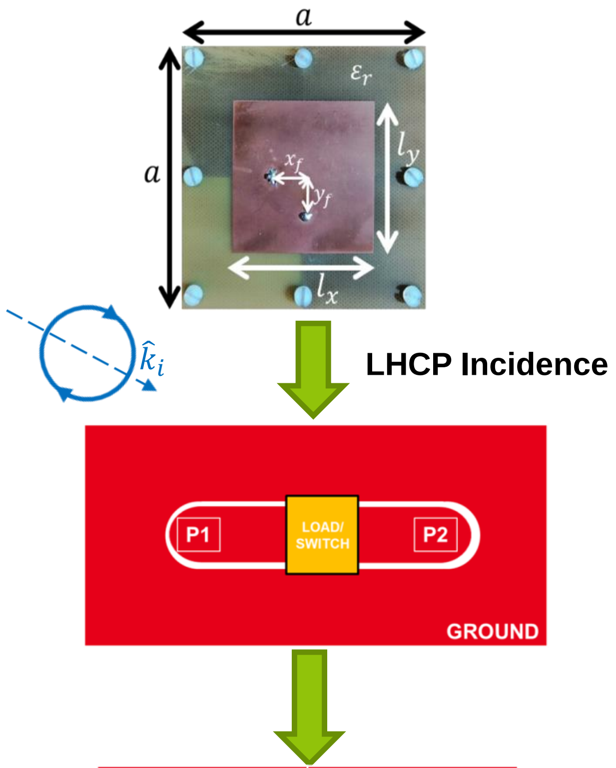


AR Comparison

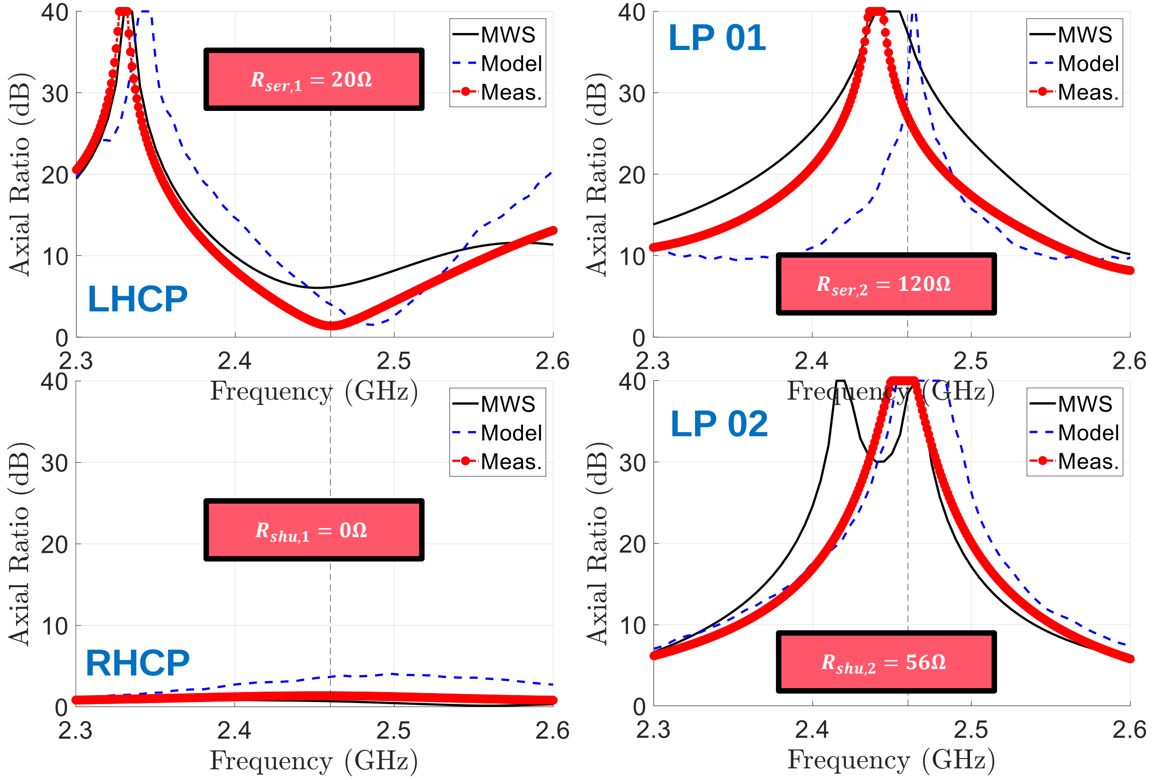


→ Taux d'ellipticité mesuré inférieur à 0,3 dB

APPLICATION – N-BITS POLARIZATION STATE



Polarization	Load
~VP	$R_{shu} = 56\ \Omega$
HP	$R_{ser} = 120\ \Omega$
LHCP	$R_{ser} = 20\ \Omega$
RHCP	$R_{shu} = 0\ \Omega$



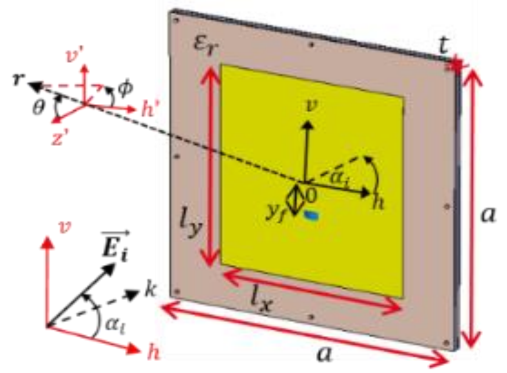
Evolution du rapport axial en fonction de la fréquence pour différentes charges

APPLICATION – CAPTEUR SANS FILS PAR MESURE DE LA POLARISATION

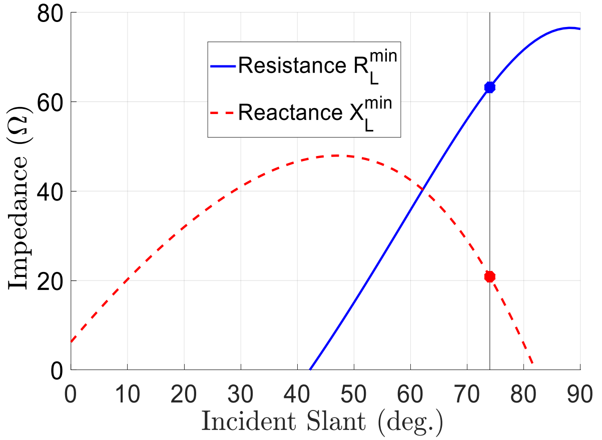
- **For 1-P Simulation:**

Antenna Sensor

$\Delta T, \Delta p$ etc. → ΔZ_L → ΔAR ← $[\rho_i]$



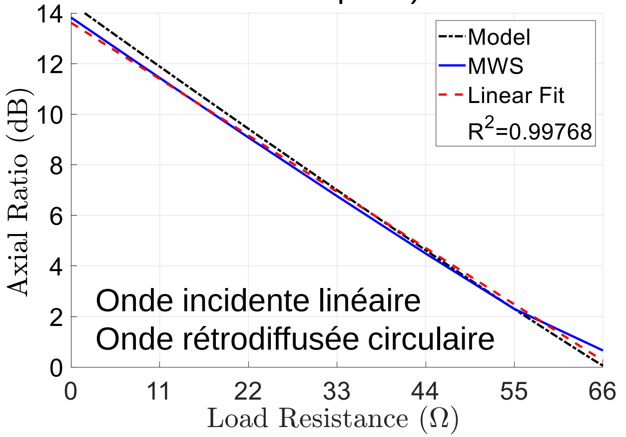
Sélection d'un ΔZ pour un angle donné



$\Delta Z_L = \Delta R_L$

X_L is constant

Evolution du rapport axial en fonction de la résistance (du capteur)



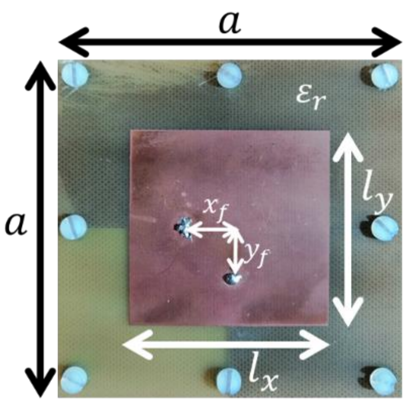
$\Delta R_L = 66\Omega$; ΔAR $= 14$ dB

APPLICATION – CAPTEUR SANS FILS PAR MESURE DE LA POLARISATION

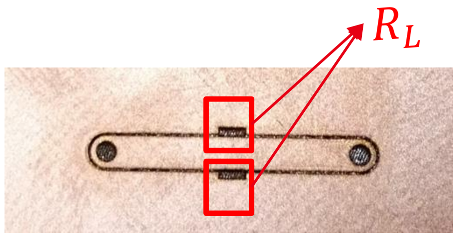
- **Antenne à 2-P**
  - Résultats expérimentaux

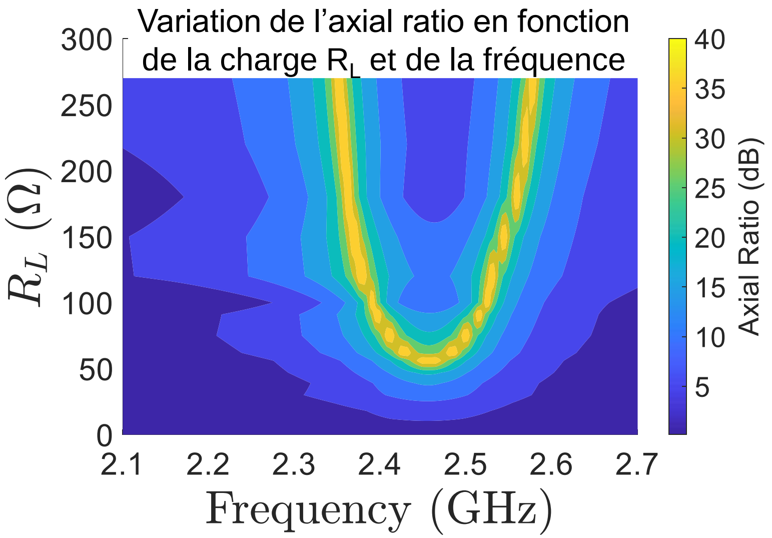
$$\begin{bmatrix} d_v^s \\ d_h^s \end{bmatrix} = \left(\begin{bmatrix} S_{vv}^0 & S_{vh}^0 \\ S_{hv}^0 & S_{hh}^0 \end{bmatrix} - \frac{1}{2} \begin{bmatrix} S_{v1}^a & S_{v2}^a \\ S_{h1}^a & S_{h2}^a \end{bmatrix} \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \begin{bmatrix} I_{1v}^0 & I_{1h}^0 \\ I_{2v}^0 & I_{2h}^0 \end{bmatrix} \right) [\hat{\rho}_i]$$

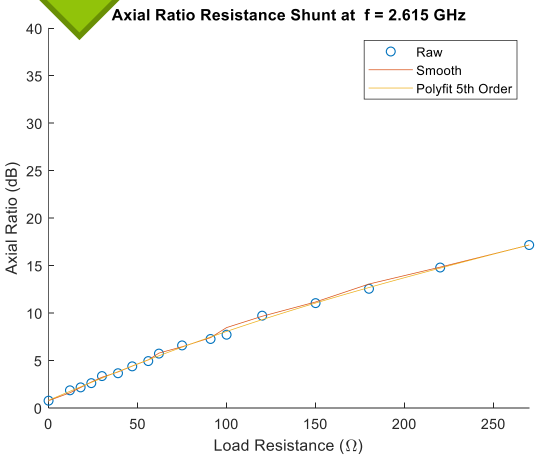
Antenne microruban à 2 accès



Détail de l'implémentation des charges







Evolution du rapport axial en fonction de la résistance (du capteur)

[2] "Dispositif de mesure d'au moins une grandeur physique et procédé de détermination associé », L. Fonseca Dias, C. Jouvaud, C. Delaveaud, H. Aubert, dépôt de brevet en cours

CONCLUSIONS ET PERSPECTIVES

- Développement et application d'un modèle général de rétrodiffusion polarimétrique

- Validation expérimentale validée pour une antenne à un port et pour une antenne à 2 ports

- Différentes applications dans le domaine des capteurs sans fils (passifs ou non)

PERSPECTIVES

Mesures	Caractérisation général	Choix du capteur	Antenne optimale
Mesure en extérieur – environnement non contrôlé	Développer une méthode pour ne pas à avoir à mesurer $[S^a]$ pour déterminer le modèle	Fabriquer ou choisir un capteur compatible avec l'antenne	Travailler sur le choix de l'antenne pour maximiser (ou non) les composantes croisées
Réaliser des analyses de portées		Développe une $[\hat{S}]$ optimal pour Polarisation	Travailler sur le contrôle du déphasage entre le mode de structure et le mode antenne

Merci pour votre attention

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Minatec Campus | 17 rue des Martyrs | 38054 Grenoble Cedex | France
www.leti.fr

FIGURES LINKS

1. P4: https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQRCA4lxazPpkZZmZzvTY9zavRE2KAiRfSFvQ&usqp=CAU
2. P4: https://www.researchgate.net/figure/Expected-number-of-connected-devices-to-the-Internet-This-chart-is-obtained-from-recent_fig1_279068905
3. P6: From PhD Day 2021 Poster
4. P5: https://buildingcontext.me/2014/10/20/iot-reference-model-introduced-at-iot-world-forum-2014/

VALIDATION – 1-PORT ANTENNA (1)

- Conversion de Polarisation Linéaire à Circulaire à l'aide d'un Tag Chargé par une Impédance Passive

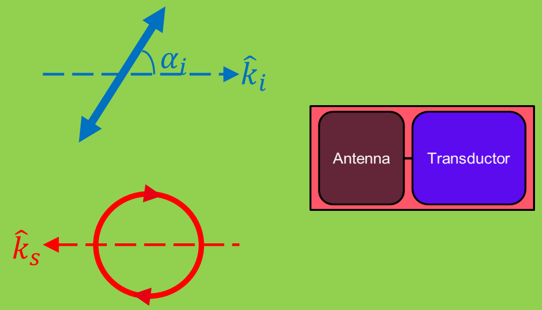
$$[\boldsymbol{d}^s] = \left([\boldsymbol{S}^0] - \frac{1}{2}[\boldsymbol{S}^a][\boldsymbol{K}][\boldsymbol{I}^0]\right)[\boldsymbol{\rho}_i]$$

→ 1-Port Antenna →

$$\begin{cases} E_v^s = E_v^0(\alpha_i, \delta_i) - \dfrac{Z_L}{Z_L + Z_a} A_v(\alpha_i, \delta_i) \\ E_h^s = E_h^0(\alpha_i) \end{cases}$$

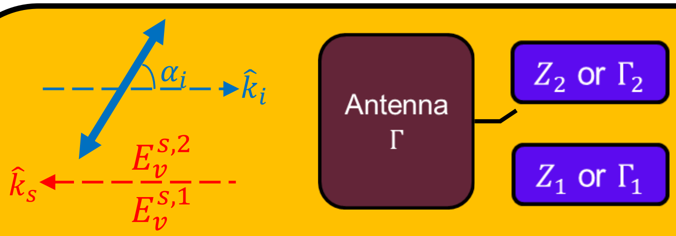
$$A_v = S_{v1}^a I_{1V}^0 \sin\alpha_i \, e^{j\delta_i}$$

LP to CP Conversion



$$Z_L^{\pm} = \frac{Z_a}{\dfrac{A_v(\alpha_i, \delta_i)}{E_v^0(\alpha_i, \delta_i) \pm jE_h^0(\alpha_i)} - 1}$$

1-P Characterization

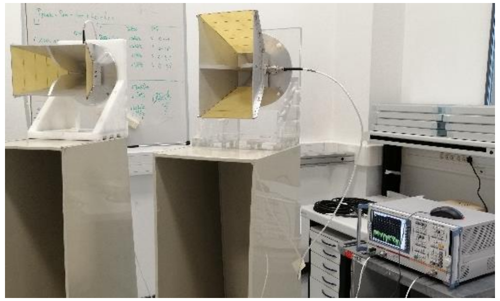


$$A_v = 2\frac{(1 - \Gamma\Gamma_1)(1 - \Gamma\Gamma_2)}{(1 - \Gamma^2)(\Gamma_1 - \Gamma_2)}\left(E_v^{s,2} - E_v^{s,1}\right)$$

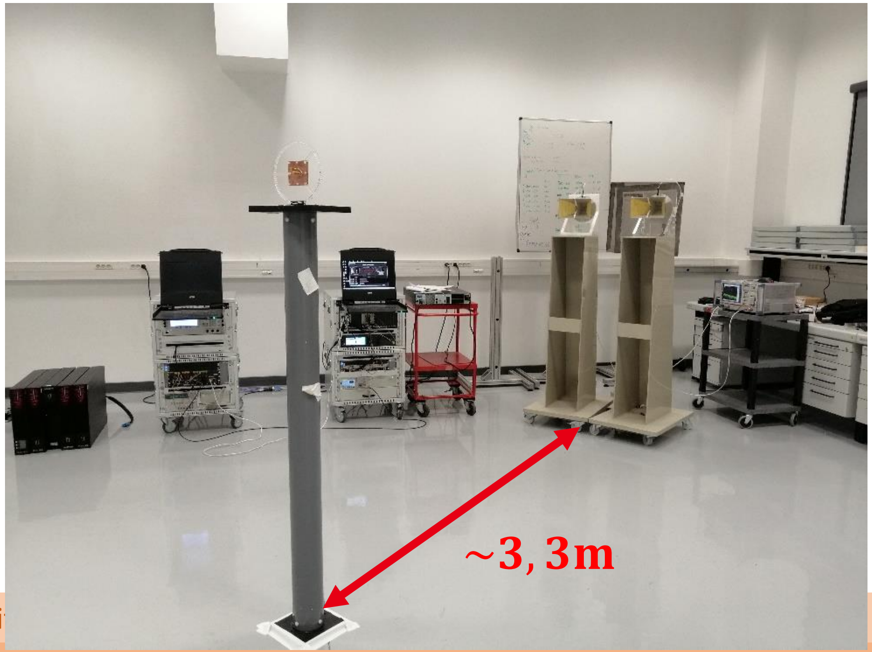
$$E_0^v = E_v^{s,1} + \frac{Z_1}{Z_1 + Z_a} A_v$$

SETUP

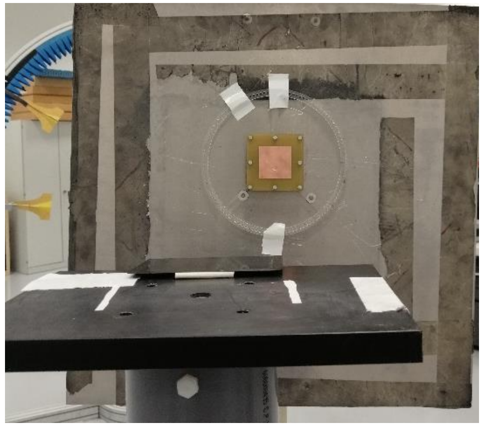
- Indoor measurements (no chamber)
- Two setups (Co- and X-Pol.):



No Metal Plate setup



Metal Plate setup



$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \\ d_v \\ d_h \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} & S_{1V} & S_{1H} \\ S_{21} & S_{22} & & S_{2N} & S_{2V} & S_{2H} \\ \vdots & & \ddots & & \vdots & \\ S_{N1} & S_{n2} & & S_{NN} & S_{NV} & S_{NH} \\ S_{v1} & S_{v2} & \cdots & S_{vN} & S_{vV} & S_{vH} \\ S_{h1} & S_{h2} & & S_{hN} & S_{hV} & S_{hH} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \\ c_V \\ c_H \end{bmatrix}$$

- $[S]$ - NxN S-parameters from Antenna
- $[R]$ - Nx2 Receiving Matrix (Transceiver to Sensor)
- $[T]$ - 2xN Transmitting Matrix (Sensor to Transceiver)
- $[P]$ - 2x2 Depolarizing Matrix (Sensor & Environment)

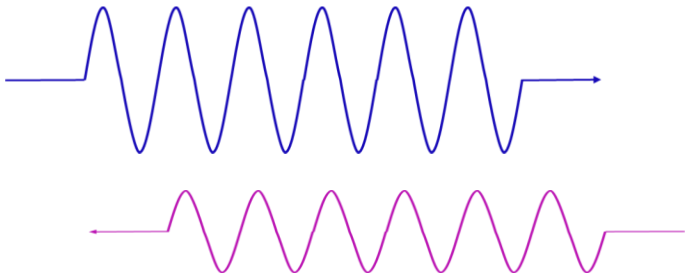
30/06/2022 Journée scientifique - « Communication par rétrodiffusion et rétro modulation »

THE MODEL – GENERAL MODEL (4)

$$[d^s] = \left([S^0] - \frac{1}{2}[S^a][K][I^0]\right)[\rho_i]..?$$

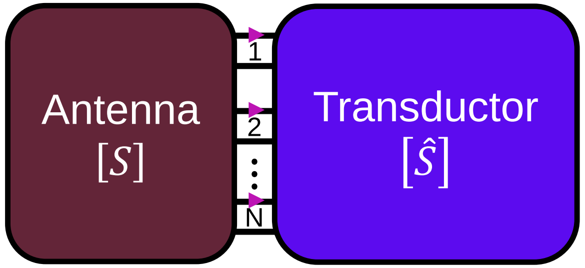
Incident Wave

$[\rho_i]$



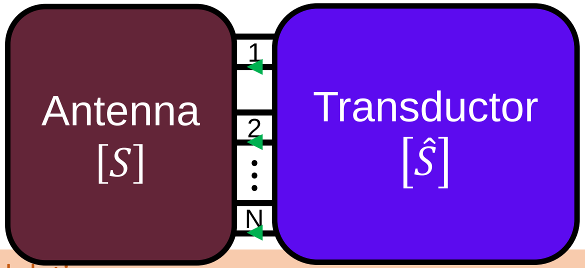
Structural Mode

$$[S^0] = \begin{bmatrix} S^0_{vV} & S^0_{vH} \\ S^0_{hV} & S^0_{hH} \end{bmatrix}$$



Surface Currents Proportional to

$$[I^0] = \begin{bmatrix} I^0_{1V} & I^0_{1H} \\ \vdots & \vdots \\ I^0_{NV} & I^0_{NH} \end{bmatrix}$$



Antenna-Load Interface

$$[K] = \begin{bmatrix} K_{11} & \cdots & K_{1N} \\ \vdots & \ddots & \vdots \\ K_{N1} & \cdots & K_{NN} \end{bmatrix}$$

reflects/transmits new currents

Antenna Mode

$$\frac{1}{2}[S^a][K][I^0]$$

New fields are generated proportional to the

RCS SETUP – CALIBRATION (1)

- Calibration's Flow, based on the setup « B » from Yueh:

Isolation → Metal Sphere → Corner Reflector → Rotated CR

Isolation ↓ Empty Chamber Once a day

Metal Sphere ↓

$$[S^{c1}] = \begin{bmatrix} a & 0 \\ 0 & a \end{bmatrix}$$

Corner Reflector ↓

$$[S^{c2}] = \begin{bmatrix} b & 0 \\ 0 & c \end{bmatrix}$$

Rotated CR ↓

$$[S^{c3}] = [Rot]^{-1} \begin{bmatrix} b & 0 \\ 0 & c \end{bmatrix} [Rot] = \begin{bmatrix} d & e \\ e & f \end{bmatrix}$$

Where:

$$[Rot] = \begin{bmatrix} \cos\rho & \sin\rho \\ -\sin\rho & \cos\rho \end{bmatrix}$$

If $\rho = 45°, d = f$

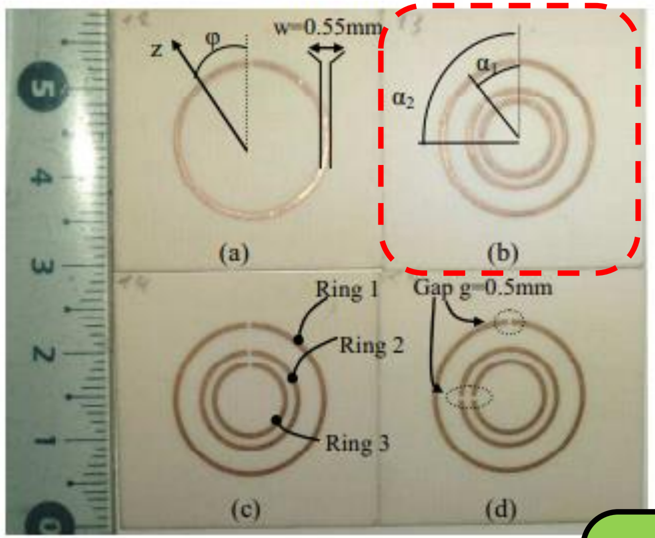
STATE OF THE ART – WHAT HAS BEEN MISSING (1)

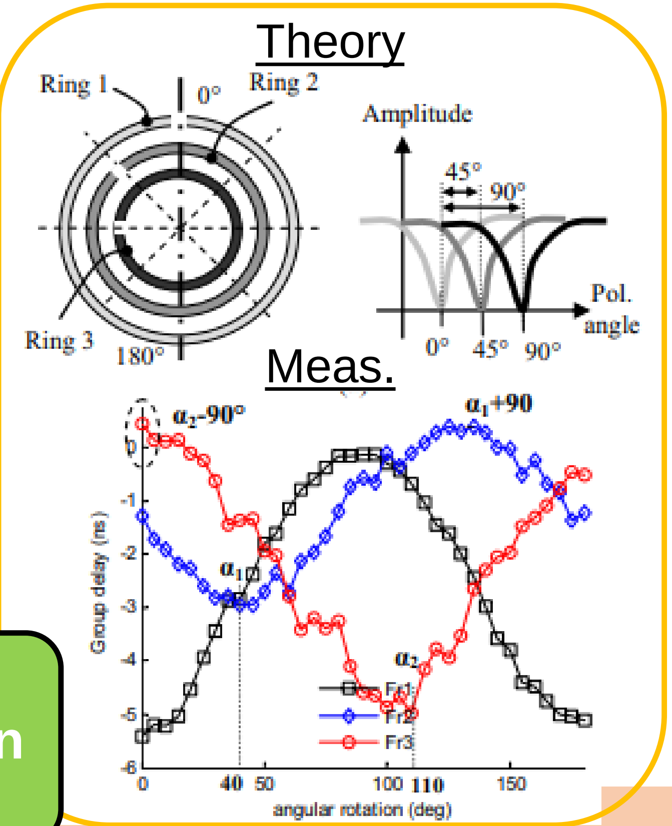
What has been done with Polarization Diversity so far?

Interrogation Principle

- Frequency or Amplitude Modulation
- Clutter reduction techniques
- **Polarization Control!**

- Chipless RFID





No Polarization Control !

[4] A. Vena, E. Perret and S. Tedjini, "A Compact Chipless RFID Tag Using Polarization Diversity for Encoding and Sensing", 2012 IEEE International Conference on RFID (RFID), Orlando, USA, April 2012

STATE OF THE ART – CLUTTER REDUCTION

Interrogation Principle

Frequency or Amplitude Modulation

Clutter reduction techniques

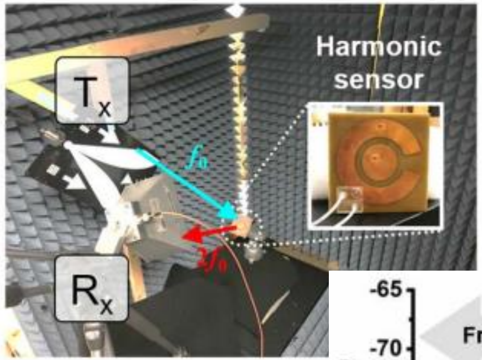
Polarization Control!

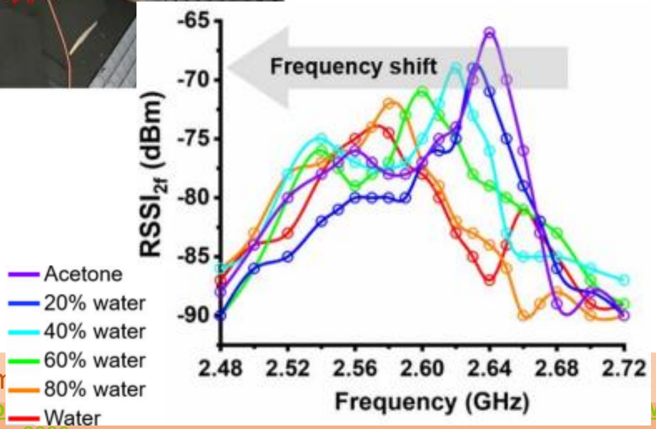
2 Possibilities

Frequency

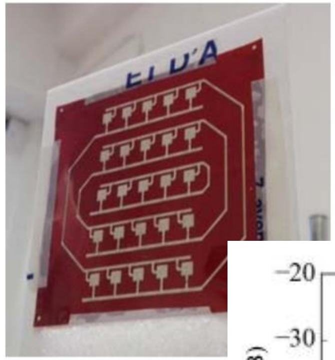
Amplitude

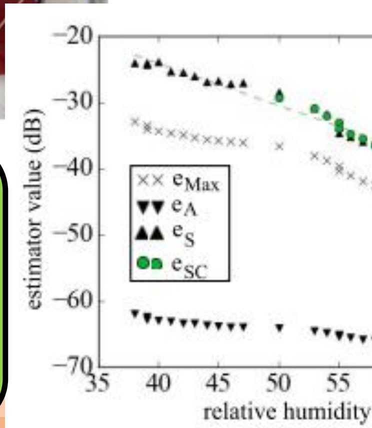
- Frequency Hopping





- Cross-Polarization





No Information on the Polarization State !

[2] L. Zhu, M. Farhat, Y.-C. Chen, K. K. Salama and P.-Y. Chen, **"A Comp**... Antenna", *IEEE Sensors Journal*, pp. 124..., Vol. 20, Issue 21, Nov. 2020

[3] D. Henry, J. G. D. Hester, H. Aubert, ... M. M. Tentzeris, **"Long-Range Wireless Interrogation of Passive Humidity Sensors Using Van-Atta Cross-Polarization Effect and Different Beam Scanning Techniques"**, *IEEE Transactions on Microw. Theory & Techn.*, pp. 5345-5354, Vol. 65, Issue 12, Dec. 2017