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Lecture 5

Digital & Analogue Signals and Data Acquisition

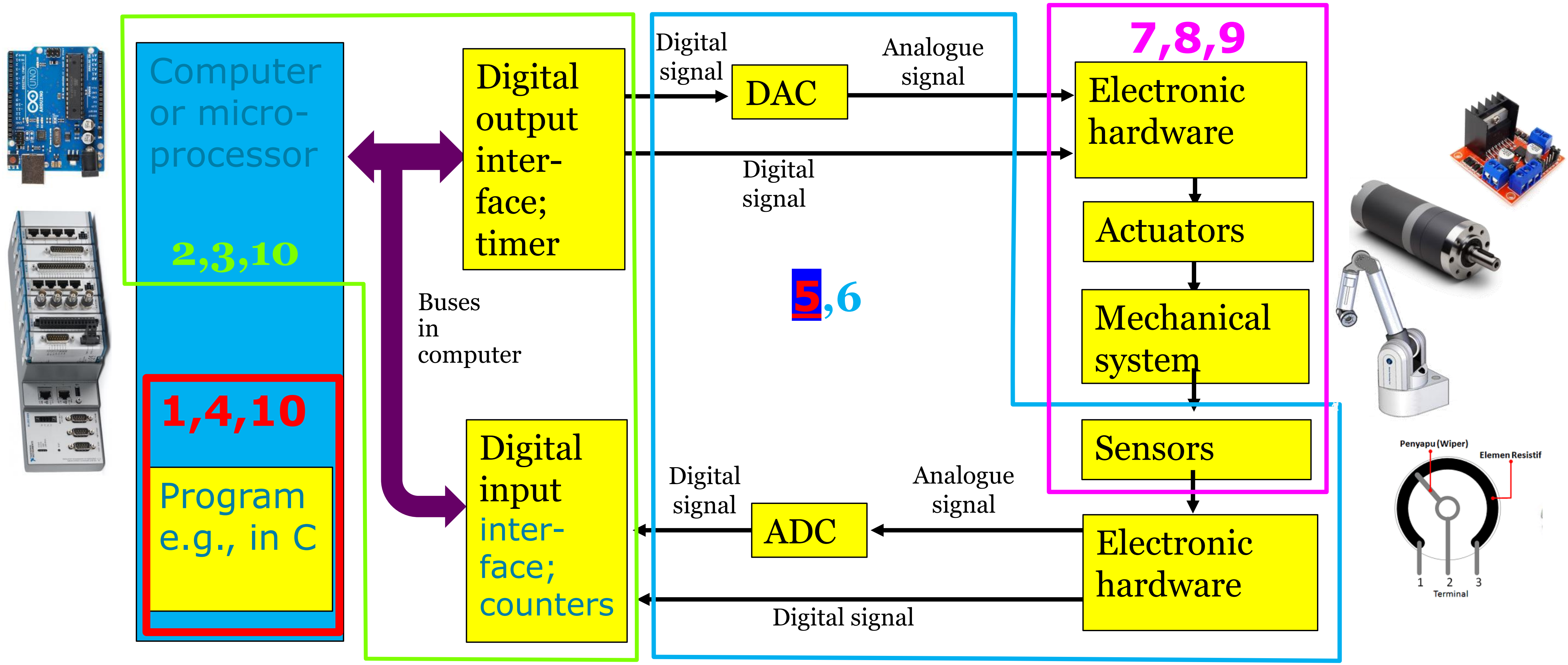
Mechatronics
MMME3085

Module Convenor – Abdelkhalick Mohammad

Lecture Objectives

- To reinforce existing knowledge of analogue and digital signals
- To introduce issues of signal handling, grounding and related issues
- To introduce some simple digital-to-analogue and analogue-to-digital conversion approaches

A typical Mechatronics System



Recap

From last lecture

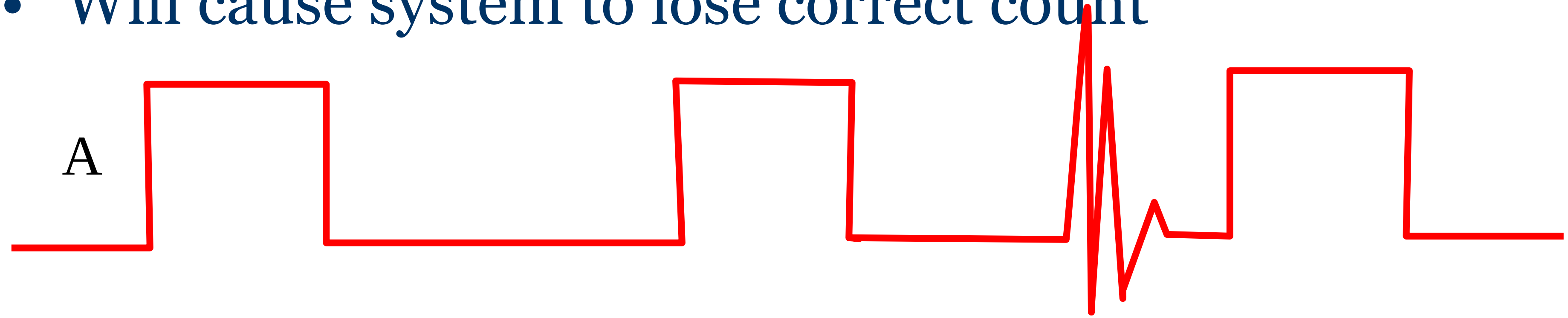
Last time we looked at

- Concept of simple state table introduced
- Concept of state diagram introduced
- Finite state machine
- State machine using 2D state table
- State machine based on case statement
- Simple examples:
  - Traffic lights
  - Traffic lights with car/pedestrian crossing
- Introduction to Lab 1
- Interrupt

Digital signals handling

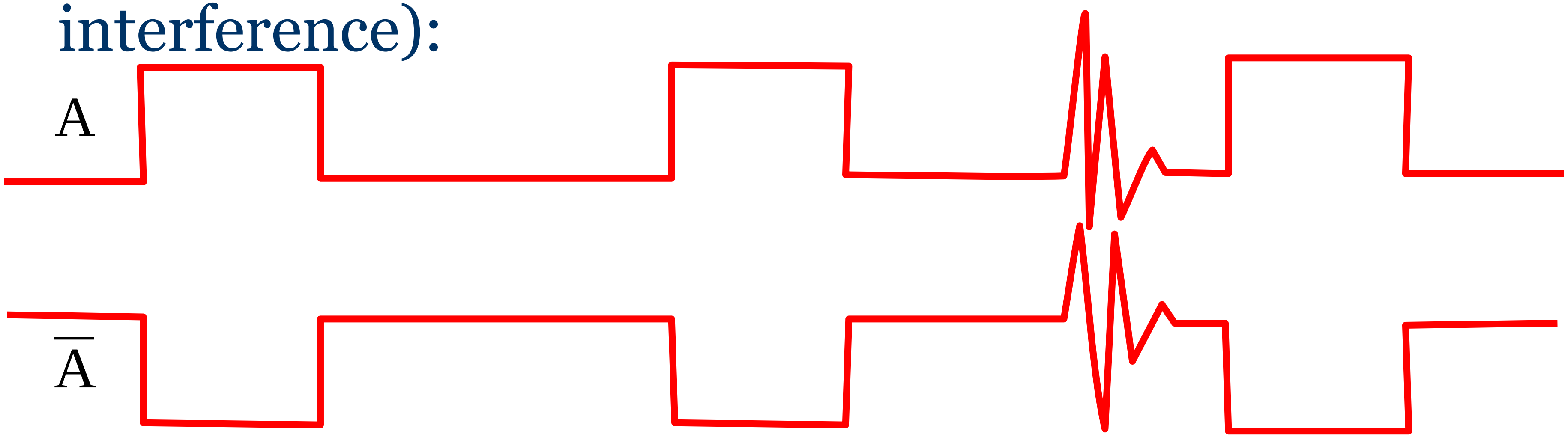
Digital signals and interference

- Usually, digital signals are "single ended": voltage is referenced to ground (GND)
- Not normally a problem, but…
- Digital signals can be subject to **interference**
- If interference causes a "spike", this can be wrongly interpreted as a pulse
- Will cause system to lose correct count



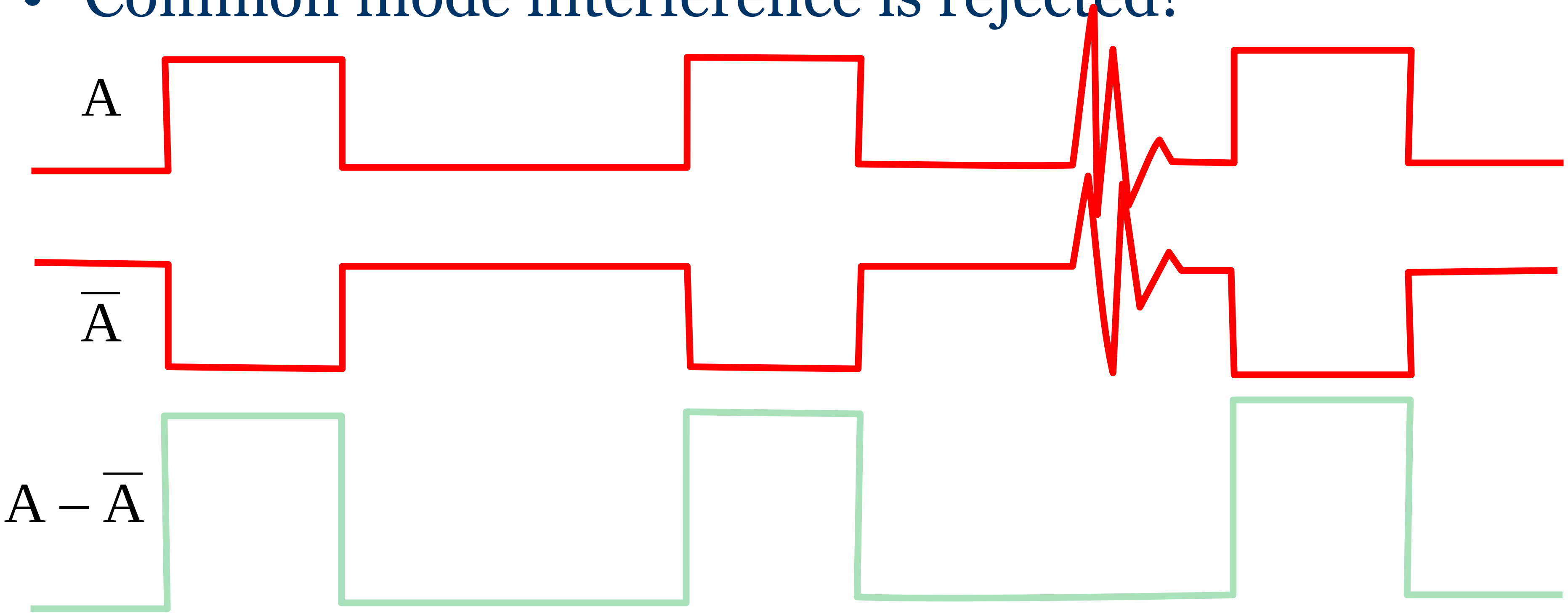
Digital signals: differential signals

- To avoid this, we sometimes use differential signals
- Each signal involves 2 complementary lines (one goes up when other goes down),
- Both pick up same spike (common mode interference):



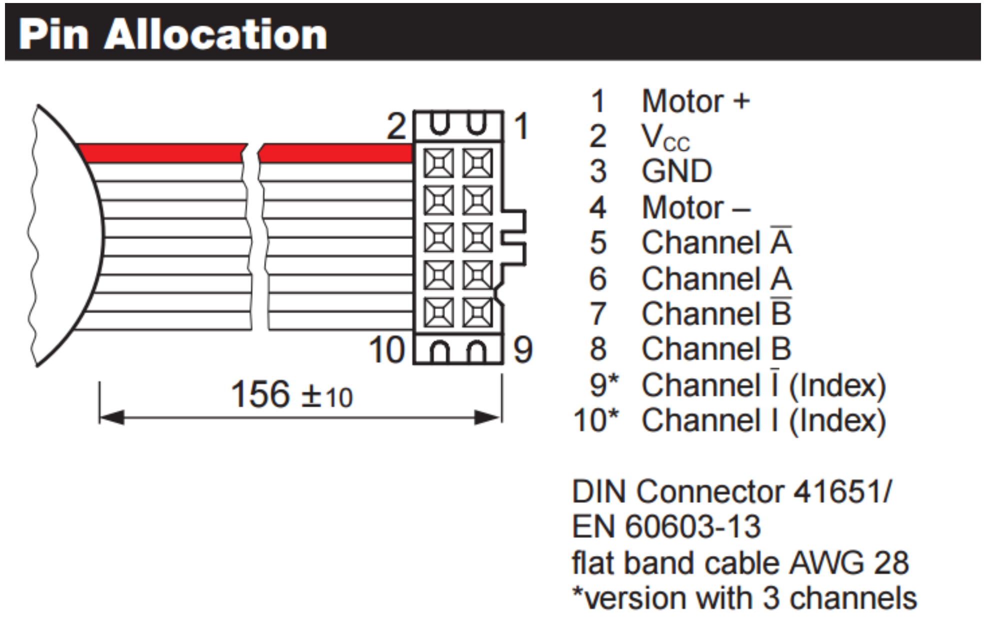
Digital signals: differential signals

- Circuitry which takes in these signals is only sensitive to the difference between them
- Common mode interference is rejected!



Digital signals: differential signals

- Sometimes used on things like optical encoders where critical to avoid false pulses



Digital signals handling

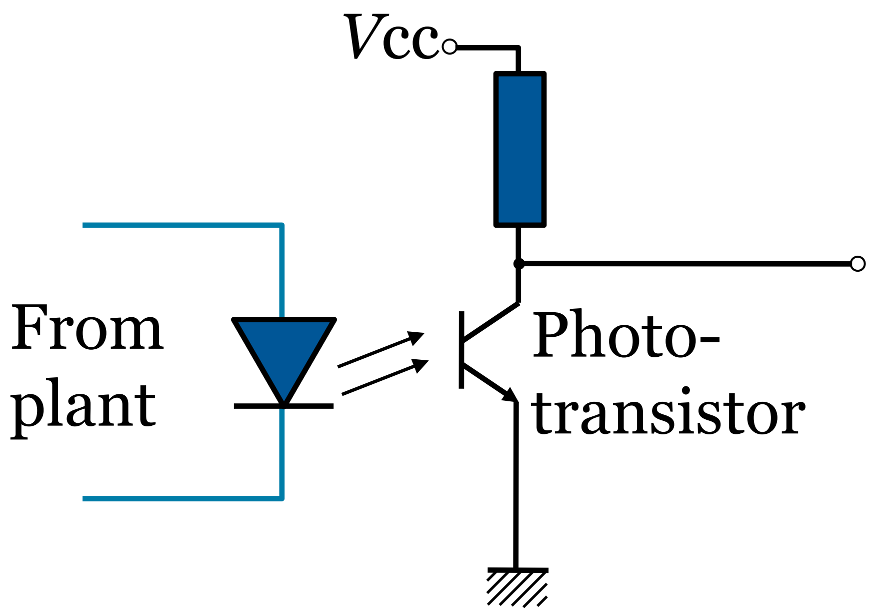
Optical isolation

Digital signals: optical isolation

- Try to avoid having direct electrical connection between the plant and computer
- This is in case:
  - A fault develops on the plant (want to avoid high voltages etc. damaging computer)
  - There is interference e.g. potential difference between plant and computer
- Instead, have optical isolation between plant and computer

Digital signals: optical isolation

- Signal from (say) plant operates LED which shines on phototransistor
- Information is transferred without connection!



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Analogue signals

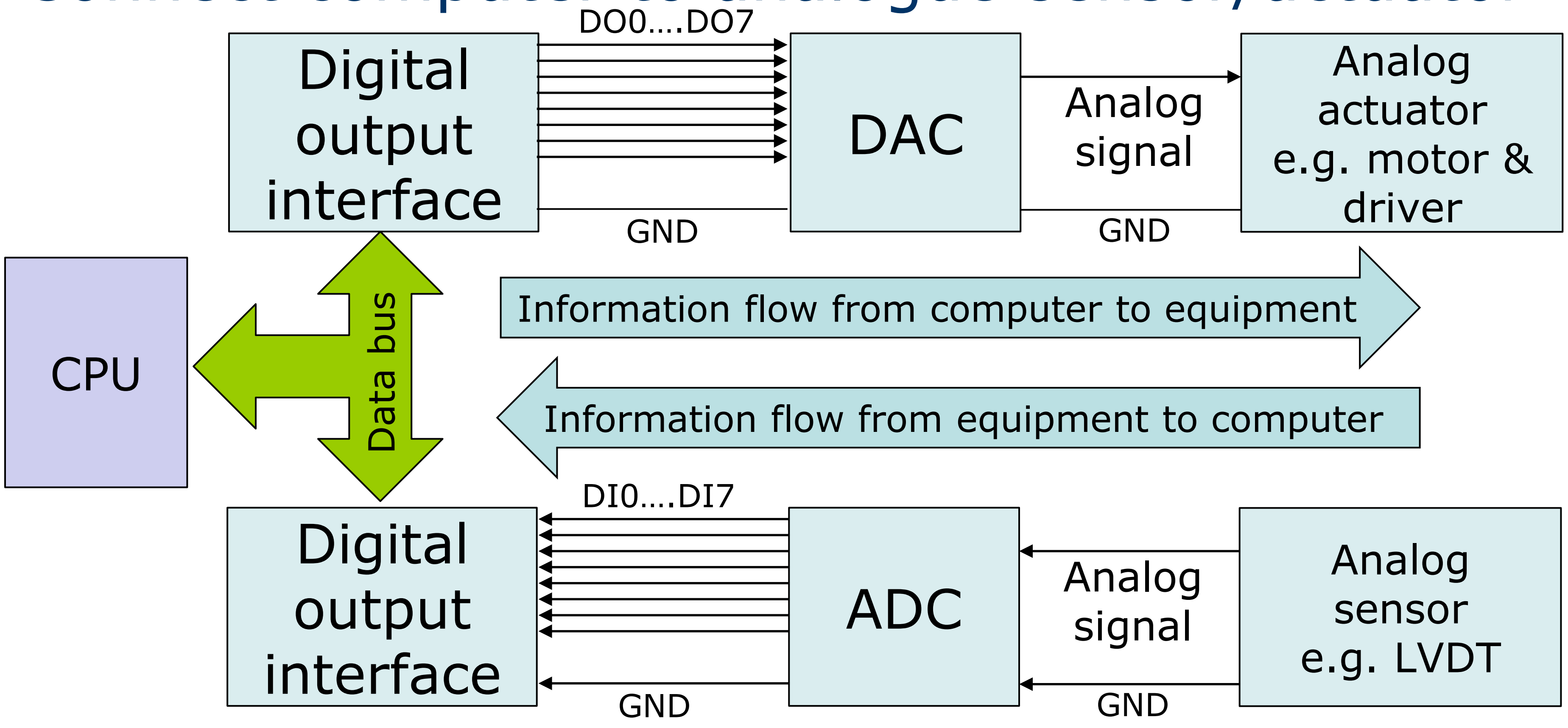
Introduction

Analogue signals

- Value e.g. voltage “analogous to” a quantity
- May be AC (Hz, kHz, MHz…) or DC;
- Very often a voltage (0/10 V or -10/+10 V)
- Can be a current: 4/20 mA is often used in process plant control
- Infinitely variable: resolution is limited by interference.
- Cannot connect directly to computer - need analogue/digital conversion

Why/how do we want to interface to computer?

Connect computer to analogue sensor/actuator



Analogue signals

Types

Analogue signals: single ended or differential?

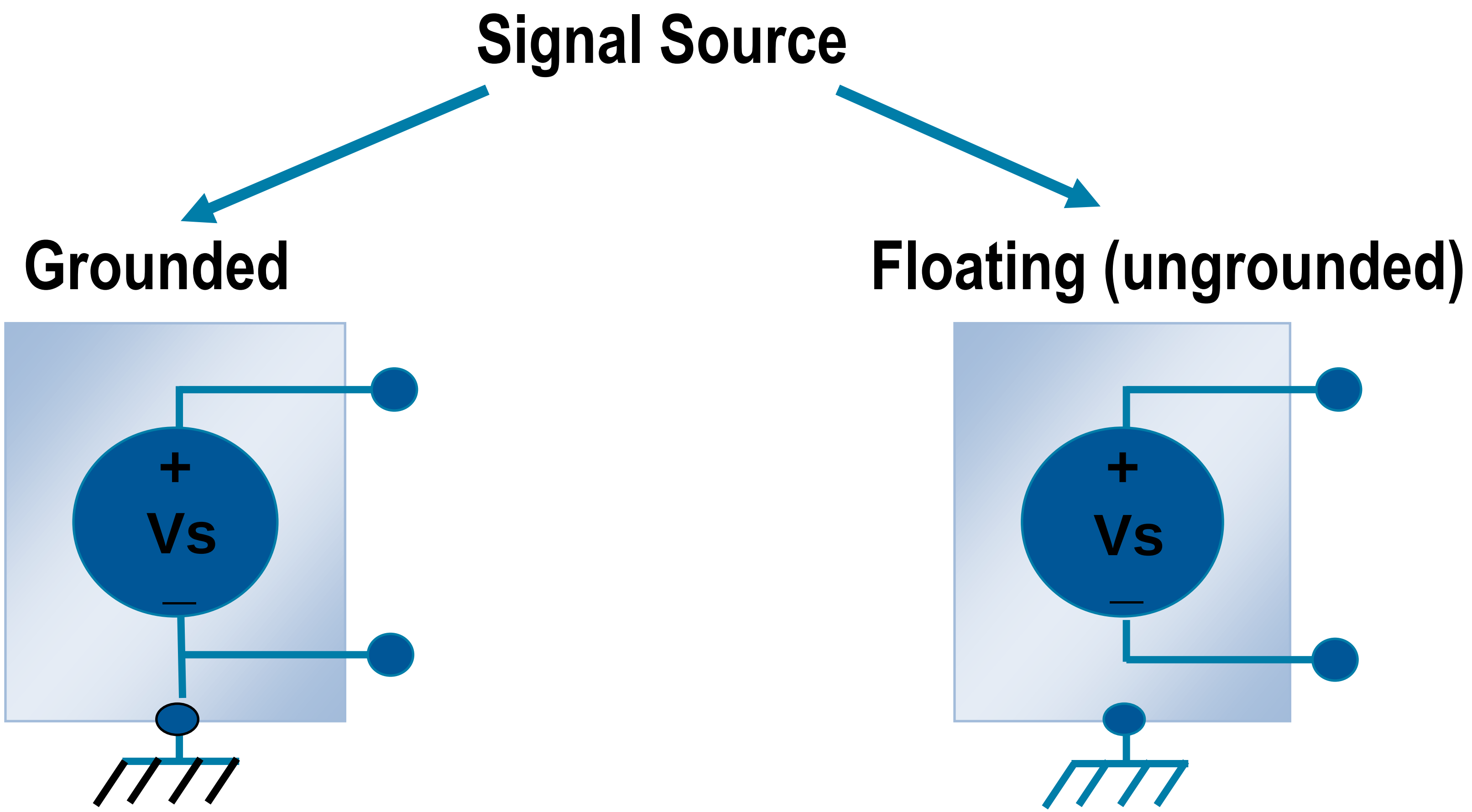
- Our sensor, signal source etc. produces a voltage related to (proportional to) value we try to measure
- Voltage here means potential difference
- But potential difference (PD) between what and what?
  - PD of a wire with respect to ground?
  - PD of a wire with respect to another wire?
  - What if the second wire is not at ground?

Analogue signals: single ended or differential?

In other words, do we treat it as:

- Single ended: referenced for example to ground, earth, chassis etc.
- Differential: carried on two wires, absolute voltage unimportant, interested only in difference

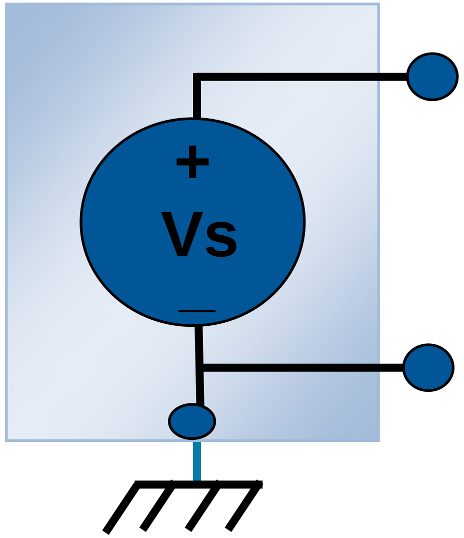
Signal Source Categories



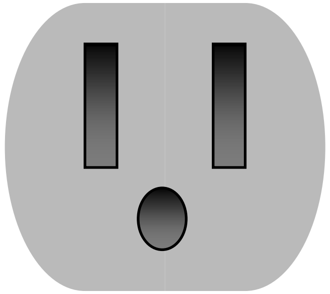
Signal Source Categories

- Signal is referenced to a system ground
  - Earth ground
  - Building ground
- Examples:
  - Power supplies
  - Signal Generators
  - Anything that plugs into a grounded, electrical wall socket

Grounded

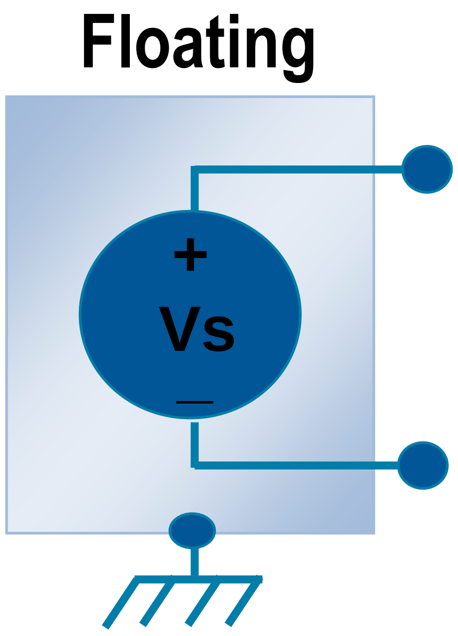


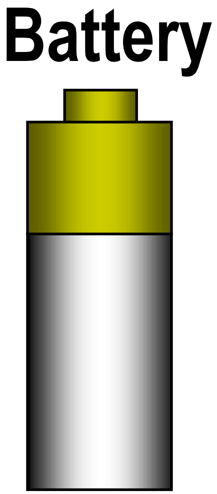
Grounded wall socket



Signal Source Categories

- Signal is NOT referenced to a system ground
  - Earth ground
  - Building ground
- Examples:
  - Batteries
  - Thermocouples
  - Transformers
  - Isolation Amplifiers





Analogue signals: single ended or differential?

- Analogue signals have (theoretically) infinite resolution, but our enemy is interference
- A good differential input will reject common-mode voltages
- But differential inputs tend to cost more than single-ended (typically referenced to ground)

Analogue signals

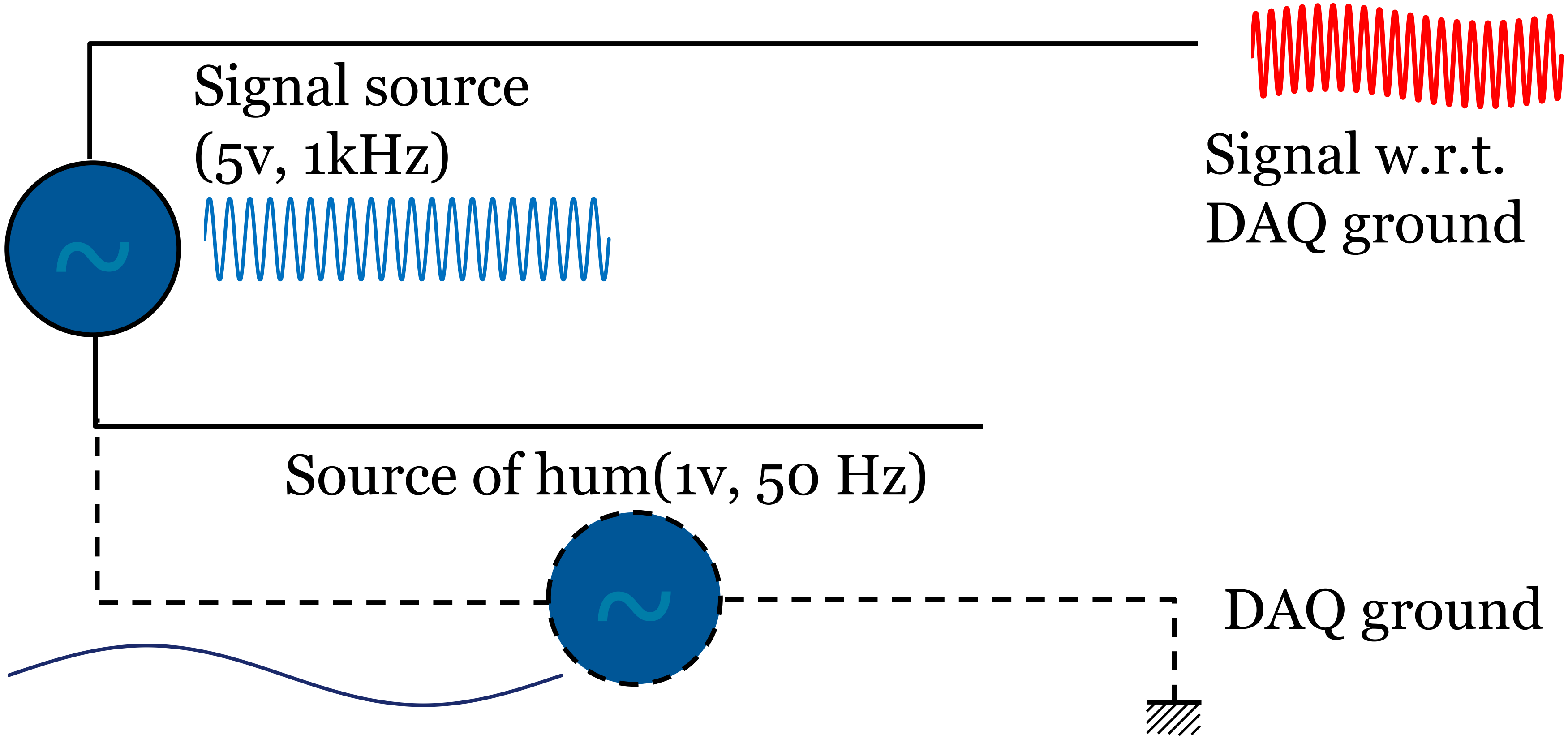
Common mode rejection for single-ended

Common mode rejection for single-ended: Example

Common mode rejection for single-ended

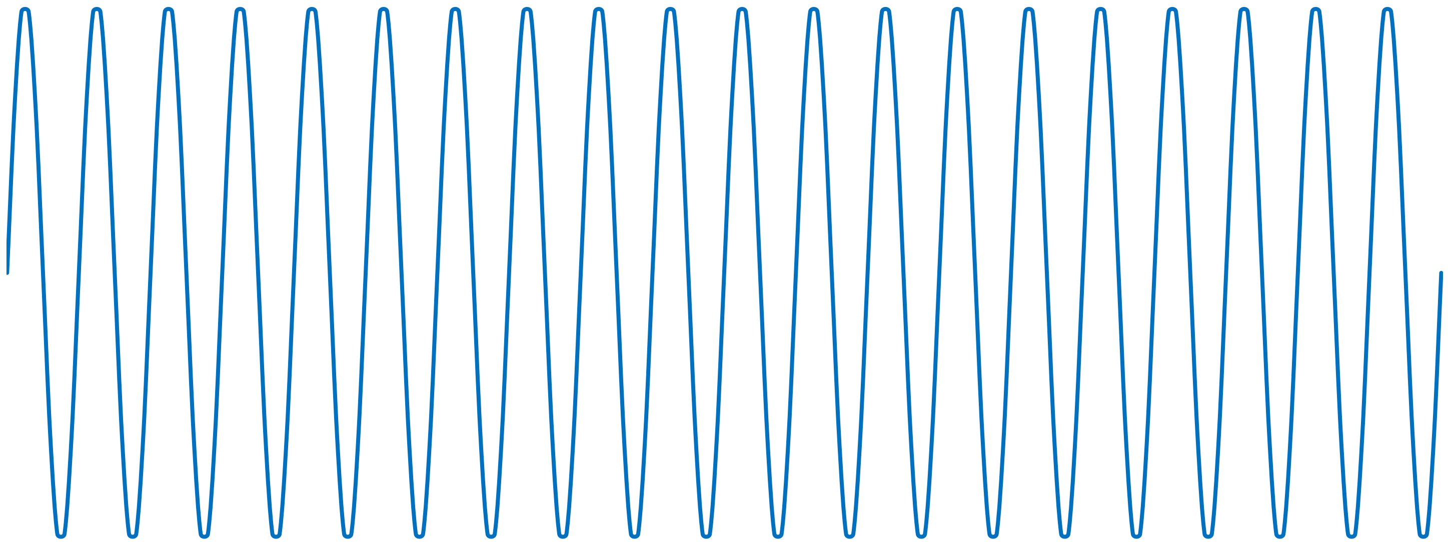
- Example: supposed we have a signal source consisting of a 1 kHz signal
- Nominally it is of amplitude 5v with respect to the signal source's ground (0v rail)
- But source is not properly grounded and its 0v rail fluctuates with 1v, 50 Hz ("huming"), with respect to the measuring system (DAQ) ground
- We want to ignore the hum (reject common mode) and measure only the true signal

Common mode rejection for single-ended: Example

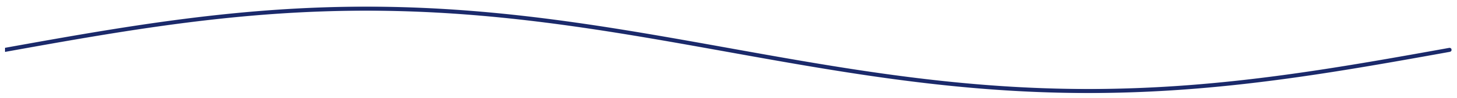


Common mode rejection for single-ended: Example

Signal
wrt source
0v

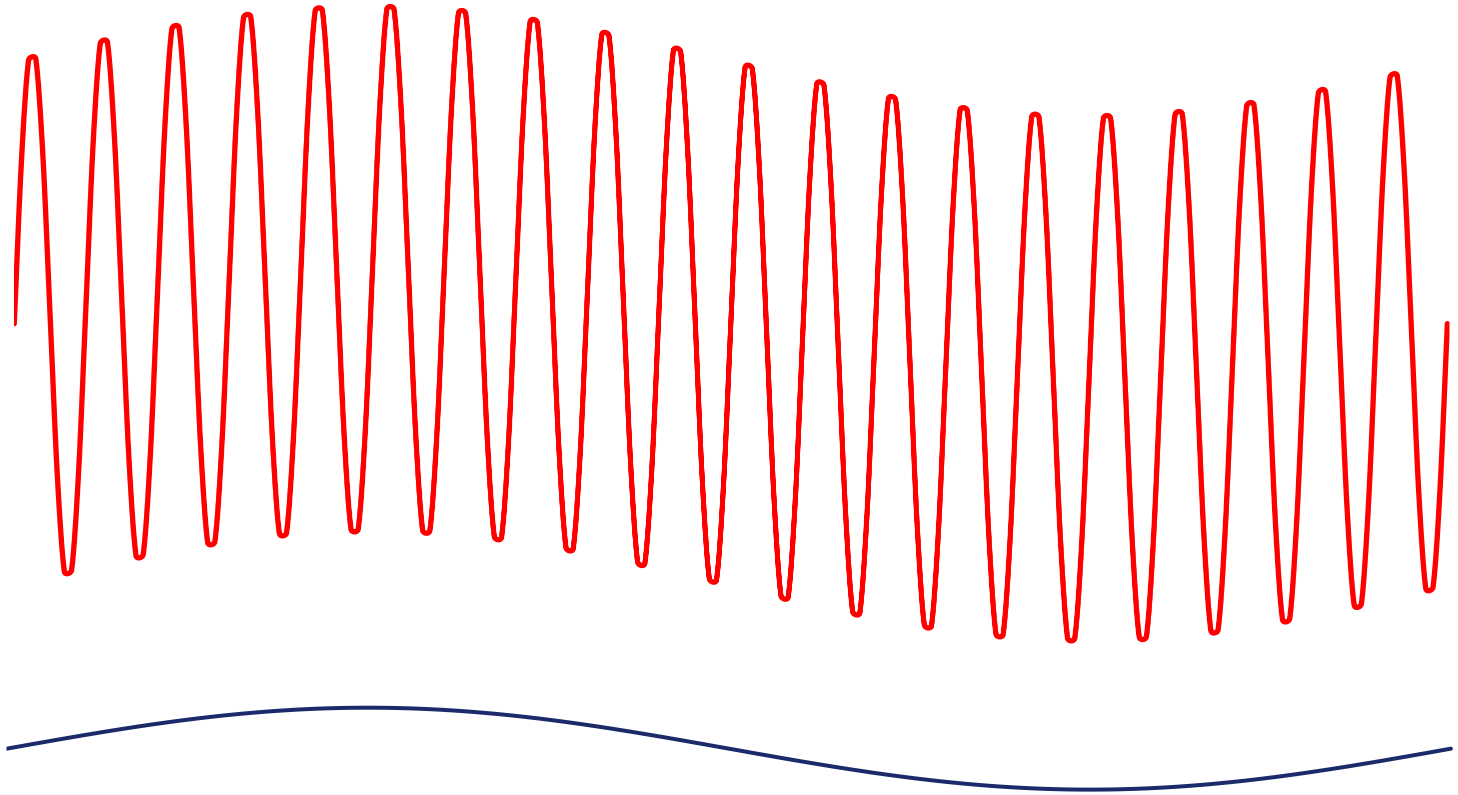


Source 0v
wrt DAQ GND



Common mode rejection for single-ended: Example

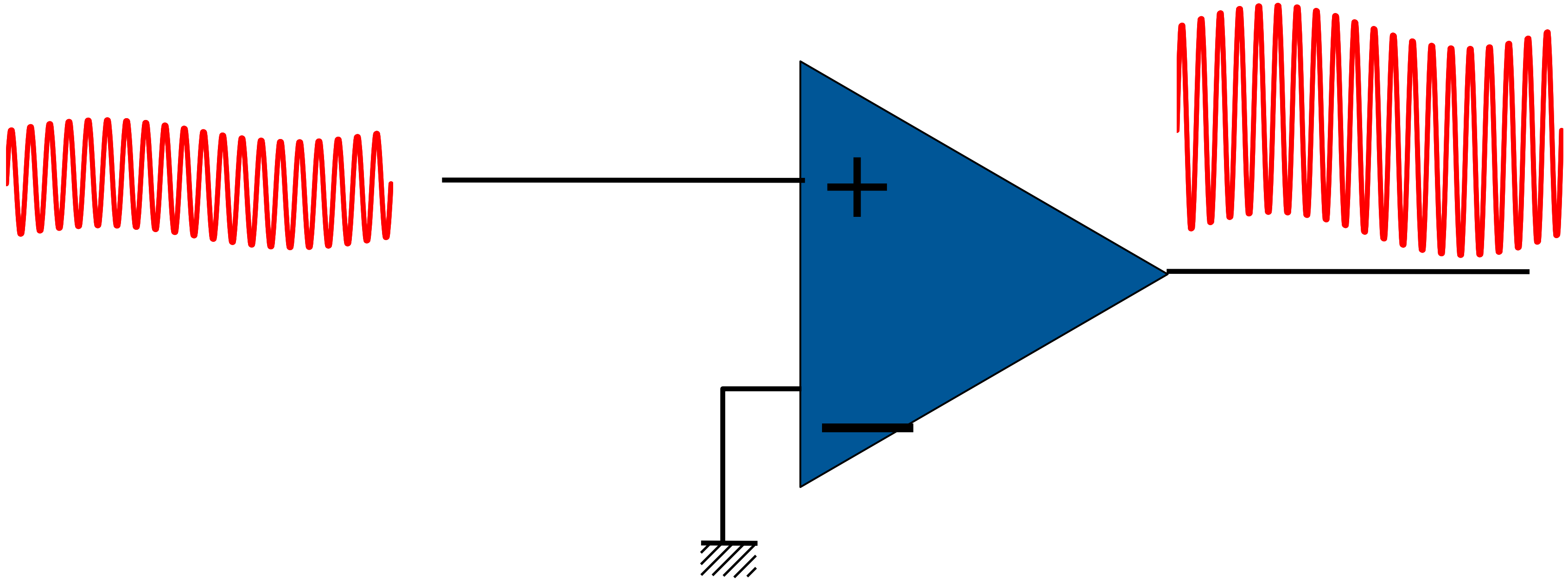
Signal wrt DAQ ground



Source GND wrt DAQ GND

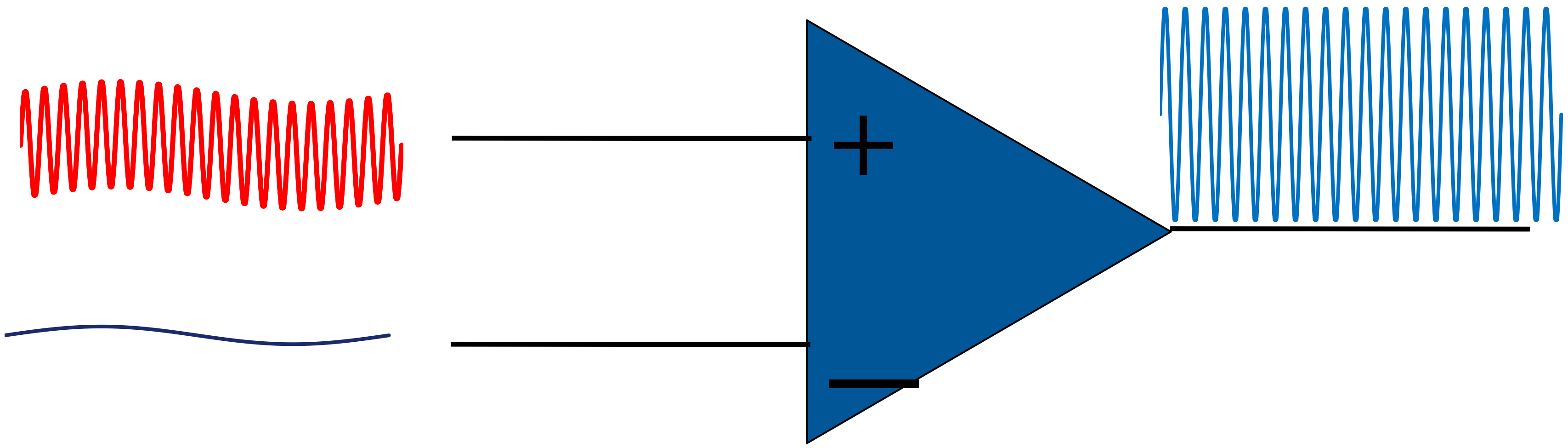
Common mode rejection for single-ended: Example

- Taking the signal directly into a single-ended DAQ system (measuring wrt its own GND) will measure the signal plus the hum

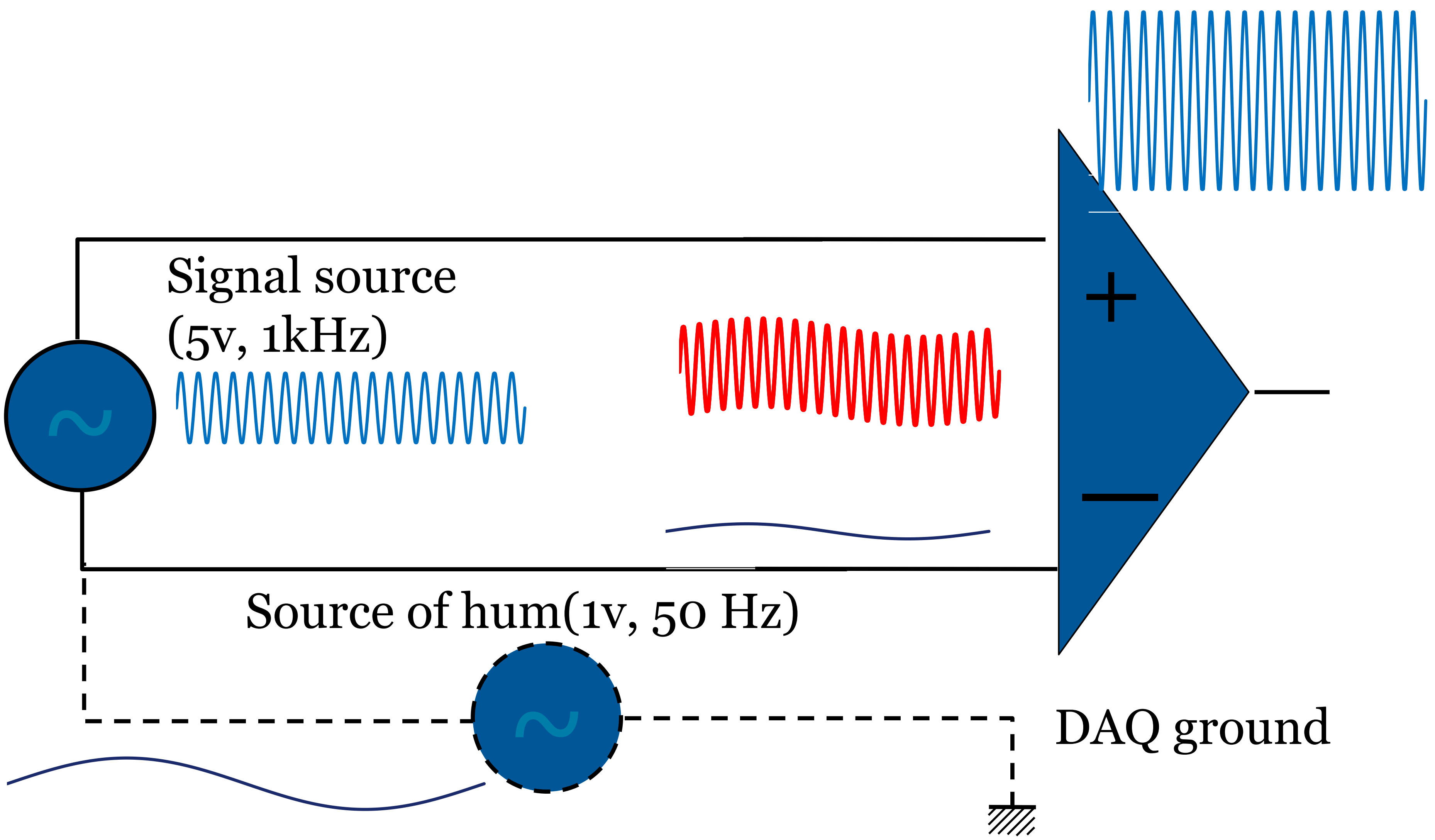


Common mode rejection for single-ended: Example

- Taking the signal and 0v lines from the source into differential inputs will reject the common mode hum and recovers pure signal

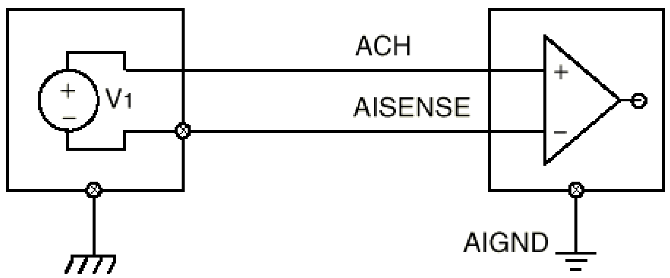


Common mode rejection for single-ended: Example



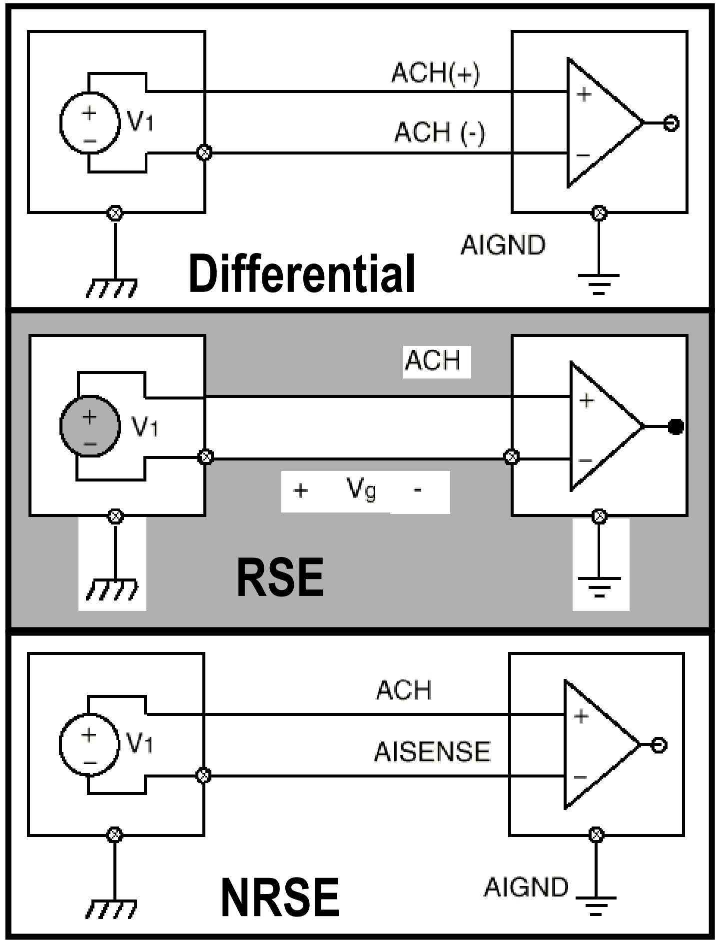
Common mode rejection for single-ended: Problems

- A problem: N channels of input can only be used for $N/2$ differential signals
- A partial solution: can use a single “sensing” input to eliminate changes in potential of remote ground: “non-referenced single ended” input



Common mode rejection for single-ended: Problems

Options for Grounded Signal Sources



Better

\+ Rejects common-mode voltage

– Cuts channel count in half

Not Recommended

– Voltage difference (Vg) between the two grounds makes a ground loop that could damage the device

Good

\+ Allows use of entire channel count

– Does not reject common-mode voltage

Common mode rejection for single-ended: Conclusion

What do we conclude from all this?

- Unless we are sure our signal source is floating (not grounded), or unless the signal source shares an earth with the ADC, best to use differential input
- But differential ADCs tend to be more expensive and/or involve using twice the number of input channels

Digital to Analoge Converter (DAC)

Why DAC/ADC is needed?!

Reminder of **why** we need data conversion…

- Computers are inherently **digital**
- Sometimes input data from sensor are also in digital form

- However we often need to collect data from **analogue** devices within a control loop:
  - Position (e.g. Potentiometer or LVDT)
  - Temperature (from thermocouple)

  Etc.

Data conversion requirement!

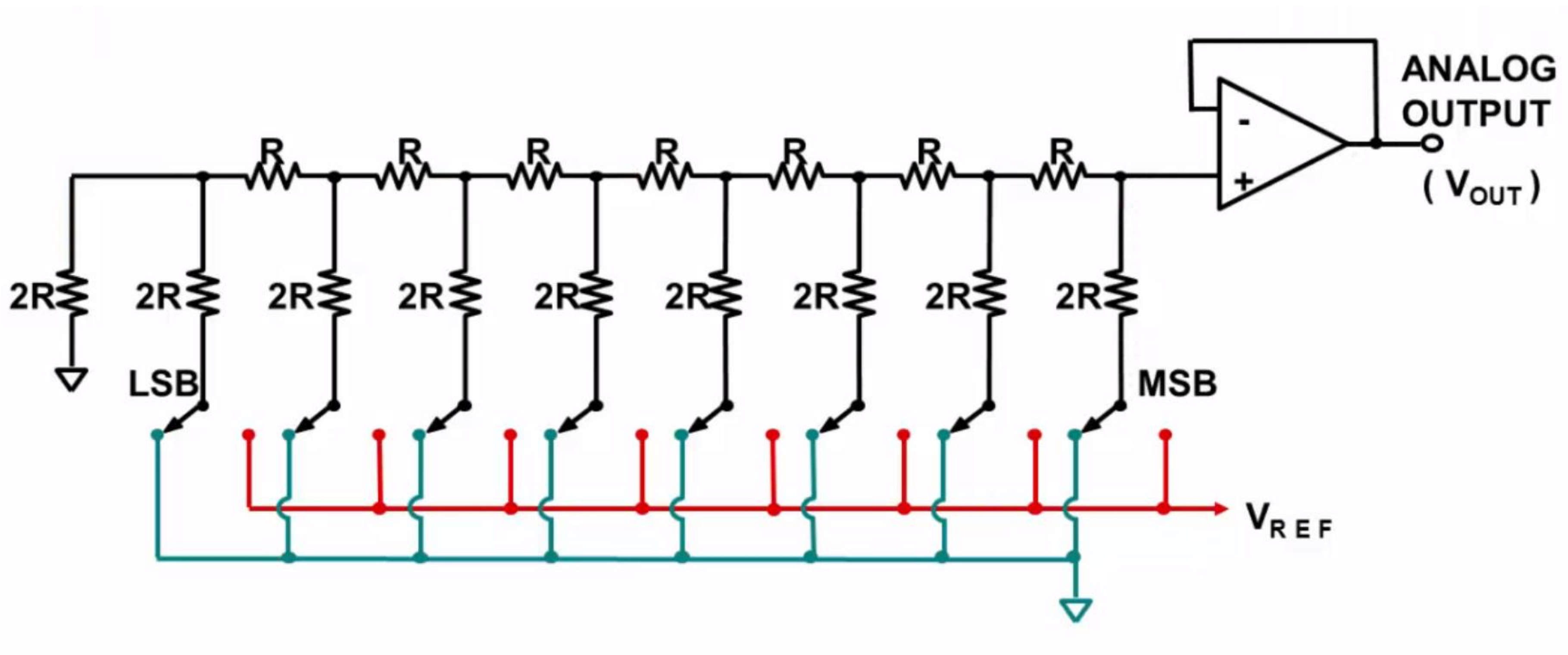
- Need to convert between analogue and digital formats at:
  - The right time (synchronisation)
  - The right rate (conversion rate/frequency)
  - The right accuracy (precision, no. of bits)
- Need to revise and enhance our understanding of:
  - Digital/analogue converters (DACs)
  - Analog/digital converters (ADCs)

Digital-To-Analogue Converters

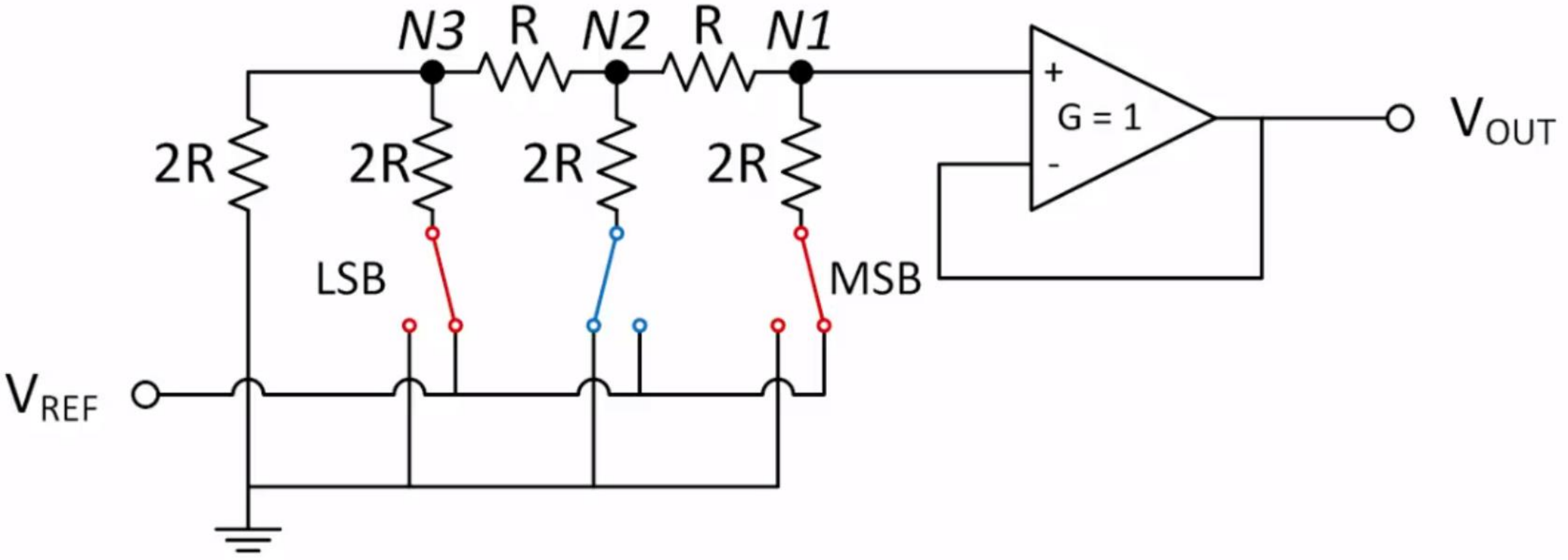
- These take digital data from a parallel data source e.g. an output port, on a number (e.g. 8) of parallel wires, and produces an analogue output proportional to the numerical value of the binary data.

- In the following examples, the data lines may be regarded as operating (solid-state) switches in the DAC circuitry.

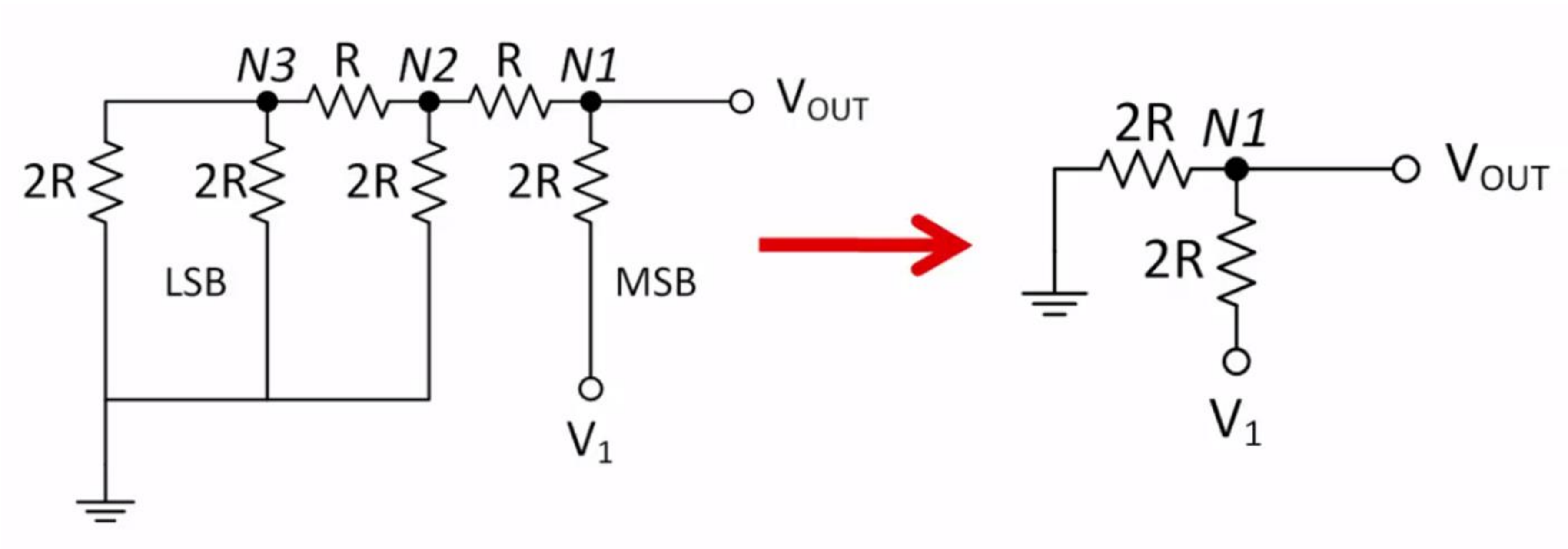
R-2R Ladder DAC



R-2R Ladder DAC: How does it work?!



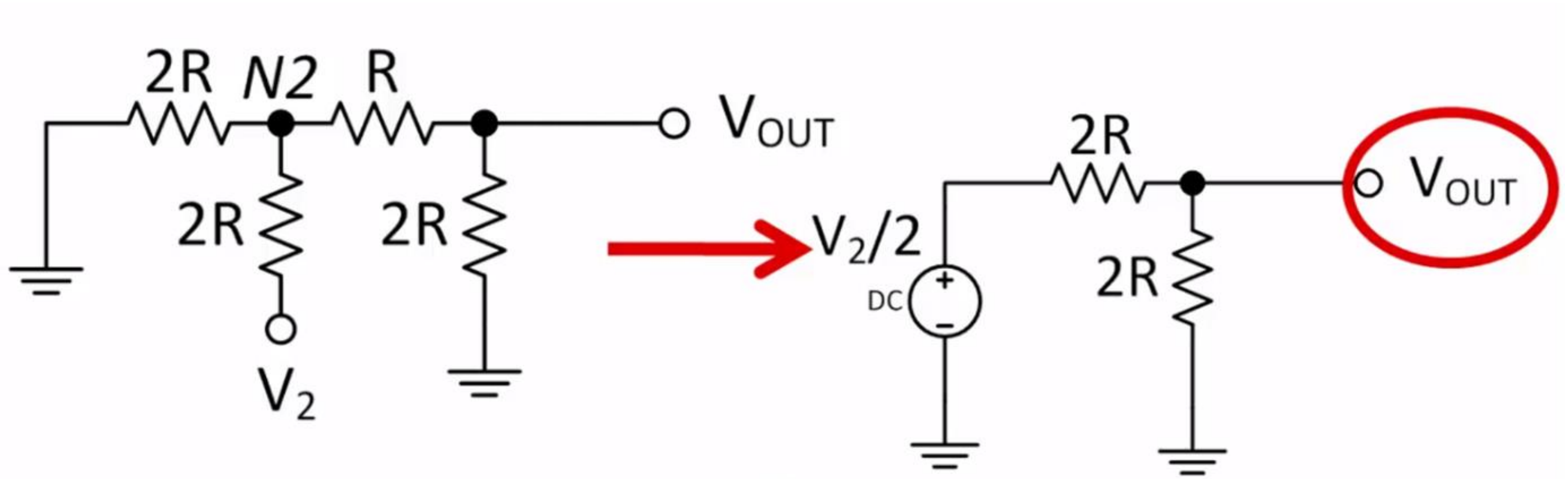
R-2R Ladder DAC: How does it work?!



Superposition method
V1 is on V2 and V3 are off

$$V_{OUT,1} = \frac{V_1}{2}$$

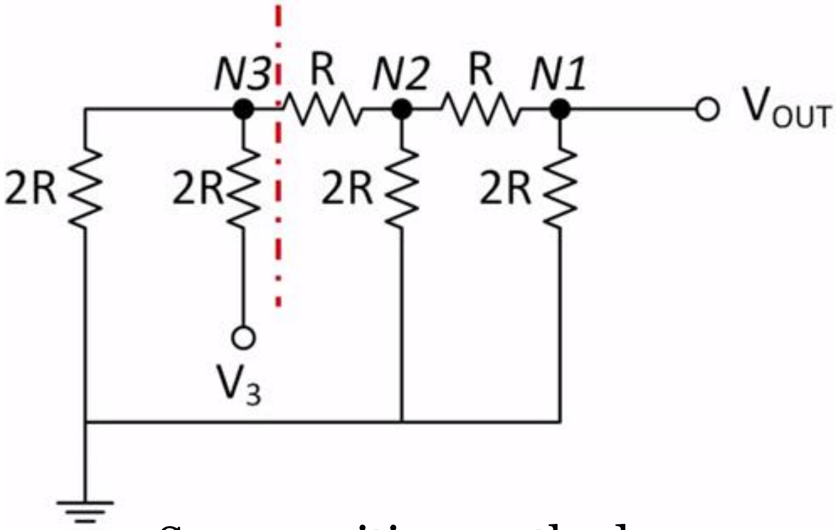
R-2R Ladder DAC

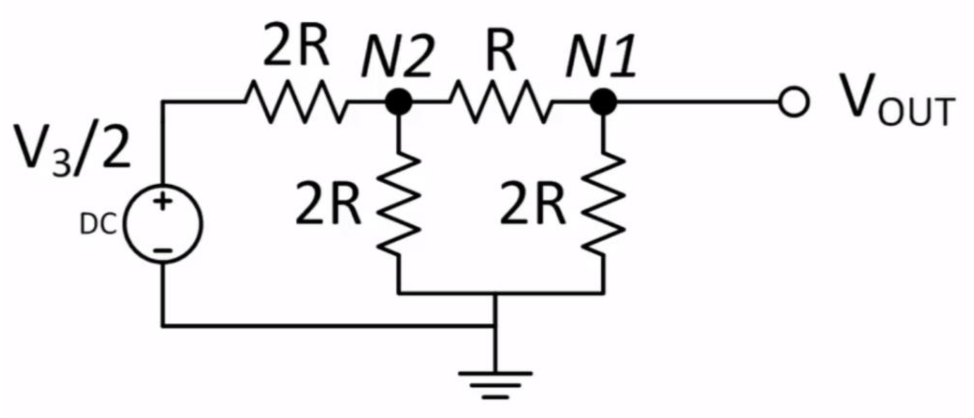


$$V_{OUT,2} = \frac{V_2}{4}$$

Superposition method
V2 is on V1 and V3 are off
+
Thevenin theory

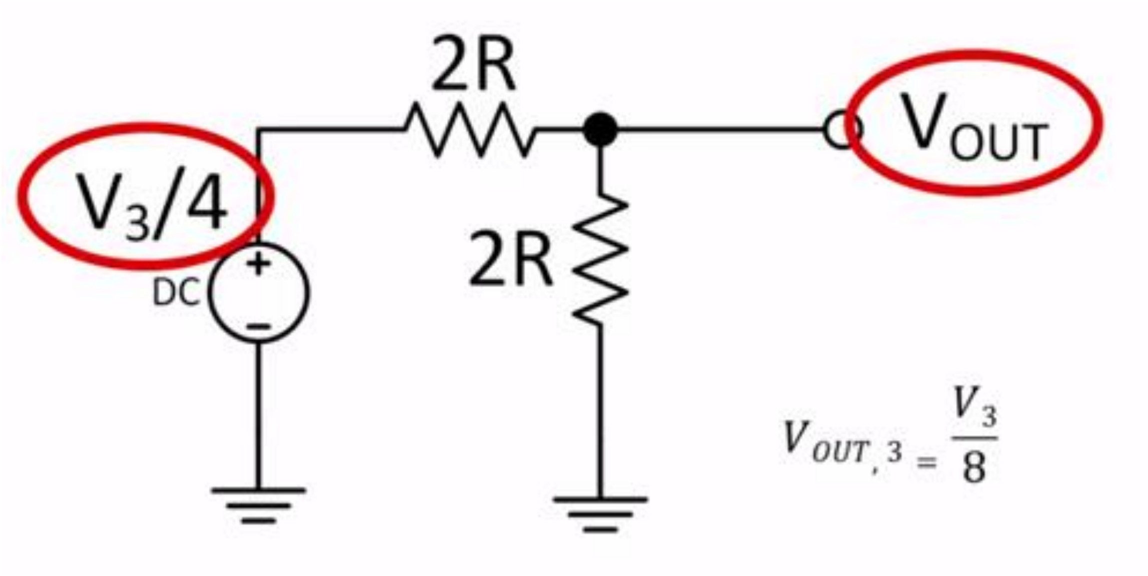
R-2R Ladder DAC





Superposition method
V3 is on V1 and V2 are off
+
Thevenin theory

R-2R Ladder DAC



Superposition method
V3 is on V1 and V2 are off
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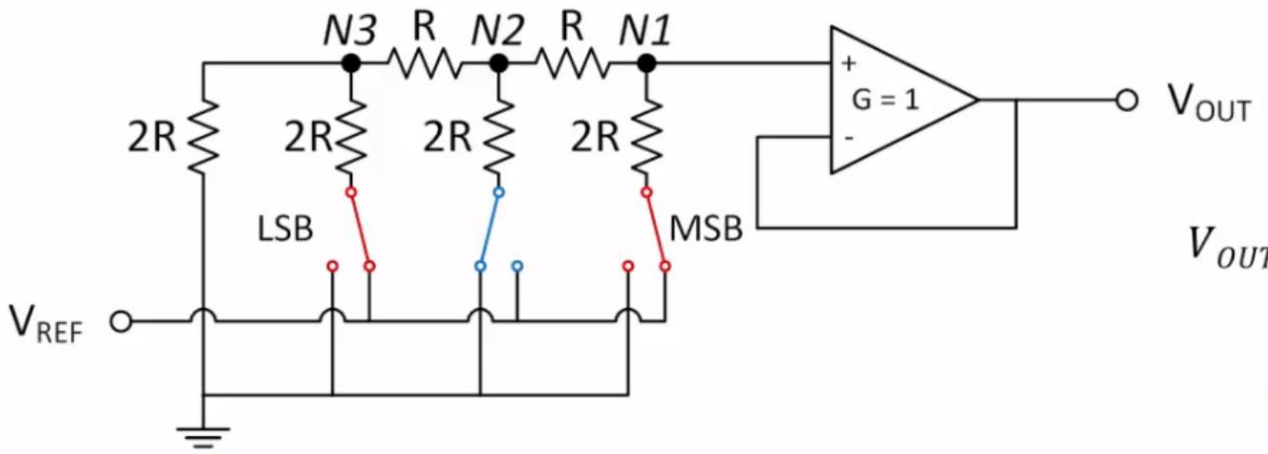
Thevenin theory

R-2R Ladder DAC



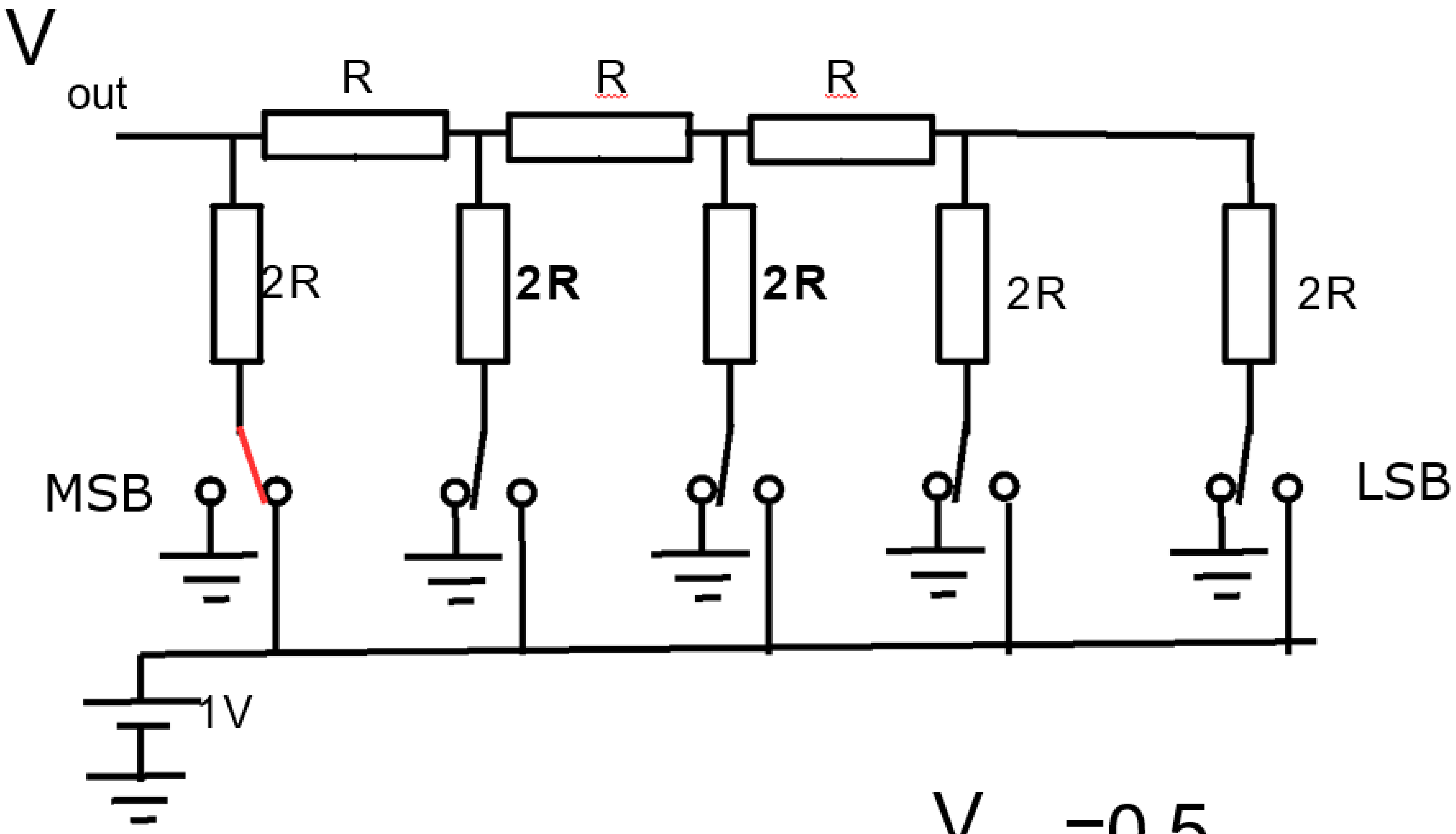
$$V_{OUT} = V_{REF}\left(\frac{1}{2} + \frac{0}{4} + \frac{1}{8}\right)$$

$$V_{OUT} = V_{REF}\left(\frac{5}{8}\right)$$

3-bit ladder: $V_{OUT} = \frac{V_1}{2} + \frac{V_2}{4} + \frac{V_3}{8}$

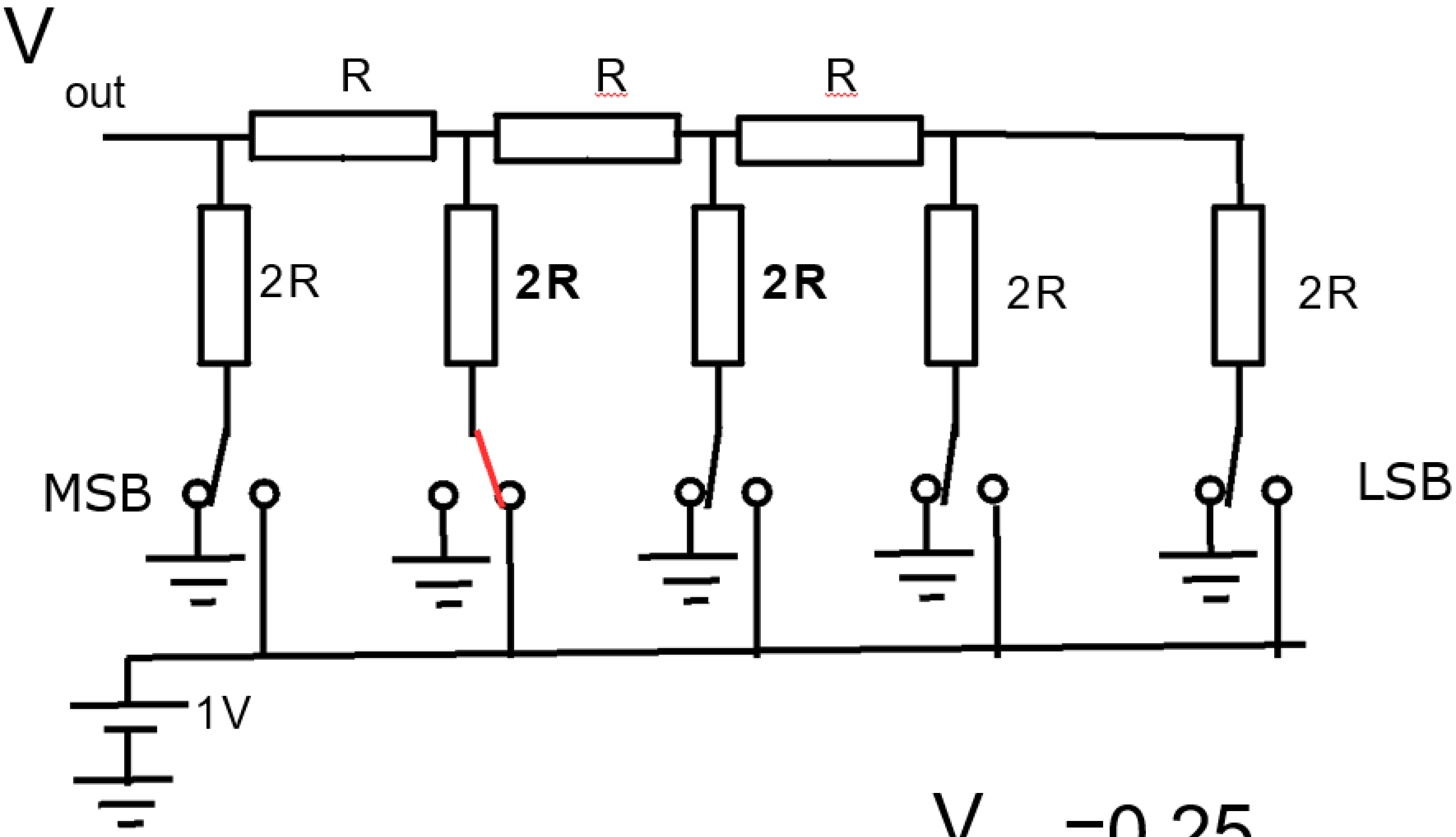
N-bit ladder: $V_{OUT} = V_{REF}\left(\frac{BIT1}{2} + \frac{BIT2}{4} + \cdots + \frac{BITn}{2^n}\right)$

Input 1 representing binary 10000



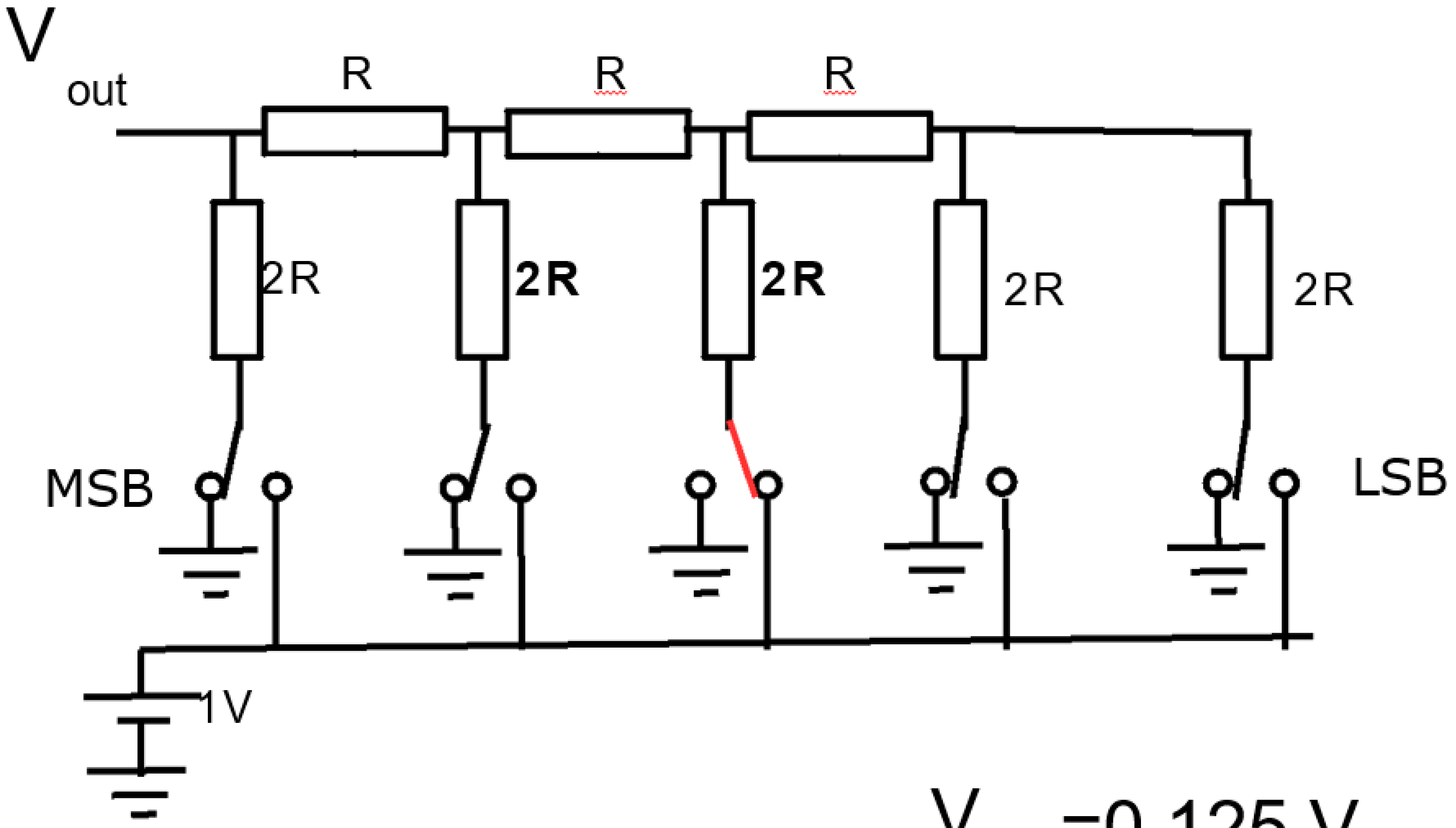
$V_{out} = 0.5$

Input 2 representing binary 01000



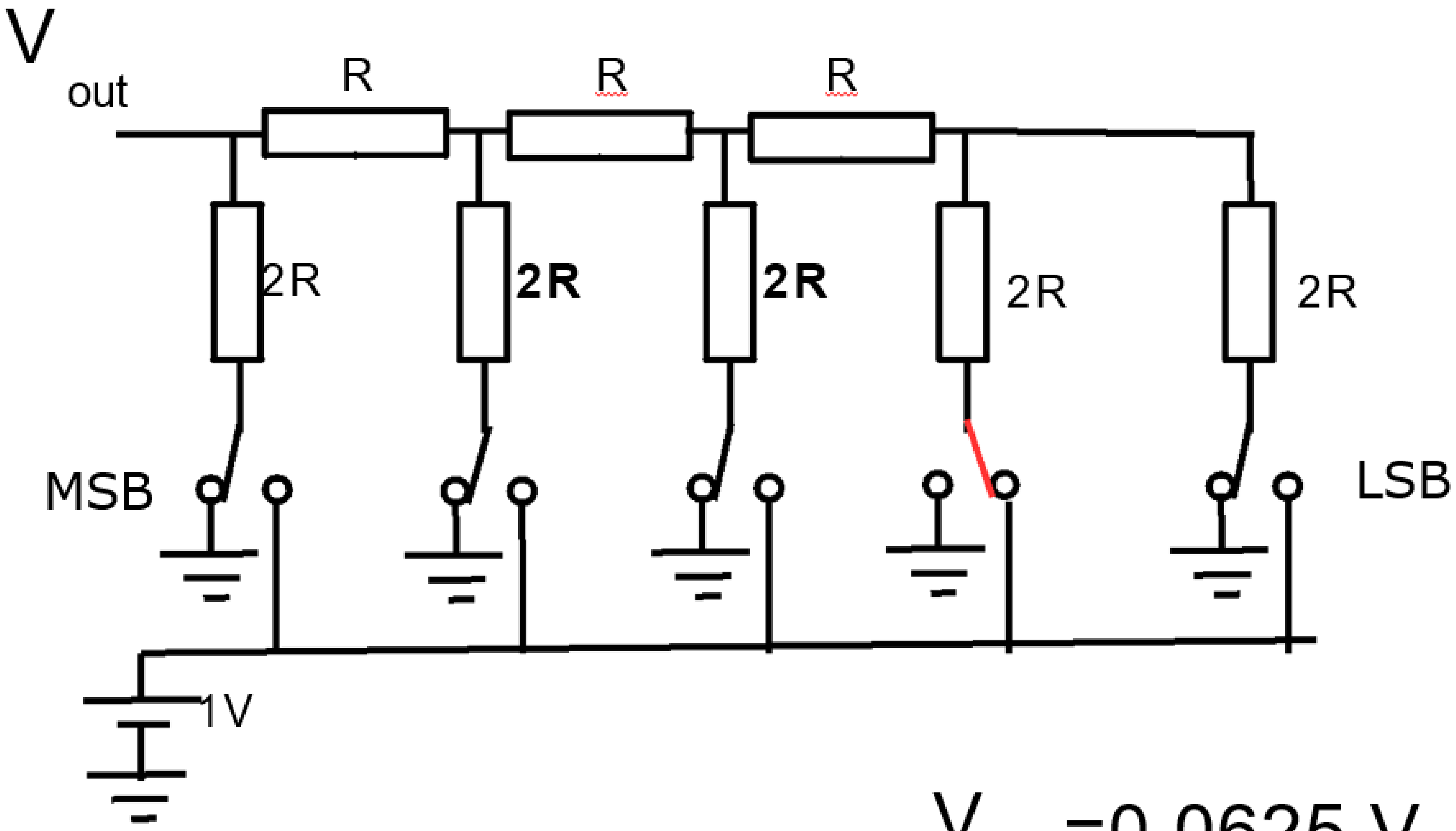
V_{out}=0.25

Input 3 representing binary 00100



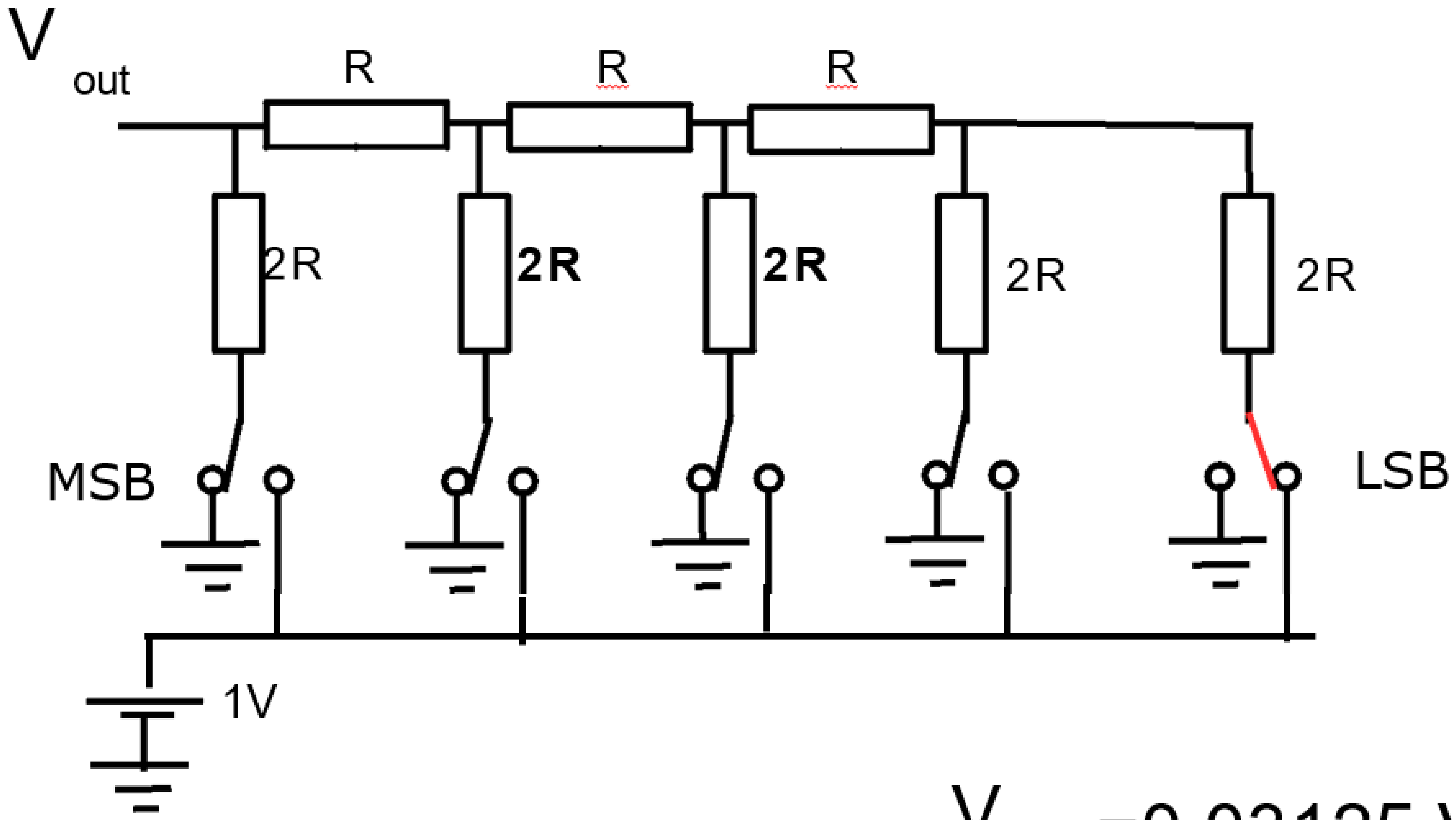
V_{out}=0.125 V

Input 4 representing binary 00010



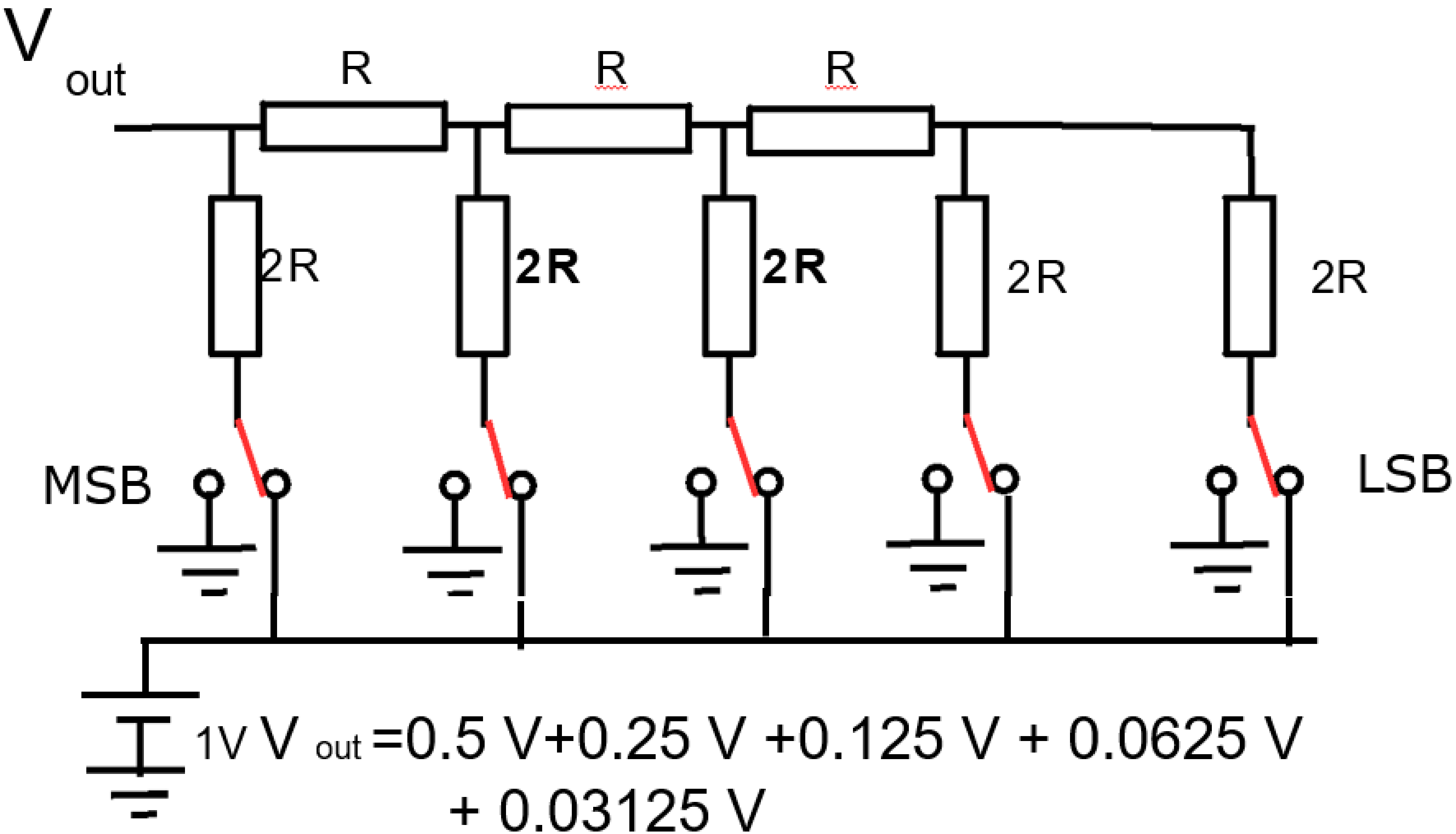
$V_{out} = 0.0625\ V$

Input 5 representing binary 00001



V_{out} =0.03125 V

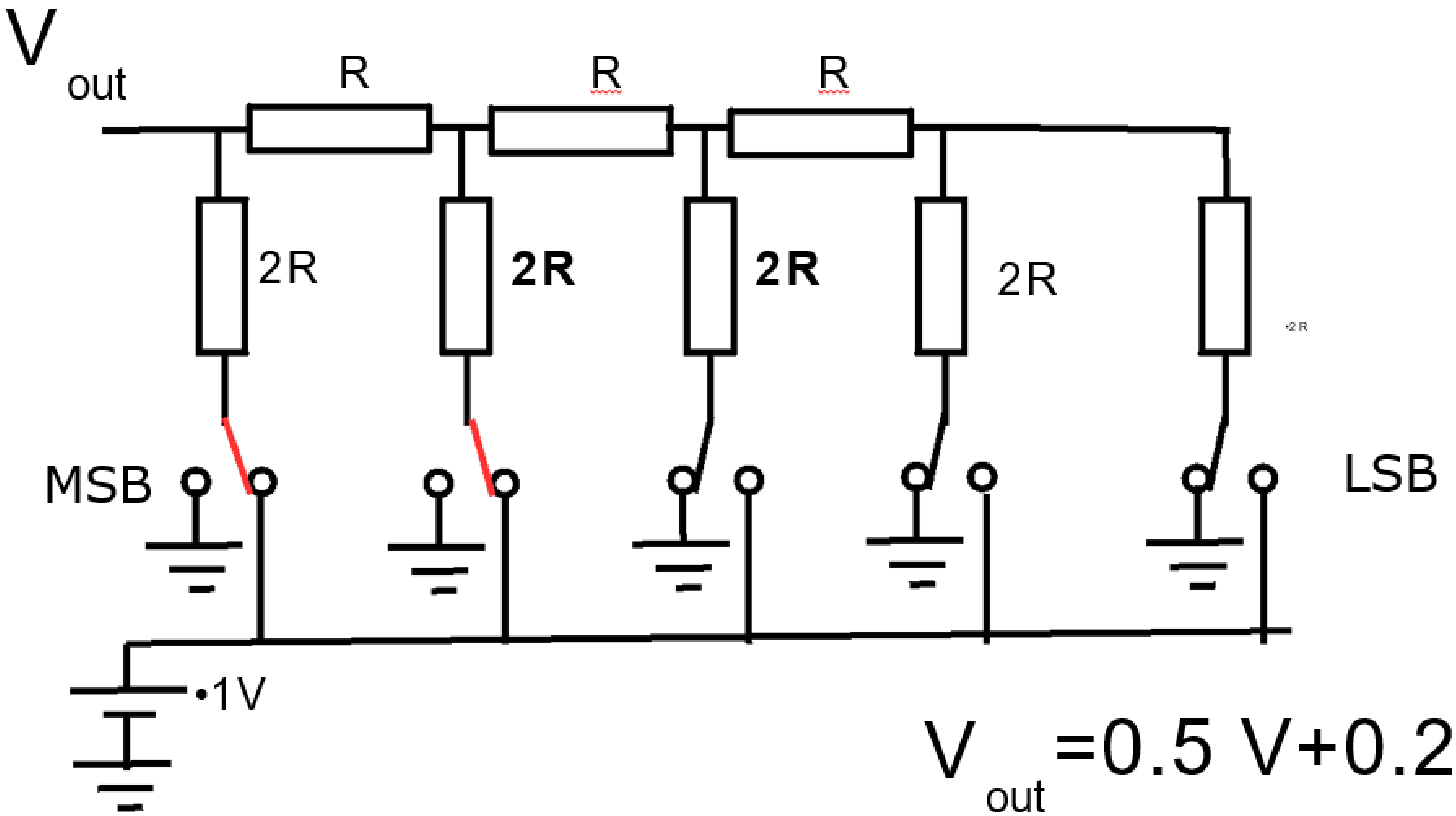
All five inputs represent binary 11111



$$V_{out} = 0.5\ V + 0.25\ V + 0.125\ V + 0.0625\ V + 0.03125\ V$$

$$V_{out} = 1\ V$$

We can turn any combination on (e.g., 11000)



$$V_{out} = 0.5\ V + 0.25\ V$$

$$V_{out} = 0.75\ V$$

Digital to Analoge Converter (DAC)

DAC on Arduino

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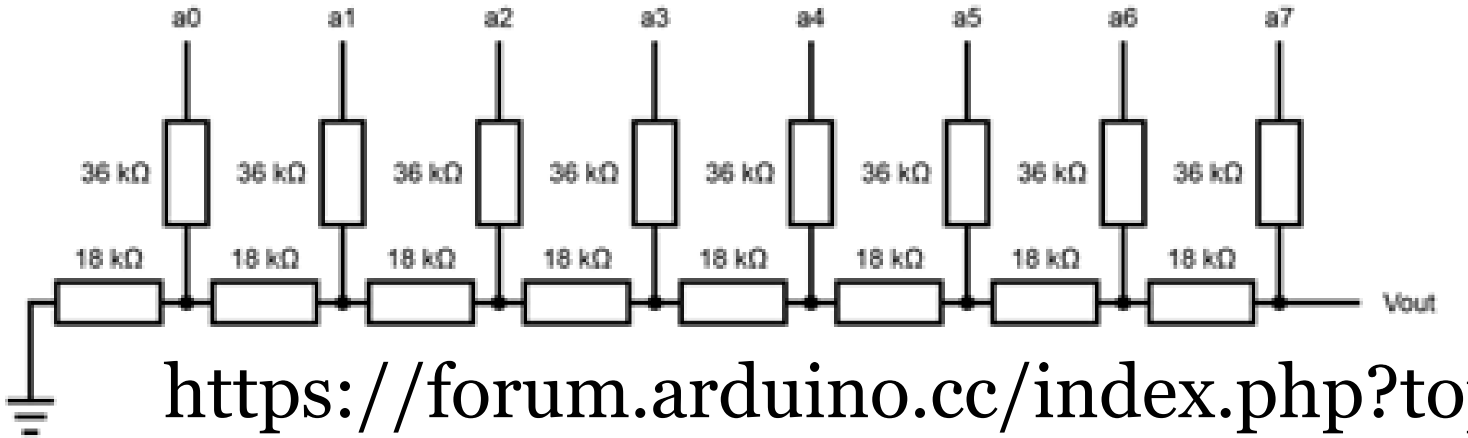
Ladder DAC on the Arduino?

- Surprisingly not accessible on AVR/Arduino!
- Can make own crude and inaccurate version using (say) 8 digital outputs and resistors



https://forum.arduino.cc/index.php?topic=150147.0

- Better: buy a ready-made DAC chip and connect to a digital port

A completely different approach...

- Very often we use a completely different approach to generating an approximation to an analogue signal
- Instead of using a DAC with many levels of output, simply switch rapidly between two levels
- A 1-bit DAC
- For example, **pulse width modulation**

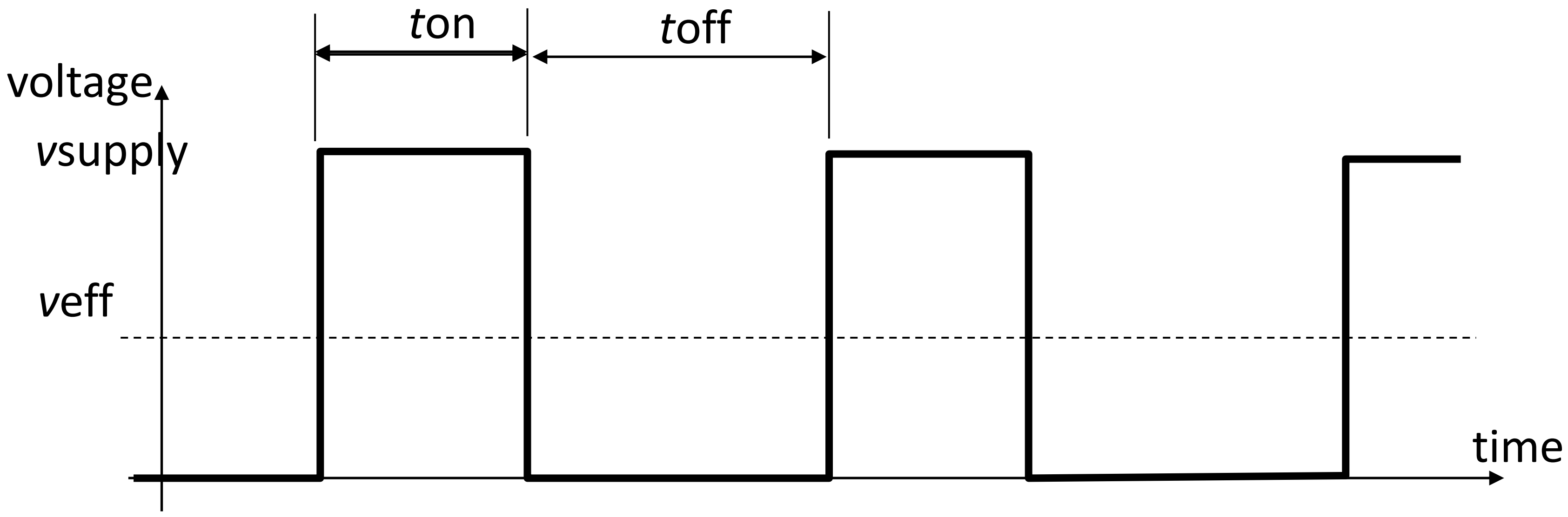
Pulse width modulation

- Train of pulses of constant frequency but varying width
- Vary the “duty cycle” of a pulse train to obtain a varying effective voltage

$$V_{eff} = V_{supply} \frac{t_{on}}{t_{off} + t_{on}}$$

Pulse width modulation

$$v_{eff} = v_{supply} \frac{t_{on}}{t_{off} + t_{on}}$$



Pulse width modulation

- Result is that motor sees a voltage whose value is proportional to the duty cycle
- Widely used in servo motor drives
- Simple and versatile
- Very effective/efficient
- This is the basis of AnalogWrite in Arduino

arduino.org

Analogue-To-Digital Converters

- Converting digital data to analogue quantity is straightforward: just a matter of operating switches in a circuit
- But going the other way needs some “intelligence” and “decision making”
- Typically make use of the D-to-A converters already described by means of a "trial and error" comparison between true signal value and the digital estimate
- Will revisit this in detail next lecture

Signals - conclusions

- Considered differential digital signals and optical isolation
- Analogue signals: grounding issues, differential signals
- Digital to analogue conversion
- Pulse width modulation: a one-bit ADC