FH CAMPUS WIEN
UNIVERSITY OF APPLIED SCIENCES

DIE HOCHSCHULE,
DIE MEHR KANN.

Electronic and Microcontroller

Analog or Digital ?

Analog: continously valued signal with infinite possible values, such as temperature

Digital: discretely valued signal, such as integers encoded in binary

$1{,}609 \cdot 10^{-19}\,C$

Discussion about electric current

$I = Q/t$

$U = 3{,}5\,V$

$= 3{,}5178347$

Pi V

DAC – Transfer Characteristics

- >Binary numbers need to be converted to analog voltage.
- >Example 8-Bit number (0-255) to voltage (0-2,55V)
  1-Bit (LSB) ⇔ 0,01V

$\Delta T = -40°C \ldots +60°C$

$100°C \ldots 200 \times 0{,}5°$

Temp → 8-Bit

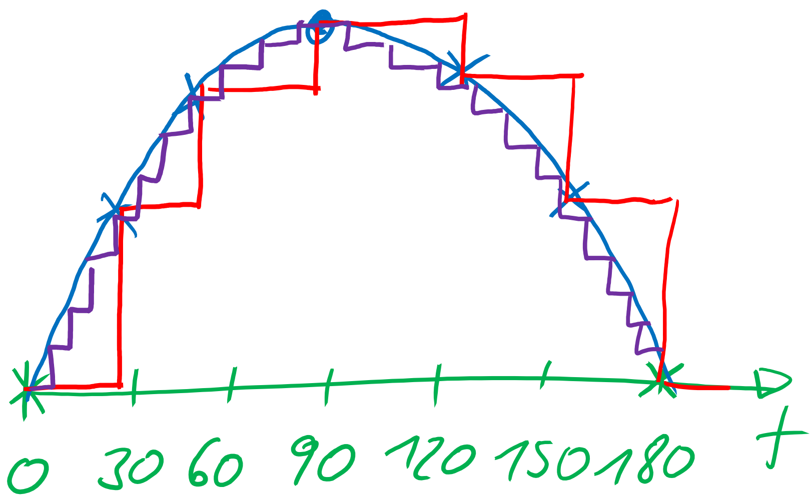
DAC – Time-varying voltage

a) Array -> Werte im Speicher

>Table with values for every timeslice. (1*sin(t))

b) CPU -> Wert berechnen

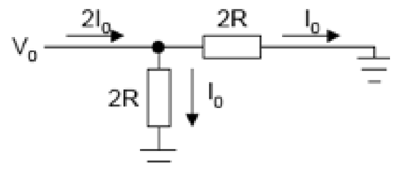
Vout	t
0	0
0,5	30
0,71	45
0,87	60
1	90
0,87	120
0,71	135
0,5	150



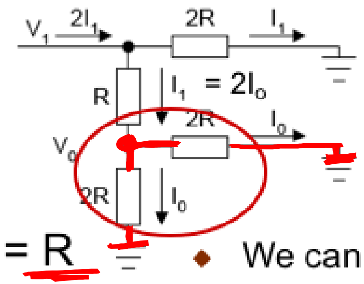
DMA

DAC – R-2R Ladder

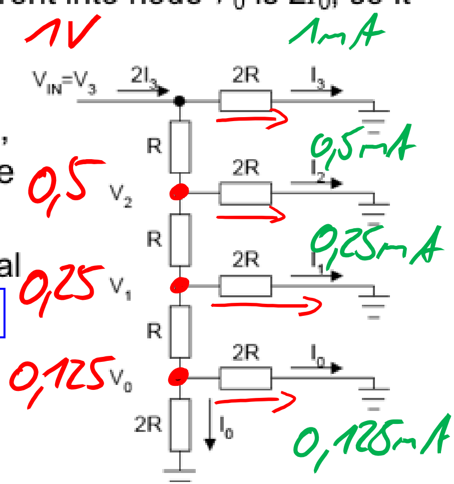
We want to generate currents I_0, $2I_0$, $4I_0$, …



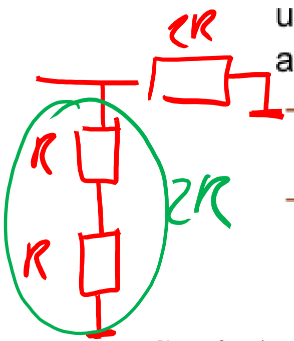
- Two $2R$ resistors in parallel means that the $2I_0$ current will split equally and equivalent resistance R



- The Thévenin resistances of the two branches at V_1 both equal $2R$ so the current into this node will split evenly
  - We already know that the current into node V_0 is $2I_0$, so it follows that I_1=$2I_0$



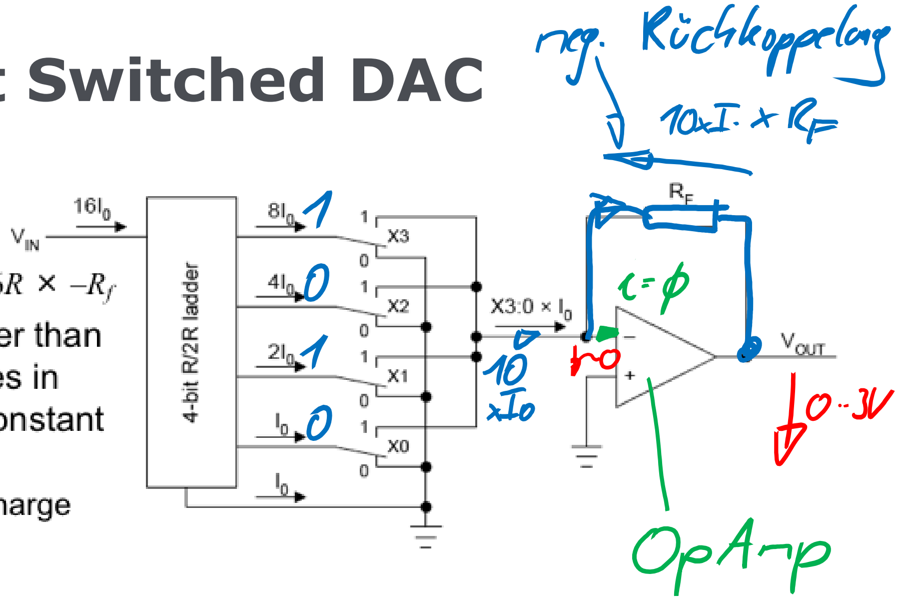
- We can repeat this process indefinitely and, using only two resistor values, can generate a whole series of currents where I_n=$2^n I_0$
  - From the voltage drop across the horizontal resistors, we see that $V_n = 2RI_n = 2^{n+1}RI_0$
  - For an N-bit ladder the input voltage is therefore $V_{in} = 2^N RI_0 \Rightarrow I_0 = 2^{-N} V_{in}/R$



> Picture from http://www.ee.ic.ac.uk/pcheung/teaching/ee2_digital/Lecture%209%20-%20Digital-to-Analogue%20Conversion.pdf

DAC – Current Switched DAC

- Total current into summing junction is $X3{:}0 \times I_0$
  - Hence $V_{out} = X3{:}0 \times V_{in} / 16R \times -R_f$
    - We switch currents rather than voltages so that all nodes in the circuit remain at a constant voltage
      ⇒ no need to charge/discharge node capacitances
      ⇒ faster

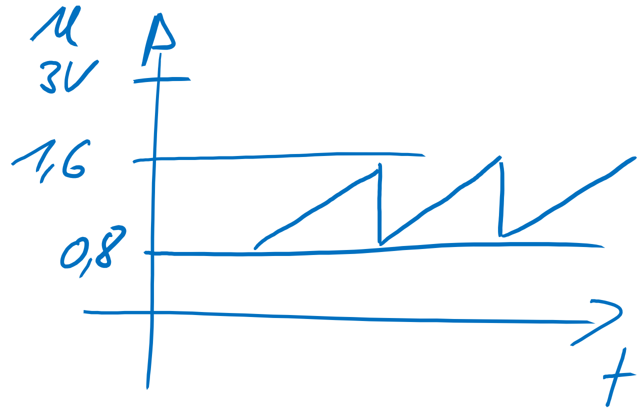


- Use CMOS transmission gates as switches: adjust ladder resistors to account for switch resistance
  - Each 2-way switch needs four transistors
- As required by R/2R ladder, all the switch output terminals are at 0 V.
  - ladder outputs are always connected either to ground or to a virtual earth

> Picture from http://www.ee.ic.ac.uk/pcheung/teaching/ee2_digital/Lecture%209%20-%20Digital-to-Analogue%20Conversion.pdf

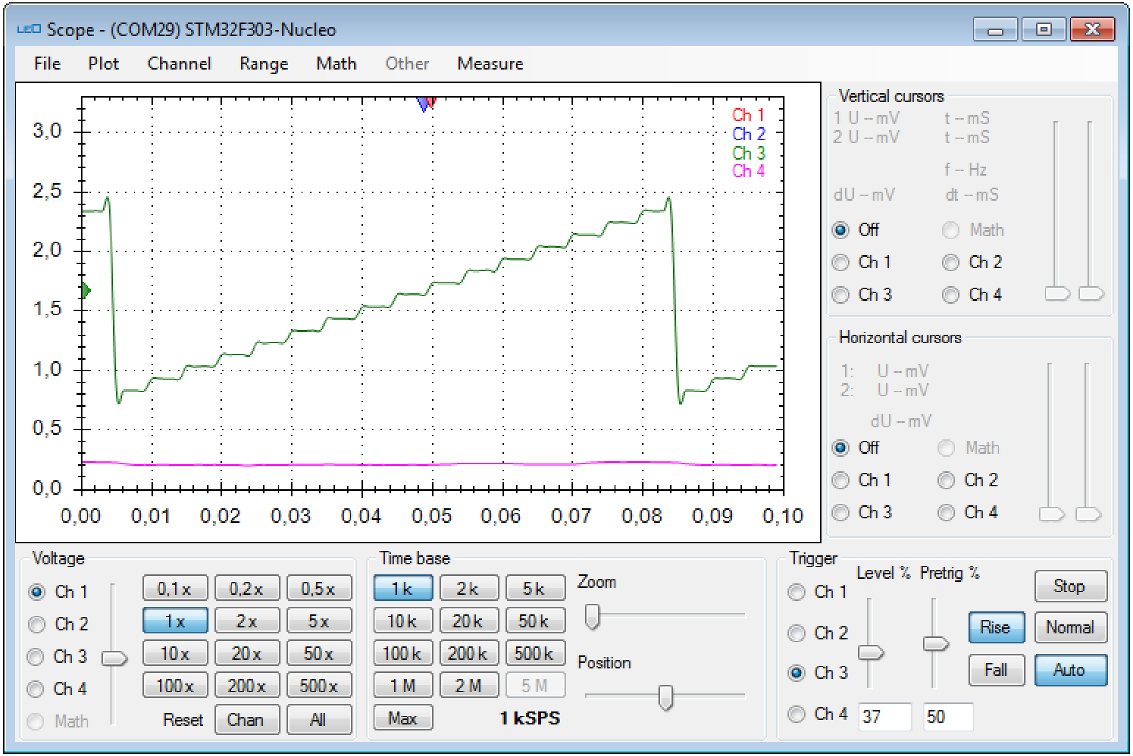
DAC – STM32 - mbed

```
#include "mbed.h"

// The sinewave is created on this pin
AnalogOut aout(PA_4);

int main()
{
    const double amplitude = 1000;
    const double offset = 16000;
    uint16_t sample = 0;

    while(1) {
        // ramp output
        for (int i = 0; i < 16; i++) {
            sample = (uint16_t)(amplitude * i + offset);
            aout.write_u16(sample);
            wait_ms(5);
        }
    }
}
```



DAC – STM32 - LEO

Connect L476-A2 with F303-A3

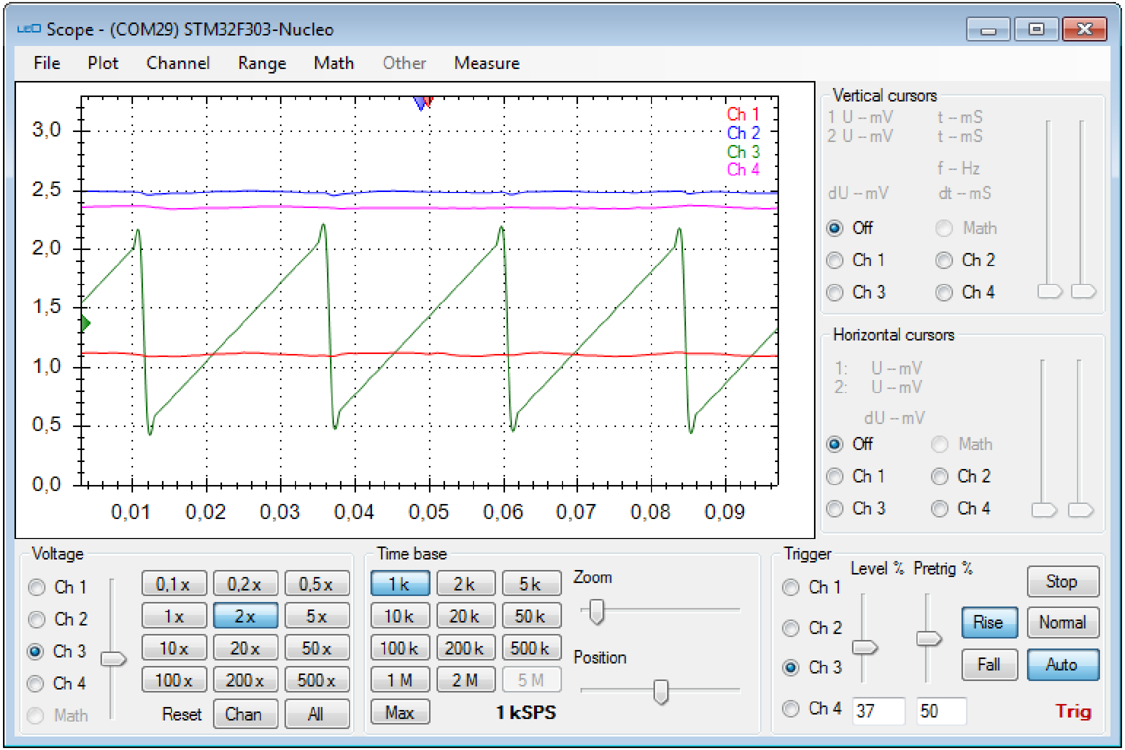


DAC – STM32 - mbed

```
#include "mbed.h"

// The sinewave is created on this pin
AnalogOut aout(PA_4);

int main()
{
    const double amplitude = 10;
    const double offset = 16000;
    uint16_t sample = 0;

    while(1) {
        // ramp output
        for (int i = 1; i < 1600; i++) {
            sample = (uint16_t)(amplitude * i + offset);
            aout.write_u16(sample);
            wait_ms(0.1);
        }
    }
}
```

DAC – STM32 - LEO

Connect L476-A2 with F303-A3

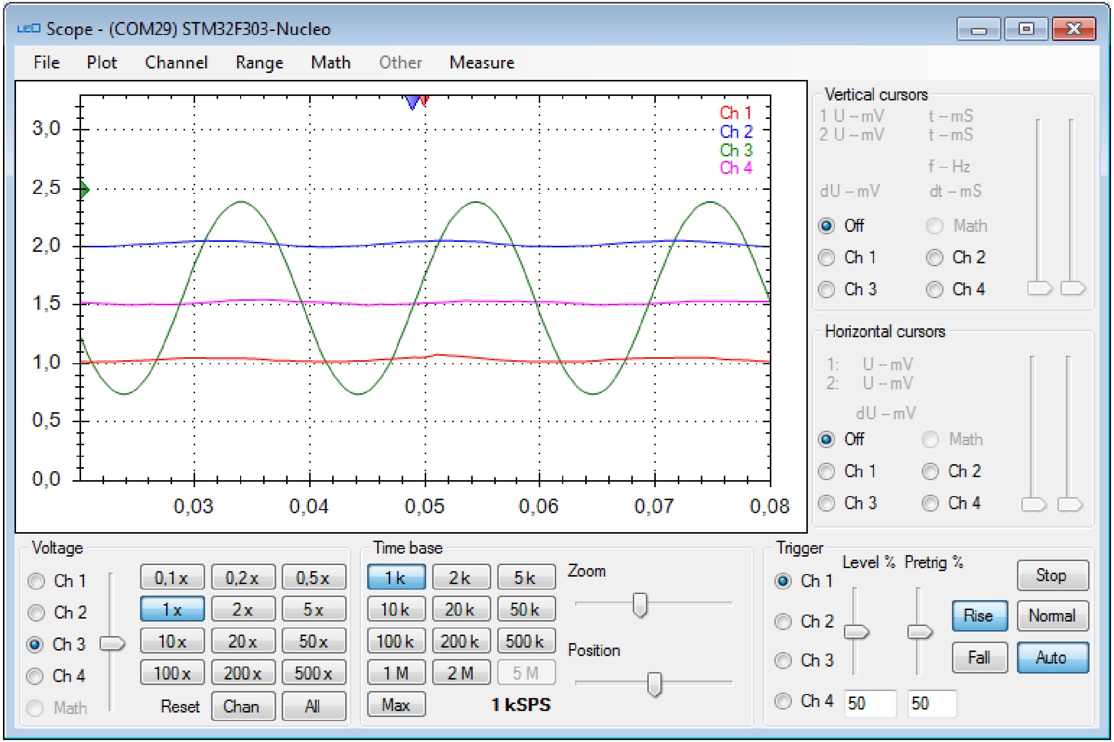


DAC – STM32 - mbed

```
#include "mbed.h"

// The sinewave is created on this pin
AnalogOut aout(PA_4);

int main()
{
    const double pi = 3.141592653589793238462;
    const double amplitude = 0.5f;
    const double offset = 65535/2;
    double rads = 0.0;
    uint16_t sample = 0;

    while(1) {
        // sinewave output
        for (int i = 0; i < 360; i++) {
            rads = (pi * i) / 180.0f;
            sample = (uint16_t)(amplitude * (offset * (cos(rads + pi))) + offset);
            aout.write_u16(sample);
            wait_ms(0.1);
        }
    }
}
```

DAC – STM32 - LEO

Connect L476-A2 with F303-A3



Analog Voltage OUT