Non-Stationary Signal Analysis Using Phase Diagram-based Techniques

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Non-Stationary Signal Analysis Using Phase Diagram-Based Techniques

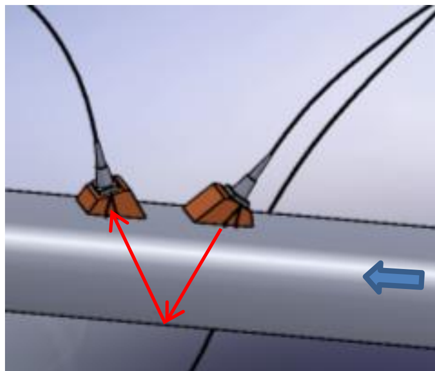
OVERVIEW

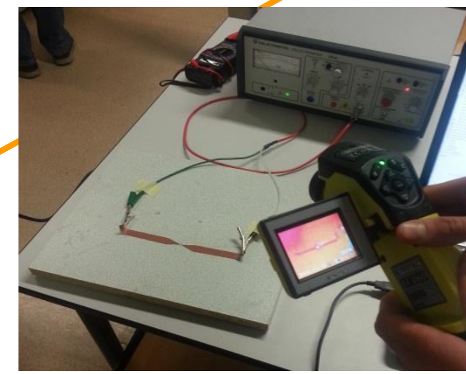
1. Introduction

- **Work context –** analysis of non-stationary and transient signals – *a lot of applications…*

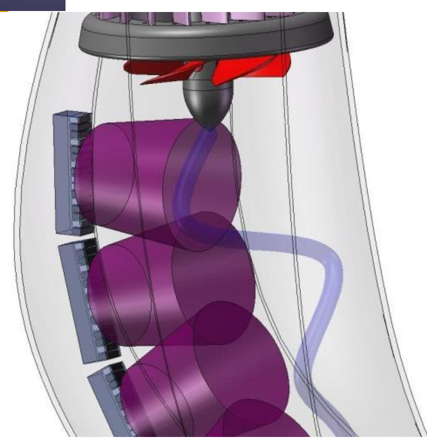
Frequency

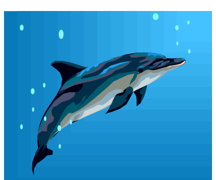
Ultrasound measurements

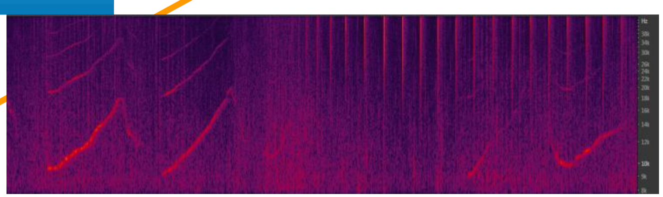




Electrical discharges

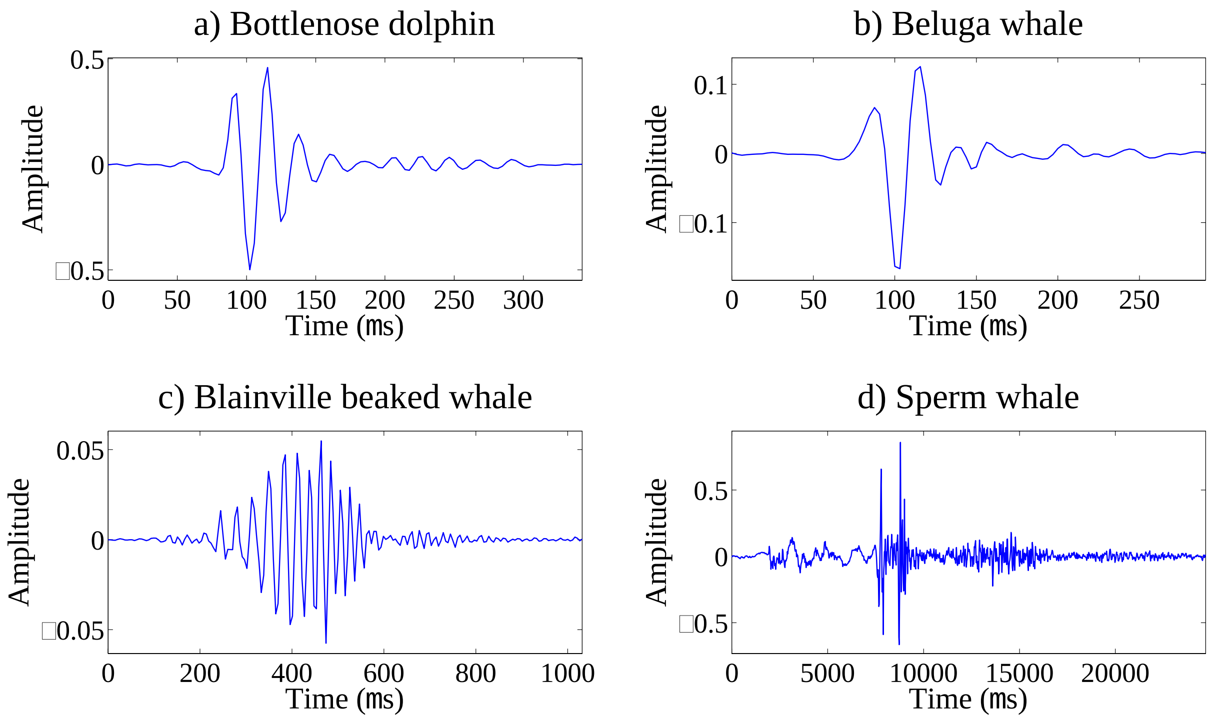






1. Introduction

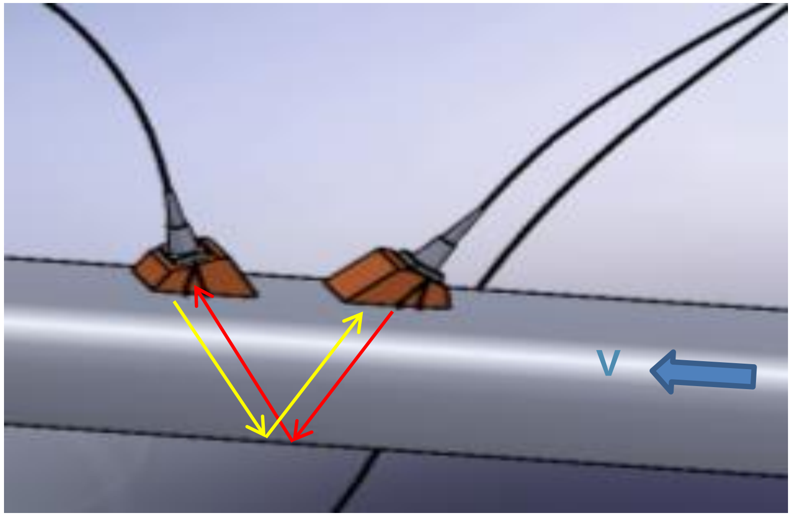
- **Acoustic signals processing – *detection and localisation of underwater mammal, in order to ensure the fauna's protection in coastal zone***

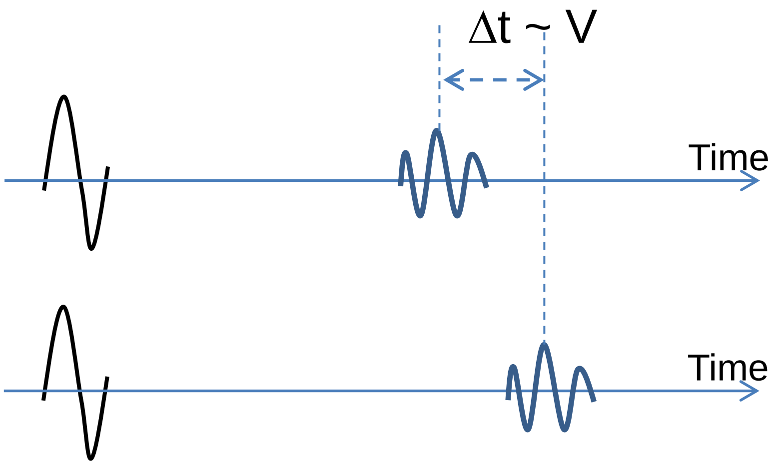


Difficulties in terms of signal processing : impulsive, Very short (few μs), Emitted signal unknown, Sensitive to propagation

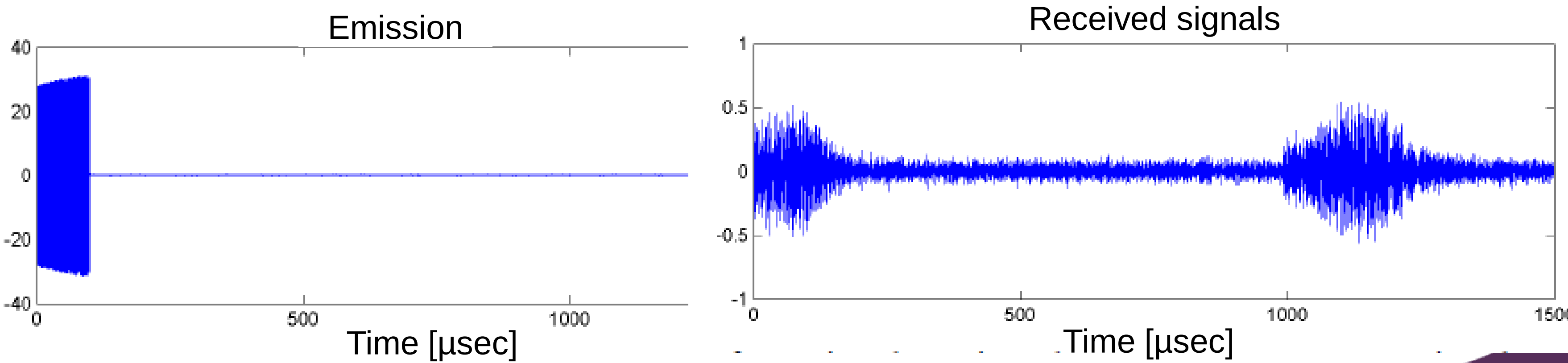
1. Introduction

- **Ultrasound transient processing -** ***part of non-intrusive testing and measurement***



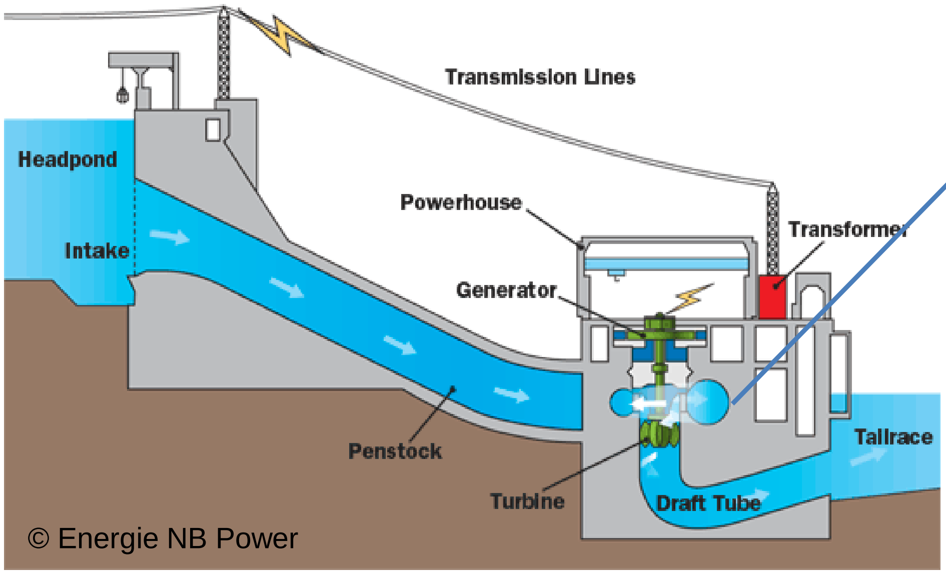


- **But, in practice, the processing must deal with deformed signals**



1. Introduction

- **Ultrasound transient processing – *monitoring of rotating machinery***



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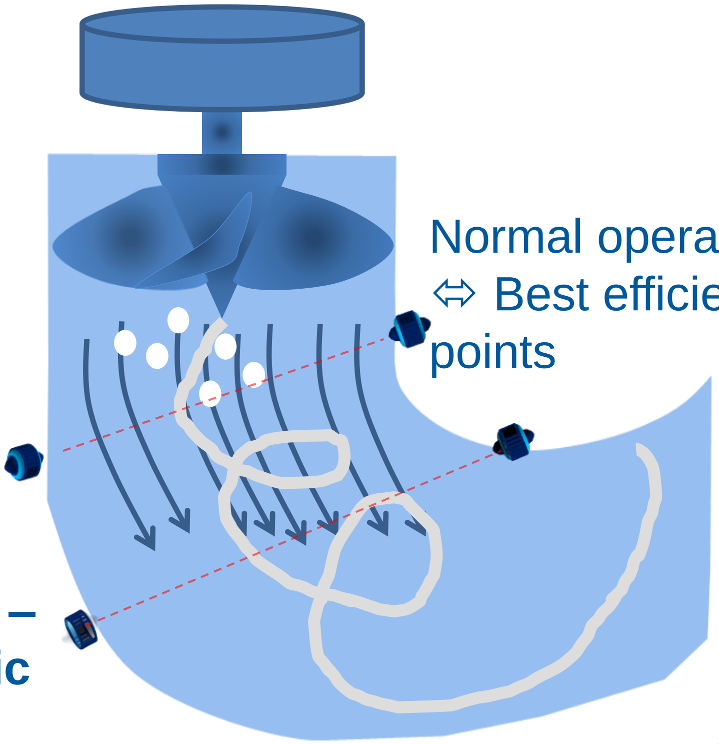
Turbines – vital part that must be carefully monitored – crucial for health of the system and production efficiency



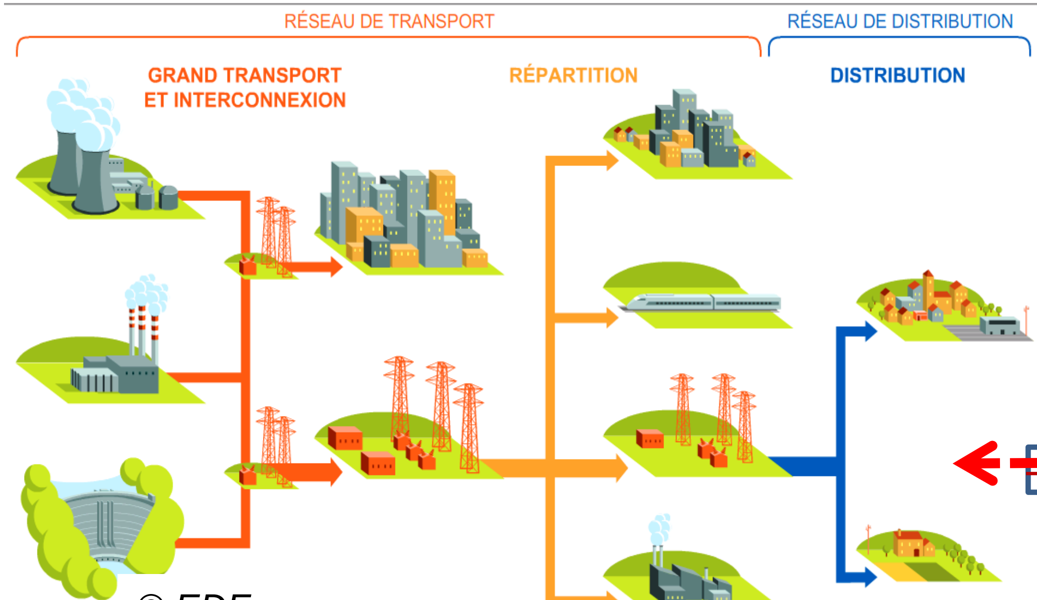
Normal operation ⇔ Best efficiency points

Sub-optimal operation (Vortex, cavitation,..) ⇔ Losses of efficiency, possible damages

Need for monitoring system – current and challenging topic

1. Introduction

- **Global and continuos monitoring of power systems**



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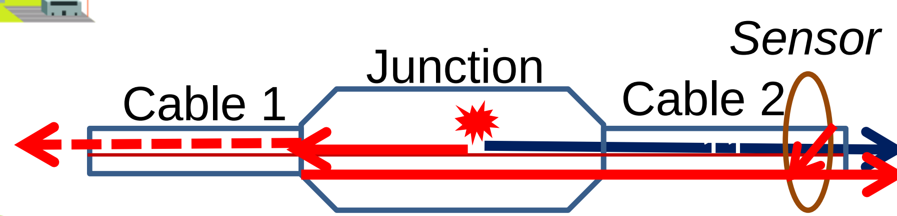
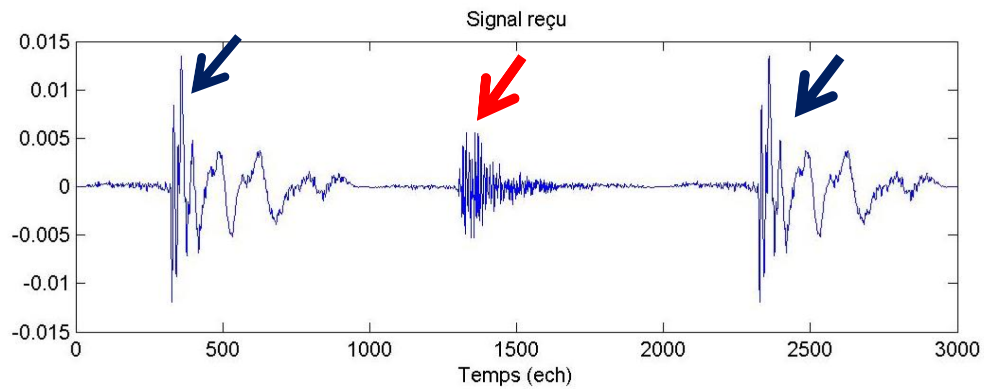
- **"Brick" of any power system**





Building sparse network of distributed sensors ⇔

Requires new representation spaces…

Non-Stationary Signal Analysis Using Phase Diagram-Based Techniques

OVERVIEW

1. Introduction

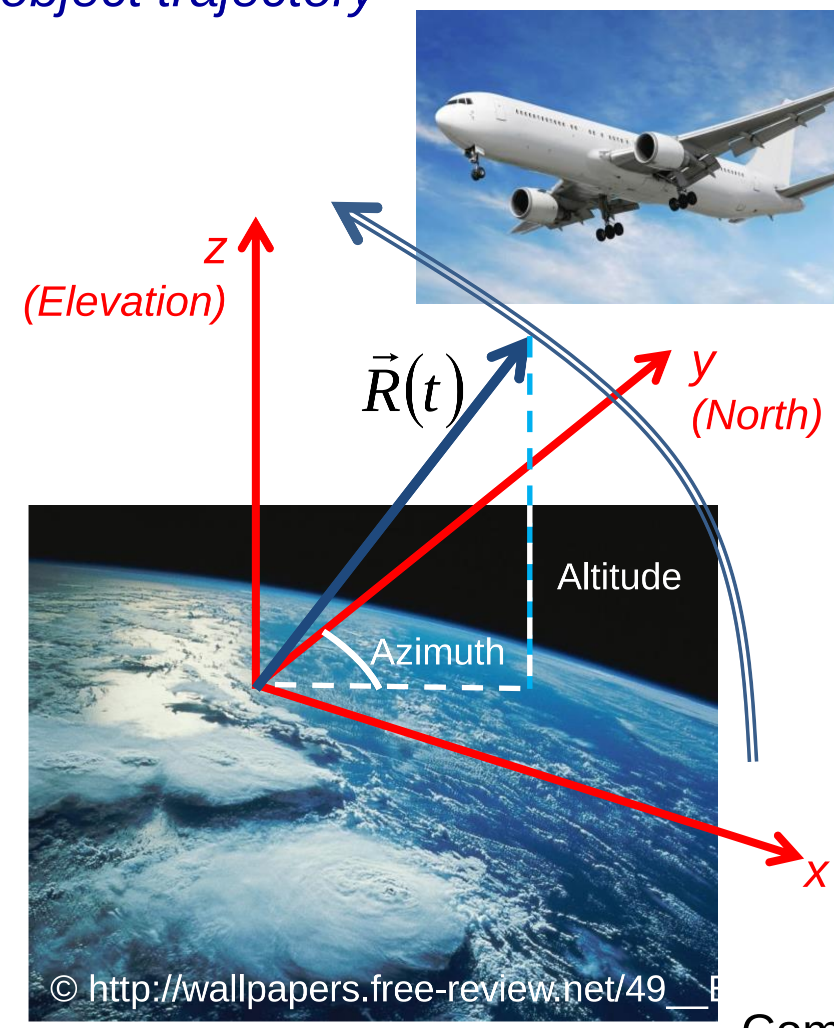
2. Signal processing methodology based on RPA

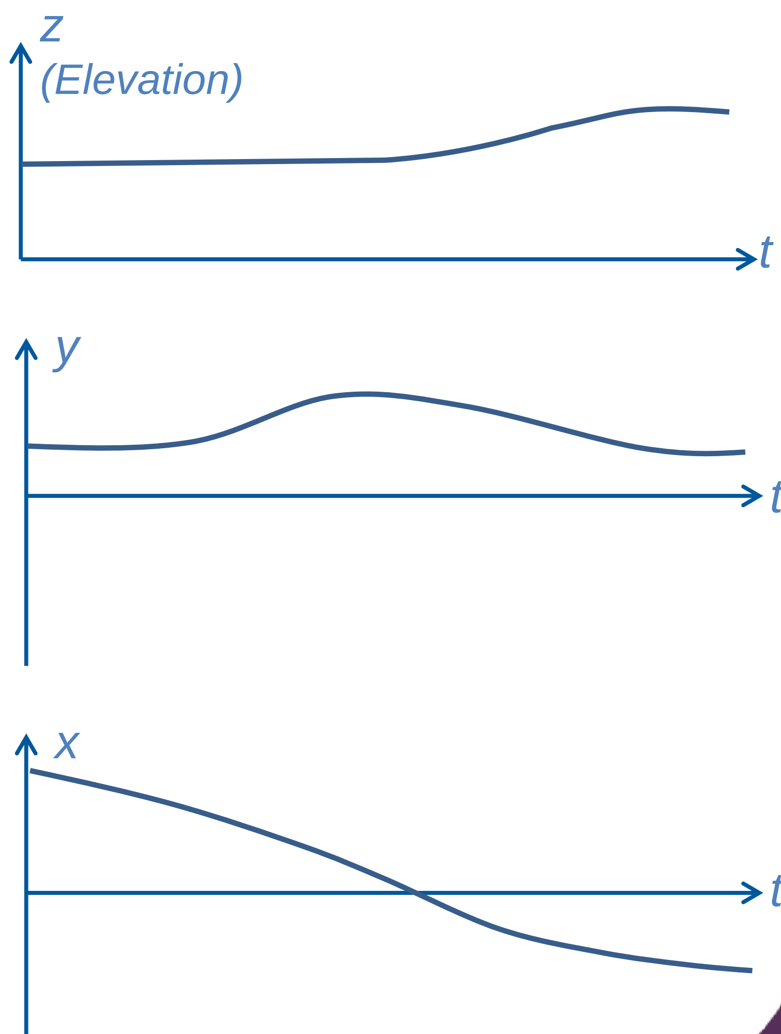
3. Results in applied contexts

4. Conclusions and Perspective

2. Signal processing methodology based on RPA

- **Signal's representation using phase diagrams –** *analogy with moving object trajectory*





Complete description of the motion !

2. Signal processing methodology based on RPA

- **Signal's representation using phase diagrams (**N. Marwan *et al***)**

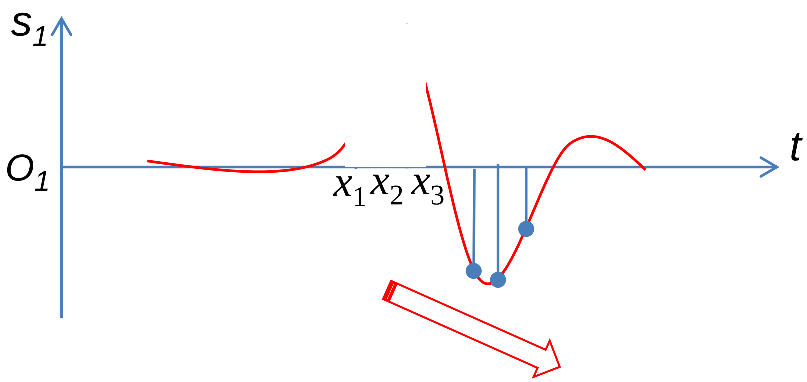
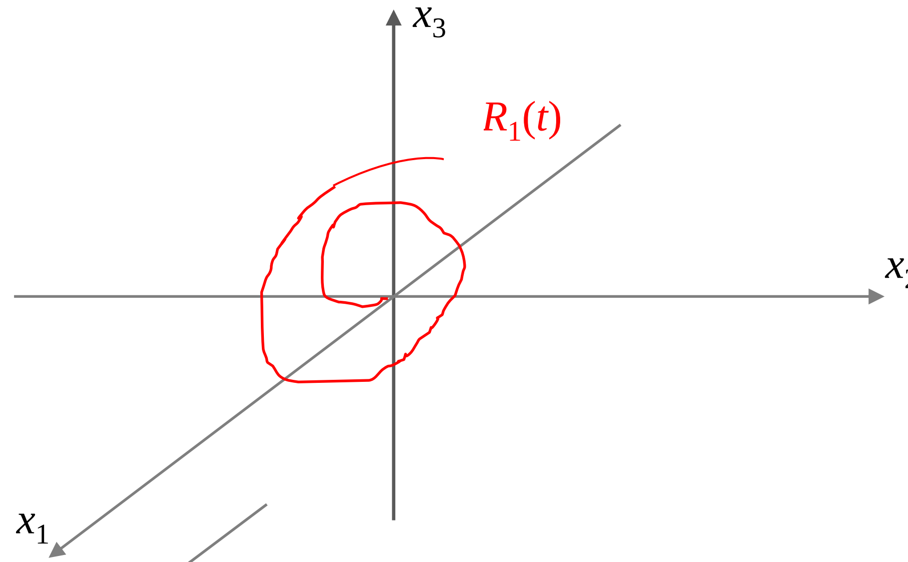
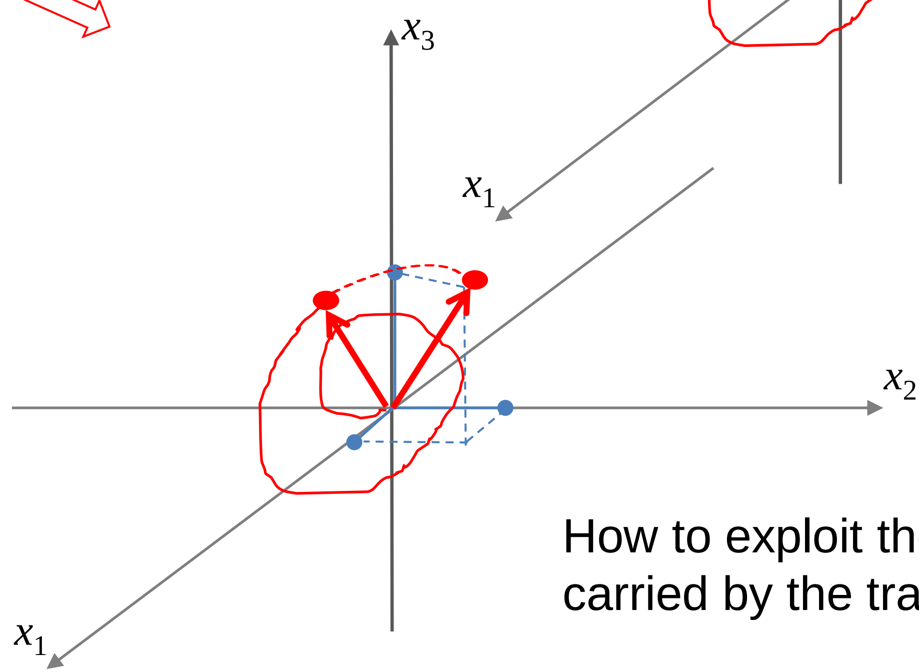


Illustration in 3D case



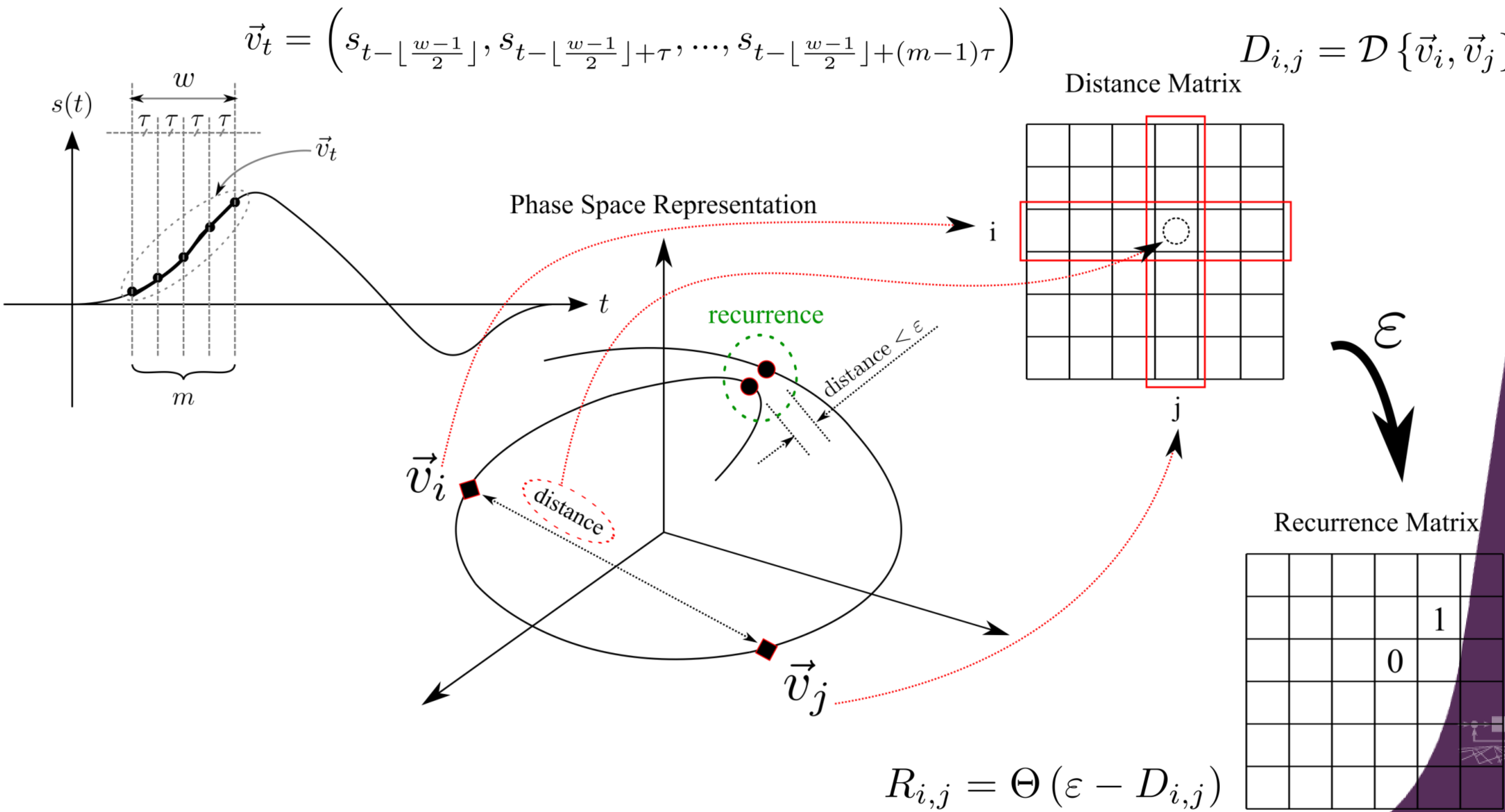


$$\bigcup_t R_1(t)$$

How to exploit the information carried by the trajectory ?

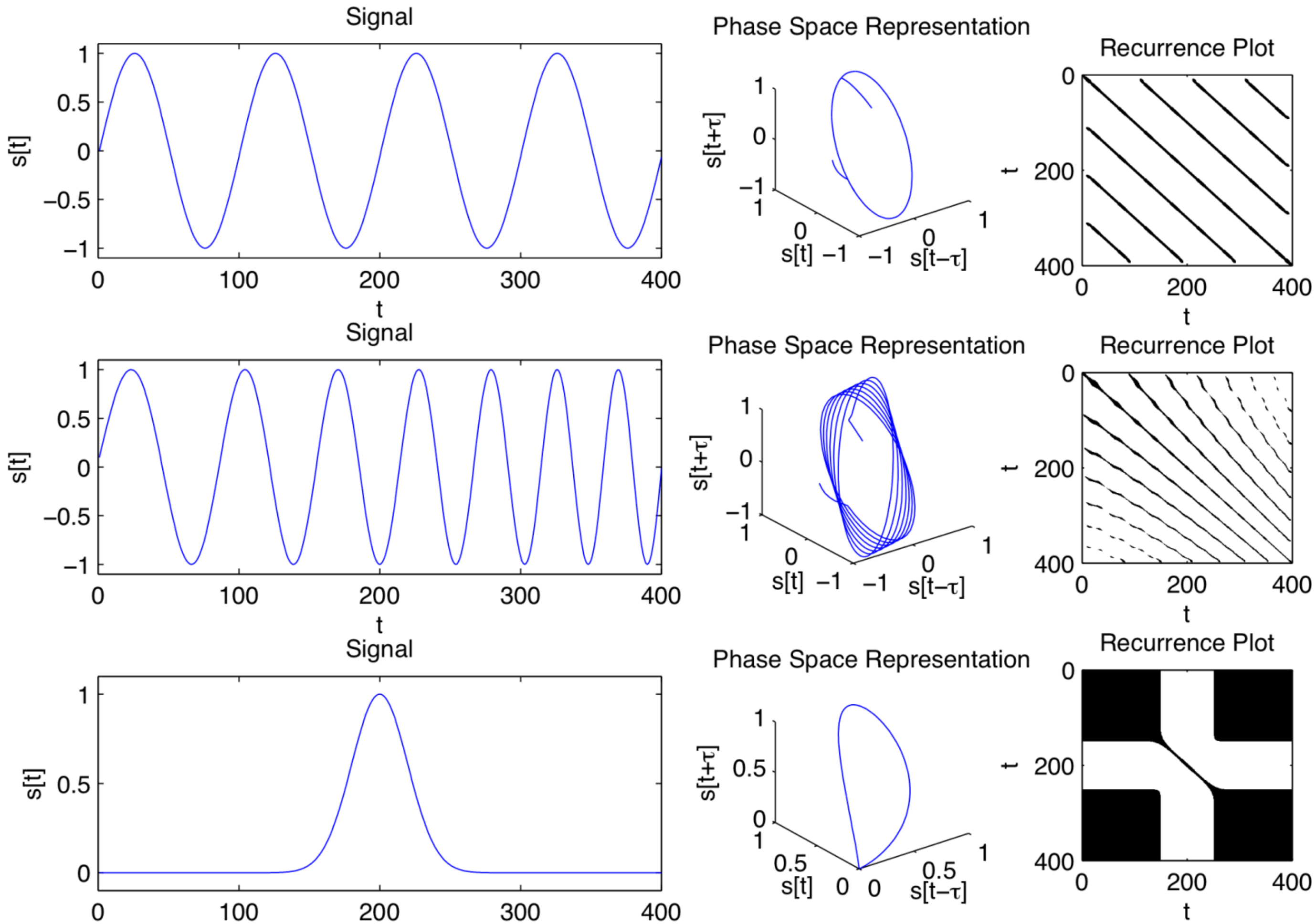
2. Signal processing methodology based on RPA

- **Central idea :** Computing the recurrence of the signal's trajectory



2. Signal processing methodology based on RPA

Recurrence plot analysis – few examples



Physically -inspired setup of RPA parameters : lag and vector dimension size

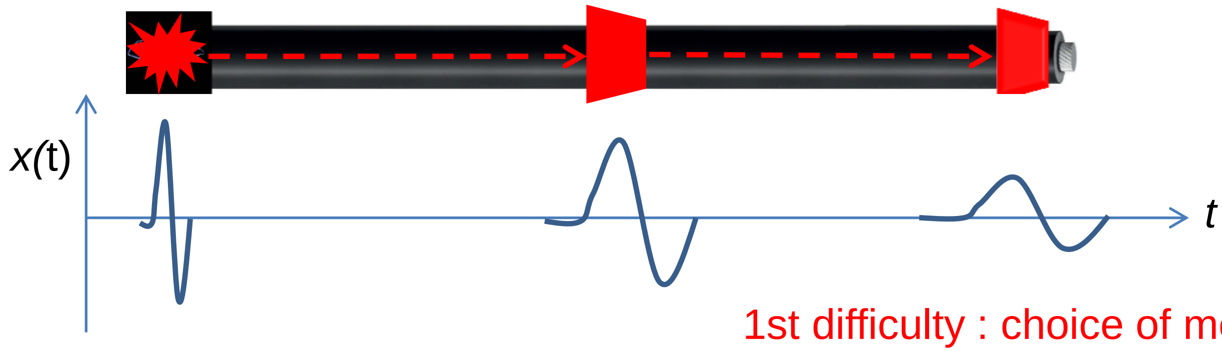
New representation tools based on RPA

2. Signal processing methodology based on RPA

Physically-driven parameter setup - *alternative definition of the distance required for RPA*

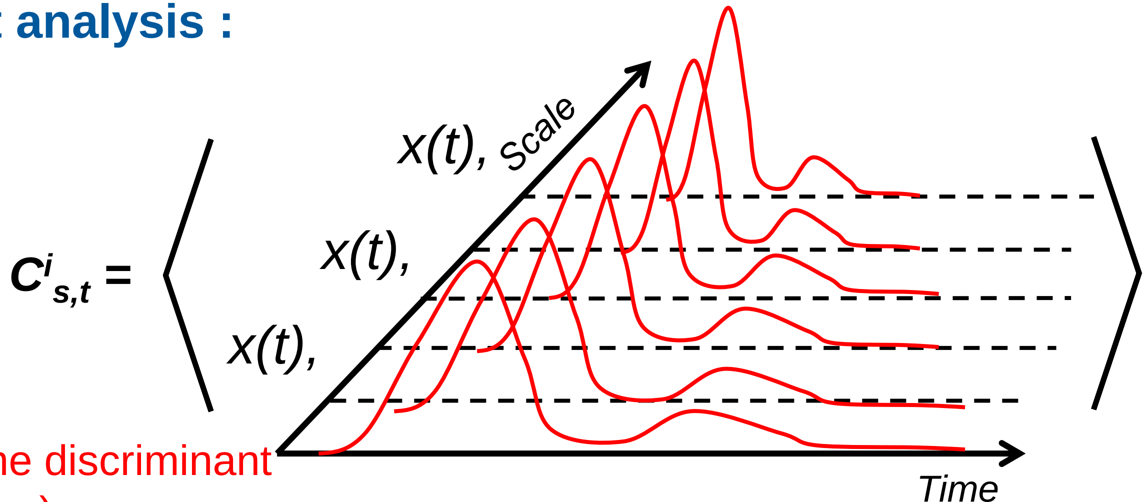
In practical application, many signals can be modelled as : $x(t) \sim \sum_k a_k \cdot s(\alpha_k \cdot t - t_k)$

Ex. Transient propagation in Power lines



1st difficulty : choice of mother wavelet

Traditionally, wavelet analysis :

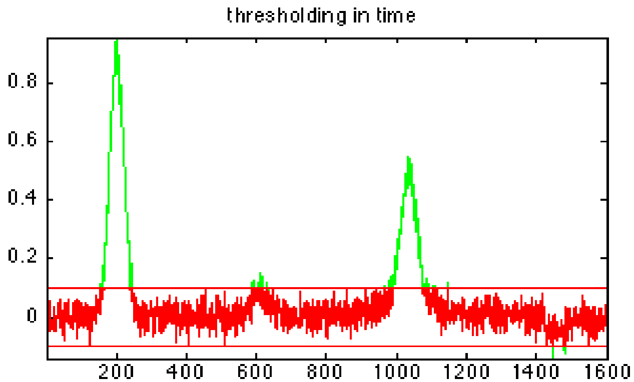


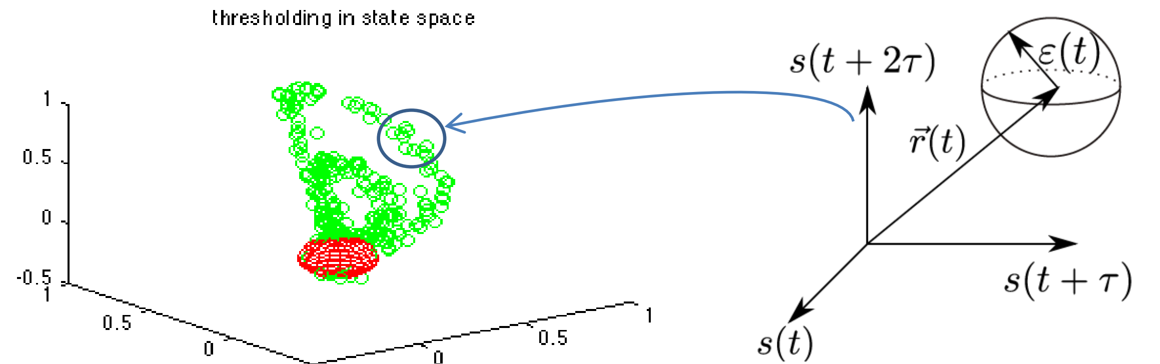
2nd difficulty : choice of the discriminant coefficients (scale definition)

2. Signal processing methodology based on RPA

Physically-driven parameter setup - *alternative definition of the distance required for RPA*

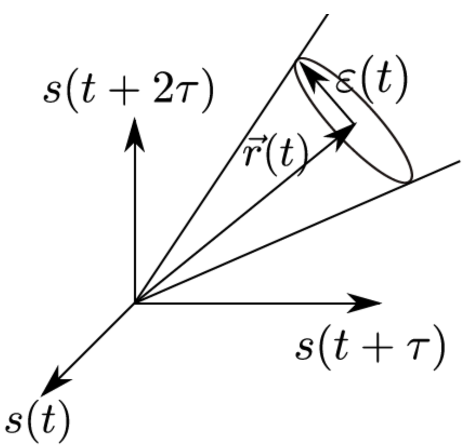
In practical application, many signals can be modelled as : $x(t) \sim \sum_k a_k \cdot s(\alpha_k \cdot t)$

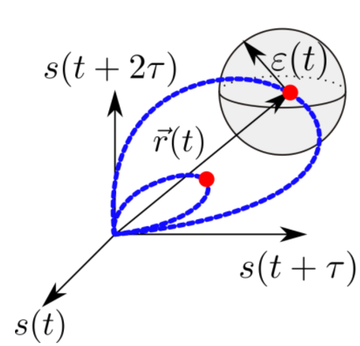


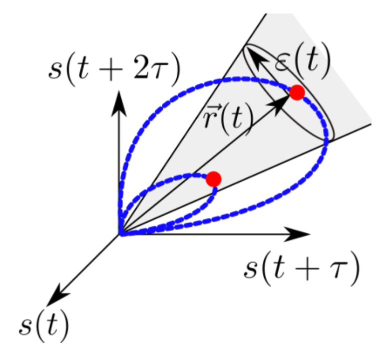


$$D\left(\vec{r}(i), \vec{r}(j)\right) = \|\vec{r}(i) - \vec{r}(j)\|$$

Defining angular distance : $D\left(\vec{r}(i), \vec{r}(j)\right) = \arccos\left(\frac{\vec{r}(i) \cdot \vec{r}(j)}{\|\vec{r}(i)\| \cdot \|\vec{r}(j)\|}\right)$

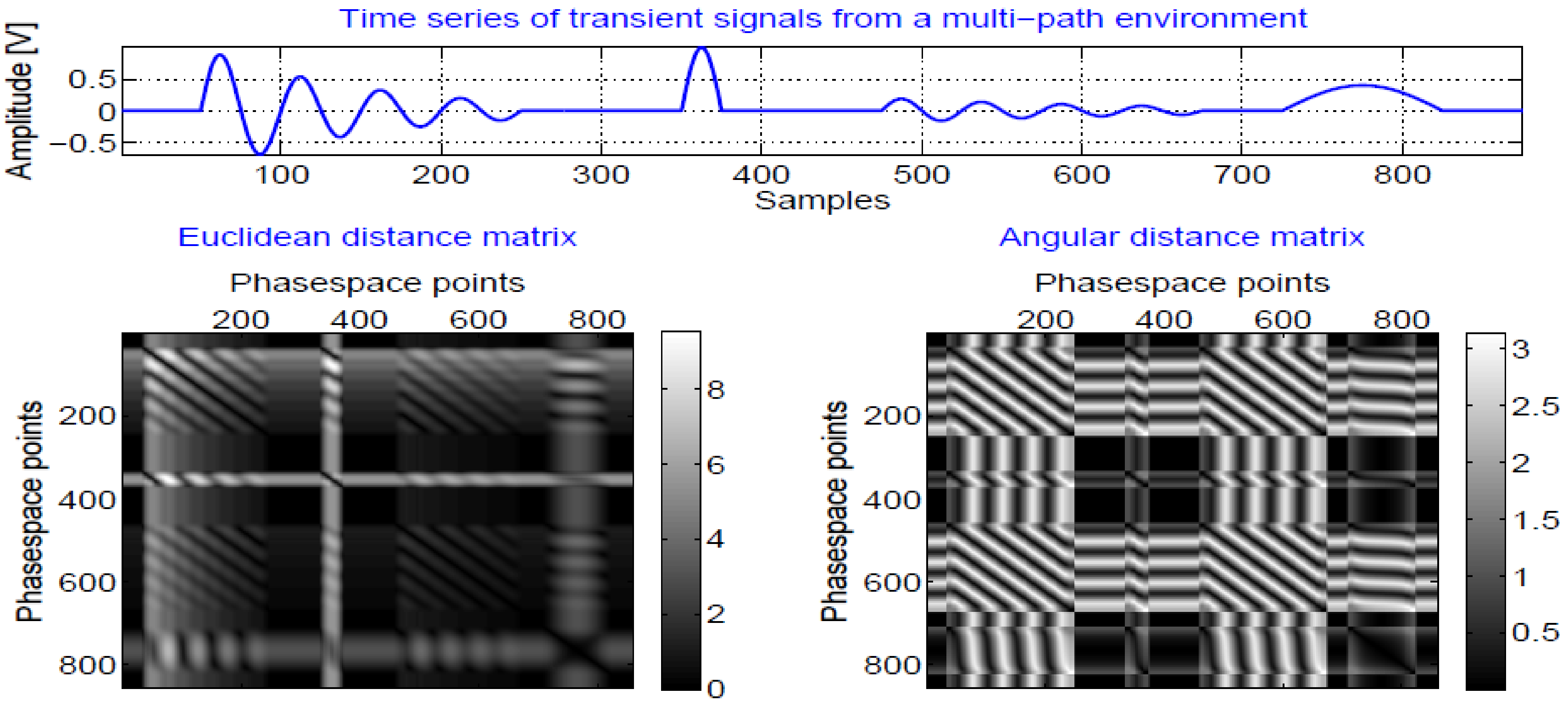






2. Signal processing methodology based on RPA

Physically-driven parameter setup – *angular distance allows highlighting the signals with similar patterns despite the amplitude/scale changings*

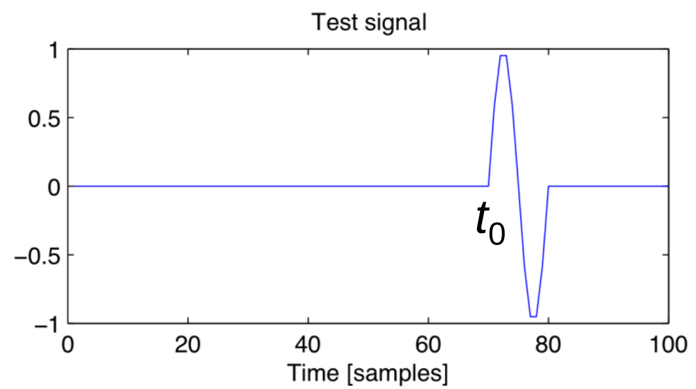


2. Signal processing methodology based on RPA

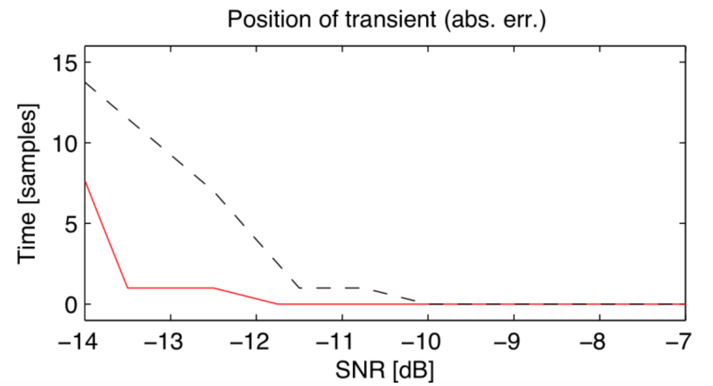
New signal's representations tools based on RPA – *Vectorial Signal Processing (VeSP)*

Correlation

$$C = \frac{1}{N}\sum_{i=1}^{N}(s_i - \langle s \rangle)\cdot(r_i - \langle r \rangle) \xrightarrow{\text{VeSP}} C^{(w)} = \frac{1}{N}\sum_{i=1}^{N}\left(\vec{s}_i^{(w)} - \langle \vec{s}^{(w)} \rangle\right)\cdot\left(\vec{r}_i^{(w)} - \langle \vec{r}^{(w)} \rangle\right)$$



$$t_0 = \arg\max_t C^{(w)}$$



Légende :

—— VeSP C (w=10)

- - - C

2. Signal processing methodology based on RPA

New signal's representations tools based on RPA – *Vectorial Signal Processing (VeSP) relation with RQA*

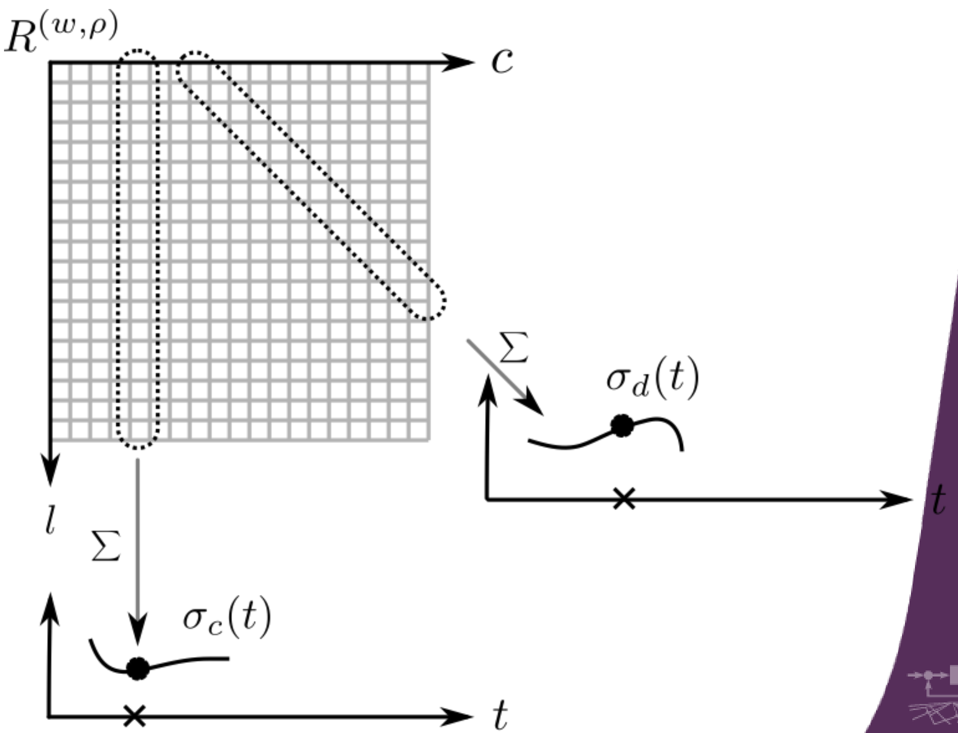
ACF - Auto-correlation function; AMDF – Average Magnitude Difference Function
TDH – Time distributed histrogram

RQA ACF
RQA AMDF → **Sum of diagonals**

$$ACF_n^{(w)} = \sum_{i=1}^{N} R_{i,i+n}$$

$$AMDF_n^{(w)} = \frac{1}{N-n} \boxed{\sum_{i=1}^{N-n} R_{i,i+n}}$$

σ_d



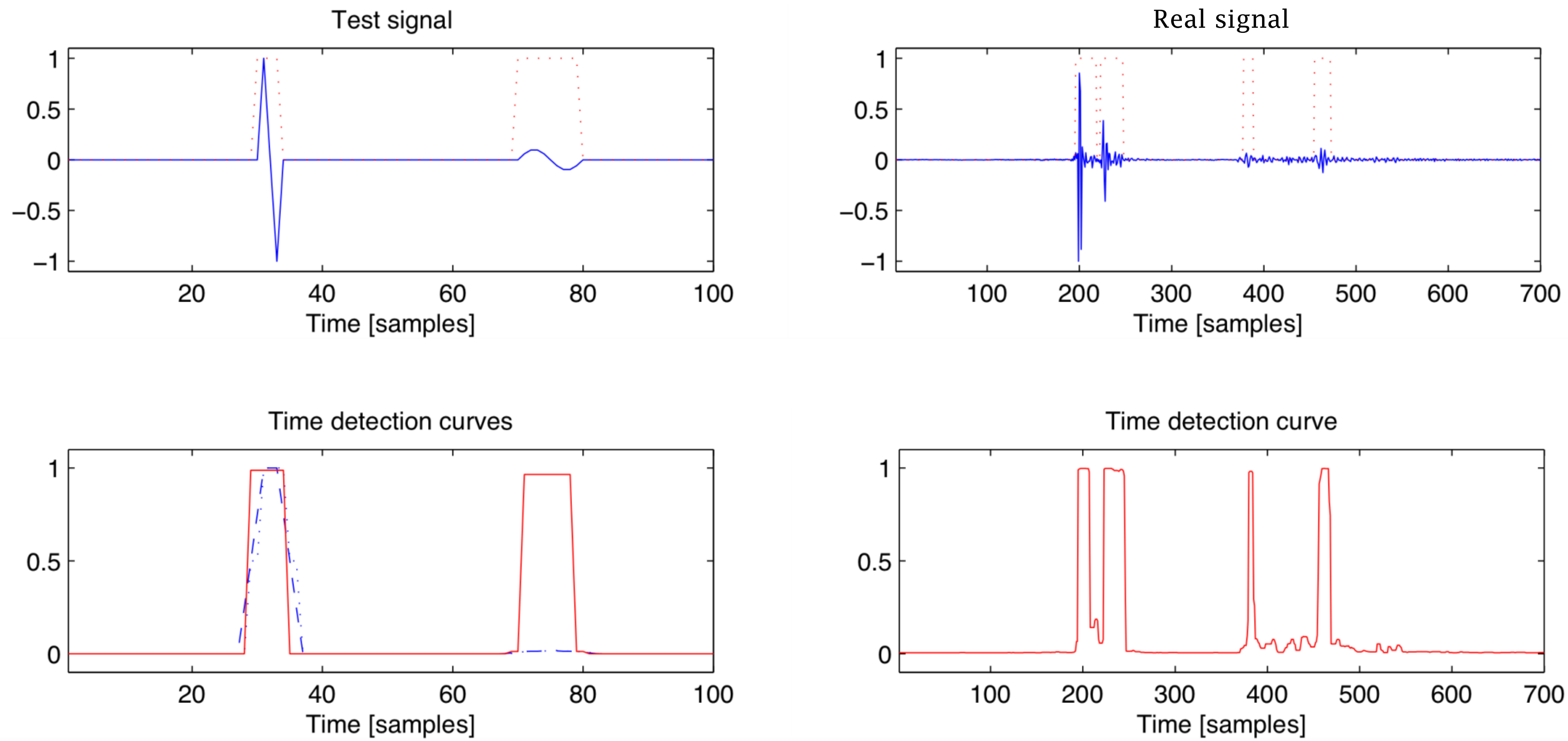
RQA TDH → **Sum of columns**

$$TDH_n^{(w)} = \frac{1}{N} \boxed{\sum_{i=1}^{N} R_{i,n}}$$

σ_c

2. Signal processing methodology based on RPA

New signal’s representations tools based on RPA – *DETECTION (1)*



2. Signal processing methodology based on RPA

New signal's representations tools based on RPA – *DETECTION (2)*

Compared methods :

— RQA TDH

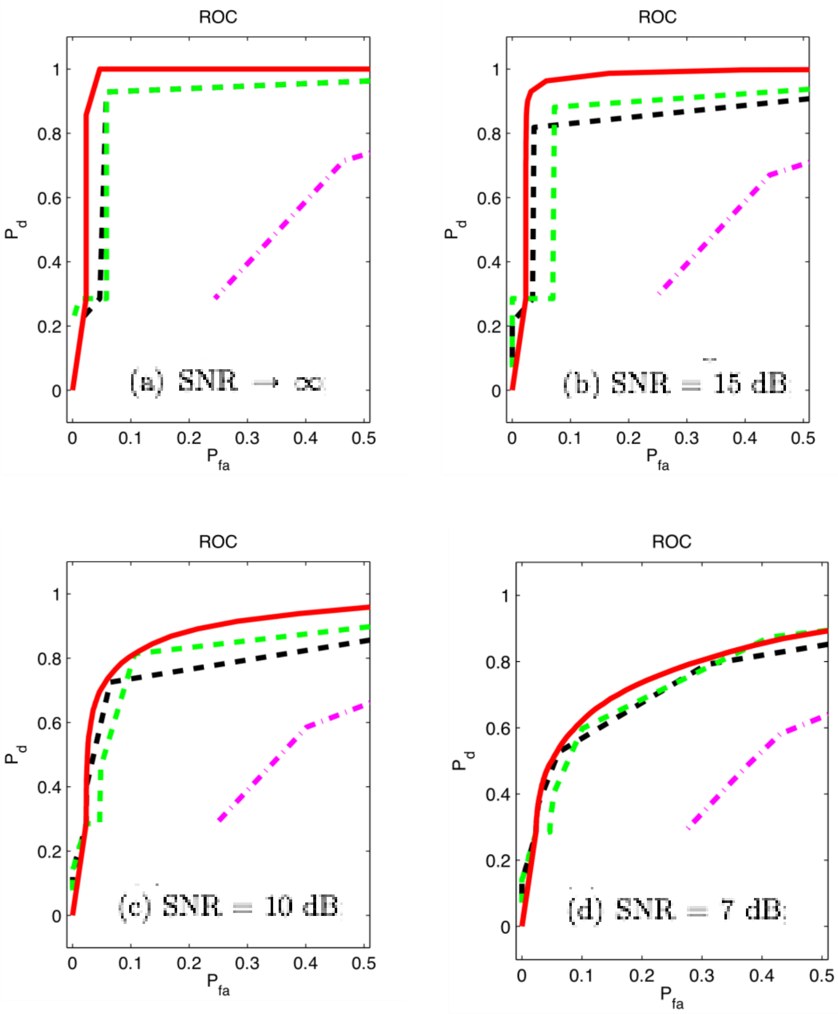
- - - **Energy**

$$E = \sum_{i=1}^{N} s_i^2$$

- - - **VeSP Energy**

$$E^{(w)} = \sum_{i=1}^{N} \vec{s}_i^{(w)} \cdot \vec{s}_i^{(w)}$$

- - - Wavelet transform + High order statistics



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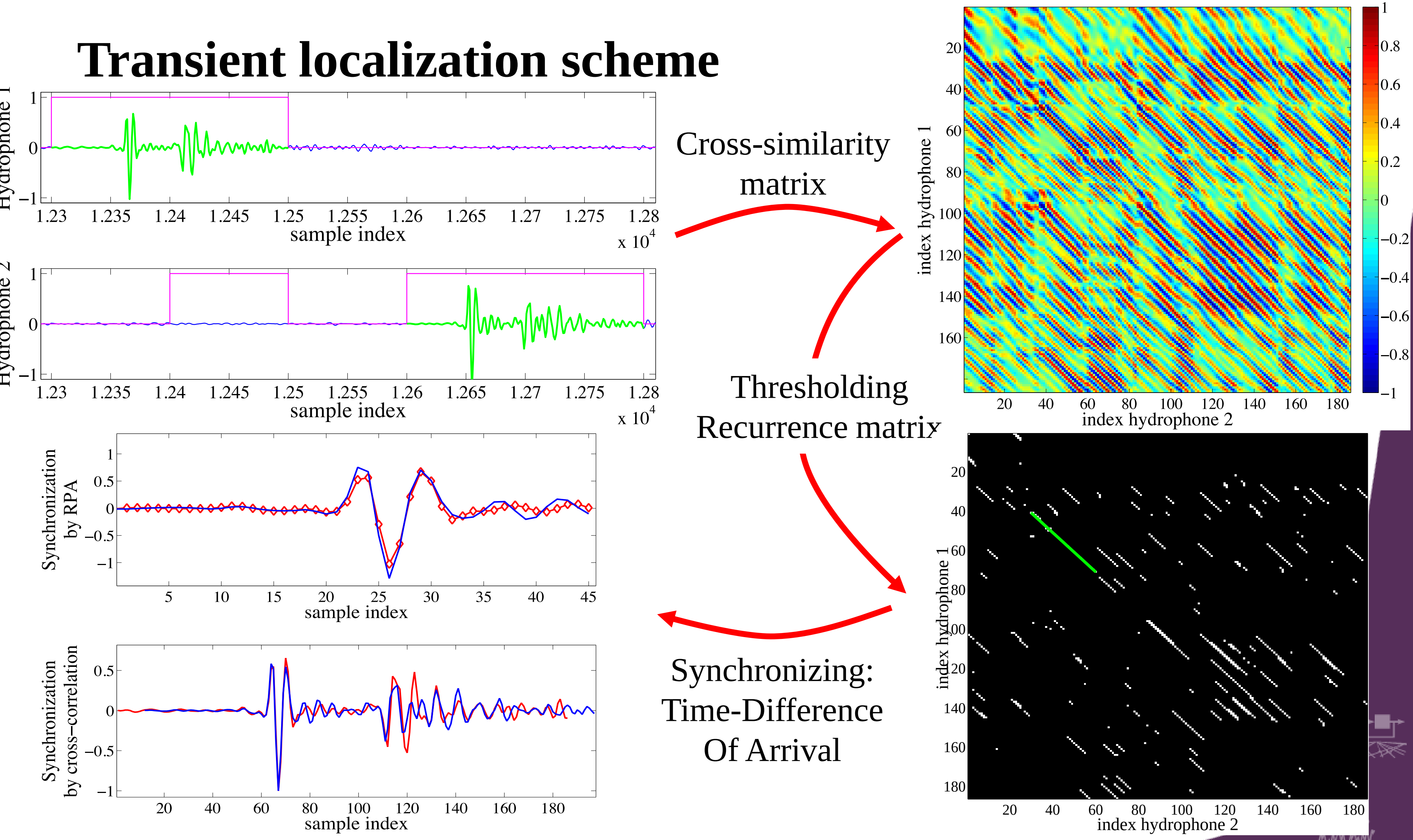
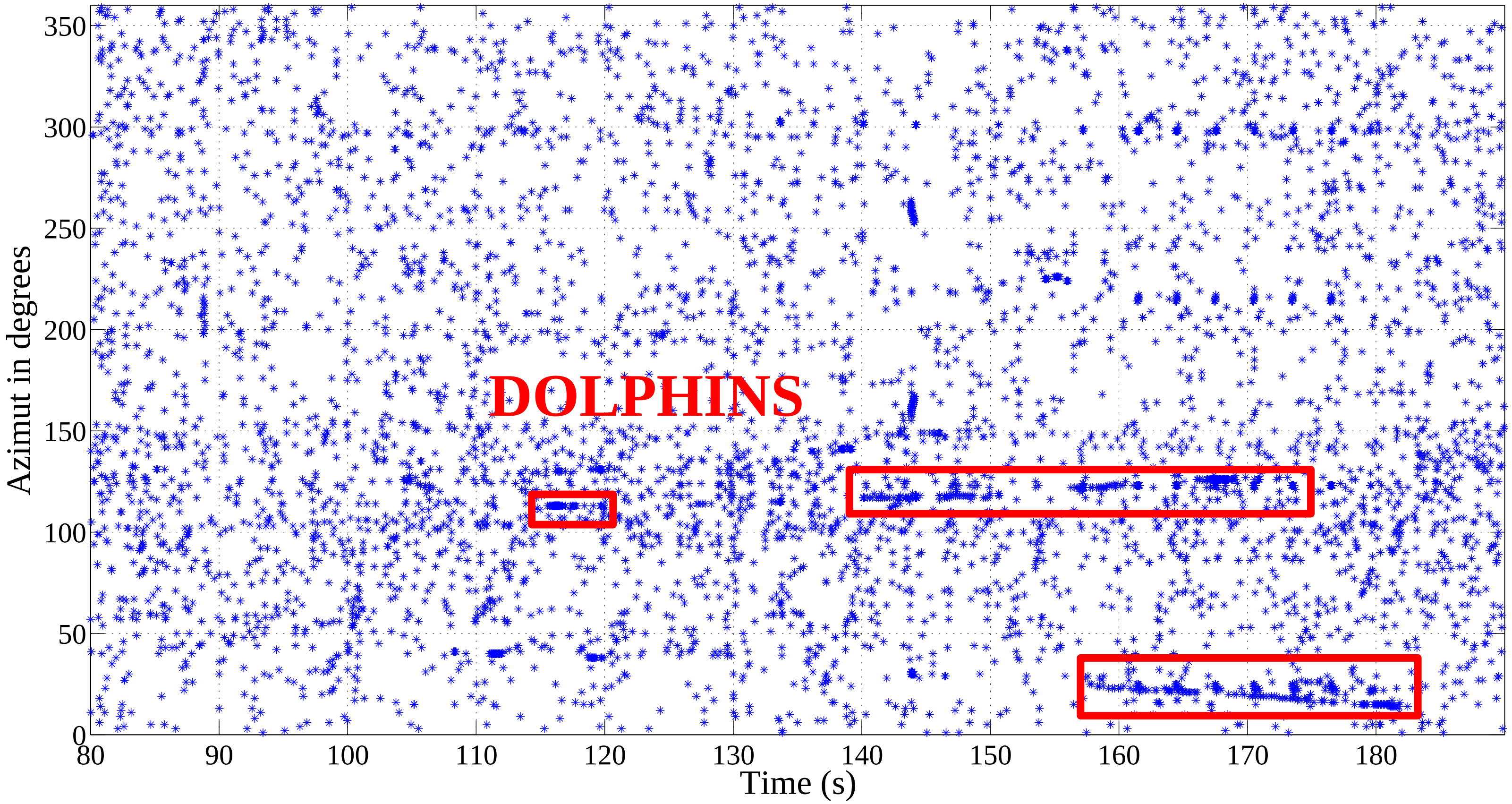
3. Results in applied context – *Acoustic signal processing – localisation of underwater mammals based on their emissions*

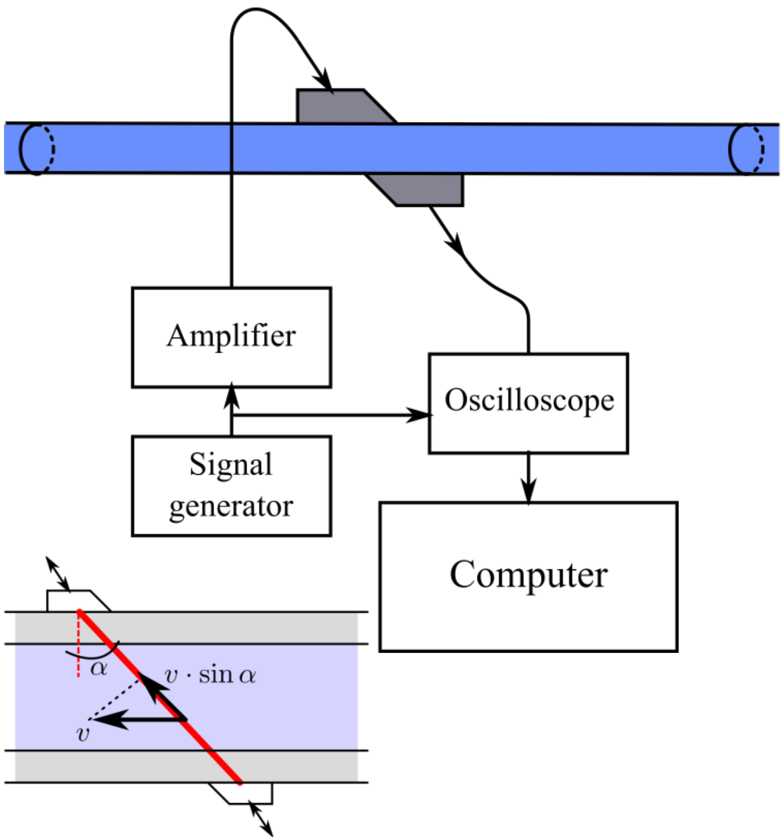


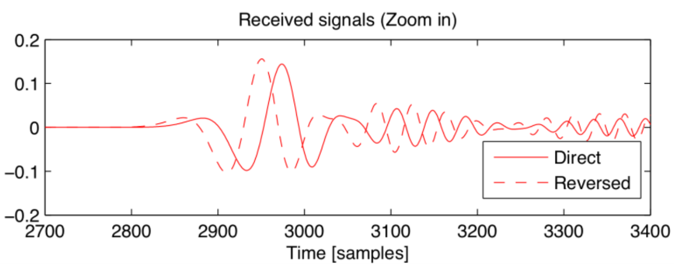
Transient localization scheme

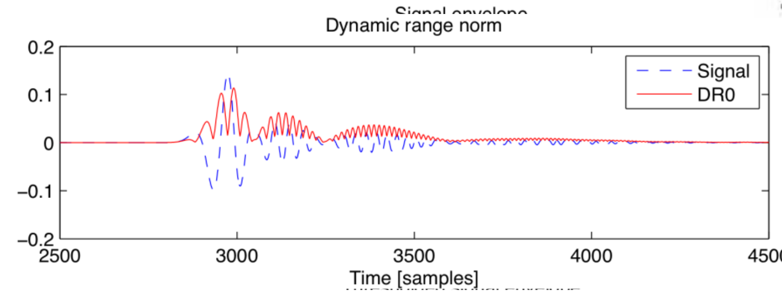
- TDOA measured by cross-RPA on 3 hydrophones
- Minimization and inversion from TDOA to DOA

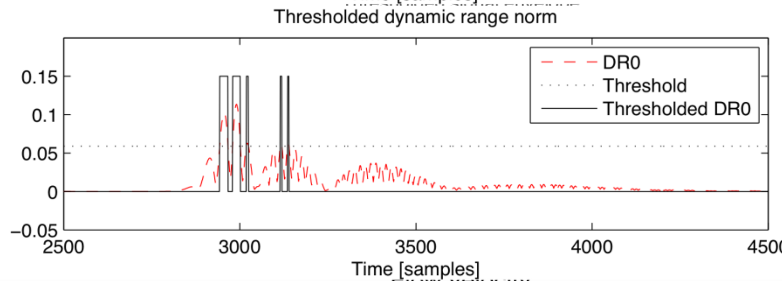


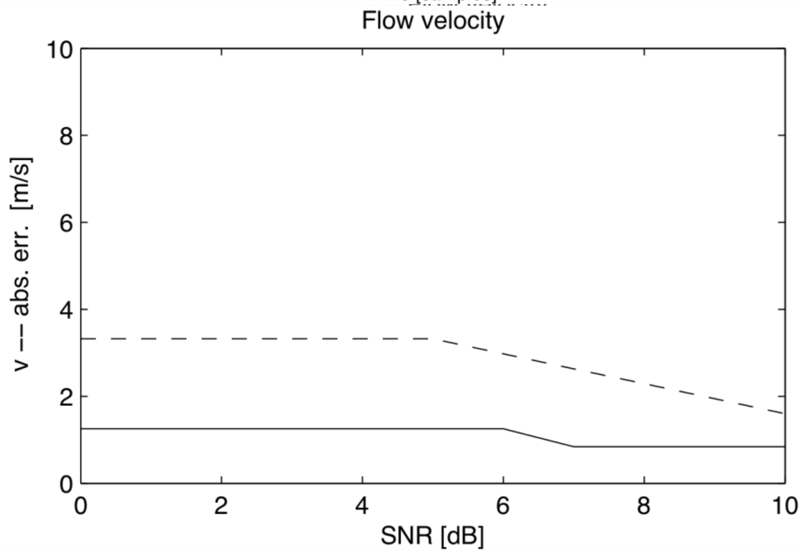
3. Results in applied context – *Ultrasound measurements*



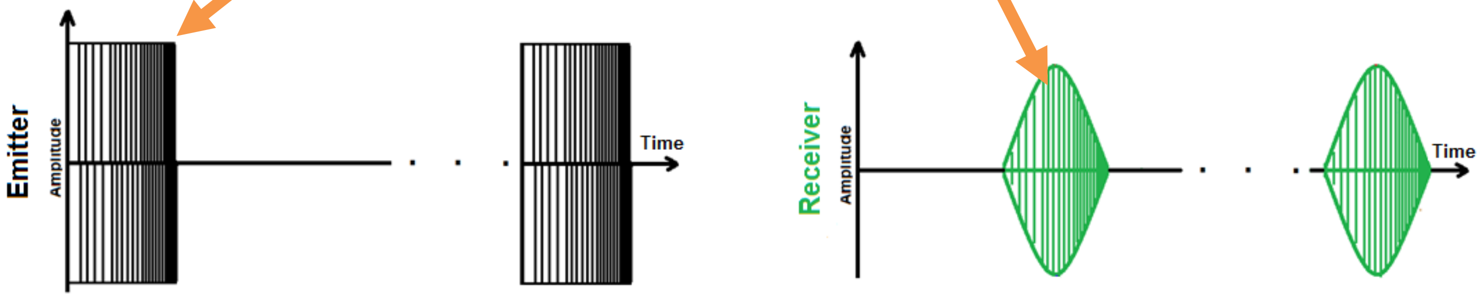


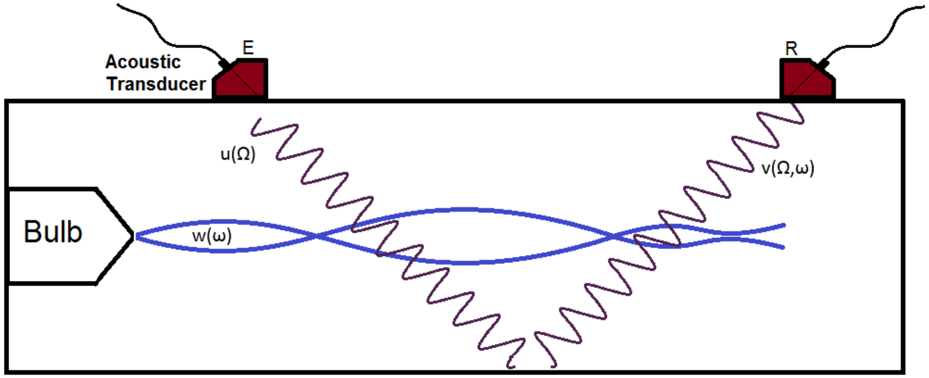






3. Results in applied context – *Ultrasound measurements in hydraulic machinery monitoring*

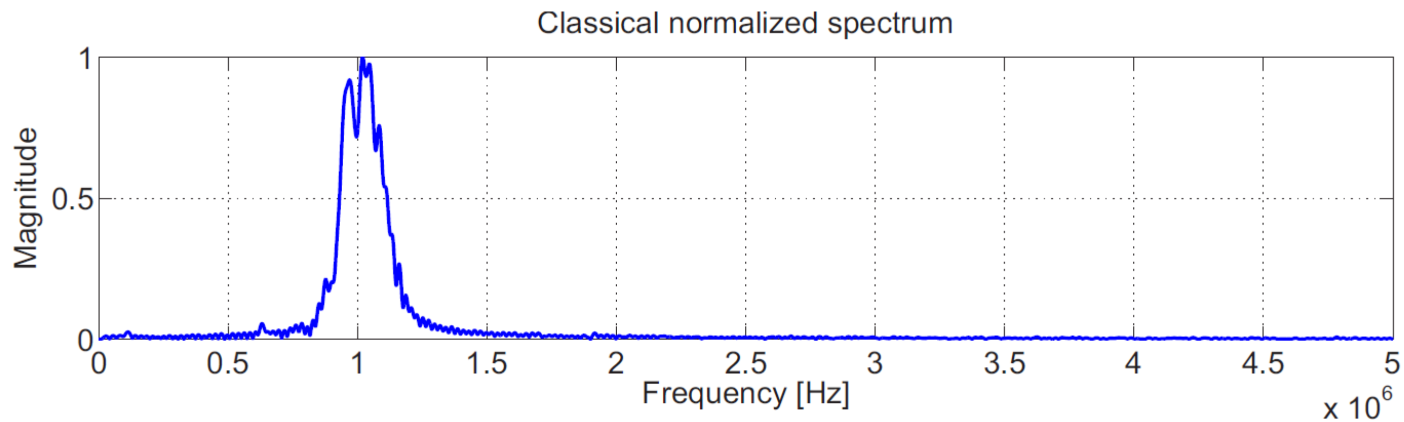


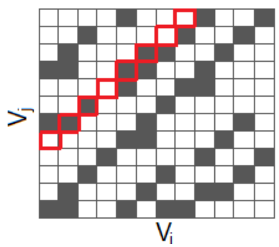


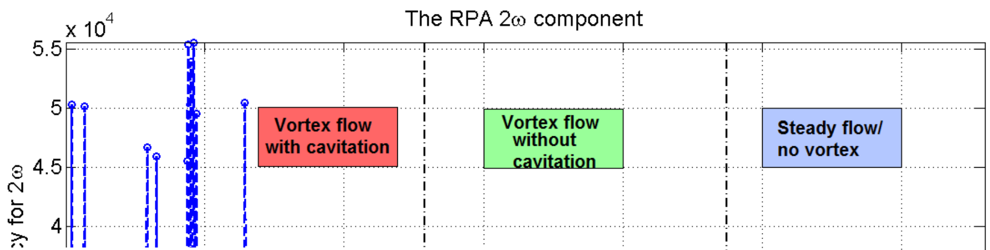
$$v[n] = \cos(\Omega n)\cdot\cos(\omega n),\ \ \Omega >> \omega$$

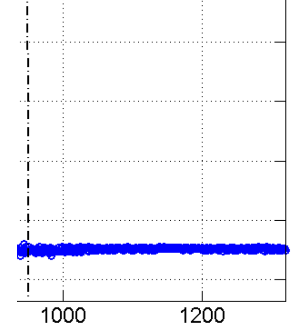
ω - Vortex frequency

3. Results in applied context – *Ultrasound measurements in hydraulic machinery monitoring*









$$sd[n] \sim D(v_i, v_{i+n}) =$$

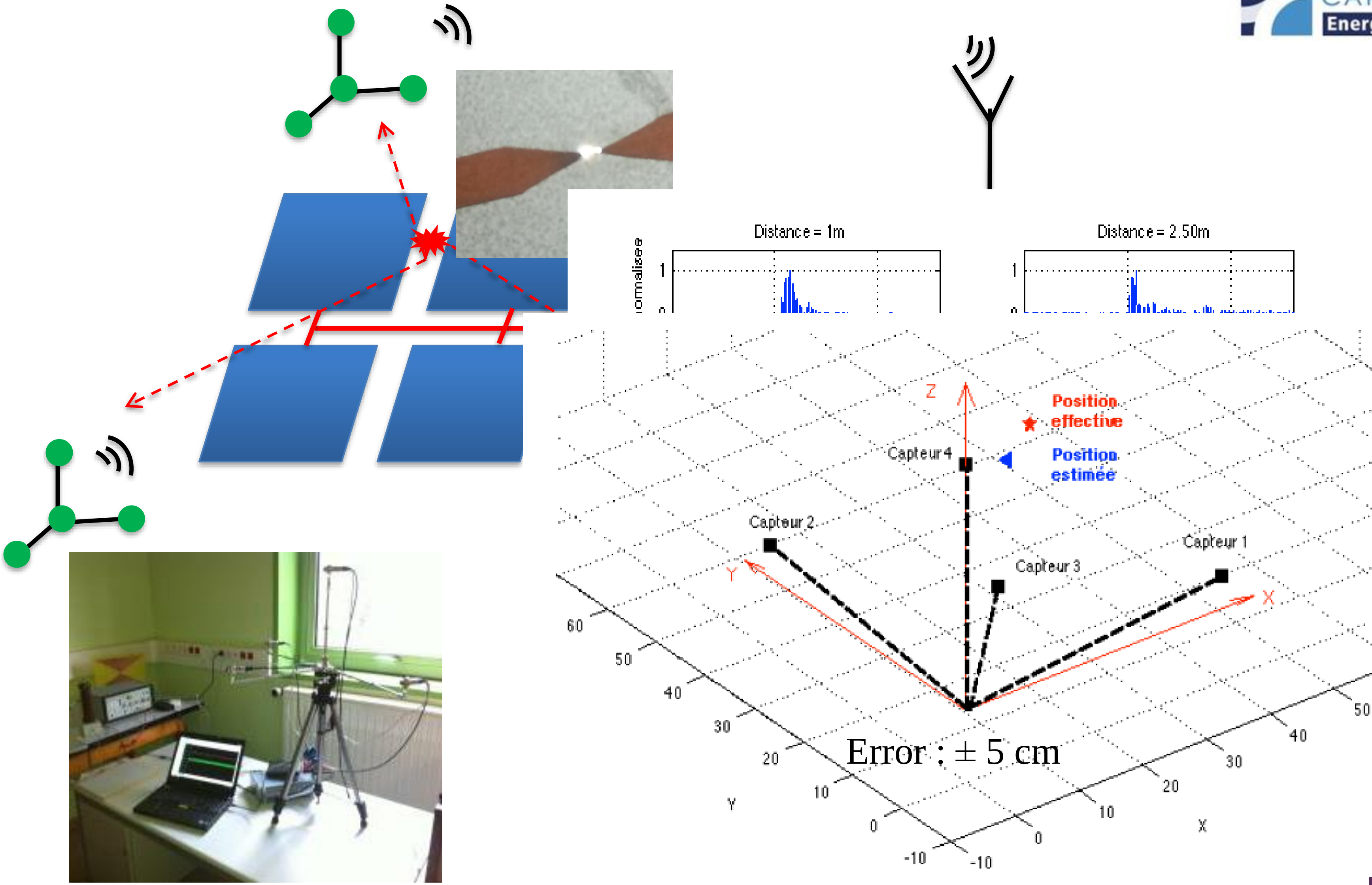
$$= \alpha^2 (cos[2\Omega(i + \frac{n}{2})] cos[2\omega(i + \frac{n}{2})] -$$

$$- cos[2\Omega(i + \frac{n}{2})] - cos[2\omega(i + \frac{n}{2})] + 1$$

$$+ cos[2\Omega(i + d + \frac{n}{2})] cos[2\omega(i + d + \frac{n}{2})] -$$

$$- cos[2\Omega(i + d + \frac{n}{2})] - cos[2\omega(i + d + \frac{n}{2})] + 1)$$

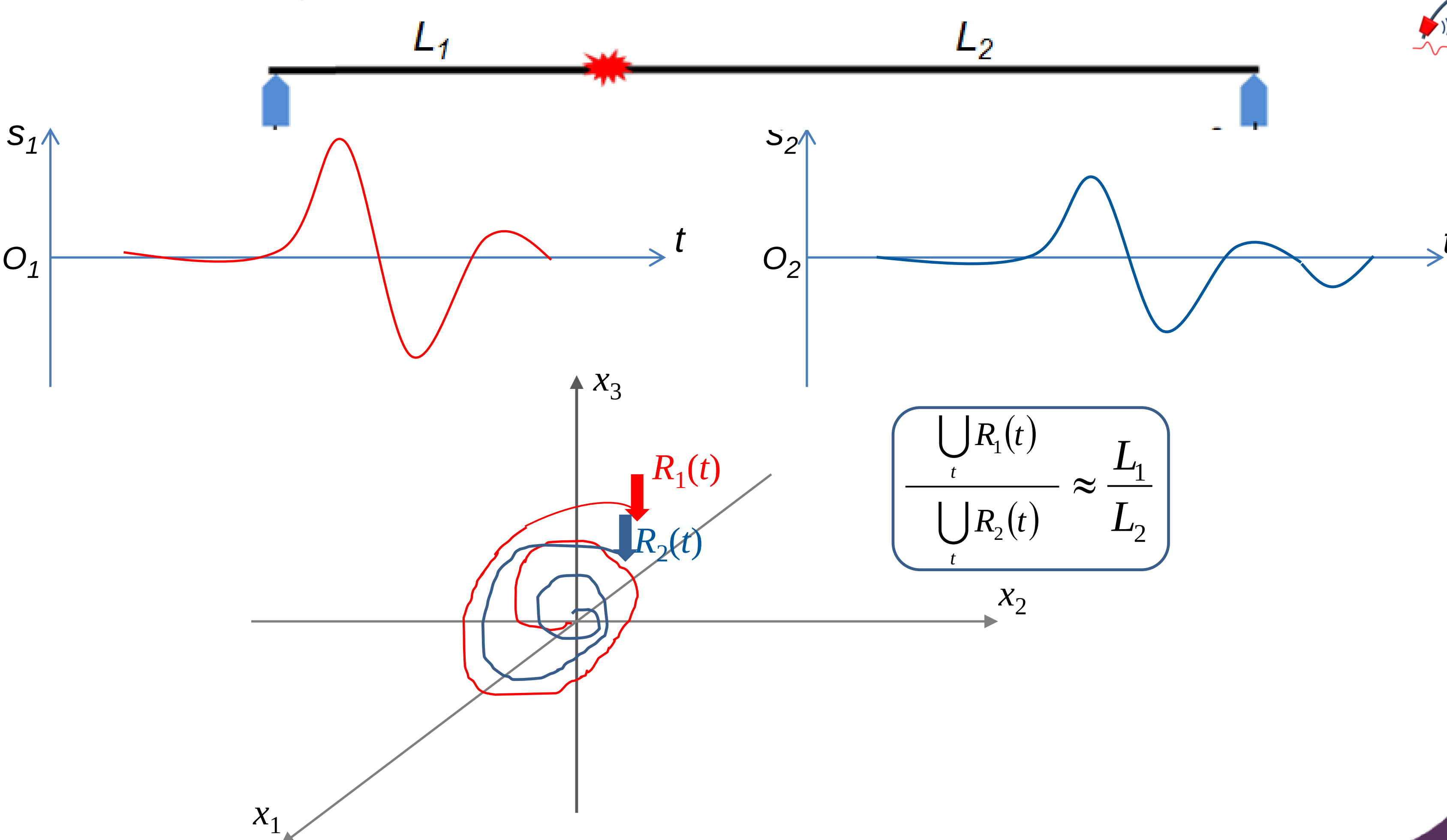
3. Results in applied context – *Monitoring electrical discharges in photovoltaic production system*



3. Results in applied context – *Power lines surveillance using distributed sensing*

TRANSLOCATOR – *new concept for synchronisation-free localisation !*

French patent : no. 14/50348 – based on Phase analysis



$$\frac{\bigcup_t R_1(t)}{\bigcup_t R_2(t)} \approx \frac{L_1}{L_2}$$

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4. Conclusions

- RPA/RQA – interesting representation space, driven by data;
- Alternative for detection, classification, …..
- Very good results in practical applications

and Perspective

- *Toward data-driven multi-resolution analysis –* ***MULTI-LAG RPA***
- *Parameters setup inspired by physics*
- *Extend the application area*

THANK YOU !!!

Perspective - *MULTI-LAG RPA – study the cub of RPA computed for a set of lag – identify common points*