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# An Improved Sensor Model for Efficient Guided Wave Based Structural Health Monitoring Simulation

Sanjay SHARMA, Olivier MESNIL, Arnaud RECOQUILLAY and Bastien CHAPUIS

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### Guide Wave-SHM:

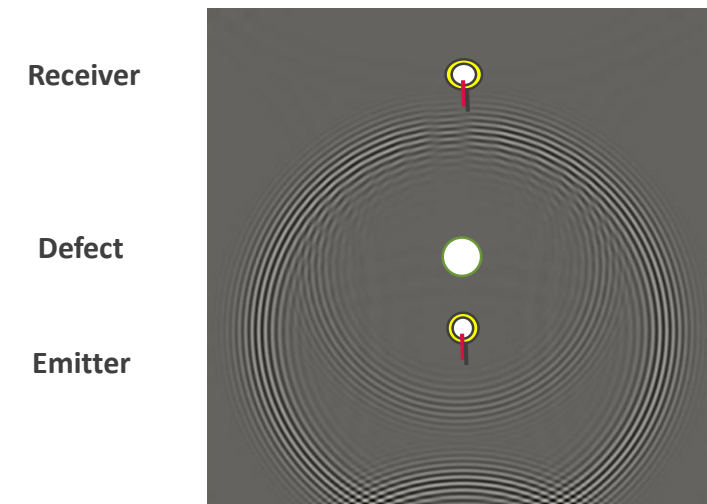
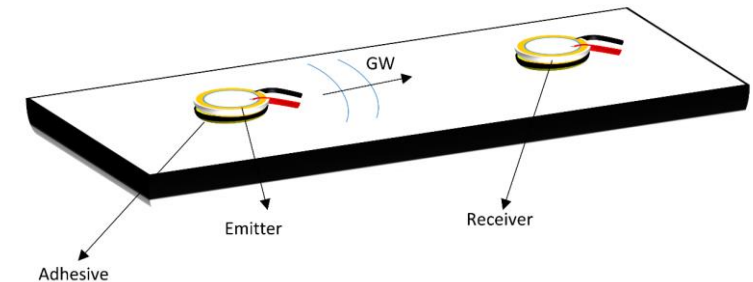
- Permanently installed sensors on the structure to monitor structural health.
- Towards condition-based maintenance.
- Long range propagation
- Applications : Aerospace, Oil&Gas, Nuclear

### Challenges:

- Extensive research has been done but still not undertaken by the industry, especially in **Aerospace**.
- Multimode and sensitive to operational conditions.
- Difficult to describe the damage signature.
- Need of performance demonstration similar to **NDT Probability of Detection ( POD )**.

### Performance demonstration:

- Need lots of **repeated experiments for POD computation**.
- Correct interpretation of damage in the signals.



**Objective :**

- To construct a general methodology and framework to demonstrate the performance of GW-SHM such as NDT via simulations.

**Simulation tools for GW-SHM**

- Mesnil, O. et al, *ASME J Nondestructive Evaluation* “Experimental Validation of Transient Spectral Finite Element Simulation Tools Dedicated to Guided Wave-Based Structural Health Monitoring” **2021**

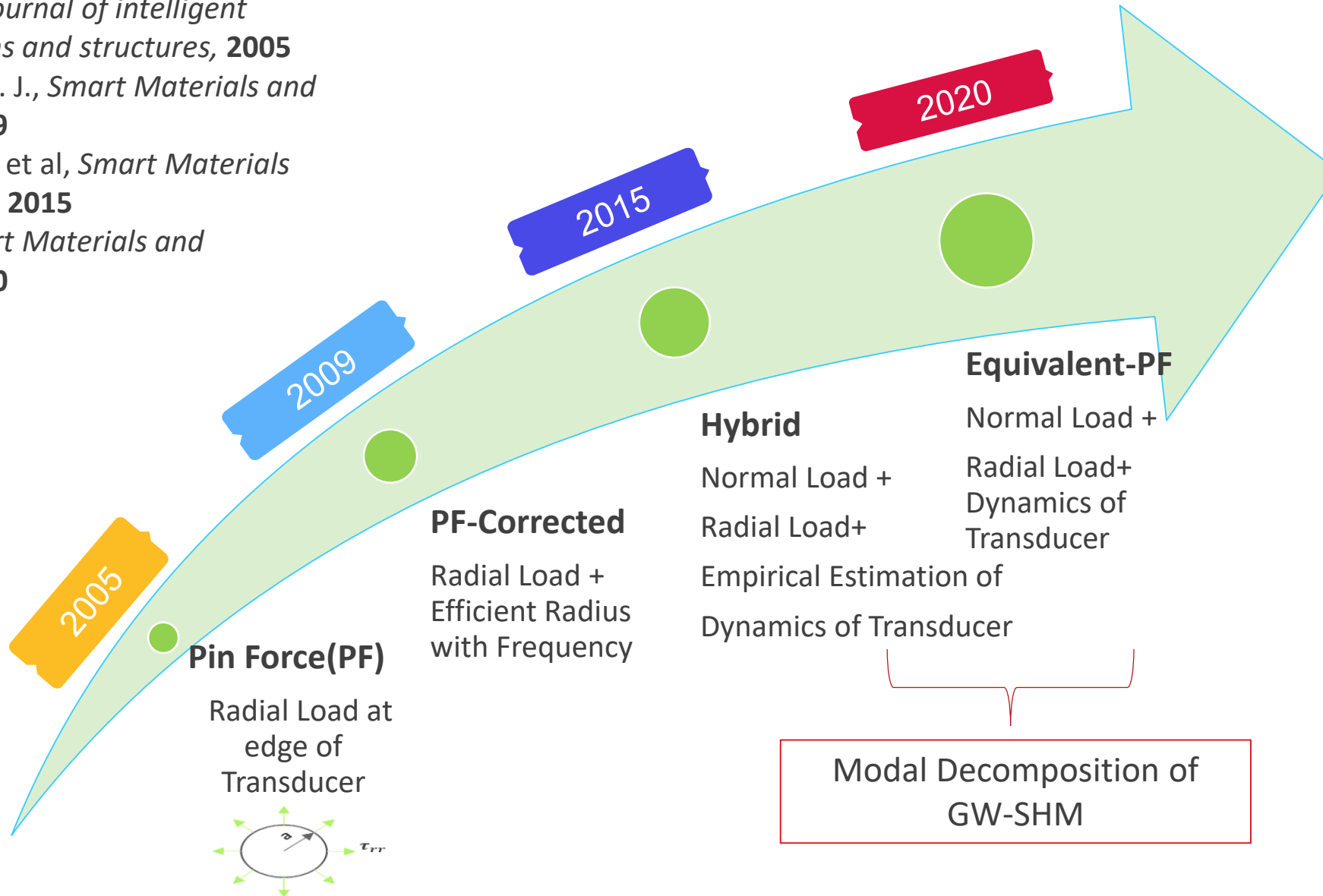
**Objective of this presentation :**

- To improve the transducer model for higher frequency range.

## OUTLINE

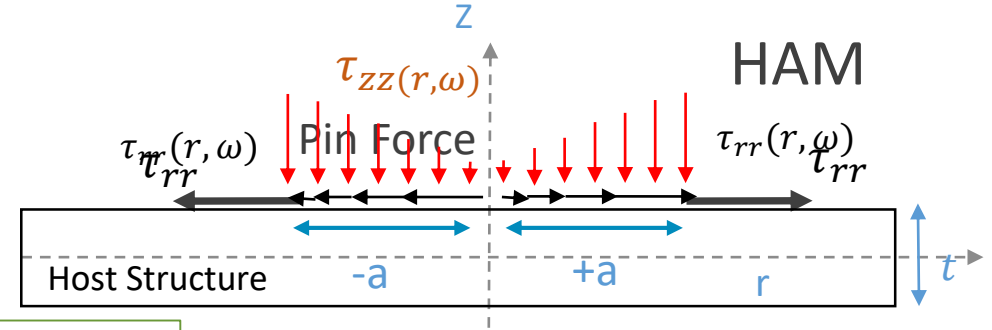
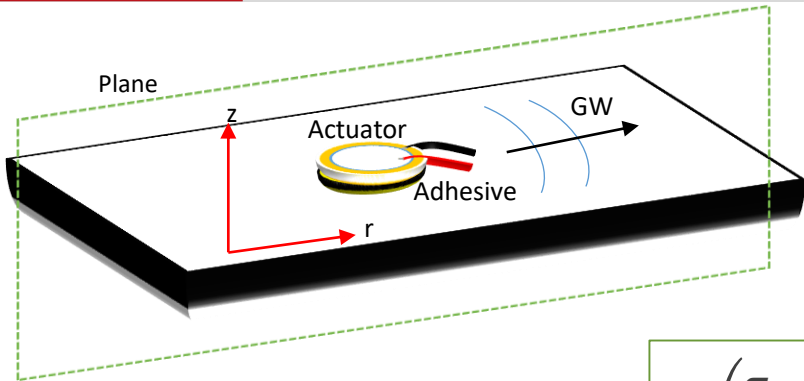
- State of Art
- Theoretical Formulation
- Validation
- Discussion & Conclusion

1. Giurgiutiu, V., *Journal of intelligent material systems and structures*, **2005**
2. Sohn, H. et al, S. J., *Smart Materials and Structures*, **2009**
3. Quaegebeur, N. et al, *Smart Materials and Structures*, **2015**
4. Li, J. et al , *Smart Materials and Structures*, **2020**



## OUTLINE

- Literature Review
- **Theoretical Formulation**
- Validation
- Discussion & Conclusion



Excitation Functions:

$$\begin{pmatrix} \tau_{rr}(r, \omega) \\ \tau_{zz}(r, \omega) \end{pmatrix} = \begin{pmatrix} a_e^{rr} \tau^{rr}(\omega) \delta(r - a_e^{rr}) \\ a_e^{zz} \tau^{zz}(\omega) \delta(r - a_e^{zz}) \end{pmatrix}$$

Dynamics of Transducer:

$$\begin{pmatrix} \tau^{rr}(\omega) \\ \tau^{zz}(\omega) \end{pmatrix} = \frac{1}{a_e^2} \begin{pmatrix} \int_0^a \tau_{rr}(r, \omega) r dr \\ \int_0^a \tau_{zz}(r, \omega) r dr \end{pmatrix}$$

Estimation of  $a_e$ :

$$a_e = \left| \frac{Y_{bondedPiezo}(\omega)}{Y_{freePiezo}(\omega)} \right| a$$

Assumptions :

- Coupled dynamics of Transducer and adhesive are independent of space excitation.
- Effective radius :  $a_e^{rr} = a_e^{zz} = a_e$

Integration over the area of Transducer  $dA = 2\pi r dr$ .

Where :

$a$  = radius of PZT transducer

$a_e^{rr}, a_e^{zz}$  = effective point excitation for the  $r$  direction load and  $z$  direction load

$\tau^{rr}(\omega), \tau^{zz}(\omega)$  = Frequency dependent term for  $r$  direction and  $z$  direction

$Y_{freePiezo}(\omega)$  = admittance of free Piezo,  $Y_{bondedPiezo}(\omega)$  = admittance of bonded piezo

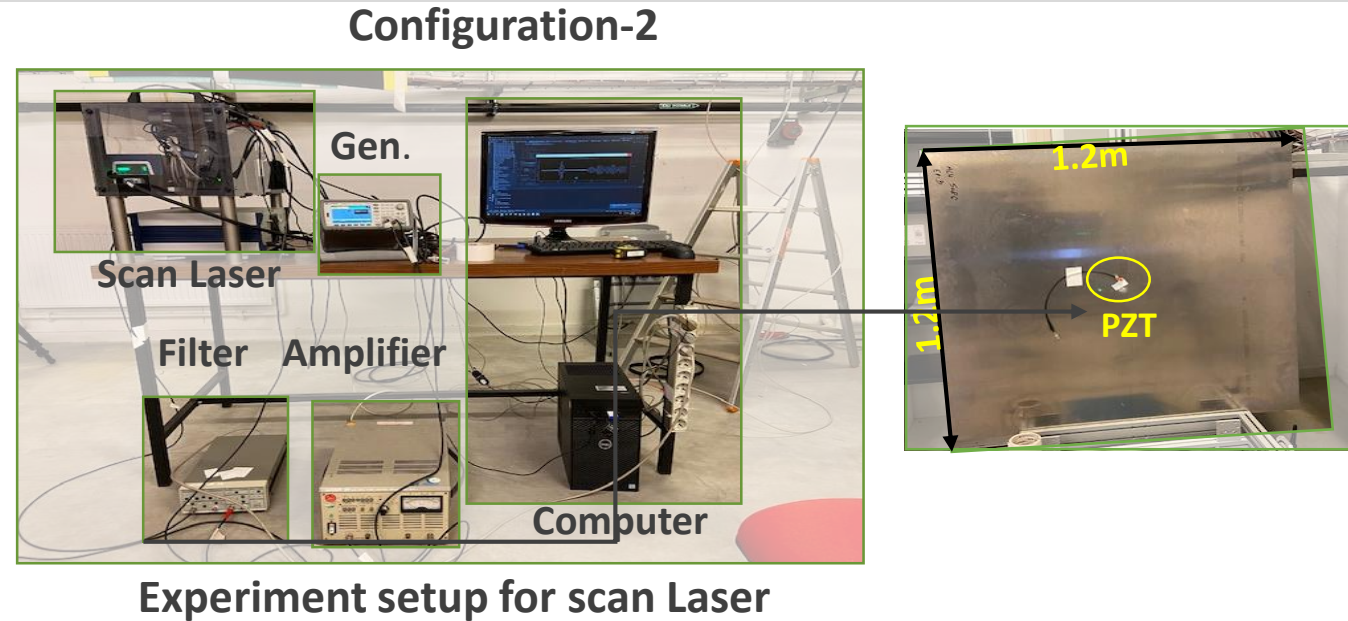
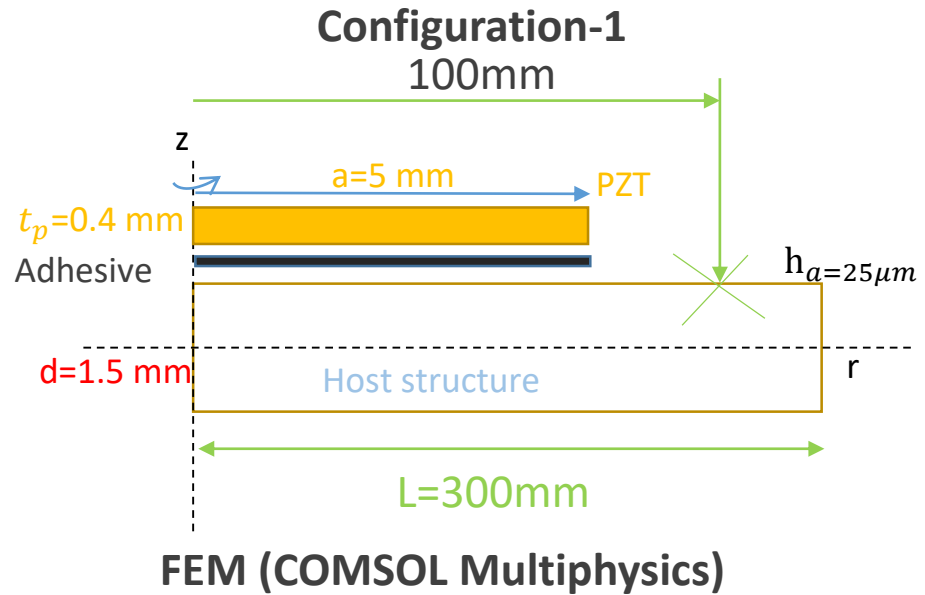
Sohn, H. & Lee, S. J.

Lamb wave tuning curve calibration for surface-bonded piezoelectric transducers  
*Smart Materials and Structures*, IOP Publishing, 2009, 19, 015007

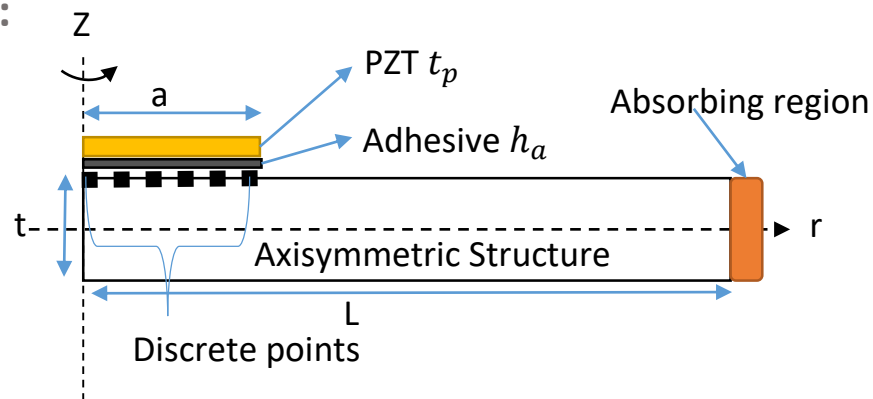


## OUTLINE

- Literature Review
- Theoretical Formulation
- **Validation**
- Discussion & Conclusion



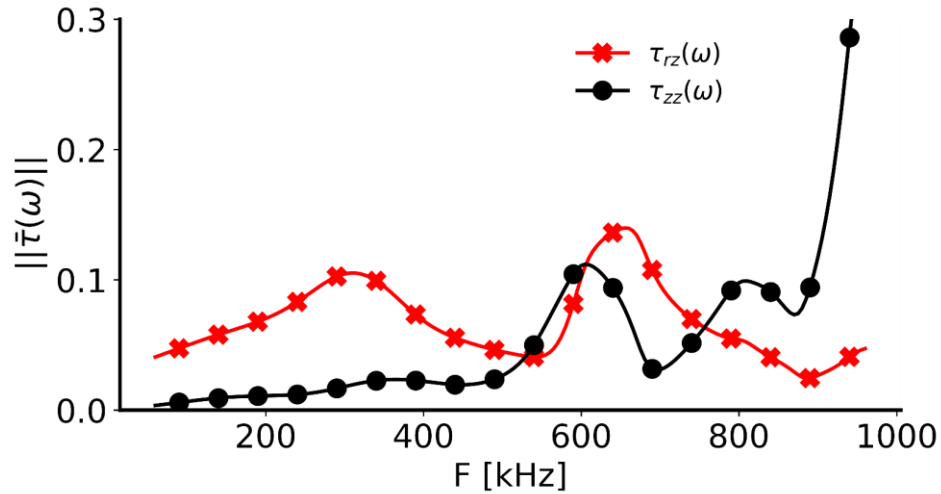
Computation of  $\tau_{rr}(r, \omega)$  and  $\tau_{zz}(r, \omega)$ :



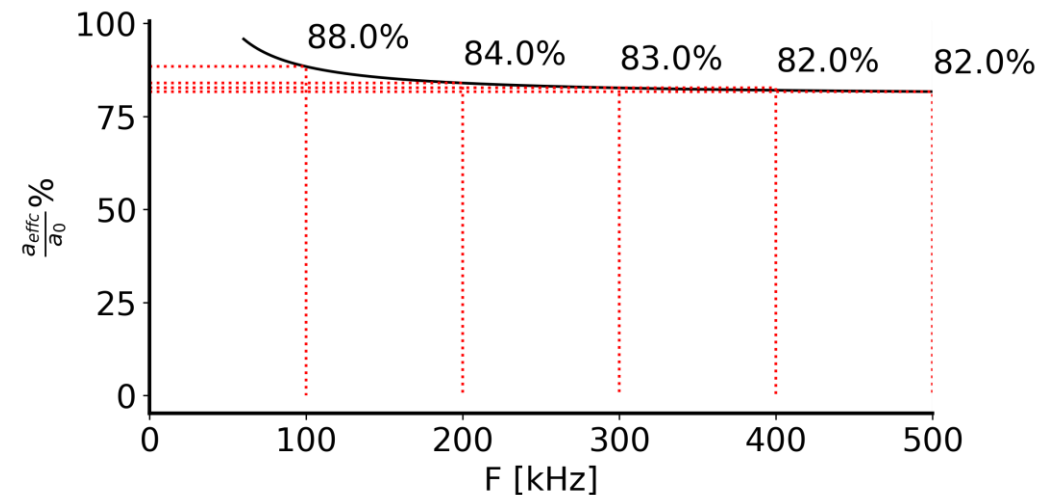
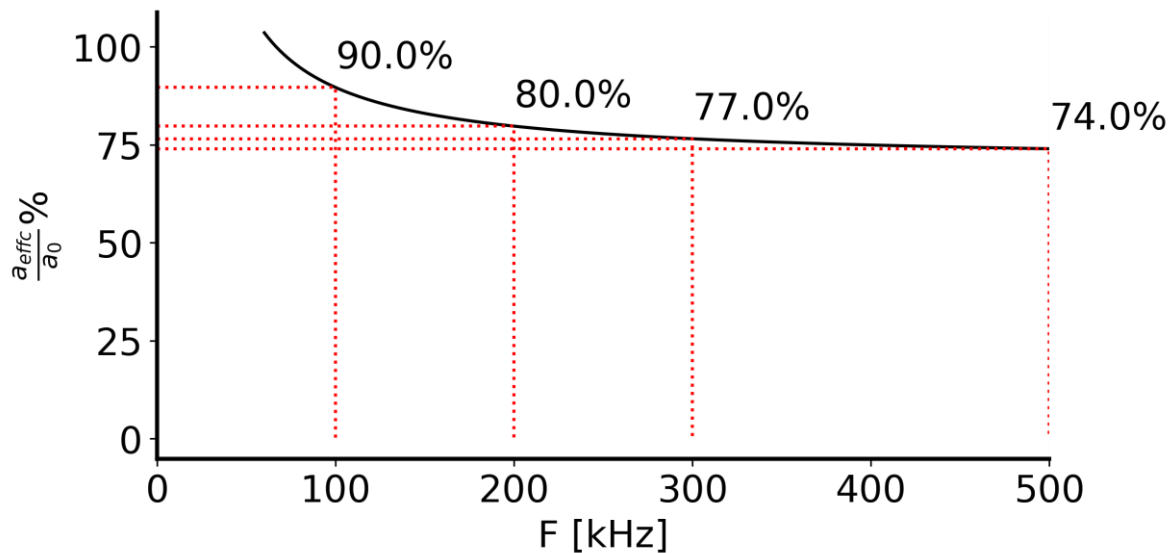
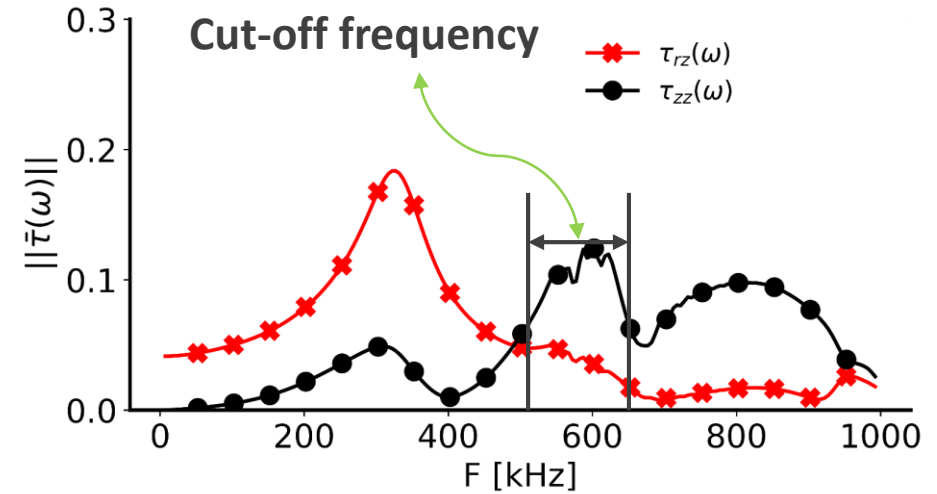
Analysis:

- Frequency range of interest :
  - For each  $\omega_i$   
 $\tau_{rr}(r, \omega_i)$  and  $\tau_{zz}(r, \omega_i)$

Configuration-1



Configuration-2

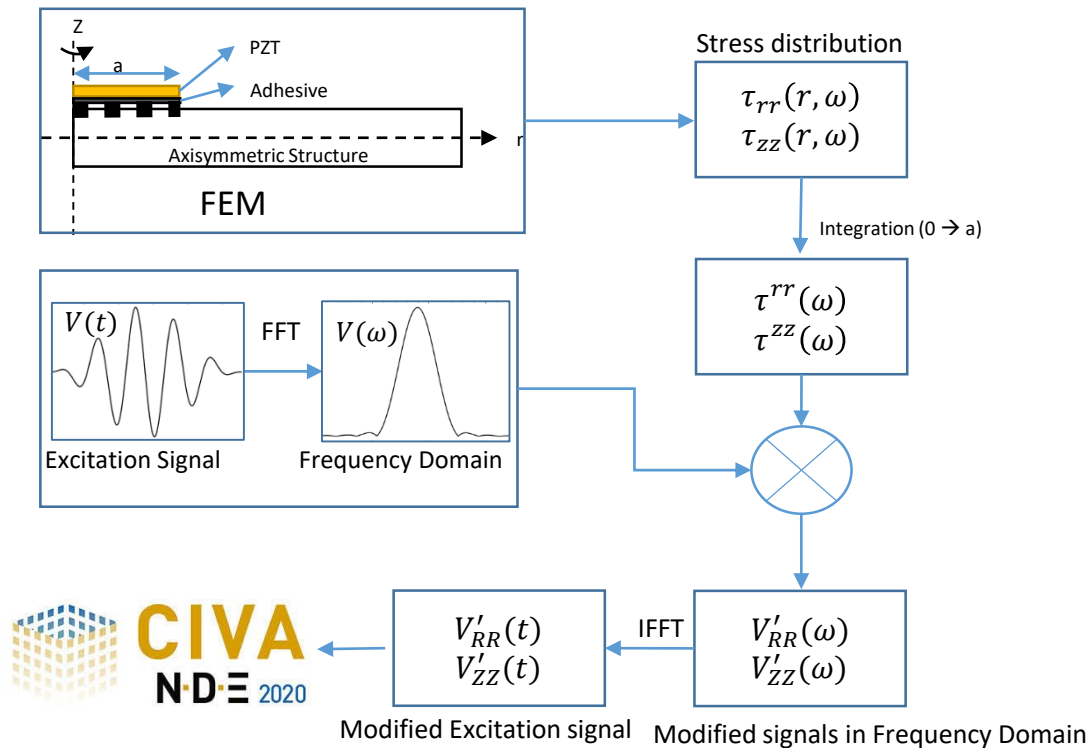


- Transient Spectral Finite Element Simulation (CIVA)

- Input of Excitation Function:

- Pin force Model (Previous Model):  $\tau_{rr} = \tau_0 [\delta(x - a)]$

- HAM input:

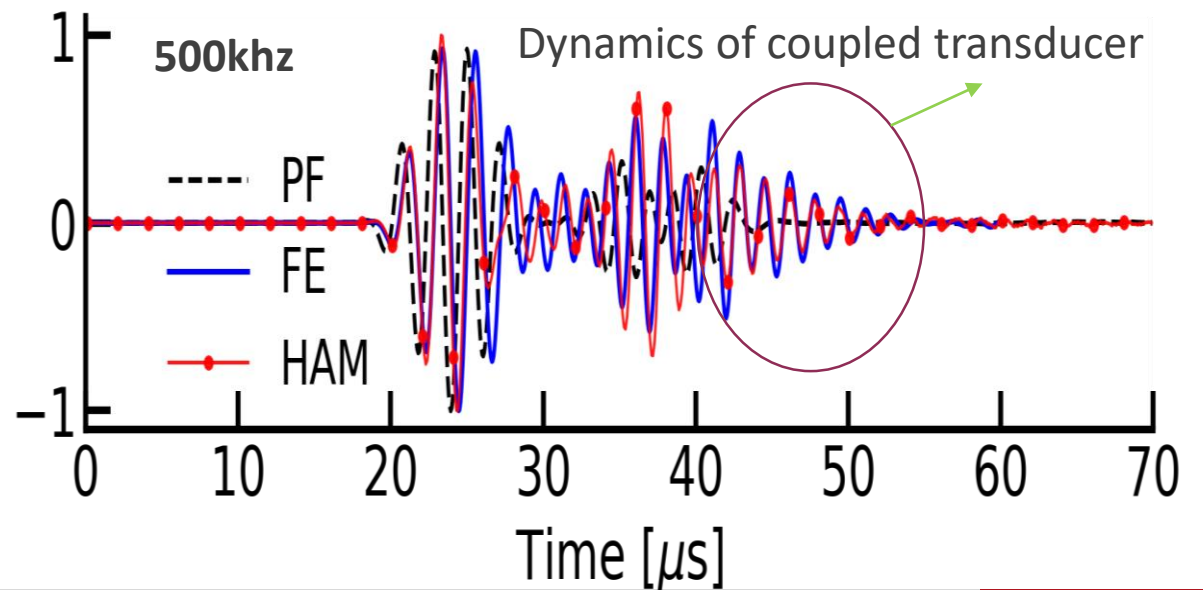
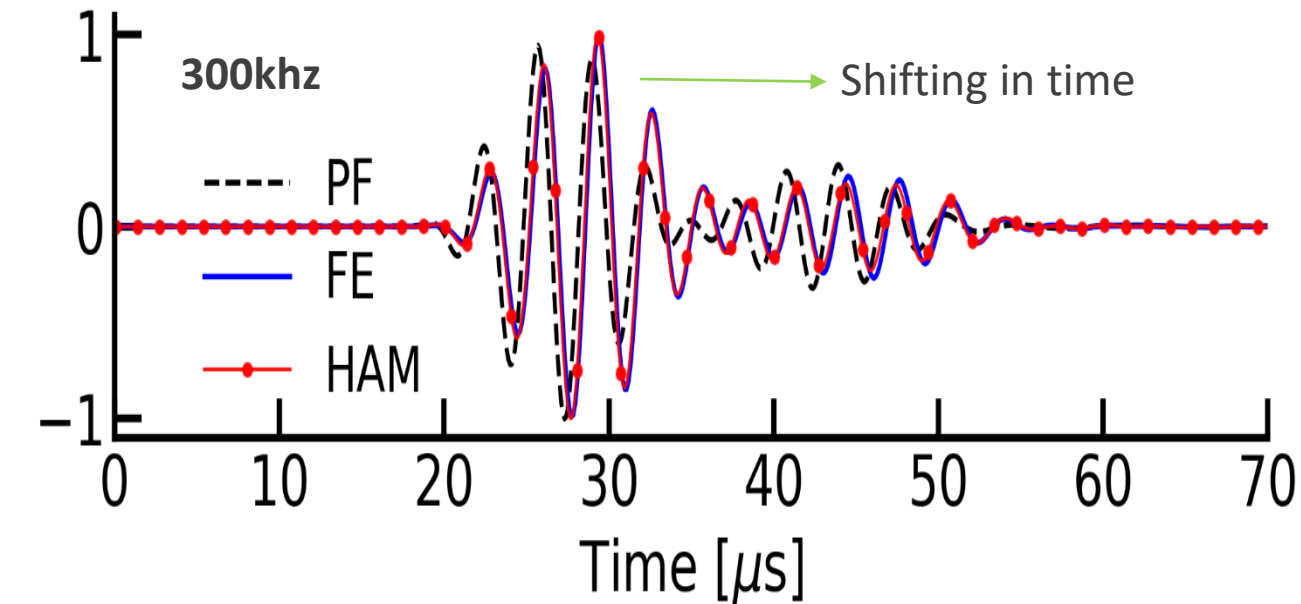
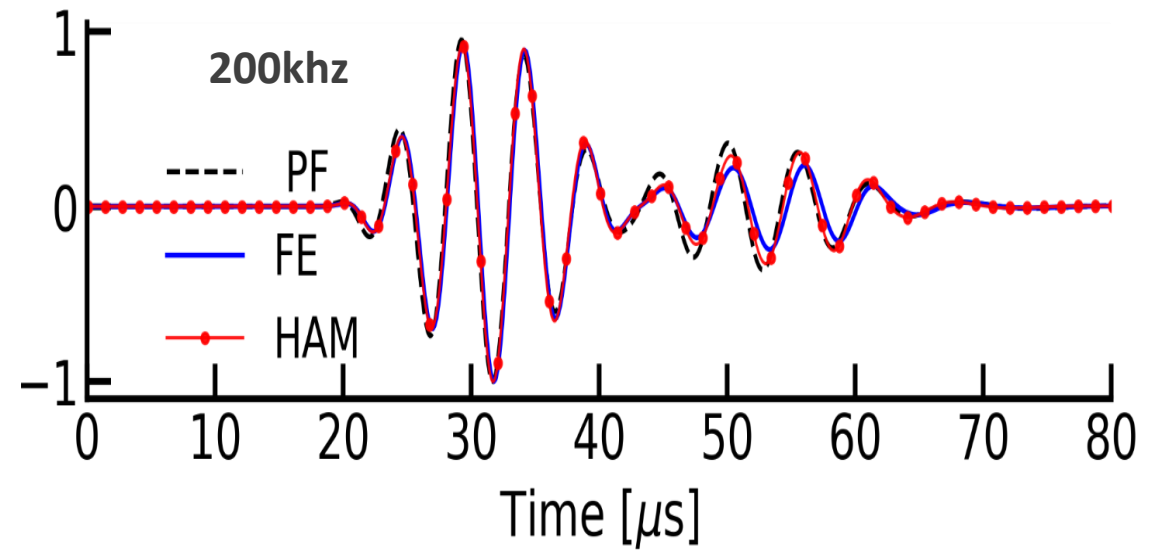
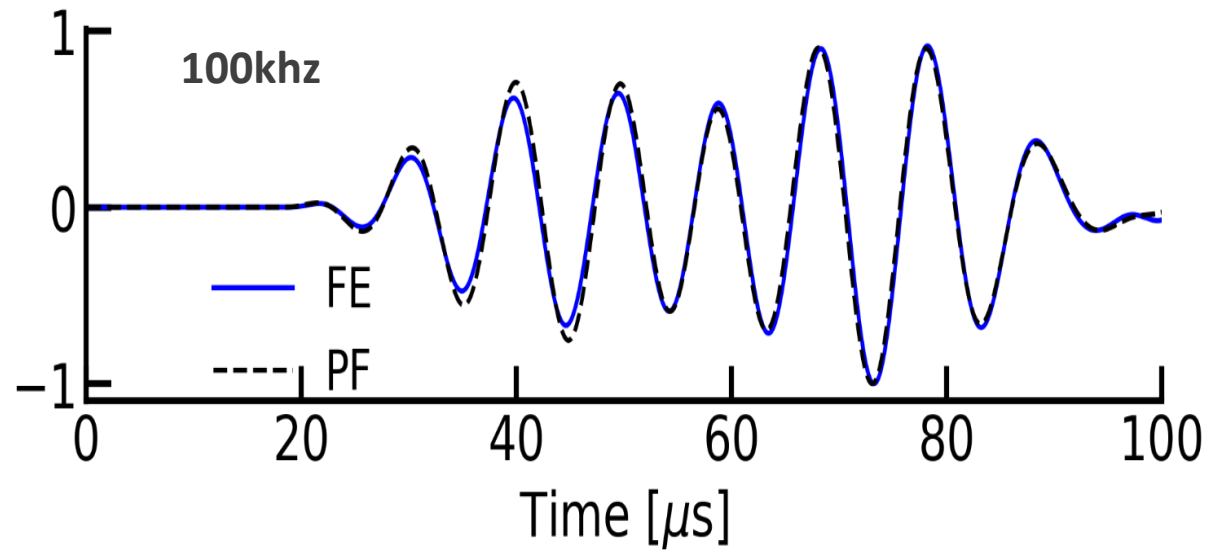


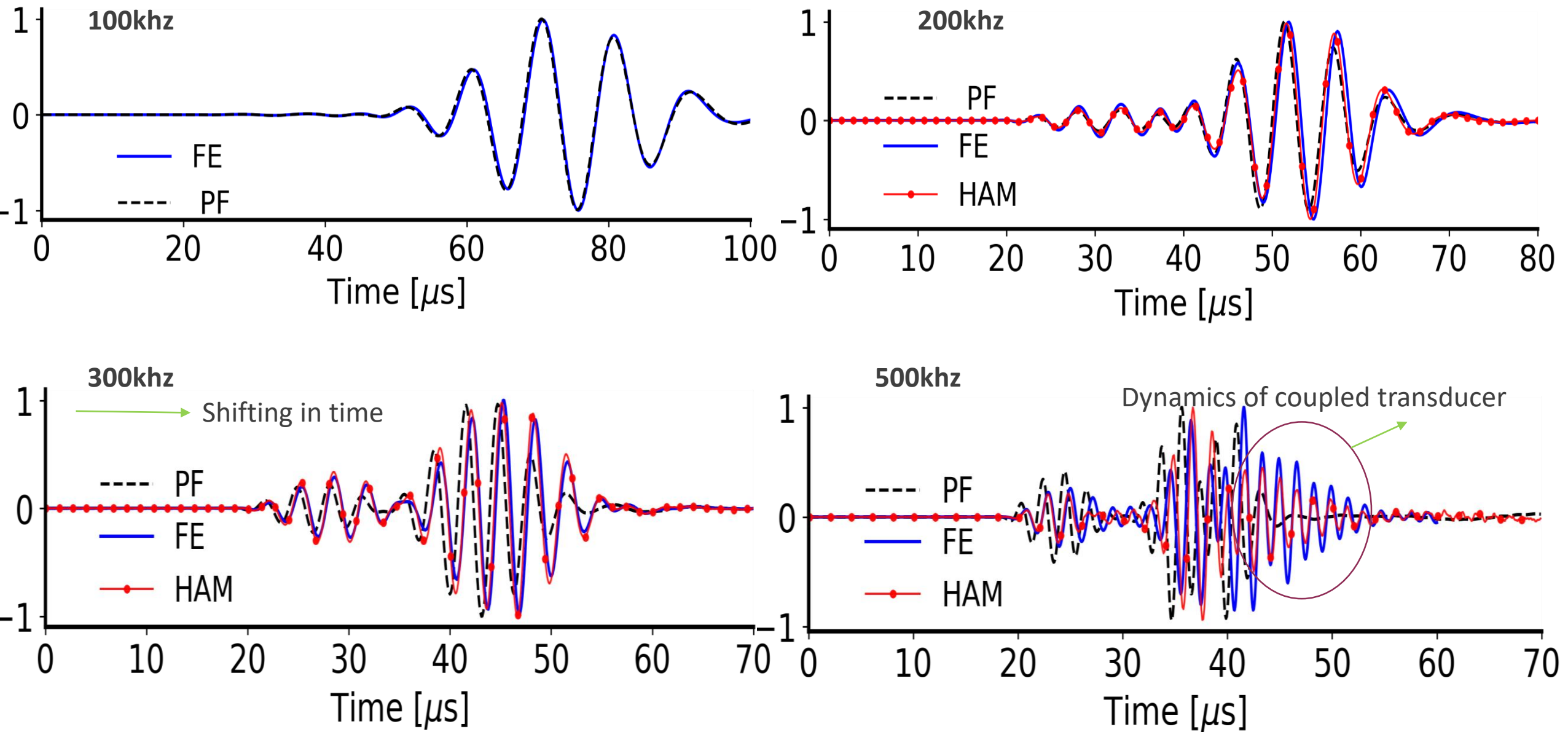
- Study:

- Time domain
- Displacement Field

# Numerical Validation

## Configuration: 1



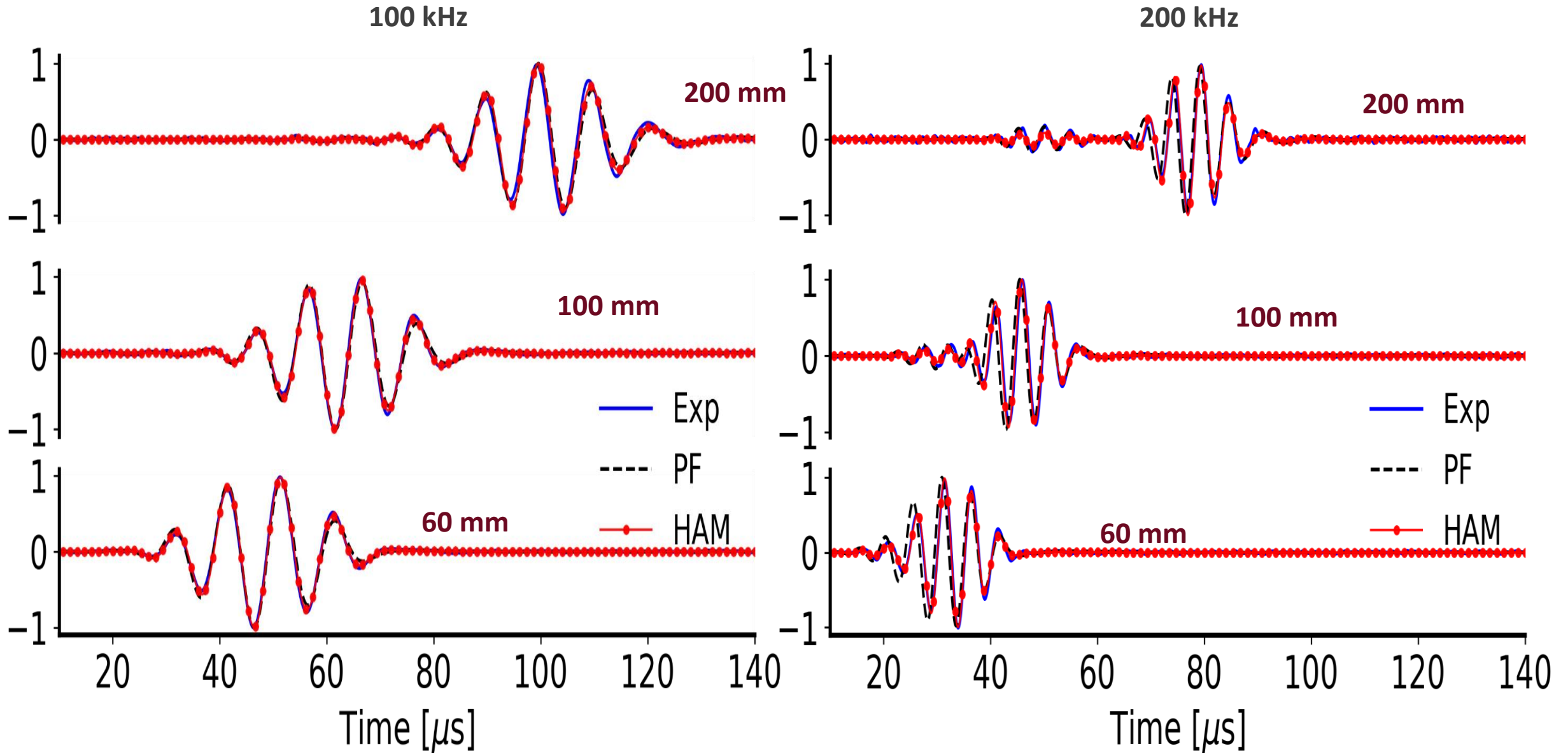


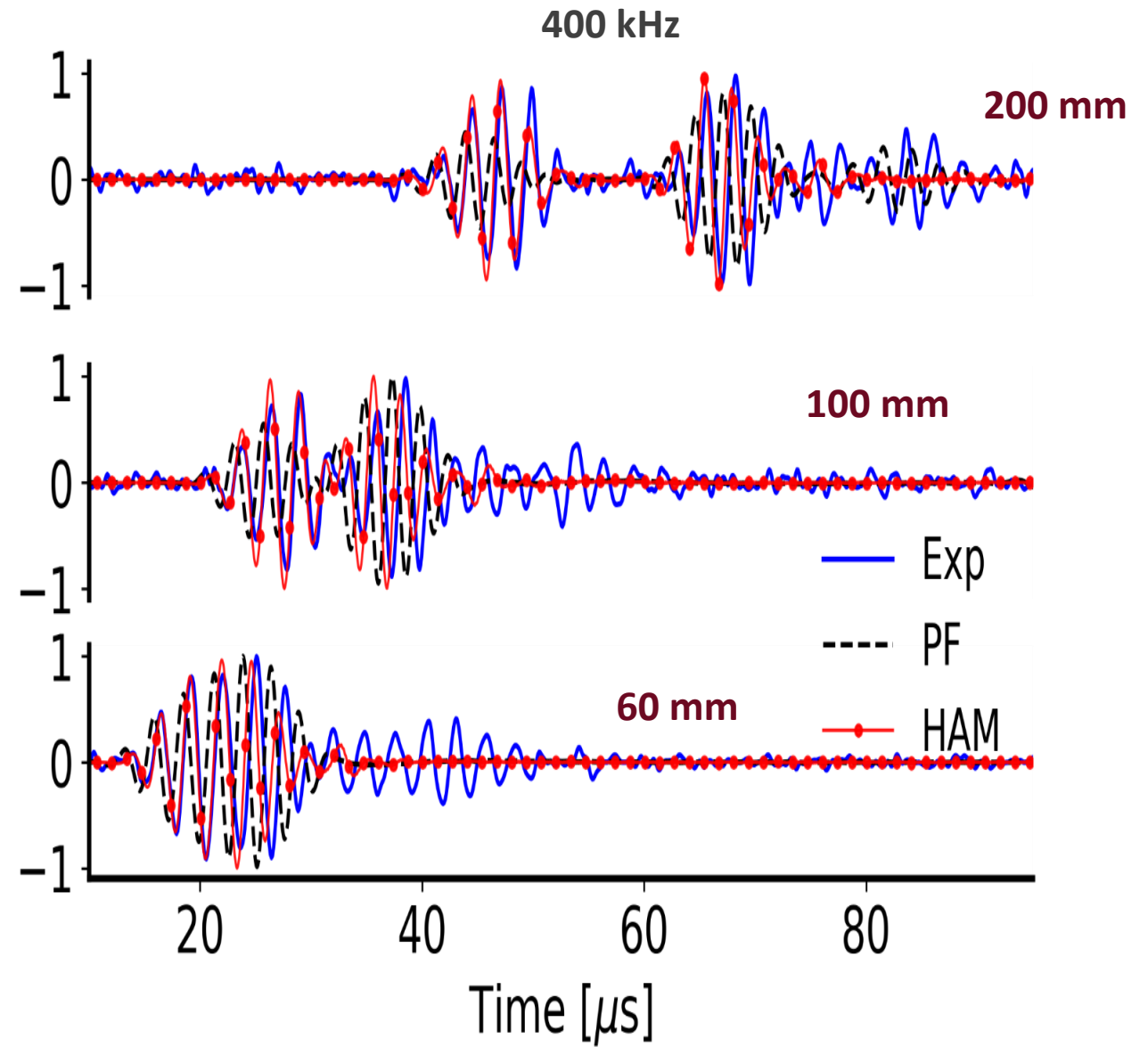
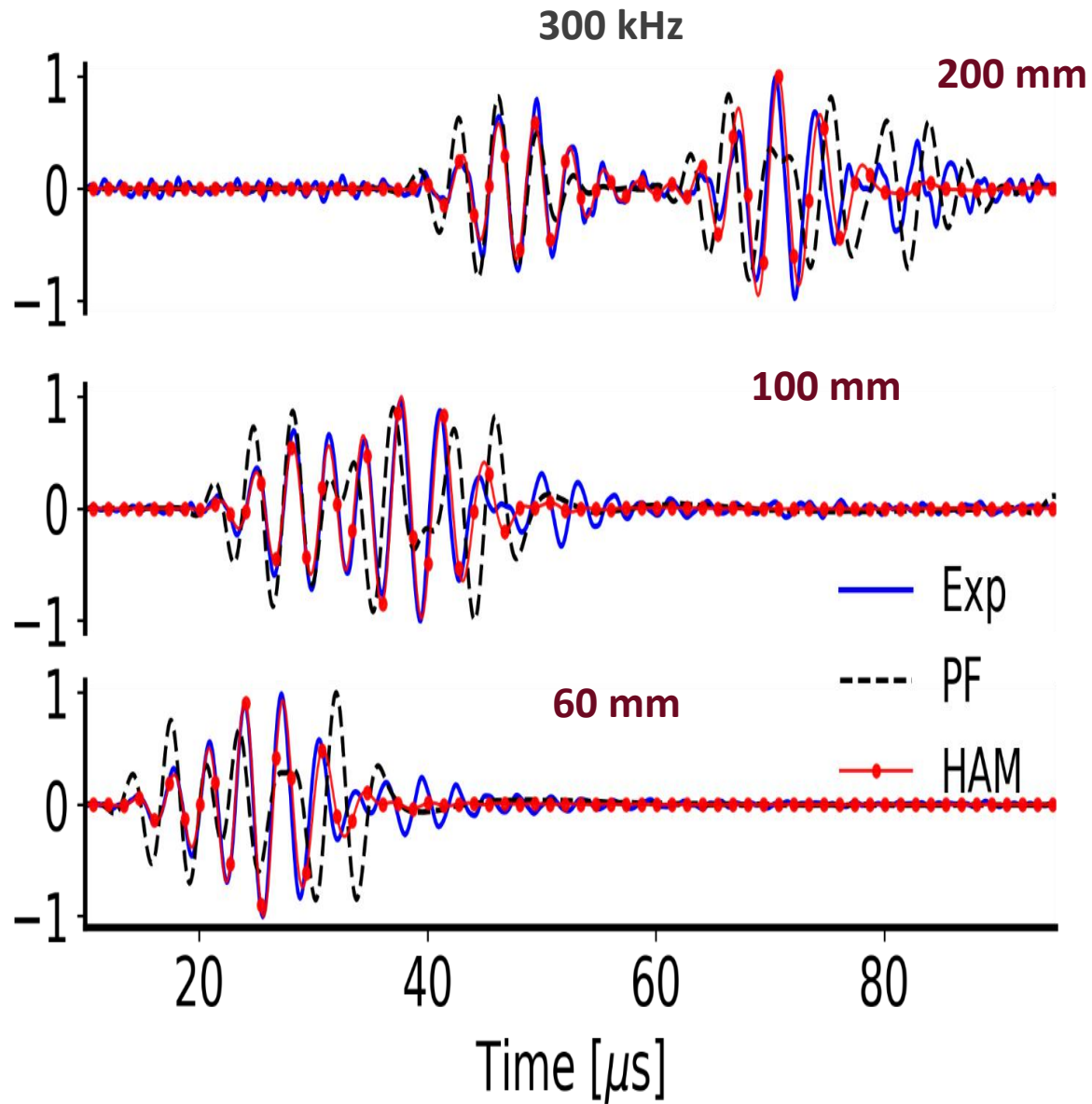


# Experimental Validation

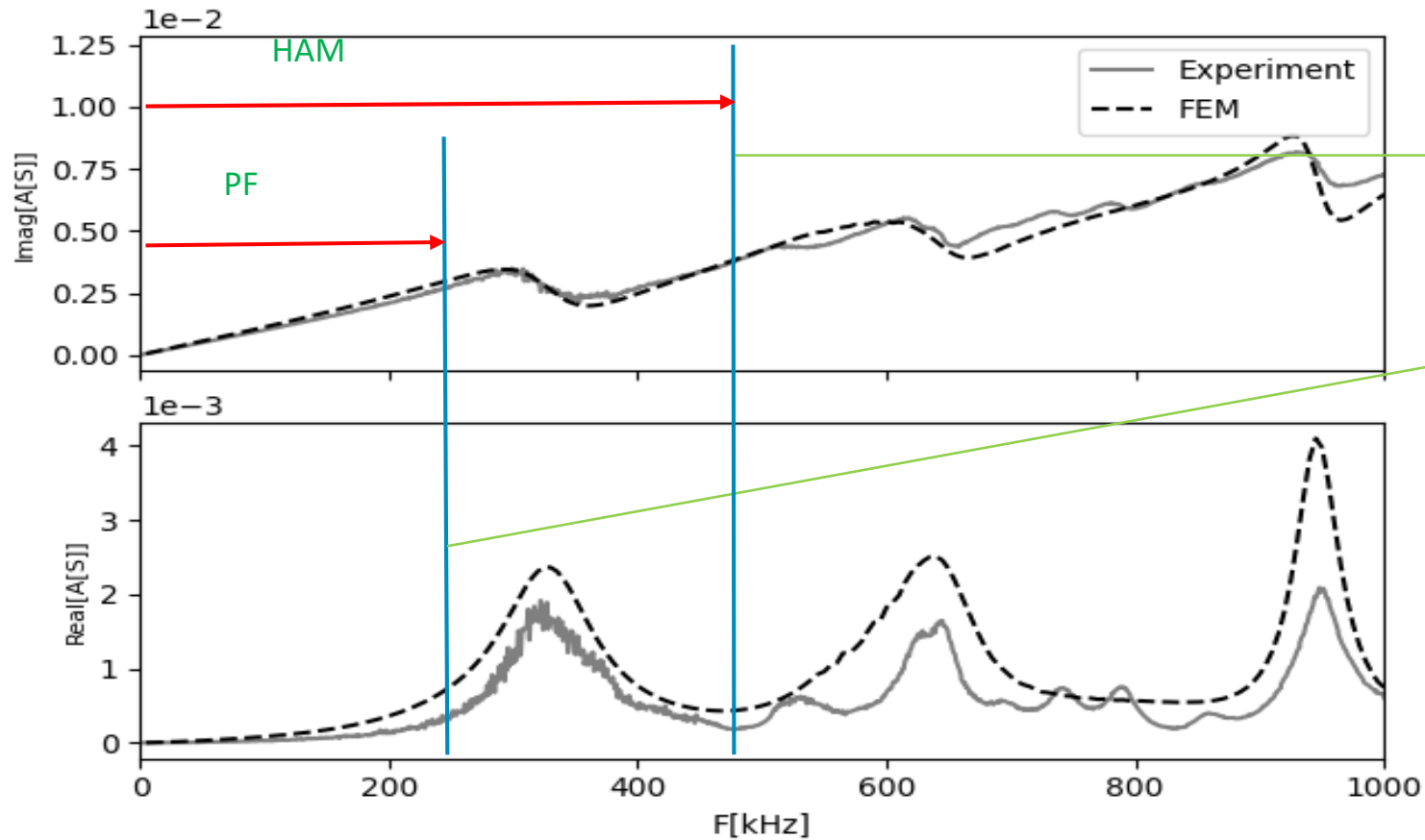
## Configuration: 2







Admittance Curve for Epoxy-Bonded PZT



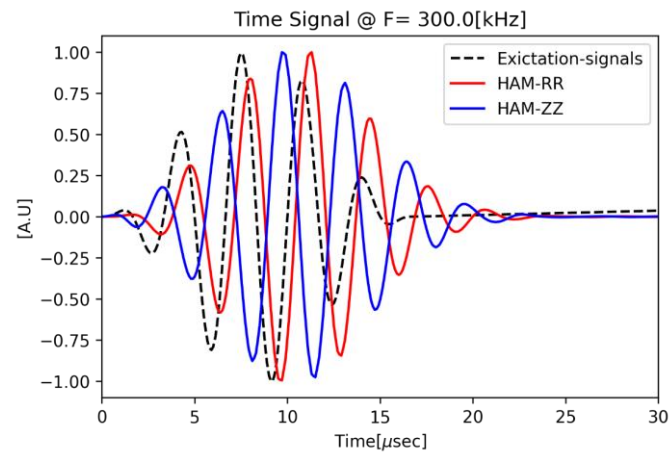
Validate after the First Natural Frequency

Validate up to 200kHz

## OUTLINE

- Literature Review
- Theoretical Formulation
- Validation
- Discussion & Conclusion

- Increased the validation range above the first natural frequency of transducer.
- Transducer-adhesive dynamics → phase shift + amplitude difference
- Coupled transducer dynamics (normal + radial) + effective radius → Improvement of GW signals at higher frequencies (both simulations and experiments)
  - Material properties of the host structure, adhesive, and thickness of adhesive layer → change in admittance



- **Future work**
  - Model assisted probability of detection

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