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Smart UWSS

INVERSE METHODS FOR BLOCKAGE DETECTION IN PIPELINES

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CAUSE OF BLOCKAGE IN WATER SUPPLY PIPES

- DEPOSITION OF MINERALS

- FORMATION OF ICE IN COLD CLIMATE

INEFFICIENCIES CAUSED BY BLOCKAGES

- ENERGY LOSS

- INCREASE IN POTENTIAL CONTAMINATION

- INCREASE IN POTENTIAL LEAKS

- NON SATISFACTION OF COSTUMERS

Blockage detection is important

OUTLINE OF THE PRESENTATION

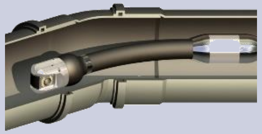
- BLOCKAGE DETECTION METHODS IN THE **LITERATURE**
  - FREQUENCY RESPONSE ANALYSIS
  - PERTURBATION BASED METHOD
  - OTHER METHODS
- **PROPOSED** BLOCKAGE DETECTION METHODS
  - MATCHED FIELD PROCESSING
  - IMPULSE RESPONSE METHOD

HOW TO IDENTIFY BLOCKAGES ?

Visualization

- No Visual trace

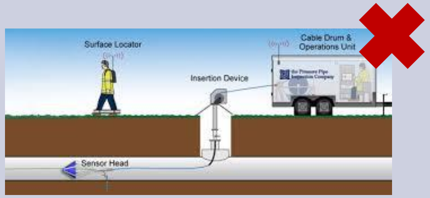
- Camera inspections



>> Very expensive
(Note: >8000 Km of pipes in HK)

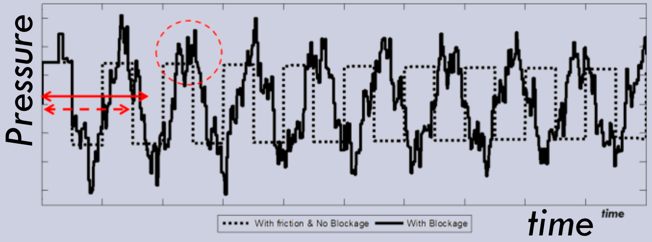
Listening

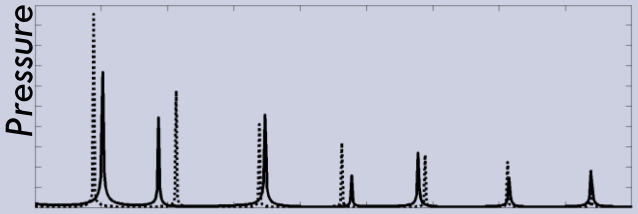
- Do not induce a detectable sound, if passively inspected



Transient

- Acoustic waves propagation is modified by the presence of defects





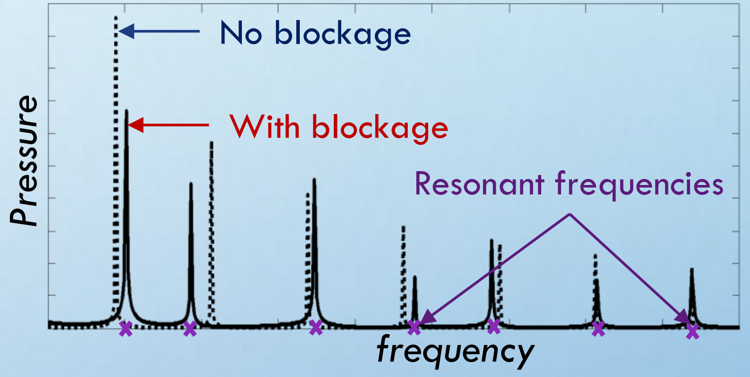
BLOCKAGE DETECTION METHODS:

1. Frequency Response Analysis (FRA) method (Duan et al., 2012)

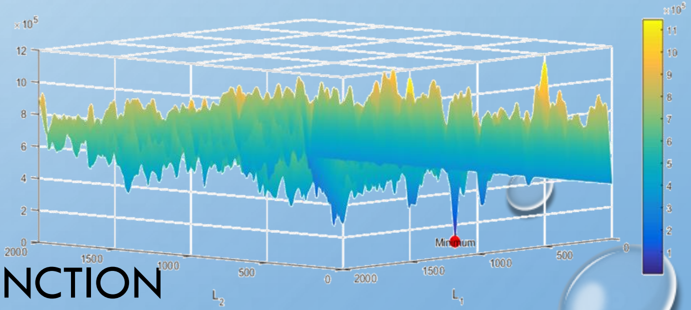
- IDEA OF THE METHOD

$$f(\omega, l_1, l_2, \delta A) = 0$$

$$\underset{l_1, l_2, \delta A}{\arg\min} \sum_i |f(\omega_i, l_1, l_2, \delta A)|$$



- ADVANTAGES
  - INDEPENDENT OF THE INPUT SIGNAL
  - INDEPENDENT OF THE MEASUREMENT LOCATION



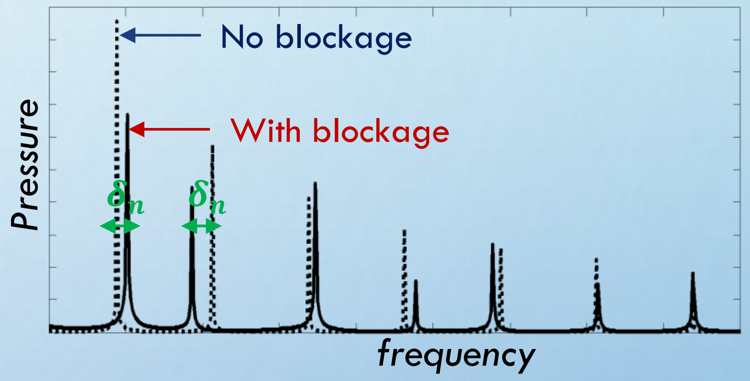
- LIMITATIONS
  - OPTIMIZATION OF **AT LEAST 3 VARIABLES** OF A **HIGHLY NON-CONVEX** FUNCTION
  - REQUIRE ACCURATE IDENTIFICATION OF THE RESONANT FREQUENCIES

BLOCKAGE DETECTION METHODS:

2. Perturbation-based method (Schroeder, 1966)

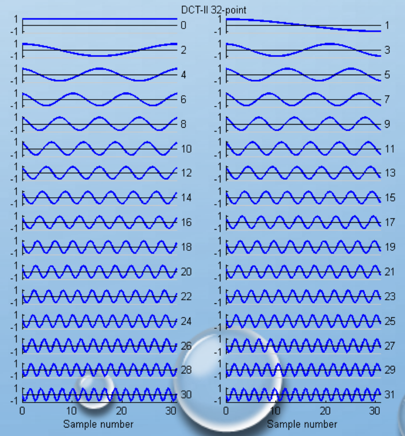
- IDEA OF THE METHOD

$$A(x) = A_0 \exp\left[-\sum_{n=1}\left(\frac{L}{n\pi}\right)^2 \delta_n \cos\left(\frac{2n\pi x}{L}\right) - \sum_{n=1}\left(\frac{2L}{(2n-1)\pi}\right)^2 \gamma_n \cos\left(\frac{(2n-1)\pi x}{L}\right)\right]$$



- ADVANTAGES
  - EASY TO IMPLEMENT

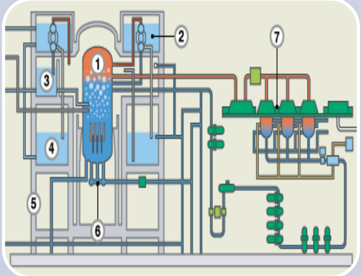
- LIMITATIONS
  - ASSUMES SMALL CHANGE IN AREA
  - RESTRICT THE AREA TO A **FOURIER-BASED FUNCTION**
  - **SLOW CONVERGENCE** TO THE ACTUAL AREA



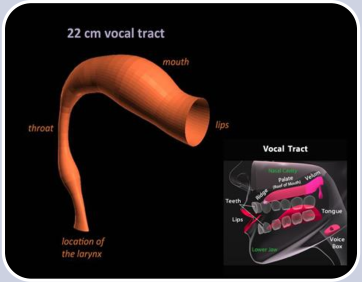
BLOCKAGE DETECTION METHODS:

3. Other methods

Blockage detection in Sewage lines



Blockage detection in nuclear reactors



Vocal tract shape reconstruction

Design of musical instruments

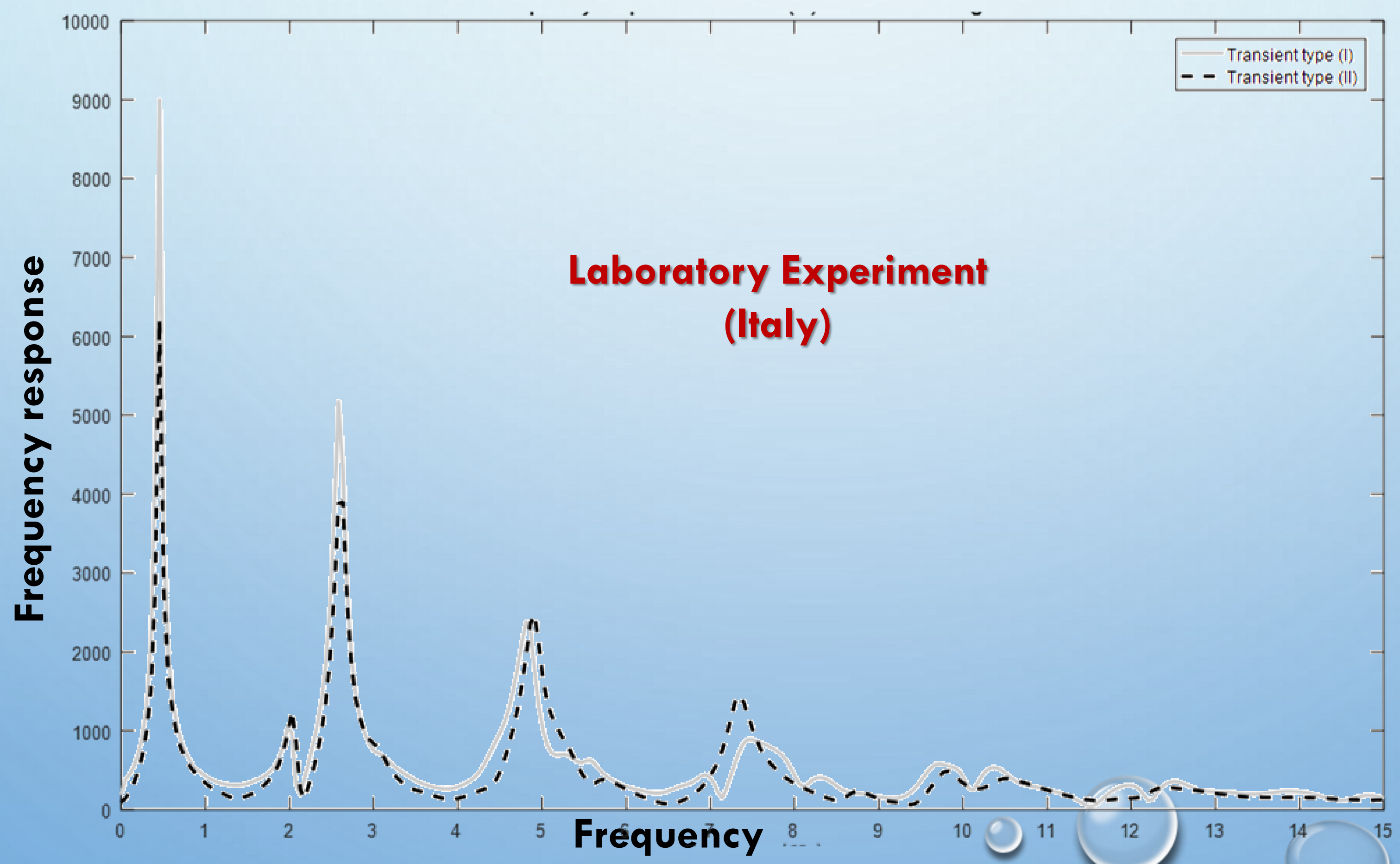
Identification of conductivity in electrical lines

PROPOSED BLOCKAGE DETECTION METHODS

- **MATCHED FIELD PROCESSING (MFP) METHOD**
  - FREQUENCY DOMAIN METHOD
- **IMPULSE RESPONSE METHOD**
  - TIME DOMAIN METHOD

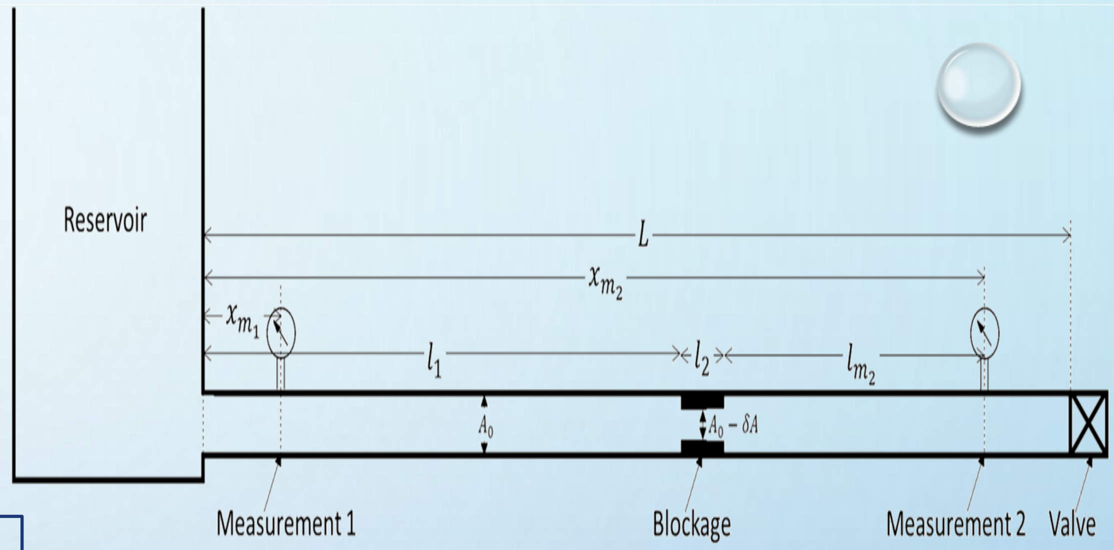
MATCHED-FIELD PROCESSING (MFP) METHOD

MOTIVATION



Frequency response
Frequency
Laboratory Experiment
(Italy)
Transient type (I)
Transient type (II)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
7
8
9
10
11
12
13
14
15

MODEL BASED MFP



Using the Transfer matrix method:

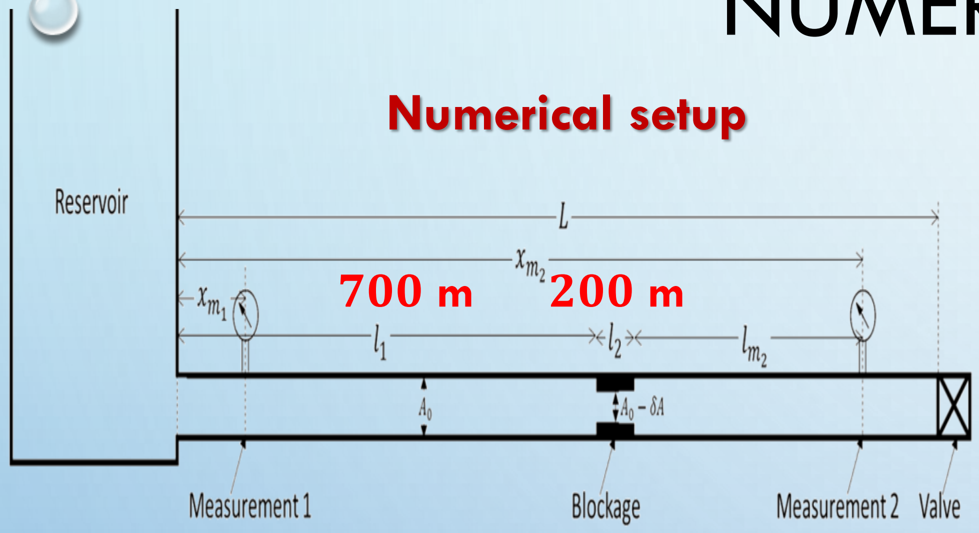
$$\underbrace{\boldsymbol{S}_{\boldsymbol{m}_i}}_{\text{Measurement}} = \underbrace{\boldsymbol{G}_{\boldsymbol{m}_i}(l_1, l_2)\boldsymbol{\alpha}(\delta A)}_{\text{Model}} + \underbrace{\mathbf{n}}_{\text{Noise}}$$

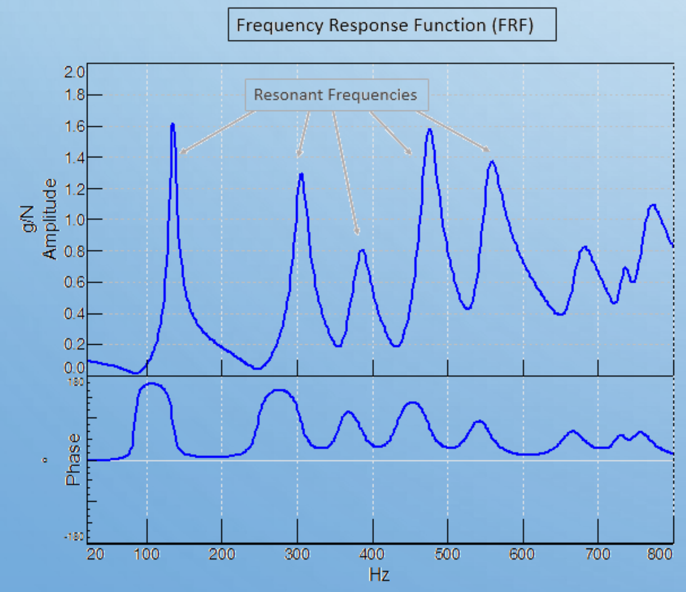
Matched-Field Processing (**MFP**) Approach: Similar to (Wang X. & Ghidaoui M. S., 2017)

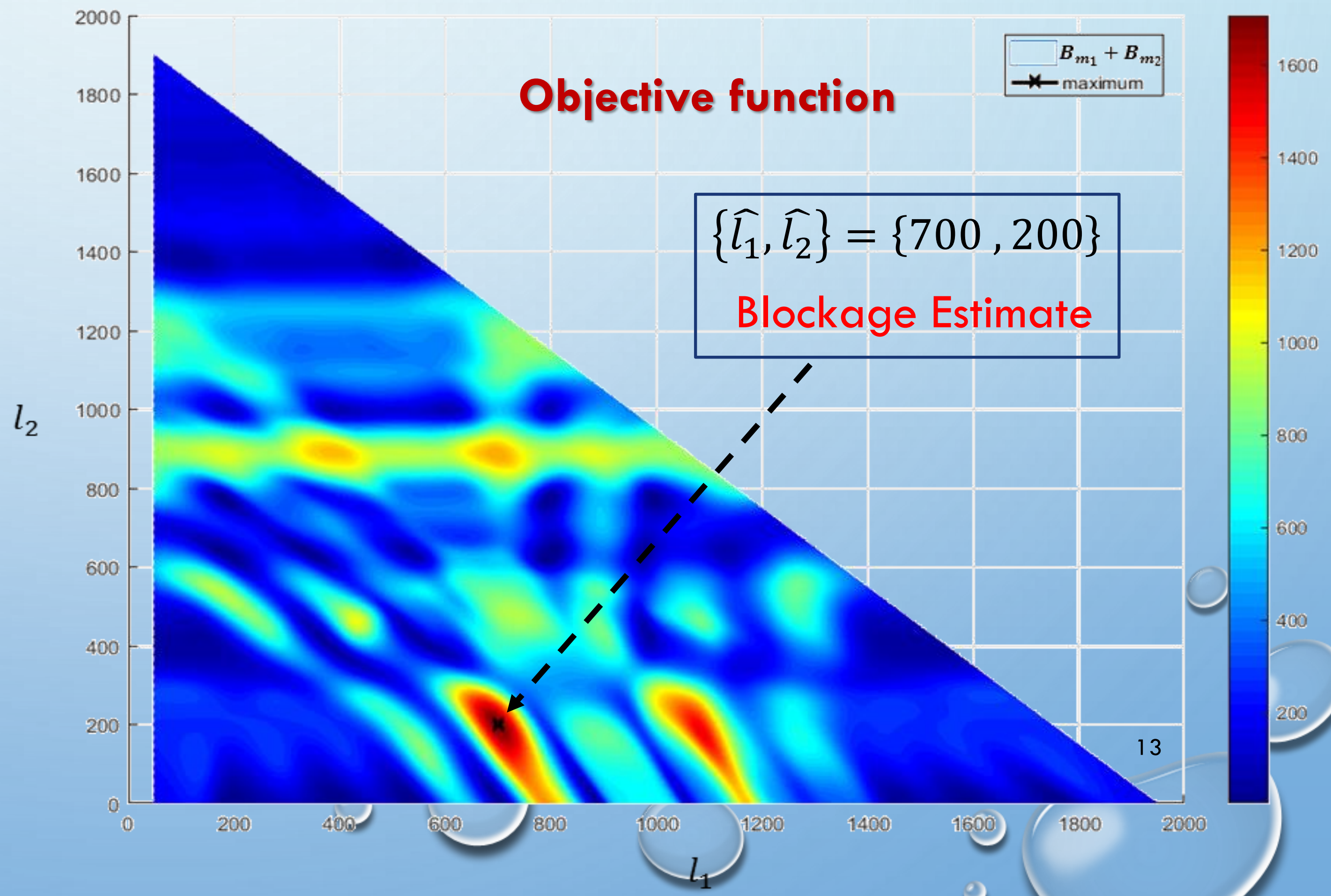
$$\widehat{\boldsymbol{\alpha}} = \left(\boldsymbol{G}_{\boldsymbol{m}_i}^{\boldsymbol{H}}\boldsymbol{G}_{\boldsymbol{m}_i}\right)^{-1}\boldsymbol{G}_{\boldsymbol{m}_i}^{\boldsymbol{H}}\boldsymbol{S}_{\boldsymbol{m}_i}$$

$$\underbrace{\{\widehat{l_1}, \widehat{l_2}\}}_{\text{Blockage Estimate}} = \arg\max_{l_1, l_2} \underbrace{\boldsymbol{S}_{\boldsymbol{m}_i}^{\boldsymbol{H}}\boldsymbol{G}_{\boldsymbol{m}_i}\left(\boldsymbol{G}_{\boldsymbol{m}_i}^{\boldsymbol{H}}\boldsymbol{G}_{\boldsymbol{m}_i}\right)^{-1}\boldsymbol{G}_{\boldsymbol{m}_i}^{\boldsymbol{H}}\boldsymbol{S}_{\boldsymbol{m}_i}}_{\text{Objective function}}$$

NUMERICAL SIMULATION



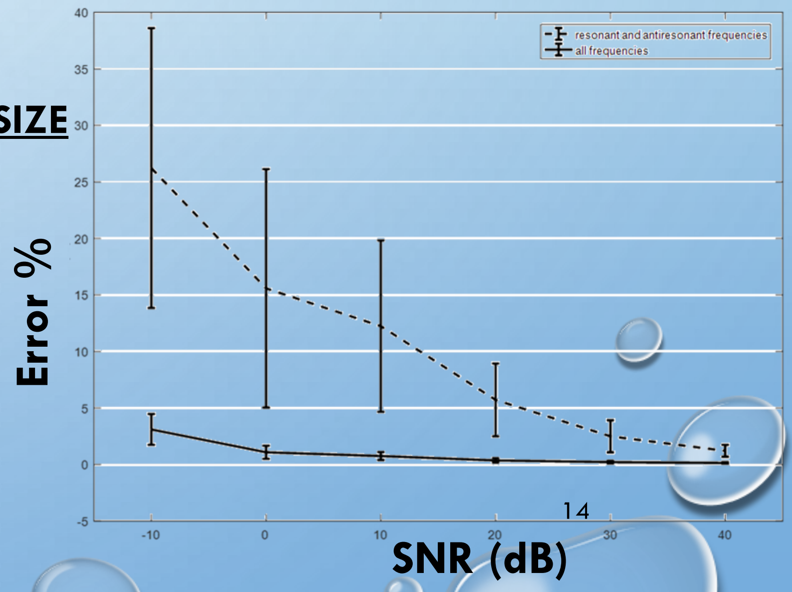




ADVANTAGES AND LIMITATIONS

ADVANTAGES:

- HAS THE ABILITY OF USING **FREQUENCIES OTHER THAN THE RESONANT FREQUENCIES**
- **DOES NOT REQUIRE ACCURATE IDENTIFICATION** OF THE RESONANT AND THE ANTI-RESONANT FREQUENCIES
- **TOLERATE** THE PRESENCE OF **NOISE**
- FINDS THE **LENGTH AND THE LOCATION** OF THE BLOCKAGE **INDEPENDENTLY** FROM ITS **SIZE**



LIMITATIONS:

- NOT EASILY EXTENDABLE TO MULTIPLE BLOCKAGES
- REQUIRES THE KNOWLEDGE OF THE INPUT SIGNAL

IMPULSE RESPONSE METHOD