Ultrasonic Pig Detection at Pipelines

or

The Power of Acoustic Methods

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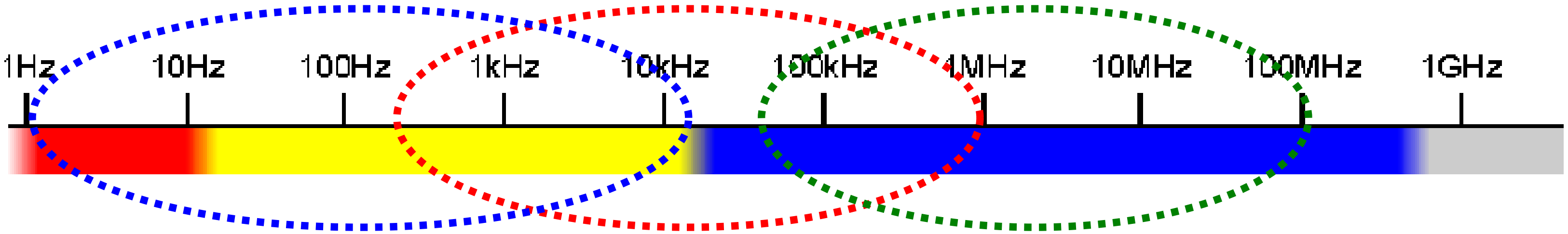
Fundamentals

Frequencies for acoustic and ultrasonic engineering solutions



Technical acoustics

& vibrations

Sound emission

(„passive“)

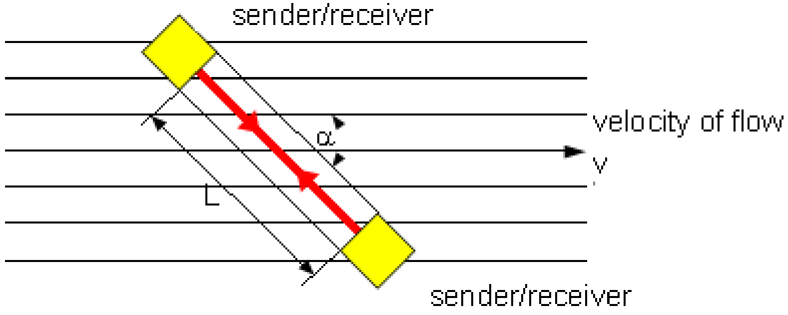
NDT

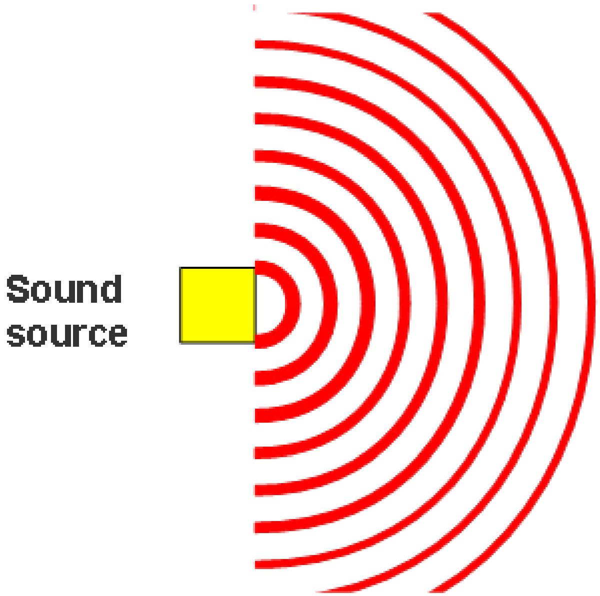
***n**on-**d**estructive **t**esting*

& “active” US

Basic Effects

Propagation / Sound fields

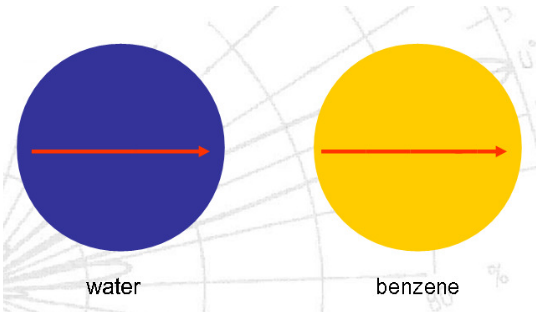




→ estimation of travel times

→ attenuation

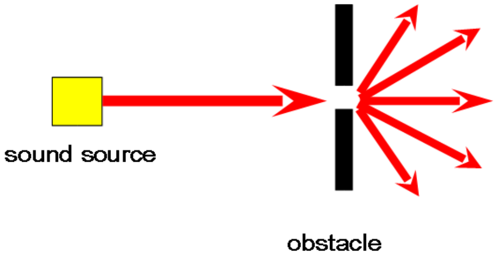
Sound speed depends on material



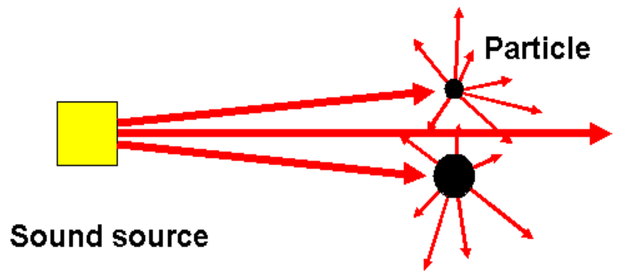
Basic Effects

- → **propagation of waves**
- → **material properties**
- → **surfaces / geometry**

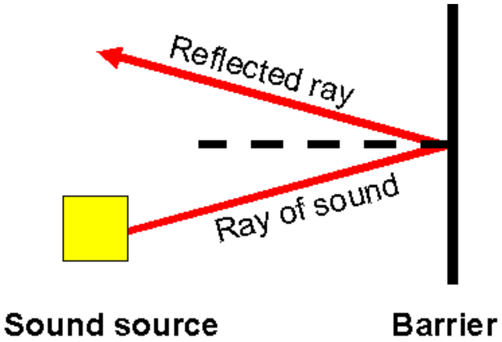
→ Diffraction



→ (Back-)Scattering e.g. Doppler-Effect in Fluids

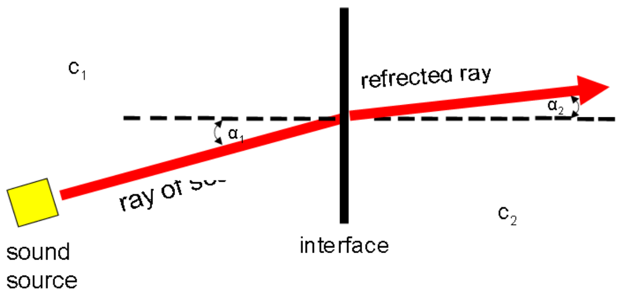


→ Reflection



→ Refraction

$$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{c_1}{c_2}$$



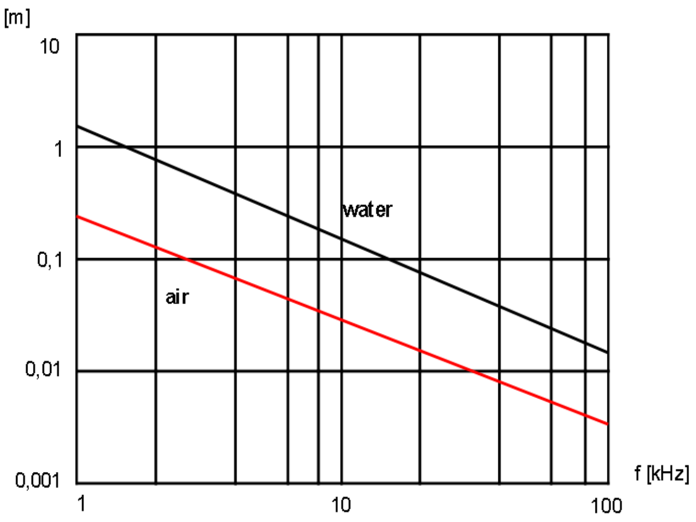
important formula
(simplified)

$$c = \lambda \cdot f$$

$$I = I_0 \, e^{-\alpha x}$$

$$R = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

material dependent !



Source: Helke, Piezoelektrische Keramiken, TAE 2008, page 21

material	*density (kgm⁻³)*	*sound velocity (ms⁻¹)*	*impedance (kgm⁻²s⁻¹)*
steel	7850	5920	$3.92 \cdot 10^7$
water	1000	1484	$1.48 \cdot 10^6$
air (1 bar)	1.04	343	$4.13 \cdot 10^2$

Applications for Ultrasonic Probes

→ Non-intrusive material testing

→ Automation

→ Process measurement techniques

→ Medical technologies

→ Consumer techniques

Requirements for Ultrasonic Probes

→ Acoustic parameters

→ Constructive parameters

→ Electric parameters

→ Application specific parameters

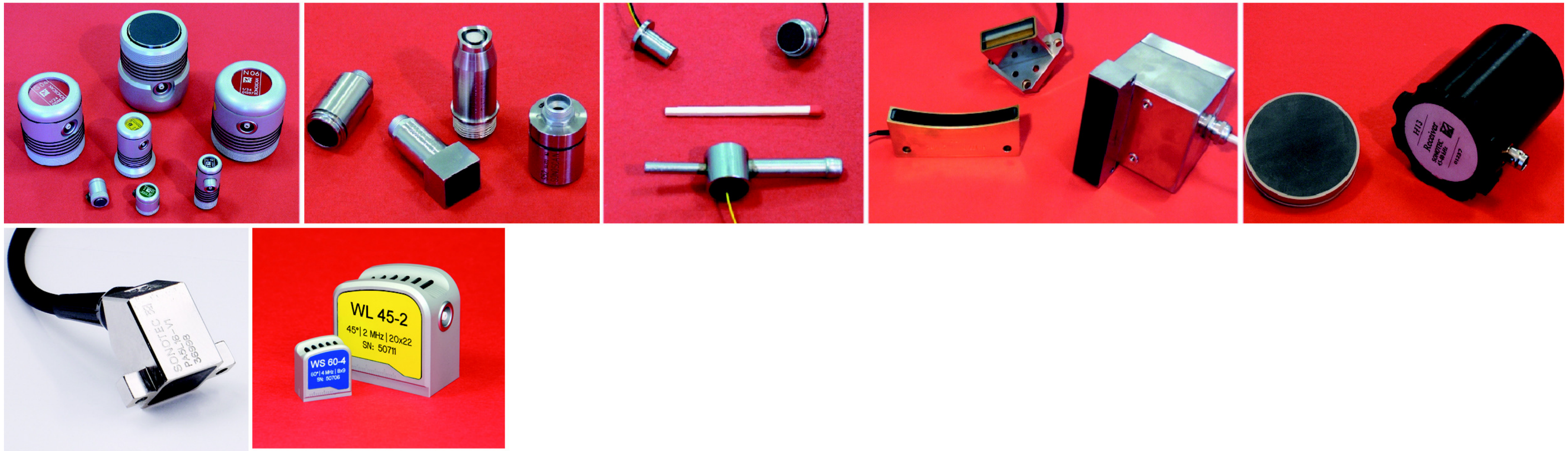
→ Economic parameters

→ Design

- *Sound field characteristic*
- *Operating frequency*
- *Sensitivity*
- *Signal-to-noise ratio*
- *Acoustic impedance*
- *Pulse shape*
- *Focusing*

- *Material resistance*
- *Pressure resistance*
- *Radiation resistance*
- *Explosion-proof version*

Selection of Industrial Ultrasonic Probes



from left:
contact technique, immersion, miniatur, multi-channel, low frequency, phased-array, angle transmitter-receiver

Applications

limit switch

object detection
(e.g. pigs)

Applications in Pipeline Industry and Service (selection)

Active pulse methods

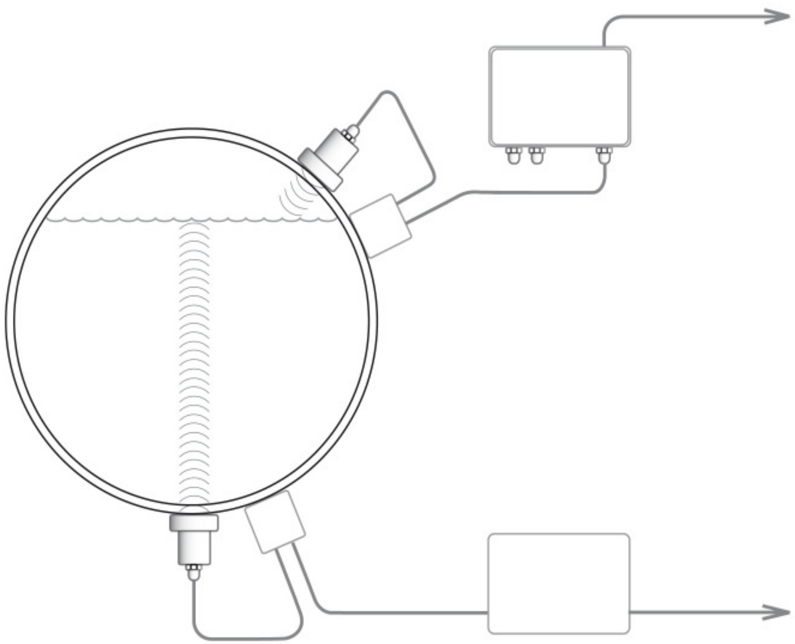
→ Liquid level estimation
→ Recognition of different liquids
→ Measurement of wall thickness
→ Level limits
→ Inspection and monitoring of sedimentation and deposits
→ Measurement of the accumulation of sand, debris, incrustation in tanks, pipelines, barrels
→ Advanced NDT-tasks (e.g. „intelligent“ pigging, material testing)

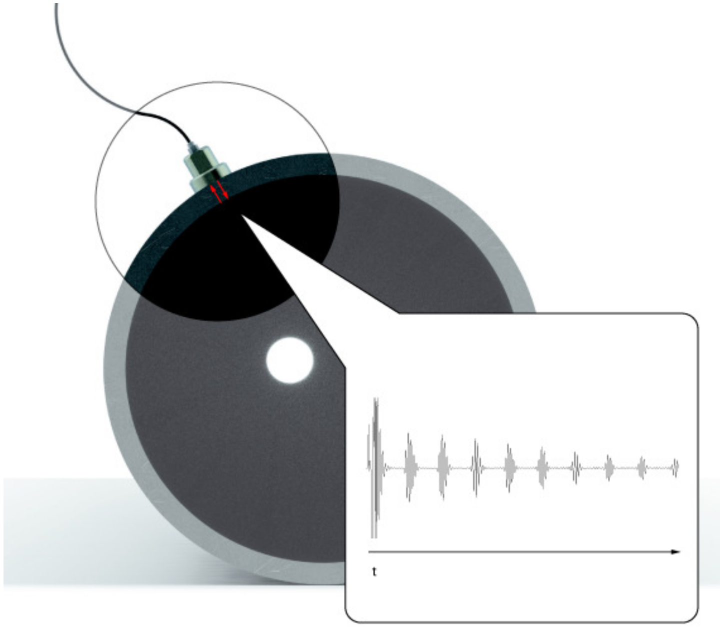
Passive Sound Emission Methods

→ Acoustic detection of moving sand in pipelines
→ Amount of debris
→ Condensate inspection (e.g. in valves and traps)
→ Detection of leakages
→ Flowing sand and debris in pipelines
→ Monitoring of materials and constructions

Typical Industrial Applications

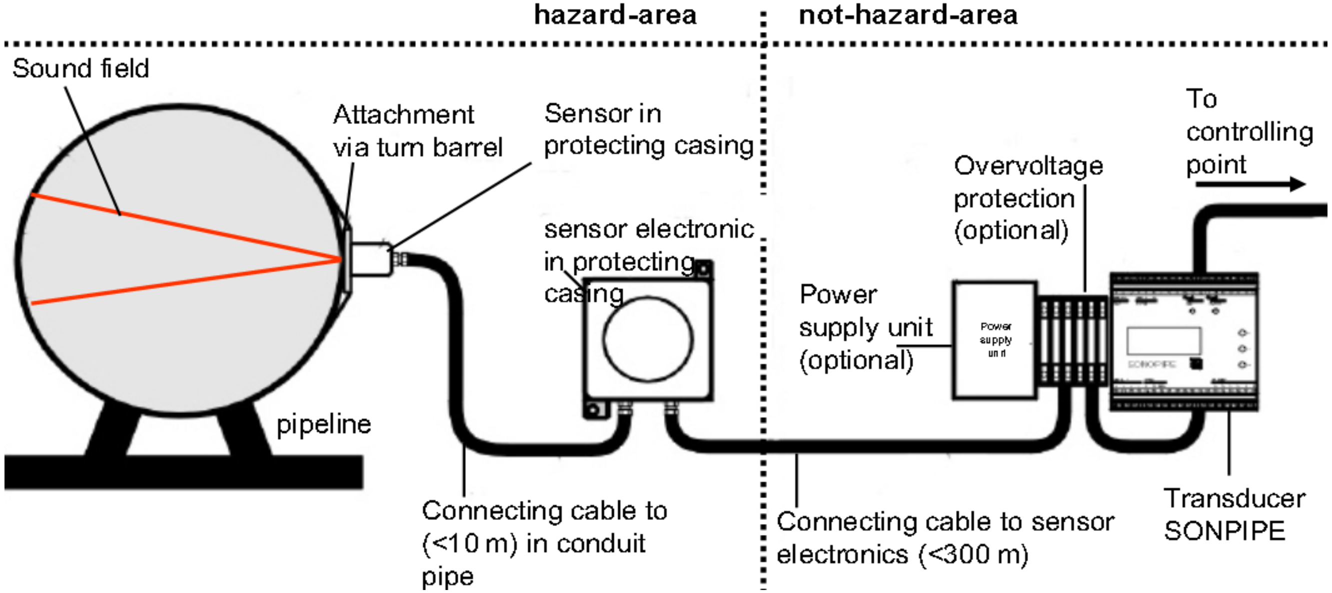
Measurement through the wall





left: **level control of liquids** (travel time and intensity are used for the estimation of filling heights or for the control of defined filling levels)
right: **measurement of wall thickness** (travel time of the echo(s))

Pig Detection in Oil Pipelines

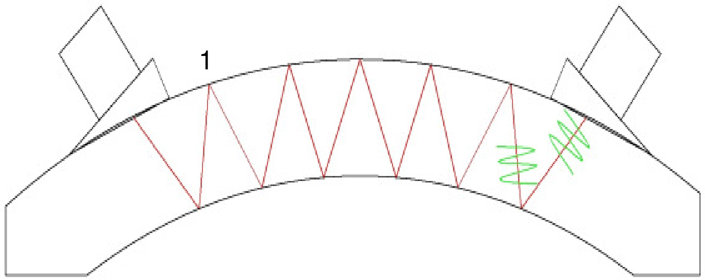


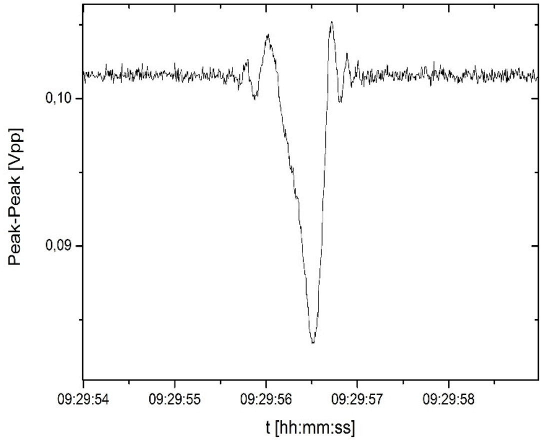
Standard configuration of a transmitting ultrasonic probe for the application at crude **oil pipelines**

… in Gas Pipelines

Active Ultrasonics

Principle of pig signalling by means of an attenuation technique



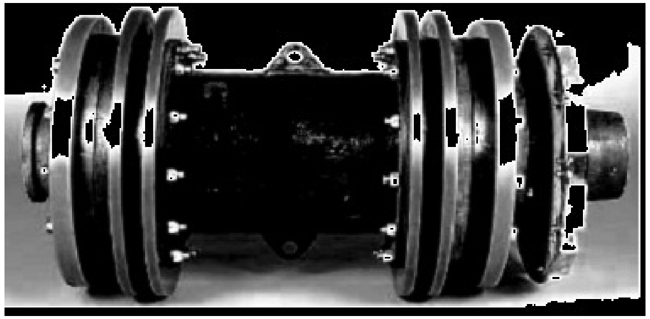


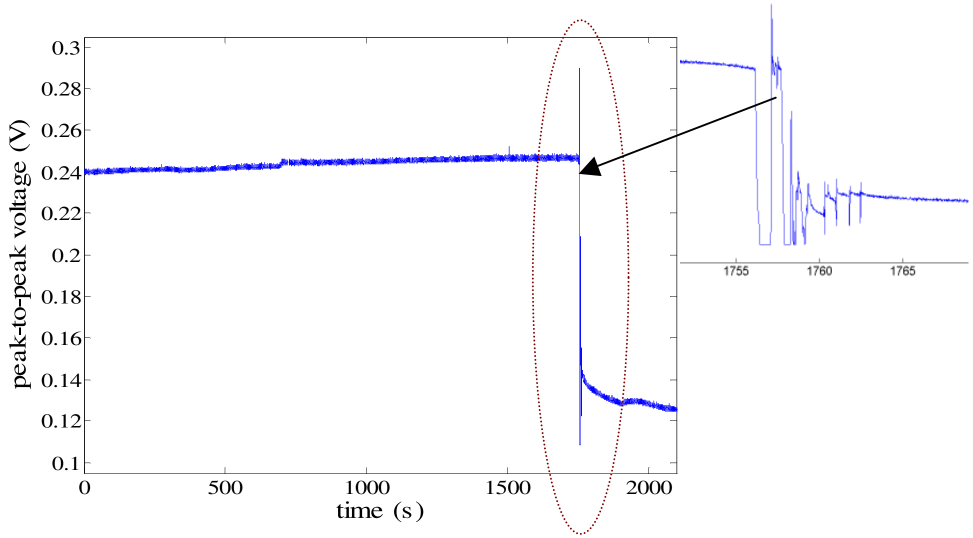
→ The probes are radially arranged on the circumference
→ Ultrasonic pulses via probe 1 (→ multi-reflections)
→ Enhanced attenuation (probe 2) in the moment of pig passing

*righ*t: lab exp. (intensity of echo vs. time)

Active Ultrasonic Detection

Field experiment (cleaning pig run)

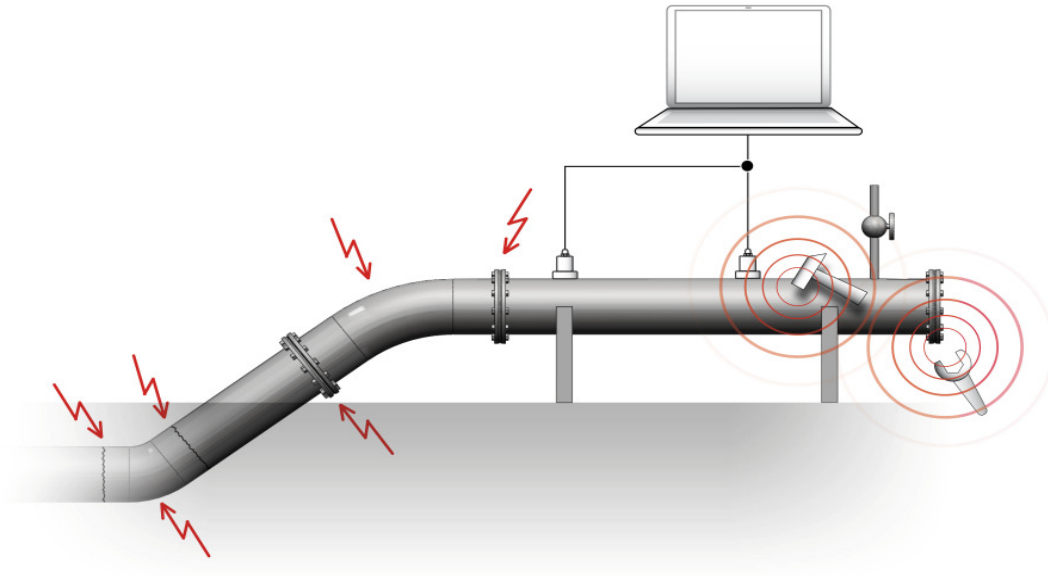




The baseline is also affected since the inner side of the wall has been influenced by residual oil collected by the pig in that pipeline.

Passive Acoustics
Sound Emission as Pig Signalling Tool

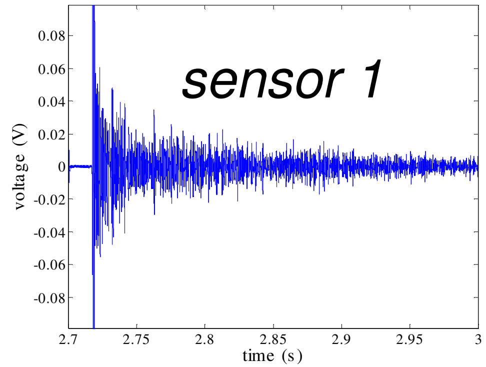
Typical sensor installations
(for permanent operation
or for temporary service)

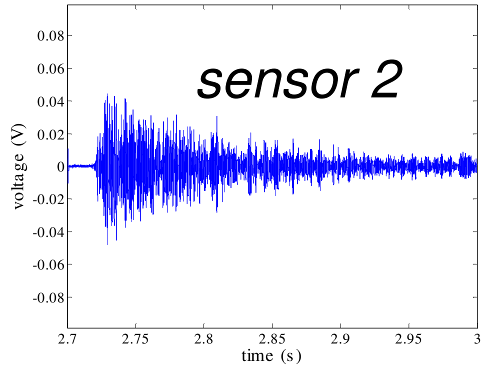


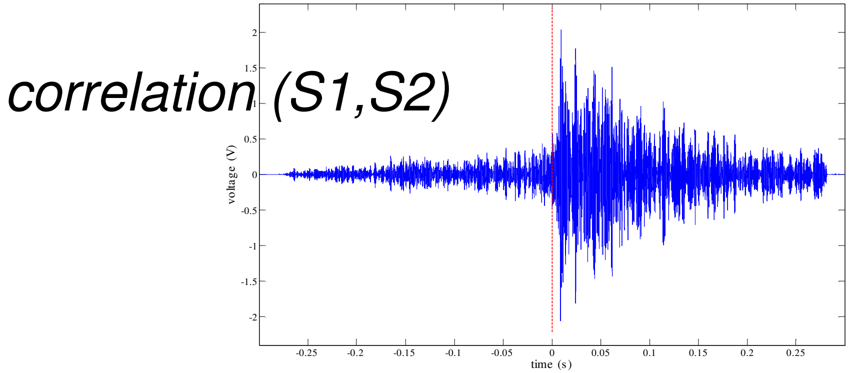
Schematic sketch of a typical situation at pig receiver trap of a gas pipeline. The sensors are axially arranged (in contrast to the „active“ method).

Real-time

Correlation of
an acoustic signal







(Excitation by means of a (low intensity) hammer pulse at sensor 1, sensor 2 in a distance of about 10 m).
The dashed line illustrates the lag of the shift.

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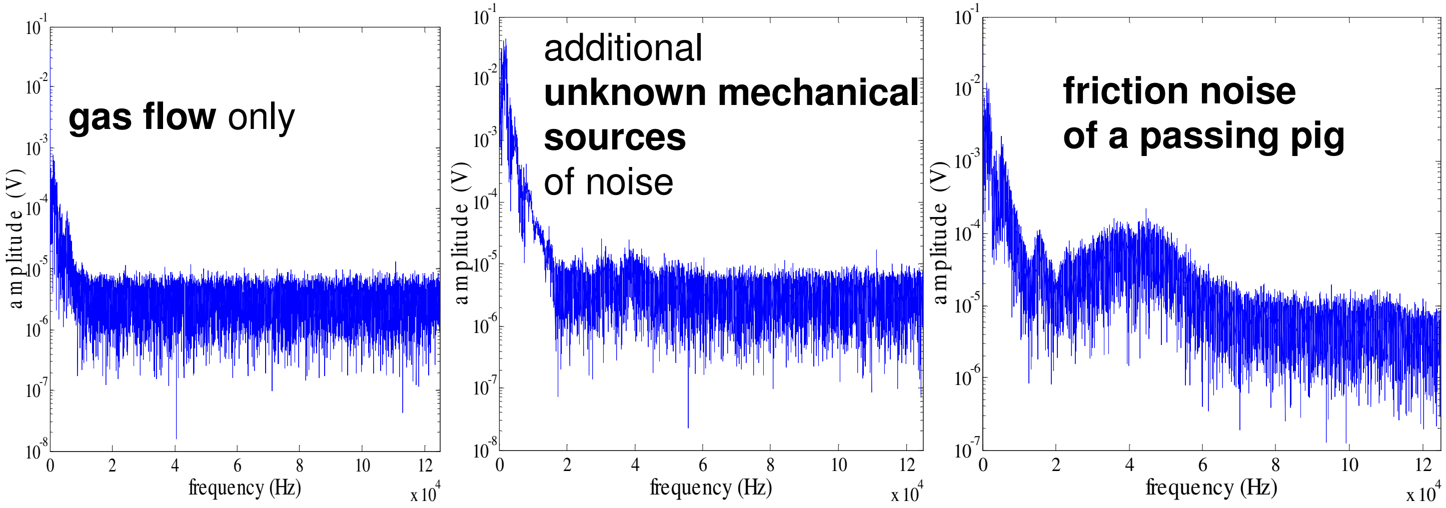
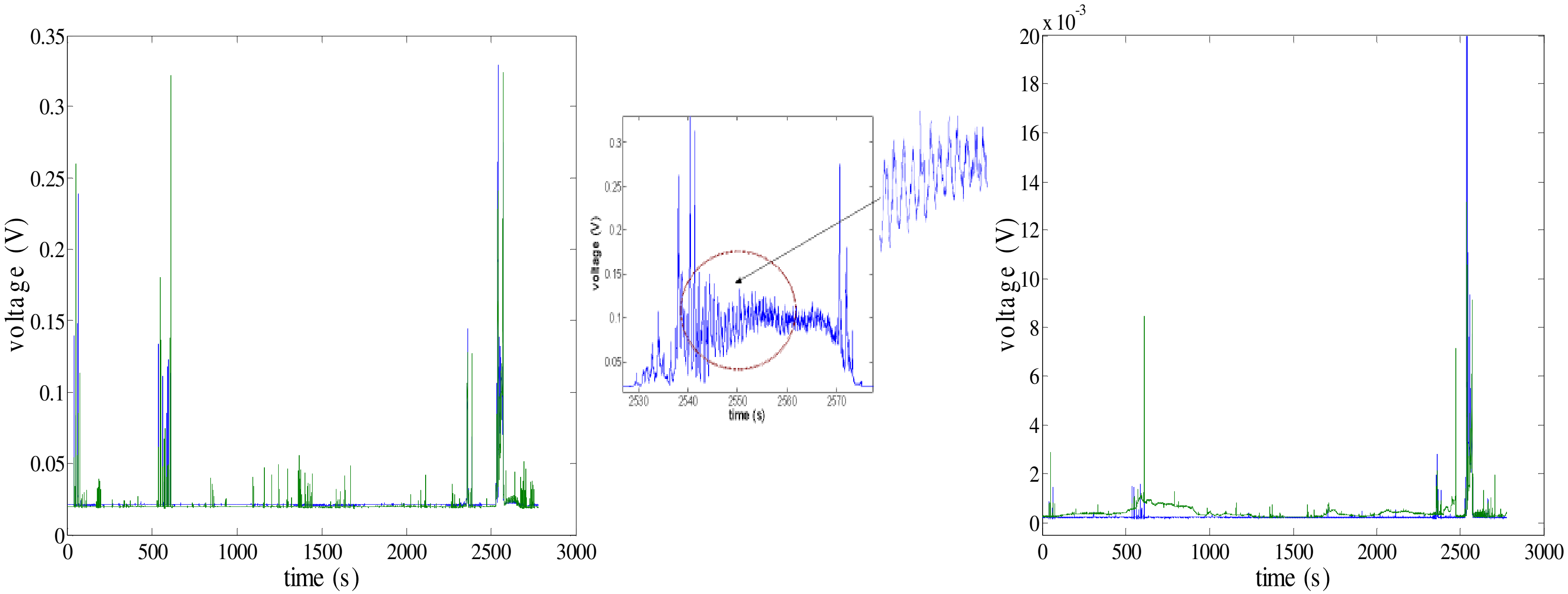
Spectral Behaviour of Pipeline Noise



Frequency characteristics (5 s intervals) of noise during a pig run in a (gas transportation) pipeline

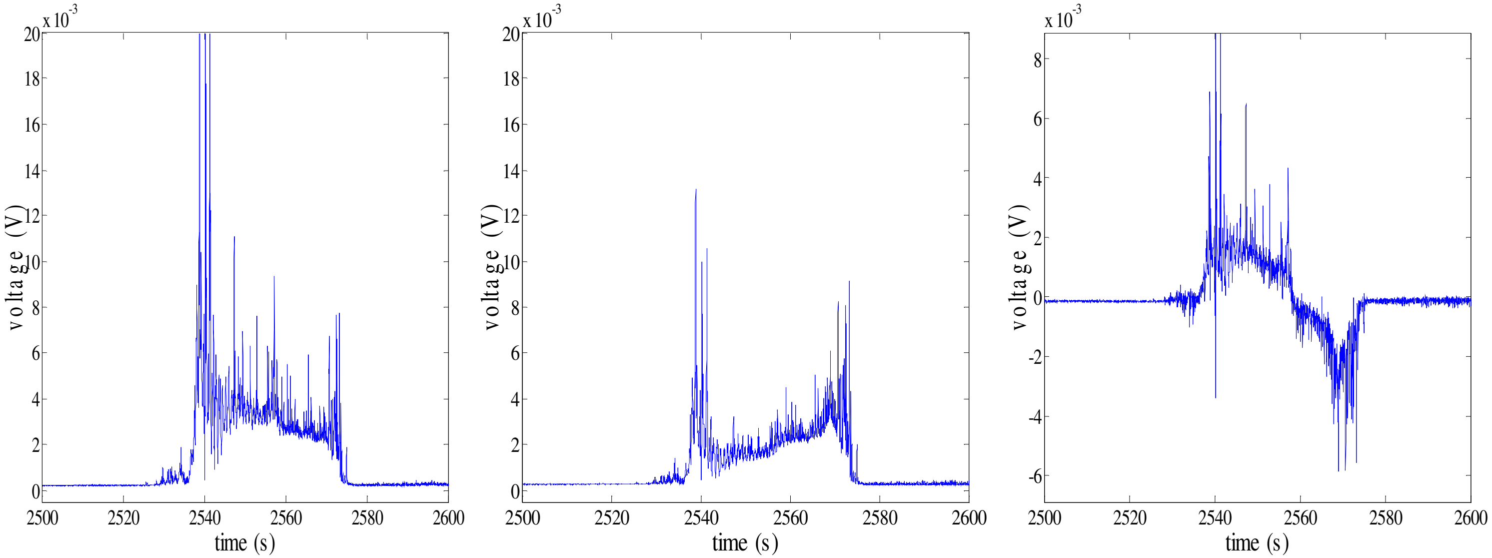
The clearly **enhanced** signal part at **ultrasonic frequencies** is obvious **when a moving pig passes** the sensor position.

A Complete Scenario

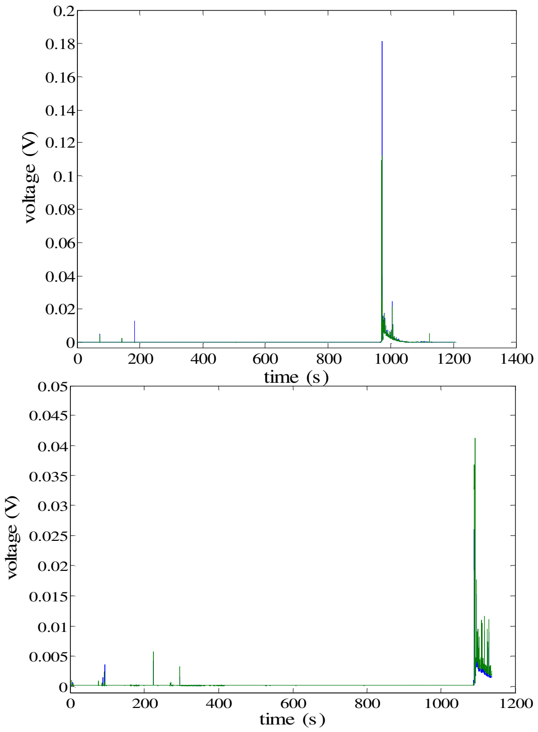


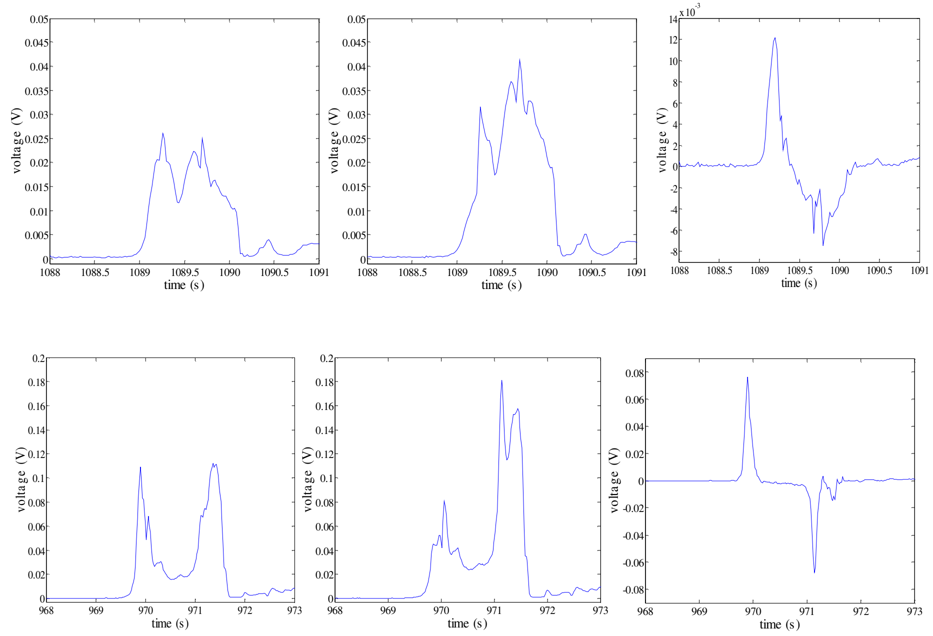
Long time recording of the acoustic signals (**cleaning pig, 900 mm pipeline diameter, uncoated**) received at the sensors 1 and 2 – left: r.m.s. (**root mean square**) signal without filtering,
middle: the pig passage (unfiltered) at sensor 1. This signal in the proximity of the pig receiver results from a fairly complicated motion. There is no smooth travel of the pig. It moves rather in a **stick-slip-procedure** which makes it impossible to use a „simple“ level indicator as an alarm for a passage.
right: the same recording but re-calculated with a **filter for ultrasonic frequencies**. Consequently, the intensity is drastically reduced but still sufficient. Furthermore, „longe range“ distortions can be eliminated more effectively.

Ultrasonic Signal during Passage of a Pig



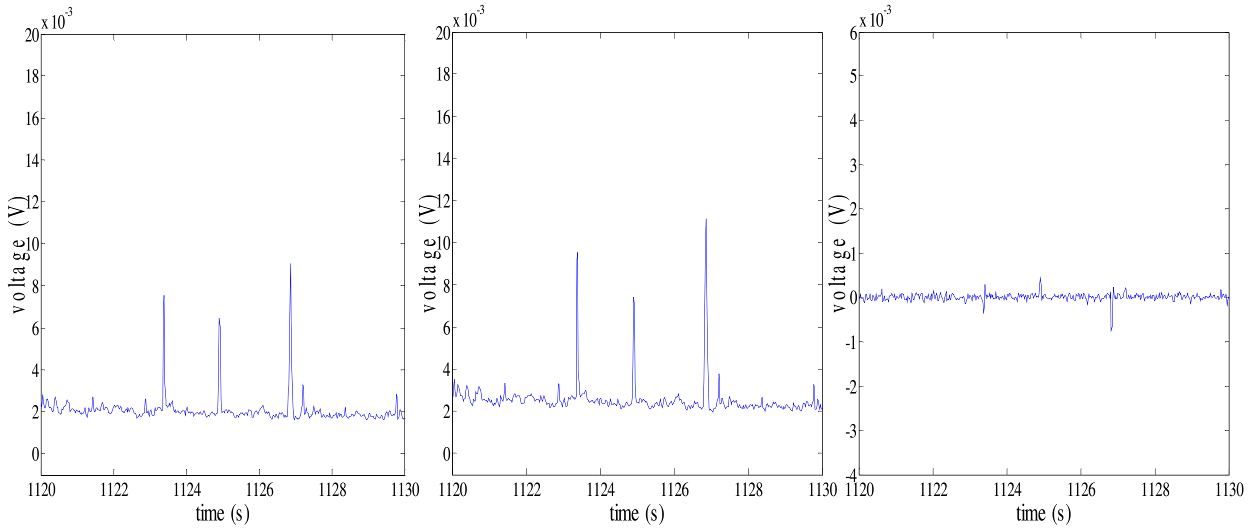
The digitally r.m.s. filtered signals (20 ...60 kHz) of the **passing pig at sensor 1** (left) **and 2** (middle). The difference (right) signal (which is the source for the alarm) is fed into an integration algorithm.





Two further examples of **caliper** and **cleaning pig** runs (in the same campaign / identical sensor positions)
The **ultrasonic signal** is given only.

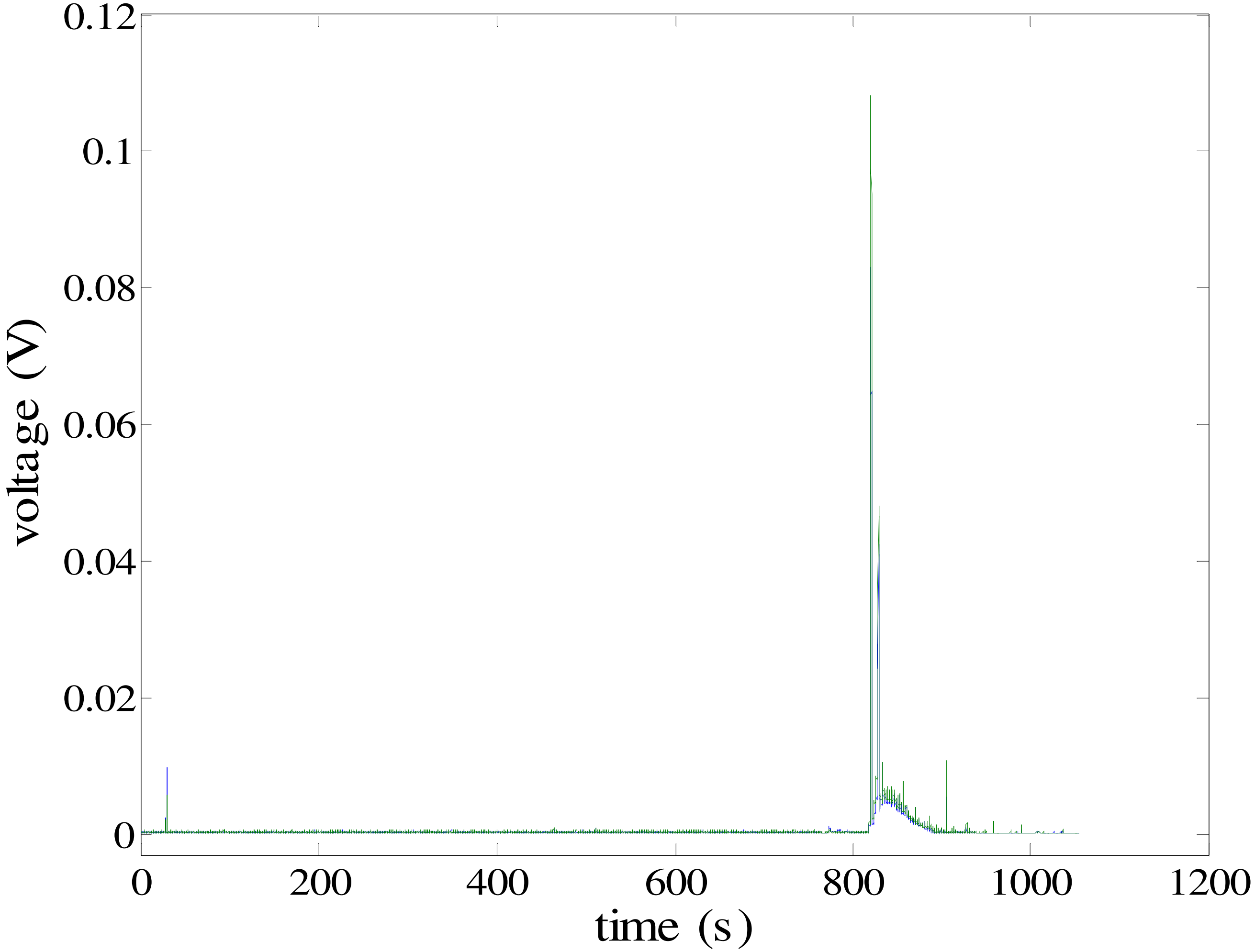
Elimination of distortions



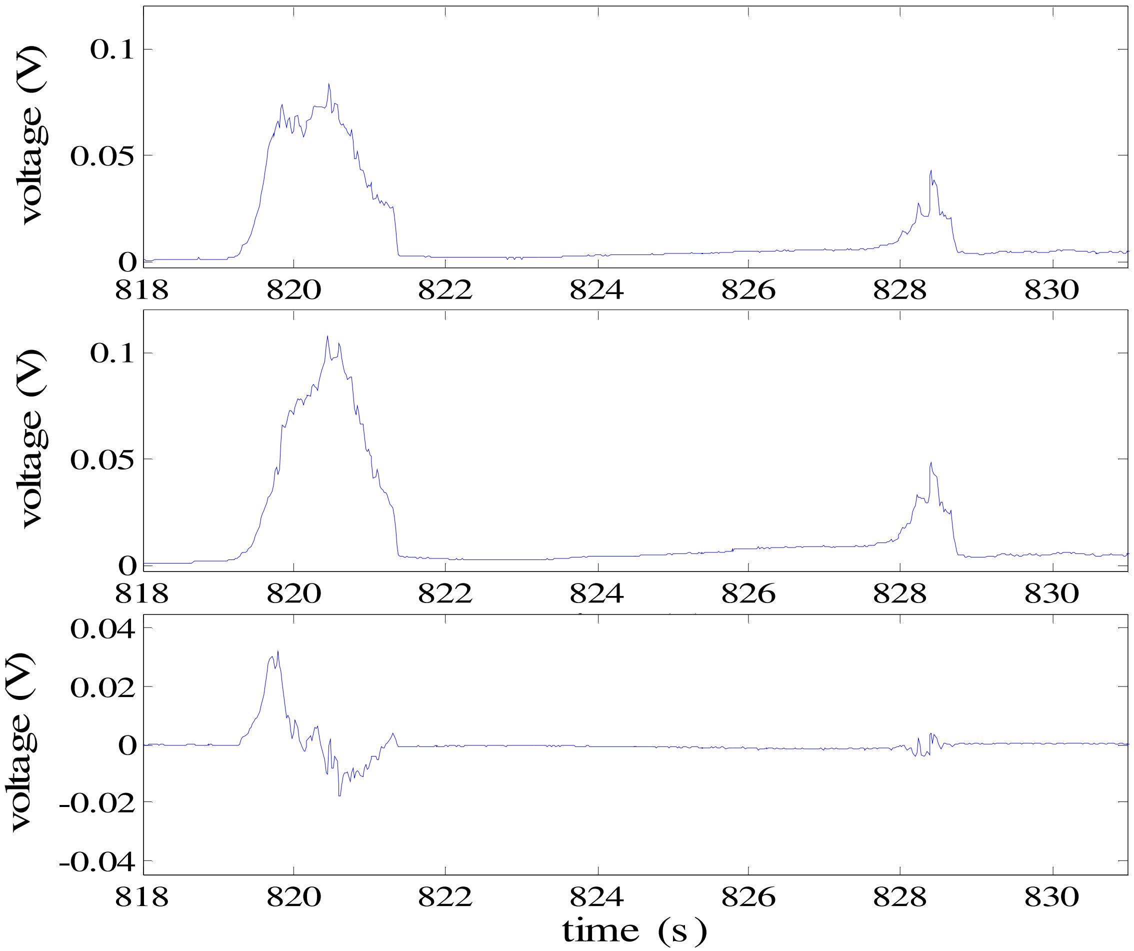
Calibration of probes and choosing the „right“ integration time -

Signals from distant sources (even with complicate signal patterns) can be *“easily”* removed by suitable filters or algorithms. The distortions of other noisy sources such as rain can be suppressed, too.

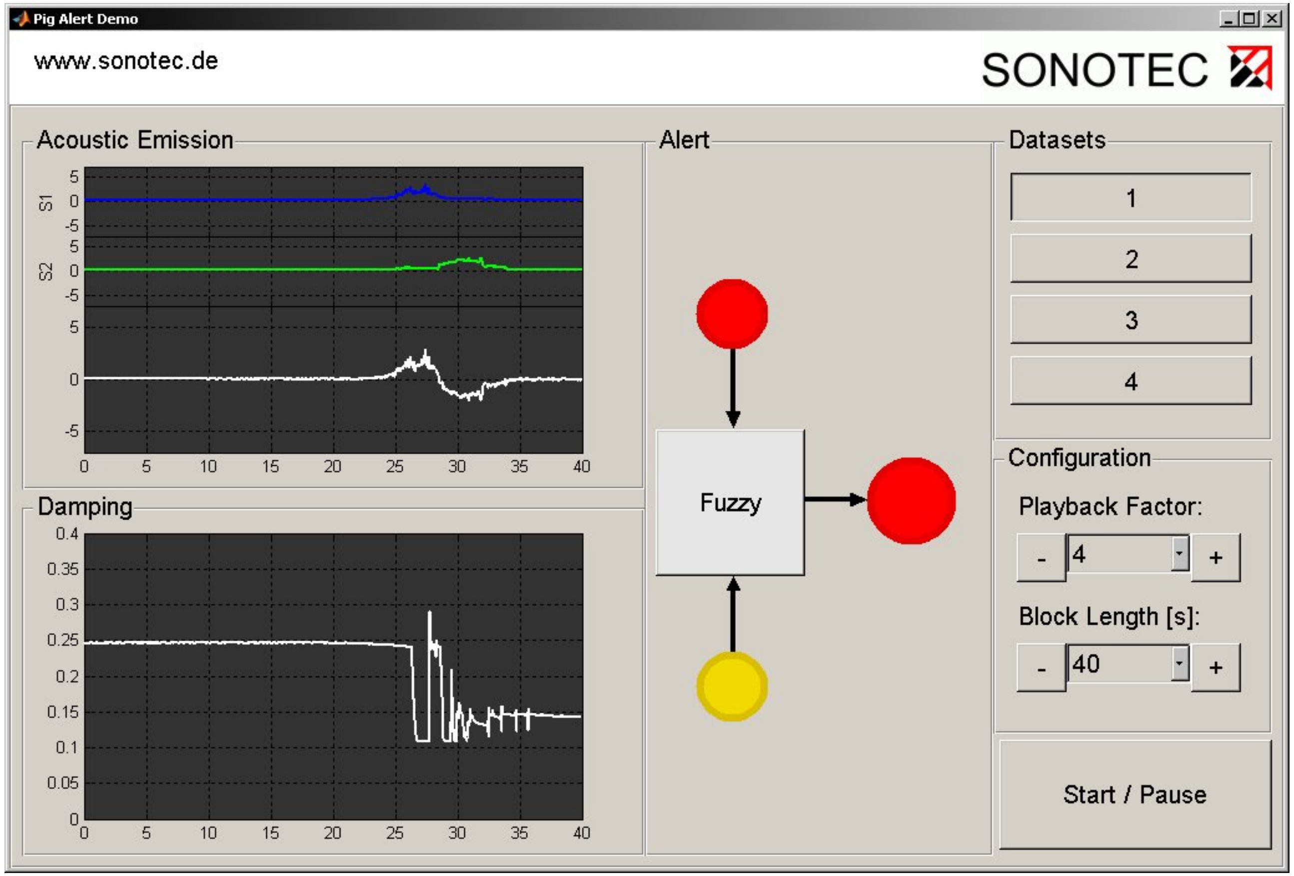
A Complete Example



Passage vs. Distortions



Combination of Methods



Highly flexible data processing tools and alarm functions!

Conclusions

→ acoustical technologies are powerful and versatile for the application in pig detection and signalling
→ new applications of ultrasonic methods for pig detection purposes
→ no *a priori* knowledge about the type of the pig and the operational conditions is necessary
→ improvement of reliability by a combination of different acoustical techniques
→ increased onboard calculation power and new algorithms
→ the method carries the potential to be extended to pig localization

We believe, that the potential of the use of ultrasonic techniques is still underestimated in the pipeline and pigging sector as well.

Acknowledgements

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Thank you for your attention!