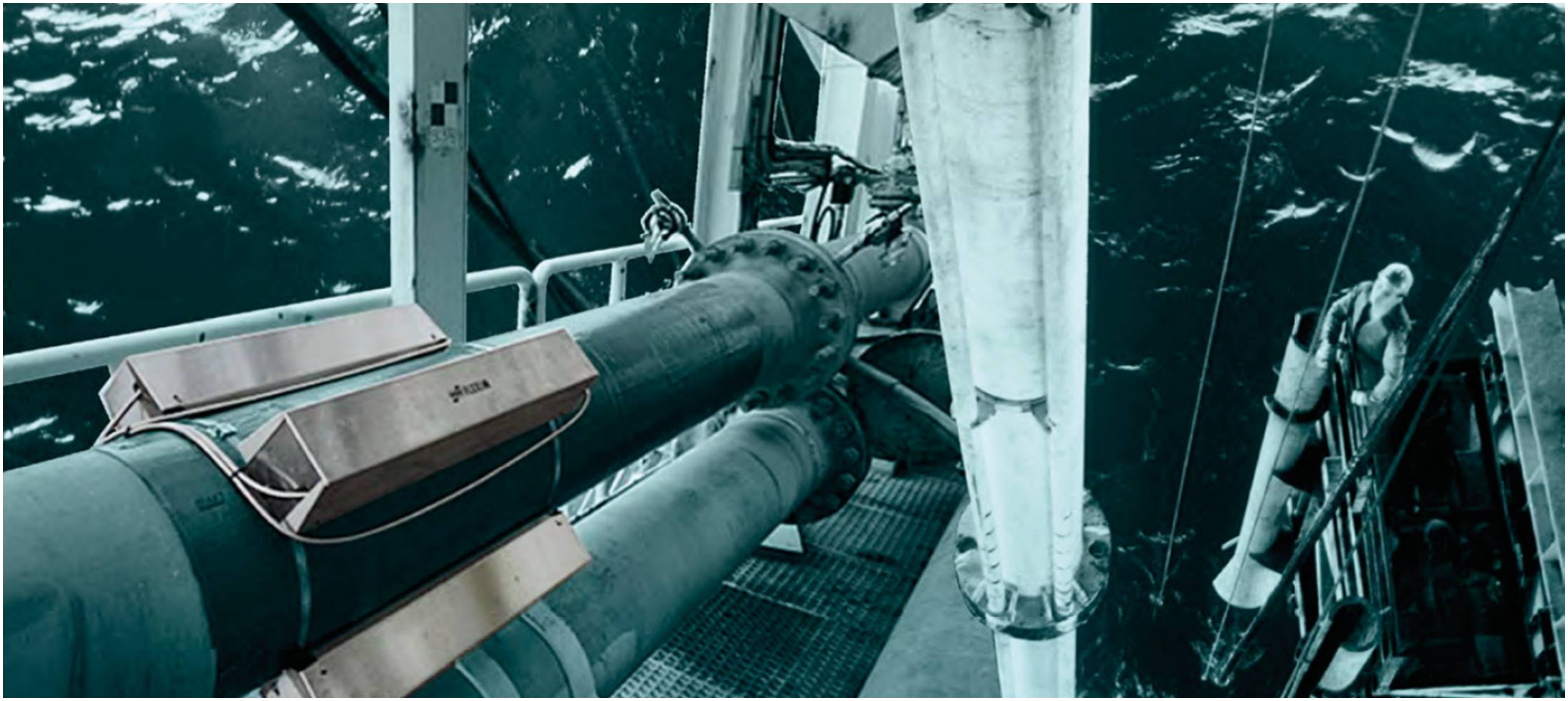
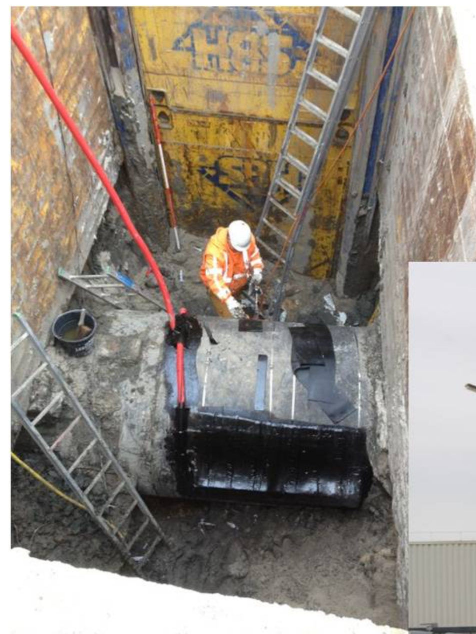
Calibration methods for Ultrasonic Clamp-on flowmeter

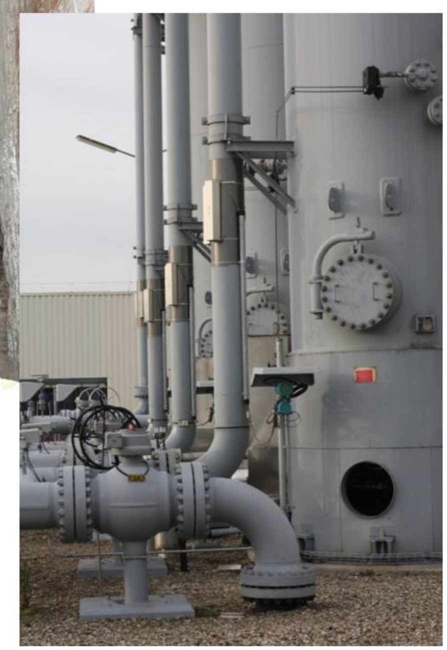
IEC seminar Mumbai, Nov 2018



How can we know measurement accuracy in the field?

→ ***Calibration and Uncertainty analysis***





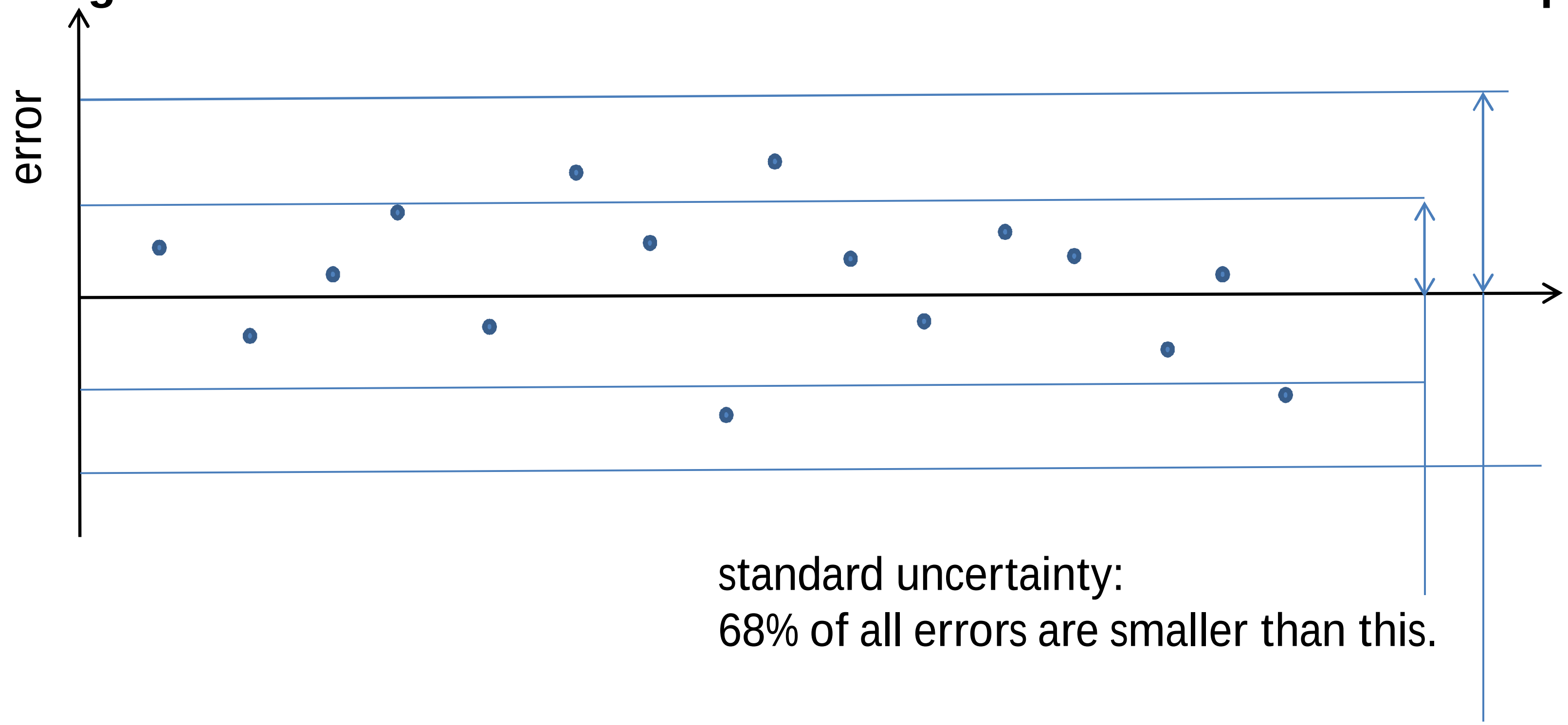
Content

- **Terms and Methods**
  - Accuracy, error, uncertainty
- **Uncertainty analysis**
- **Calibration concept**
- **Specification of Measurement uncertainty**

Knowing accuracy in the field

Option one: The experimental approach

Imagine to test the meter under similar conditions on various similar pipes:



standard uncertainty:
68% of all errors are smaller than this.

expanded uncertainty (k=2)
95% of all errors are smaller than this.

The term accuracy

Can we call uncertainty accuracy?

International vocabulary of metrology
– Basic and general concepts and associated terms (VIM):

2.13 (3.5)
measurement accuracy
accuracy of measurement
accuracy

closeness of agreement between a **measured quantity value** and a **true quantity value** of a **measurand**

NOTE 1 The concept 'measurement accuracy' is not a **quantity** and is not given a **numerical quantity value**. A **measurement** is said to be more accurate when it offers a smaller **measurement error**.

Knowing accuracy in the field

Is the experimental approach practical?

Can we assess uncertainty for our whole application range experimentally?

Test program for our total application range would include:

(at minimum)

- about 10 pipe sizes
- each with 4 transducer types (2 frequencies, Lamb and shear)
- repeats at 10 Labs
- all of this with liquid and gas

→10x4x10x2= 800 Tests, without even taken inflow conditions into account!

→ Impossible

Pro:

- **very reliable result**

Con:

- **Expensive: Practical only for a single application in rare cases**
- **Reason for the errors is not visible**

Knowing accuracy in the field

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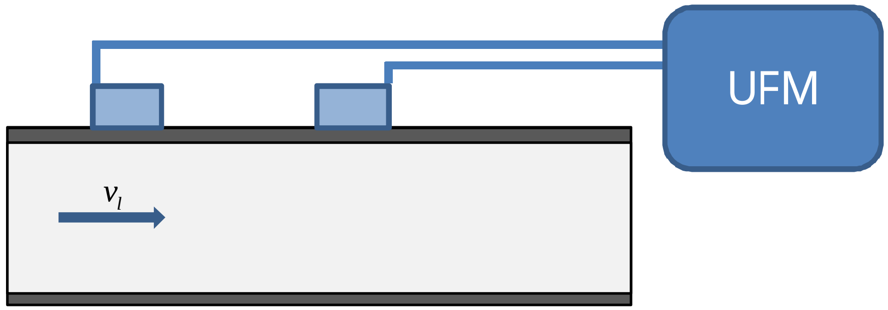
Alternative: Uncertainty analysis



Components:	pipe area	flow profile	Transducer	transmitter
Parameters:	wall thickness pipe ID	Re, inflow conditions	Ka	dt, tfluid, t0
assessing uncertainties:	uncertainty of measurement	experimental: Type calibration	Factory calibration	Factory calibration

Meter formular: $\dot{V} = A \cdot K_{\mathrm{Re}} \cdot K_a \cdot \frac{\Delta t}{2 t_{fl}}$ → weight of each uncertainty contribution → total measurement uncertainty at site

Knowing accuracy in the field

Uncertainty analysis:

Pro:

- covers the whole application range
- inexpensive
- shows contribution of each parameter

→we learn why a certain application is more or less accurate

Con:

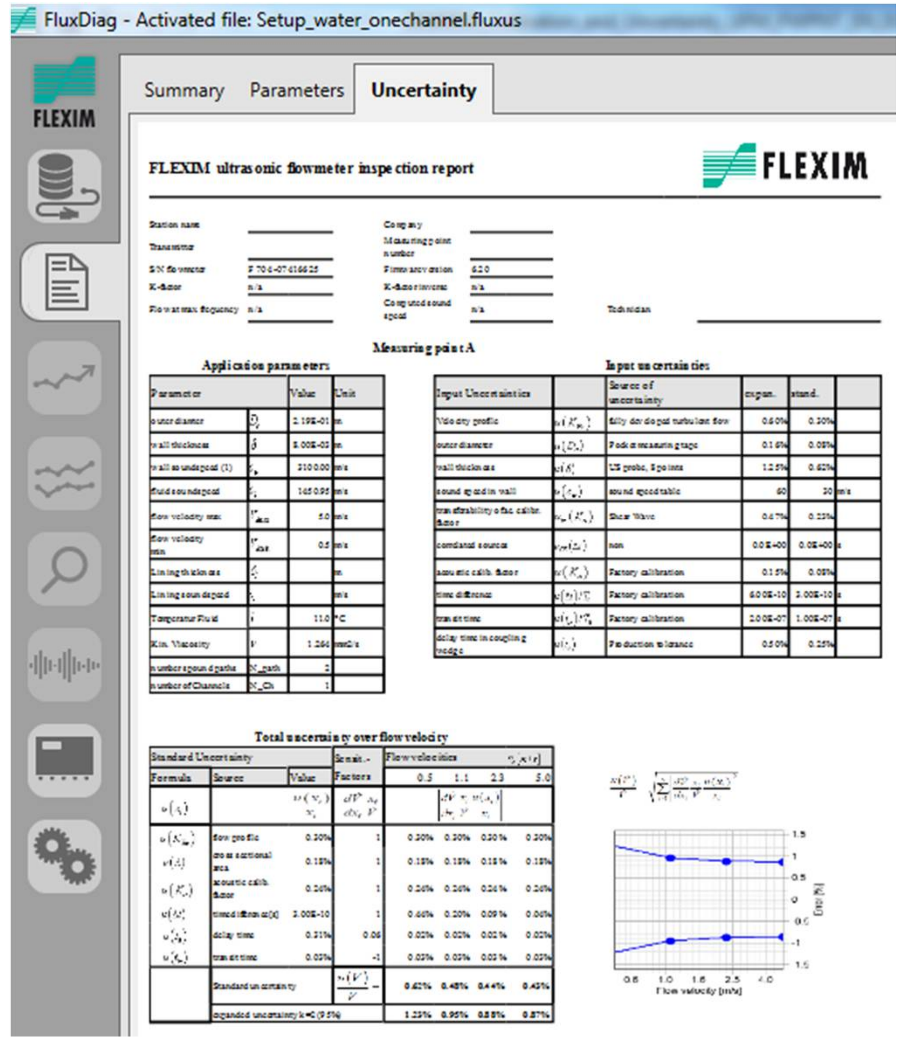
- precision is limited to the limits of the meter model

Knowing accuracy in the field

Recomendations for uncertainty analysis are provided by
ISO/IEC Guide 98-3:2008, Uncertainty of measurement — Part 3:
Guide to the expression of uncertainty in measurement (“GUM”)

This is applied to ultrasonic flow meters in
ISO 12242:2012, Measurement of fluid flow in closed conduits
— Ultrasonic transit-time meters for liquid

The Calculation is implemented in Fluxdiag



Calibration concept

Each component of the measurement is calibrated individually:

Transmitter

Transducers

Pipe geometry

Flow profile

$$\dot{V} = K_{\mathrm{Re}} \cdot A \cdot K_a \frac{\Delta t}{2 t_{fl}}$$

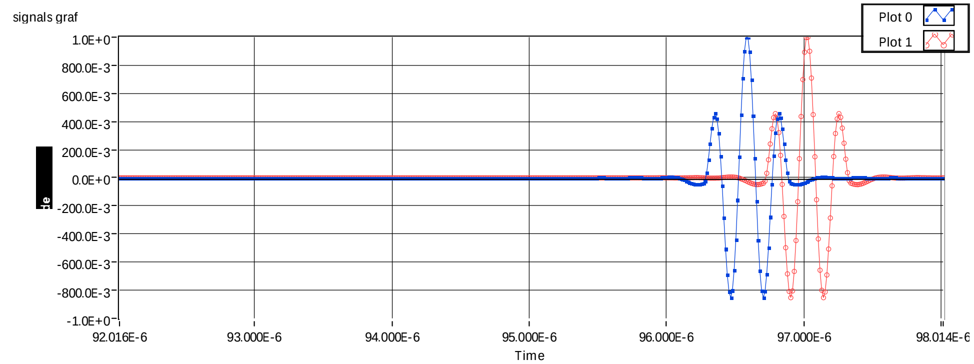
Factory calibration

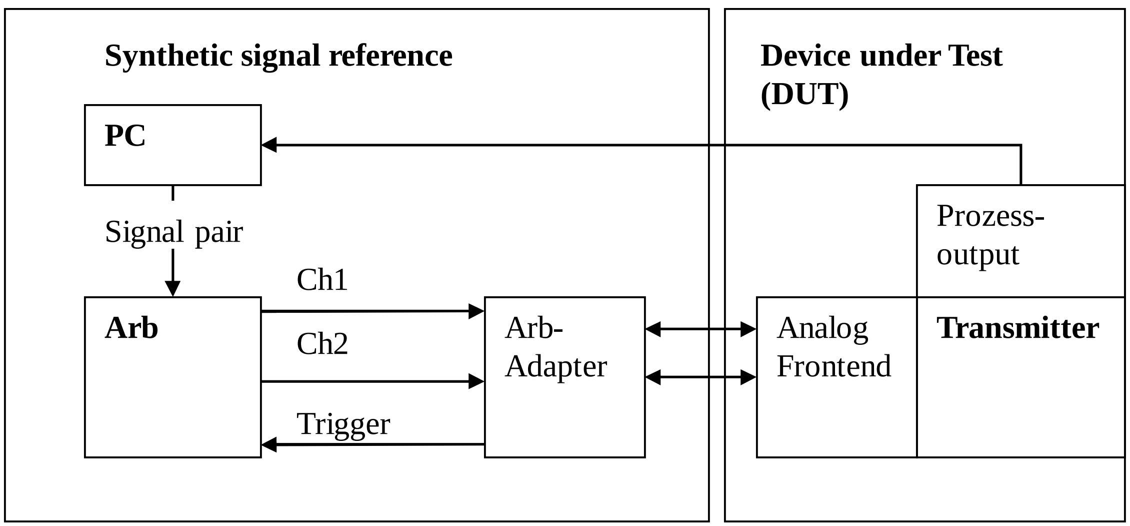
Measurement in the field

Type calibration

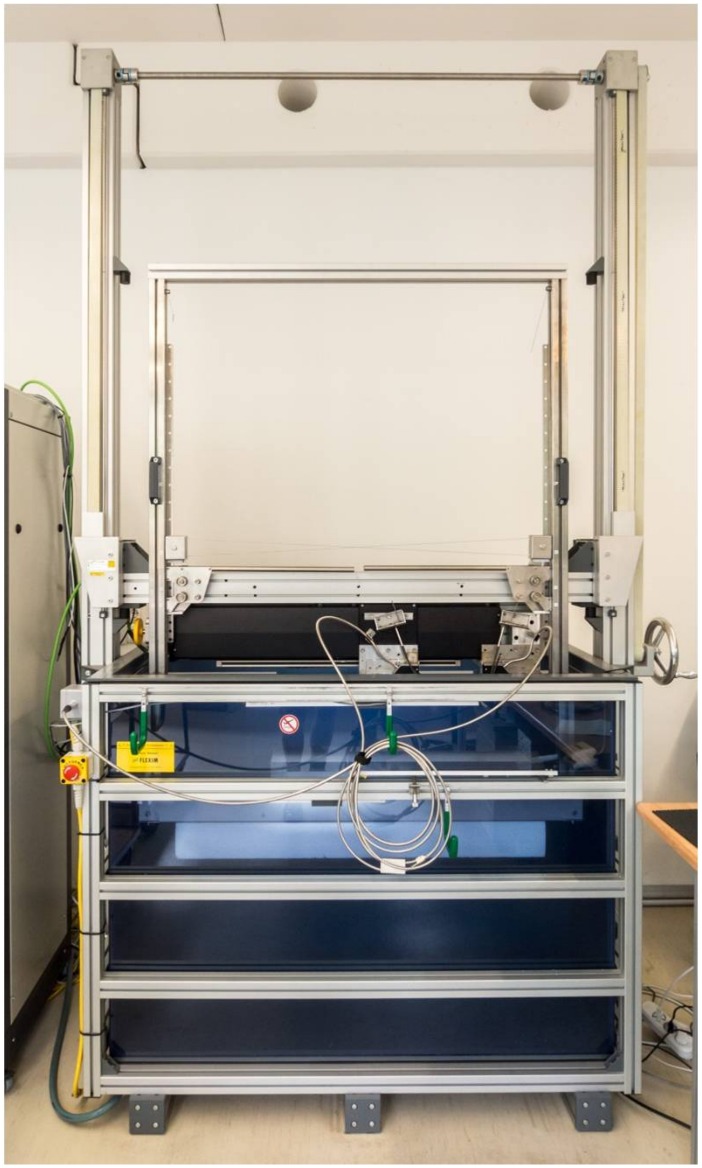
Calibration concept - Transmitter

Calibration of time measurement by using synthetic signals with pre-defined transit time and time difference





Calibration concept - Transducer



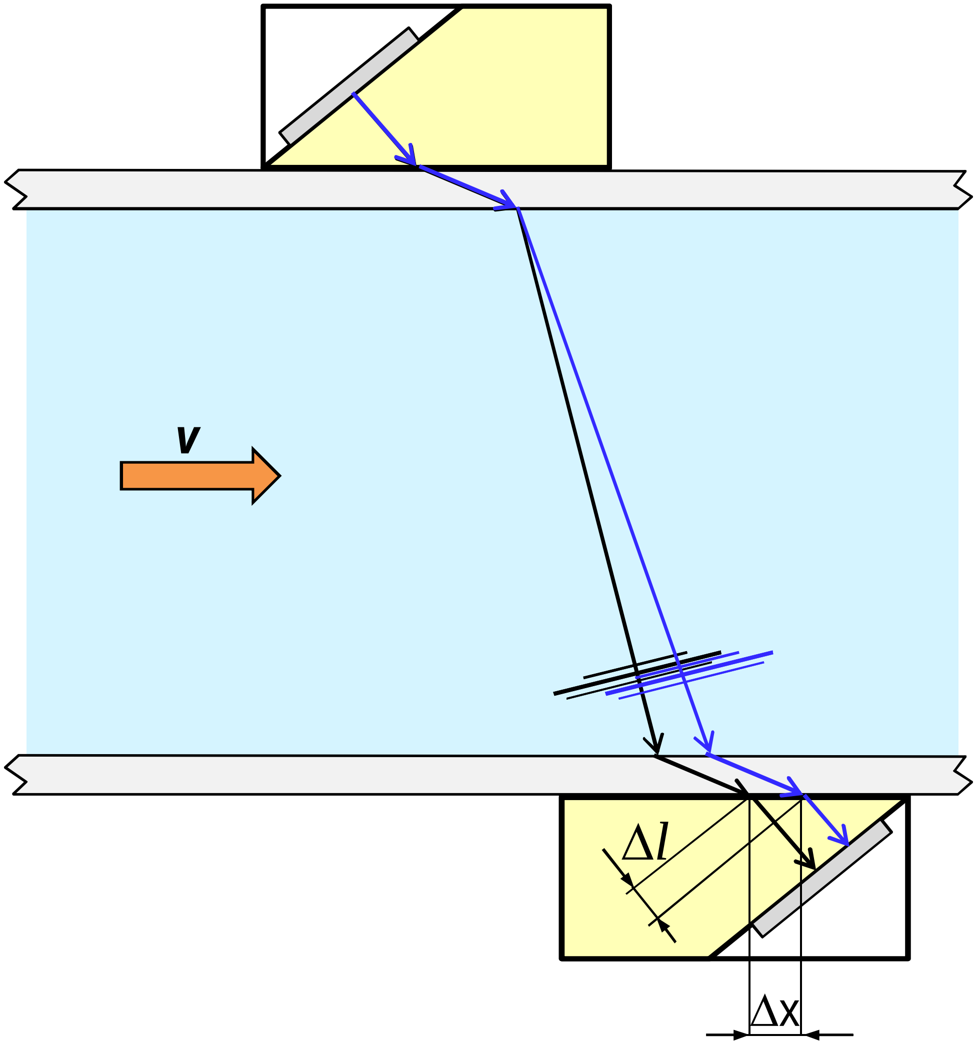
Aperture Calibration

- **direct measurement of transducer constant by measuring distance and time**

  - **Uncertainty of distance measurement: 1 µm**
  - **Uncertainty of time difference: 1/5000 of signal period**
  - **Total uncertainty of Reference: 0.16 %,**

Calibration concept - Transducer

Based on the principal of measurement:



Acoustical calibration factor is

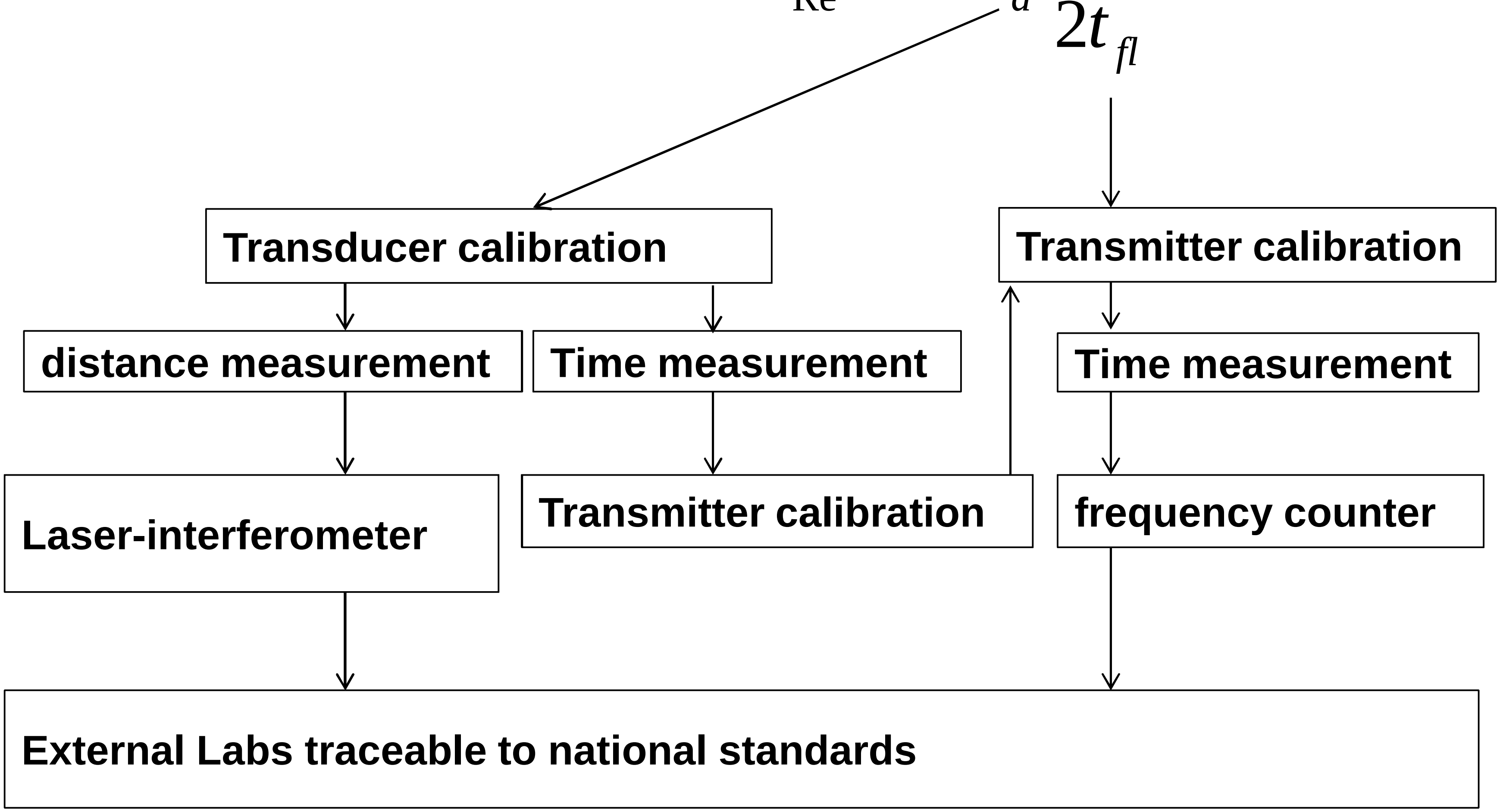
$$K_a = \frac{\Delta x}{\Delta t}$$

Calibration method:

Relocation of transducers is equivalent to relocation of the beam caused by the flow

Factory calibration: Traceability chain

$$\dot{V} = K_{\mathrm{Re}} \cdot A \cdot K_a \frac{\Delta t}{2t_{fl}}$$



Calibration concept: Transfereability

Calibration of Transducer and Transmitter is independent off pipe and fluid.

→ Calibration transferable to all pipe sizes and fluids within application range

Calibration concept: Repeatability of Calibration

Transducer and Transmitter are calibrated independent off each other and independent off pipe and fluid.

→ Calibration of the installation is not effected by
- **replacing or recalibrating transducers after installation**
- **replacing or recalibrating transmitters after installation**

Specification of measurement uncertainty

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How to derive the specification from uncertainty calculation?

How to provide a specification the customer understands?

Most of the contributions are independent of flow velocity.

The contribution of time difference depends on flow velocity.

Uncertainty contributions and total uncertainty:

X% +Ycm/s

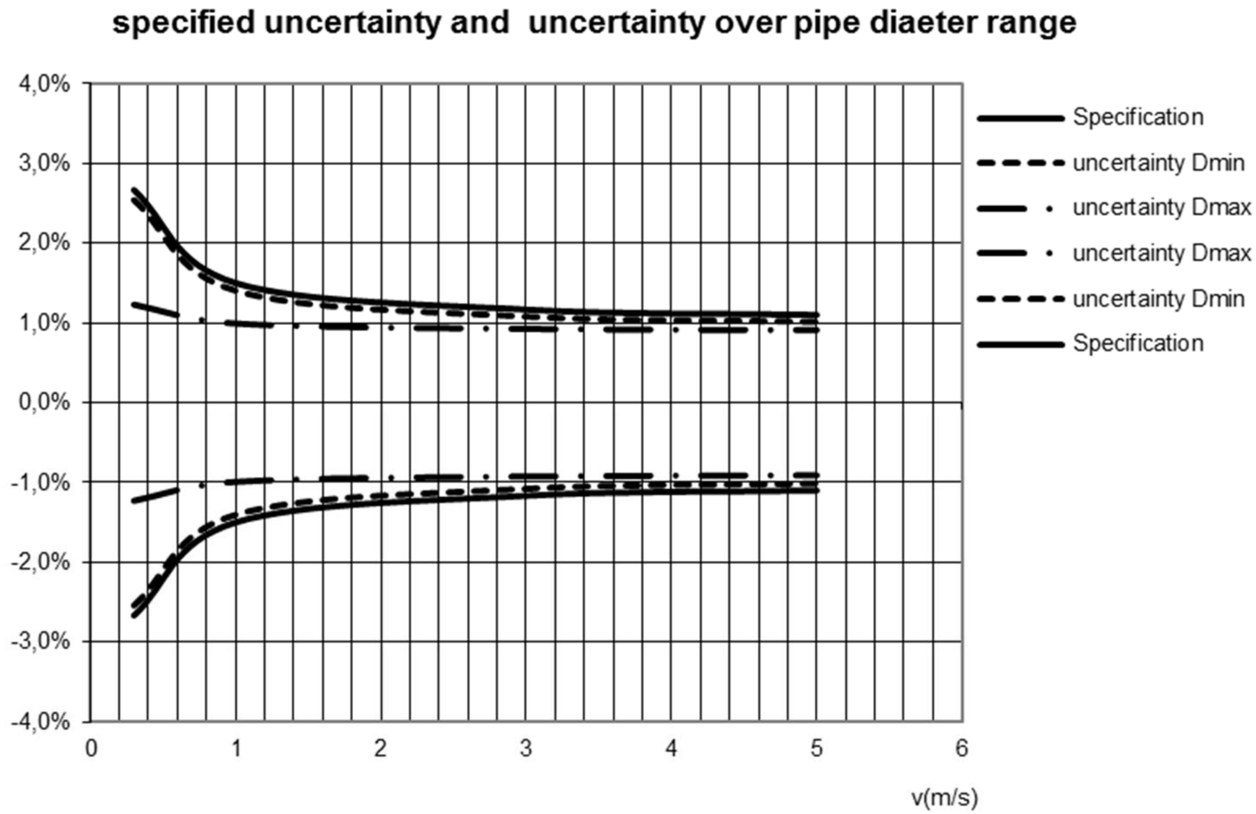
Total uncertainties for V= 3,00 m/s					Total uncertainty over flow velocity				
Standard Uncertainty			Sensitivi	Contri-	$\bar{v}_a\,[m/s]$	0,3	1	3	5
Formula	Source	Value	Factors	bution		Contribution			
$u(x_i)$		$\frac{u(x_i)}{x_i}$	$\frac{d\dot{V}}{dx_i}\frac{x_i}{\dot{V}}$	$\frac{d\dot{V}}{dx_i}\frac{x_i}{\dot{V}}\frac{u(x_i)}{x_i}$	$u(x_i)$	$\frac{d\dot{V}}{dx_i}\frac{x_i}{\dot{V}}\frac{u(x_i)}{x_i}$	$\frac{d\dot{V}}{dx_i}\frac{x_i}{\dot{V}}\frac{u(x_i)}{x_i}$	$\frac{d\dot{V}}{dx_i}\frac{x_i}{\dot{V}}\frac{u(x_i)}{x_i}$	$\frac{d\dot{V}}{dx_i}\frac{x_i}{\dot{V}}\frac{u(x_i)}{x_i}$
$u(K_{Re})$	flow profile	0,30%	1	0,30%					
$u(A)$	cross sectional area	0,23%	1	0,23%					
$u(K_a)$	acoustic calib. factor	0,26%	1	0,26%					
$u(\Delta t)$	time difference	0,08%	1	0,08%					
$u(t_0)$	delay time $\frac{t_0}{t_{tr}-t_0}=$	0,39%	0,06	0,02%					
$u(t_{tr})$	transit time	0,03%	-1	0,03%					
	Standard uncertainty		$\frac{u(\dot{V})}{\dot{V}}=$	**0,47%**	$\frac{u(\dot{V})}{\dot{V}}=$	**0,91%**	**0,52%**	**0,47%**	**0,46%**
	expanded uncertainty k=2 (95%)			**0,94%**	**k=2 (95%)**	**1,83%**	**1,04%**	**0,94%**	**0,93%**

Specification of Measurement uncertainty

Total measurement uncertainty varies with site parameters.

How to specify measurement uncertainty independent of site parameters?

→Total measurement uncertainty needs to be smaller than specified uncertainty within full specified application range.



Summary

Advantages of Flexims calibration concept:

- **Traceable Calibration of Transmitter and Transducers**
- **Transmitter and Transducers are calibrated separately.**
  - Transducer and/or transmitter can be replaced without losing the calibration of the system → repeatable calibration
  - Calibration is transferable to all pipe sizes and fluids within application range
- **Re-calibration of Transmitter and Transducers without process interruption**
- **Measurement uncertainty in the field can be calculated based on calibration and site parameters.**

Thank You!