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IYPT
International Young Physicists' Tournament

1. Invent yourself

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1. Invent Yourself

Create a non-invasive device that determines the direction of fluid flow inside an opaque pipe. Optimise your device so that you can measure the smallest flow possible.

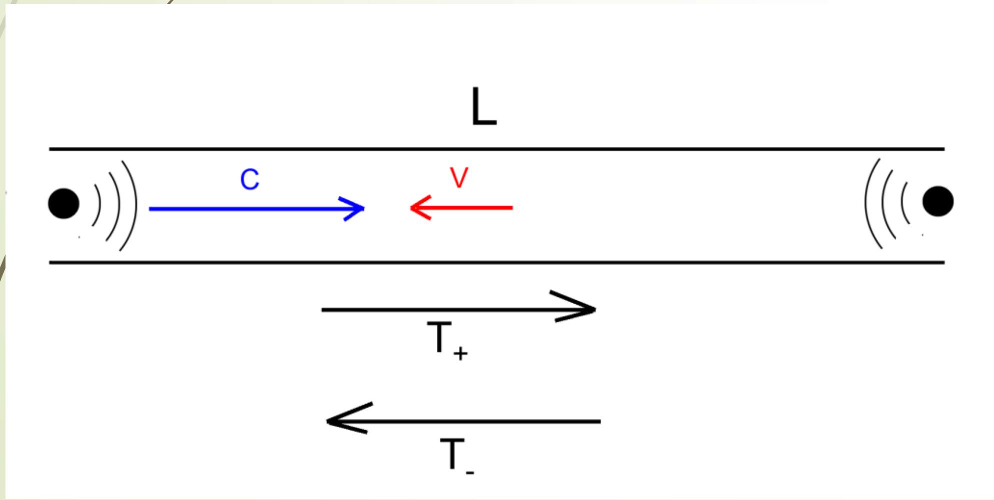
Fluid = liquid, gas?

Methods used in flow-meters

- Quick search the Internet:
  - Mechanical (pistons + cycles count)
  - Turbine, object levitating in a conical vertical flow
  - Pressure differences on obstacles (small opening, Pitot tube, ...)
  - Optical (observing small object or bubbles)
  - Vortex (measuring frequency of vortices behind the obstacle)
  - Ultrasonic sonar velocimeters
  - Thermal mass flowmeters
  - Magnetic (electromagnetic induction, ...)
  - ...

Ultrasonic devices - principle

- The velocity of the wave is influenced by the flow of the fluid
- L – distance between sender and receiver
  c – sound velocity
  v – fluid velocity
  T_+/T_- - sound travel time in forward/backward direction



$$T_+ = \frac{L}{c-v} \qquad T_- = \frac{L}{c+v} \qquad \Delta T = \frac{2Lv}{(c-v)(c+v)}$$

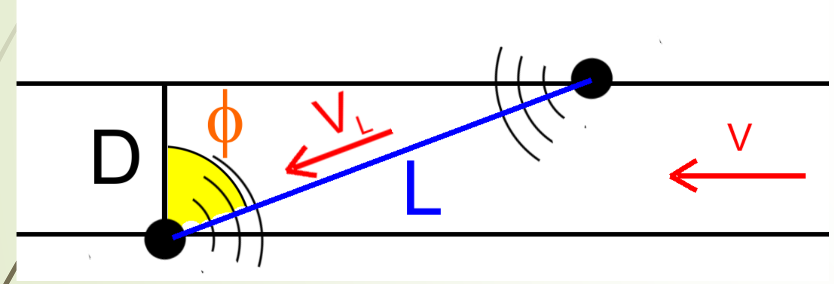
$$T_+T_- = \frac{L^2}{(c-v)(c+v)}$$

$$\boxed{v = \frac{L\Delta T}{2T_+T_-}}$$

Ultrasonic devices - principle

- Non-invasive configuration

$$L = \frac{D}{\cos\Phi} \qquad v_L = v \sin\Phi$$



$$T_+ = \frac{D}{\cos\Phi(c - v\sin\Phi)} \qquad T_- = \frac{D}{\cos\Phi(c + v\sin\Phi)}$$

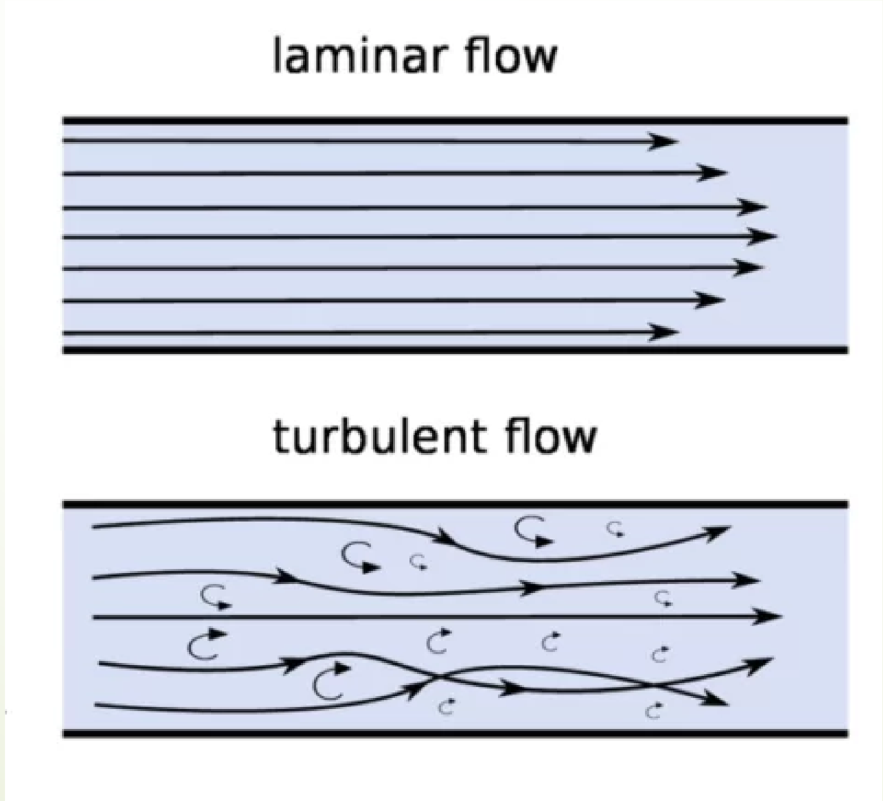
$$\Delta T = \frac{2\,D\,v\sin\Phi}{\cos\Phi(c - v\sin\Phi)(c + v\sin\Phi)}$$

$$T_+T_- = \frac{D^2}{\cos^2\Phi(c - v\sin\Phi)(c + v\sin\Phi)}$$

$$v = \frac{D\Delta T}{2\sin 2\Phi\; T_+T_-}$$

Ultrasonic devices - principle

- Measures average velocity along the US path
- Velocity profile depends on the type of the flow (laminar, turbulent)
- Laminar flow in the cylindrical pipe: parabolic

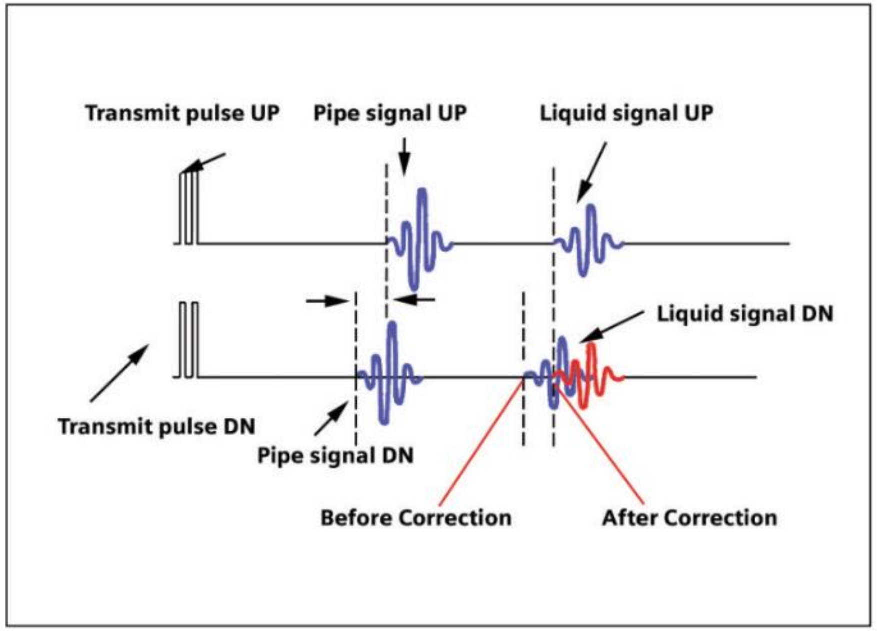


Ultrasonic devices – technical notes

- Ultrasound – over 20 kHz
- The duration of the US pulse – at least 2-3 periods (T)
- Time resolution – ca T/4
- Ultrasound velocity:
  - Air: 340 m/s
  - Water: 1500 m/s

$$v = \frac{L\Delta T}{2T_+T_-} \approx \frac{L\left(\frac{1}{4f}\right)}{2\left(\frac{L}{c}\right)^2} = \frac{c^2}{8Lf}$$

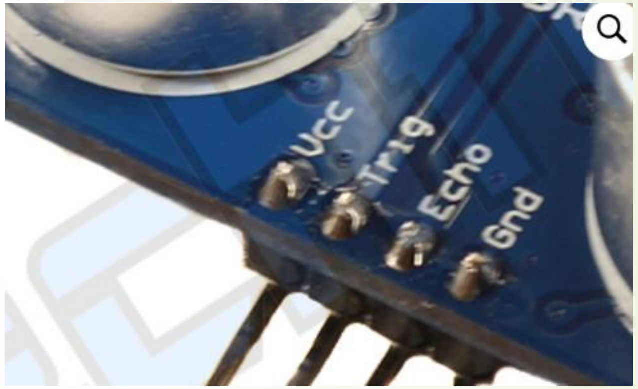
$$f_{min} = \frac{c^2}{8Lv_{min}}$$



- Minimum frequency for 1 m/s resolution at the path L = 1 m (transducers distance of 0.5 m):
  - Air: 15 kHz
  - Water: 280 kHz
- Typical frequencies of US devices: 40 kHz (cheap) to 10 MHz (professional)
- For higher fluid velocities only

Ultrasonic devices – technical notes

- Very cheap ultrasound devices (a few EUR) operating at 40 kHz
- Typical distance resolution in air: 1-3 mm (6 – 20 μs)
- 2 control wires:
  - Trig (1 – sending the US)
  - Echo (1 – signal is detected)
- Power: 5V (Vcc-Gnd)



HC-SR04 Ultrazvukový senzor vzdialenosti

1,45€ (bez DPH 1,21€)

Populárny ultrazvukový senzor na meranie vzdialenosti

165 na sklade

Vode odolný ultrazvukový modul JSN-SR04T pre meranie vzdialenosti

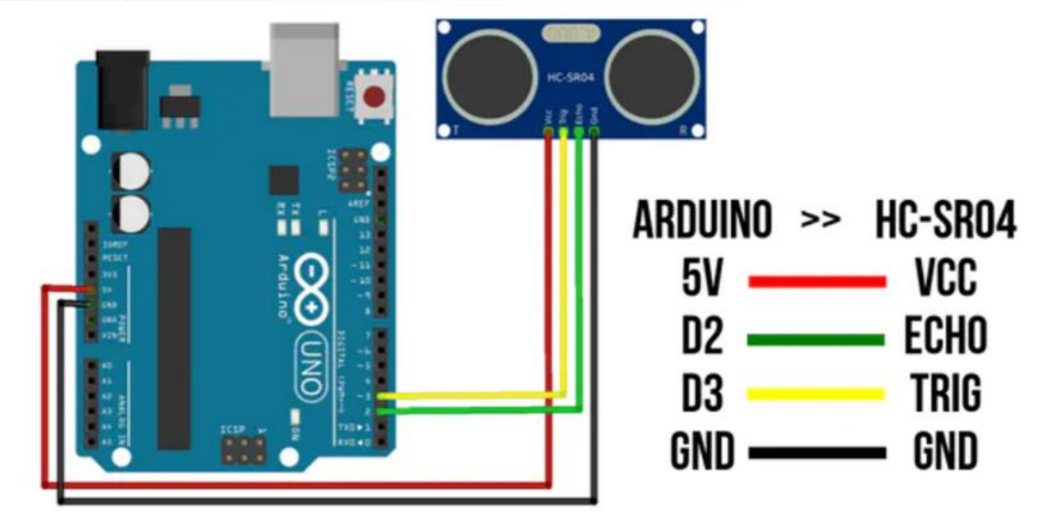
9,30€ (bez DPH 7,75€)

Vode odolný ultrazvukový senzor vzdialenosti s vysokou presnosťou a rozsahom

44 na sklade

Ultrasonic devices – technical notes

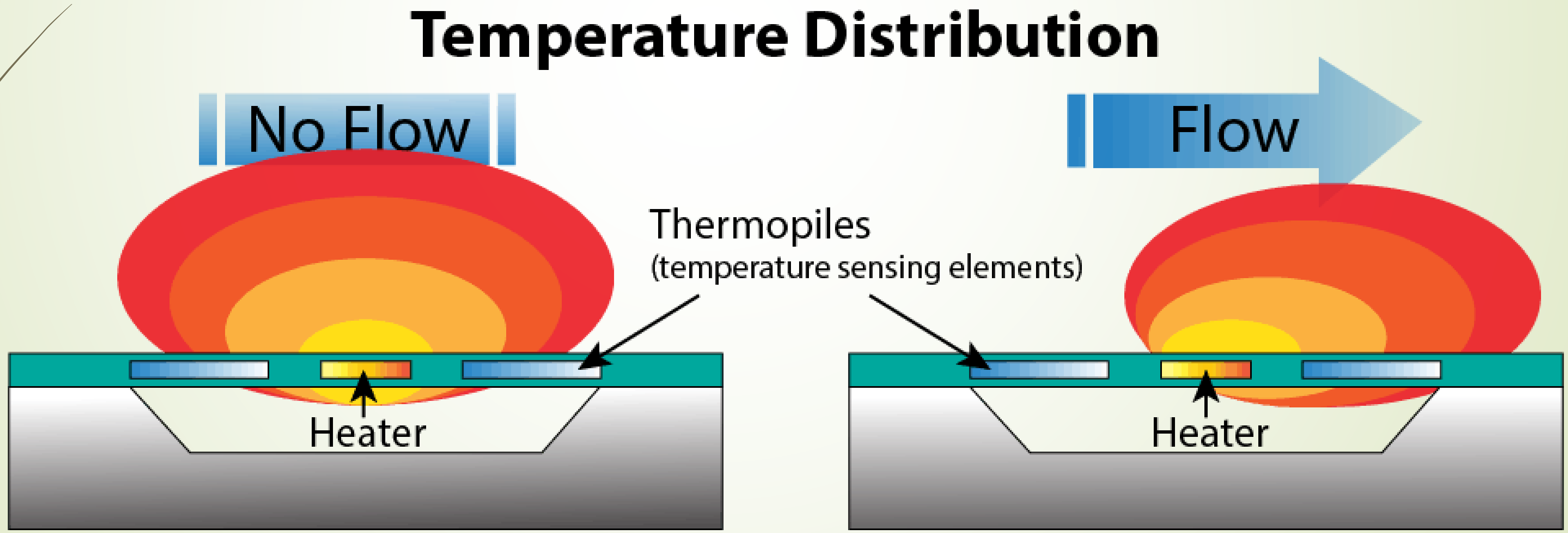
- https://create.arduino.cc/projecthub/abdularbi17/ultrasonic-sensor-hc-sr04-with-arduino-tutorial-327ff6




```
}
void loop() {
  // Clears the trigPin condition
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  // Sets the trigPin HIGH (ACTIVE) for 10 microsecor
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  // Reads the echoPin, returns the sound wave travel
  duration = pulseIn(echoPin, HIGH);
  // Calculating the distance
  distance = duration * 0.034 / 2; // Speed of sound
  // Displays the distance on the Serial Monitor
  Serial.print("Distance: ");
```

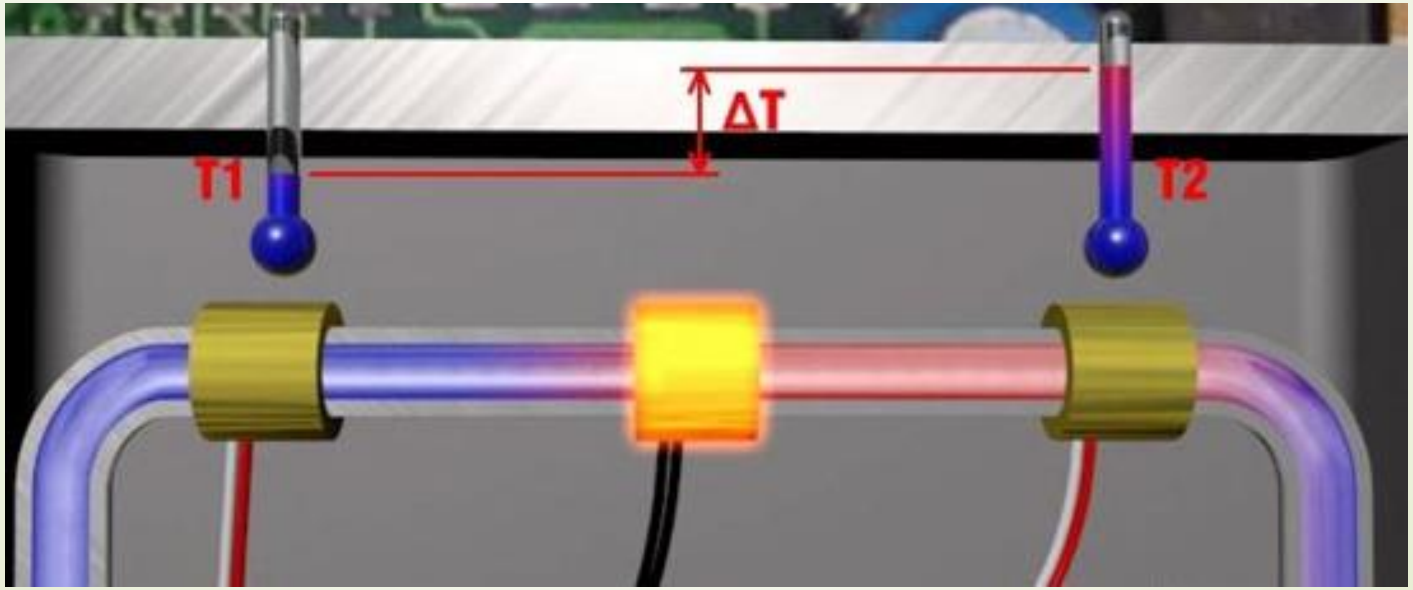
Thermal mass flowmeter - principle

- The tube is heated locally
- Fluid flow makes the temperature field asymmetric



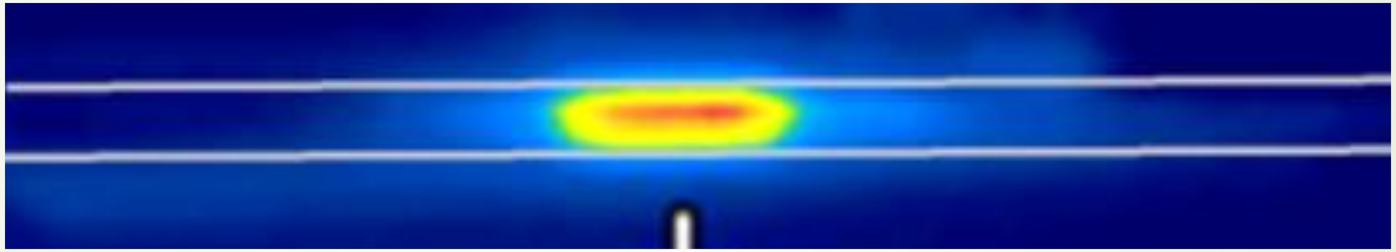
Thermal mass flowmeter - principle

- Should work also for lower fluid velocities
- Especially good for water (high thermal capacity)
- Heating element + 2 thermometers
- Temperature difference depends on the velocity of fluid

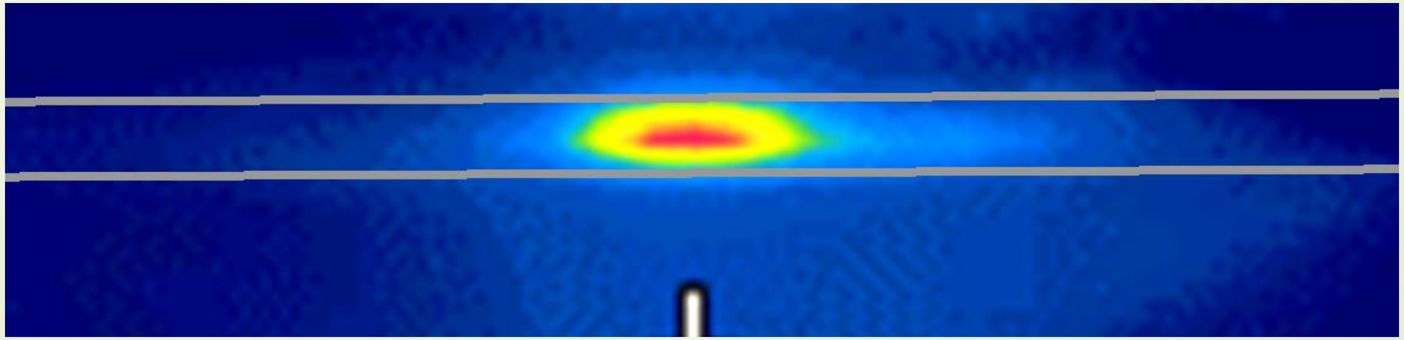


Thermal mass flowmeter - experiment

- Preliminary experiment:
  - Water in brass pipe (5mm diameter, 0.4mm wall thickness)
  - Water flow: 10 cm/s
  - Heating by directional hot-air jet
  - Measurement device – thermocamera FLIR
  - No flow:

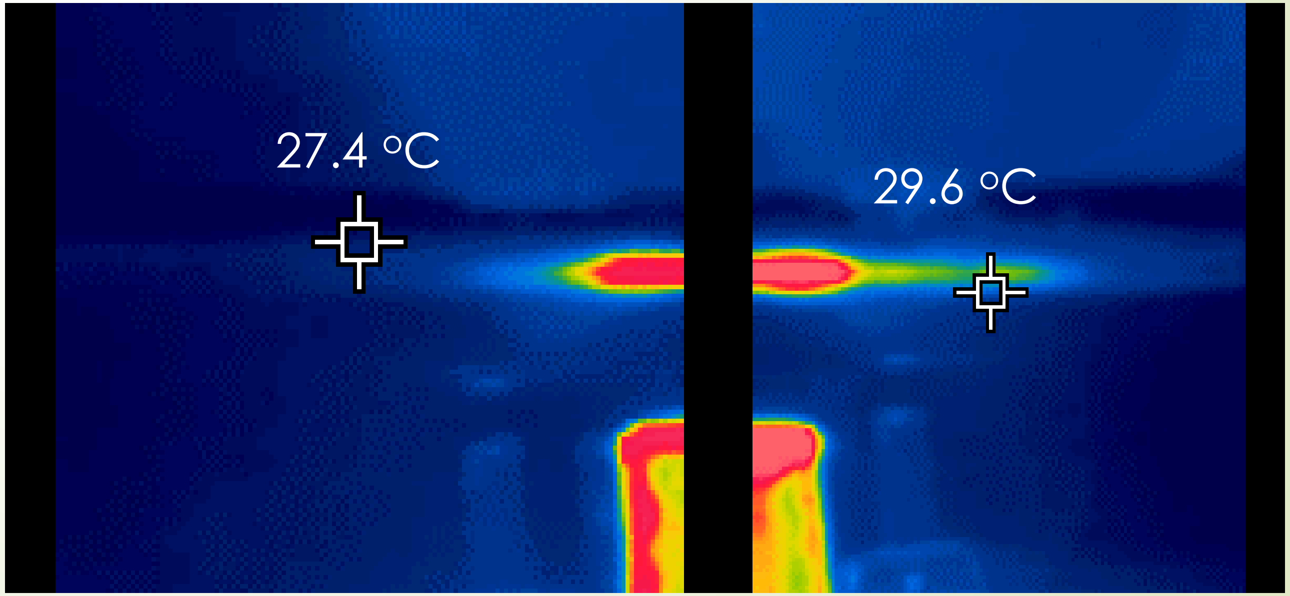


  - Flow:



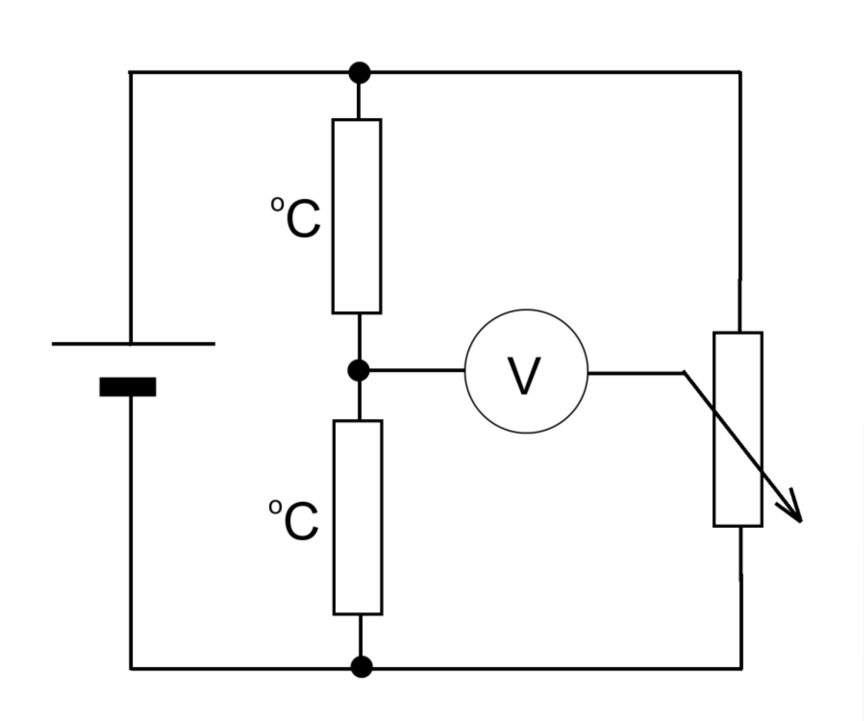
Thermal mass flowmeter - experiment

- Ca 2 °C difference at 10 cm/s
- Sensitivity of 1 cm/s can be achieved very easily
- Sensitivity of 1 mm/s achievable
- Depends on:
  - Material and dimension of the pipe
  - Fluid type
  - Thermometer



Thermal mass flowmeter – technical notes

- Thermistor – device very sensitive to the temperature
- Bridge measurement
  - Very sensitive
  - Easy setup of the zero level



Invent yourself – what to do?

- Perhaps start with themal mass method
- Investigate the material of the pipe
- Investigate the dimensions of the pipe and position of sensors
- Try to find the optimum setup for minimal flow detection
- Velocity calibration – by measuring the volume/mass of liquid flowing into the container
- Eventually try to build an ultrasound device for air flow measurements
- Search the literature
  - https://www.soundwatertech.com/news/how-ultrasound-flow-measurement-works
  - https://techfun.sk/produkt/vode-odolny-ultrazvukovy-modul-jsn-sr04t-pre-meranie-vzdialenosti/
  - https://www.gaimc.com/products/ultrasonic-flow-meter/How_ultrasonic_flow_meter_works.html?gclid=Cj0KCQjw5oiMBhDtARIsAJi0qk11qKm-Eu1JFPkt9ii8A_SLd140JAWU8nuv1wbKKzNbfCFXfjUbyq8aAnB7EALw_wcB
  - https://www.envirotech-online.com/article/flow-level-pressure/12/siemens/transittime-flow-measurement/297/download