



COSINUS

COMMANDE OPTIMALE DE SENSEURS INTELLIGENTS POUR LA
NONLINÉARITÉ ULTRASONORE

Sébastien MÉNIGOT, Volodymyr GATSA & Vincent
TOURNAT

Décembre 2020

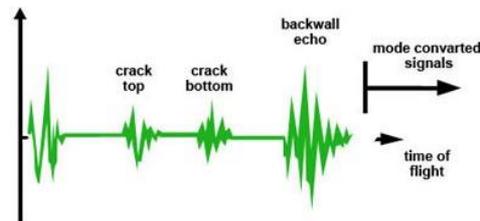
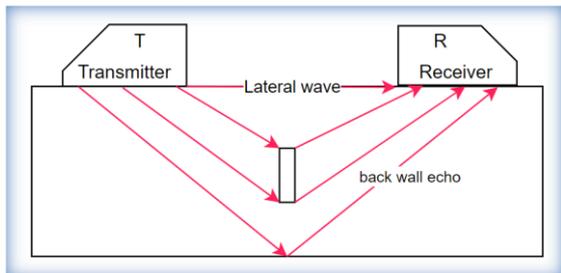


INTRODUCTION

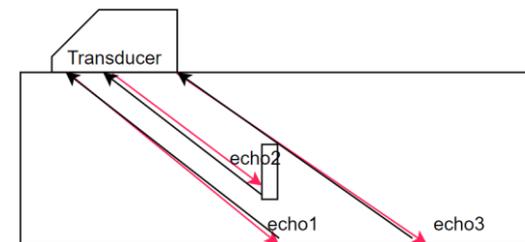
Systeme d'imagerie ultrasonore pour le controle non destructif (CND)



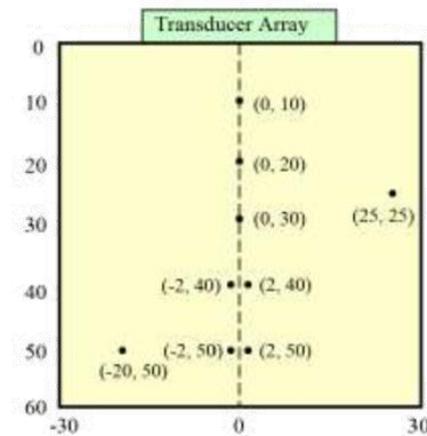
Time of Flight Diffraction experiment (TOFD)



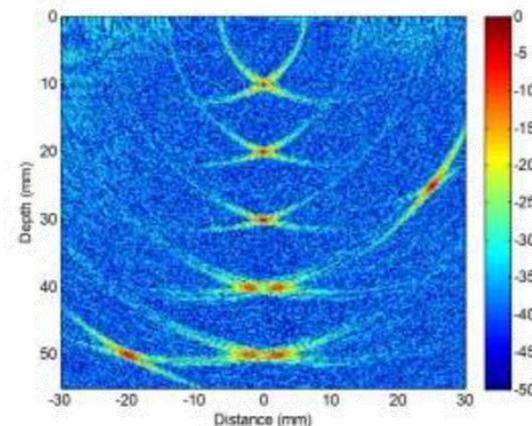
Echo experiment (A-scan)



Tournat, 2014



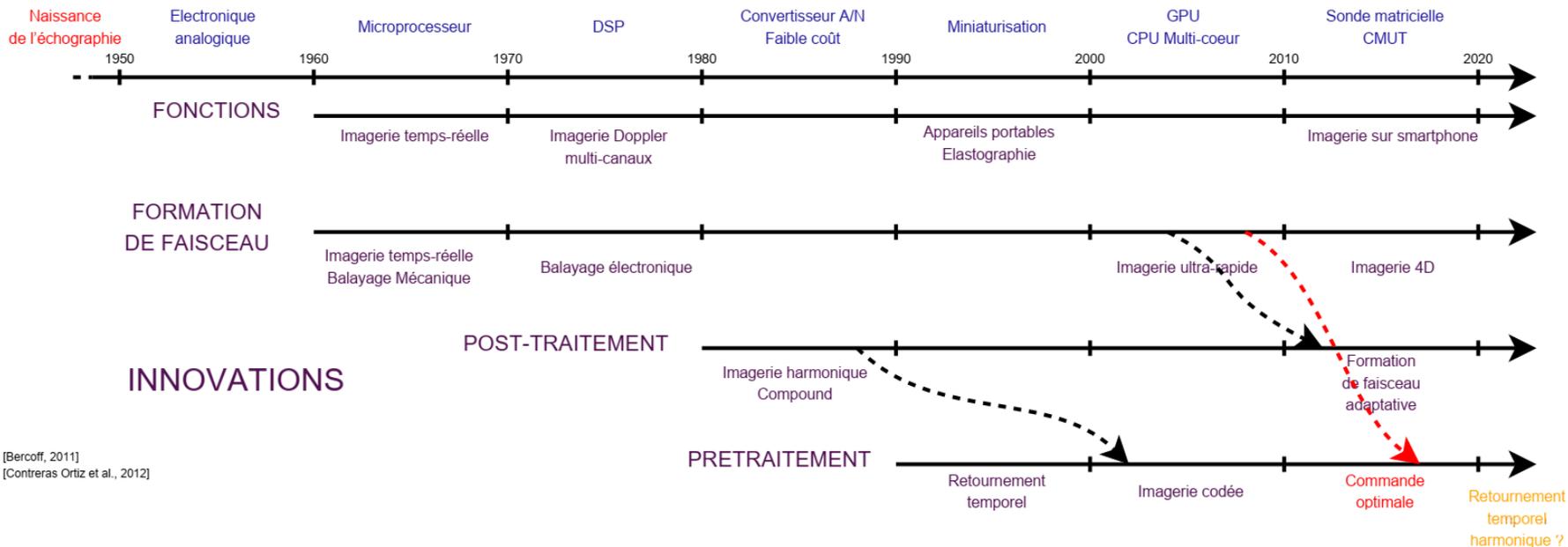
Présentation ESEO



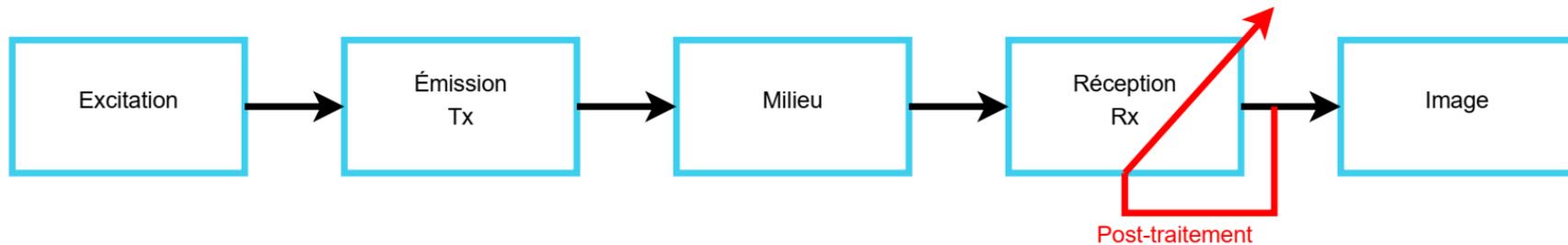
Li, 2012



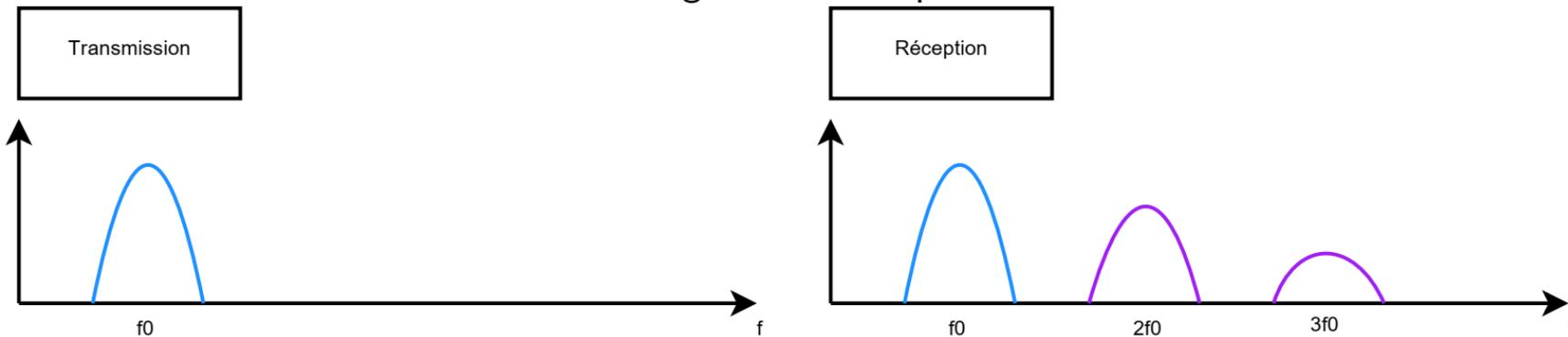
TECHNOLOGIES

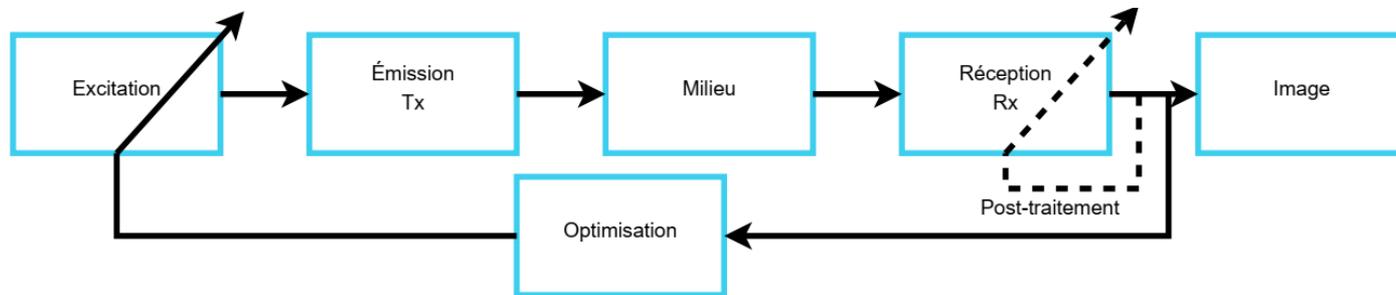


[Bercoff, 2011]
[Contreras Ortiz et al., 2012]

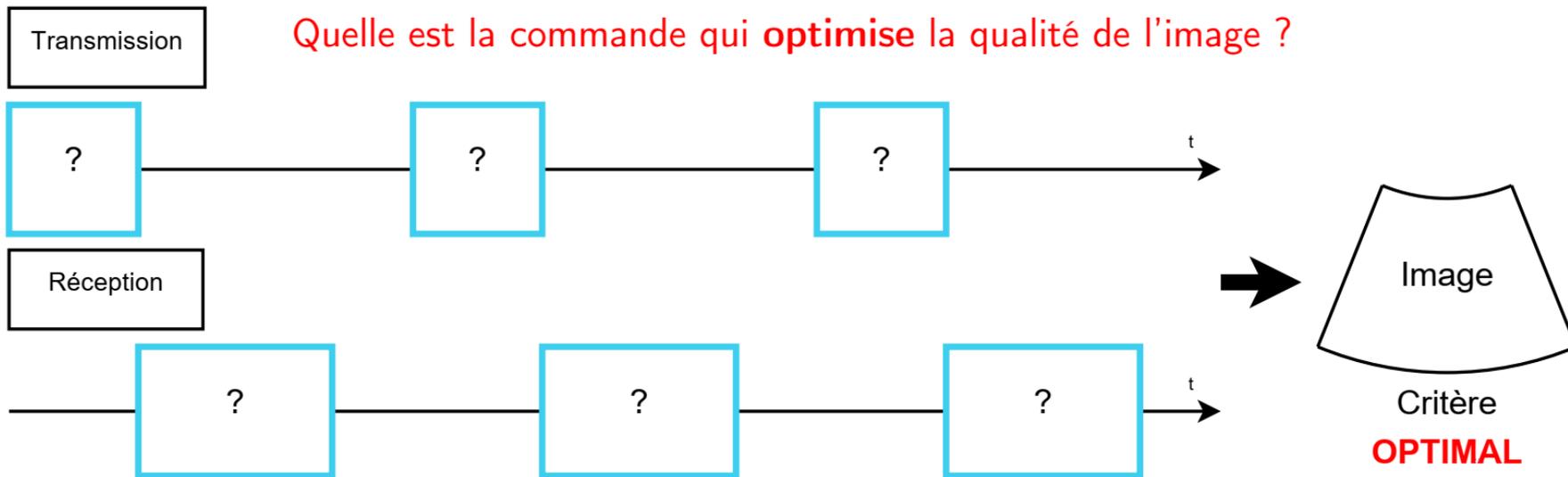


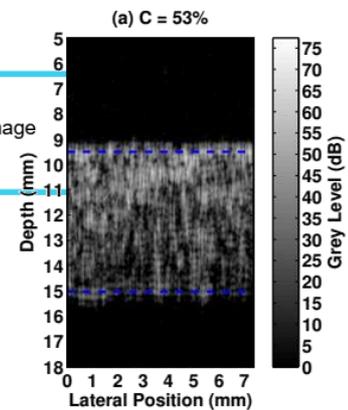
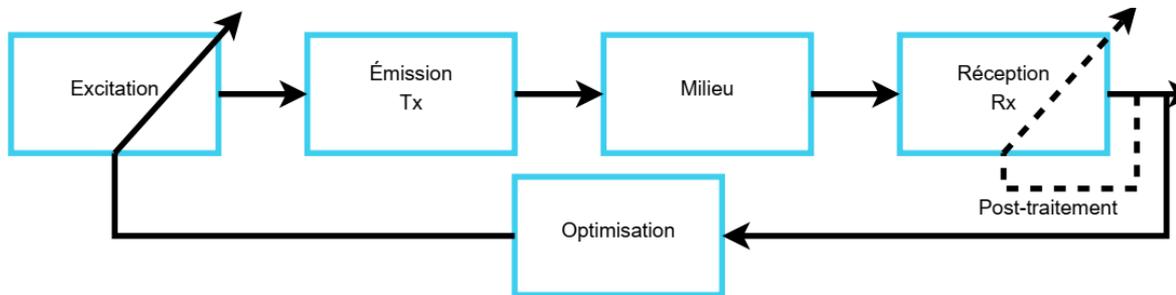
Imagerie harmonique





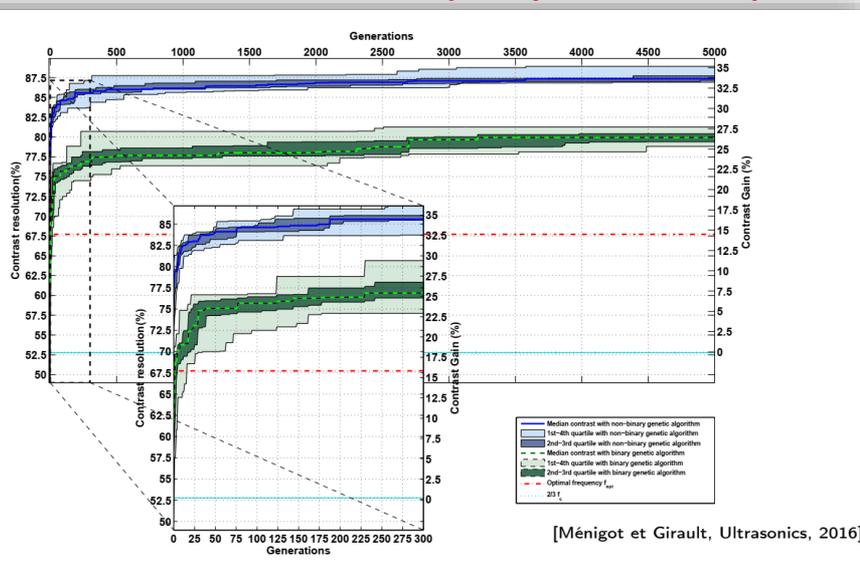
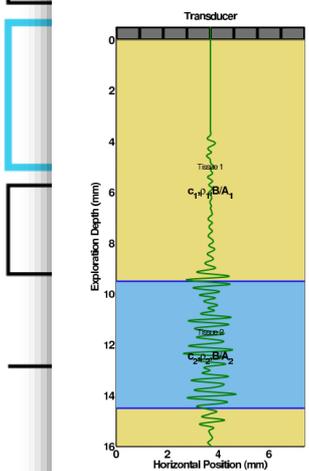
Quelle est la commande qui **optimise** la qualité de l'image ?





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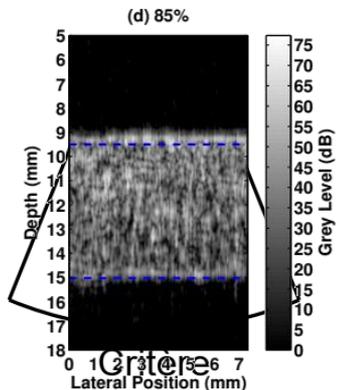
Transmission

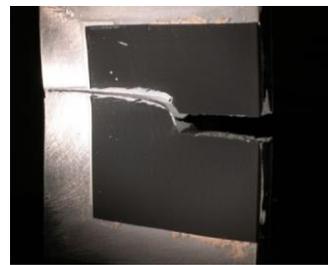
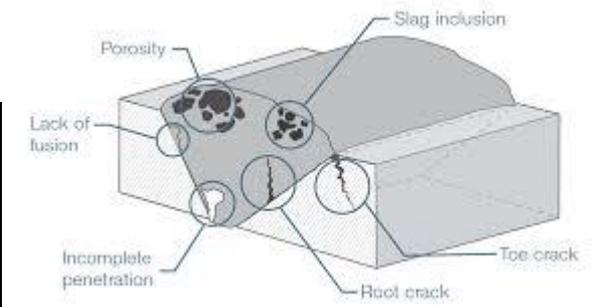
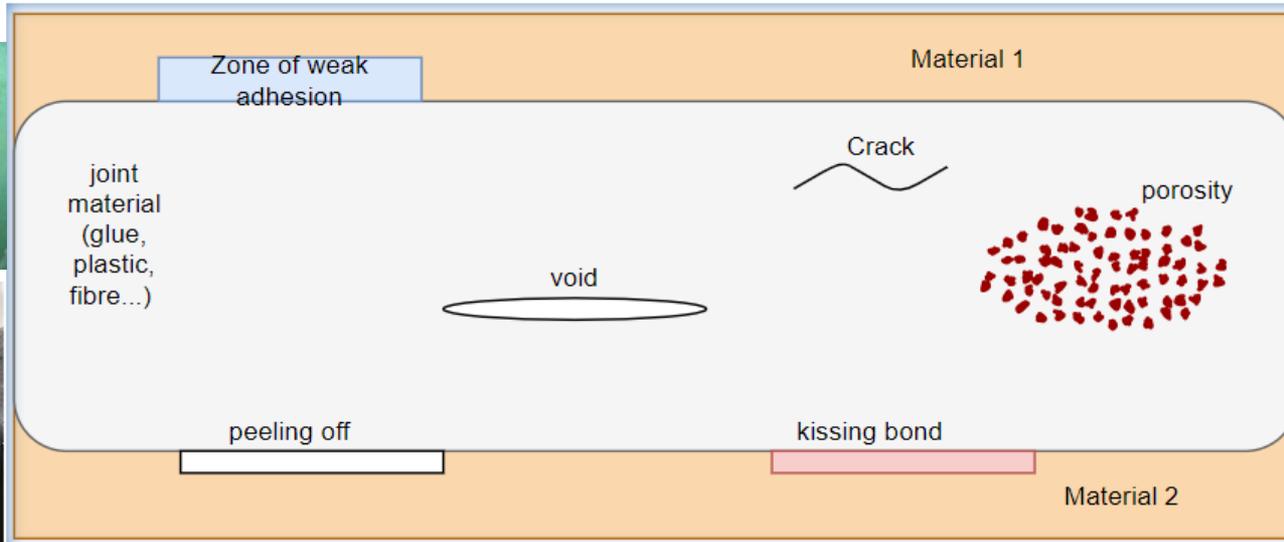


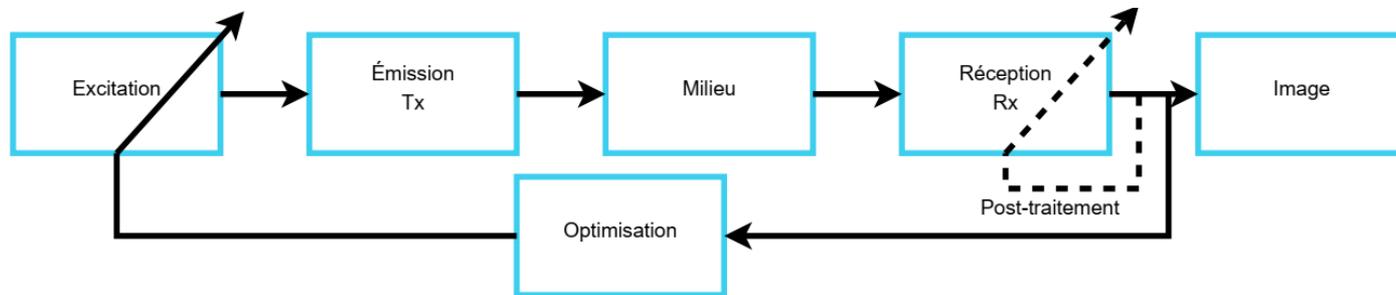
t



t

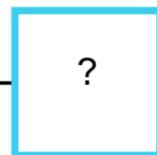
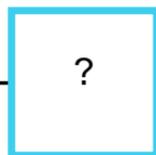






Transmission

Quelle est la commande qui maximise la probabilité de détection des défauts ?



t

Réception



t

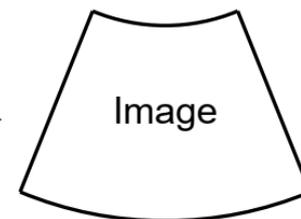


Image
Critère
OPTIMAL

Projet COSINUS :
Thèse de V. Gatsa



Paramétrique

- Solution sous-optimale
 - ▶ Fréquence
 - ▶ Modulation de fréquence
 - ▶ Rapport des composantes harmoniques
 - ▶ Intermodulation
- **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

Thèse de
N. Houhat



Projet international
NITRAT
Post-doctorat de N.
Bouhlef



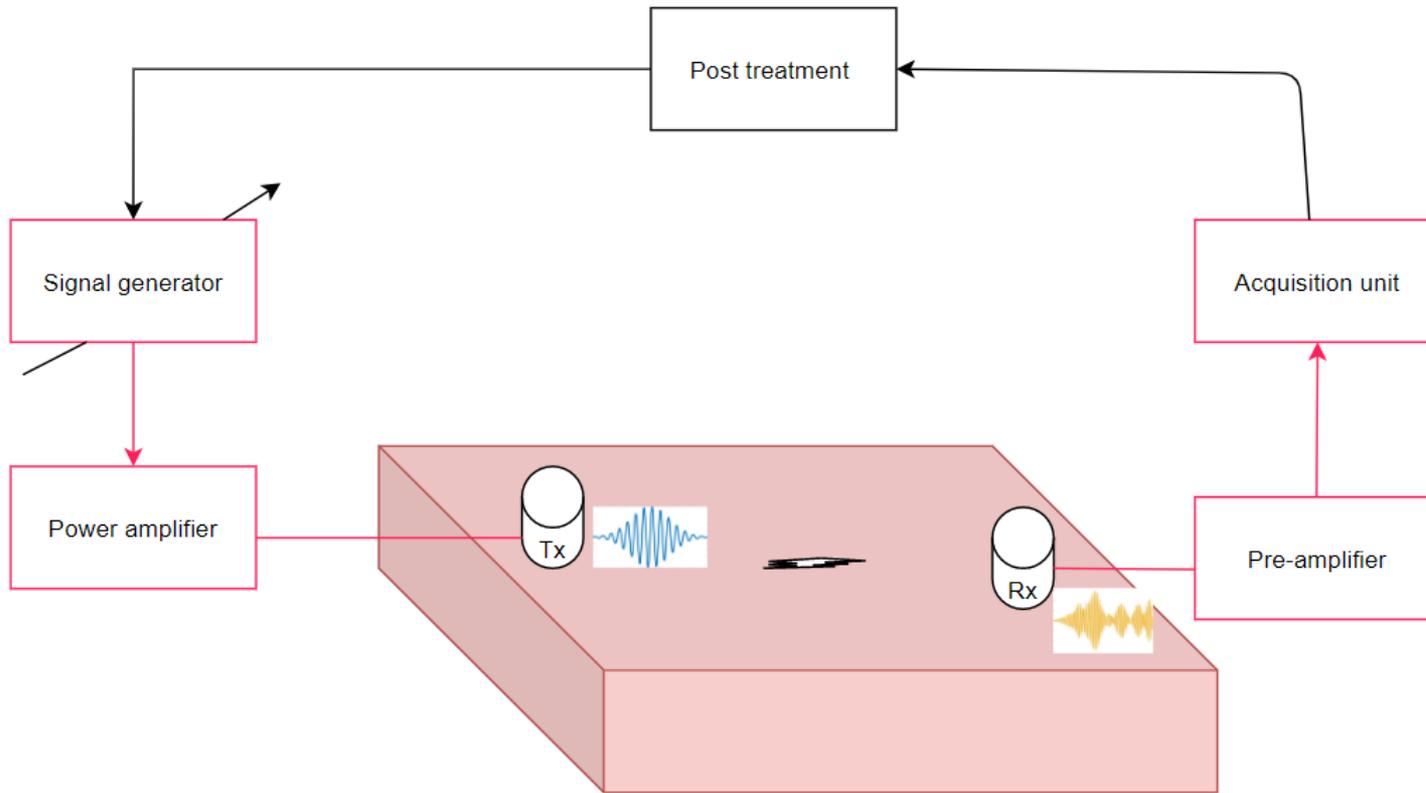
Non-paramétrique

- **Uniquement pour les systèmes linéaires**
 - ▶ Retournement temporel [Fink, IEEE T UFFC, 1992]
 - ▶ Filtre adapté
- Tentative pour les systèmes nonlinéaires [Ménigot et al., IEEE IUS, 2016]



COMMANDE OPTIMALE ET OPTIMISATION

THÈSE DE VOLODYMYR GATSA



1. Choix de la fonction de coût $J(\theta)$

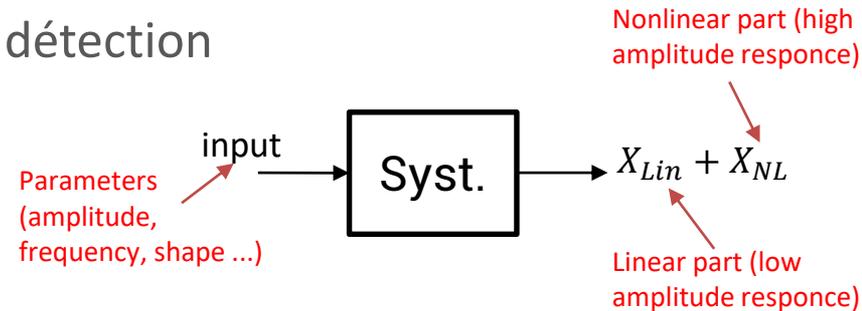
Objectif : maximiser la probabilité de détection

→ Signature nonlinéaire des défauts

Contraintes

Extraction des nonlinéairités
en sortie du système :

- Filtrage du signal de sortie ←
- Codage
- Modélisation (Hammerstein, Volterra...) ←



$$\left. \begin{array}{l} \max(E_{NL}) \rightarrow +\infty \\ \min(E_{Lin}) \rightarrow 0 \end{array} \right\}$$

$$\max(J) = \max\left(\frac{E_{NL}}{E_{Lin}}\right)$$

1. Choix de la fonction de coût $J(\theta)$

Objectif : maximiser la probabilité de détection

→ Signature nonlinéaire des défauts

2. Choix des paramètres θ d'entrée

Simplicité

Hypothèse physique : résonance...

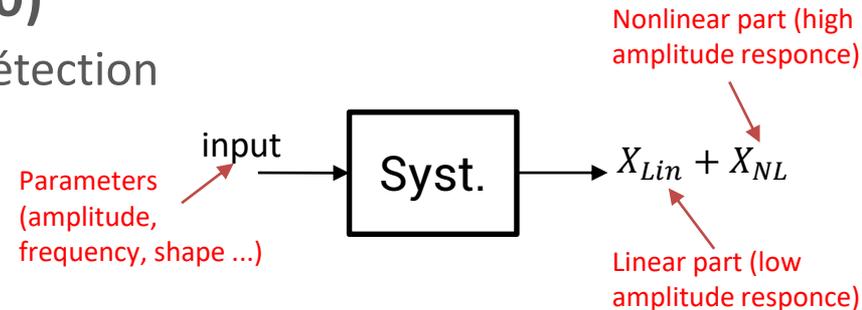
→ θ : Fréquence

3. Choix de l'algorithme d'optimisation

Si fonction $J(\theta)$ convexe → algorithme d'optimisation locale

Si fonction $J(\theta)$ avec plusieurs optimum locaux → métaheuristique

→ algorithme d'optimisation locale : Simplex downhill



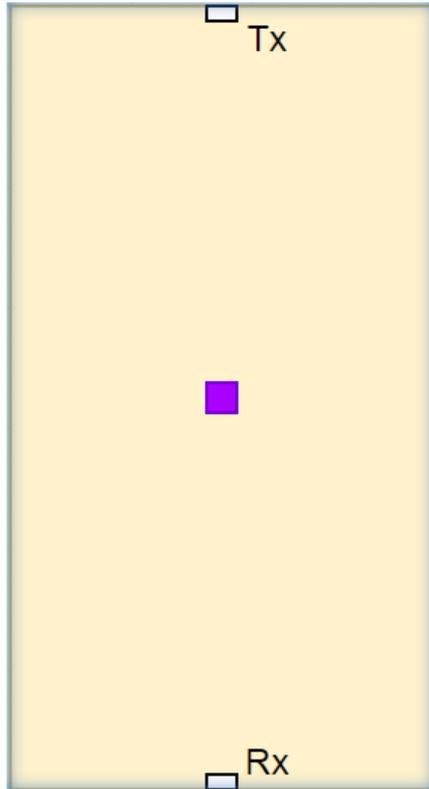
$$\left. \begin{array}{l} \min(E_{NL}) \rightarrow +\infty \\ \max(E_{Lin}) \rightarrow 0 \end{array} \right\} \\ \max(J) = \max\left(\frac{E_{NL}}{E_{Lin}}\right)$$



APPLICATIONS DE LA COMMANDE OPTIMALE

Simulation : propagation et crack

2D aluminium plate

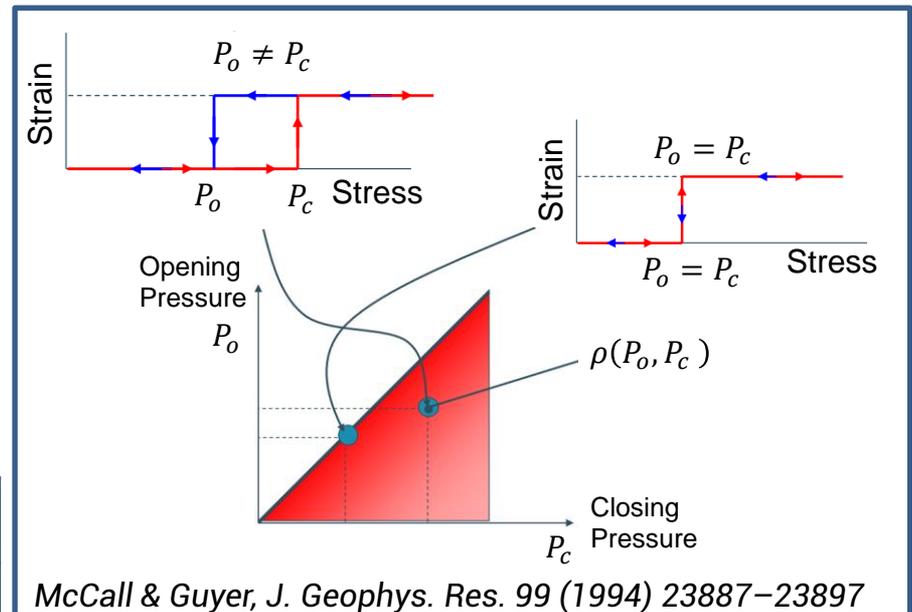


P-wave speed [m/s]	6398
S-wave speed [m/s]	3030
Density [kg/m ³]	3122

Young modulus [Pa/m ²]	$70 \cdot 10^9$
Poisson ratio	0.33
Density [kg/m ³]	2966

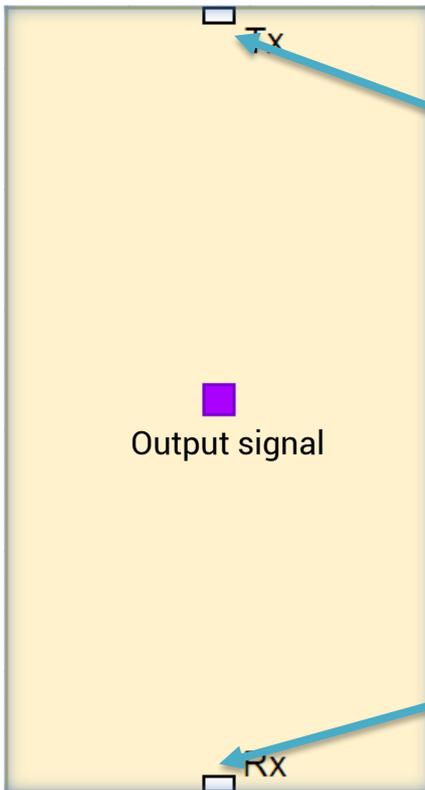
Sample dimensions	[100 ; 50] mm
Crack dimensions	[8 ; 8] mm

- Propagation : Pseudospectral / staggered A-B method, with linear propagation of longitudinal and shear waves.
- Crack hysteresis behavior described by hysteretic elementary units (HEU)

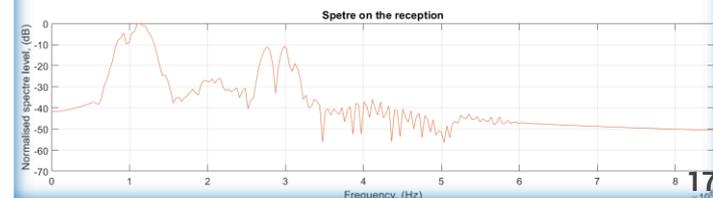
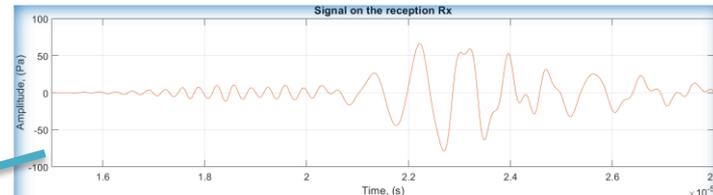
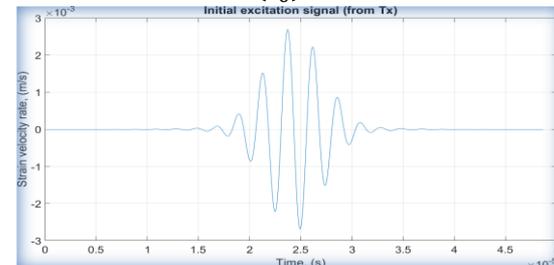
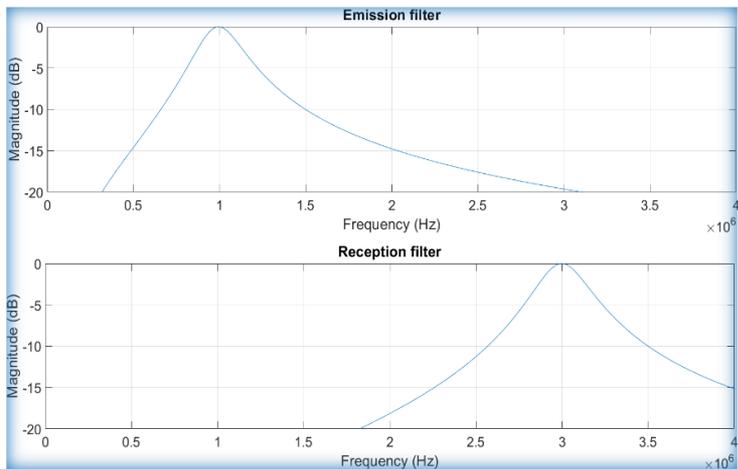


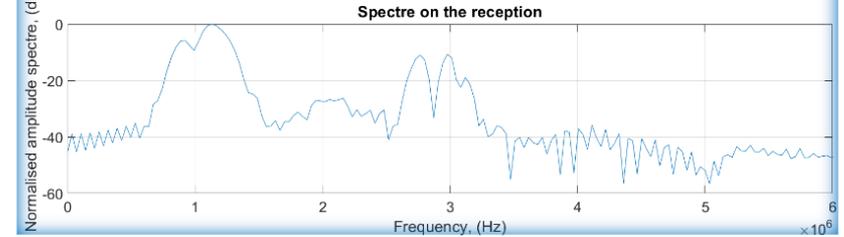
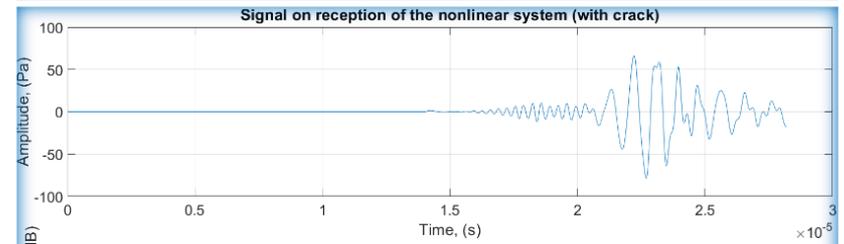
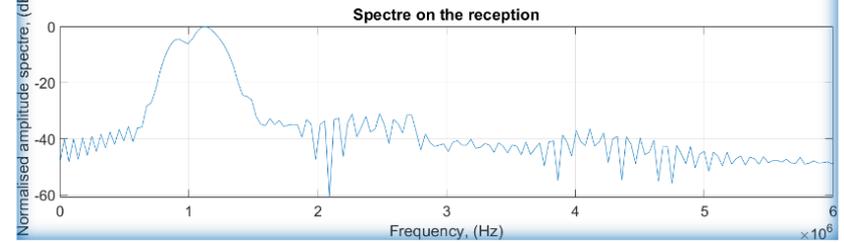
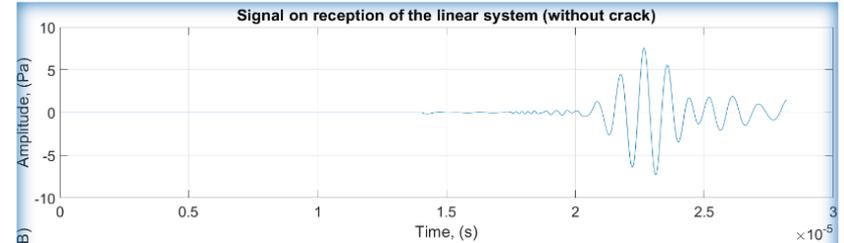
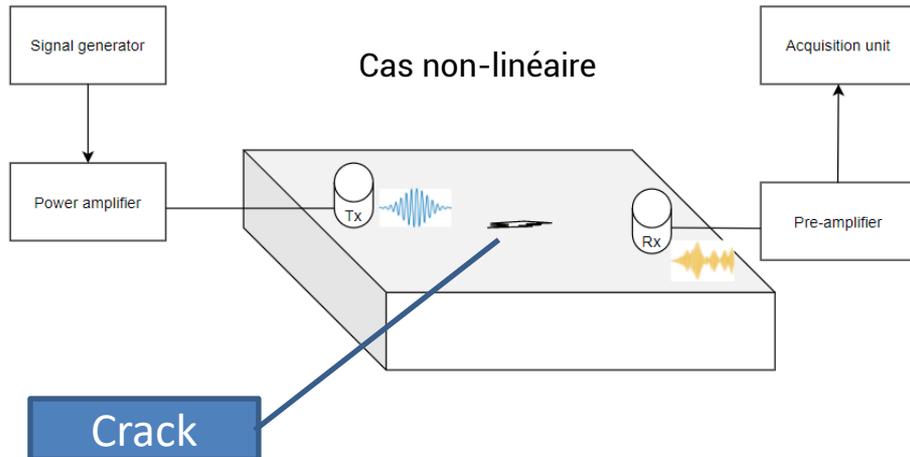
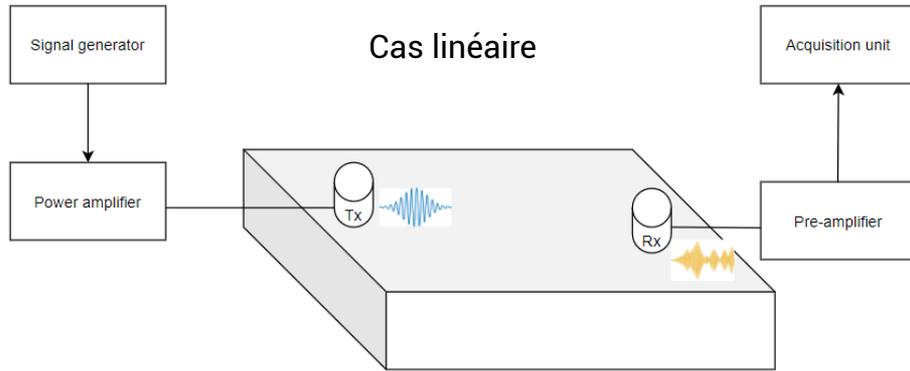
Tx	Band-pass filter [fc = 1MHz]
Rx	Band-pass filter [fc = 3MHz]

2D aluminium plate

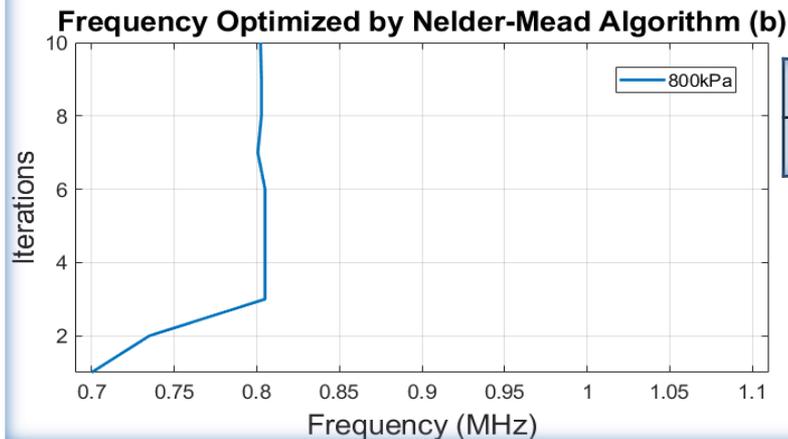
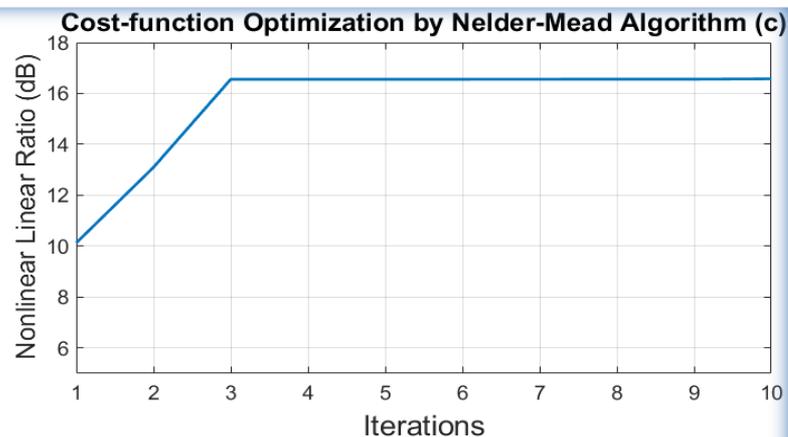
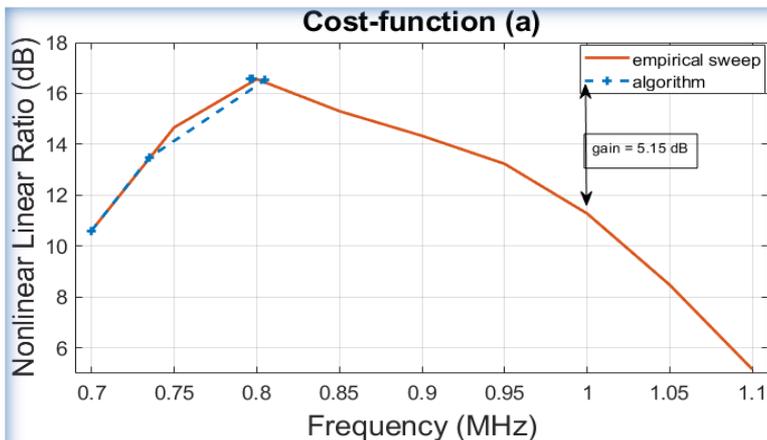


$$x_{ext}(t) = A \cdot \exp\left(-\frac{(t - t_0)^2}{(t_0)^2}\right) \cdot \sin(t \cdot 2\pi \cdot f_{ext})$$





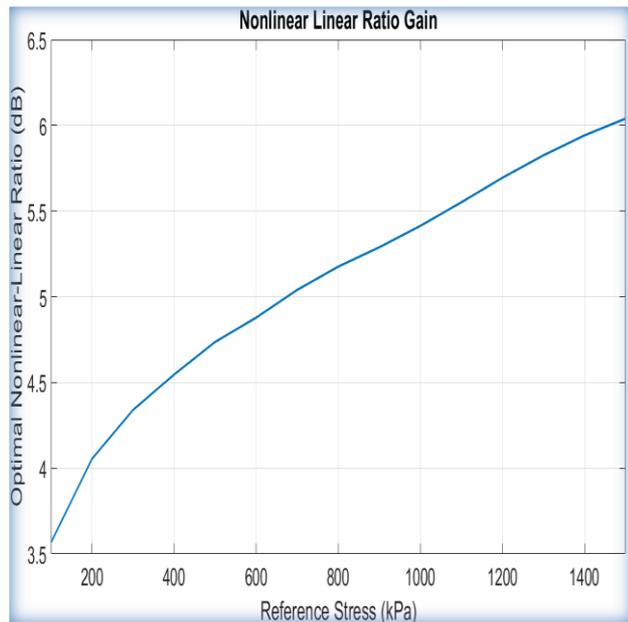
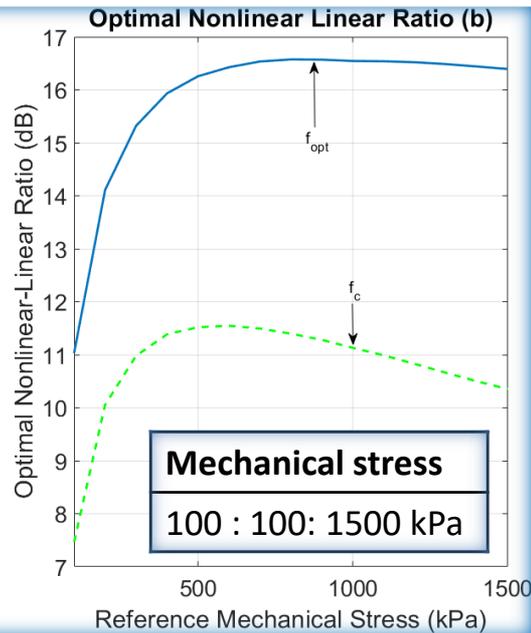
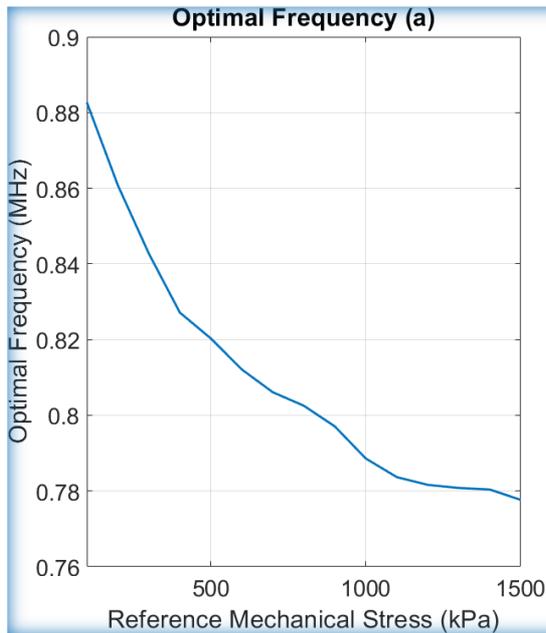
Exemple de optimisation for 800 kPa



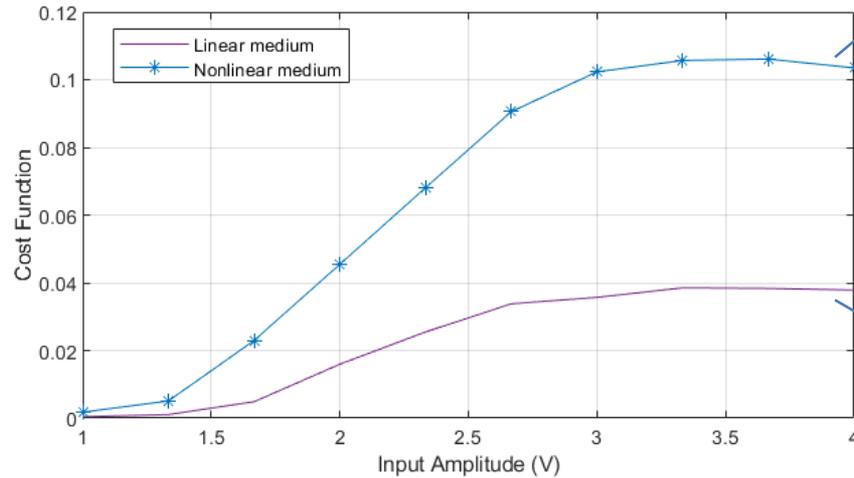
Frequency empirical sweep	Mechanical stress
700:25:1100 kHz	800 kPa (1 kPa = 1000 N/m ²)

The optimal nonlinear ratio and optimal frequency for different stresses

The gain of nonlinear linear ratio between optimal frequencies and central frequency of the transducer



- Mise en place du démonstrateur





CONCLUSION

- **Adaptation de la commande optimale au CND**
 - Cas paramétrique → fréquence
 - Application en simulation
 - *Présentation au Forum Acusticum, Lyon, décembre 2020*
- **Mise en œuvre du démonstrateur**
 - En cours
 - Problématique : plusieurs sources de non-linéarités
 - ➔ Développement de méthode d'extraction des non-linéarités à partir de modèle de Hammerstein



MERCI DE VOTRE ATTENTION

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