



# Transmission des mesures d'un réseau de capteurs environnementaux en bande ISM. Une approche semilogicielle

**Authors :** G.Hellbourg<sup>3</sup>, , R. Weber<sup>2,3</sup>, A.Millot<sup>1,3</sup>, C. Capdessus<sup>3</sup>

<sup>1</sup> ATCOM Telemetrie, 15 rue jean Bertin, BP 79, 45430 Checy, France

<sup>2</sup> Observatoire de Paris, Station de radioastronomie, F-18330 Nançay, France

<sup>3</sup> Université d'Orléans, PRISME, Site Galilée, 12 rue de Blois, 45067 Orléans cedex 2, France

# Context and Objectives



## ✓ Context

- Need from the French public institution involved in the Earth Science field
  - Automatic Water quality monitoring



## ✓ Current application limitations

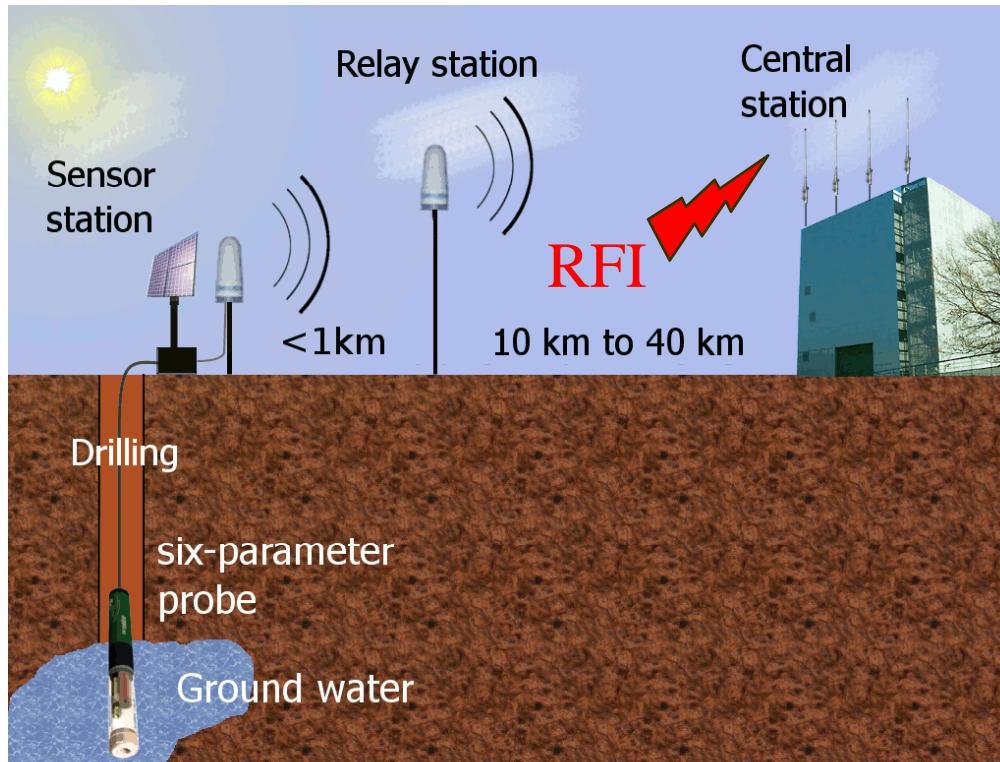
- data loggers requiring manual downloading
- No « real time » sampling (e.g. monthly)



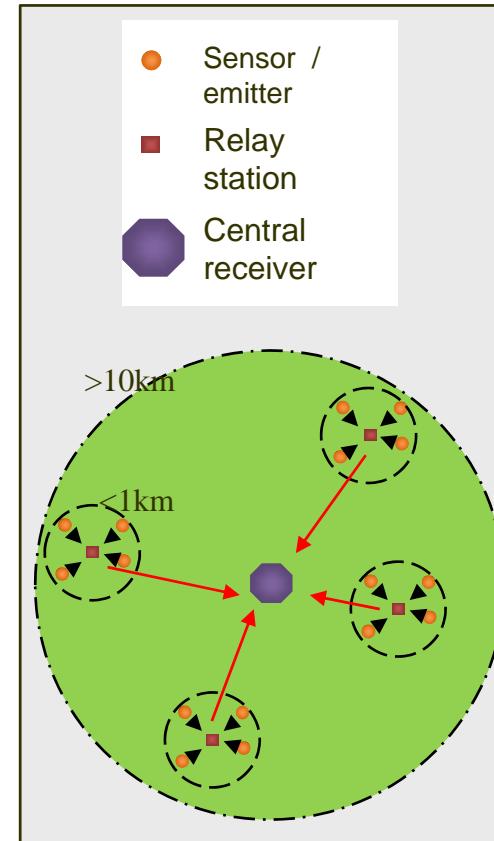
## ✓ Objectives

- Design of a remote sensor network :
  - Autonomous low cost sensors
  - Central receiver in a urban area (radio frequency interference)
  - Emitter/Receiver range >10 km
  - Daily sampling
  - free Band (no fees)

# Sensor network characteristics



The diagram illustrates a sensor network architecture. A **Sensor station** (represented by a blue cube with a solar panel and antenna) is located above ground, connected to a **six-parameter probe** (represented by a green cylinder) in the **Ground water** layer. The probe transmits data to the Sensor station. The Sensor station then communicates with a **Relay station** (represented by a red cube with an antenna) via a short-range link (<1km). The Relay station further transmits data to a **Central station** (represented by a grey building with multiple antennas) via a long-range link (10 km to 40 km). A red lightning bolt icon labeled **RFI** indicates potential interference.

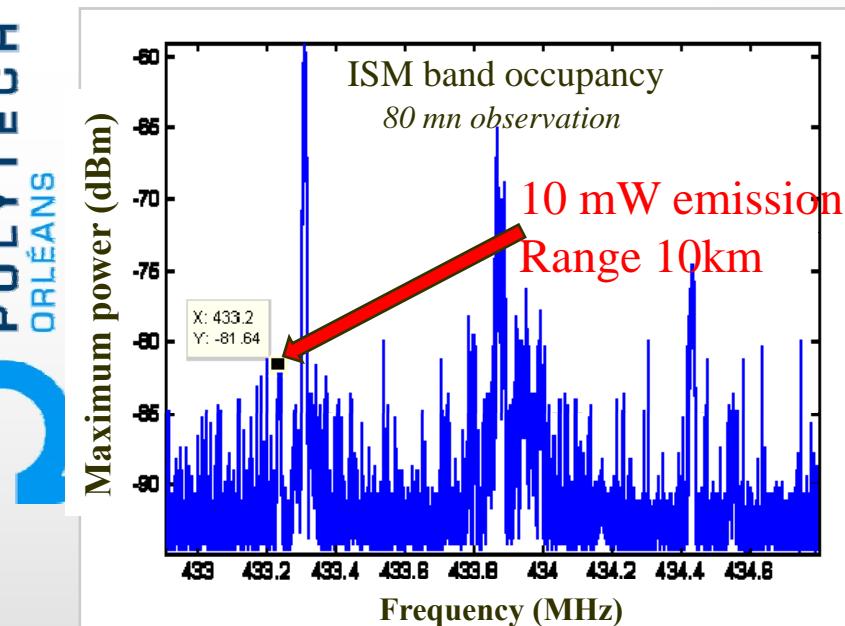


This diagram shows a network topology. A central purple hexagon represents the **Central receiver**. It is connected to three relay stations, represented by red squares. Each relay station is connected to a cluster of sensor/emitter nodes, represented by orange circles. The distance between the central receiver and the relay stations is indicated as >10km. The distance between the relay stations and the sensor/emitter nodes is indicated as <1km. Arrows indicate the flow of data from the sensor/emitter nodes through the relay stations to the central receiver.

✓ **RF transmission**

- BPSK (ISM band at 433MHz, baud rate=1200 bit/s)
- TDMA

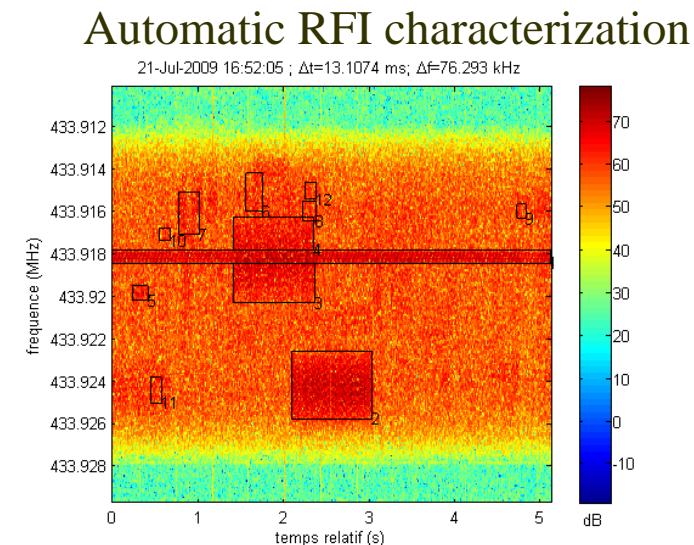
STIC 2011, St-Etienne, France



4

n° , when	$f_0$ (MHz)	RFI per hour	$\Delta T$ (s)	$\Delta F$ (kHz)
1, day	433.92	5277	0.3	1.6
2, night	433.92	4549	0.36	1.58
3, day	434.2	2864	0.28	1.31
4, night	434.2	567	0.32	1.33

# RFI monitoring in the 433MHz band

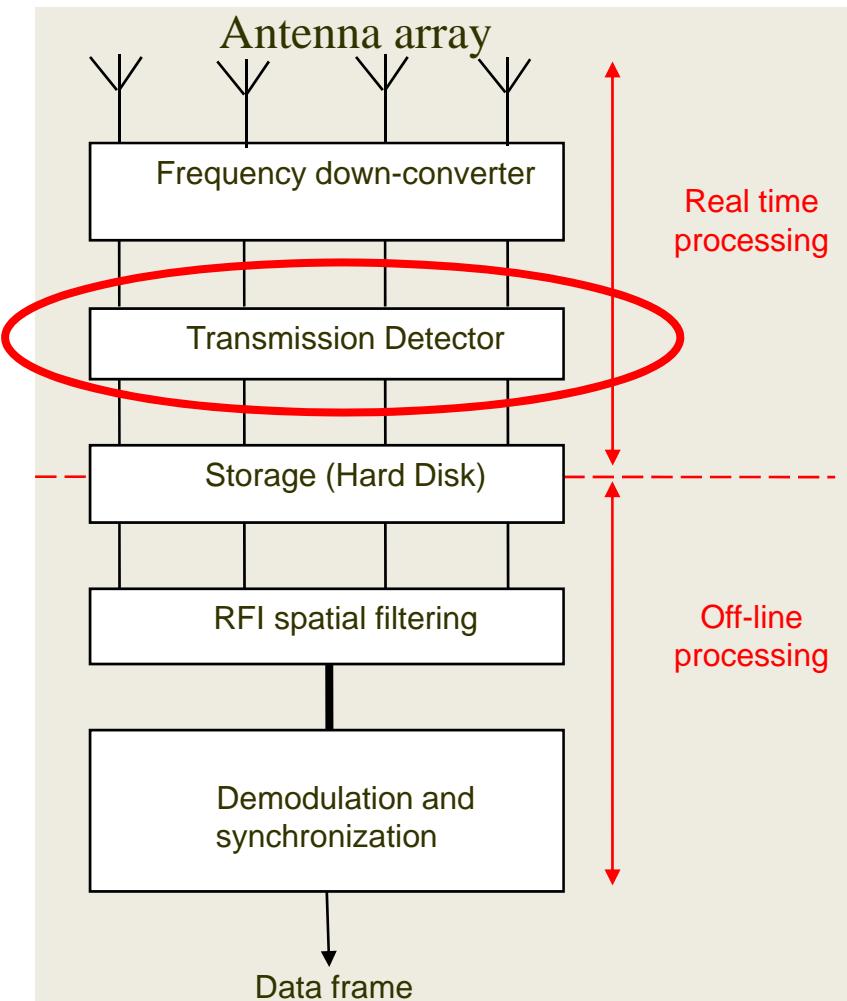


## ✓ Results

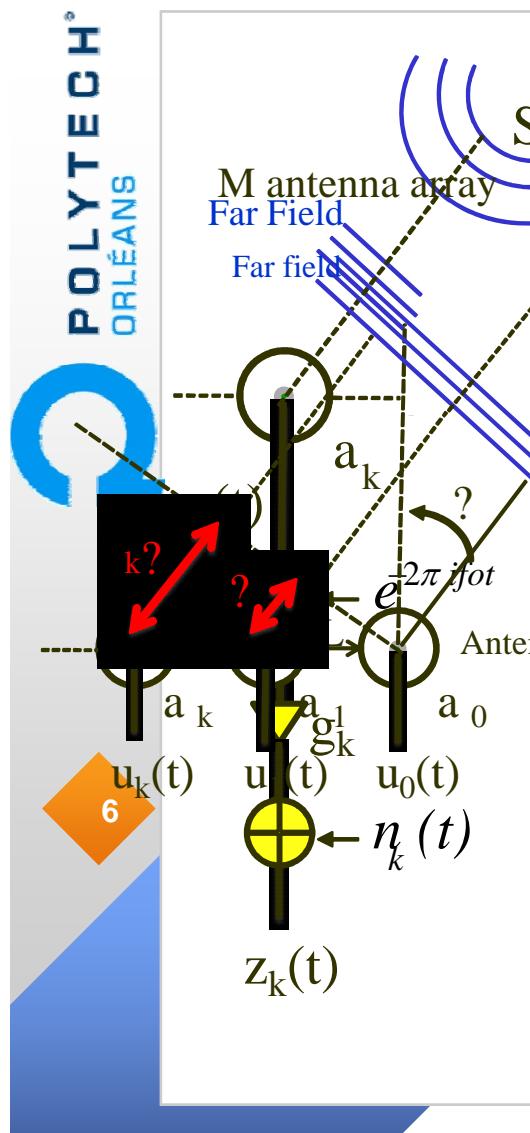
- High RFI occupancy
- 95% RFI < 1s
- Average duration  $\Delta T$ : 30 ms
- Average bandwidth  $\Delta F$ : ~1,3 kHz
- Low activity during the night

# Our approach : selective acquisition and off-line processing

- ✓ **Specifications**
  - Short data frame (<100ms)
  - Daily transmission
- Don't need a continuous reception
- ✓ **Concept**
  - Selective acquisition by detecting sensor transmission
  - Data waveform storage
  - Antenna array for spatial processing



# Antenna array model



✓ **Signal**

$$s(t)e^{i(2\pi f_0 t + \varphi_o)}$$

$$u_k(t) = s(t - k\tau)e^{i(2\pi f_0(t - k\tau) + \varphi_o)}$$

$$u_k(t) = s(t)e^{-i2\pi f_0 k\tau + i\varphi_o} e^{i2\pi f_0 t}$$

✓ **antenna output**

$$z_k(t) = \underbrace{g_k e^{-i2\pi f_0 k\tau + i\varphi_o}}_{a_{sk}} s(t) + n_k(t)$$

✓ **Antenna array model**

$$\mathbf{z}(t) = \begin{bmatrix} a_{s0} \\ \vdots \\ a_{sM-1} \end{bmatrix} s(t) + \underbrace{\mathbf{a}_r r(t)}_{\text{RFI}} + \underbrace{\mathbf{n}(t)}_{\text{Noise}}$$

source

**Hypothesis**

Far field  
range > 1km

Narrow band  
 $\frac{\Delta f_0}{f_0} \ll 1$

1 source  $s(t)$   
1 RFI  $r(t)$



# Cyclostationary detector (1)

**Cyclic autocorrelation:**

$$R_{x,x^*}^\alpha(\tau) = E \left\{ x(t + \frac{\tau}{2}) x^*(t - \frac{\tau}{2}) e^{-i2\pi\alpha t} \right\}$$

✓ **Different cyclic signatures**

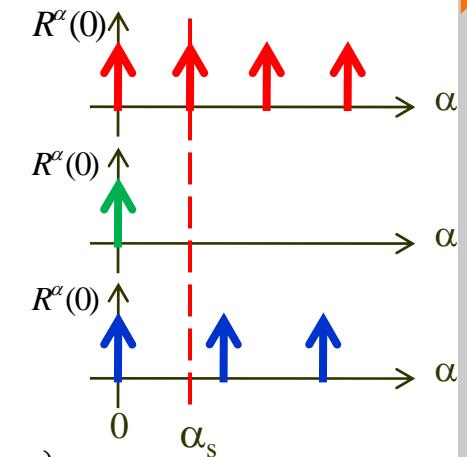
- Source (BPSK)       $\alpha_s = \frac{k}{T_{sym}}$        $\Rightarrow R_{s,s^*}^\alpha \neq 0$ 
  - Baud rate  $1/T_{sym}$
- Noise = stationary       $\Rightarrow R_{n,n^*}^{\alpha_s} = 0$
- RFI       $\alpha_r \neq \alpha_s$        $\Rightarrow R_{r,r^*}^{\alpha_s} = 0$

✓ **Multidimensional case**

$$\mathbf{R}_{z,z^*}^\alpha = E \left\{ \mathbf{z}(t) \mathbf{z}^H(t) e^{-i2\pi\alpha t} \right\}$$

$$\mathbf{R}_{z,z^*}^\alpha = \mathbf{a}_s \underbrace{E \left\{ s s^H e^{-i2\pi\alpha t} \right\}}_{R_{s,s^*}^\alpha} \mathbf{a}_s^H + \mathbf{a}_r \underbrace{E \left\{ r r^H e^{-i2\pi\alpha t} \right\}}_{R_{r,r^*}^\alpha} \mathbf{a}_r^H + \underbrace{E \left\{ \mathbf{n} \mathbf{n}^H e^{-i2\pi\alpha t} \right\}}_{R_{n,n^*}^\alpha} \mathbf{0}$$

$$\mathbf{R}_{z,z^*}^{\alpha_s} = \mathbf{a}_s \mathbf{a}_s^H R_{s,s^*}^{\alpha_s}$$





# Cyclostationary detector (2)

## ✓ Detector criteria

- Singular value decomposition

$$\mathbf{R}_{z,z^*}^\alpha = \begin{bmatrix} r_{ij} \end{bmatrix} = \mathbf{U}_c \mathbf{\Lambda}_c \mathbf{V}_c^H$$

- With  $\alpha = \alpha_s$ , asymptotically :

$$\mathbf{\Lambda}_c = \begin{bmatrix} \lambda_s & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}_\infty \quad \longrightarrow \quad \lambda_{\max} \leqslant \text{threshold}$$

Issue => Real time implementation

- Frobenius norm

$$\left\| \mathbf{R}_{z,z^*}^\alpha \right\|_F^2 = \sum_{i=1}^M \sum_{j=1}^M \left| r_{ij} \right|^2 = \sum_{k=1}^M \left| \lambda_k \right|^2$$

- With  $\alpha = \alpha_s$ , asymptotically :

$$\left\| \mathbf{R}_{z,z^*}^\alpha \right\|_F^2 = \left| \lambda_s \right|^2 \quad \longrightarrow \quad \left\| \mathbf{R}_{z,z^*}^{\alpha_s} \right\|_F^2 \leqslant \text{threshold}$$

# Simulations (1)



## ✓ Detector performance evaluation

### – Hypothesis

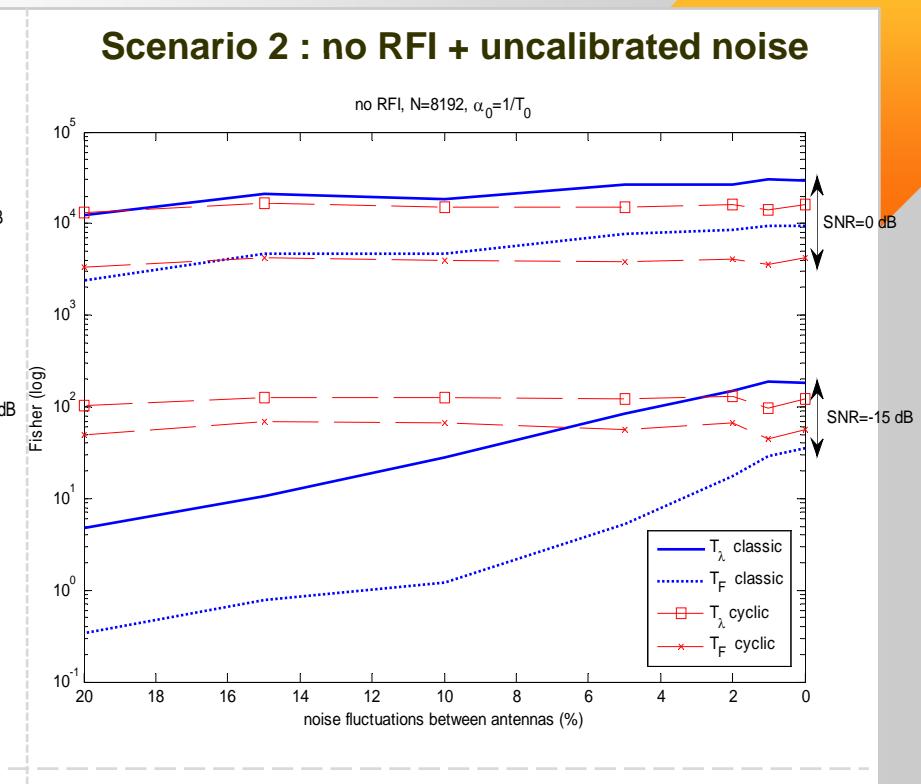
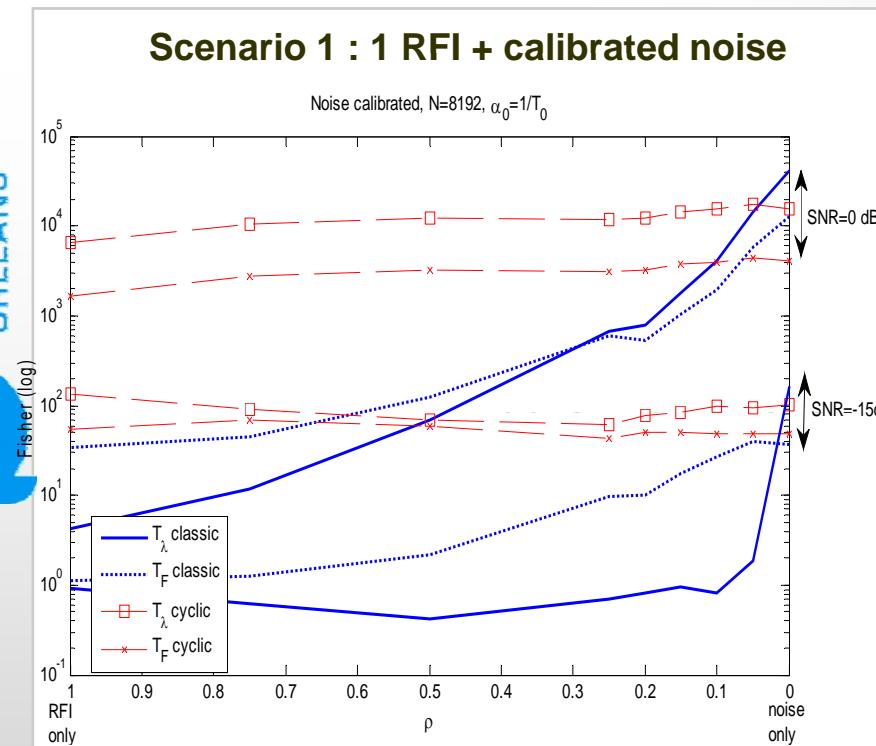
- No transmission:  $H_0 \rightarrow \mathbf{z}(t) = \sqrt{\rho} \mathbf{a}_r r(t) + \sqrt{1-\rho} \mathbf{n}(t)$
- Transmission:  $H_1 \rightarrow \mathbf{z}(t) = \sigma_s \mathbf{a}_s s(t) + \sqrt{\rho} \mathbf{a}_r r(t) + \sqrt{1-\rho} \mathbf{n}(t)$
- 4 detector criteria : 
- SNR =  $\sigma_s^2$

### – Performance criterion : Fisher criteria

$$F = \frac{(E_{H_1}[T(\mathbf{z})] - E_{H_0}[T(\mathbf{z})])^2}{Var_{H_1}[T(\mathbf{z})] + Var_{H_0}[T(\mathbf{z})]}$$

$T(\mathbf{z})$	$\mathbf{R}_{z,z}^0$	$\mathbf{R}_{z,z}^{\alpha_s}$
Dominant singular value	$T_\lambda$ classic	$T_\lambda$ cyclic
Frobenius Norm	$T_F$ classic	$T_F$ cyclic

# Simulations (2)



10

## ✓ conclusions

- In practice,  $T_F < T_\lambda$
- Cyclostationary detectors are robust

$$\left\| \mathbf{R}_{z,z^*}^\alpha \right\|_F^2 = |\lambda_s|^2 + \sum_{k=1}^M |\lambda_{N,k}|^2 \xrightarrow[N \rightarrow \infty]{} 0$$

# Filtrage spatial

## ✓ Objectifs

- Focaliser le réseau
- Annuler les brouilleurs

## ✓ Méthode de Capon

- Puissance reçue

$$y(t) = \mathbf{w}^H \mathbf{z}(t)$$

$$P = \left\langle |y(t)|^2 \right\rangle_{\infty} = \mathbf{w}^H \mathbf{R} \mathbf{w}$$

- Critère de Capon

$$\min_w \mathbf{w}^H \mathbf{R} \mathbf{w}$$

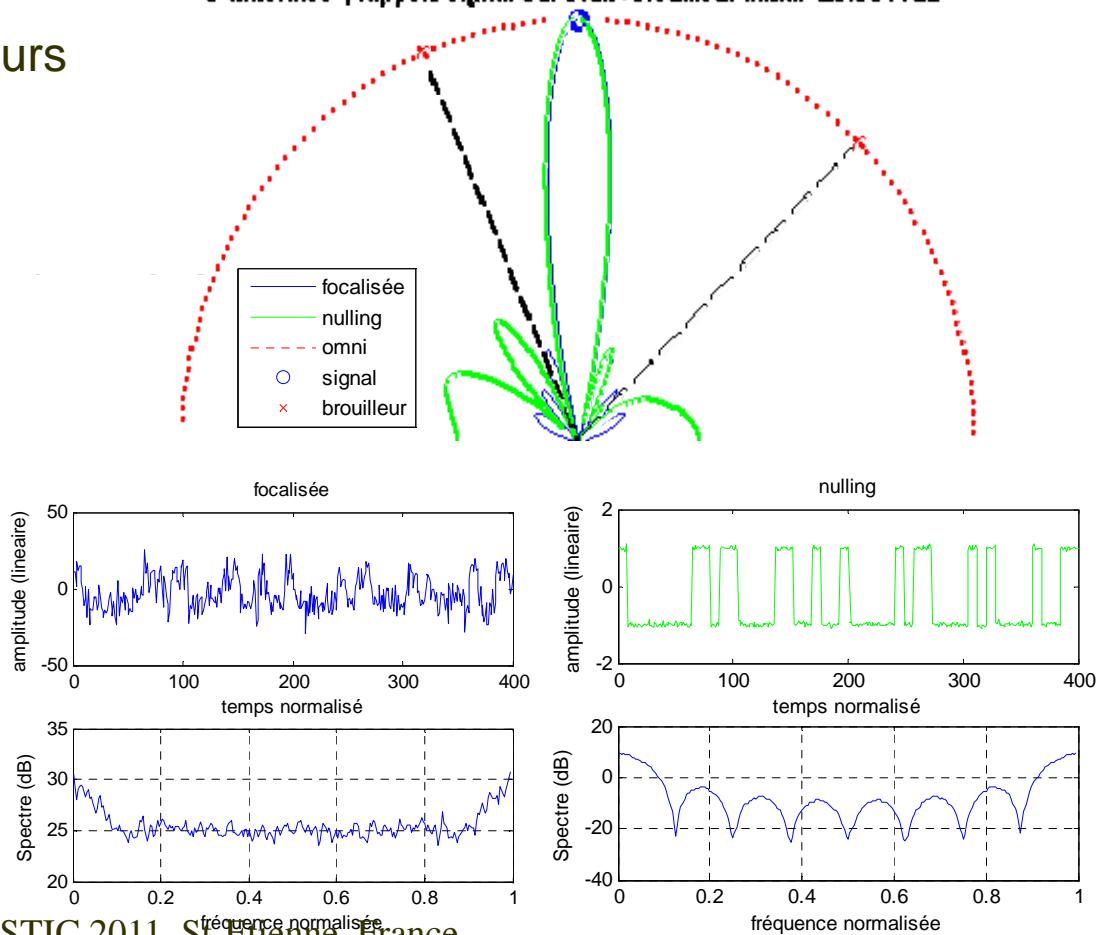
avec  $\mathbf{w}^H \mathbf{a}_s = 1$

- Solution

$$\mathbf{w}_o = \frac{\mathbf{R}^{-1} \mathbf{a}_s}{\mathbf{a}_s^H \mathbf{R}^{-1} \mathbf{a}_s}$$

## Simulations

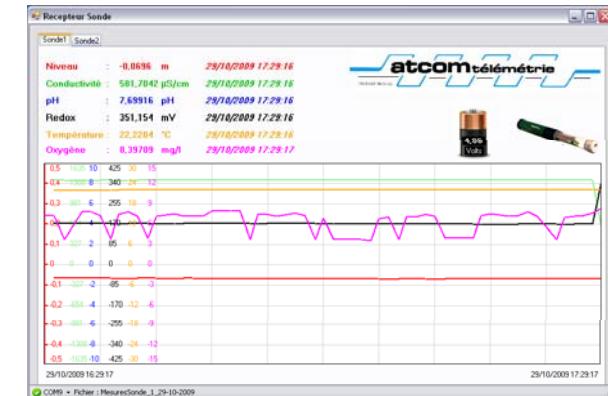
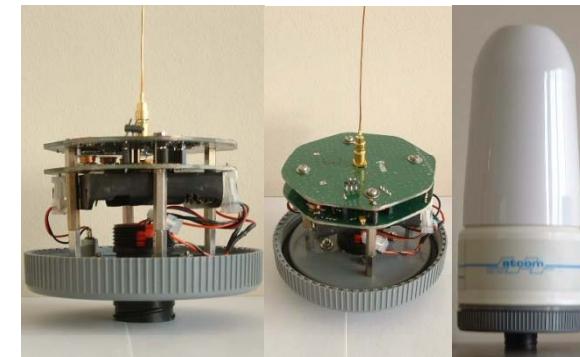
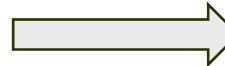
6 antennes , rapport signal sur bruit+brouilleur initial -23.0611dB





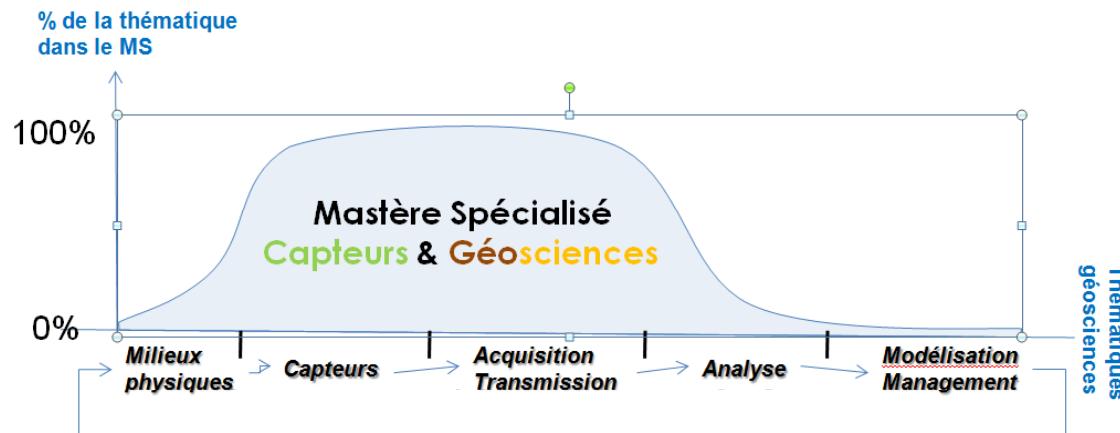
# Conclusions and perspectives (1)

- ✓ Cyclic approach is robust against RFI and uncalibrated array
- ✓ Sensor emitter and relay station have been designed
- ✓ Practical tests with simple receiver (no spatial processing) have shown that long range transmission are very difficult due to RFI
- ✓ Next step : implementation of the proposed approach



# Mastère Spécialisé Capteurs & Géosciences

Le sol intelligent au service de l'intelligence du sol



13



En partenariat avec :



STIC 2011, St-Etienne, France

