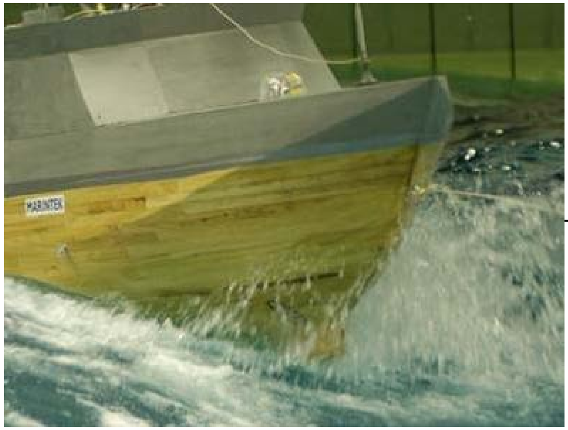
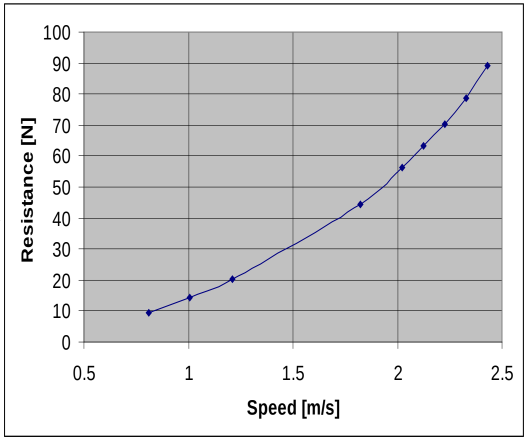
Instrumentation (ch. 4 in Lecture notes)

- Measurement systems – short introduction
- Measurement using strain gauges
- Calibration
- Data acquisition
- Different types of transducers



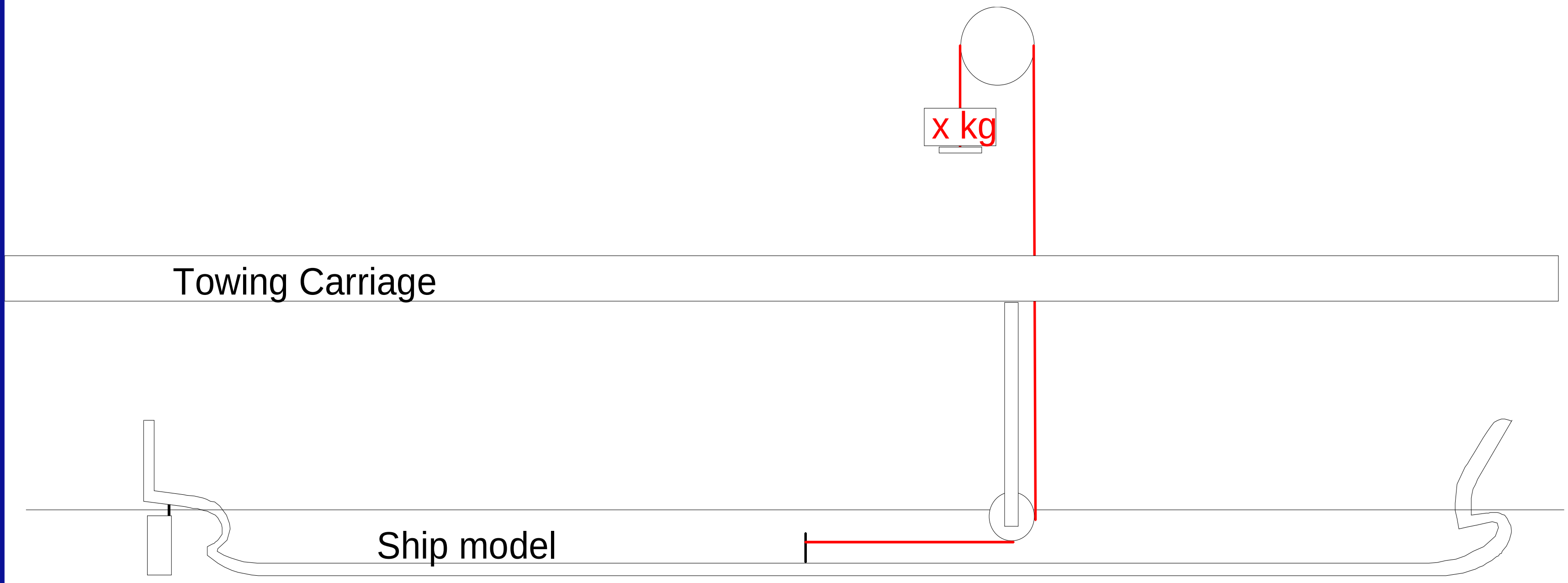
Physical process

Instrumentation and data acquisition



Measurement result (numbers)

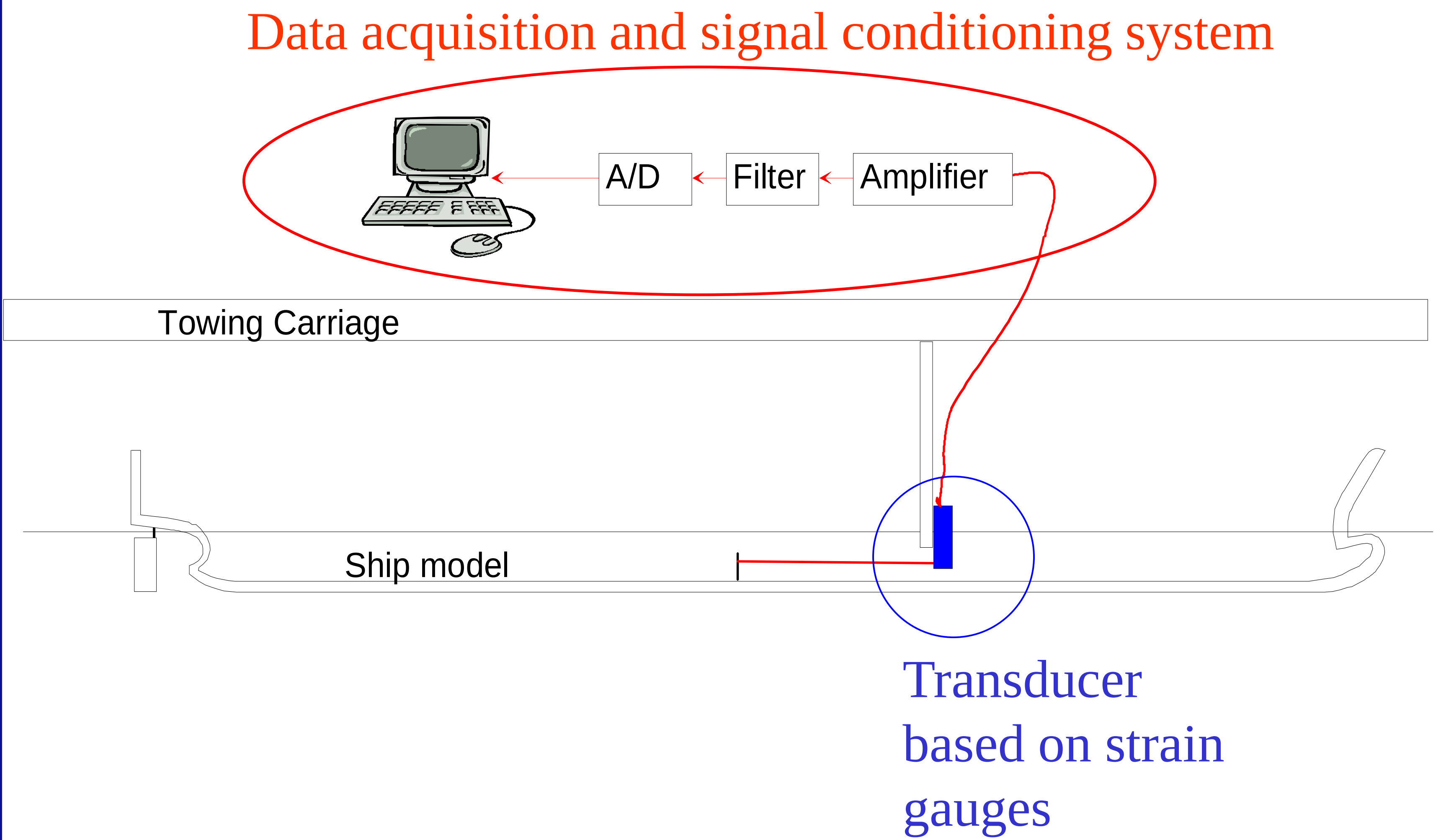
The old resistance measurement system



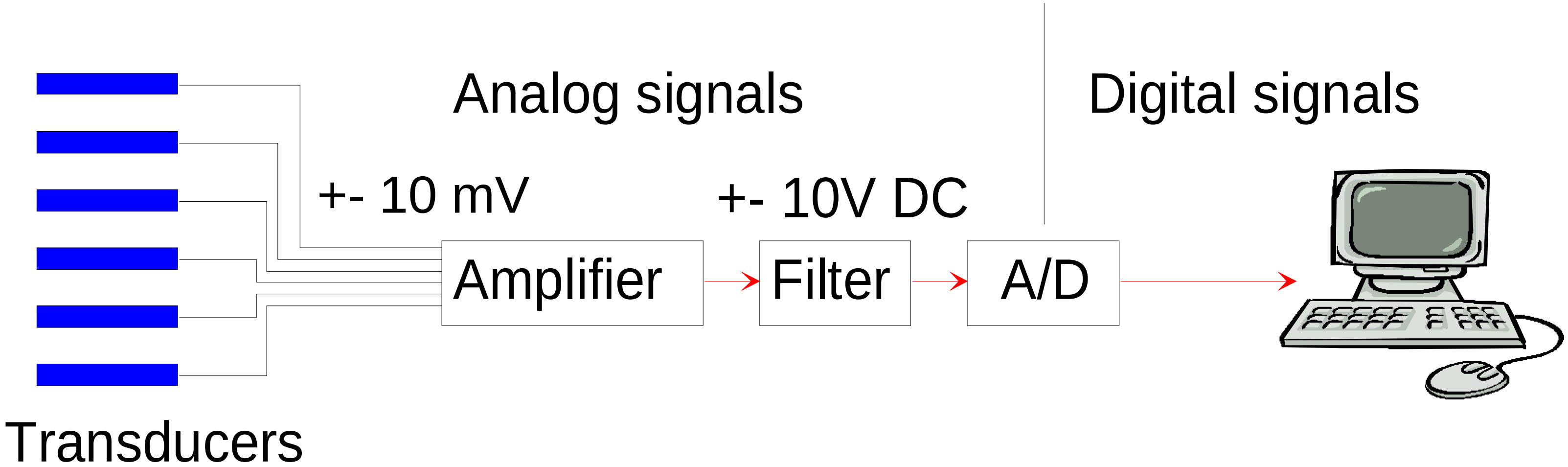
Transducer = weights, wheels and string

Data acquisition = writing down total weight

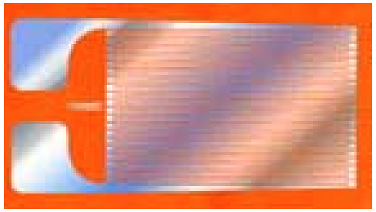
The new resistance measurement system

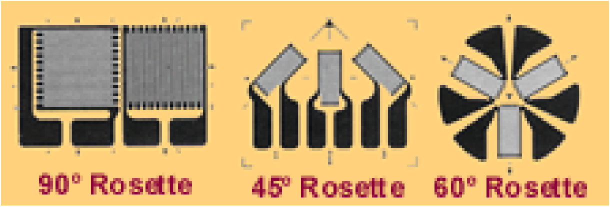


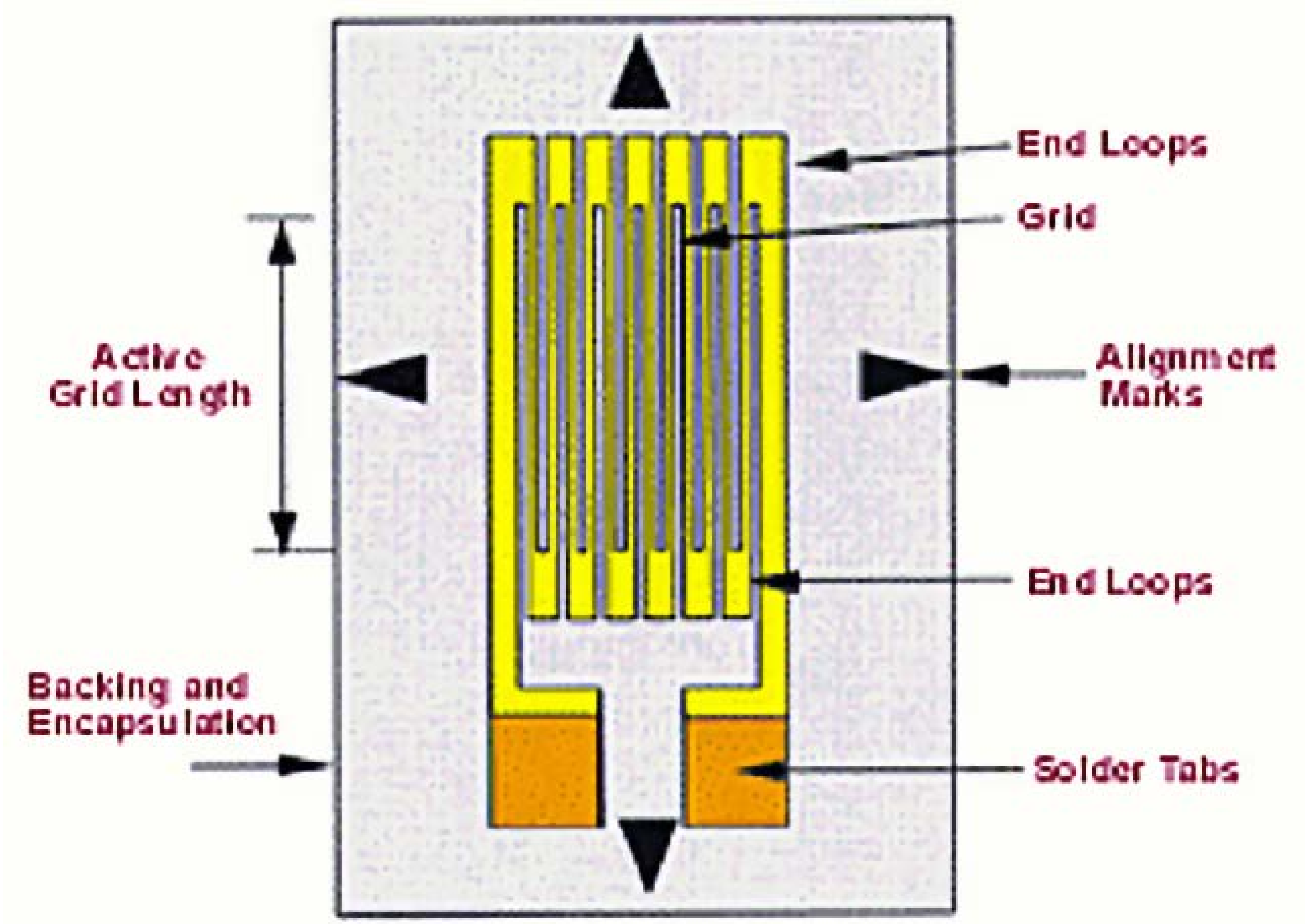
Measurement systems



Strain gauges

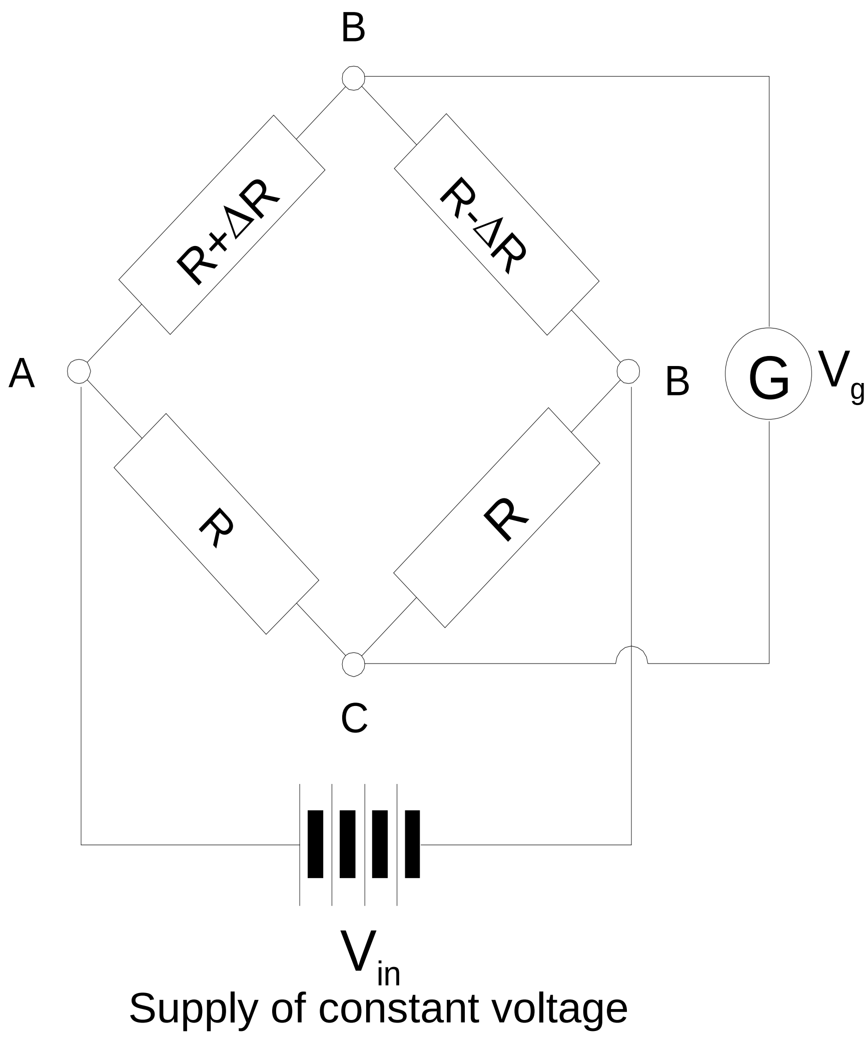






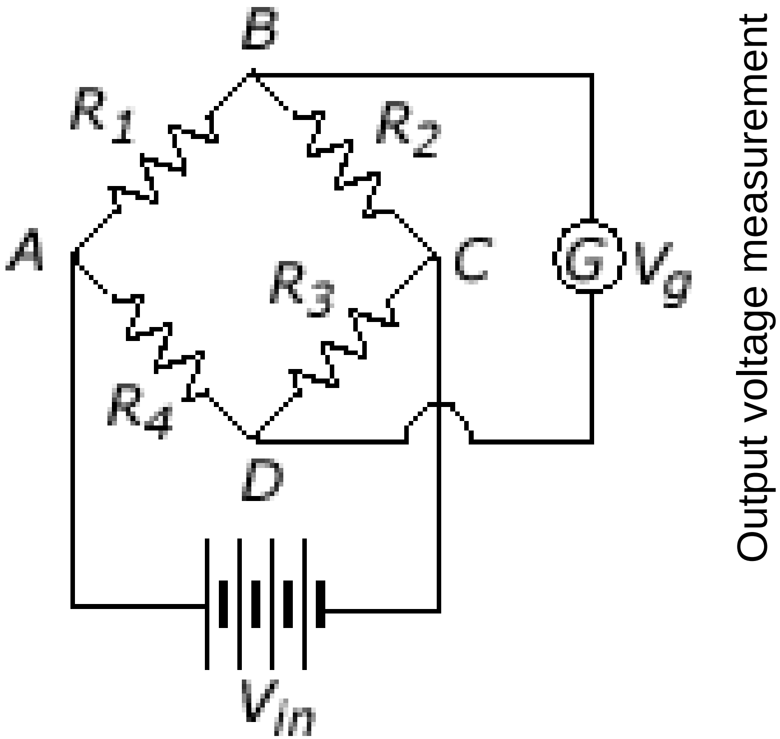
Wheatstone bridge

- ΔR is change of resistance due to elongation of the strain gauge
- R is known, variable resistances in the amplifier
- V_{in} is excitation – a known, constant voltage source
- V_g is signal



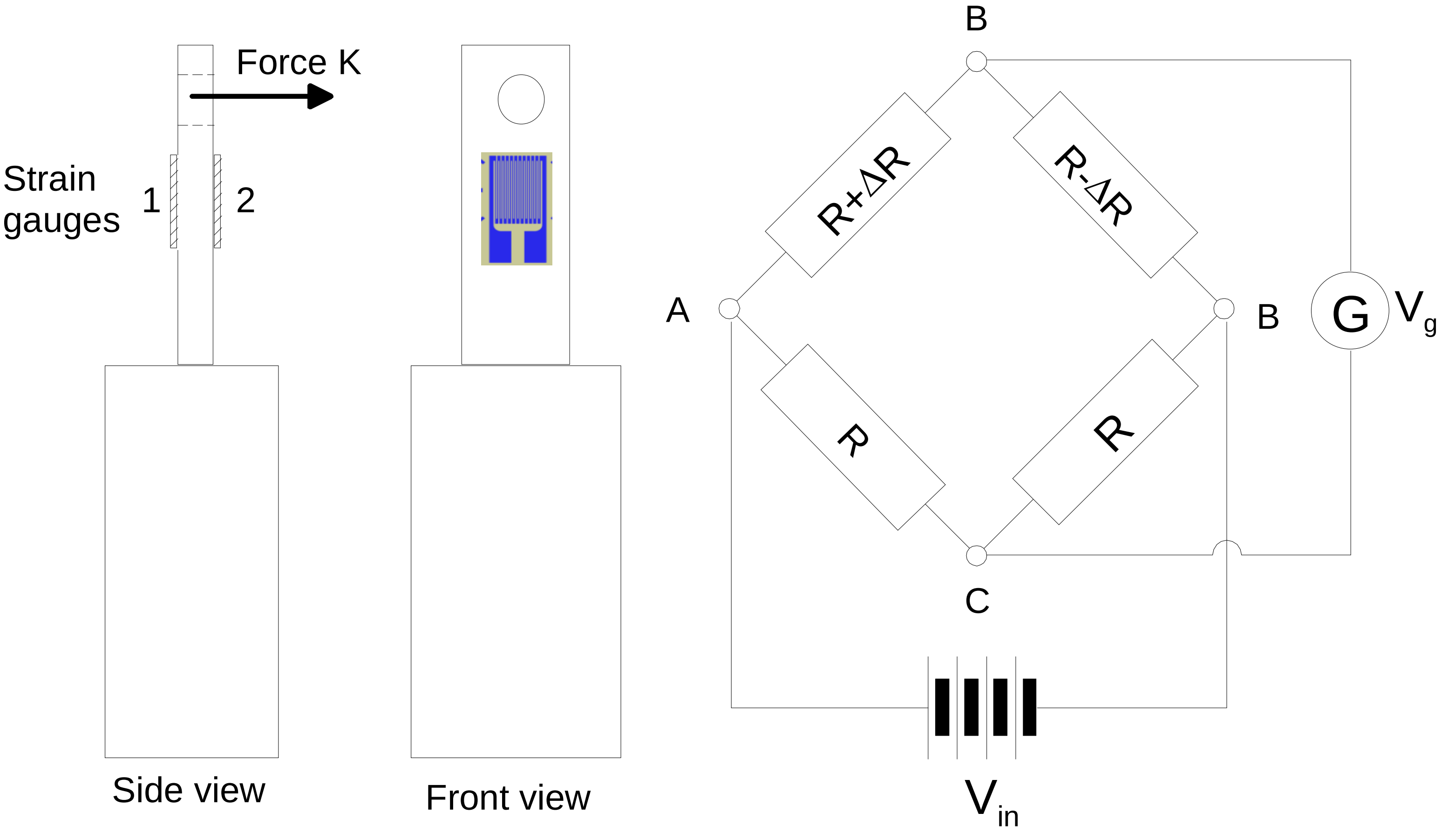
Wheatstone bridge

- Constant voltage (can also be current) is supplied between A and C
- The measured voltage (or current) between B and G depends on the difference between the resistances R_1-R_4
- One or more of the resistances R_1-R_4 are strain gauges
- If all resistances are strain gauges, it is a *full bridge circuit*
- If only one resistance is a strain gauge it is a *quarter bridge circuit*



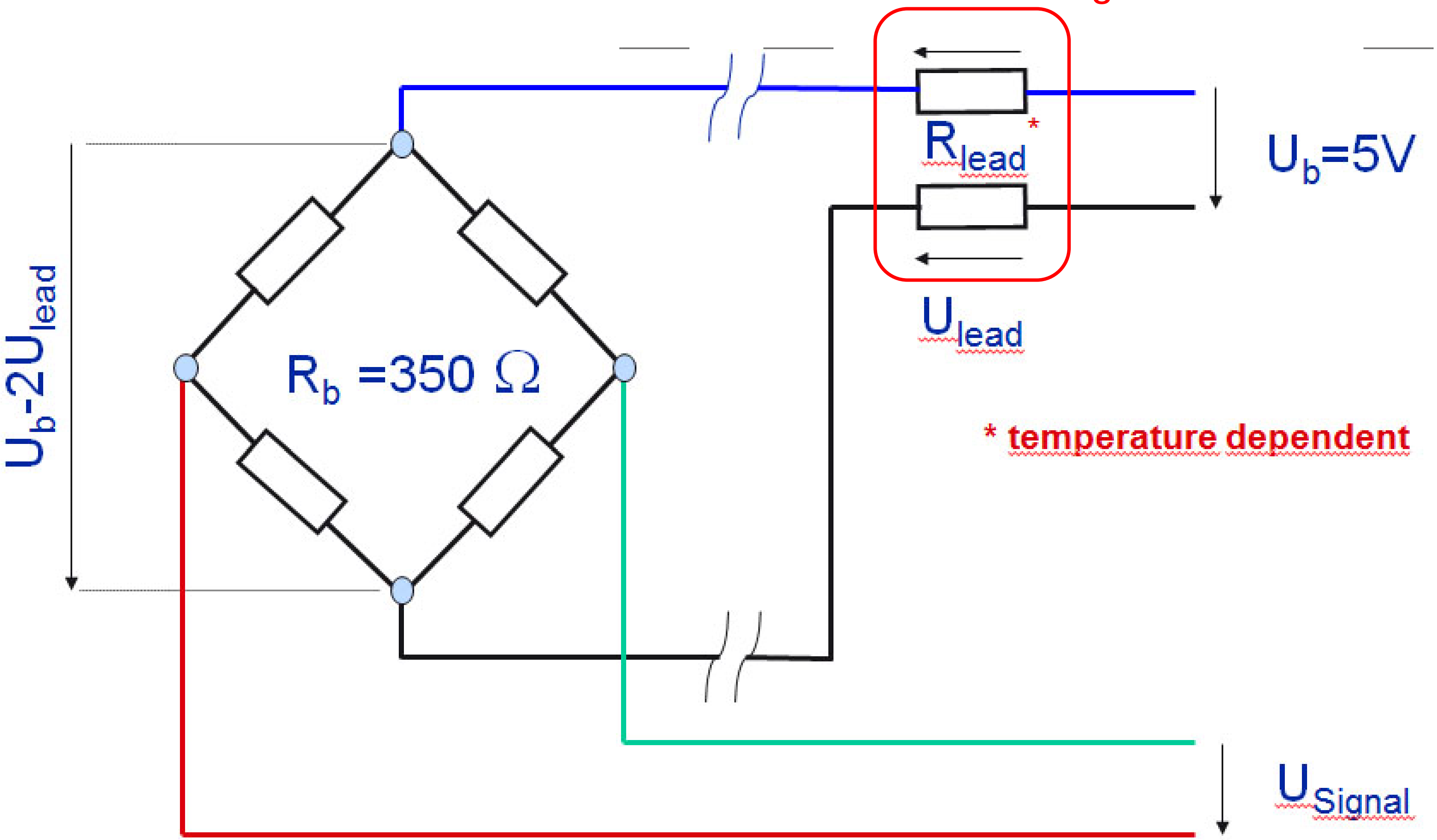
Supply of constant voltage

Force transducer with two strain gauges, using a Wheatstone half bridge



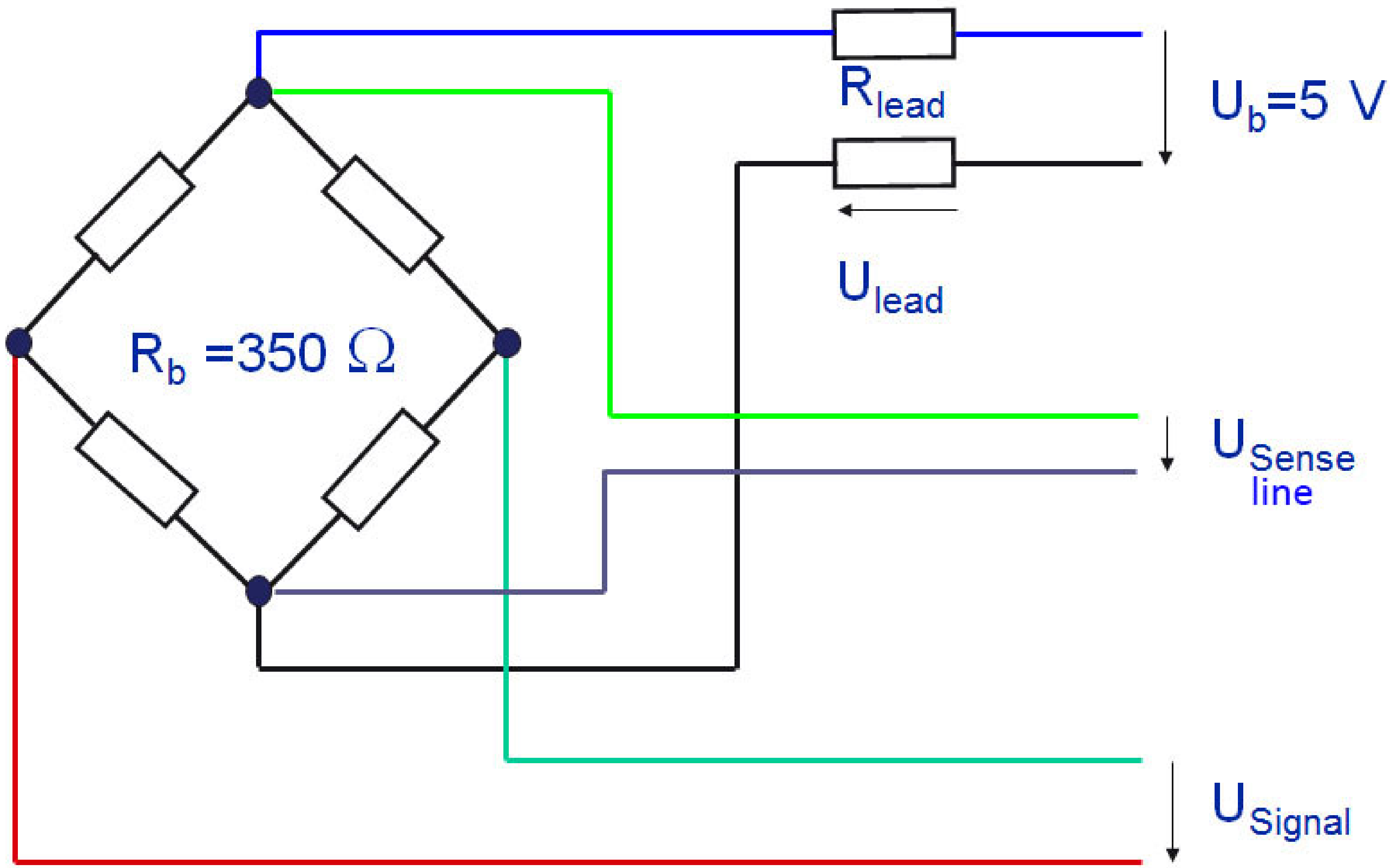
Four-wire full-bridge arrangement

Variable resistances, adjusted in order to “balance the bridge”



Source: http://www.hbm.com/

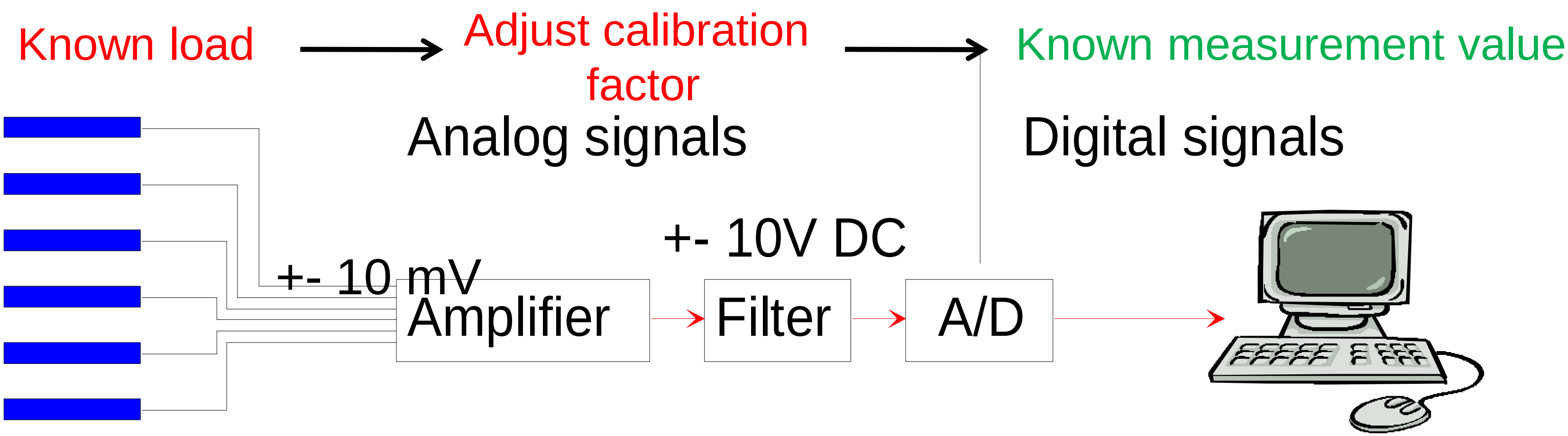
Six-wire full-bridge arrangement



Source: http://www.hbm.com/

Calibration

- How to relate an output Voltage from the amplifier to the physical quantity of interest



In a measurement:

Measurement value = transducer output · amplification · calibration factor

In a calibration:

Calibration factor = Known load / (transducer output · amplification)

What is the calibration factor dependent on?

- Type of strain gauges used (sensitivity)
- Shape of sensor and placement of strain gauges
- Length and temperature of wiring
- Excitation voltage
- Amplification factor (gain)

Sensor dependence (first three items)

Amplifier settings dependence (last two items)

This means that one shall *preferably* calibrate the sensor with the same amplifier and same settings as will be used in the experiment

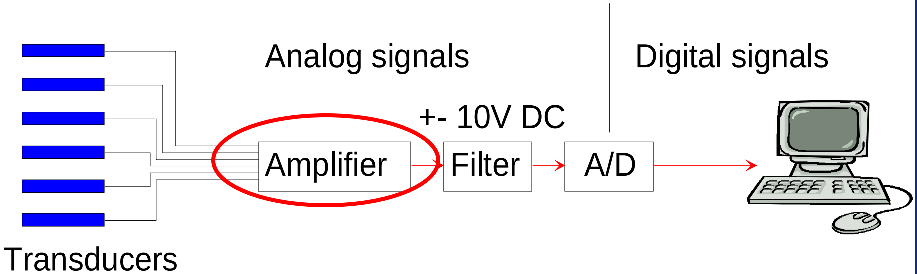
If the wiring is replaced or extended, the calibration *must* be repeated

Zero level measurement

- The measurement is made relative to a known **reference** level
  - Typically, the signal from the unloaded transducer is set as zero reference
- Two options:
  - Balancing the measurement bridge by adjusting the variable resistances in the amplifier
    - Tare/Zero adjust function in the amplifier
  - First making a measurement of the transducer in the reference condition (typically unloaded), and then subtract this measured value from all subsequent measurements
    - This is usually taken care of by the measurement sofware (Catman)
- In hydrodynamic model tests, we usually use both options in each experiment

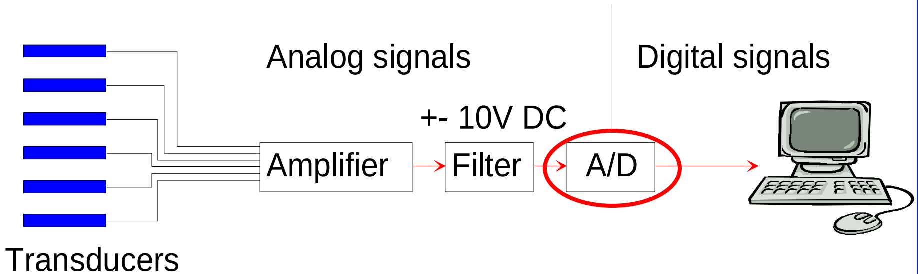
Amplifiers

- Many different types:
  - DC
  - AC
  - Charge amplifier (for piezo-electric sensors)
  - Conductive wave probe amplifier
- Provides the sensor with driving current (V_{in})
- Amplifies the sensor output from mV to (usually) ±10V DC
- Tare/zero adjust function (bridge balancing)
  - Adjusting the resistances R_1, R_2, R_3, R_4 in the Wheatstone bridge to get zero V_G in unloaded condition



A/D converters

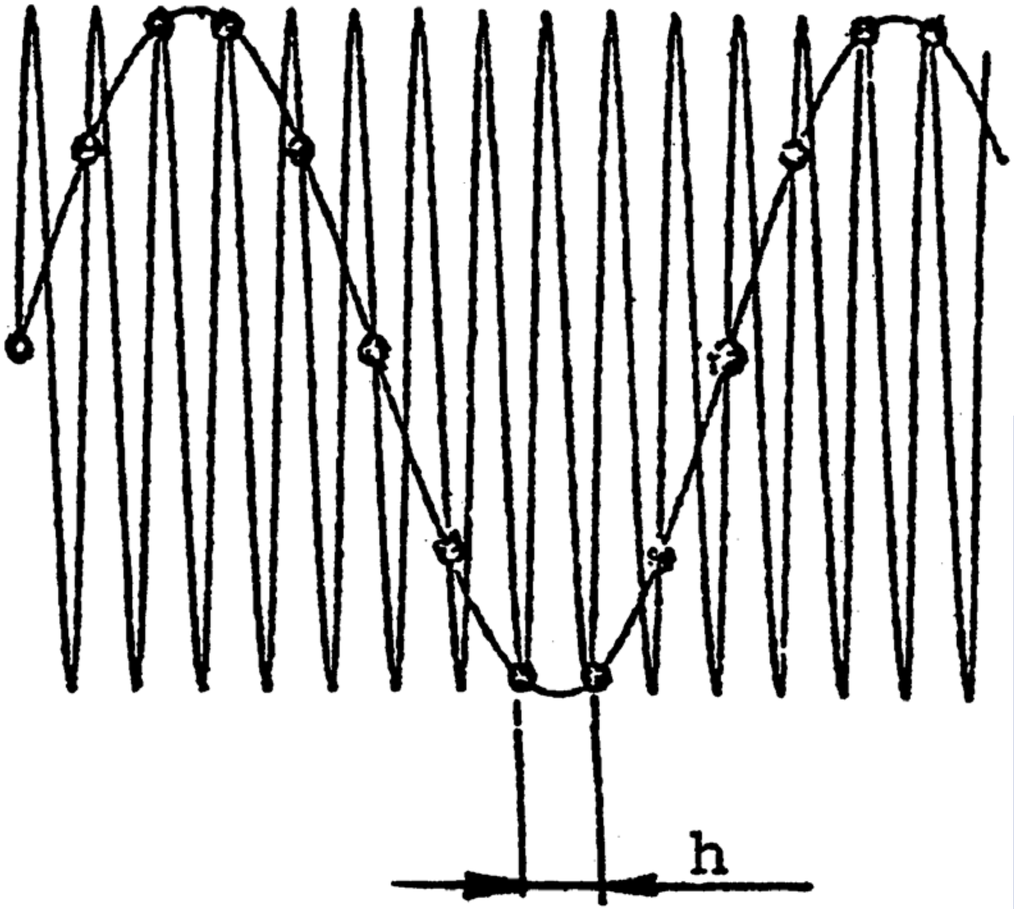
- Conversion of analog ±10V DC signal to digital
- Typically 12 to 20 bits resolution
- Typically 8 to several hundred channels
- Each brand and model requires a designated driver in the computer, and often a custom data acquisition software
- Labview works with National Instruments (NI) A/D converters, but also other brands provides drivers for Labview
- Catman is designed to work only with HBM amplifiers



A/D conversion – sampling of data

- The continuous analog signal is *sampled* at regular *intervals* - *the sampling interval h* [s]
  - The analog value at a certain instant is sensed and recorded
- The analog signal is thus represented by a number of discrete – digital – values (numbers)
- The quality of the digital representation of the signal depends on:
  - The sampling frequency f=1/h [Hz]
  - The accuracy of the number representing the analog value
    - The accuracy means the number of bits representing the number
    - 8 bit means only 2^8=256 different values are possible for the number representing the analog value => poor accuracy
    - 20 bit means 2^{20}=1048576 different values => good accuracy
  - The measurement *range* vs. the *range* of values in the experiment
  - High sampling frequency and high accuracy both means large amounts of data being recorded => large data files!
    - The reason not to use high sampling frequency is mainly to reduce file size

Sampling frequency



Nyquist frequency f_c

$$f_c = \frac{1}{2 \cdot h}$$

Means:

•You need at least two samples per wave period to properly represent the wave in in the digitized data

•You should have more samples per period to have good representation …

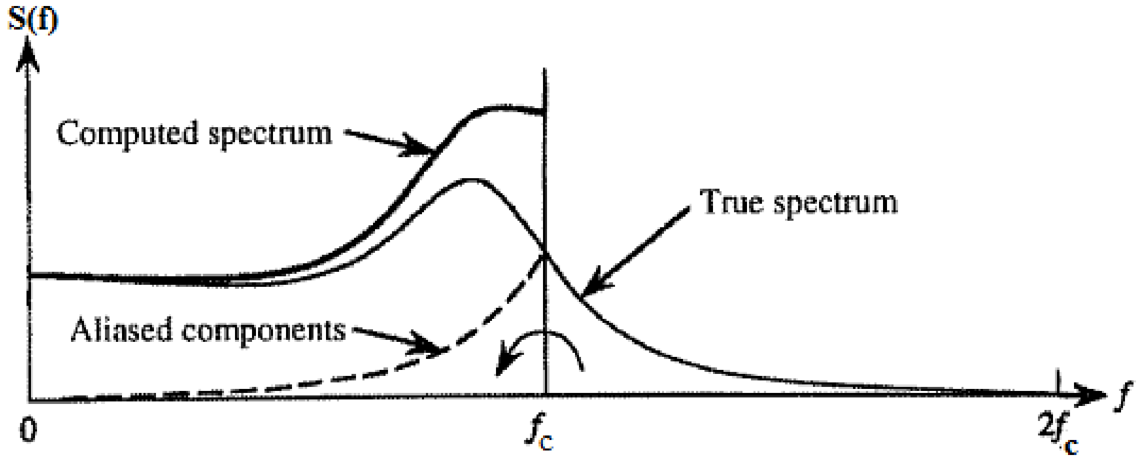
•Less than two samples per wave period will give “false signals” (downfolding)

Effect of folding

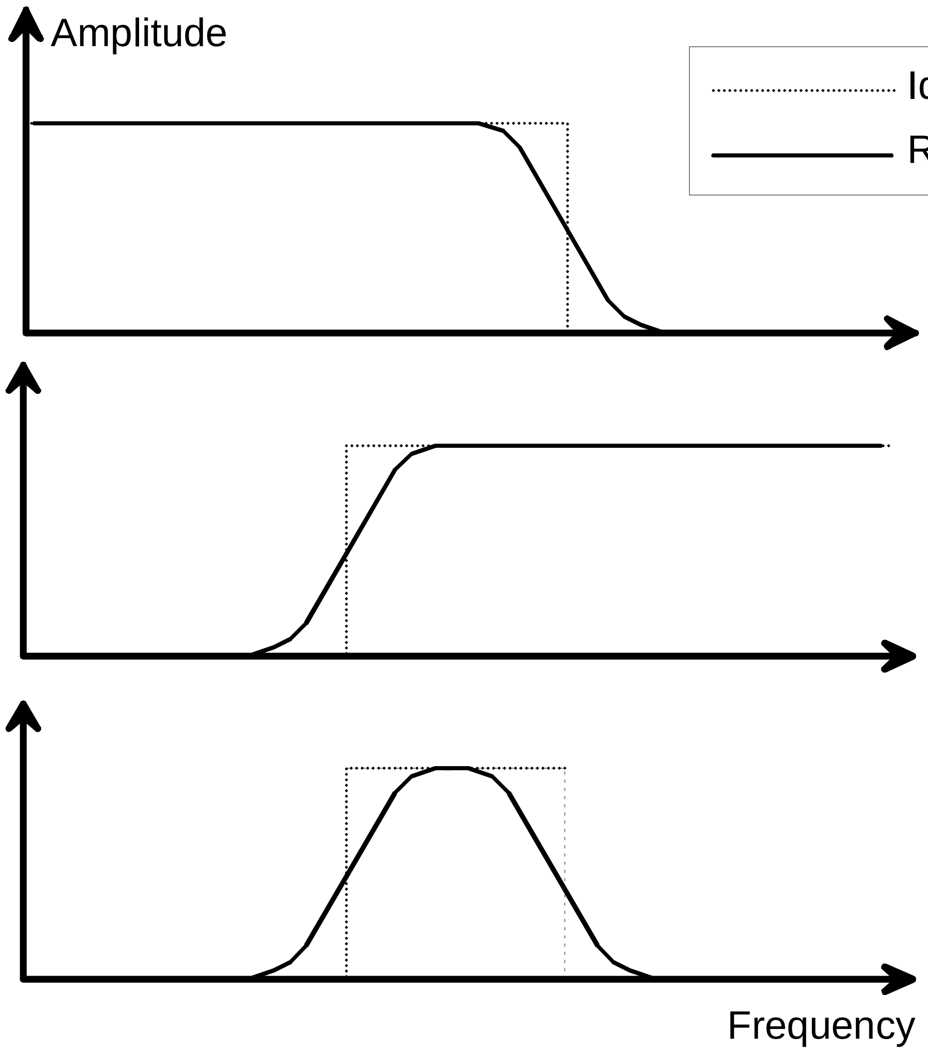
- To avoid folding:
  - Make sure f_c is high enough that all frequencies are correctly recorded

    or

  - **Apply analogue low-pass filtering** of the signal, removing all signal components at frequency above f_c before the signal is sampled



Filters – to remove parts of the signal



Low pass filter

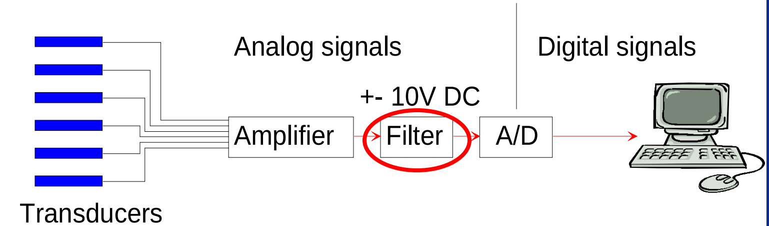
Removes high frequency part of signal (noise)

High pass filter

Removes low frequency part of signal (mean value)

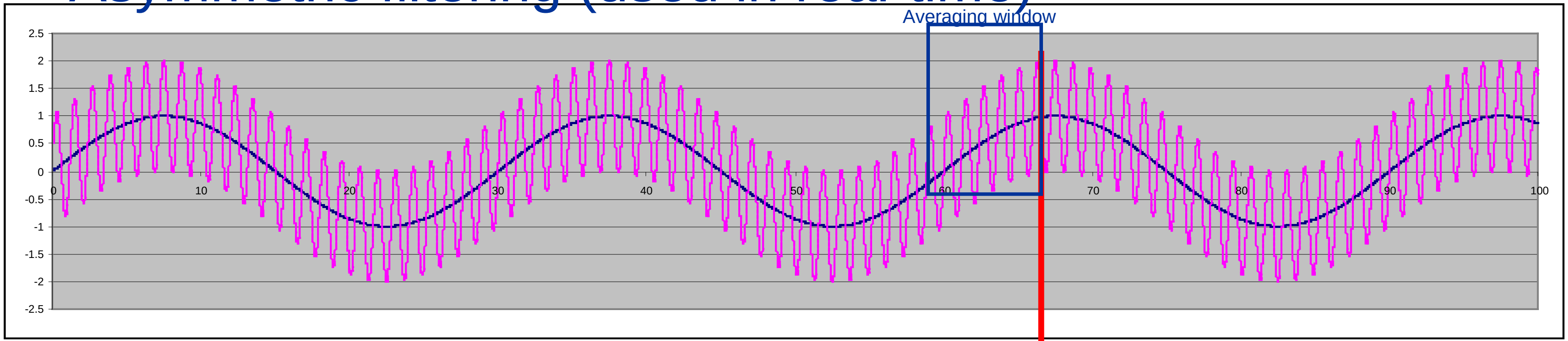
Band pass filter

Retains only signals in a certain frequency band

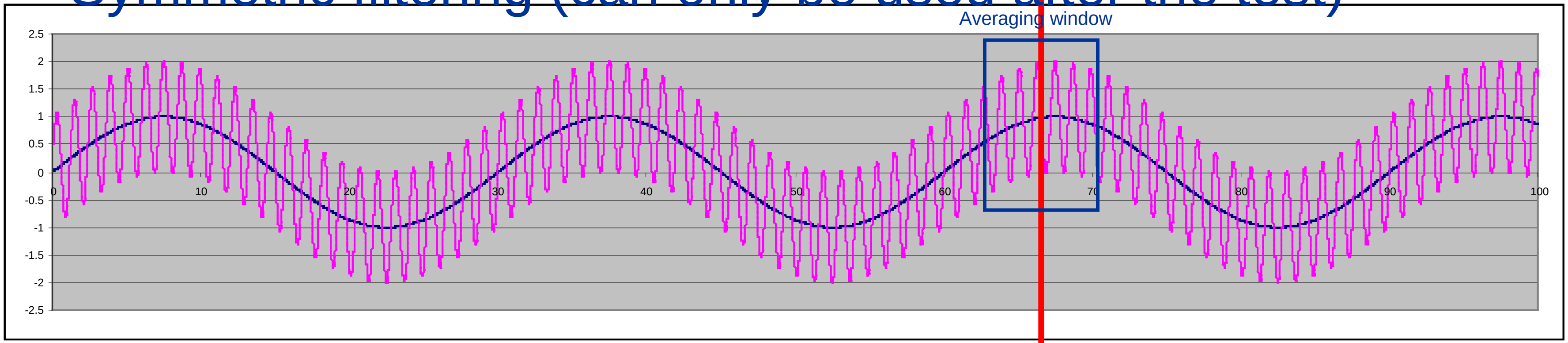


Filtering – low pass filter

Asymmetric filtering (used in real-time)



Symmetric filtering (can only be used after the test)



Now!

Real time filters always introduce a phase shift – a delay

Data acquisition without filtering

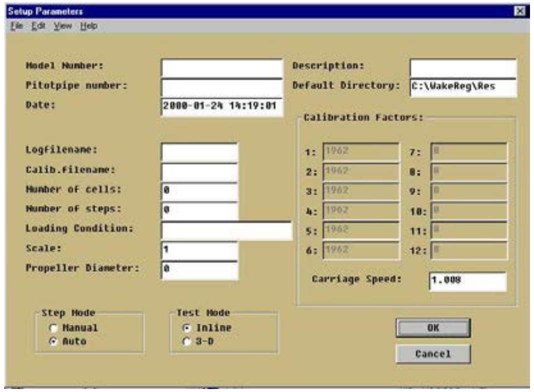
- It is OK to do data acquisition without filtering as long as there is virtually no signal above half the sampling frequency
  - so there is no noise that is folded down into the frequency range of interest
- Requires high sampling frequency
  - (>100 Hz, depending on noise sources)
- Requires knowledge of noise in unfiltered signal
  - Spectral analysis, use of oscilloscope

- Unfiltered data acquisition eliminates the filter as error source, and eliminates the problem of phase shift due to filtering
  - Drawbacks:
    - Must have good control of high-frequency noise
    - Large sampling frequency means large data files

Selection of filter and sampling frequency

- The problem with high sampling frequency is that result files become large
  - Double the sampling frequency means double the file size
  - This is less of a problem for measurement of low-frequency phenomena (ship motions etc.)
- Low-pass filter should be set just high enough to let the most high-frequency signal of interest to pass unmodified
- Sampling frequency should then be set to at least twice the low-pass filter cut-off frequency, preferably 5-10 times this value
  - 20 Hz Low-Pass filter $\rightarrow$ 200 Hz sampling

Data acquisition software



- Communicates with the A/D converter
- Conversion from ±10V DC to physical units
- Zero measurement and correction for measured zero level
- Records the time series
- Common post-processing capabilities:
  - Graphical presentation of time series
  - Calculation of simple statistical properties (average, st.dev.)
  - Storage to various file format

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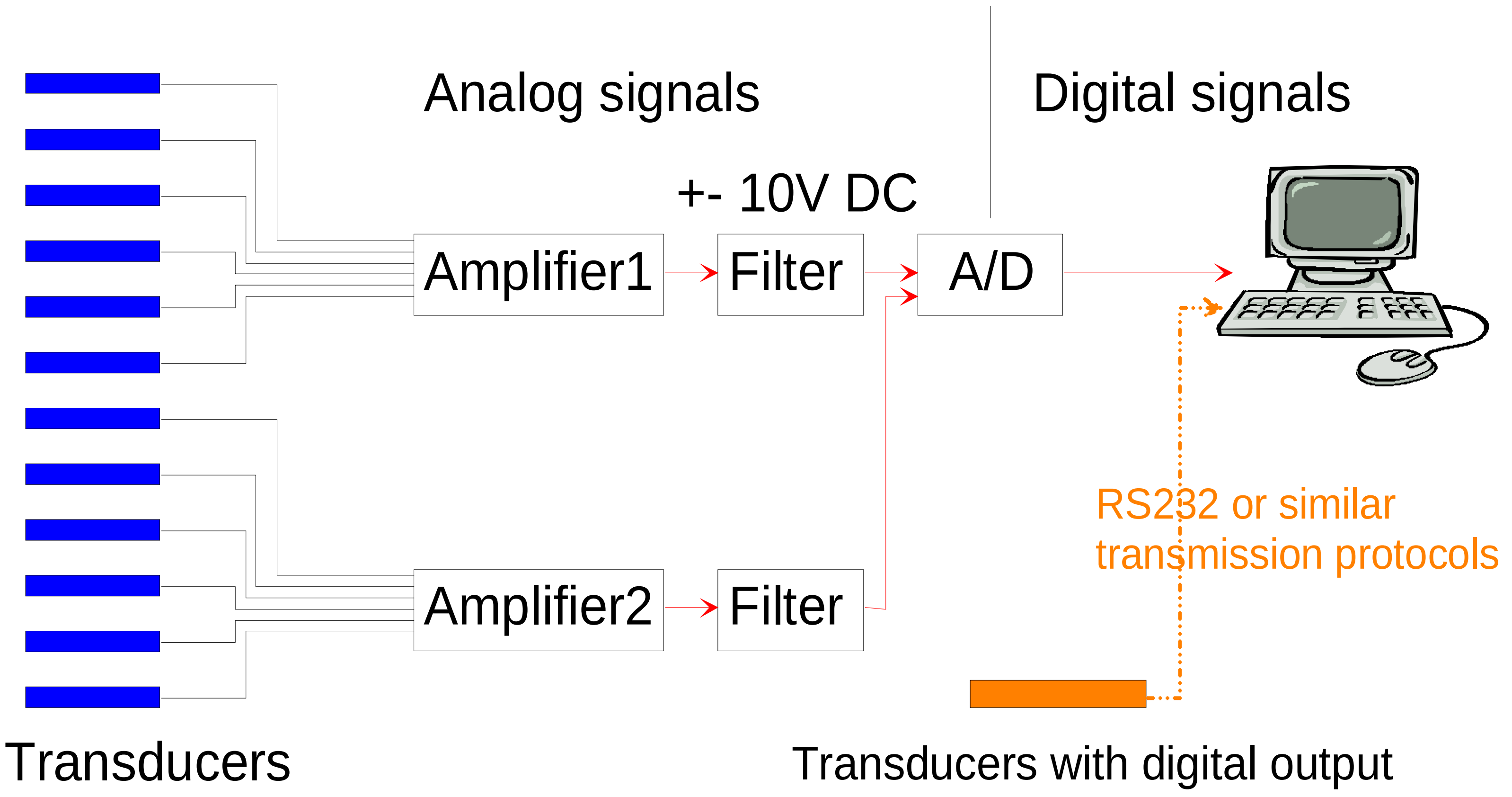
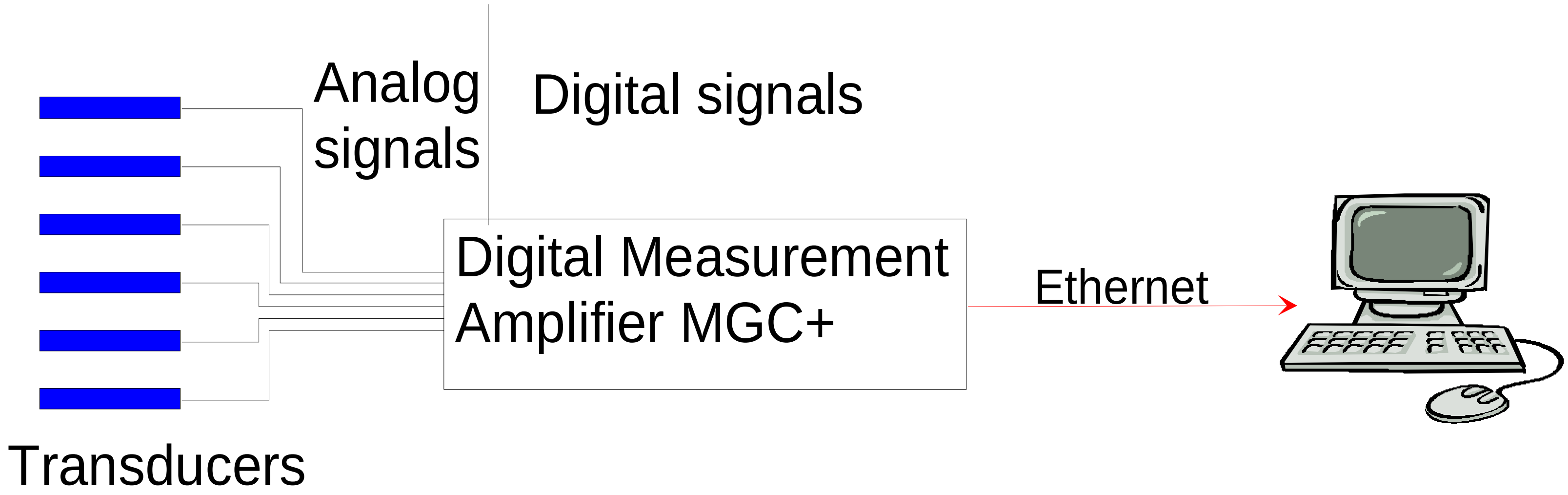
Measurement Systems (cont.)



Measurement Systems - digital



Length of records

- of irregular wave tests and other randomly varying phenomena

- The statistical accuracy is improved with increasing length of record. The required duration depends on:
  - The period of the most low frequent phenomena which occur in the tests
  - The system damping
  - The required standard deviation of the quantities determined by the statistical analysis
- Rule of thumb: 100 times the period of most low frequent phenomena of interest

Length of records
- Typical full scale record lengths:

- Wave frequency response: 15-20 minutes
- Slow-drift forces and motions: 3-5 hours (ideally ~10 hours)
- Slamming ??
- Capsize ??

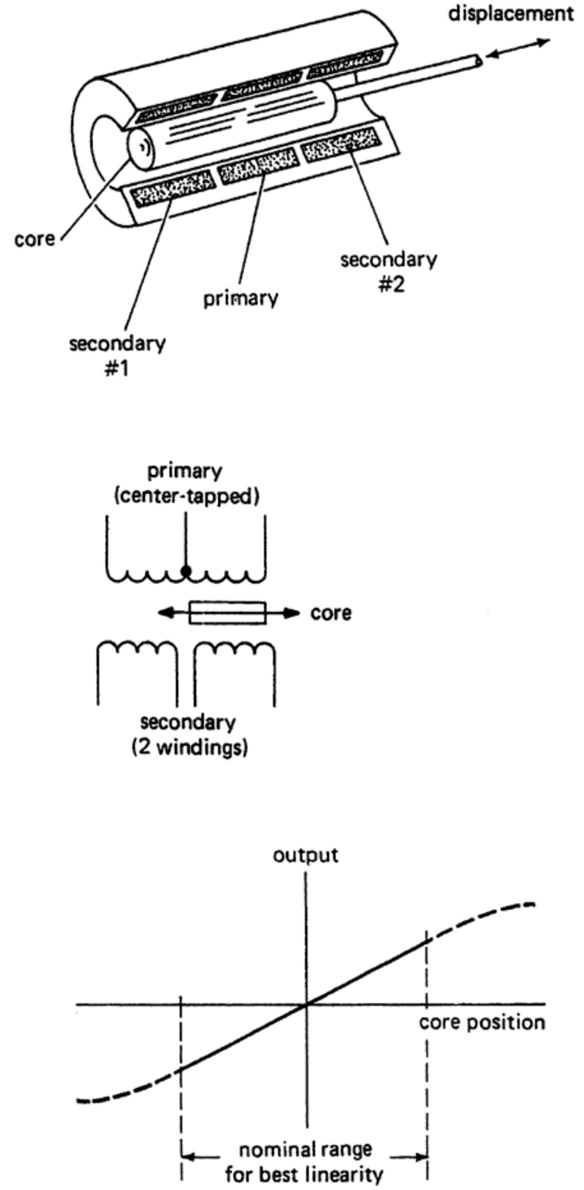
- *To study and quantify very rarely occurring events, special techniques must be applied!*

Transducer principles
- for strain and displacement measurements

- Resistive transducers
  - Change of resistance due to strain – <u>strain gauges</u>
- Inductive transducers
- Capacitance transducers

Inductive transducers

- Measures linear displacement (of the core)
- Needs A/C excitation
- Used also in force measurements in combination with a spring or membrane



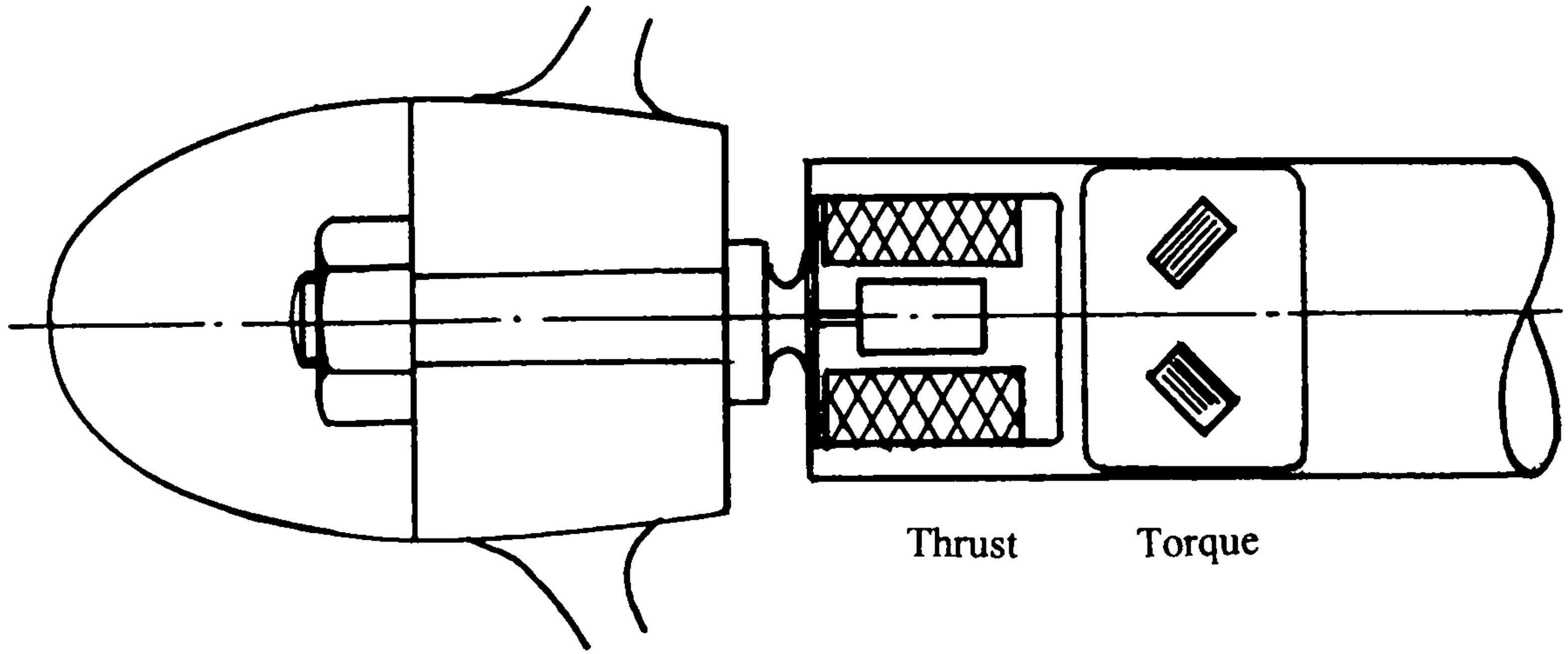
Linear variable differential transformer

Force measurement instruments:

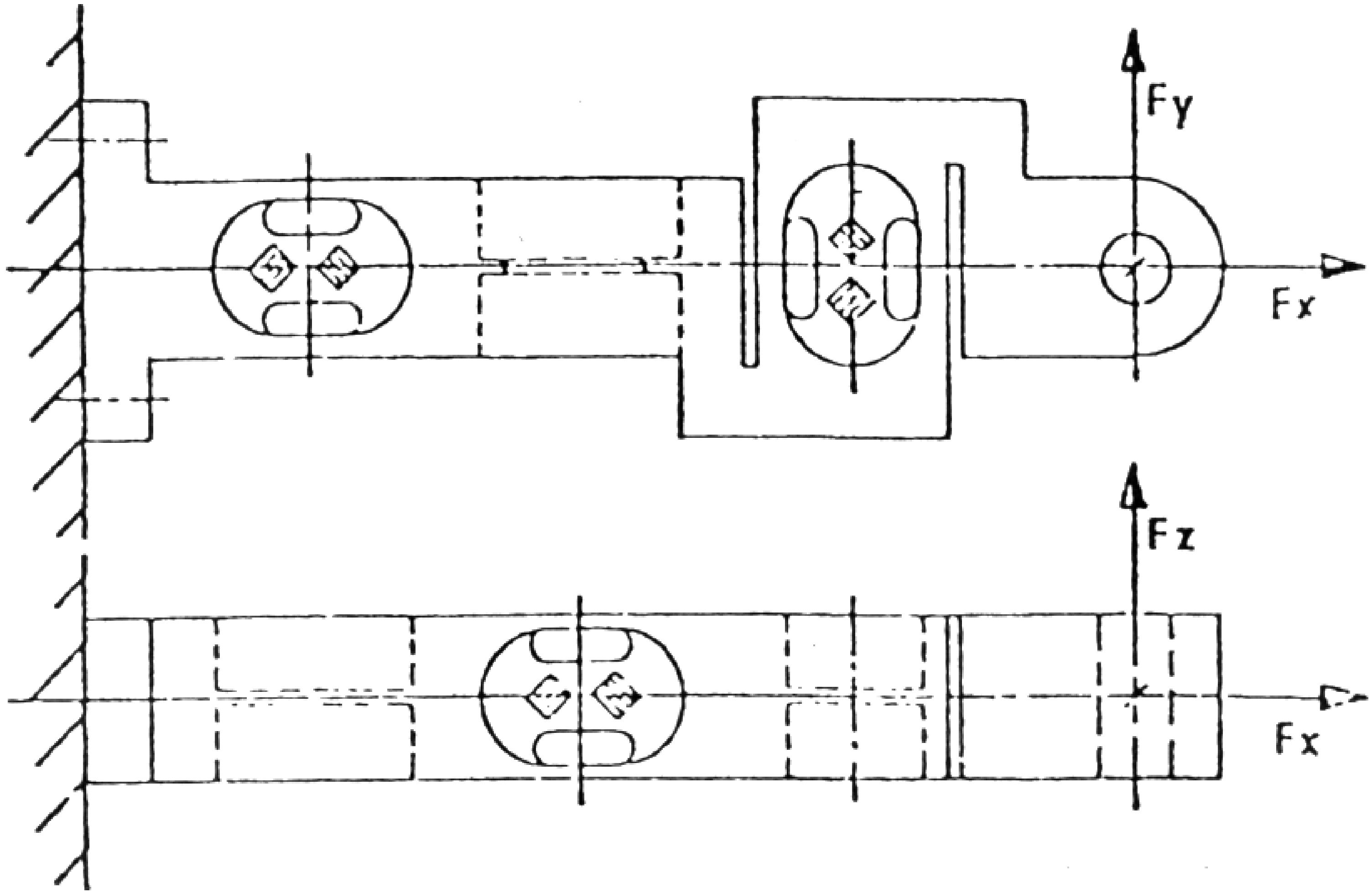
Dynamometers

- 1-6 force components can be measured
- Strain gauge based sensors are most common
- One multi-component dynamometer might be made of several one, two or three component transducers
- Many different designs are available
- Custom designs are common
- Special dynamometers for special purposes like:
  - Propeller thrust and torque
  - Rudder stock forces

Propeller dynamometer for measurement of thrust and torque



Three-component force dynamometer



6 component dynamometer

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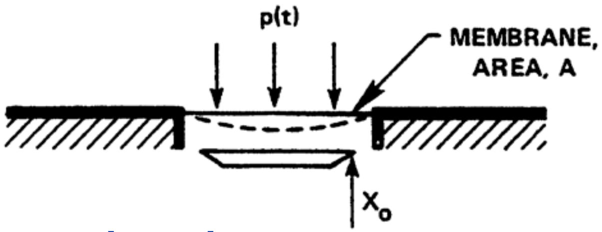
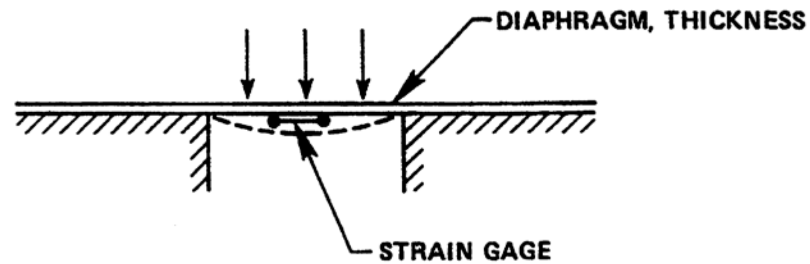
Pressure Measurements
- Transducer principles

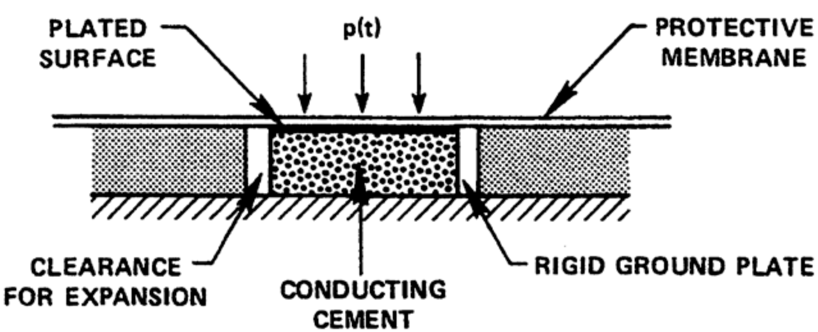


Inductive

(a)



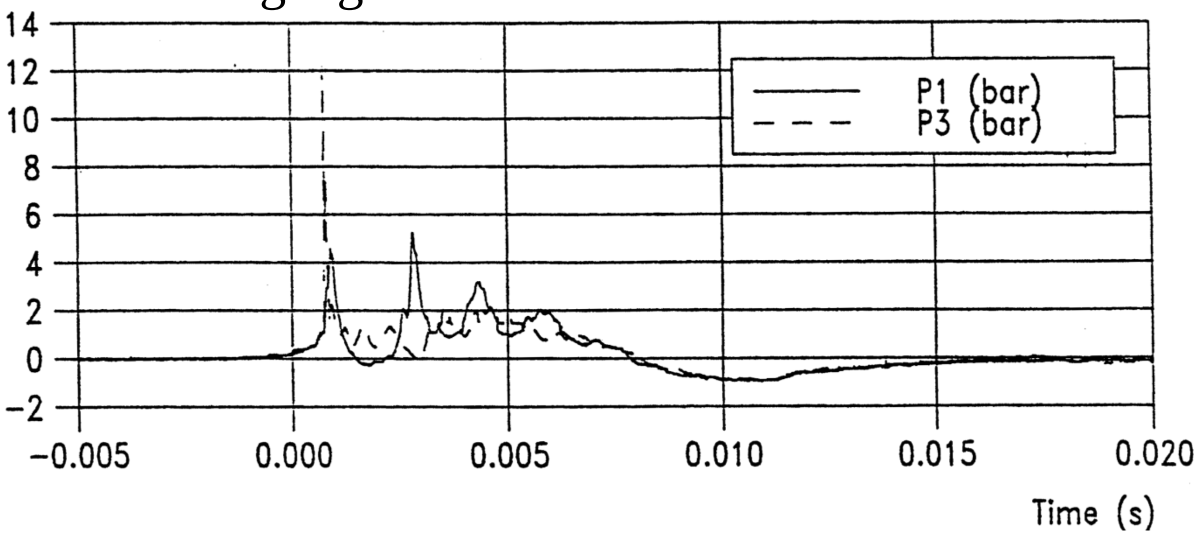
Strain gauge



Piezo-electric

Pressure Measurements
- Requirements

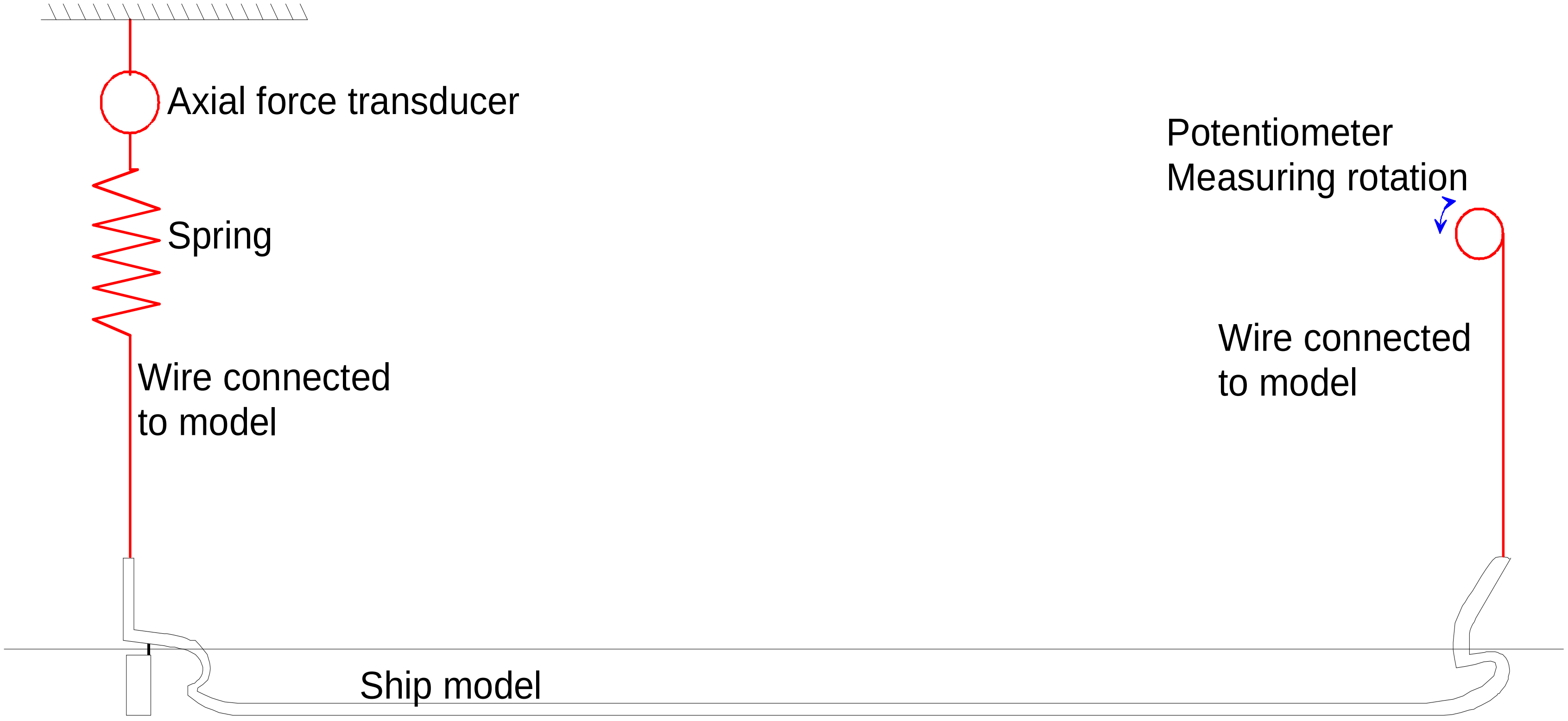
- Stability is required for velocity measurements
  - Strain gauge or inductive
- Dynamic response (rise time and resonance frequency) is important for slamming and sloshing measurements
  - Piezo-electric
  - Strain gauge



Position measurements

- Mechanical connection:
  - Inductive transducers
  - Wire-over-potentiometer
  - Wire with spring and force measurement
- Without mechanical connection:
  - Optical and video systems
  - Acoustic systems
  - Gyro, accelerometers, Inertial Measurement Units (IMU)

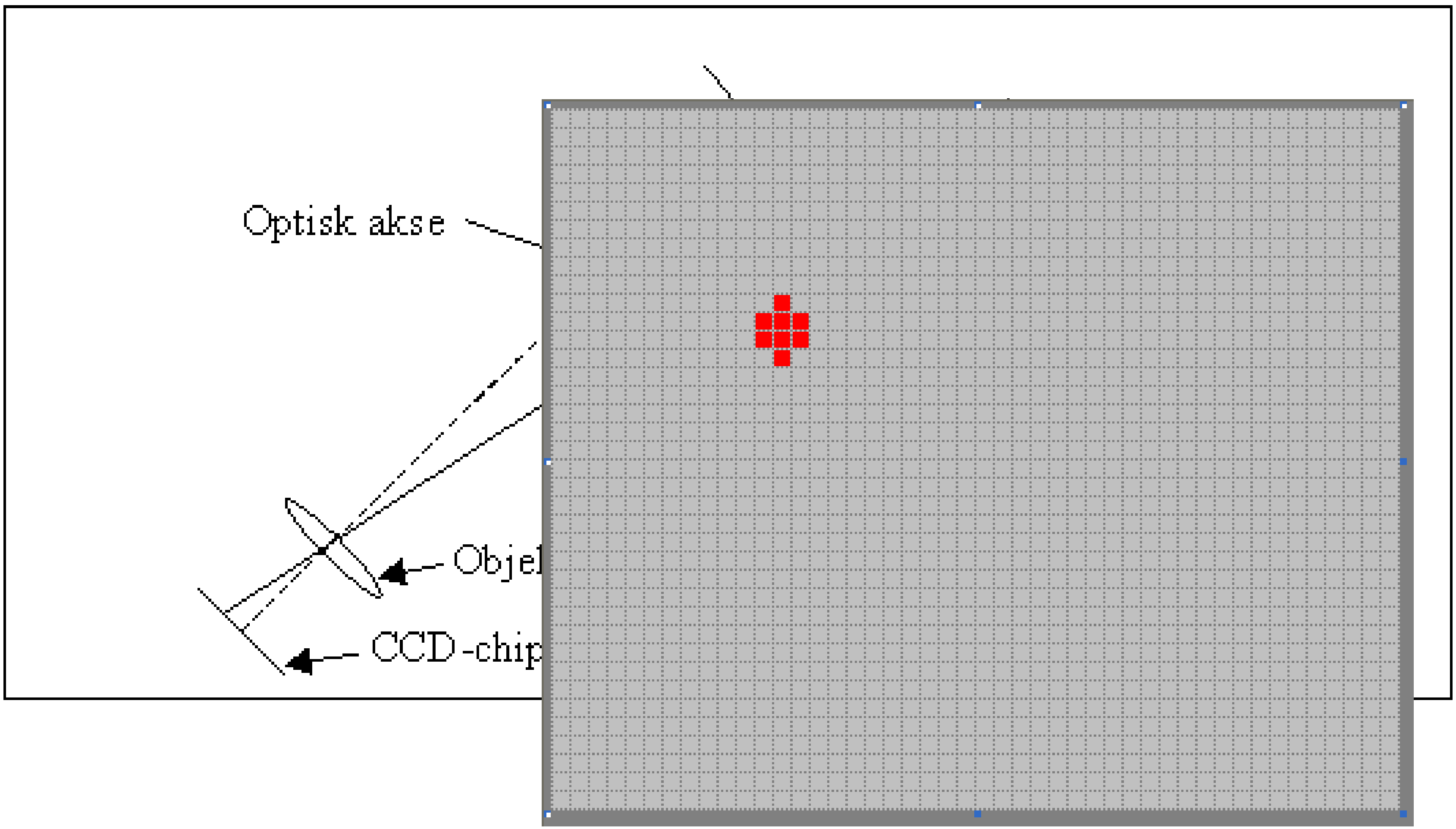
Mechanical position measurements

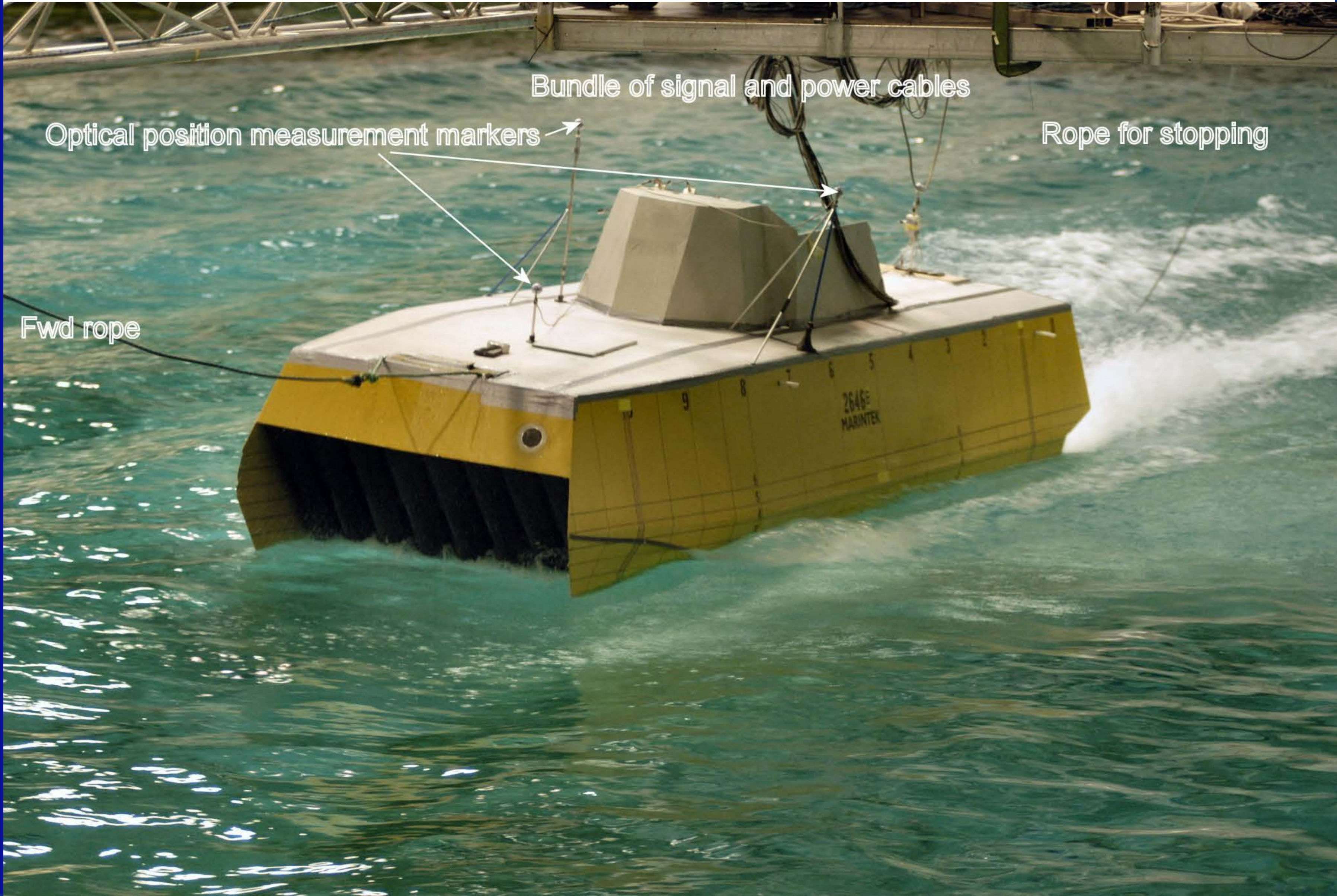


Optical position measurement

- Remote sensing, non-intrusive measurement
- Using CCD video cameras
- Each camera gives position of the marker in 2-D
- Combination of 2-D position from two cameras gives position in 3-D by triangulation
- Use of three markers on one model gives position in 6 DoF by triangulation
- Calibration is needed for the system to determine:
  - Camera positions and alignment
- The relative positions of the markers on the model must be known to the system

Optical position measurement principle




Bundle of signal and power cables
Optical position measurement markers
Rope for stopping
Fwd rope
2646
MARINTEK

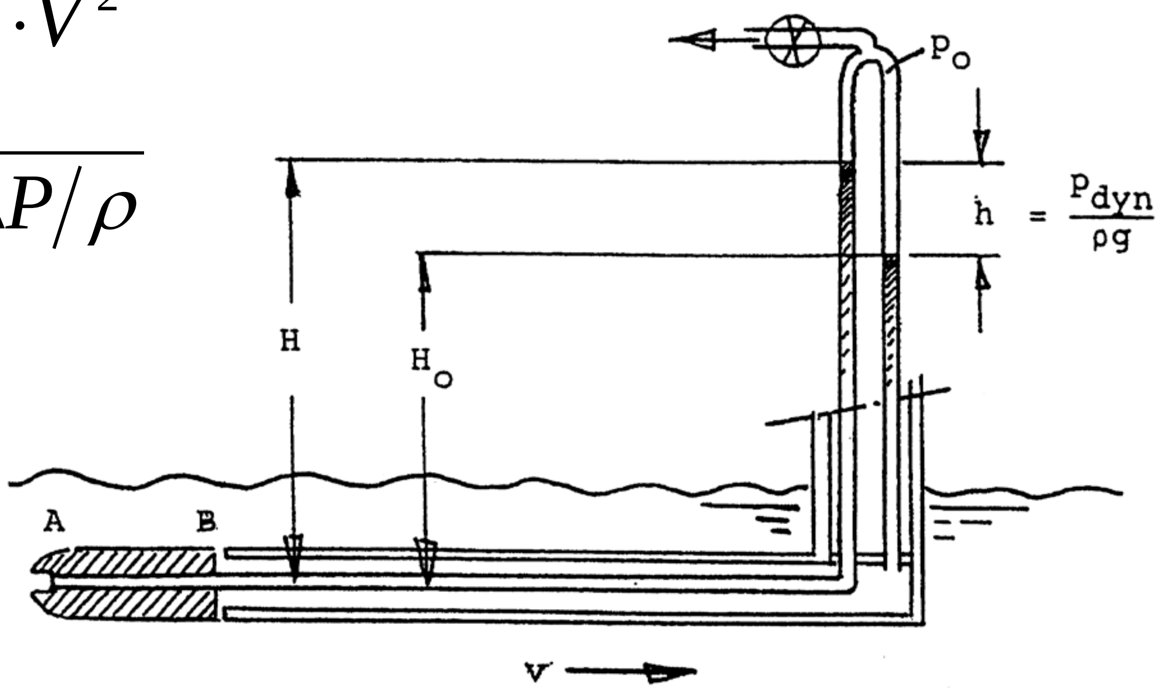
Velocity measurements

- Intrusive measurement (probe at point of measurement)
  - Pitot and prandtl tubes for axial or total velocity measurement
  - Three and five hole pitot tubes for 2 and 3-D velocity measurement
  - Various flow meter devices
- Non-intrusive measurement (no probe at point of measurement)
  - Laser Doppler Anemometry (LDA or LDV)
    - Measures velocity in a single point at each time instance
  - Particle Image Velocimetry
    - Measures flow field (2-D) in one instant

Prandtl (pitot-static) tube

$$\Delta P = \tfrac{1}{2} \cdot \rho \cdot V^2$$

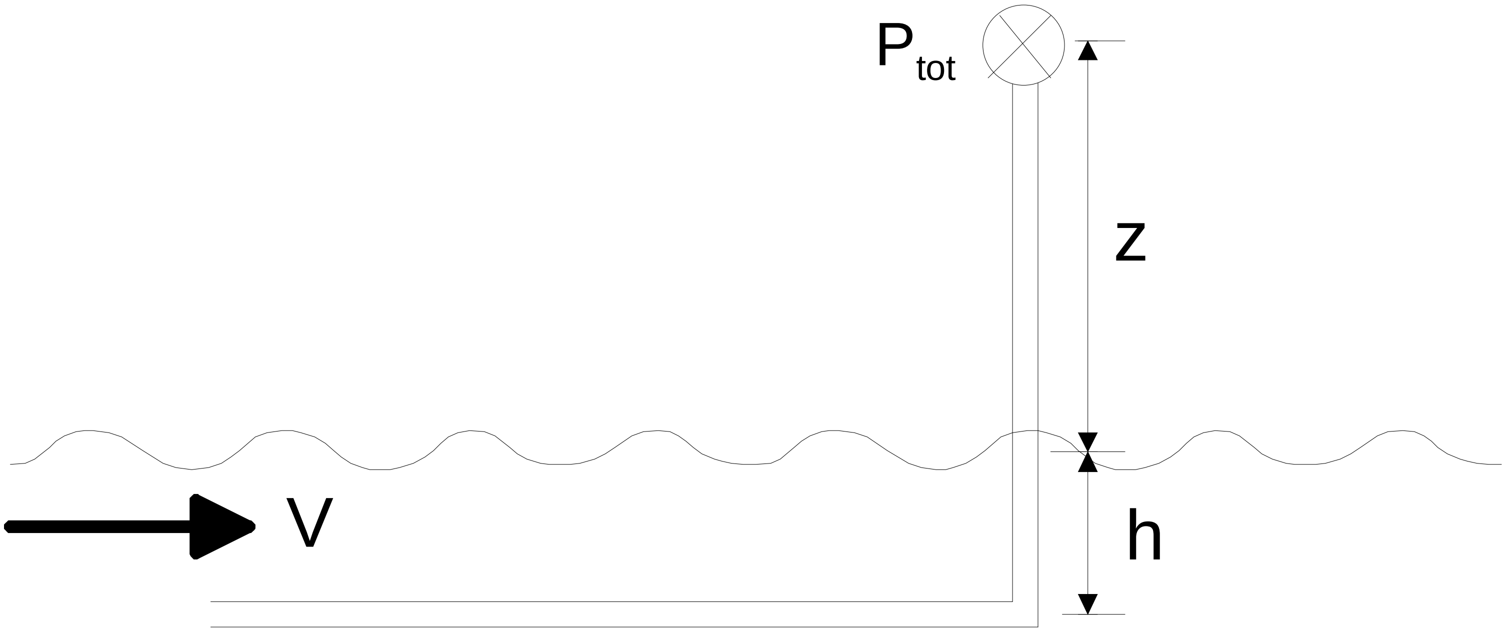
$$V = \sqrt{2 \cdot \Delta P / \rho}$$



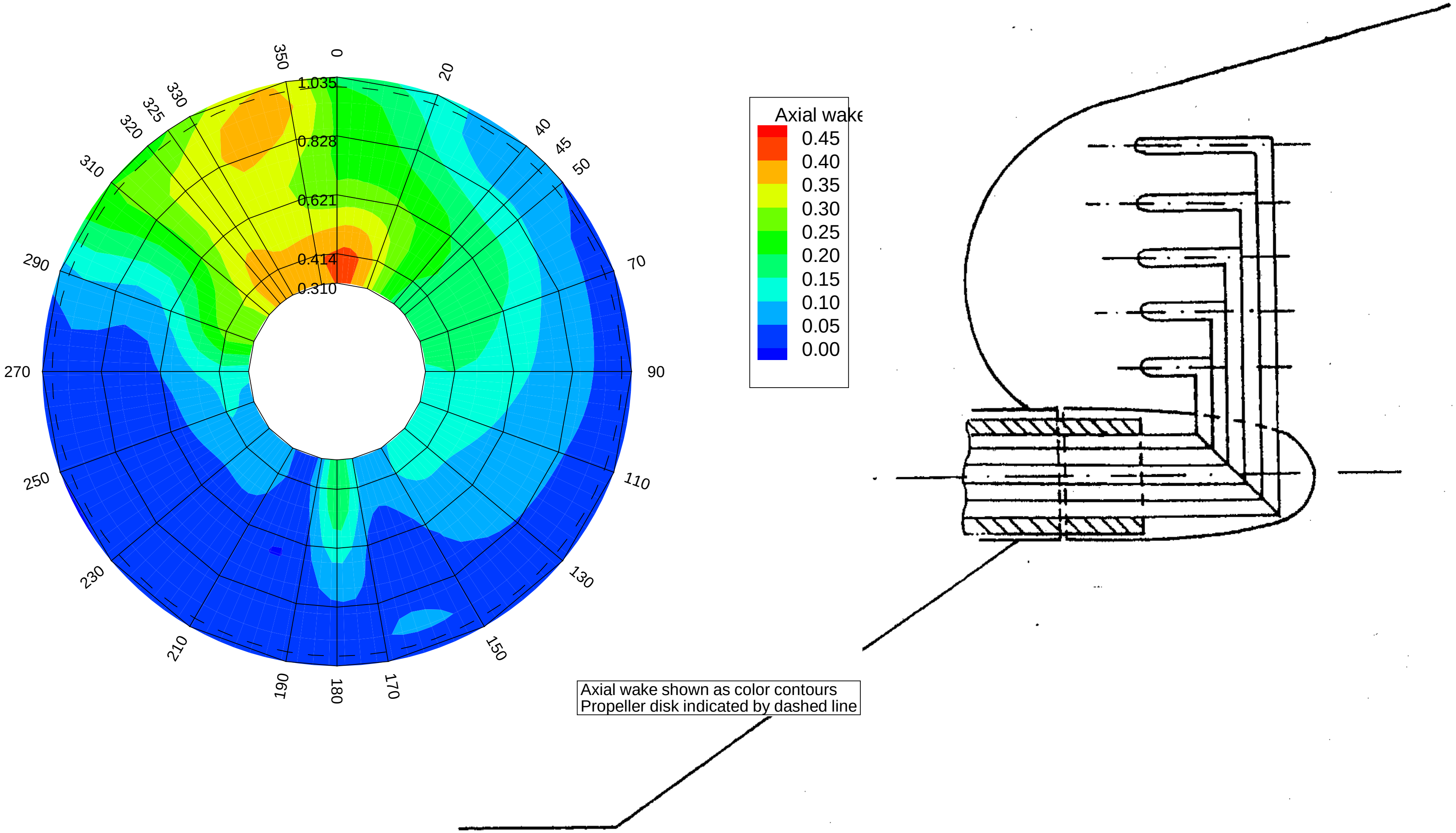
Pitot tube

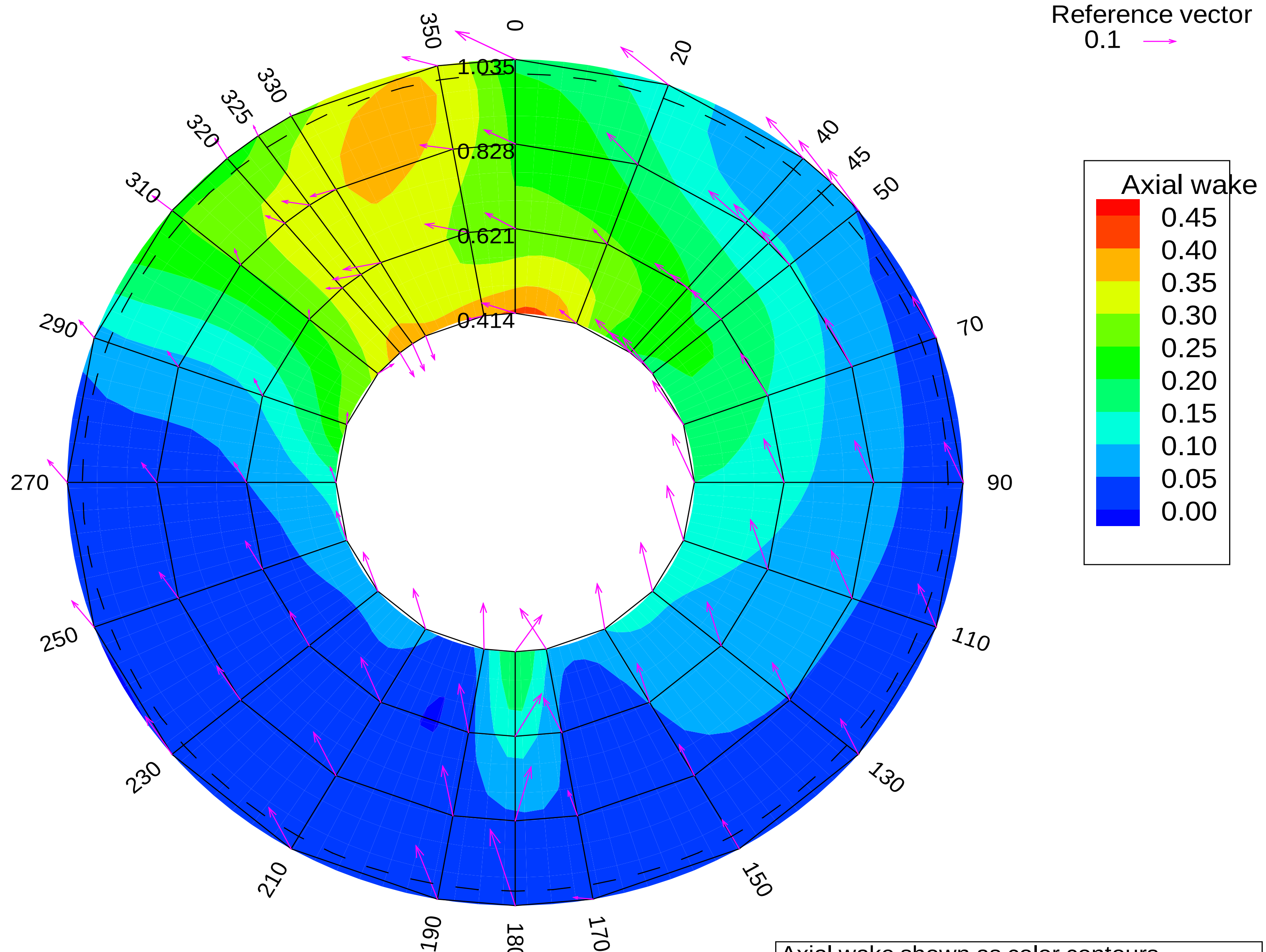
- Smaller size than Prandtl tube
- Less accurate, due to sensitivity to static pressure

$$P_{tot} = P_{dyn} + P_{stat} = \tfrac{1}{2} \cdot \rho \cdot V^2 + \rho \cdot g \cdot h - \rho \cdot g \cdot z$$



Prandtl tube rake for propeller wake measurements

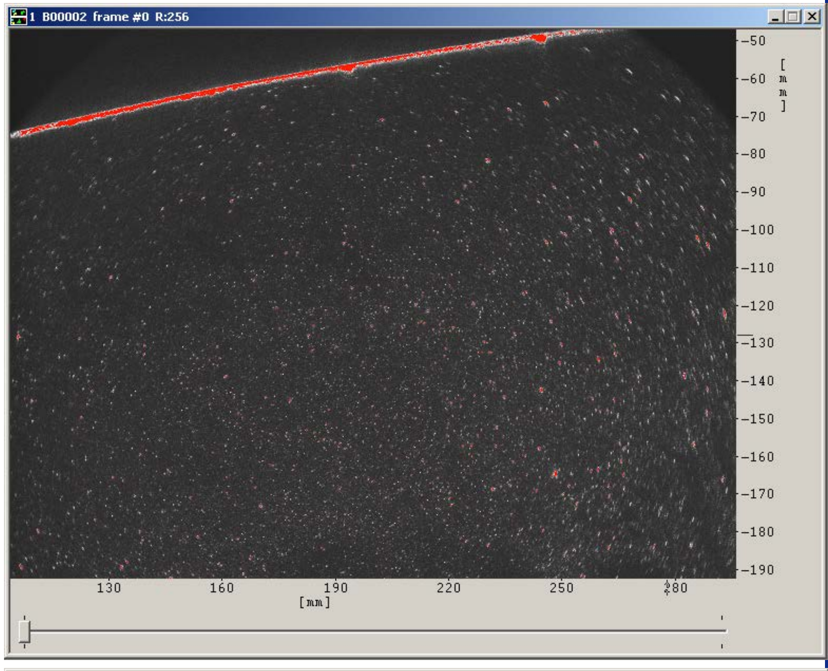


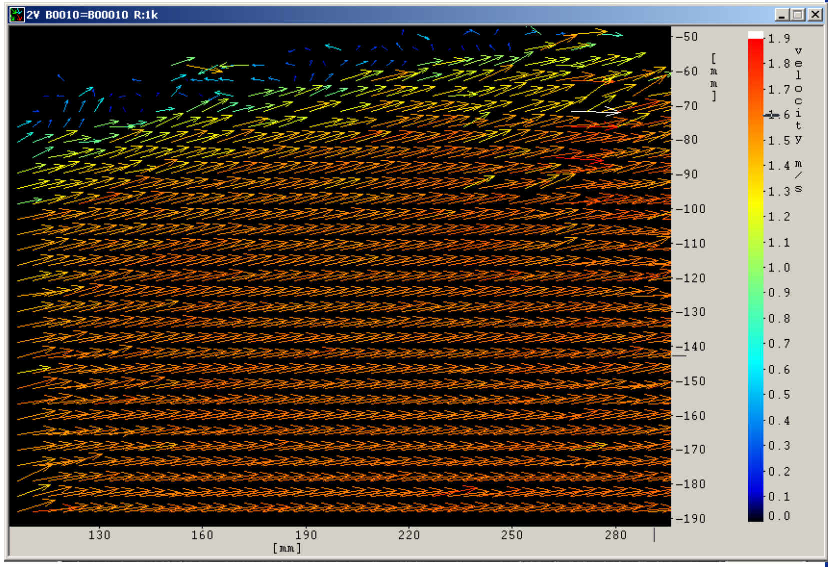


Axial wake shown as color contours
Radial and tangential wake shown as vectors
Propeller disk indicated by dashed line

Particle Image Velocimetry (PIV)

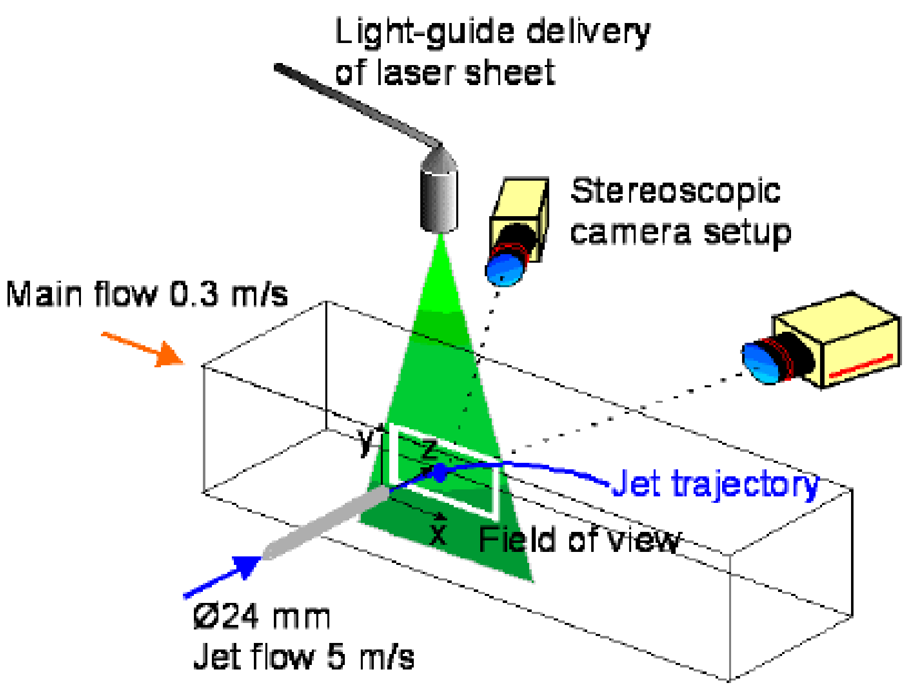
- Velocity distribution in a plane is found from the movement of particles in a short time interval
- Double-exposure photographs or high-speed video is used to capture images
- A sheet of laser light is used to illuminate the particles in the water
- Finding the velocity by comparing the two pictures is not trivial
- ”Seeding” the water with suitable tracer particles is another practical challenge

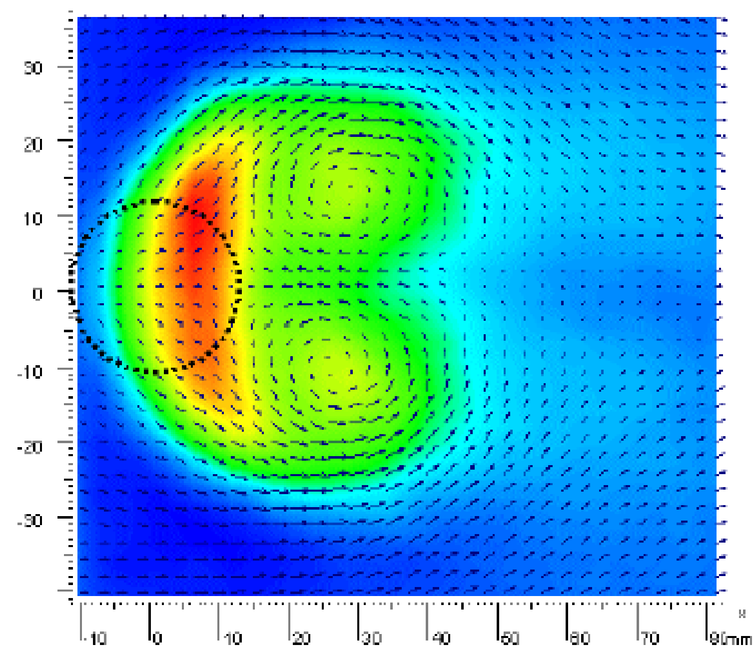




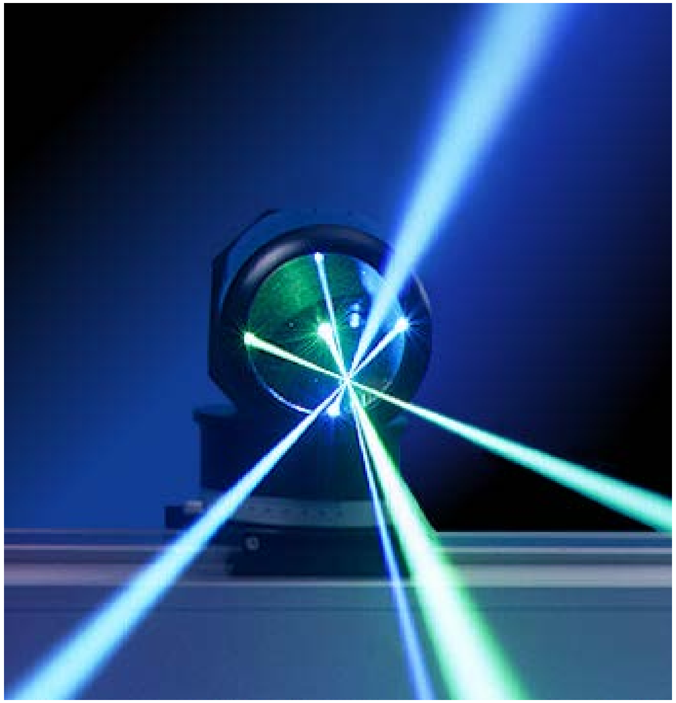
3-D Particle Image Velocimetry (PIV)

- Like 2-D PIV, except that two cameras are looking at the particles from different angles
- You obtain 3-D velocity vectors in a plane





Laser Doppler Velocimetry (LDV or LDA)



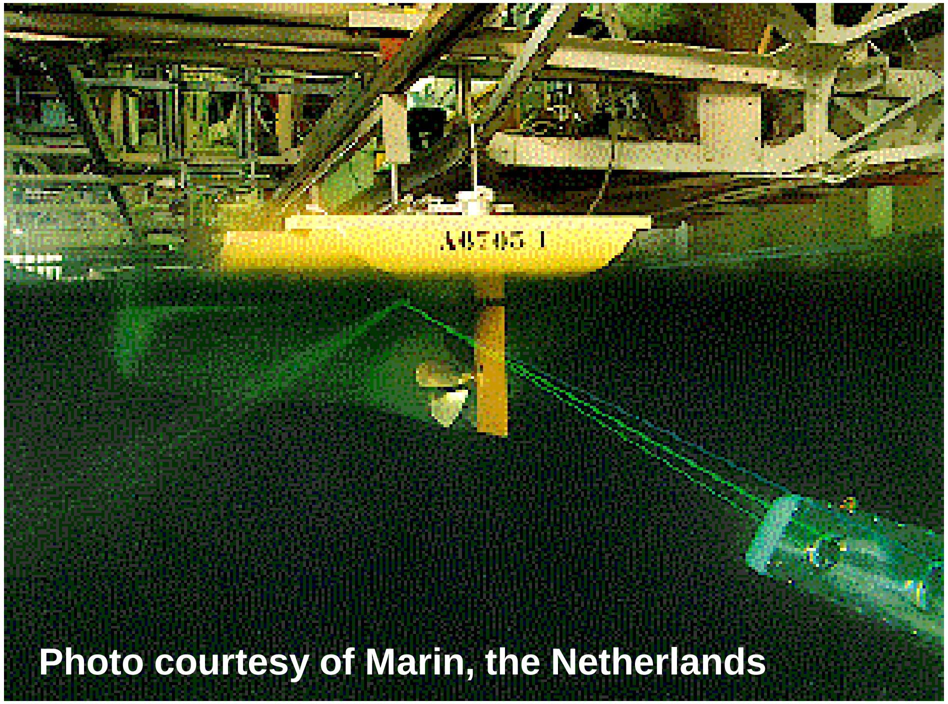
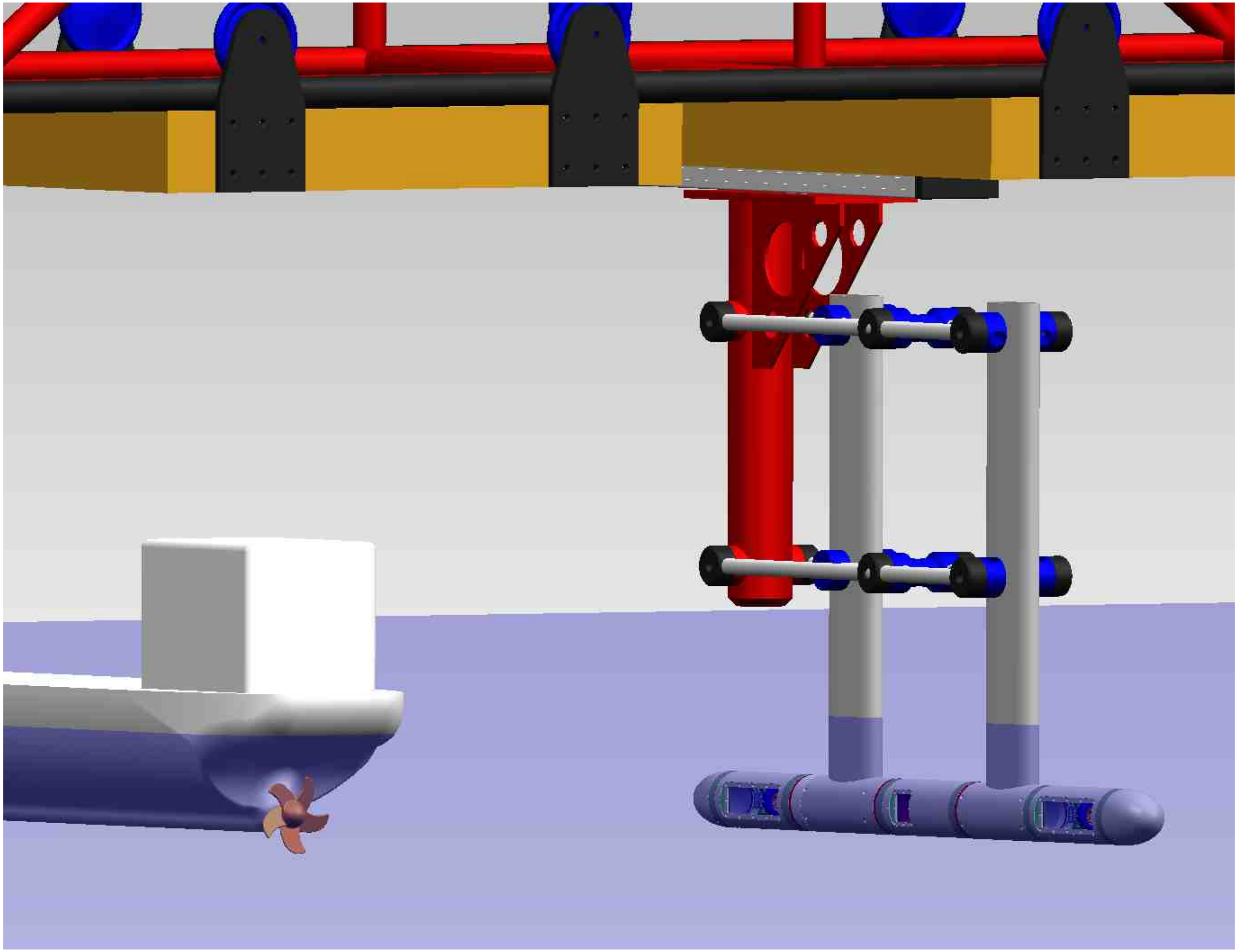


Photo courtesy of Marin, the Netherlands

- Point measurement – must move the probe to measure at different locations
- Calibration free
- Give 3-D flow velocity – also time history
  $\Rightarrow$ can measure turbulence intensity

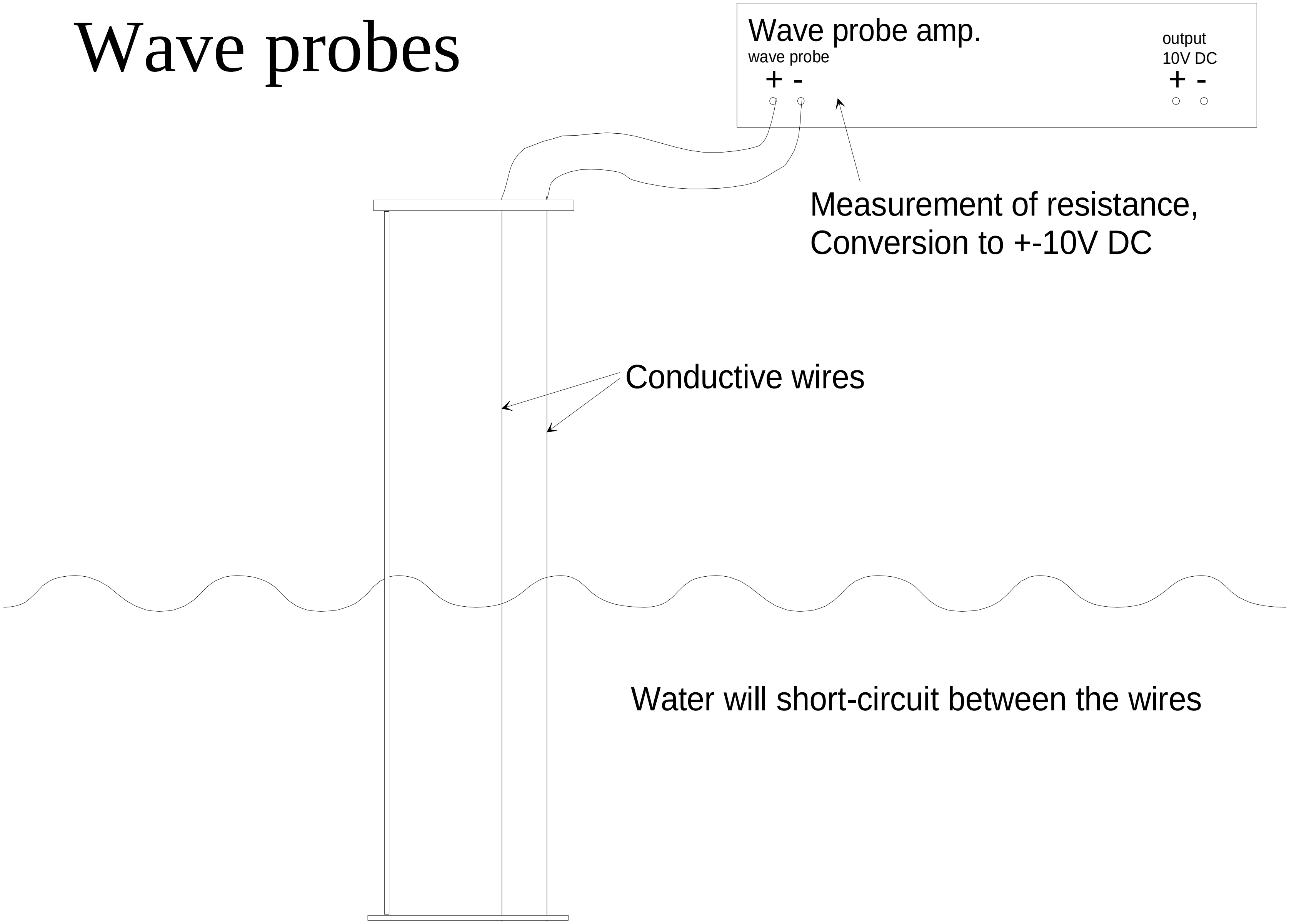
Practical arrangement for stereo LDV and PIV



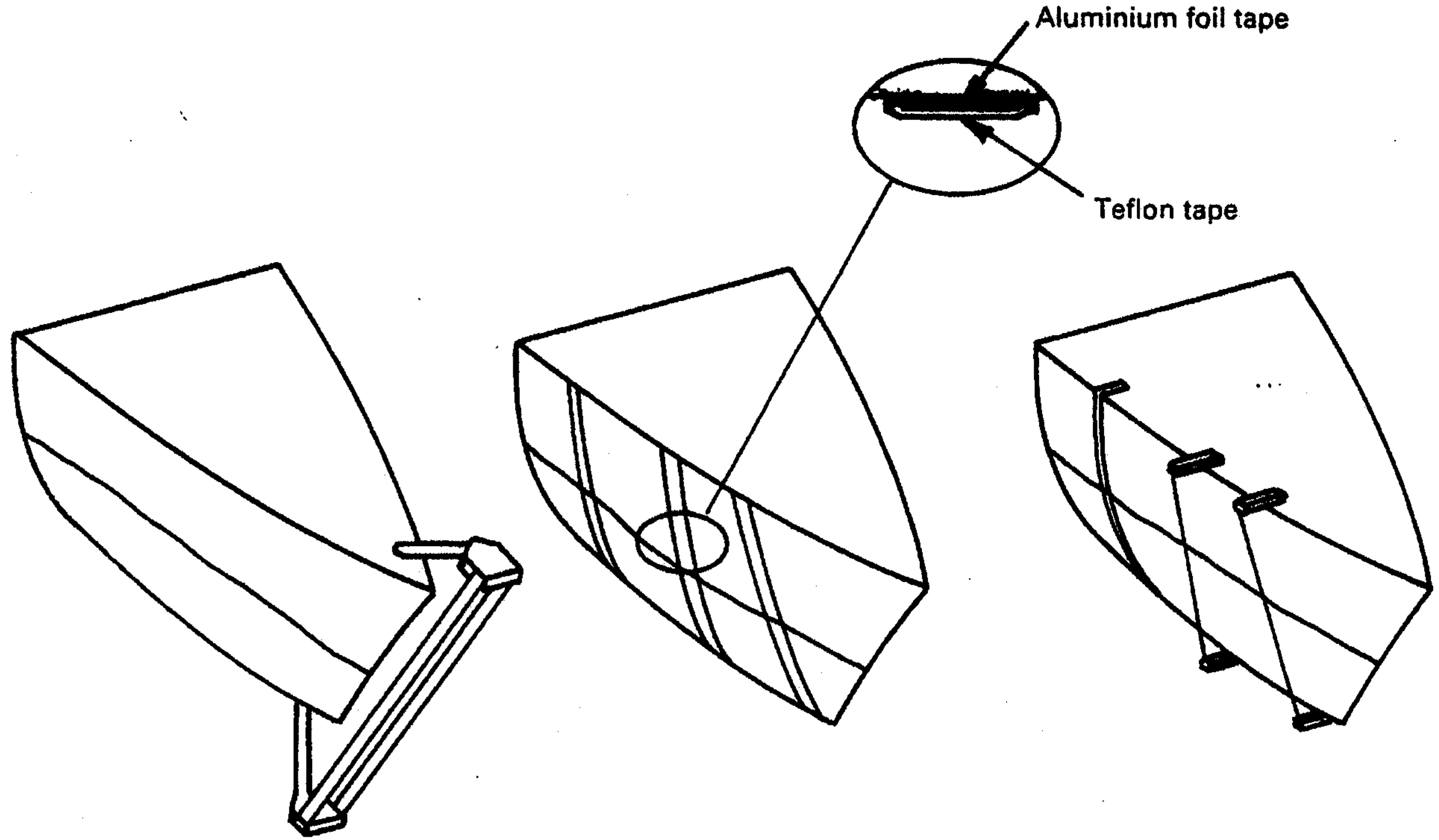
Applications of velocity measurement systems

- Pitot and Prandtl tubes:
  - Intrusive measurement of velocity at a single (or few) points
  - Cheap, simple and reasonably accurate average
- LDA/LDV
  - Very accurate, very high resolution point measurements, useful for turbulence measurements
  - Non-intrusive
  - Doesn’t require calibration
  - Costly and time consuming
- PIV
  - Measurement of flow fields
  - Non-intrusive
  - Tedious calibration required for each new test set-up
  - Very costly and time consuming

Wave probes


Wave probe amp.
wave probe
+ -
output
10V DC
+ -
Measurement of resistance,
Conversion to +-10V DC
Conductive wires
Water will short-circuit between the wires

Relative wave measurements



(a) Capacitance strips ahead of model

(b) Flush capacitance strips

(c) Resistance wires

Acoustic wave probes

- Working principle:
  A sound pulse is emitted, and the time it takes the reflected sound to reach the probe is used to calculate the distance to the water

- Benefits:
  - Works also at high forward speeds
  - Non-intrusive
  - Calibration free
- Drawbacks:
  - More costly
  - Steep waves in combination with smooth surface (no ripples) causes drop-outs, when no reflected sound reach the probe

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