

# Habilitation à diriger des recherches

## Pré et post-traitements du signal pour les systèmes ultrasonores

De l'identification nonlinéaire à la commande optimale pour des applications  
médicales et de contrôles non-destructifs

**Sébastien Ménigot**

26/04/2024

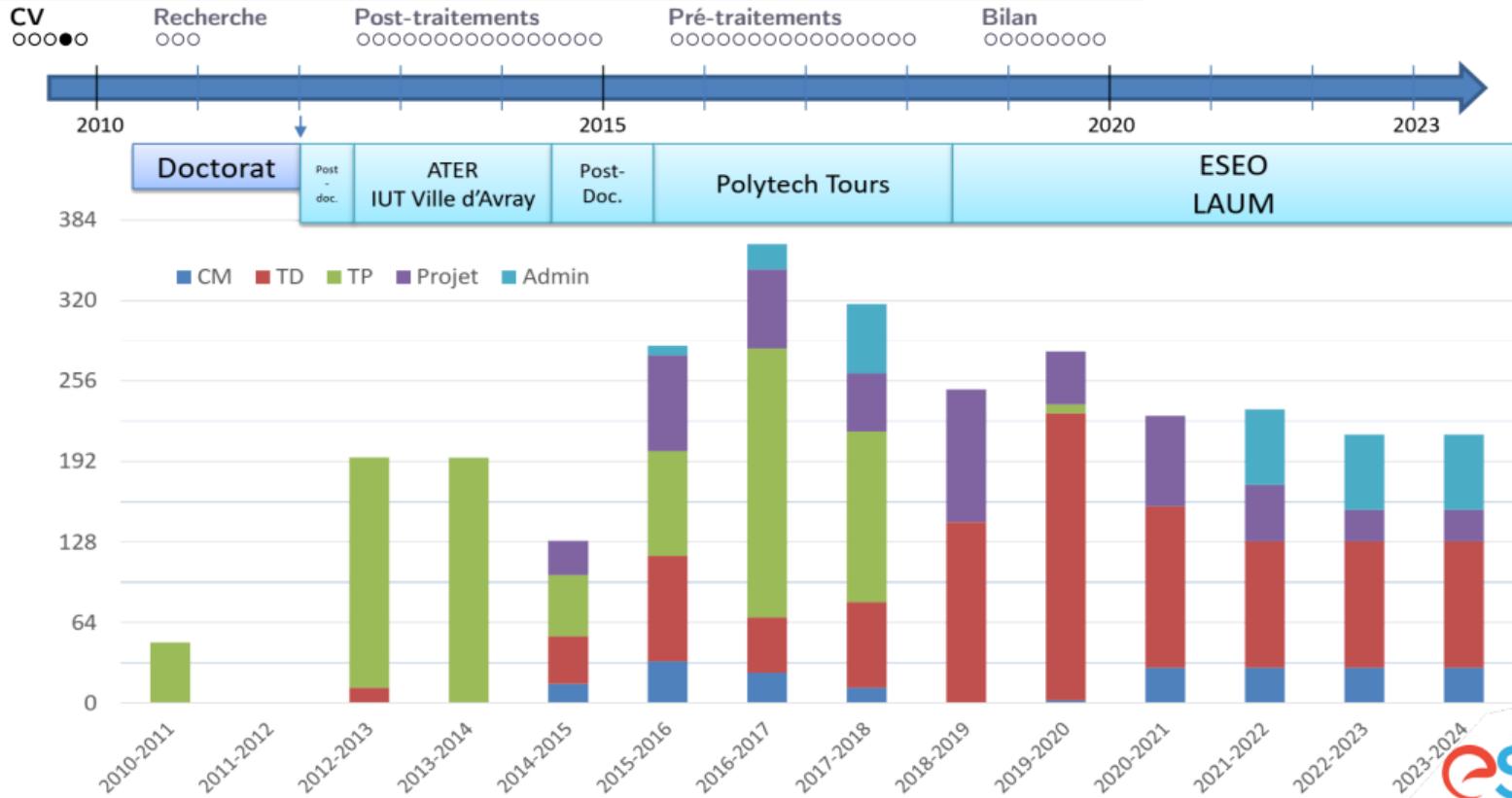
# Curriculum Vitæ



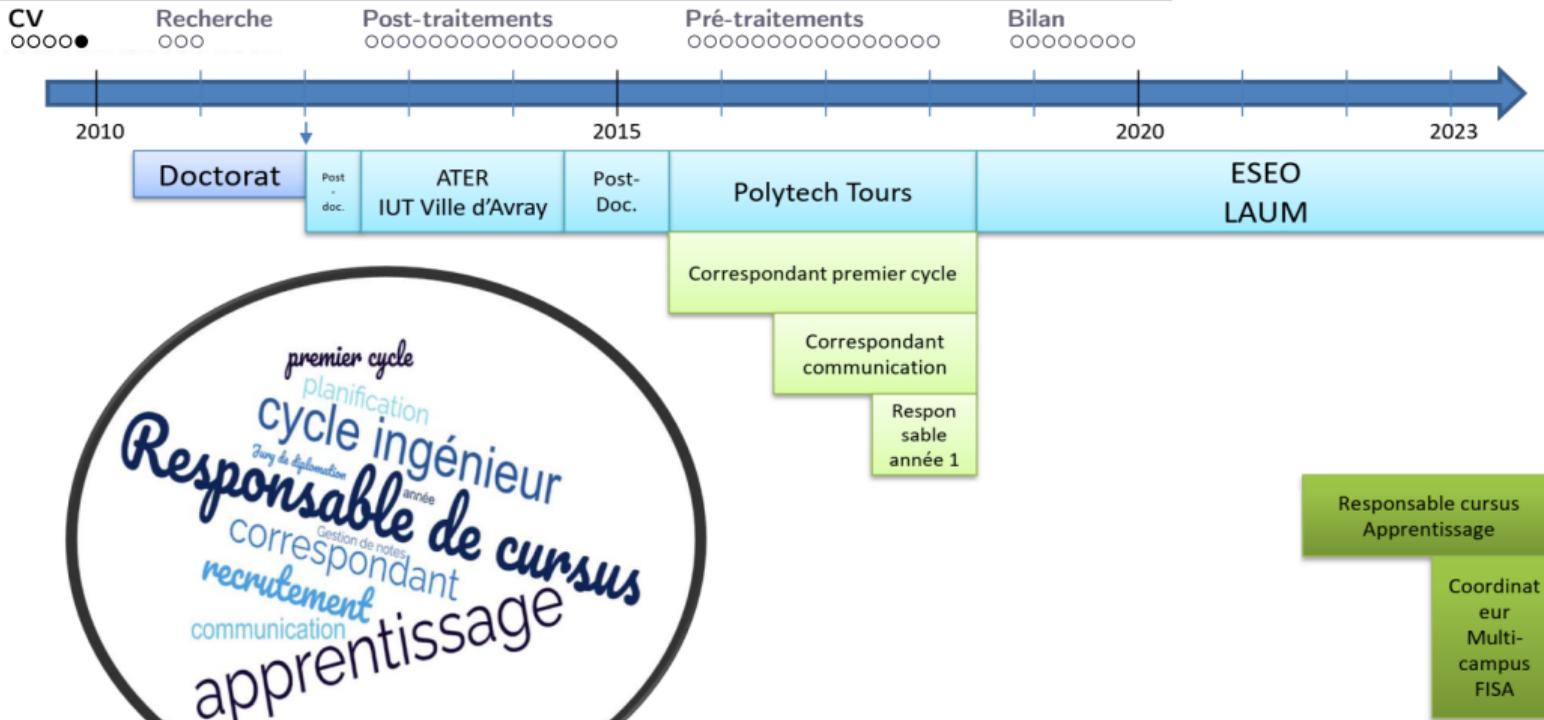




# Activités d'enseignements



# Activités administratives en enseignement



## Synthèse des activités de recherche : introduction



1985



2018



# Principe d'un système ultrasonore

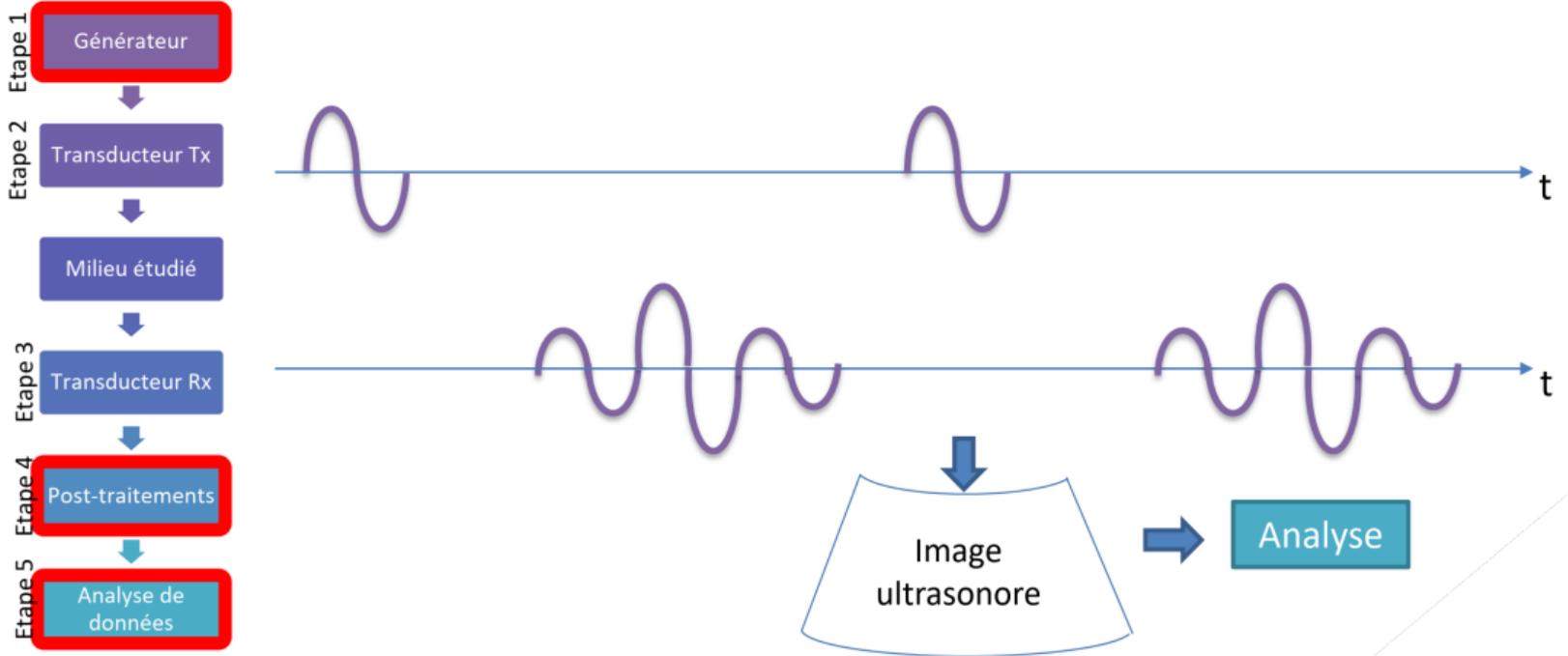
CV  
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Recherche  
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Post-traitements  
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Pré-traitements  
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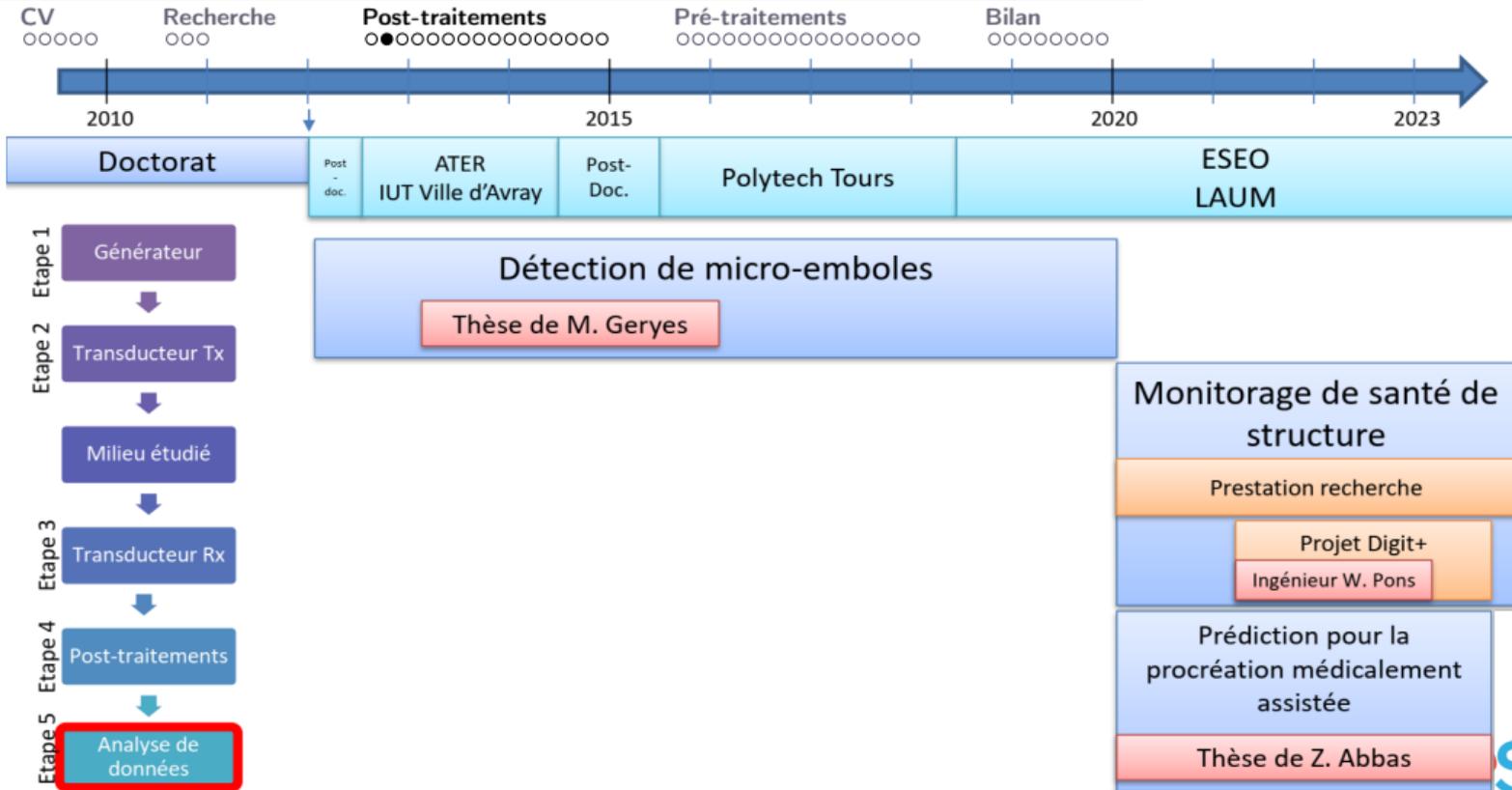
Bilan  
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# Post-traitements des systèmes ultrasonores



# Étape 5 : Analyse de données



# Étape 5 : Détection de micro-emboles

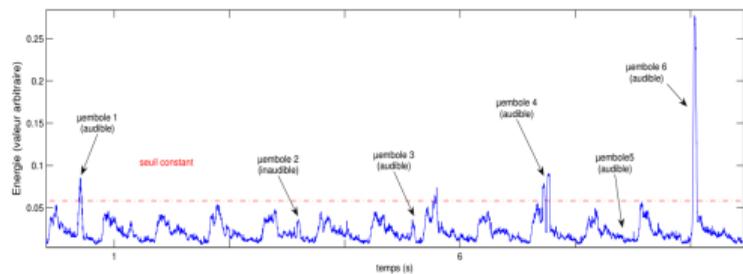
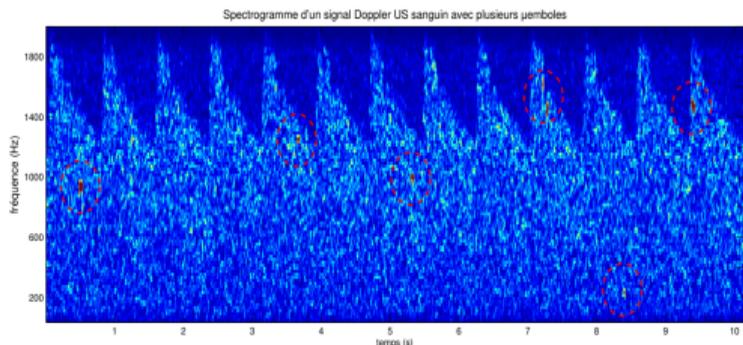
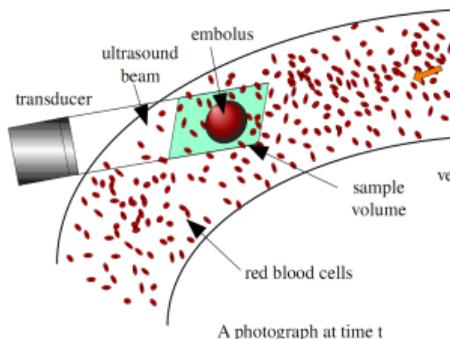
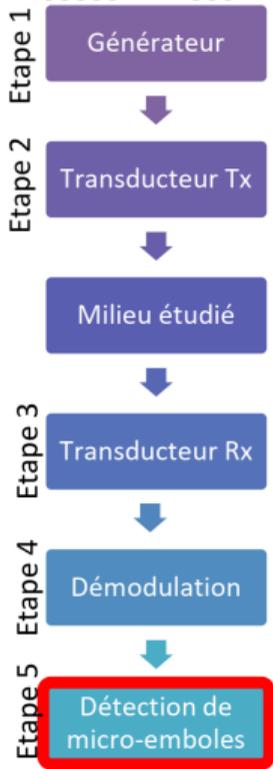
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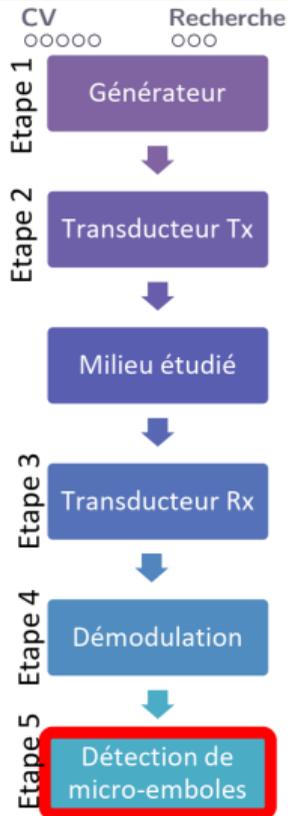
Post-traitements  
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Pré-traitements  
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Bilan  
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# Détection sur l'énergie à court terme

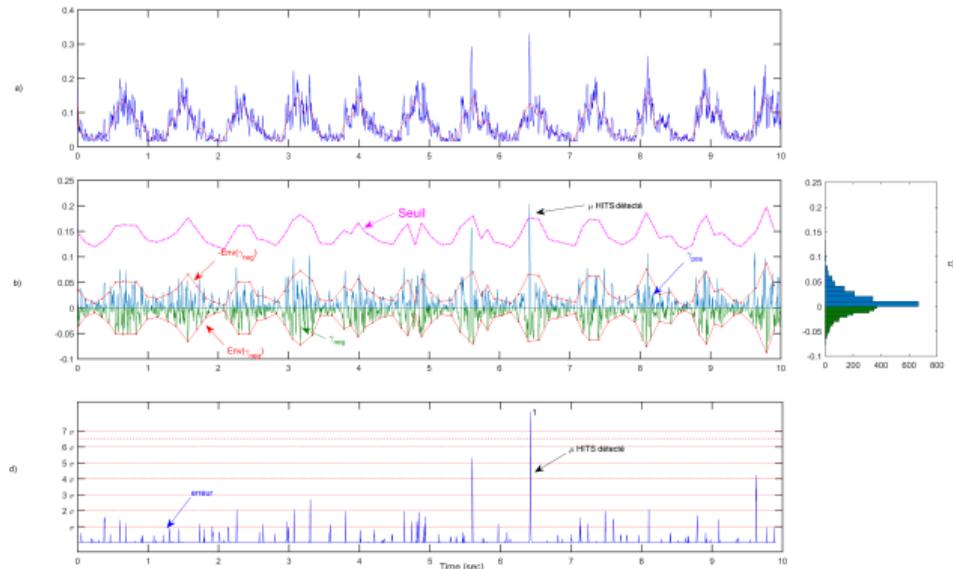


Post-traitements ○○○●○○○○○○○○○○○○○○

Pré-traitements ○○○○○○○○○○○○○○○○○○○○○

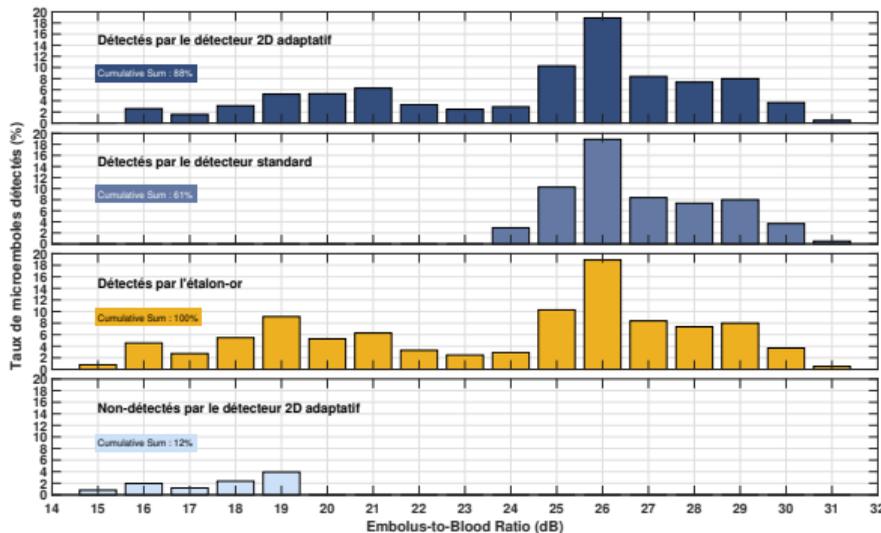
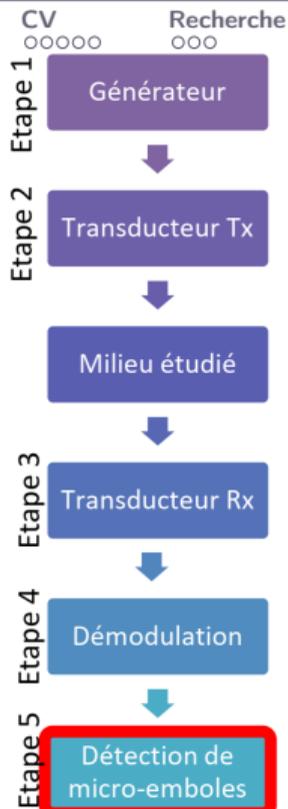
Bilan ○○○○○○○○

## Thèse de Maroun Gerys

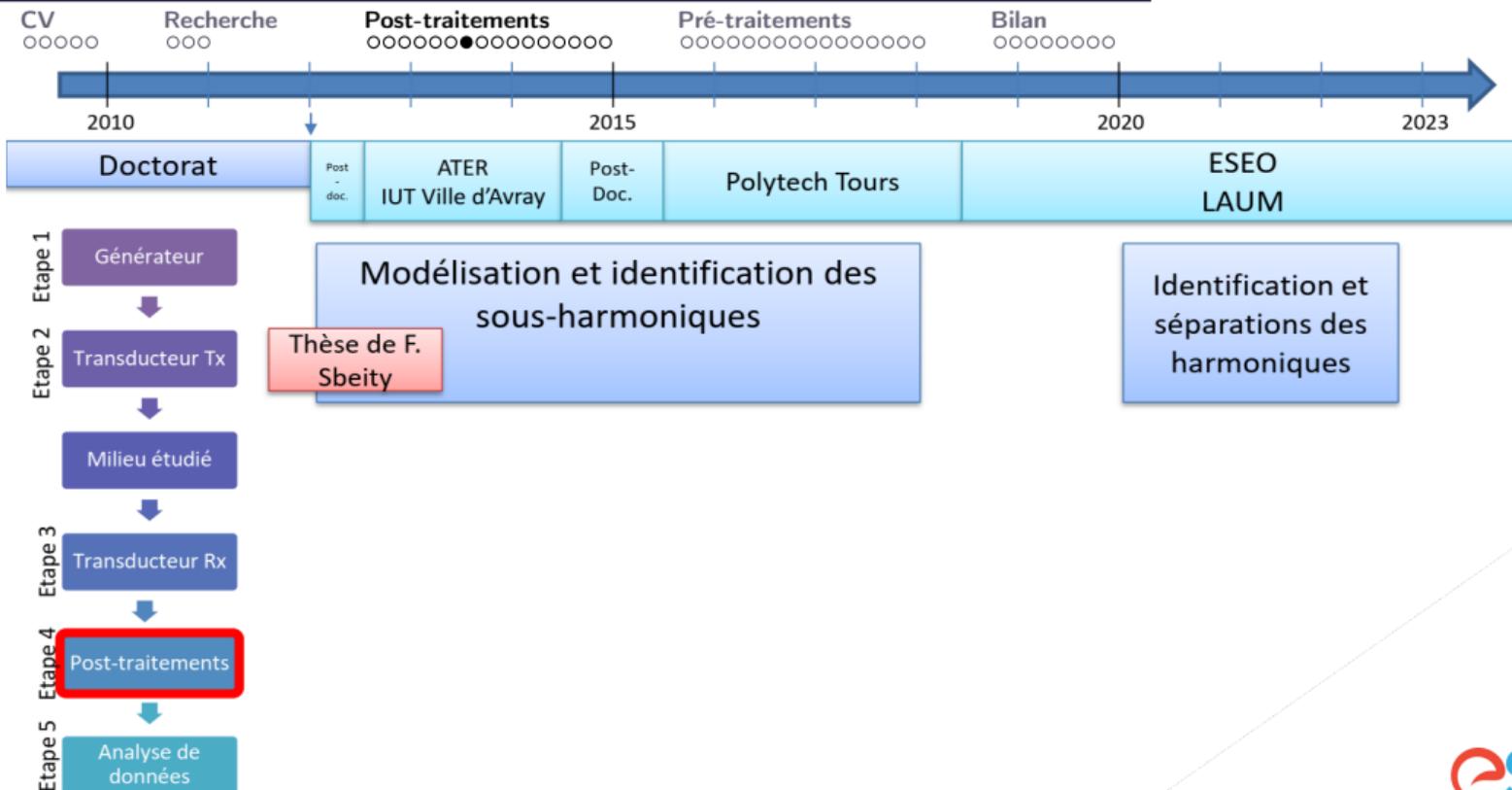




# Détection en temps-fréquence



# Étape 4 : Post-traitements



# Système ultrasonore non linéaire

CV  
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Recherche  
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Post-traitements  
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Pré-traitements  
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Bilan  
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Etape 1  
Générateur

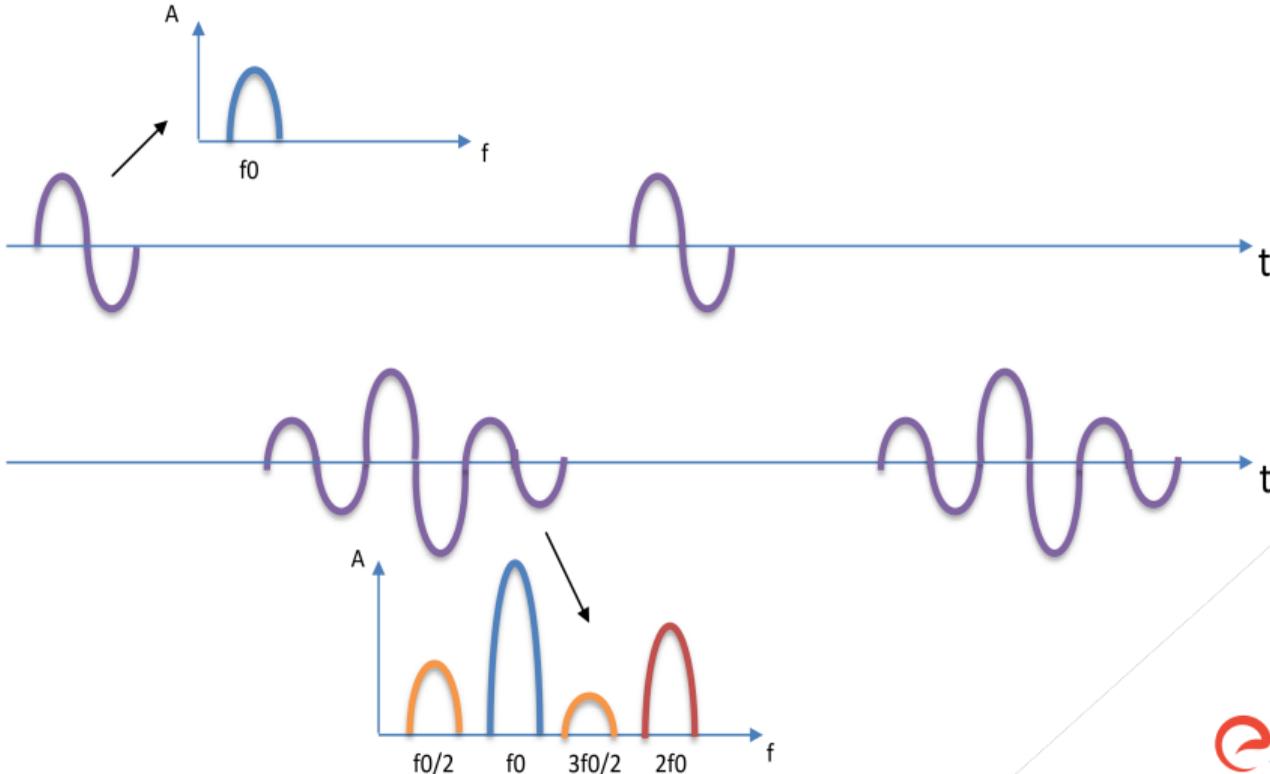
Etape 2  
Transducteur Tx

Milieu étudié

Etape 3  
Transducteur Rx

Etape 4  
Post-traitements

Etape 5  
Analyse de données



# Système ultrasonore non linéaire

CV  
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Recherche  
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Post-traitements  
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Pré-traitements  
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Bilan  
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## Imagerie harmonique

- Extraction des harmoniques
- Augmentation du contraste

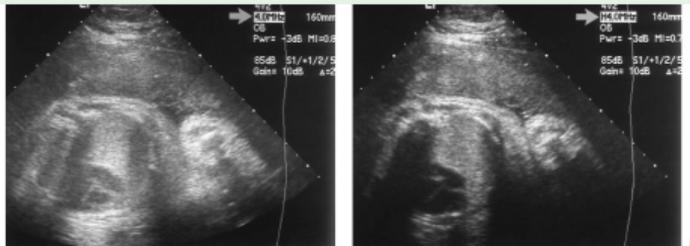


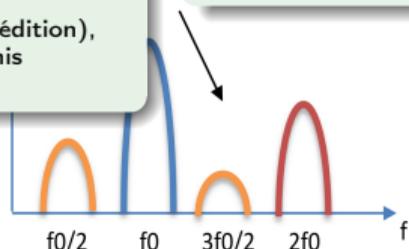
Image d'un cœur de fœtus — A : Image fondamentale / B : Image harmonique

W. E. Brant, The Core Curriculum: Ultrasound (1re édition), Lippincott Williams & Wilkins, Philadelphie, États-Unis d'Amérique

## Imagerie sous-harmonique

- Injection de produit de contraste (microbulles)
- Microbulles : sous et ultra-harmonique
- Tissus : absence de sous et ultra-harmonique
- Augmentation du contraste

Etape 5  
Analyse de données



# Identification nonlinéaire et extraction

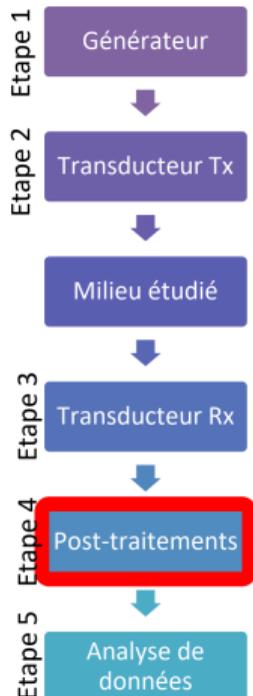
CV  
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Recherche  
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Post-traitements  
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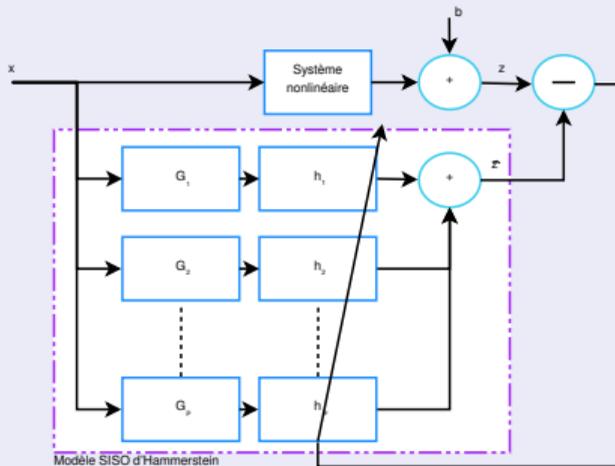
Pré-traitements  
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## Modèle de Hammerstein (polynomial si $G_n$ un polynôme)

- 😊 Filtrage optimale pour les harmoniques d'ordre entier
- 🚫 Ne fonctionne que pour les harmoniques d'ordre non-entier



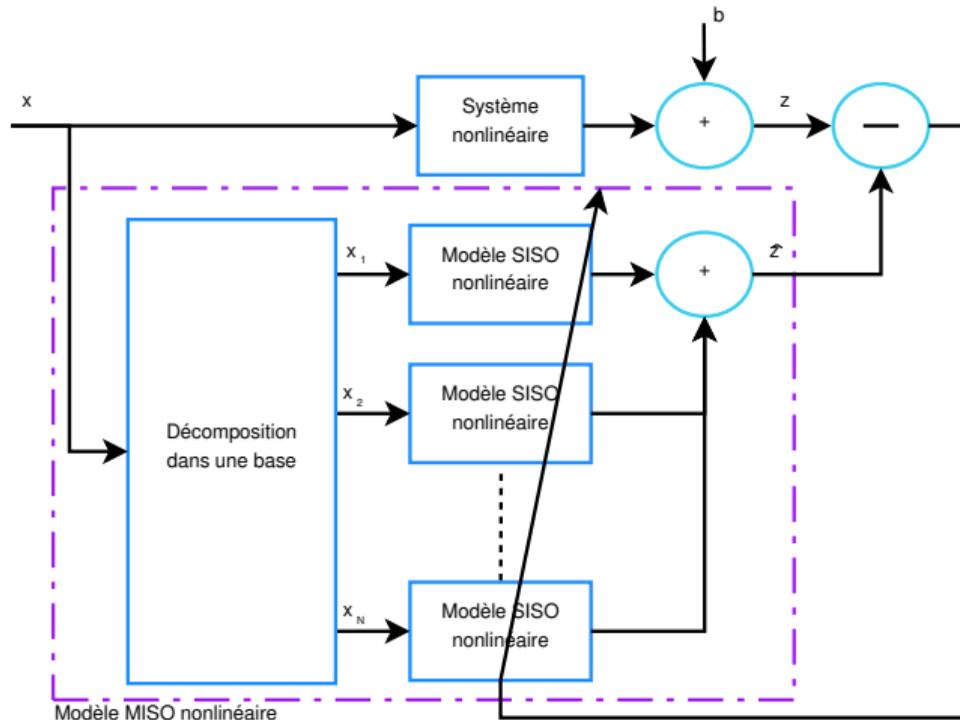
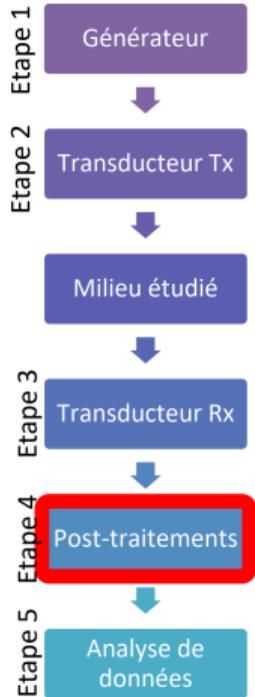
# Parallélisation des modèles

CV Recherche Post-traitements Pré-traitements Bilan

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# Parallélisation des modèles

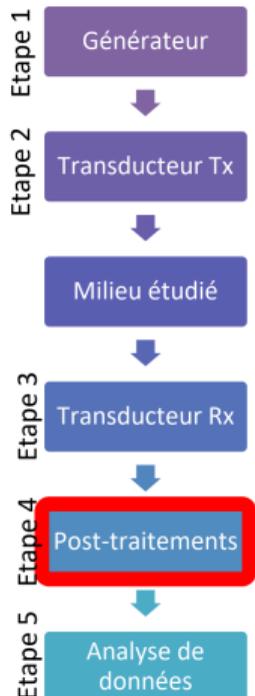
CV  
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Recherche  
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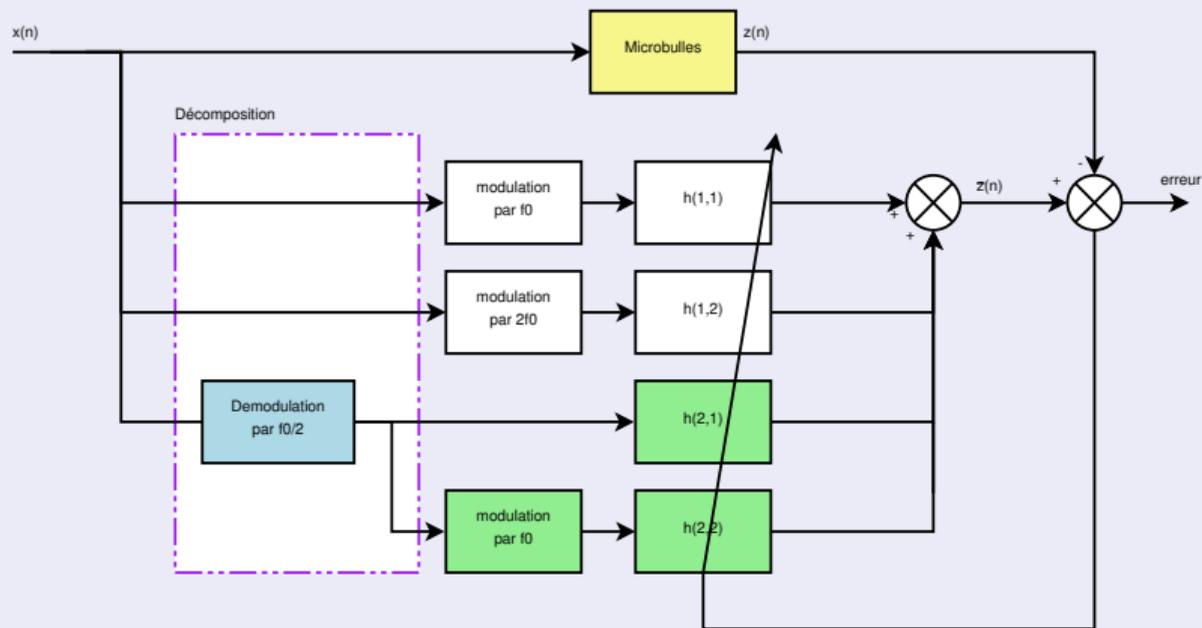
Post-traitements  
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Pré-traitements  
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## Thèse de Fatima Sbeity



# Parallélisation des modèles

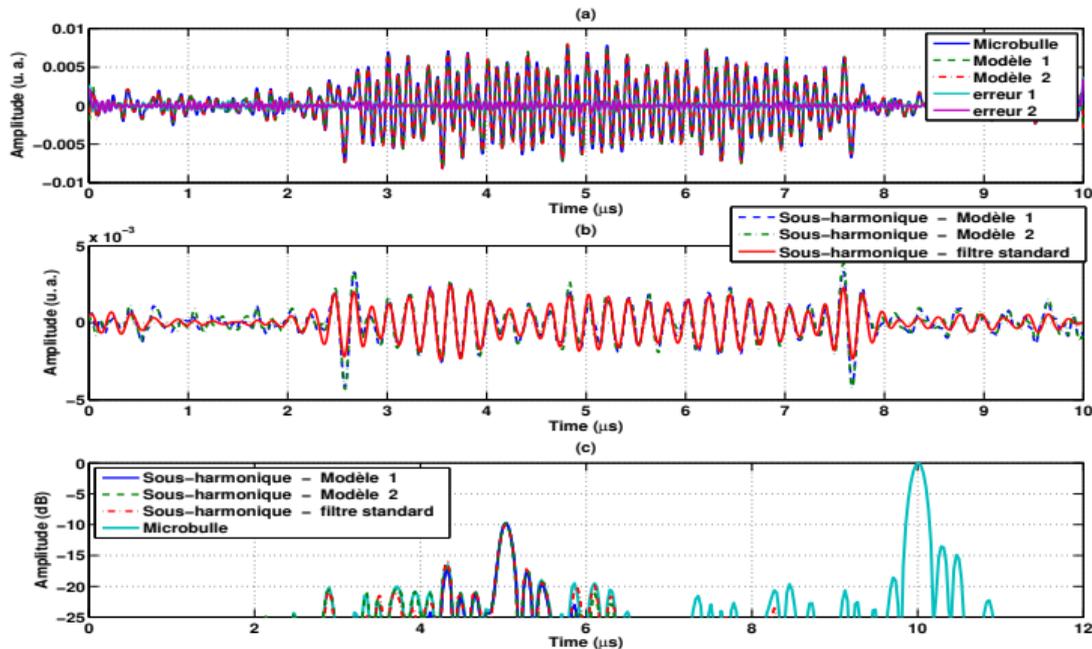
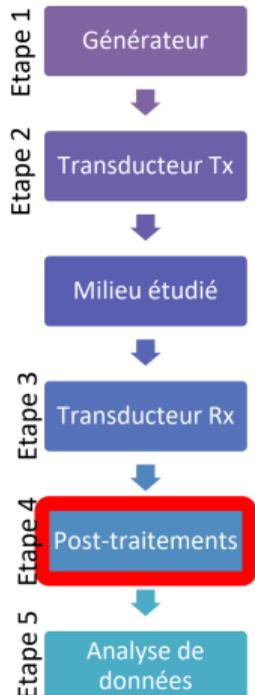
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Post-traitements  
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# Sérialisation des modèles

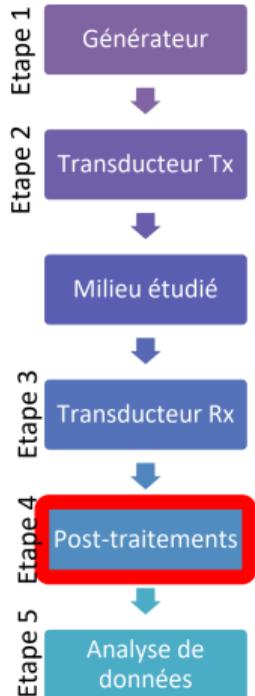
CV  
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Recherche  
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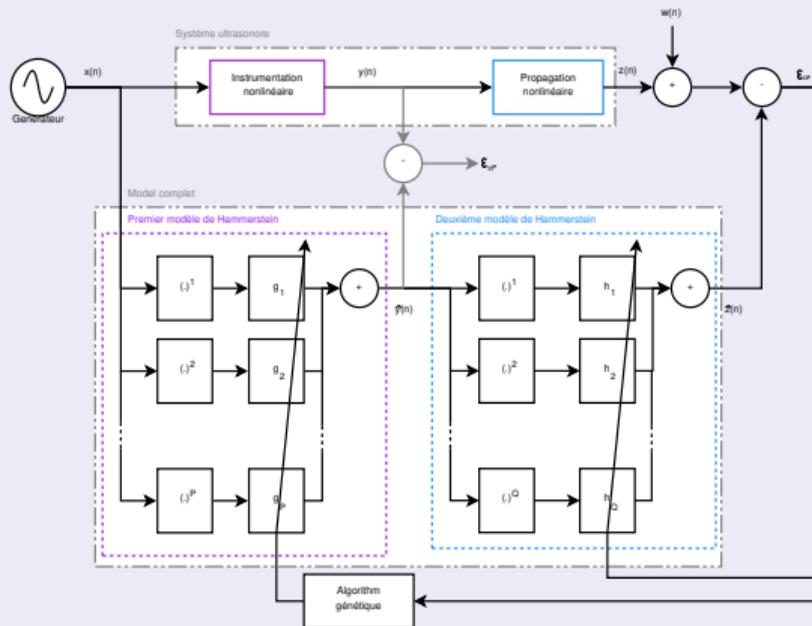
Post-traitements  
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Pré-traitements  
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## Et si l'instrumentation est aussi nonlinéaire ?



# Sérialisation des modèles

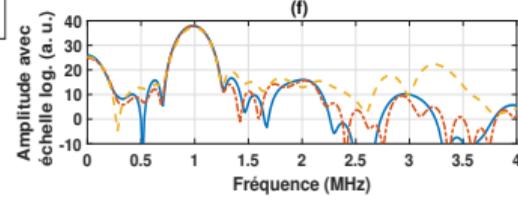
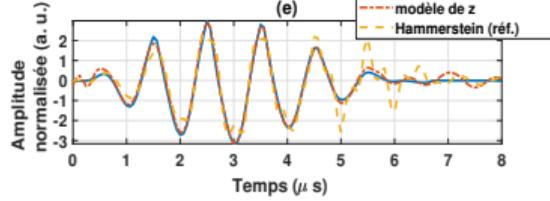
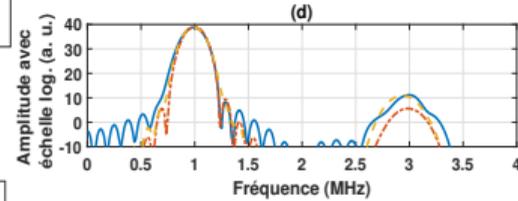
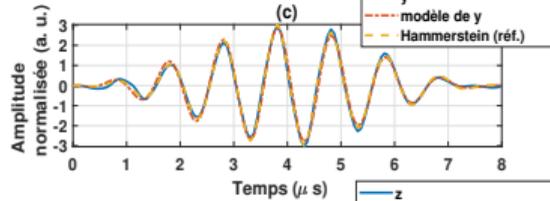
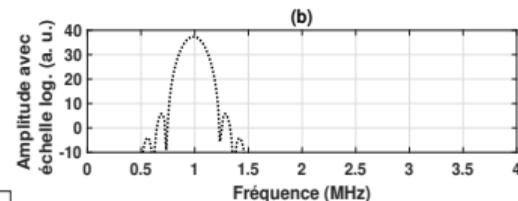
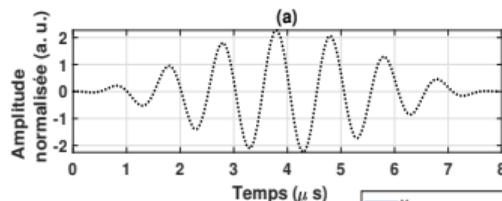
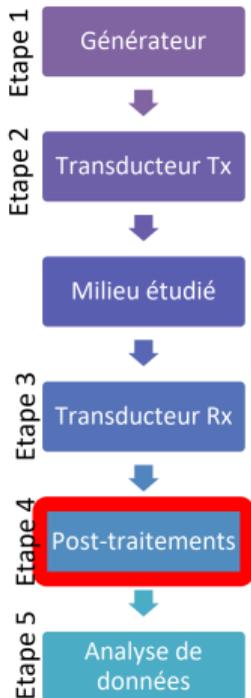
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Post-traitements  
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Pré-traitements  
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# Sérialisation des modèles

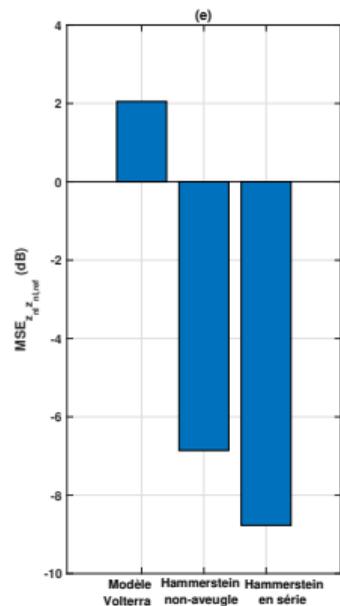
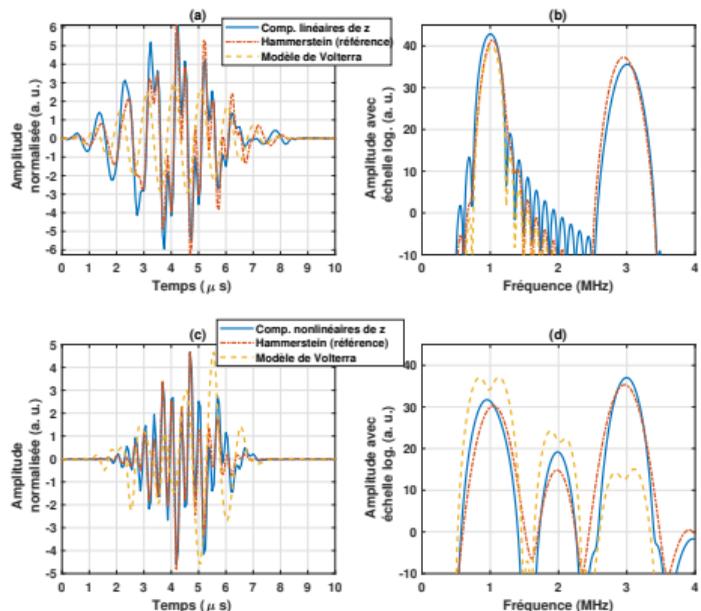
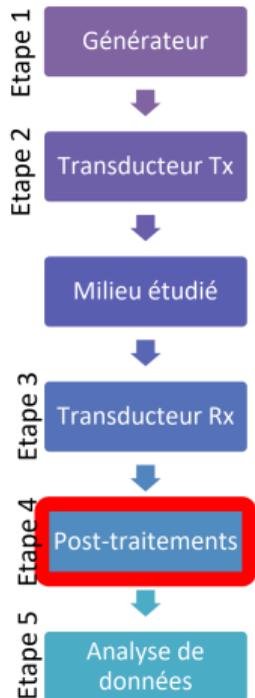
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Pré-traitements  
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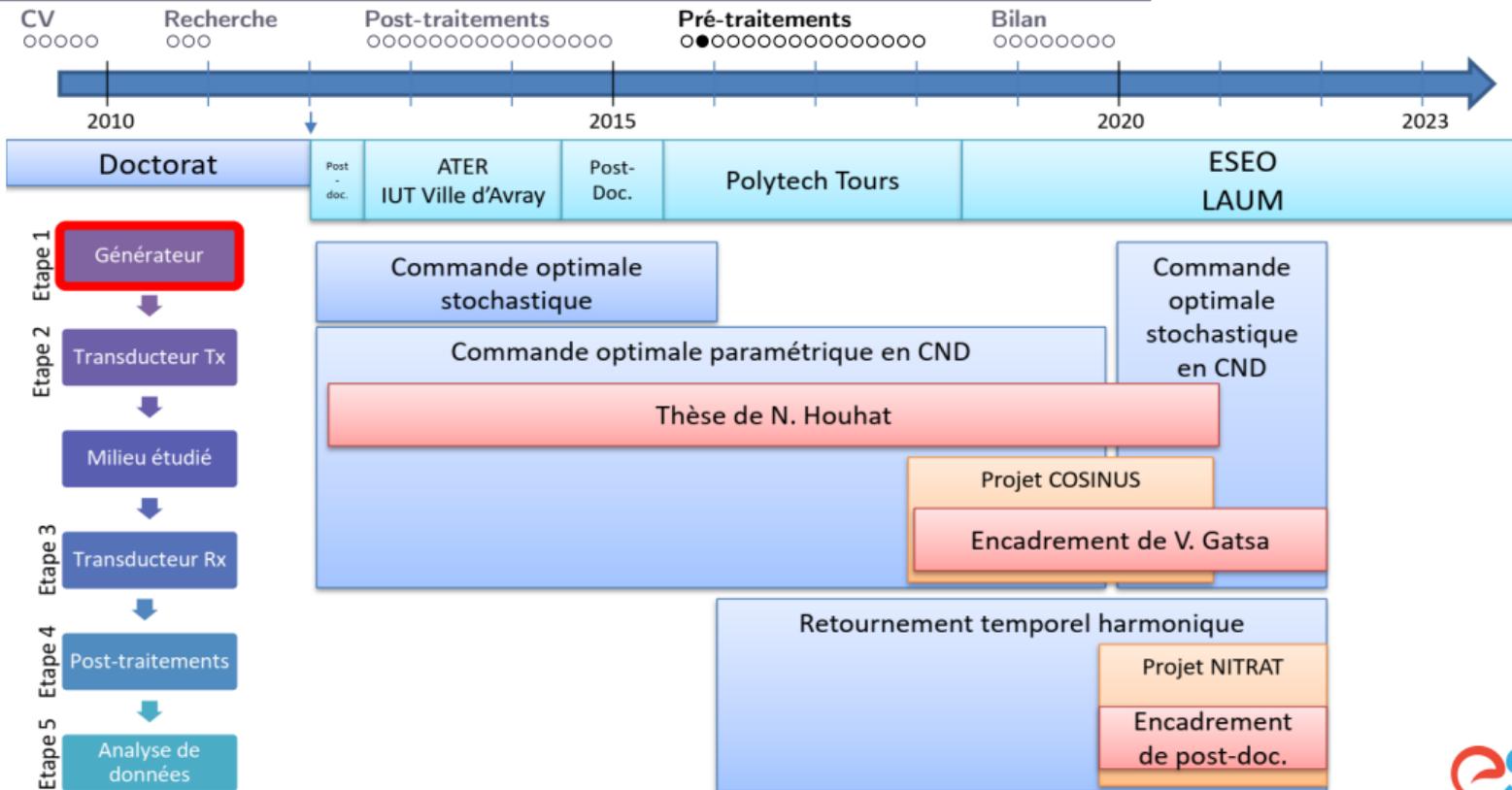
Bilan  
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# Pré-traitements des systèmes ultrasonores



# Étape 1 : Pré-traitements



# Étape 1 : Commande optimale

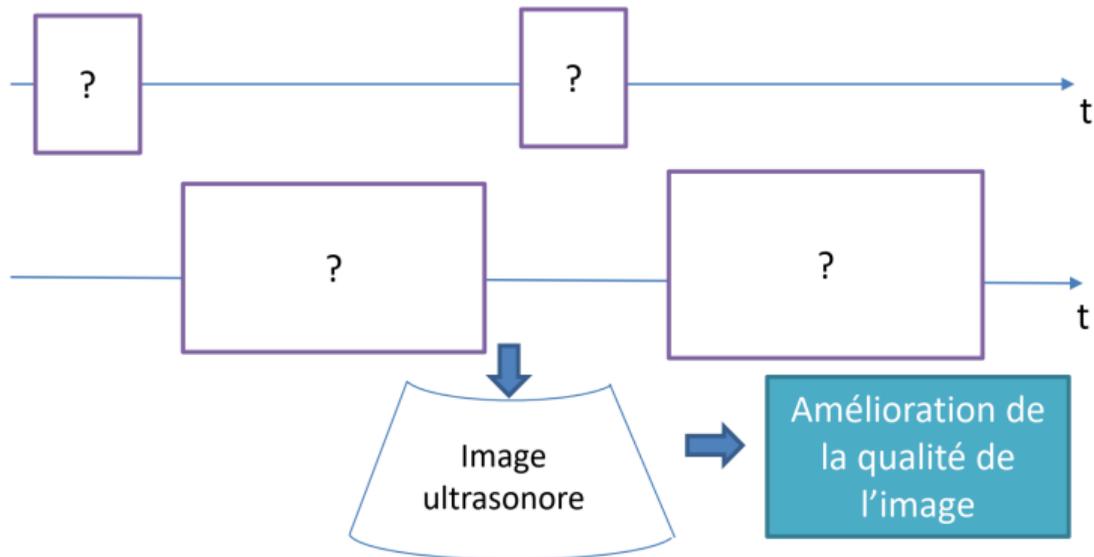
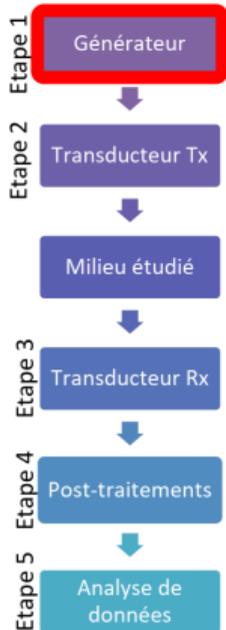
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Post-traitements  
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Pré-traitements  
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# Étape 1 : Commande optimale

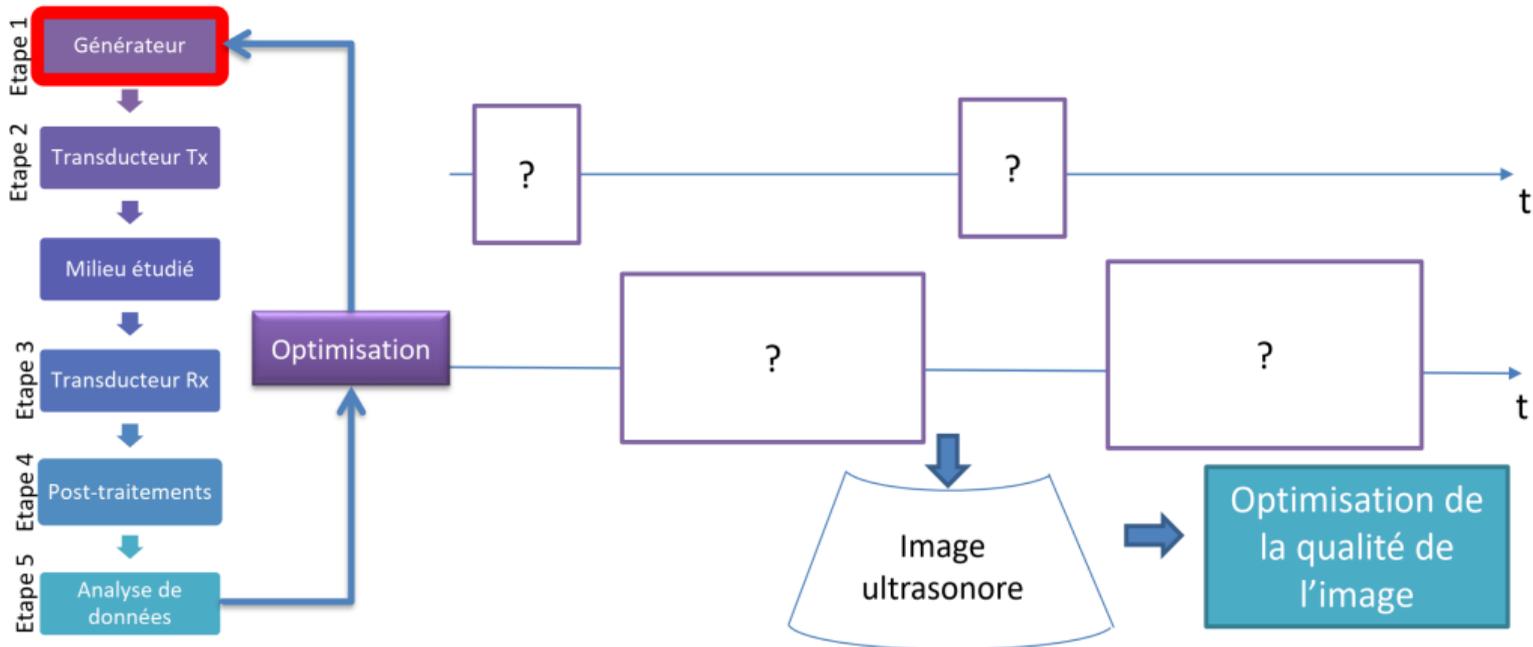
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Recherche  
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Post-traitements  
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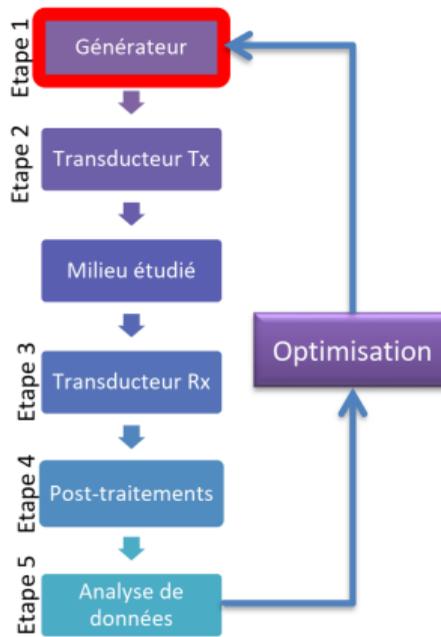
Pré-traitements  
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# Étape 1 : Commande optimale

CV ○○○○ Recherche ○○ Post-traitements ○○○○○○○○○○○○○○○○ Pré-traitements ○○○●○○○○○○○○○○○○○○○ Bilan ○○○○○○○○



### Principe de la commande optimale

- 1 Description de l'onde avec les paramètres  $\theta$
- 2 Fonction de coût  $J(\theta)$ . Par exemple, le contraste.
- 3 Optimisation par un algorithme hybride (méta-heuristique + algorithme local)

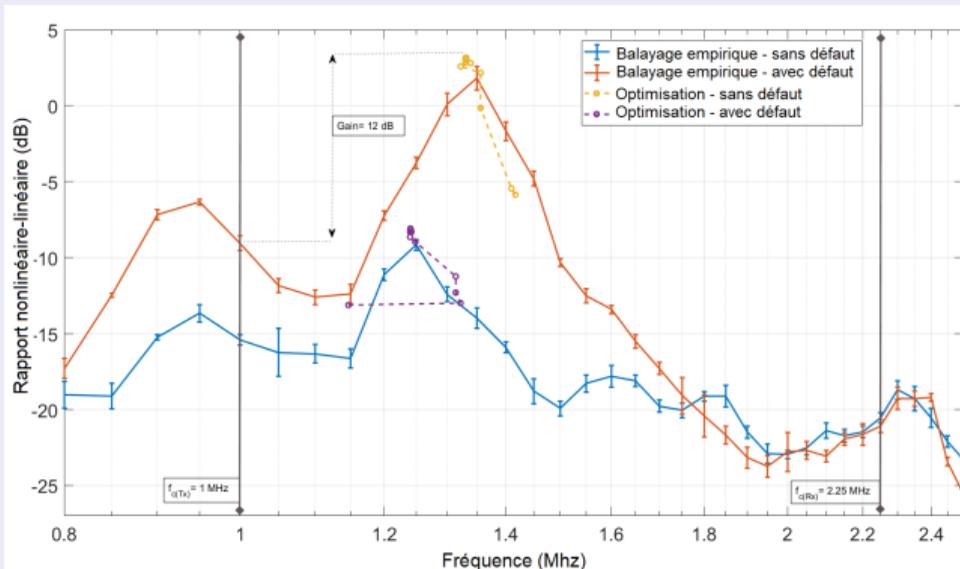
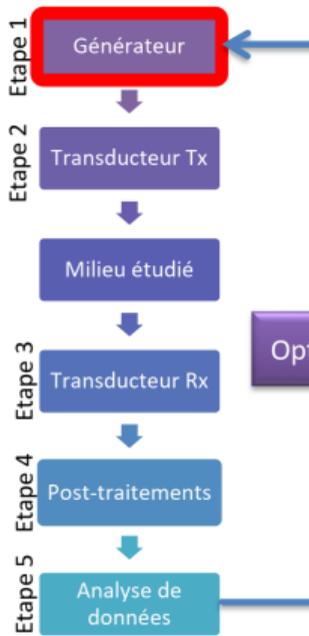
$$\theta^* = \arg \max_{\theta} [J(\theta)]$$


# Applications au CND

CV ○○○○ Recherche ○○○ Post-traitements ○○○○○○○○○○○○○○○○○○○ Pré-traitements ○○○○○●○○○○○○○○○○○○○○○○○○ Bilan ○○○○○○○○

## Commande optimale de fréquence sur un matériau solide fissuré

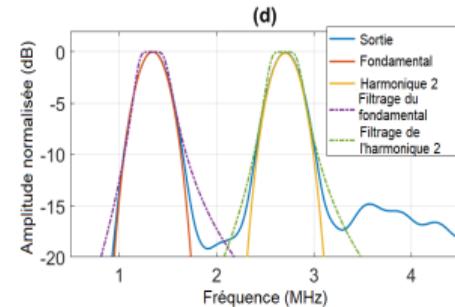
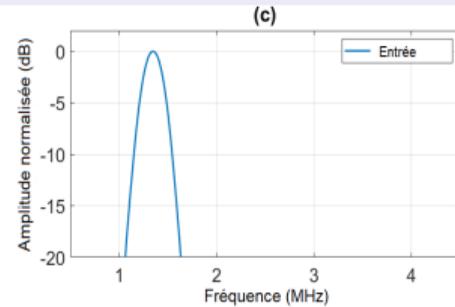
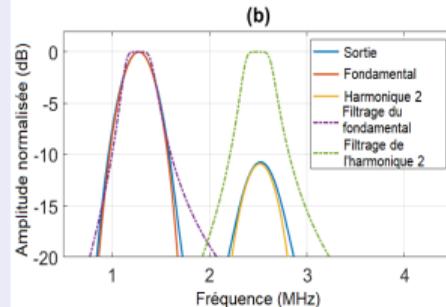
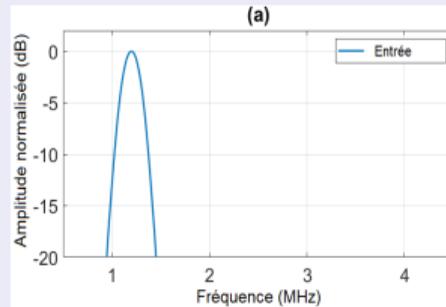
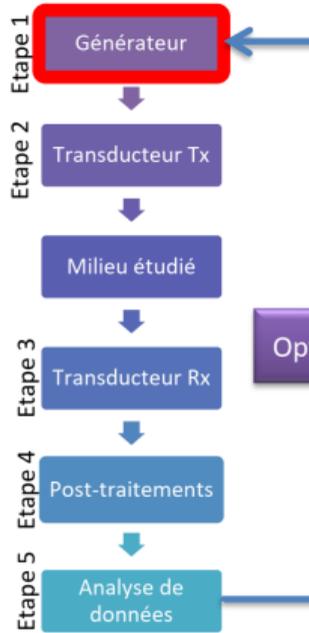
$$f^* = \arg \max_f [NLR(f)] = \arg \max_f \left[ 10 \cdot \log_{10} \left( \frac{E_{NL}}{E_{lin}} \right) \right]$$



# Applications au CND

CV ○○○○ Recherche ○○○ Post-traitements ○○○○○○○○○○○○○○○○○ Pré-traitements ○○○○○●○○○○○○○○○○ Bilan ○○○○○○○○

## Commande optimale de fréquence sur un matériau solide fissuré



# Applications au CND

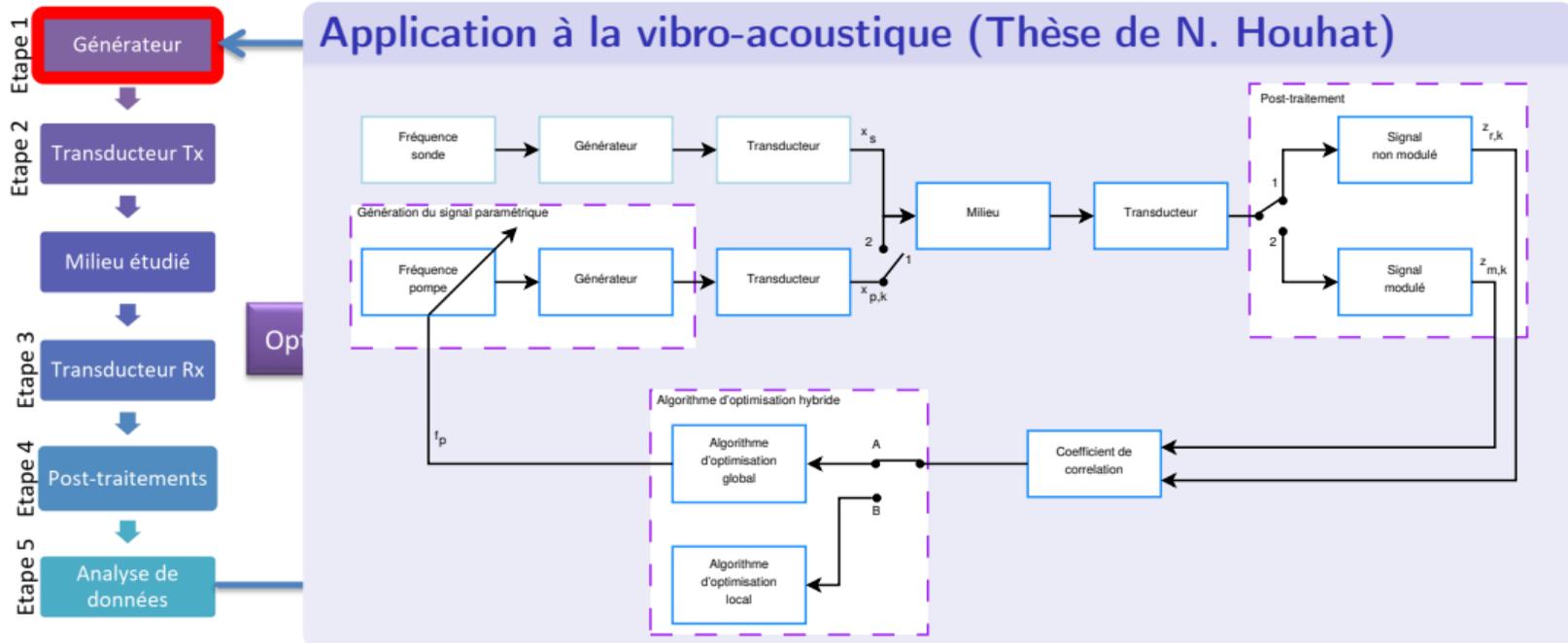
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Post-traitements  
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Pré-traitements  
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# Étape 1 : Commande stochastique

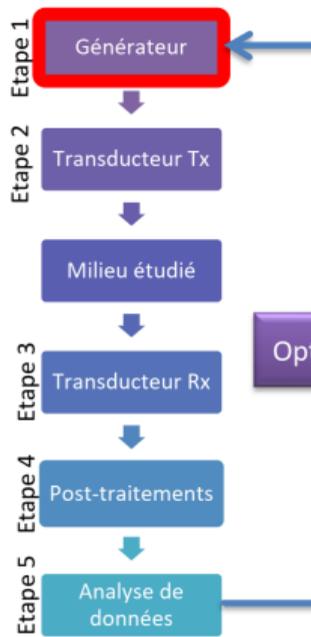
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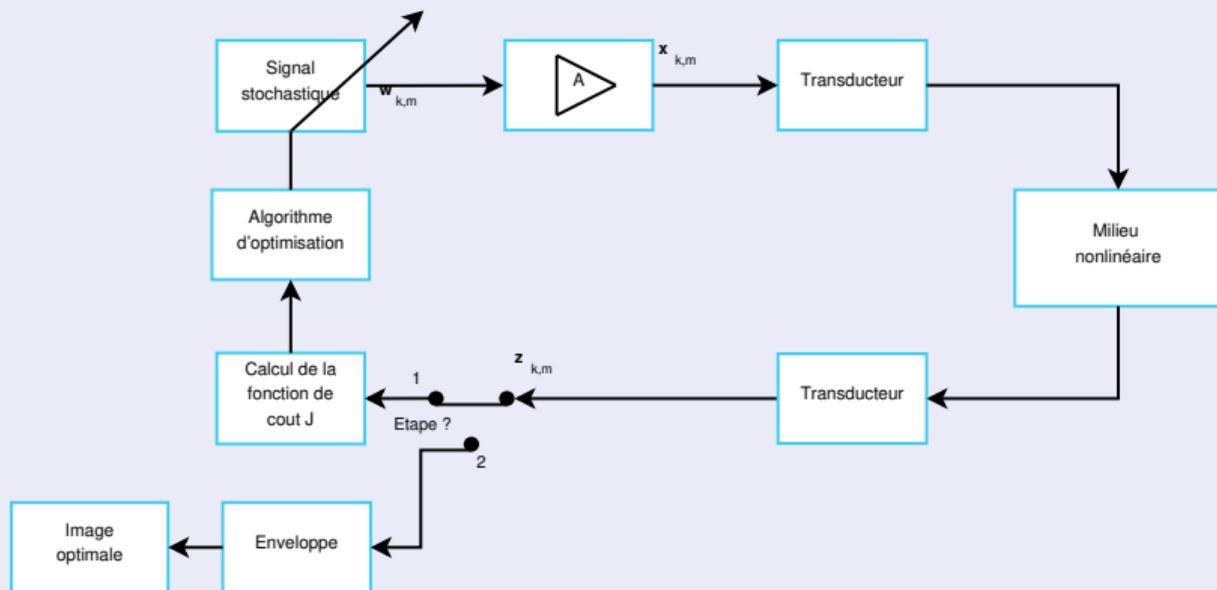
Post-traitements  
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Pré-traitements  
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## Principe de la commande stochastique



# Commande stochastique : simulations

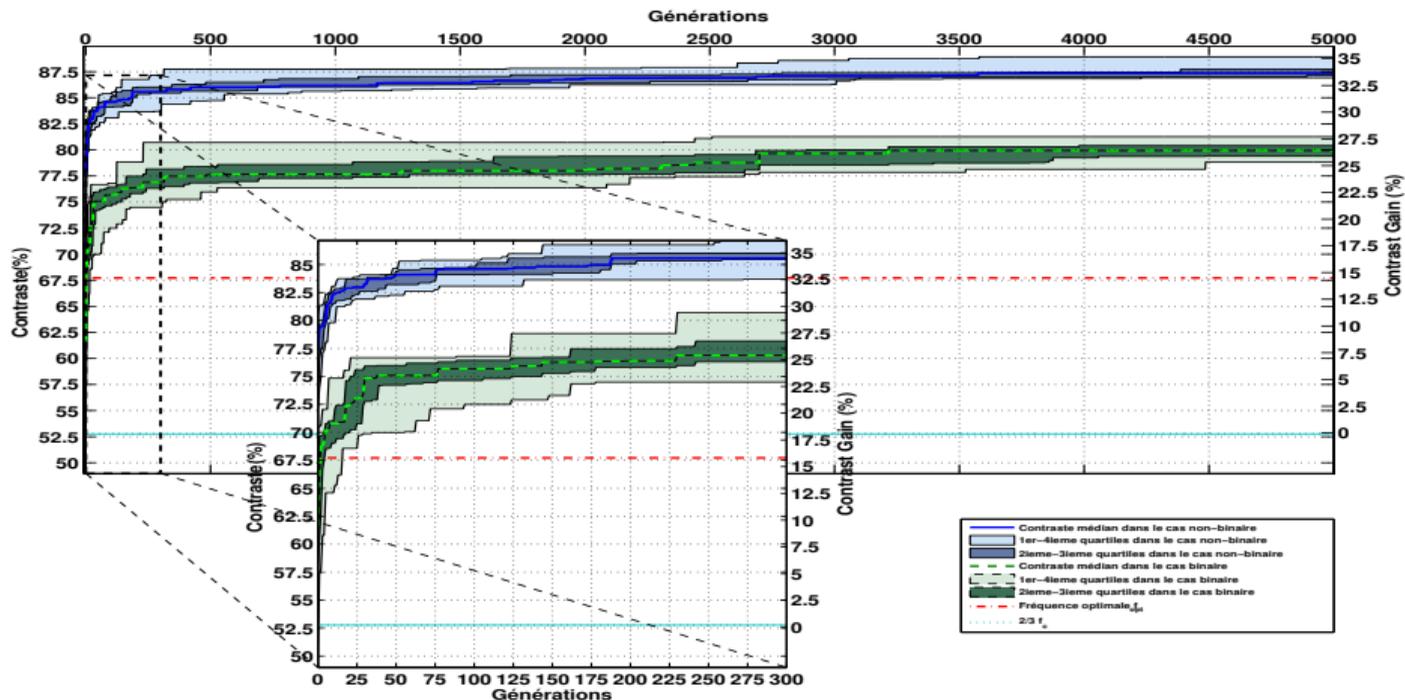
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Recherche  
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Post-traitements  
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Pré-traitements  
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Bilan  
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# Commande stochastique : expériences

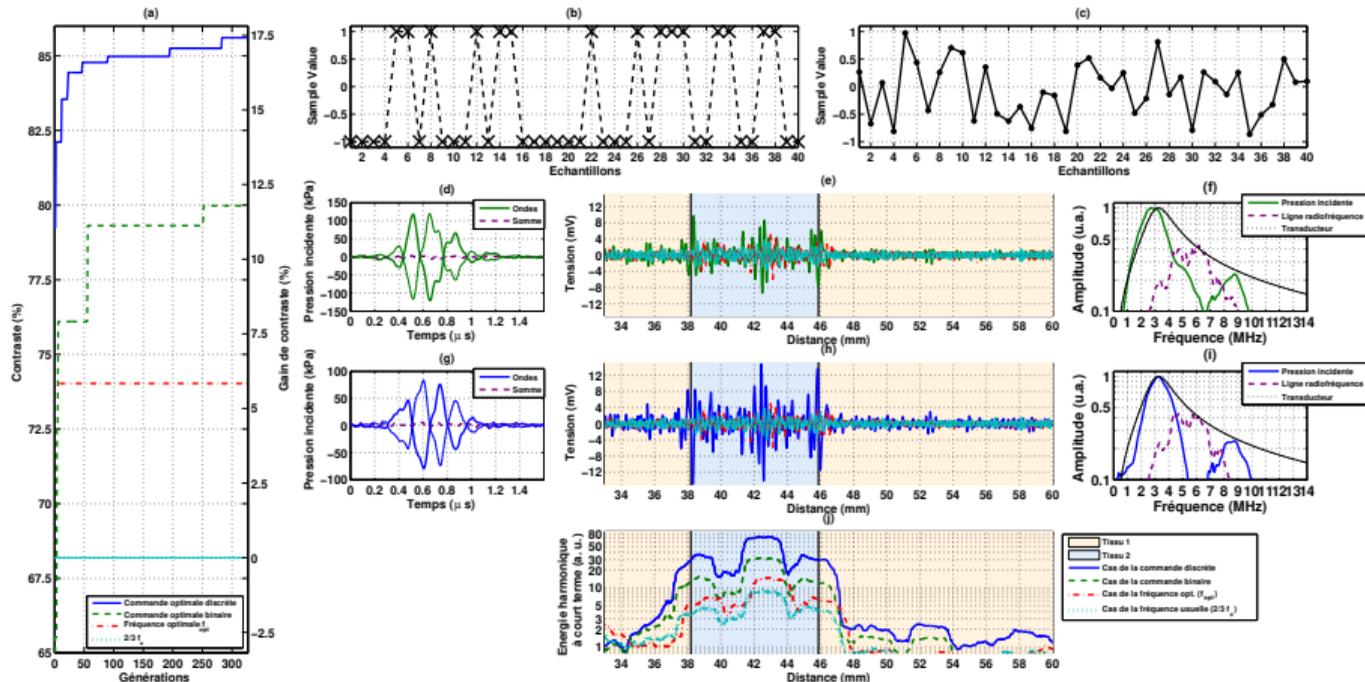
CV  
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Recherche  
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Post-traitements  
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Pré-traitements  
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Bilan  
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# Commande stochastique : images

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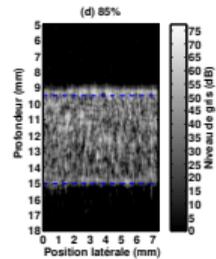
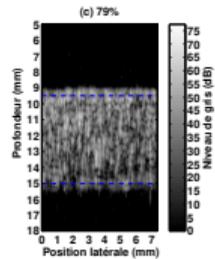
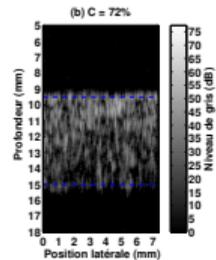
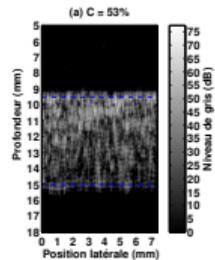
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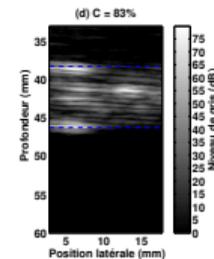
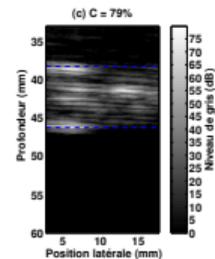
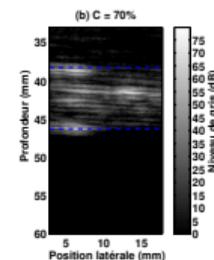
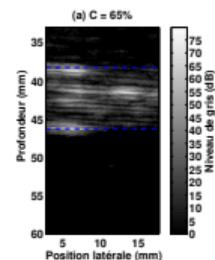
Pré-traitements  
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## Simulations

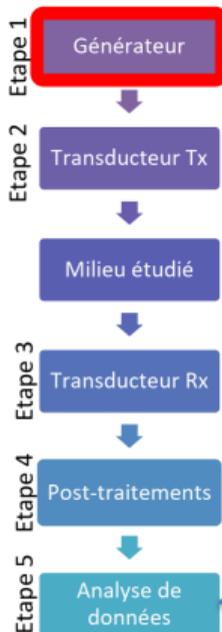


## Expériences



# Étape 1 : Commande optimale

CV ○○○○ Recherche ○○○ Post-traitements ○○○○○○○○○○○○○○○○○ Pré-traitements ○○○○○○○○○○○●○○○ Bilan ○○○○○○○○



## Commande optimale

- Solution sous-optimale
  - ▶ Fréquence
- Solution optimale : **commande optimale stochastique**
  - ▶ Design optimal temporellement, sans hypothèse sur la forme d'onde
  - ▶ Itératif
  - ▶ Si le milieu est linéaire, on retrouve la solution du retournement temporel

## Non-paramétrique

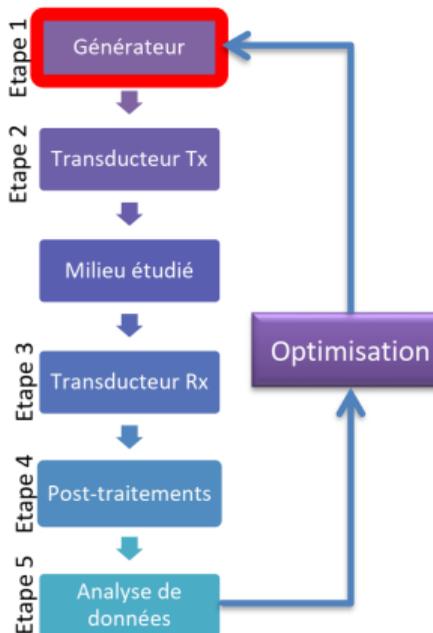
- **Uniquement pour les systèmes linéaires**

- ▶ Retournement temporel [Fink, IEEE TUFFC, 1992]
- ▶ Filtre adapté

la qualité de l'image

# Retournement temporel

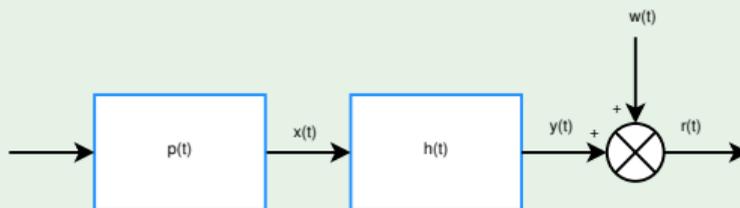
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## Objectif

- Maximiser le SNR en sortie du système  $r(t) = y(t) + w(t)$
- Appliquer le filtre  $p(t)$  sur le signal  $r(t)$

## Solution



$$p(t) = K \cdot y(-t) \Rightarrow \text{C'est le retourné temporel}$$

# Retournement temporel harmonique

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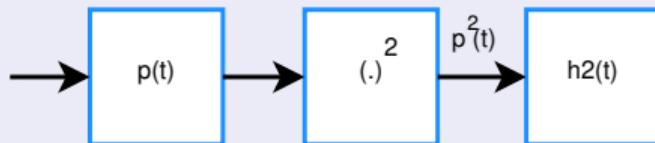
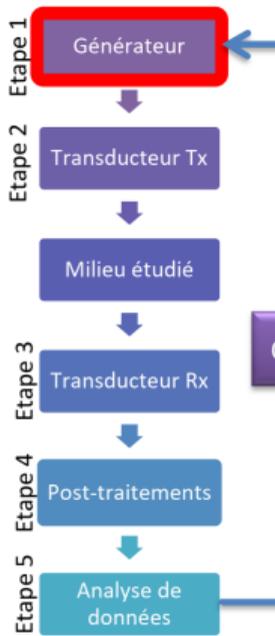
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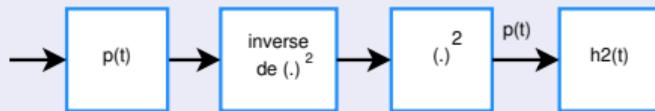
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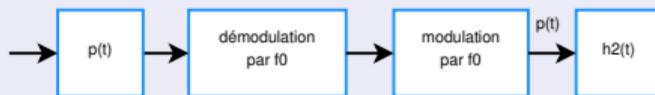
## Problème du filtre adapté pour la nonlinéarité



☠ il faut trouver une fonction inverse à la fonction nonlinéaire ☠



## Solution : modèle d'Hammerstein par démodulation



⚠ La phase doit aussi être divisée par 2 ⚠

→ initialisation avec la phase du fondamental

# Retournement temporel harmonique

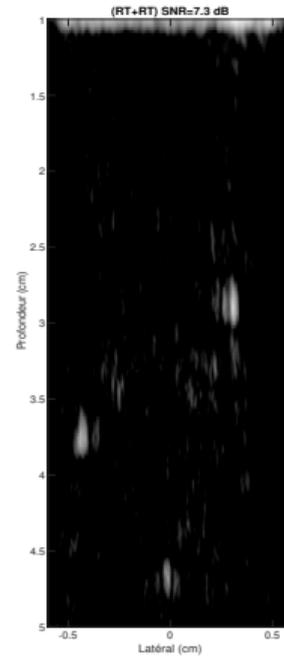
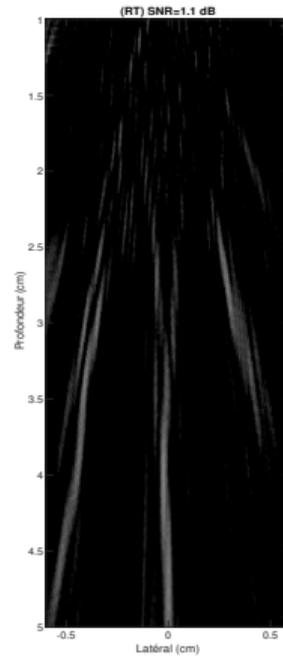
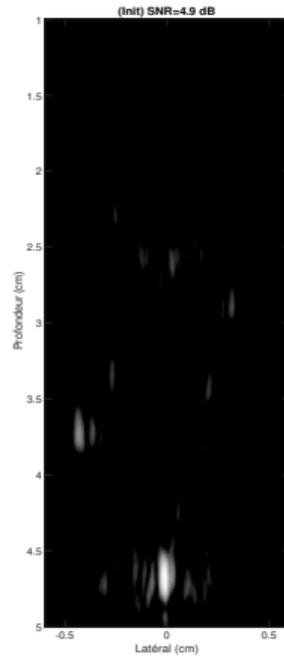
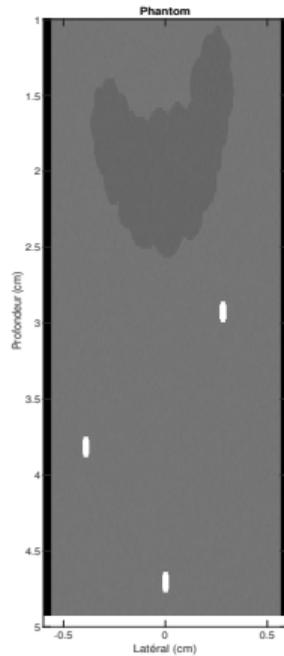
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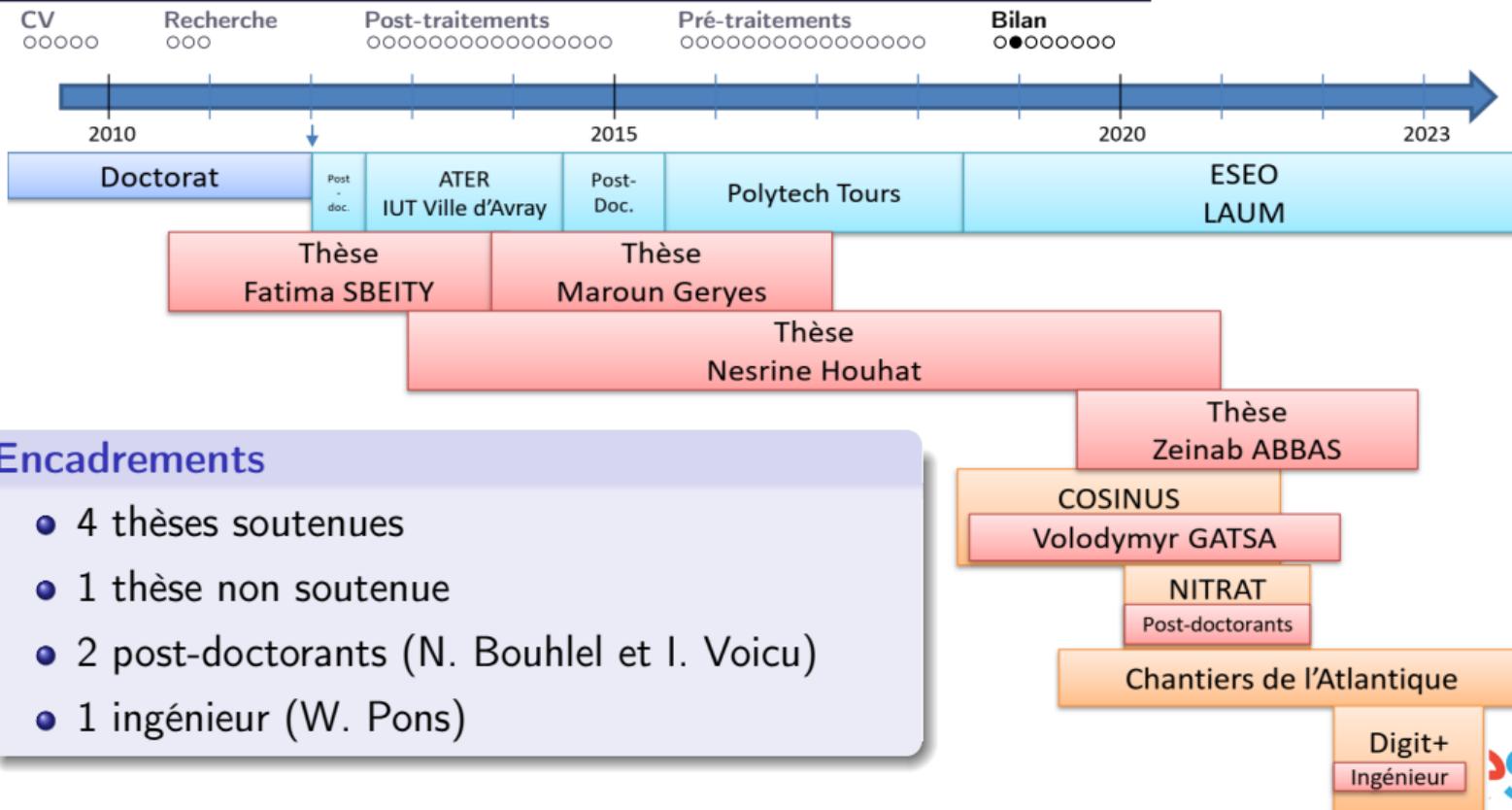
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# Bilan de recherche



# Bilan de recherche : encadrements



## Encadrements

- 4 thèses soutenues
- 1 thèse non soutenue
- 2 post-doctorants (N. Bouhlel et I. Voicu)
- 1 ingénieur (W. Pons)



# Bilan de recherche : publications

CV  
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Recherche  
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Post-traitements  
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## Encadrements

- 4 thèses soutenues
- 2 post-doctorants et 1 ingénieur

## Coordination de projets

- 2 projets RFI WISE
- 2 projets (Chantiers de l'Atlantique)

Fatima SBEITY

Maroun Geryes

## Publications

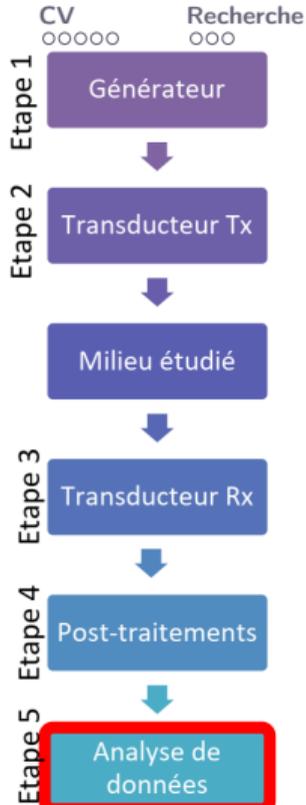
- 21 articles (6 avec les doctorants)
- 1 brevet
- 23 comm. congrès (10 avec les doctorants)
- 26 autres congrès et colloques
- 8 codes informatiques

## Expertises

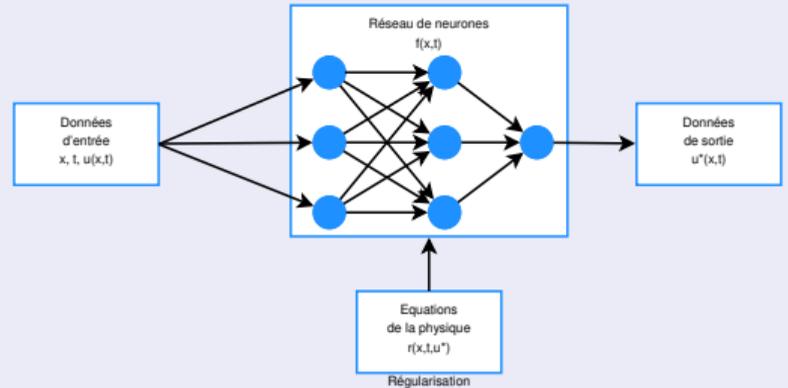
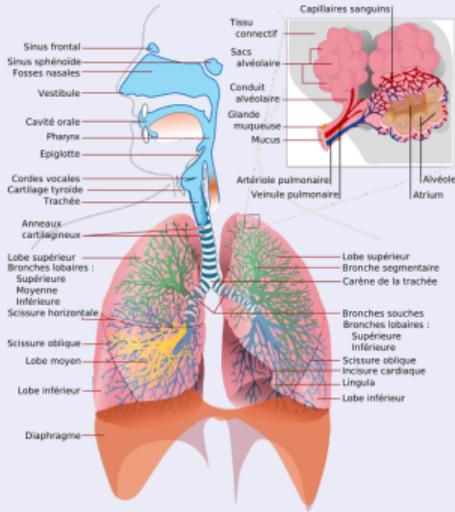
- 2 participations à des jurys de thèse
- 1 comité de suivi individuel de thèse
- *Reviewer* pour 8 journaux
- *Reviewer* pour 5 congrès
- Activités associatives (SFA et ECND PdL)



# Projet de recherche en biomédical



## Système respiratoire et apprentissage guidée par la physique



Physics-informed neural networks (PINNs)

# Projet de recherche en biomédical

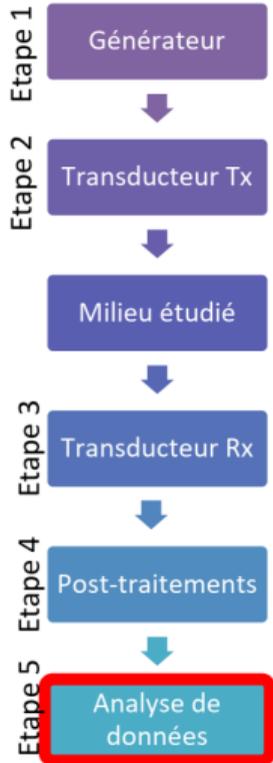
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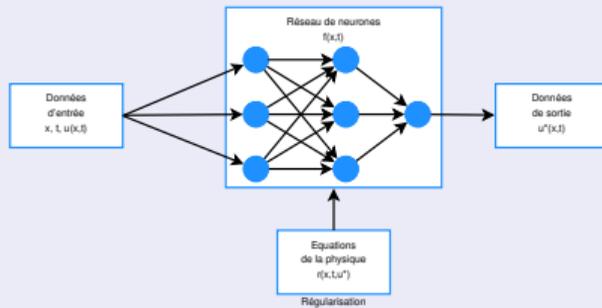
Pré-traitements  
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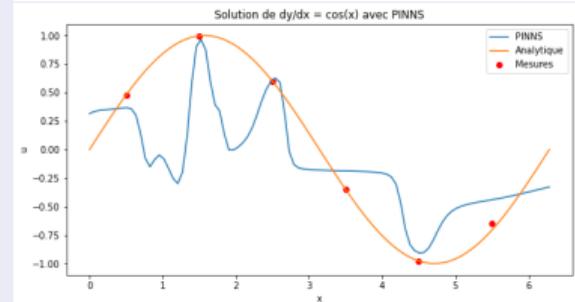
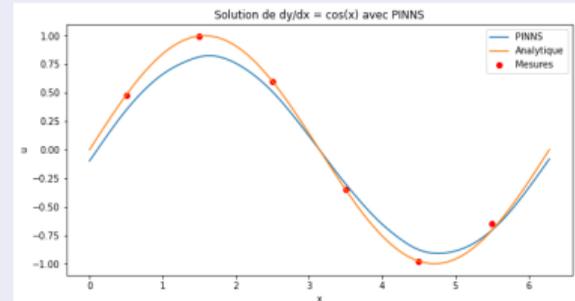


## Systeme respiratoire et apprentissage guidée par la physique

- 1 Modélisation du problème direct
- 2 Résolution du problème inverse par les PINNS



Physics-informed neural networks (PINNs)





Merci de votre attention



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