Electronic Instrumentation

Lecturer: Kofi Makinwa

K.A.A.Makinwa@TUDelft.NL

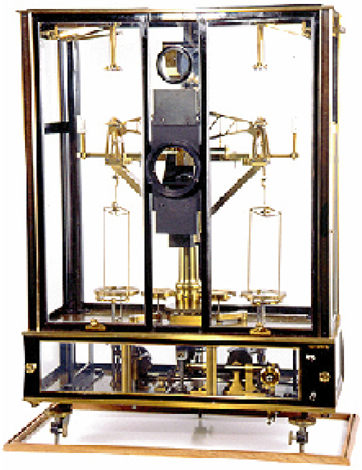
015-27 86466
Room. HB13.270 EWI building

Also involved:
Saleh Heidari (S.H. Shalmany@TUDelft.NL)

Important: Next lecture will be on Sept. 10th!!!

What is it about…

Great instruments of the past ?



No, it is about
Electronic Instrumentation

…., but many of the problems haven't changed !

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Or is it about…

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Using instruments ?

No, you are expected to be able to:

1. operate an instrument and
2. read and interpret instrument specifications

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Or perhaps about…

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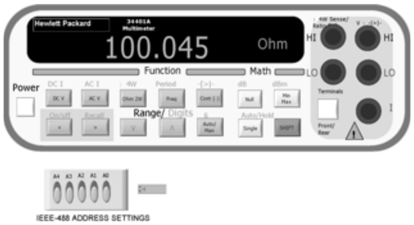
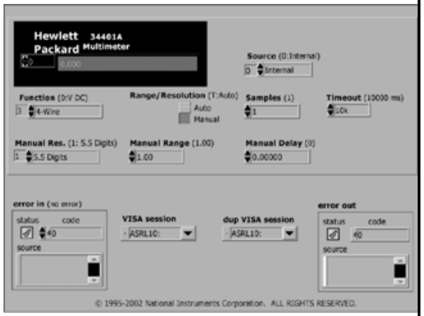
Virtual Instrumentation ?

Virtual instrument
designed in LabView
using a front panel
graphic editor

Hardware DAQ unit





Hewlett Packard 34401A Multimeter
0.000

Source (0:Internal): 0 Internal

Function (0:V DC): 3 4-Wire

Range/Resolution (T:Auto): ☐ Auto ■ Manual

Samples (1): 1

Timeout (10000 ms): 10k

Manual Res. (1: 5.5 Digits): 1 5.5 Digits

Manual Range (1.00): 1.00

Manual Delay (0): 0.00000

error in (no error): status ✓ code 40 source

VISA session: ASRL10:

dup VISA session: ASRL10:

error out: status ✓ code 40 source

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User interface

No, this is just a tool you should be able to use !

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So, what is this course about?

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Measurement Science:

Analyzing whether information on a parameter of interest (the *measurand*) has been (can be) obtained with sufficient quality, when considering interfering conditions and *specifications*.

Interfering with the measurand:

- Source loading by the measurement
- (Cross) sensitivity to undesired signals
- Electro-magnetic interference
- Many more…..

Electronic Instrumentation:

Designing a measurement instrument according to specifications

Specifications:
Imposed by measurement problem (= *problem specification*)
vs.
Offered by instrument (= *instrument specification*)
But there will be a *Detection limit* set by technology or by nature!

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Application to real-world measurement problems

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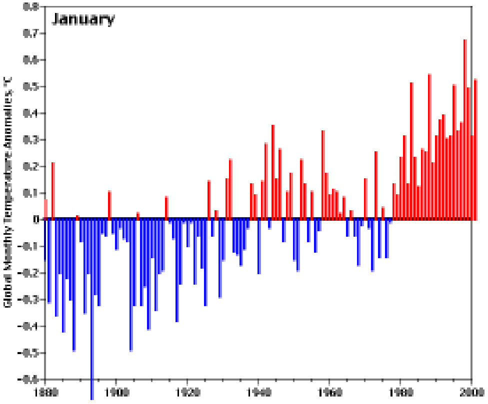
Starts with a measurement problem.

Is there global warming ?

“Of course, *everyone* knows that !
Just look at the *measured* temperatures”

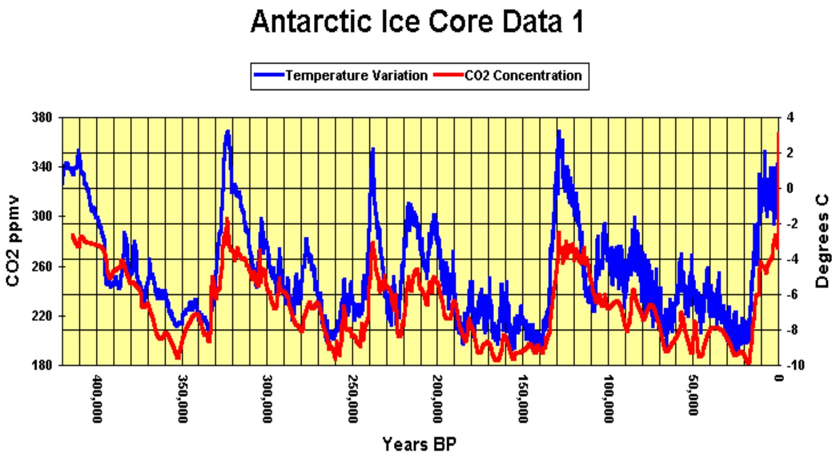


“Act now, or would you like this to happen…….”

Uncertainties in measuring global warming

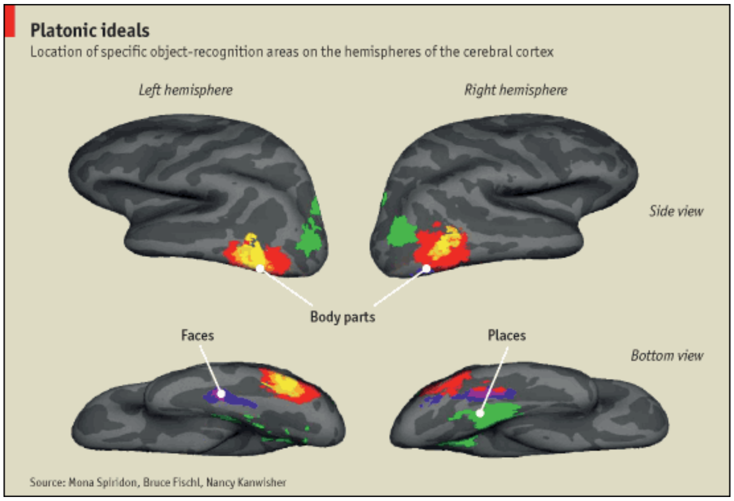
Drilling down to 3623 m in the Antarctic ice at Vostoc (equivalent to about 420 kyr BP with 4-6 kyr delay). Samples analyzed for:

- CO_2 by gas chromatography
- Temperature by measuring ^{18}O and Deuterium concentration
- Dust particle concentration.



How to access the measurand?

Medical application

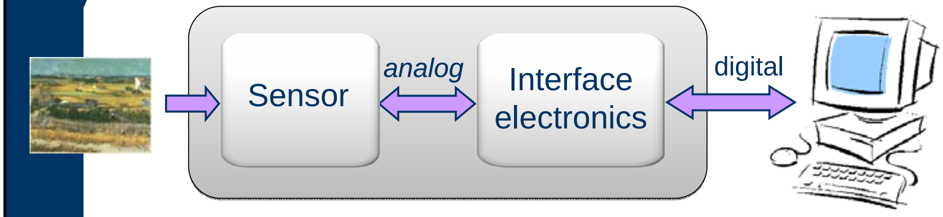


Platonic ideals

Location of specific object-recognition areas on the hemispheres of the cerebral cortex

Source: Mona Spiridon, Bruce Fischl, Nancy Kanwisher

We need (smart) sensors!

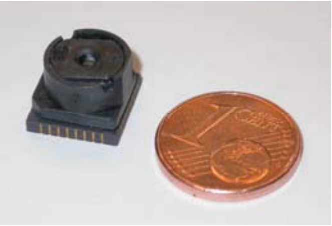


Sensor

analog

Interface electronics

digital



Smart sensor

- Analog-to-digital conversion ⇒ Interface electronics
- Smart sensor = Sensor system in a package

Sensors in our Pockets

image sensor

touch screen

compass

How many more?

microphone

(MEMS) Sensors in our Cars

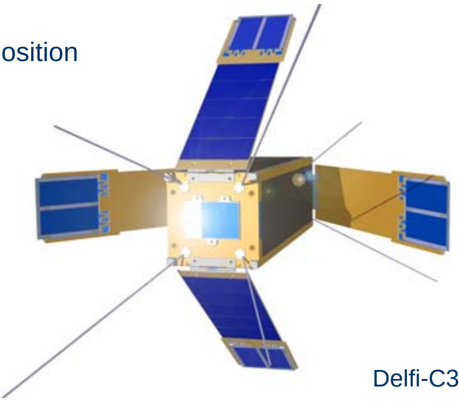
Automotive application – airbag crash detection

Airbag should only operate
when needed ⇒ crash sensor

Also for:
- side impact
- Non-passengers

Sensors in Space

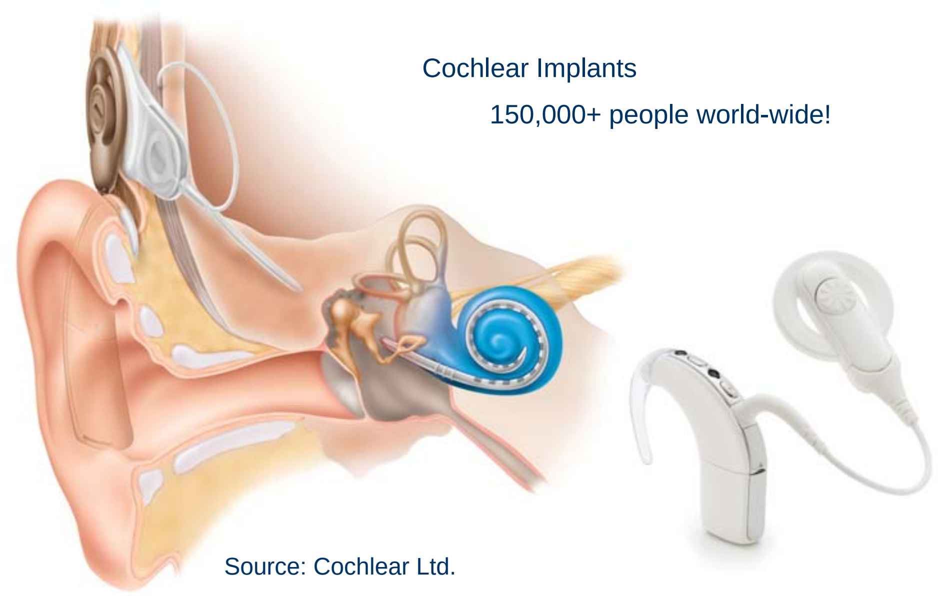
Measuring satellite position



Delfi-C3/MISAT

Purpose:
- Solar panel position control
- Antenna directional control
- Satellite attitude control

Sensors in our Bodies

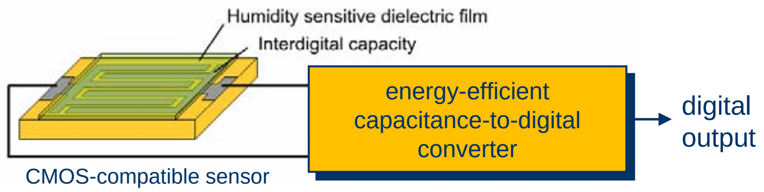


Cochlear Implants

150,000+ people world-wide!

Source: Cochlear Ltd.

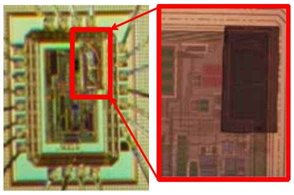
Smart Humidity Sensor



energy-efficient capacitance-to-digital converter

digital output

CMOS-compatible sensor



smart humidity sensor
(0.16µm CMOS)

- Humidity sensitive dielectric (NXP) causes capacitance changes
- These are digitized by a capacitance-to-digital converter (delta-sigma converter)
- Achieves resolution of 0.1%RH while consuming only 8.3nJ / meas

General Structure of an Instrument

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General structure of an instrument

Is a mobile phone an instrument?

General Structure of an Instrument

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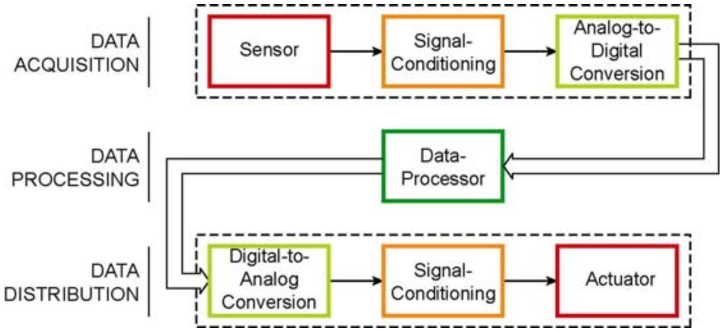
General structure of an instrument

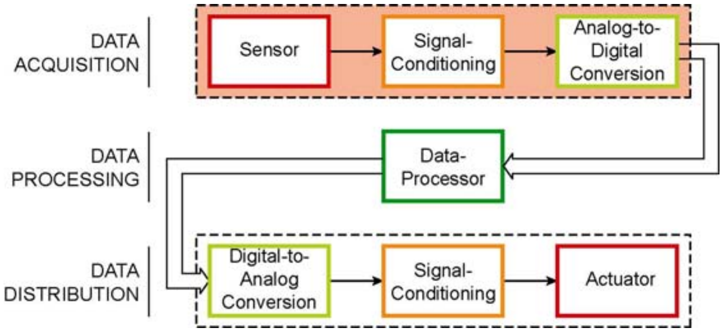
Components in an instrument



General Structure of an Instrument

General structure of an instrument

Components in an instrument



Content and Schedule-cont'd

ET8017 Class Schedule 2011

Date	Day	Time	Room	Content/Comments
4-Sep	Wed	11:00 - 13:30	Arnhem	Intro + Detection limit
10-Sep	Mon	3:30 - 5:30	EWI-IZ L	Lecture
12-Sep	Wed	08:30 - 10:30	EWI-CZ E	Tutorial
17-Sep	Mon	3:30 - 5:30	EWI-IZ L	Lecture
19-Sep	Wed	08:30 - 10:30	EWI-CZ E	Tutorial
24-Sep	Mon	3:30 - 5:30	EWI-IZ L	Tutorial
26-Sep	Wed	08:30 - 10:30	EWI-CZ E	Lecture
1-Oct	Mon	3:30 - 5:30	EWI-IZ L	Tutorial
3-Oct	Wed	08:30 - 10:30	EWI-CZ E	Lecture
8-Oct	Mon	3:30 - 5:30	EWI-IZ L	Tutorial

Electronic Instrumentation

Course Pre-requisites: basic understanding of….

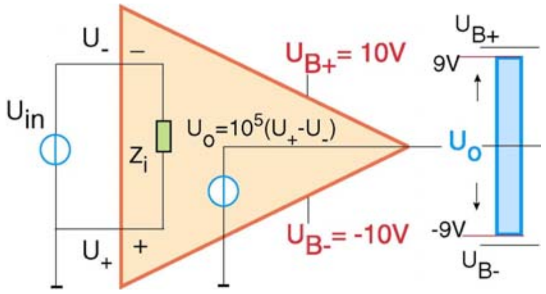
Circuit theory
- Transfer function calculation in terms of poles and zero’s
- Modulus and phase diagram (Bode plots) superposition theory
- Fourier and Laplace transform

Control theory
- Feedback and stability

Electronics
- Opamp circuits (concept of virtual ground)
- Effect of finite open-loop gain
- Basics of offset and noise analysis

Read-out using Operational Amplifiers

Using the open-loop gain



$U_{in,max}= U_{o,max}/10^5= 9/10^5= 90\ \mu V << U_{offset}$

⇒ Should be used in a feedback configuation

Read-out using Operational Amplifiers

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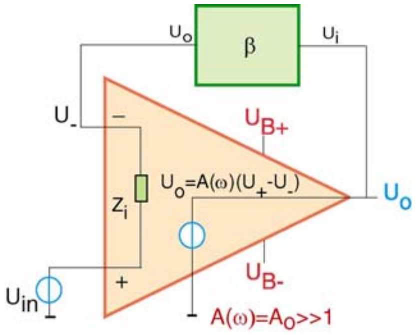
Opamp in feedback - Principle



Stability concerns !

Read-out using Operational Amplifiers

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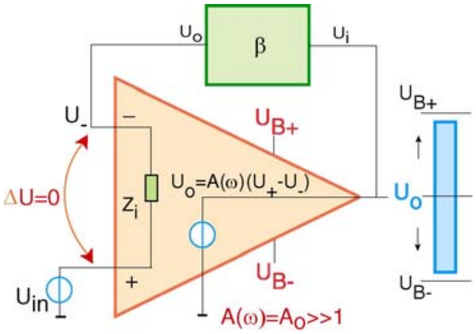

A finite value for U_o and a very high open-loop gain implies: $U_+ - U_- = 0$.

The feedback loop ensures that the value of U_o is such that: $U_- = U_+$

This implies that the potential at the opamp's non-inverting input is virtually copied to the inverting input

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Read-out using Operational Amplifiers

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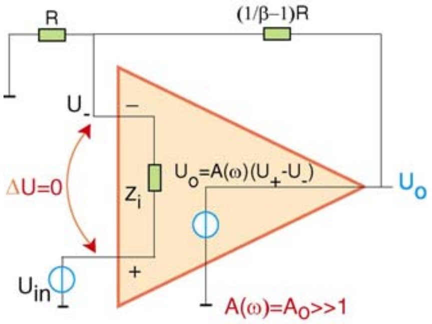
Non-inverting amplifier



Calculating the transfer function of the non-inverting amplifier:

$U_- = \beta U_o = U_o * R/[R+(1/\beta-1)R]$ and $U_+ = U_{in}$

$U_o/U_{in} = 1/\beta.$

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Read-out using Operational Amplifiers

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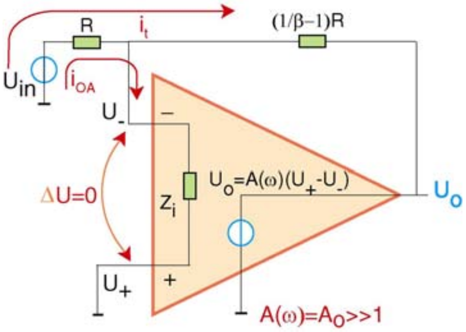
Current through the opamp input circuit

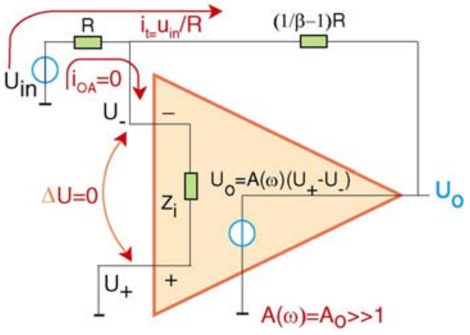


U_- is at virtual ground potential.

What can be concluded about i_{OA} ?

Read-out using Operational Amplifiers

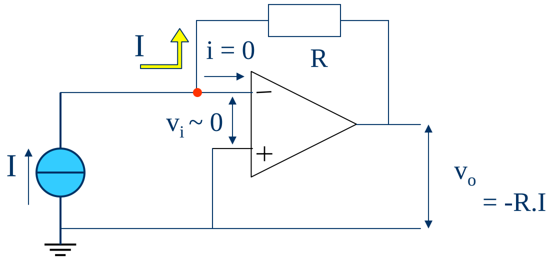
Inverting amplifier



Feedback forces: $\Delta U= i_{OA}.Z_i= 0$, hence $i_{OA}\sim 0$.

Typically, i_{OA} is at the nanoamp or even picoamp level

Two golden rules

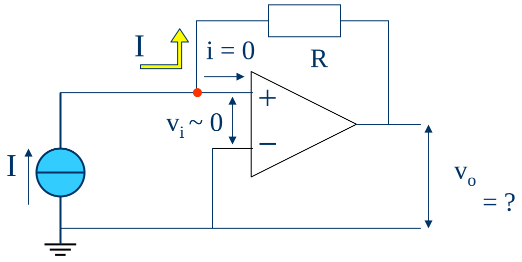


- If negative feedback is applied around an opamp, the following rules apply:

A >> 1 ⇒ Input voltage ~ 0 *First Golden Rule*
By design ⇒ Input current ~ 0 *Second Golden Rule*

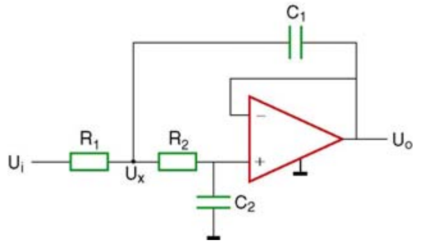
- So the red node is a virtual ground point!
- **Important!:** The rules only apply if the opamp is operating linearly

But rules don't always apply!



- Why?

Opamp-Based Active Filter



$$\frac{U_i - U_x}{R_1} = (U_x - U_o)\, j\omega C_1 + \frac{U_x - U_o}{R_2} \rightarrow$$

$$\frac{U_i}{R_1} = U_x\left(\frac{1}{R_1} + \frac{1}{R_2} + j\omega C_1\right) - U_o\left(\frac{1}{R_2} + j\omega C_1\right)$$

$$\frac{U_x - U_o}{R_2} = U_o j\omega C_2 \rightarrow U_x = U_o\left(1 + j\omega R_2 C_2\right)$$

$$\frac{U_o}{U_i} = \frac{1}{1 + j\omega\left(R_1 + R_2\right)C_2 - \omega^2 R_1 R_2 C_1 C_2}$$

2nd-order Sallen-Key low-pass filter

Content and Schedule

Today:	Introduction to **detection limit** (Chapter 1) DC detection limits in opamp circuits Assignments 1 & 2
Mon. Sept. 17:	Transduction of information (Chapter 2) - Sensitivity and cross-sensitivities - Resistive transducers - Capacitive transducers Offset (Chapter 3) - Equivalent input sources of offset - Offset in sensors and circuits

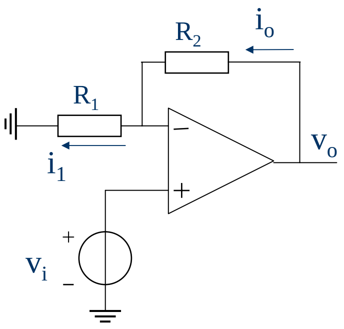
Full roster will be on Blackboard (1 lecture + 1 tutorial per week)

To enroll, please send **Saleh** an email: S.H.Shalmany@TUDelft.NL

Handouts will be distributed via Blackboard

A great book about opamp circuits is “The Art of Electronics”

Non-inverting amplifier



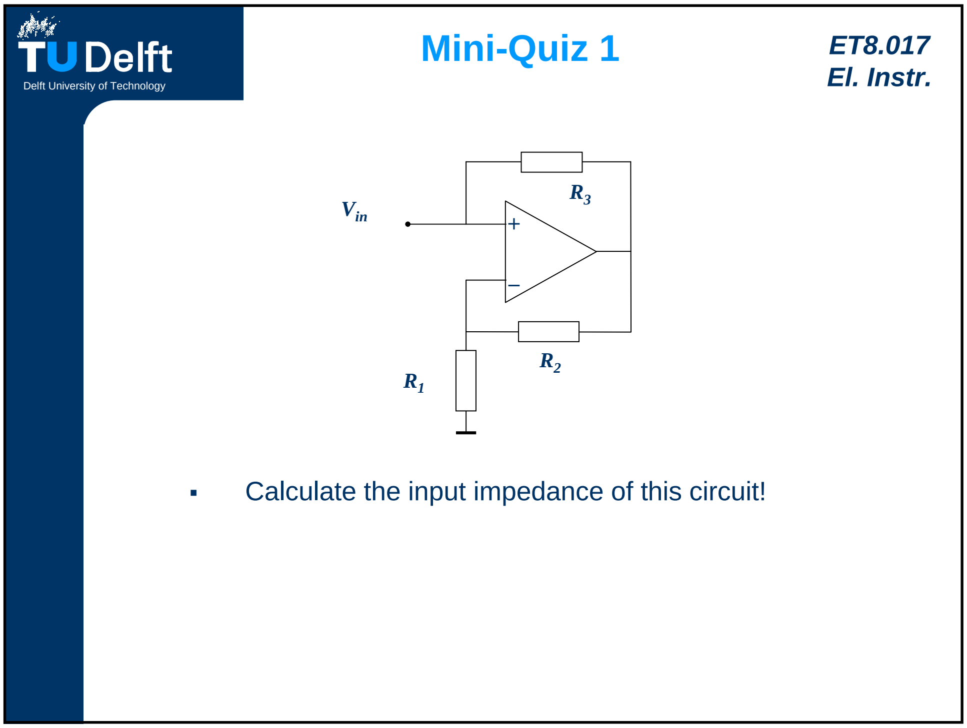
- Rule 1: $v_- = v_i$
- Rule 2: $i_1 = i_o$

So

- $i_1 = v_i / R_1$
- $v_o - v_i = i_o R_2$

$$R_{in} = \infty$$

$$\frac{v_o}{v_i} = 1 + \frac{R_2}{R_1}$$



Mini-Quiz 1

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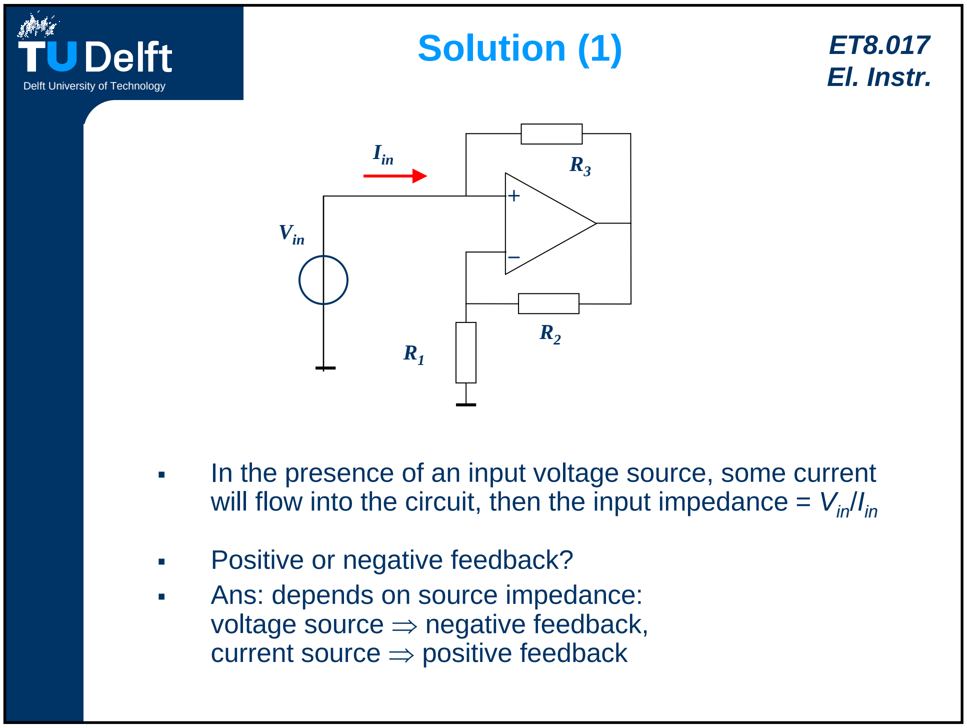
- Calculate the input impedance of this circuit!



Solution (1)

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- In the presence of an input voltage source, some current will flow into the circuit, then the input impedance = V_{in}/I_{in}
- Positive or negative feedback?
- Ans: depends on source impedance:
  voltage source ⇒ negative feedback,
  current source ⇒ positive feedback

Solution (2)

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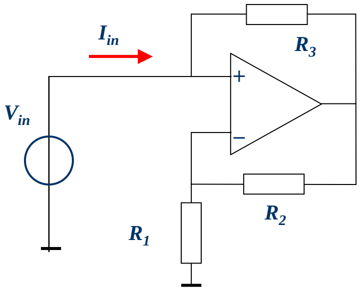

- $V_{out} = V_{in}(1+R_2/R_1)$
- $I_{in} = (V_{in} - V_{out})/R_3 = V_{in}(-R_2/R_1)/R_3$
- $Z_{in} = V_{in}/I_{in} = -R_1R_3/R_2$
- The circuit emulates a negative resistance!

Detection limit

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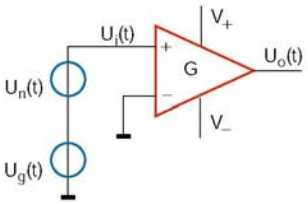
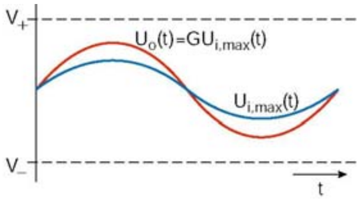
Definition: The minimum level of the input quantity that can be reproducibly measured at specified inaccuracy/SNR (default: SNR= 0 dB).

A practical signal is specified by its dynamic range: ratio between minimum and maximum signal level occurring within inaccuracy specification

Constraint due to maximum possible input level: Gain= G





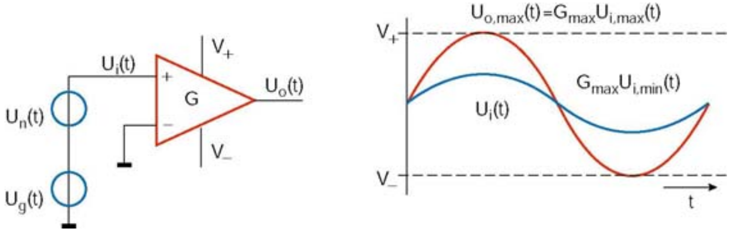
At maximum input signal the gain is insufficient for using the available dynamic range ⇒ increase gain.

Detection limit

Definition: The minimum level of the input quantity that can be reproducibly measured at specified inaccuray/SNR (default: SNR= 0 dB).

A practical signal is specified by its dynamic range: ratio between minimum and maximum signal level occurring within inaccuracy specification

Constraint due to maximum possible input level: Gain limited to G_{max}



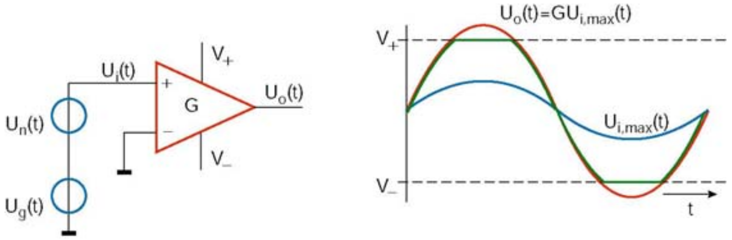
The maximum level of the input signal sets the maximum gain. However, the lower end of the input signal also results in a constraint.

Detection limit

Definition: The minimum level of the input quantity that can be reproducibly measured at specified inaccuray/SNR (default: SNR= 0 dB).

A practical signal is specified by its dynamic range: ratio between minimum and maximum signal level occurring within inaccuracy specification

Constraint due to maximum possible input level: Increasing gain G



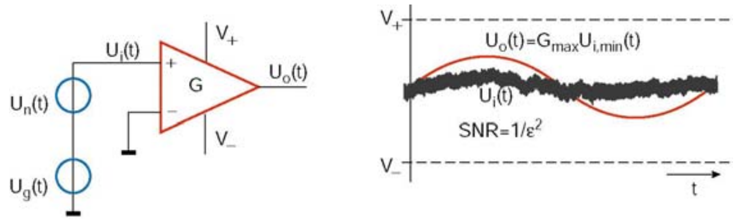
Maximum output voltage would be higher than system can deliver ⇒ saturation at maximum possible output level: Gain limited to G_{max}

Detection limit

Definition: The minimum level of the input quantity that can be reproducibly measured at specified inaccuray/SNR (default: SNR= 0 dB).

However, the minimum input signal is also limited at given inaccuracy (or Signal-to-Noise Ratio-SNR) specification when considering noise and interference

At G_{max} and specified inaccuracy,ε:



Note: output (red line) is drawn WITHOUT noise

Electronic Instrumentation

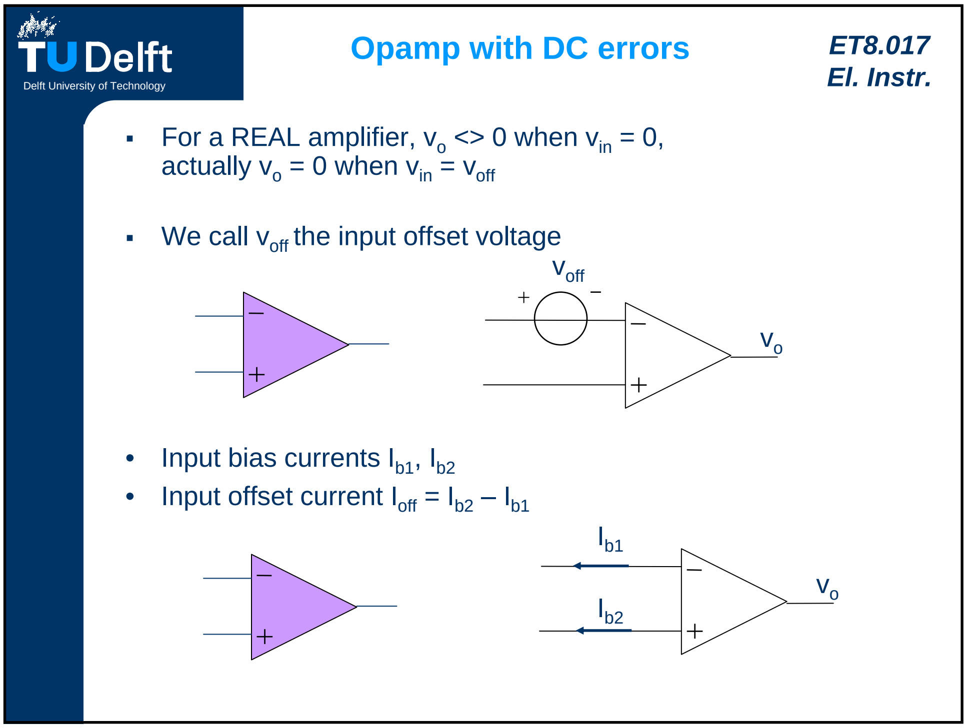
System sensitivity is not limited by the gain one can implement in the signal conditioning, but rather by the detection limit.

Procedure for finding the detection limit:

1. Determine the various error sources within the instrument and calculate the combined effect on the output.

2. Identify the dominating source of uncertainty
    a. Source loading
    b. offset
    c. Finite CMRR in a differential measurement
    d. Noise or interference

3. Calculate the input-referred equivalent sources of uncertainty.



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Opamp with DC errors

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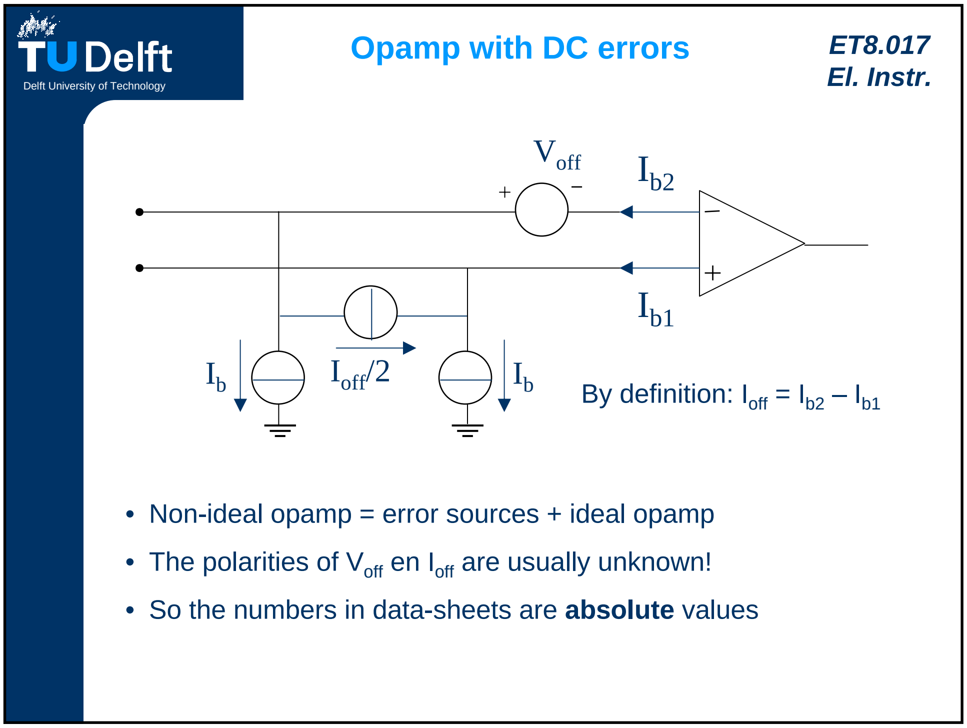
- For a REAL amplifier, v_o <> 0 when $v_{in} = 0$, actually $v_o = 0$ when $v_{in} = v_{off}$
- We call v_{off} the input offset voltage

- Input bias currents I_{b1}, I_{b2}
- Input offset current $I_{off} = I_{b2} – I_{b1}$



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Opamp with DC errors

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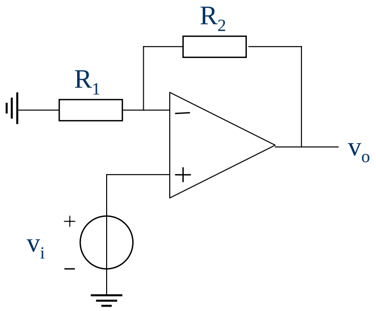
By definition: $I_{off} = I_{b2} – I_{b1}$

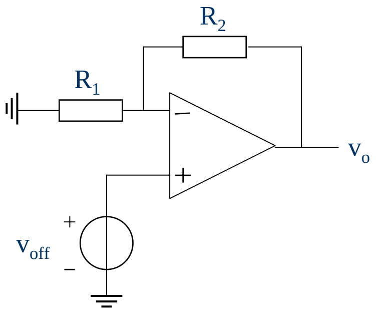
- Non-ideal opamp = error sources + ideal opamp
- The polarities of V_{off} en I_{off} are usually unknown!
- So the numbers in data-sheets are **absolute** values

Mini-Quiz 2



- If the opamp has finite offset and bias current, calculate the input-referred offset of this amplifier?

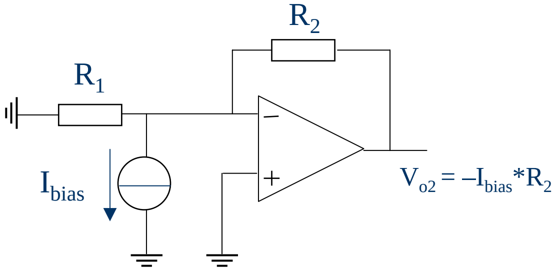
Solution (1)



- **Use superposition, since this an LTI system!**
- So the effect of every DC source can be independently determined and then summed

- Contribution of $V_{off} \Rightarrow V_{o1} = V_{off}(1+ R_2/R_1)$

Solution (2)



- Why doesn't any current flow through R_1?

Solution (3)

- The two results can be added

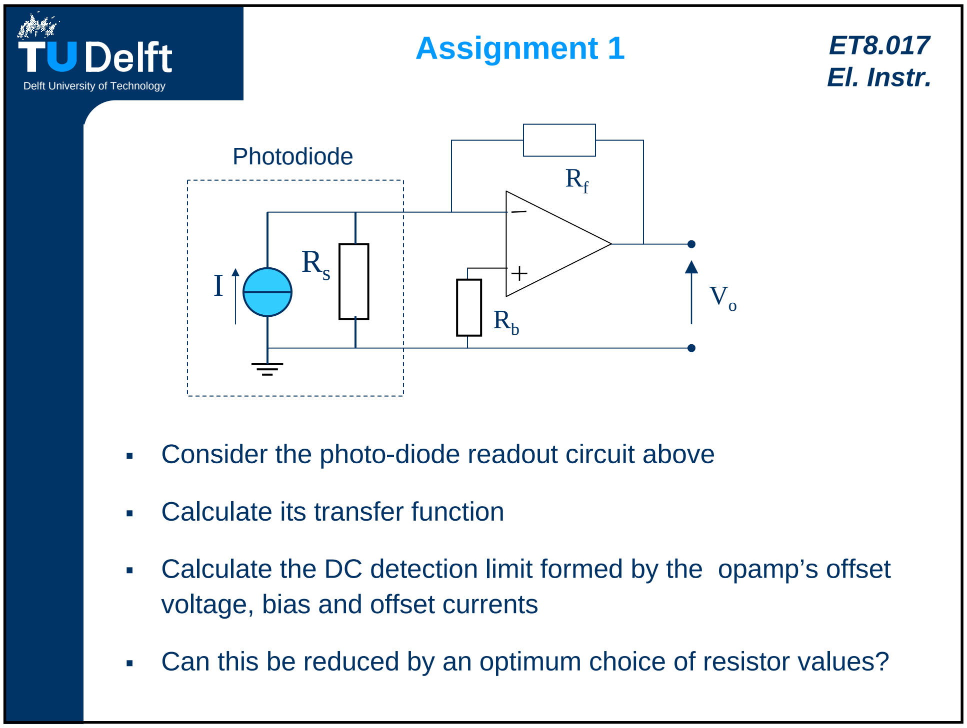
  $V_o = V_{o1} + V_{o2}$

  $V_o = V_{off}\,(1 + R_2/R_1) – I_{bias} * R_2$

- Input-referred offset $V_{in,off} = V_o/A_{CL}$

  So $V_{in,off} = V_{off} – I_{bias} * R_1 \,||R_2$

- How is this a detection limit?
- Can you name other DC detection limits?



Assignment 1

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- Consider the photo-diode readout circuit above
- Calculate its transfer function
- Calculate the DC detection limit formed by the opamp's offset voltage, bias and offset currents
- Can this be reduced by an optimum choice of resistor values?