Towards vibration measurement applications based on phase-OTDR technique

PhD student: Carolina Franciscangelis

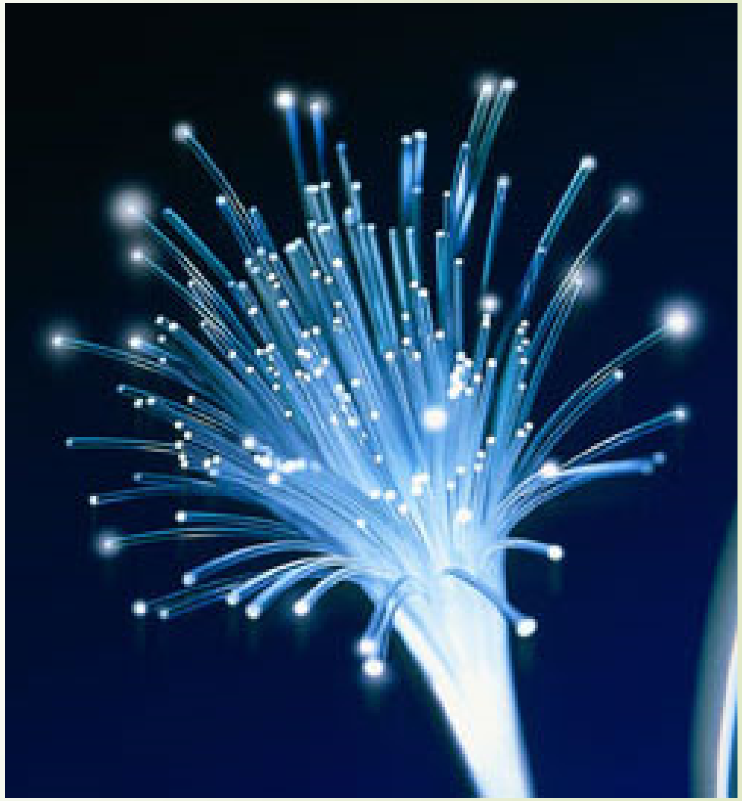
Supervisor UNICAMP: Prof. Dr. Fabiano Fruett

Supervisor Acreo: Walter Margulis

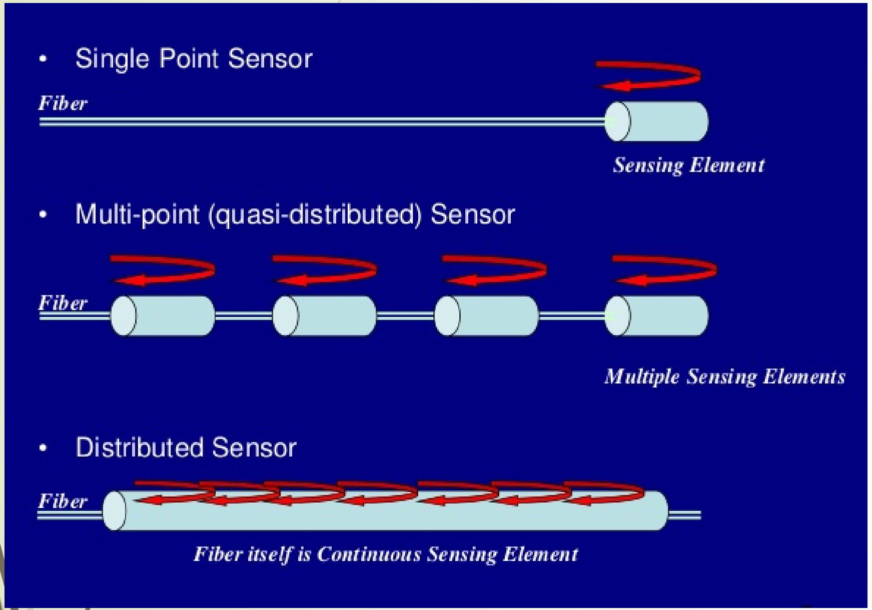
Supervisors Saab: Ingemar Soderquist and Tonny Nyman

Summary

- Distributed optical fiber sensors
- Motivations
- Rayleigh scattering theory
- Phase-OTDR: basic experimental setup
- Applications
  - SHM: Composite material with embedded optical fibers
  - SHM: Optical fiber coil mesh for 2D and 3D surfaces monitoring using phase-OTDR
  - Security & SHM: Real-time distributed optical tuneable microphone based on phase-OTDR
- Conclusion



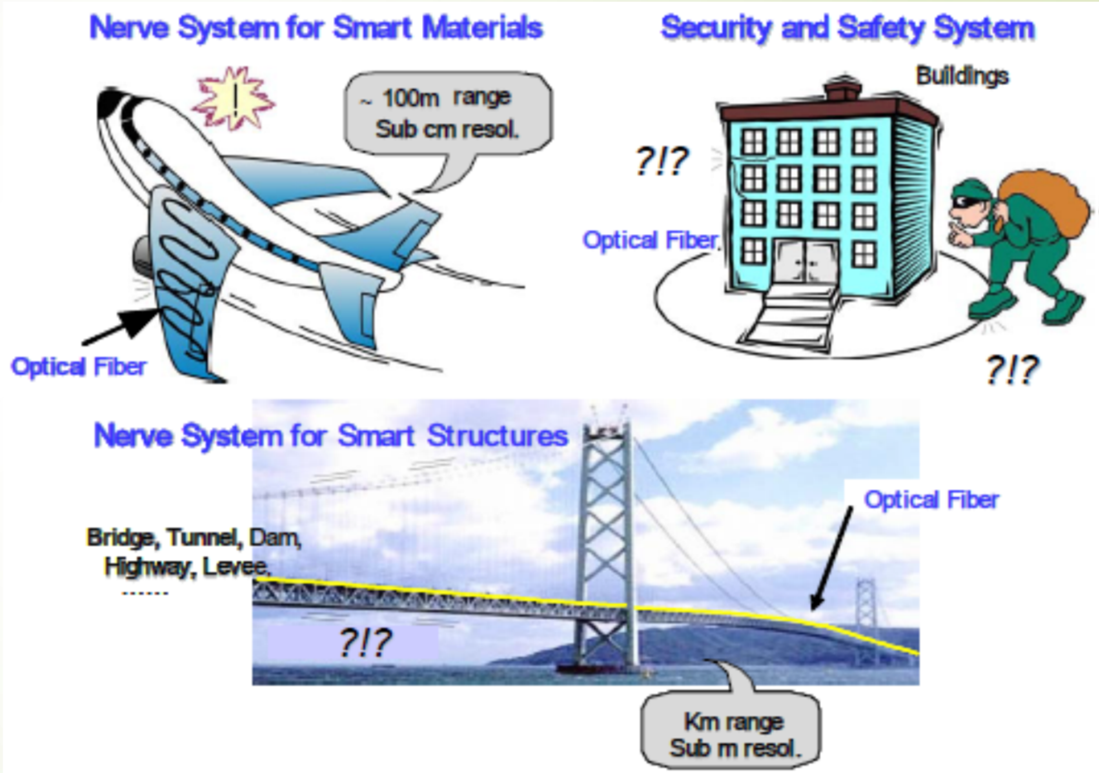
Distributed optical fiber sensors



- Based on light scattering phenomena: **Rayleigh**, Raman and Brillouin;
- Requires access to only one end of the optical fiber;

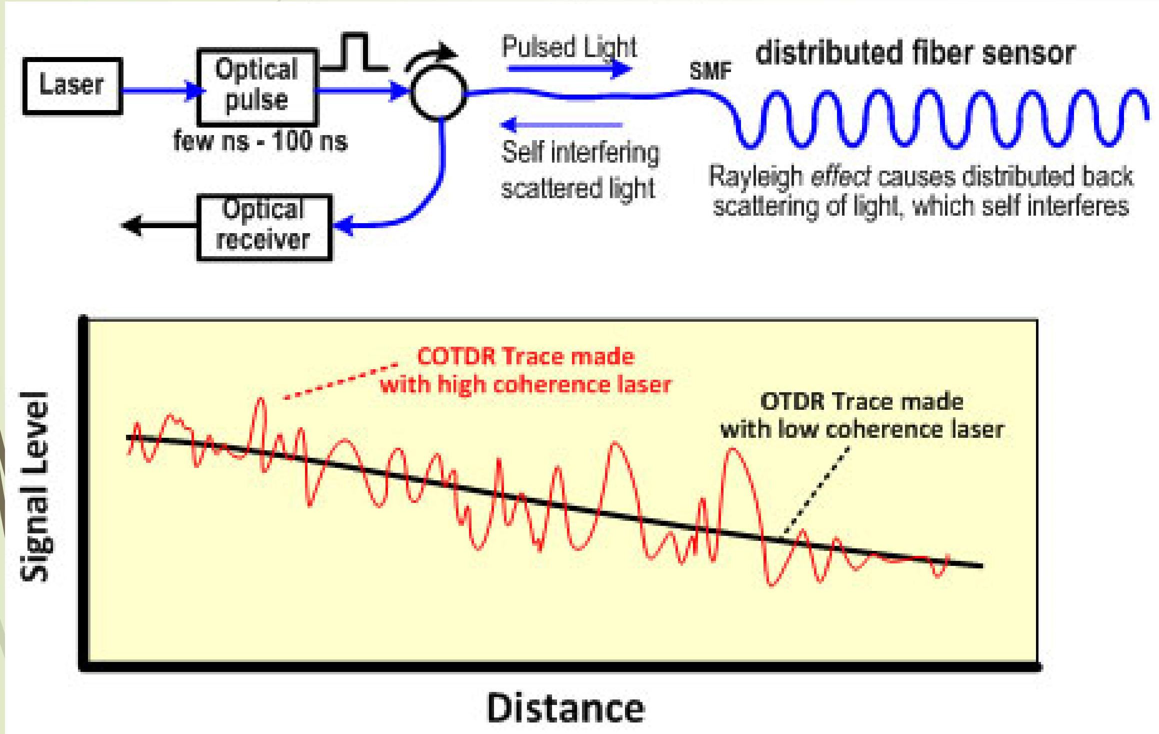
Motivations: Distributed optical fiber sensors

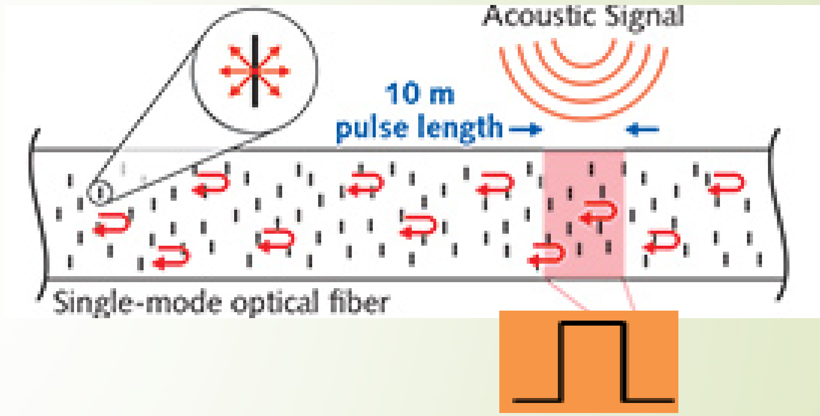
- Advantages
  - Electromagnetic immunity, feasibility for hazardous inviroments;
  - Adaptative range and resolution, high reconfigurability;
  - Small dimensions;
  - Can be embedded inside structures;
  - Feasible for multiparameter monitoring;
  - Track simultaneous events;

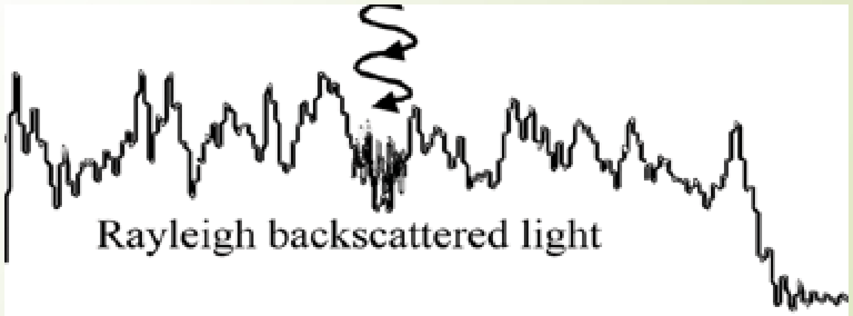


Rayleigh scattering theory

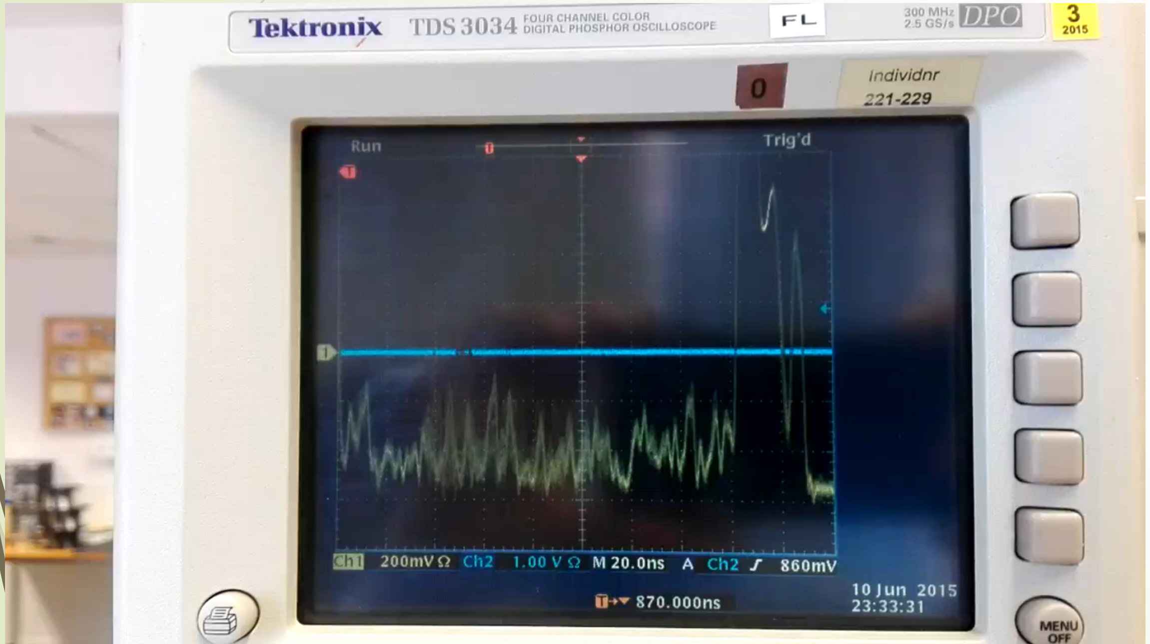
Basic phase-OTDR (DAS) configuration

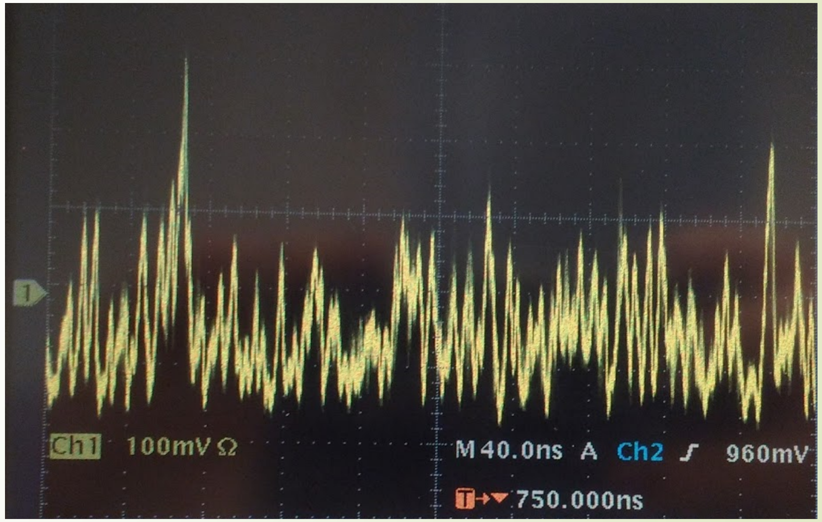




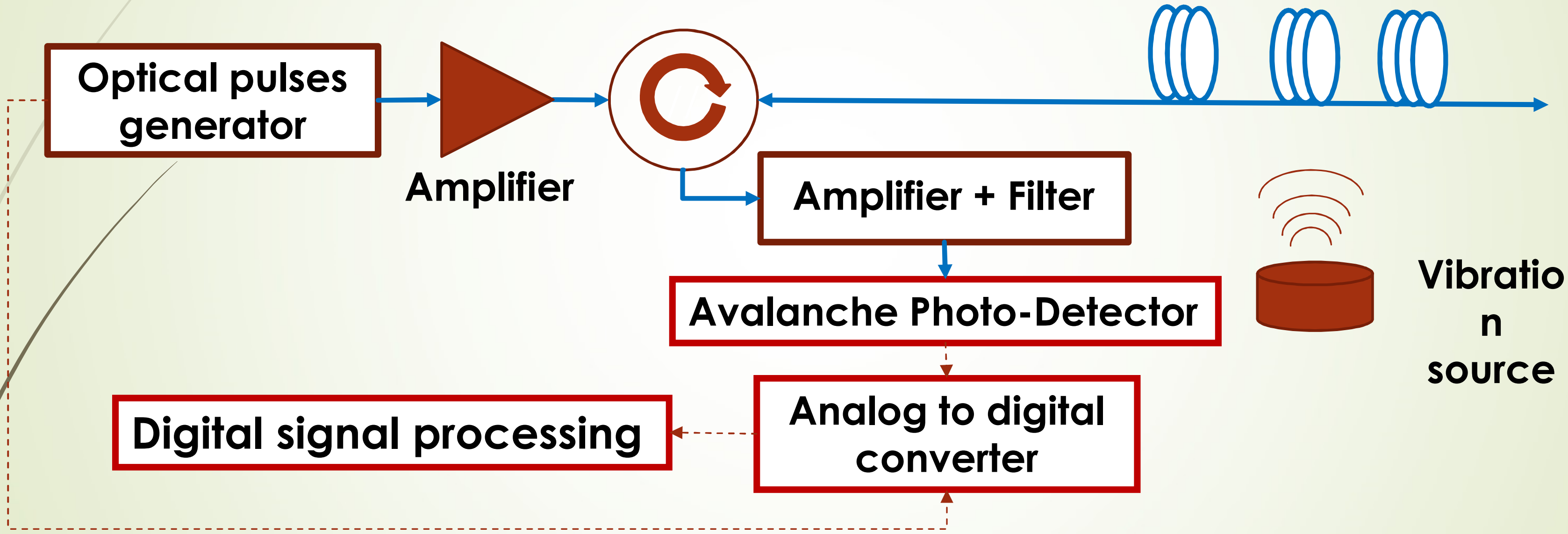


Rayleigh scattering theory



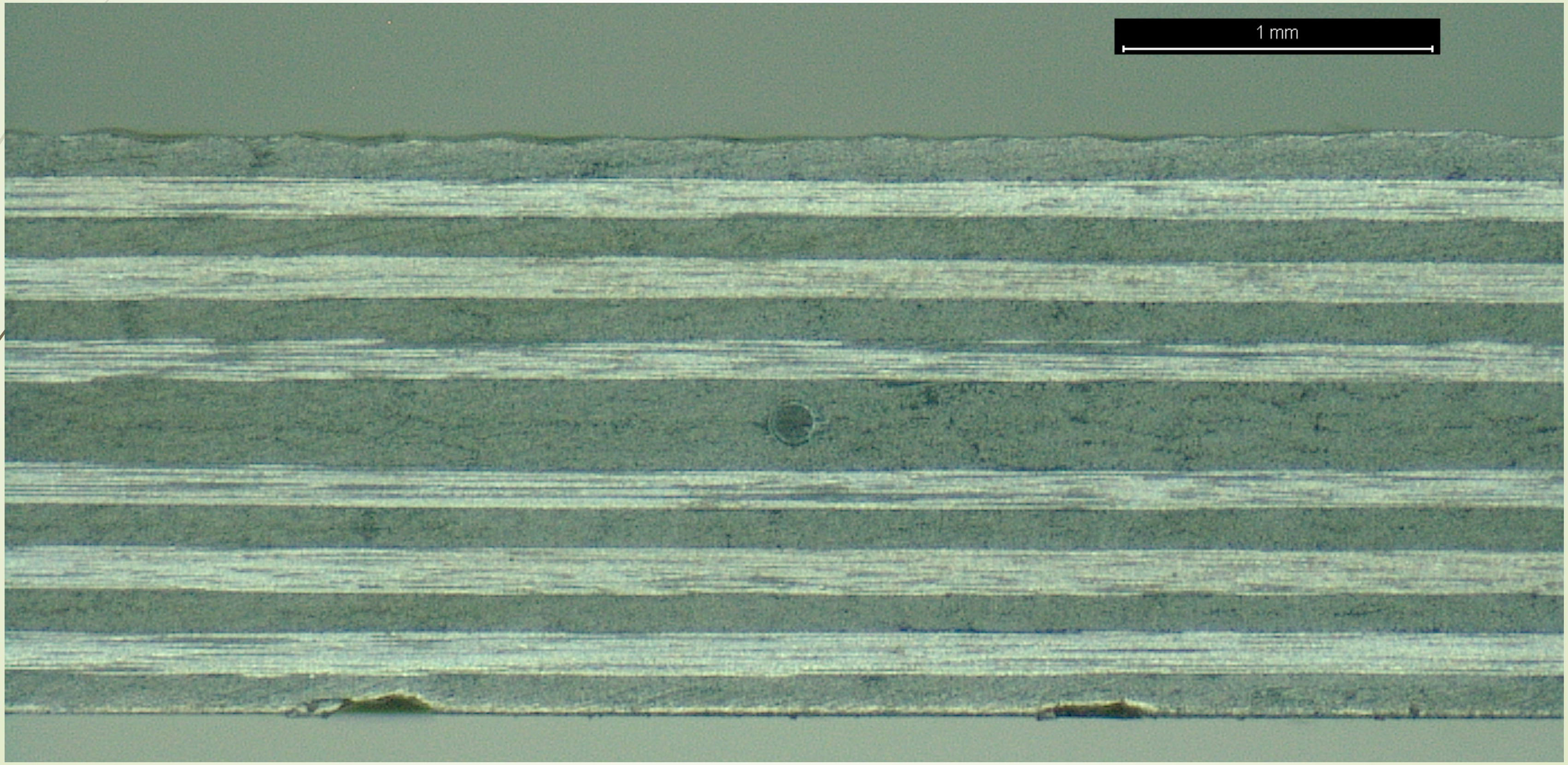


Phase-OTDR: basic experimental setup

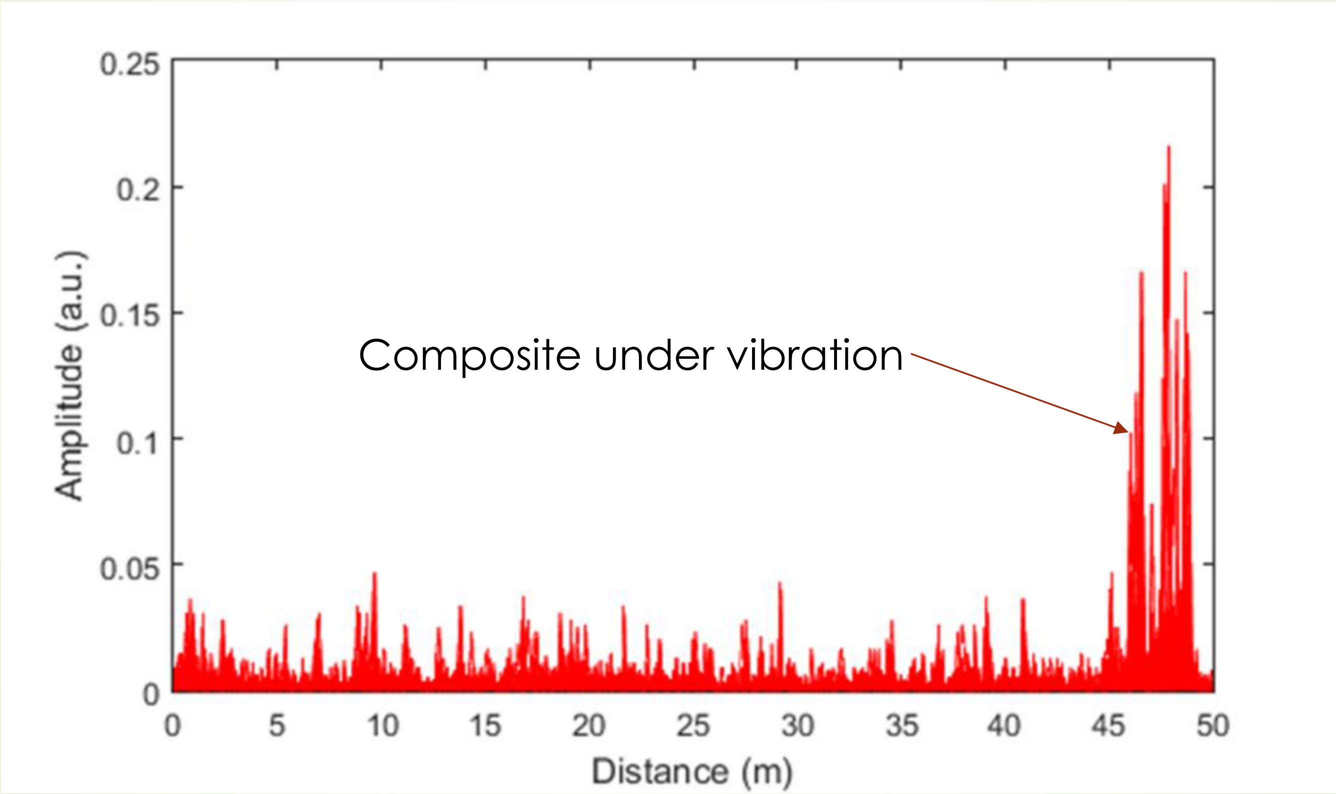


SHM: Composite material with embedded optical fibers

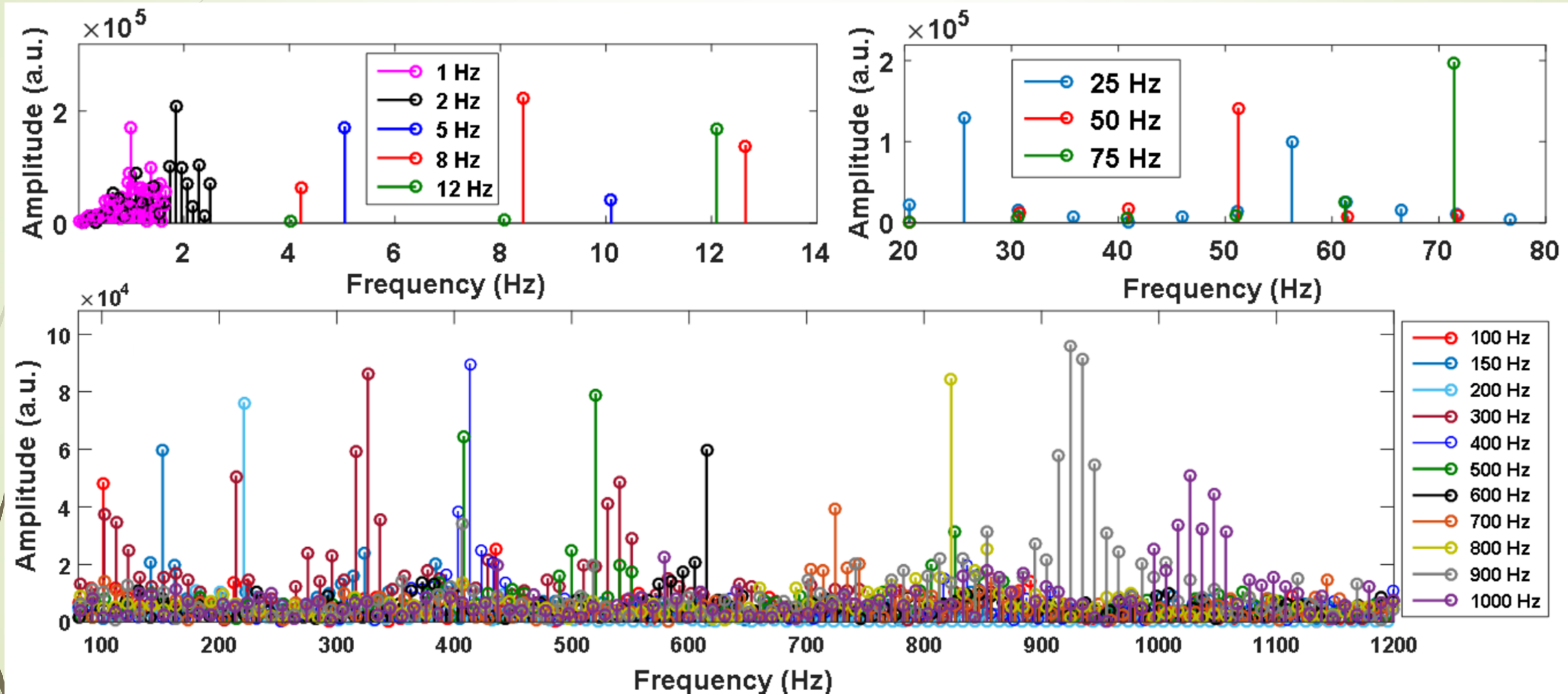
SHM: Composite material with embedded optical fibers



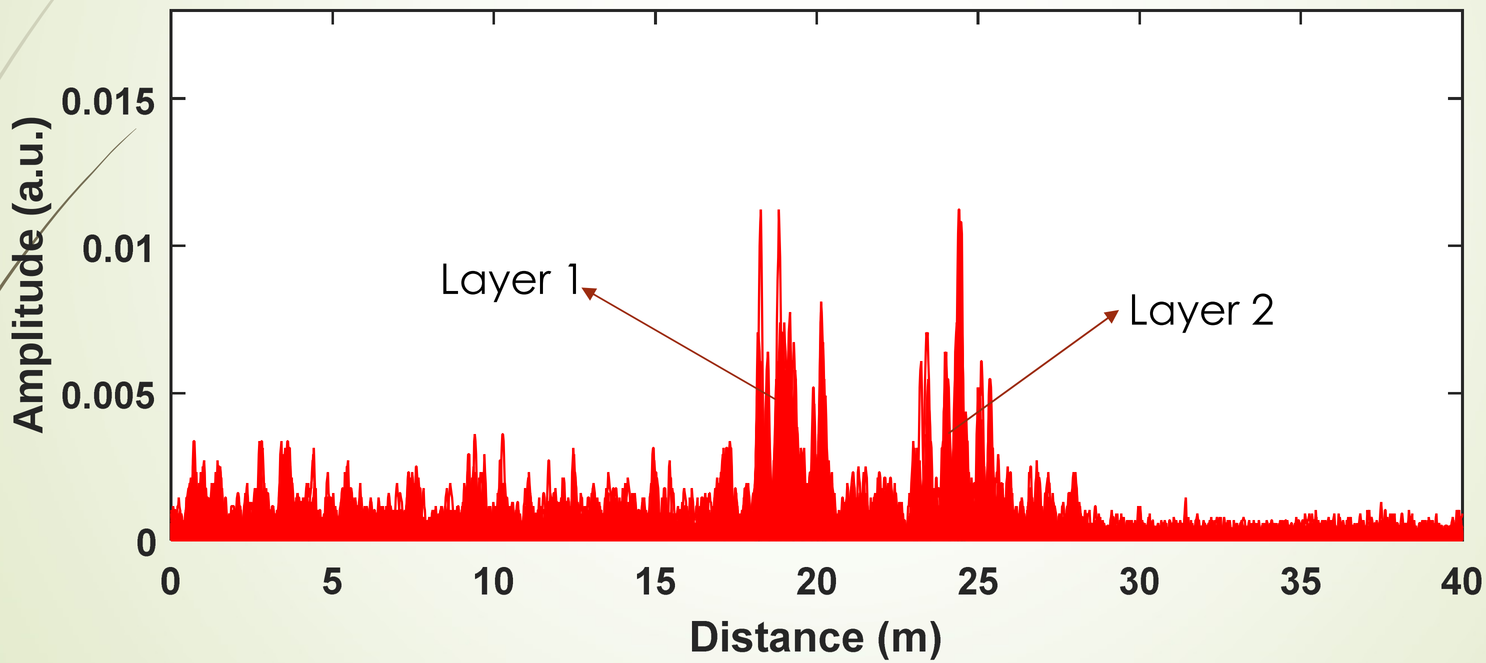
Experimental results: vibration measurements in composite material



Experimental results: vibration measurements in composite material



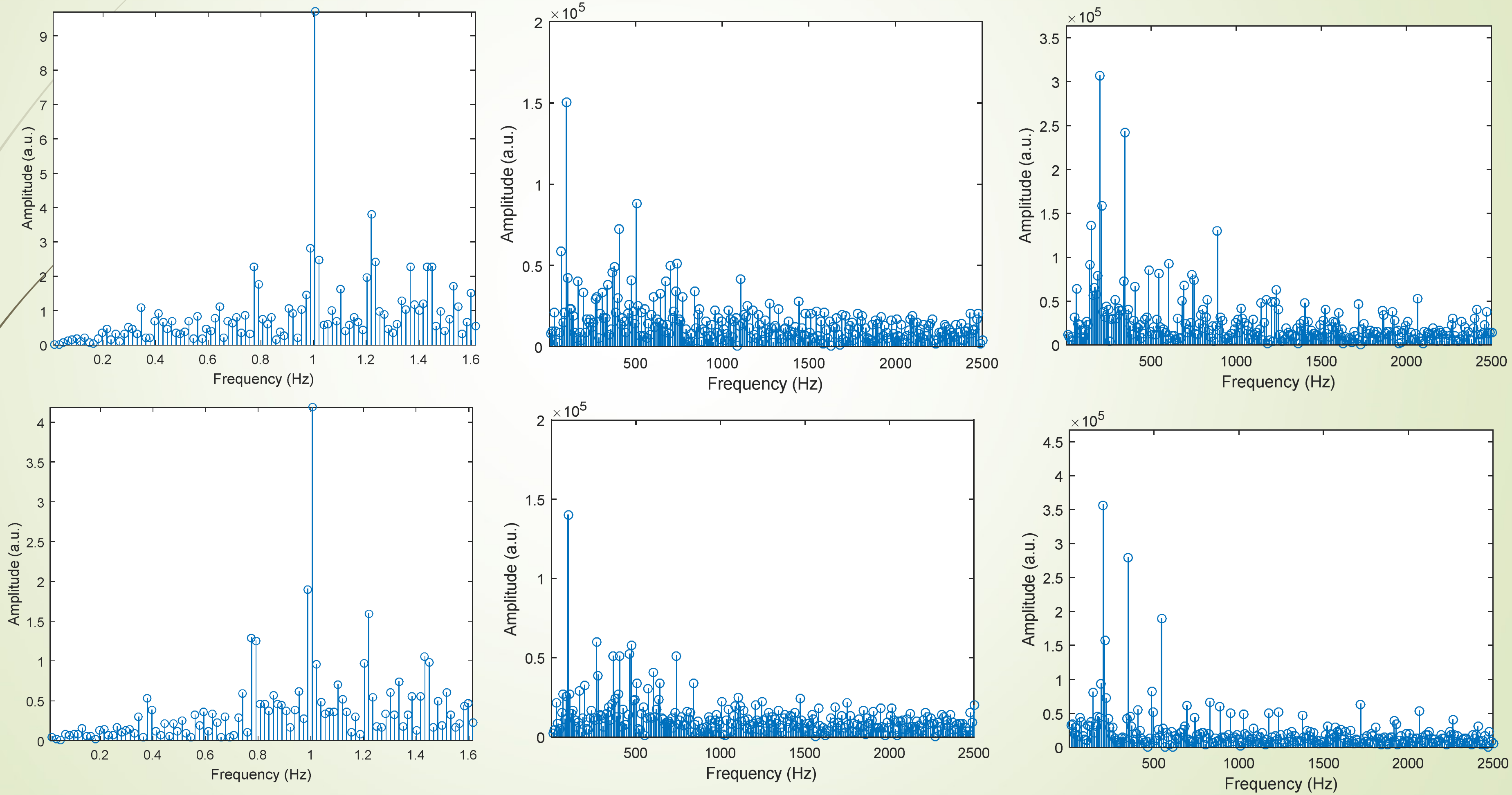
Experimental results: vibration measurements in two layers of composite



Experimental results: vibration measurements in two layers of composite

Layer 1

Layer 2

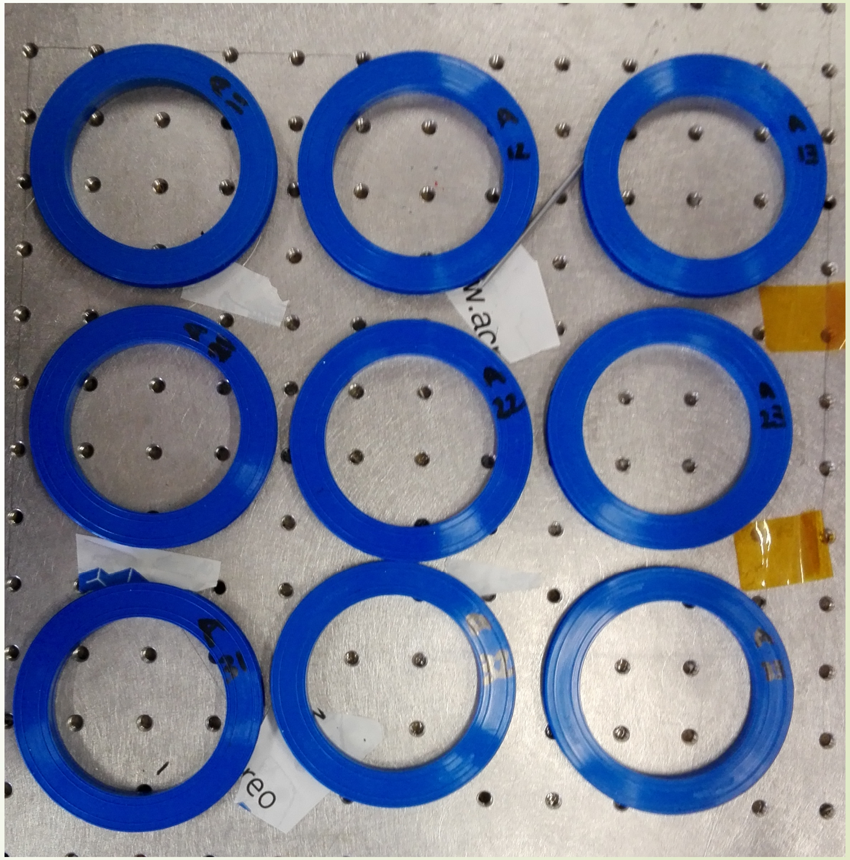


SHM: Optical fiber coil mesh for 2D and 3D surfaces monitoring using phase-OTDR

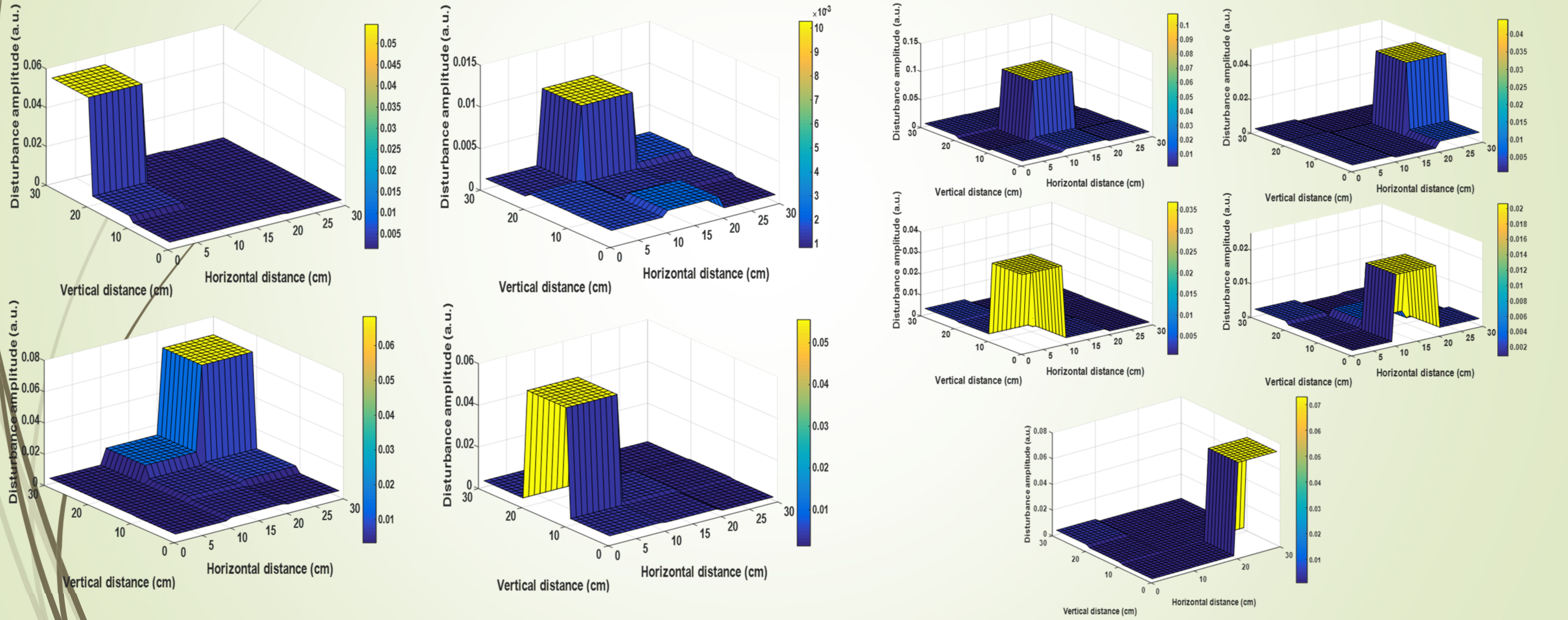
- Characterization of avionics surfaces in ground testbeds
  - 2D or 3D surfaces

- Advantage over multiple point sensors: cheaper and easier to multiplex data;

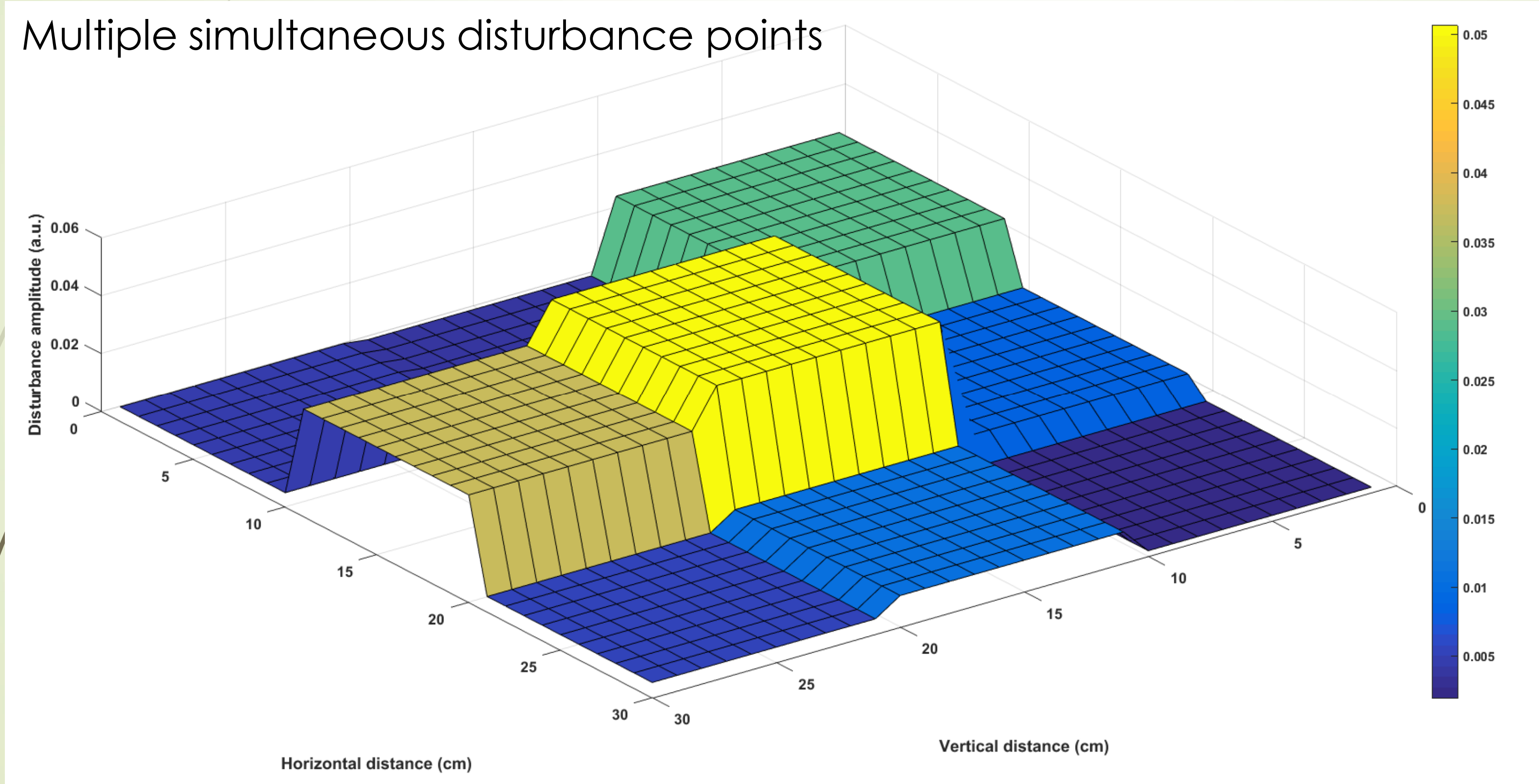
- Spatial resolution is limited by the coil diameter and can be around a few centimeters;



Experimental results:

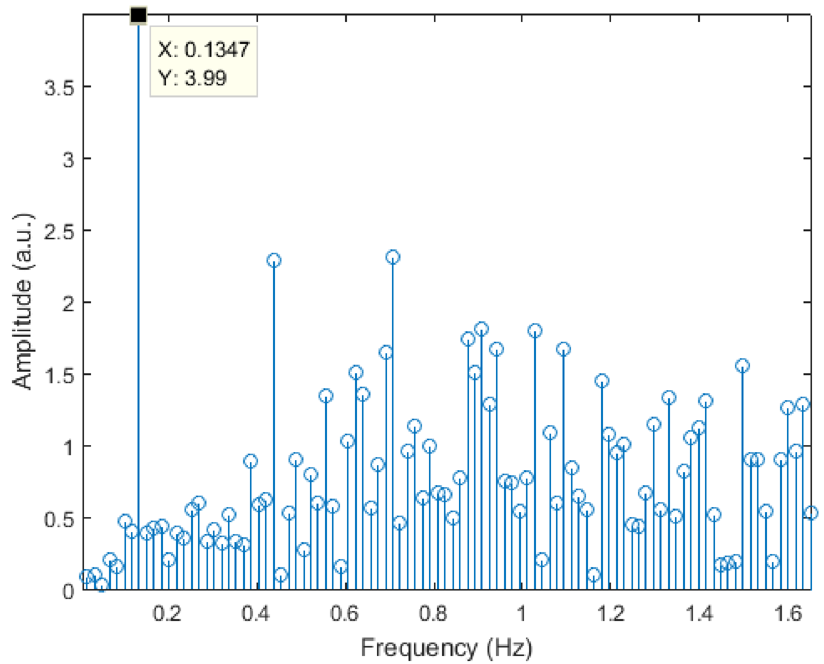


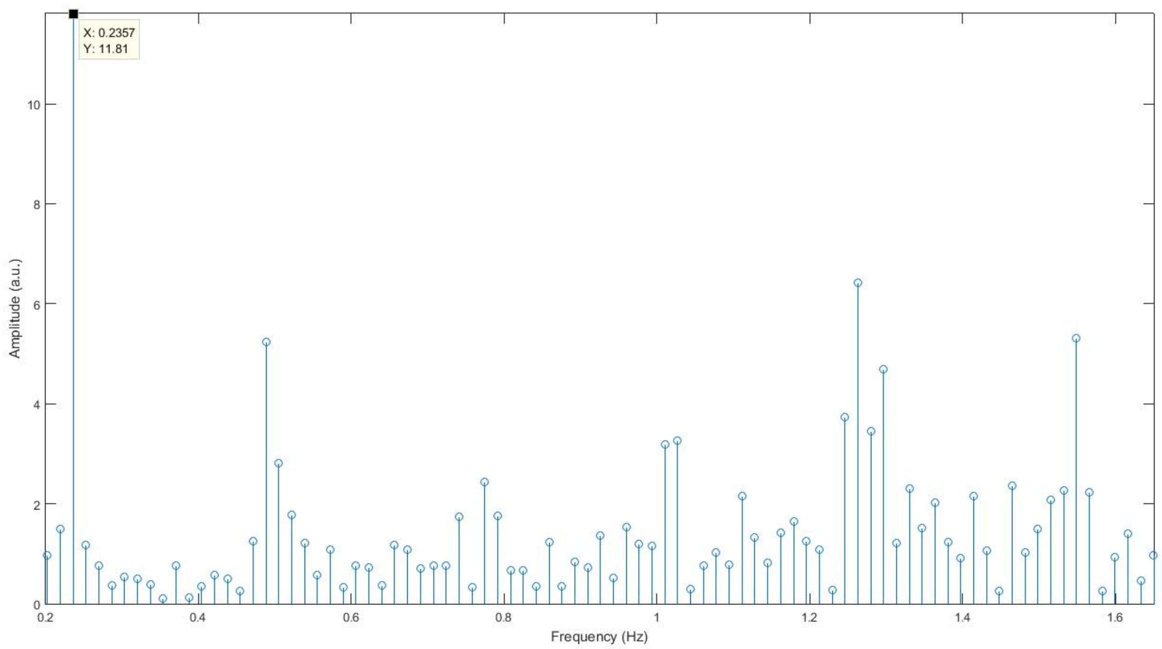
Experimental results:



Experimental results:

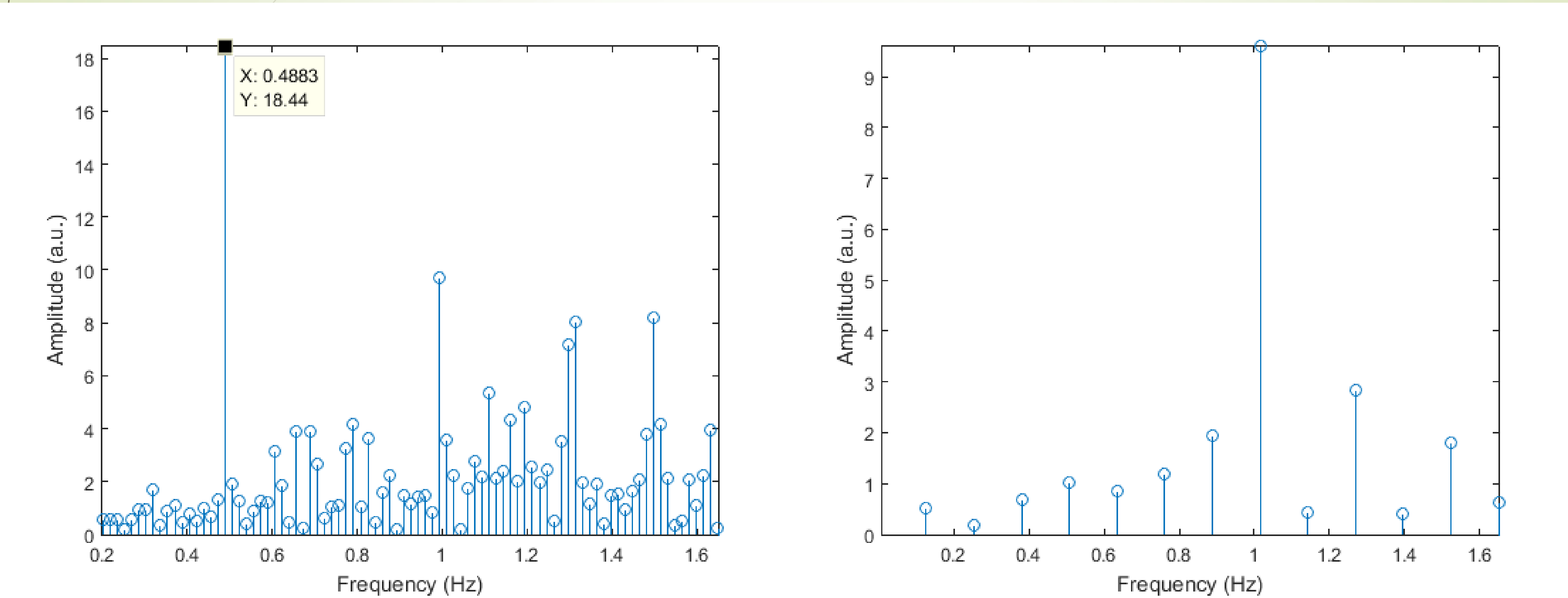
mHz vibration frequency sensitivity





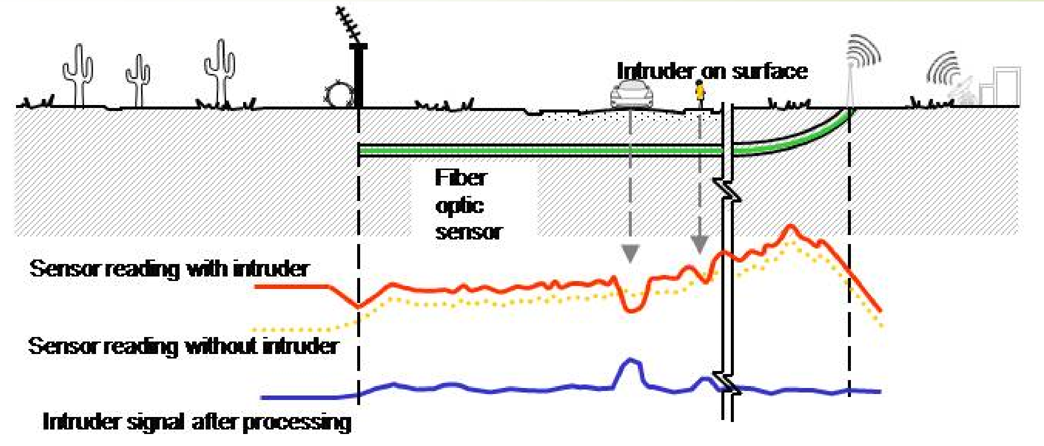
Experimental results:

mHz vibration frequency sensitivity

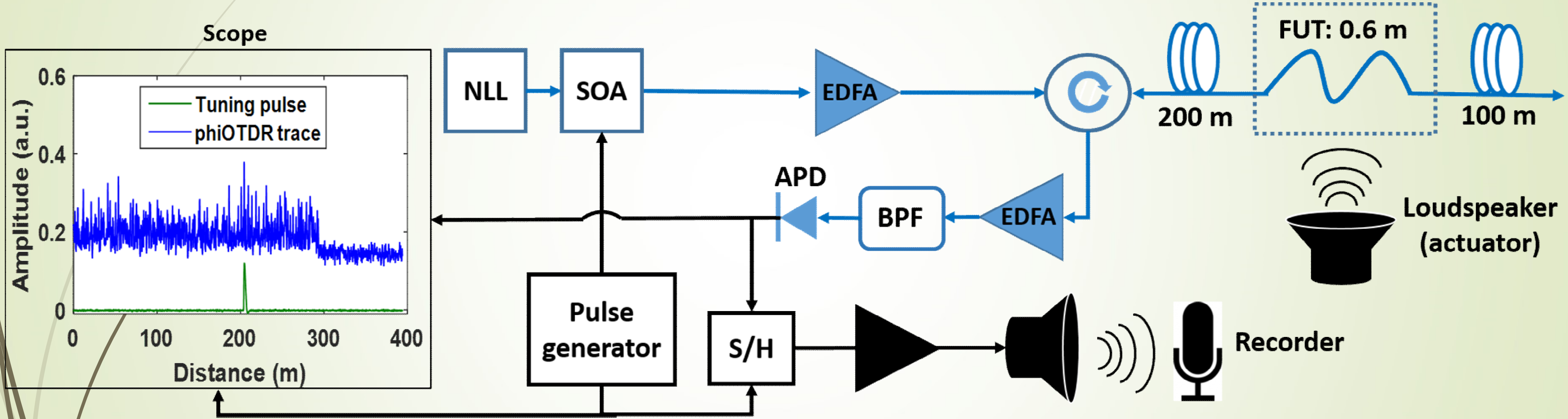


Real-time distributed optical tuneable microphone based on phase-OTDR

- Real-time detection of intruders: footsteps, vehicles, digging machines;
- Sound is created through vibrations!
  - Novel proposal: phase-OTDR technique applied as a real time distributed tuneable microphone;
- Applications
  - Surveillance: perimeter security of military facilities, borders and power plants;
  - Structure health monitoring: analysis of the structure status by evaluating how it sounds;
  - Industrial facilities: detecting malfunction in multiple machines in an workshop;

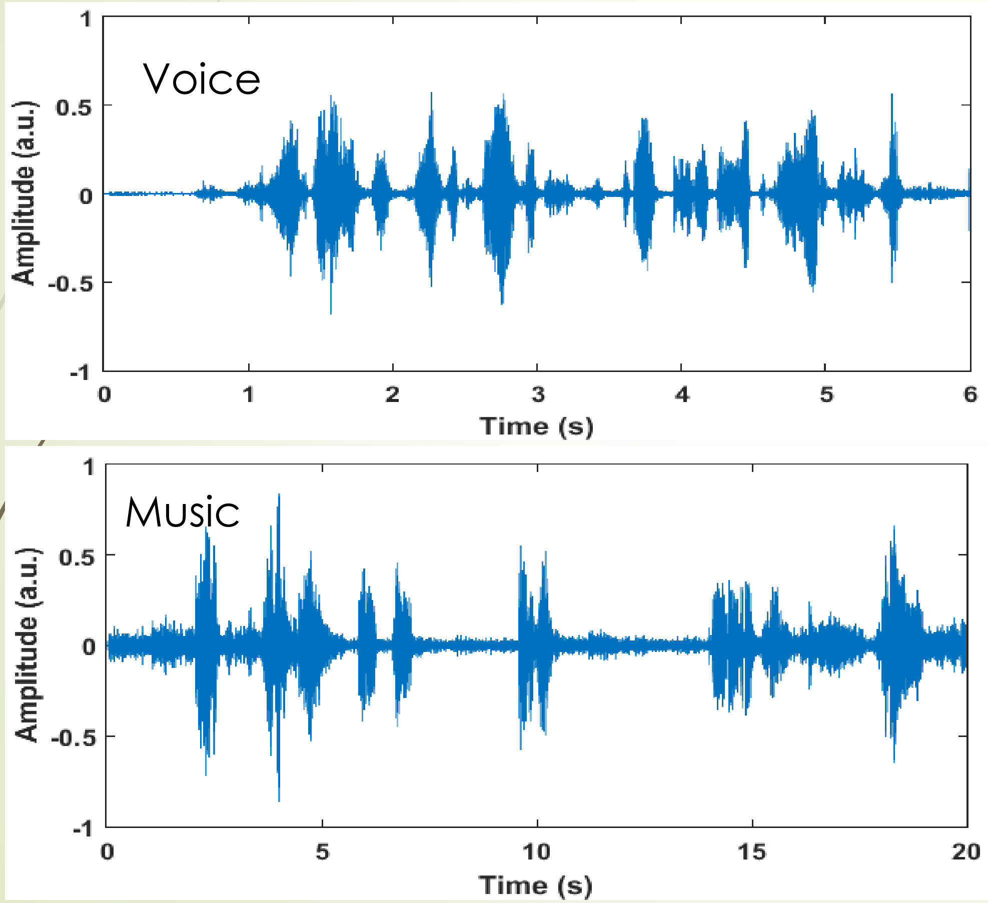


Real-time distributed optical tuneable microphone based on phase-OTDR



Experimental results

Acquired soundwaves



Composite knocking

Classic music

Conclusion

Distributed optical fiber sensing as key enabling technology!

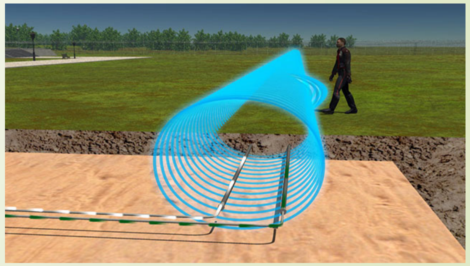
Distributed acoustic sensing

Aerospace

Distributed microphone

Structural Health Monitoring

Surveillance And Security



Thank you!

carolina.franciscangelis@acreo.se

Table 3.1 Evolution and performance data of φOTDR used for dynamic sensing

Date	REF	Sensing Range	Spatial Resolution	Detection Bandwidth	Laser linewidth	Detection Scheme	Optical Amplification
Mar-93	[28]	Intrusion Sensing Apparatus described					
Aug-98	[34]	~10 km	~10 m	Intrusion	YAG laser	Direct	-
Sep-98	[30][1]	6 km	400 m	30.5 Hz	<50 kHz	Direct	-
Jun-05	[32]	12 km	1 km	Intrusion	<3 kHz;	Direct	-
Dec-05	[39]	12 km	200 m	Intrusion	<3 kHz;	Direct	-
Apr-07	[33]	19 km	200 m	Intrusion	<3 kHz;	Direct	-
Apr-08	[68][1]	14 km	50 m	Intrusion	20 kHz	Direct	-
Oct-09	[63][1]	62 km	100 m	Intrusion	<3 kHz;	Direct	1st Raman
Nov-10	[25]	1.2 km	5 m	1 kHz	20 kHz	Coherent	-
Aug-11	[26]	~200 m (PMF)	1 m	2.25 kHz	20 kHz	Coherent	-
Nov-11	[37][1]	3 km	5 m	200 Hz	2 kHz	Coherent	-
Apr-12	[41]	1 km	0.5 m	8 kHz	4 kHz	Coherent	-
Aug-12	[40]	200 m tested; (estimated: up to 10 km)	0.2 m	Freq. Sweep between 500-1000 Hz (nonstacionary)	535 kHz	Coherent	-
Jan-13	[67] (3)	1 km	5 m (3)	3 MHz (3)	<50 kHz	Coherent	-
Feb-13	[46] (2)	74 km	20 m	Intrusion	2 kHz (?)(2)	Direct	1st Raman
Jul-13	[69]	<1 km	2 m	500-5000 Hz	Distributed-Feedback (DFB) laser	Direct	-
Sep-13	[36]	1 km	3 m	Intrusion	<50 kHz	Direct	-
Oct-13	[66] (3)	1.15 km	5 m (3)	6.3 MHz (3)	<50 kHz	Coherent	-
Dec-13	[3]	1.25 km	5 m	40 kHz	1.6 MHz	Direct	-
Apr-14	[5]	100/125 km	10 m	390/250 Hz	1.6 MHz	Direct	1st Raman
May-14	[38]	131.5 km	8 m	375 Hz	3 kHz	Coherent	1st Raman
Jun-14	[43] (1)	124 km	40 m	Intrusion	100 Hz	Coherent	Brillouin
Jun-14	[44] (1)	175 km	25 m	Intrusion	100 Hz	Coherent	1st+2nd Raman +Brillouin
Jun-14	[61] (1)	125 km	10 m	250 Hz	1.6 MHz	Direct	1st Raman
		125 km	10 m	380 Hz	1.6 MHz	Direct	2nd Raman
Jun-14	[65] (1, 4)	10 km	20 m	Sampling: 4·10 kHz (4)	Not specified	Coherent	-
		1.1 km	10 m	Sampling: 2·80 kHz (4)	<50 kHz	Coherent	-
Jun-14	[64] (1, 4)						

H. F. Martins PhD thesis