Digital-to- Analog conversion (DAC)
MEC100x-Lectures 8

Energy, Power and Intelligent Control

School of Electronics, Electrical Engineering and Computer Science

Ashby Building

Queen’s University Belfast

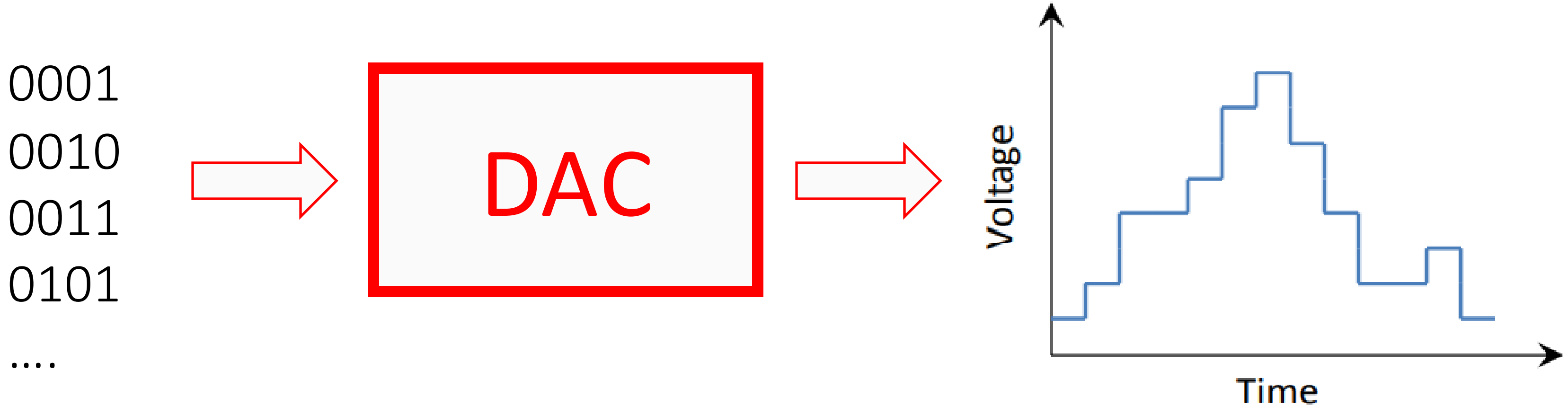
Aims

1. Why DAC?
2. DAC Essentials
3. Converter errors
4. R-2R ladder DAC- weighted resistor DAC- Multiplying DAC
5. I/O typical DAC (DAC0808- DAC0807)

ADC and DAC

Digital-to-Analog Conversion (DAC)

- Converts a Digital values to analog outputs of either Voltage or current
- Current DACs require external OP-AMP to convert back to voltage.



DAC: Digital to Analog Conversion

Analog signals

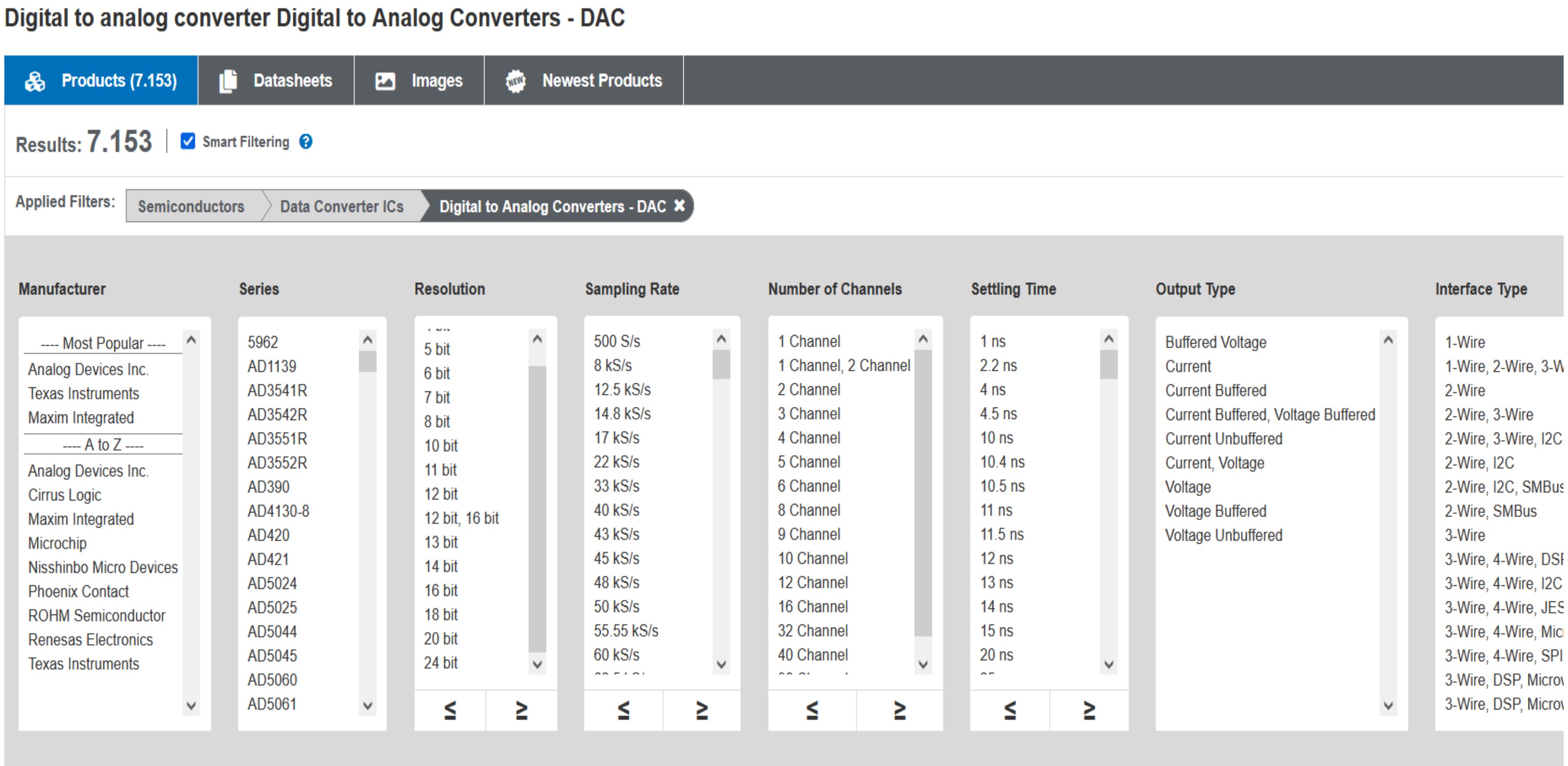
- Digital value is stored in a register (latch), then converted.
- Duration of conversion is called **settling time.**
- Output of the DAC remains the same until the next value is sent to the register- **a zero-order hold.**

$$V_{OUT} = \underbrace{(b_{N-1} \cdot 2^{N-1} + b_{N-2} \cdot 2^{N-2} + \cdots + b_1 \cdot 2^1 + b_0 \cdot 2^0)}_{\text{Integer equivalent of Binary code}} \cdot Q$$

Integer equivalent of Binary code

DAC: Digital to Analog Conversion

Mouser.com website…



https://eu.mouser.com/c/semiconductors/data-converter-ics/digital-to-analog-convertersdac/?q=Digital%20to%20analog%20converter

DAC: Digital to Analog Conversion

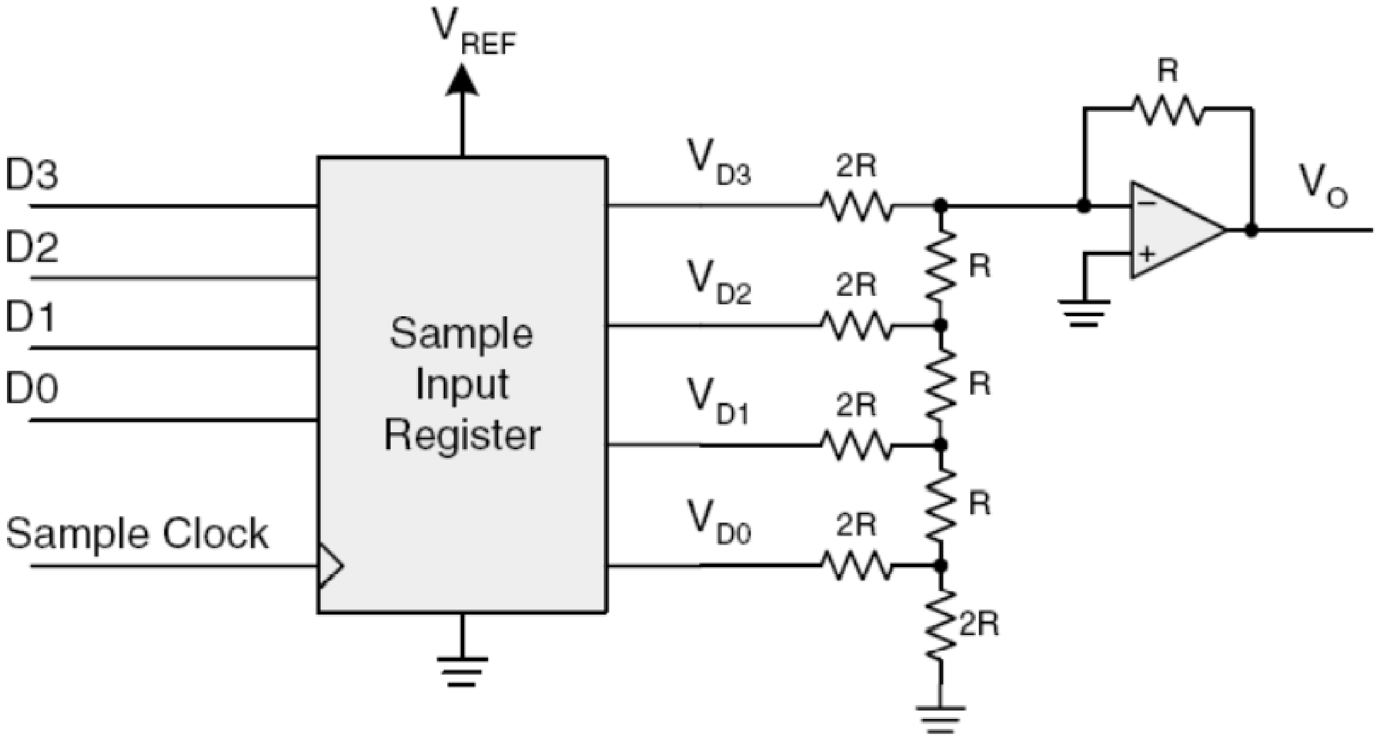
Mouser.com website…

☐		*Mfr. Part No.* MAX538BCSA+ *Mouser Part No* 700-MAX538BCSA	Maxim Integrated	Digital to Analog Converters - DAC +5V, Low-Power, Voltage-Output, Serial 12-Bit DACs	Datasheet	3.226 In Stock Alternative Packaging	**1:** 10,85 € **10:** 9,98 € **20:** 9,56 € **100:** 8,42 € **200:** View	Buy Min.: 1 Mult.: 1	RoHS Details	PCB Symbol, Footprint & 3D Model
☐		*Mfr. Part No.* MAX5223EKA+T *Mouser Part No* 700-MAX5223EKAT	Maxim Integrated	Digital to Analog Converters - DAC Low-Power, Dual, 8-Bit, Voltage-Output Serial DAC in 8-Pin SOT23	Datasheet	1.402 In Stock	**Cut Tape** **1:** 4,54 € **10:** 4,08 € **25:** 3,86 € **100:** 3,34 € **250:** View **Reel** **2.500:** 2,48 € MouseReel Available	Buy Min.: 1 Mult.: 1 **Reel: 2.500**	RoHS Details	PCB Symbol, Footprint & 3D Model
☐		*Mfr. Part No.* DAC43401DSGRQ1 *Mouser Part No*	Texas Instruments	Digital to Analog Converters - DAC Automotive, 8-bit, 1-channel, smart DAC with NVM,	Datasheet	3.692 In Stock 15.000	**Cut Tape** **1:** 1,92 € **10:** 1,73 €	Buy Min.: 1	RoHS Details	PCB Symbol, Footprint & 3D Model

https://eu.mouser.com/c/semiconductors/data-converter-ics/digital-to-analog-converters dac/?q=Digital%20to%20analog%20converter

SMART EDU 4.0

QUEEN'S UNIVERSITY BELFAST

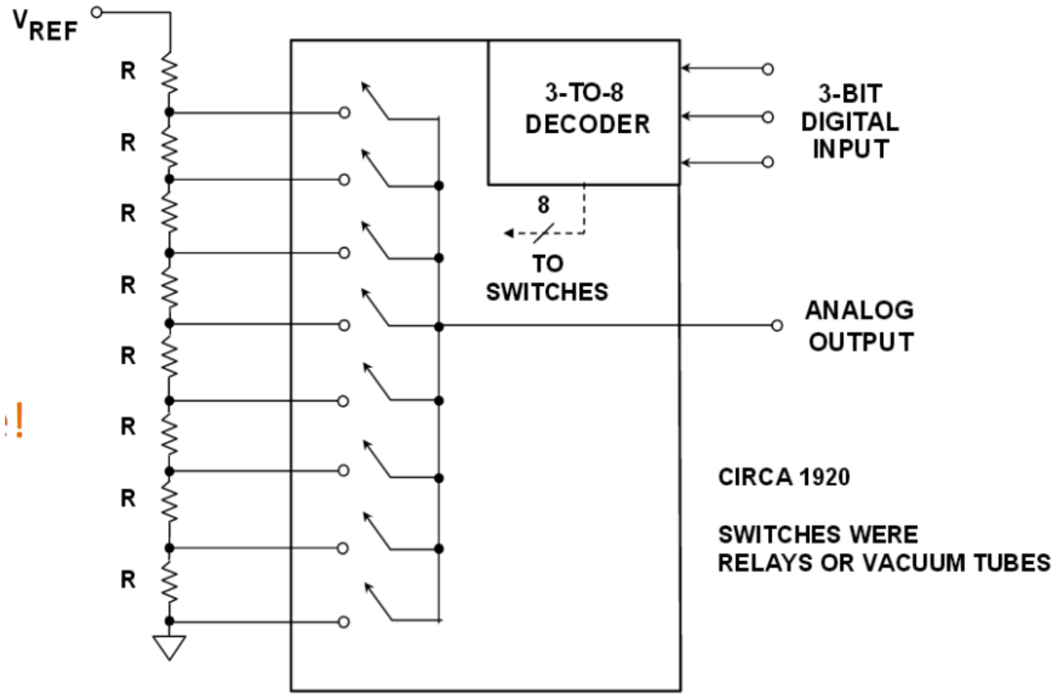


$$V_O = -V_{REF}\left[\frac{D3}{2} + \frac{D2}{4} + \frac{D1}{8} + \frac{D0}{16}\right]$$

DAC: Digital to Analog Conversion

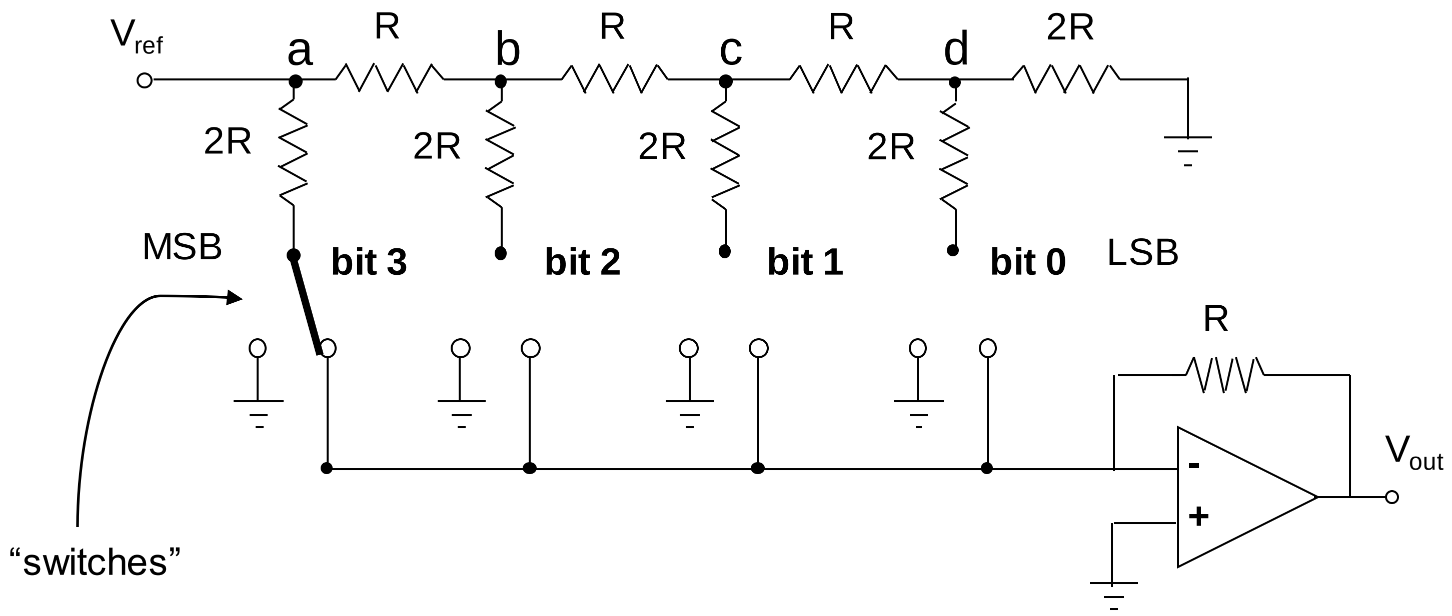
String DAC

Fast, but needs large number of Resistors



Only one switch closed at a time.

R-2R Ladder DAC (4-bit)



What are the voltages at nodes a - d?

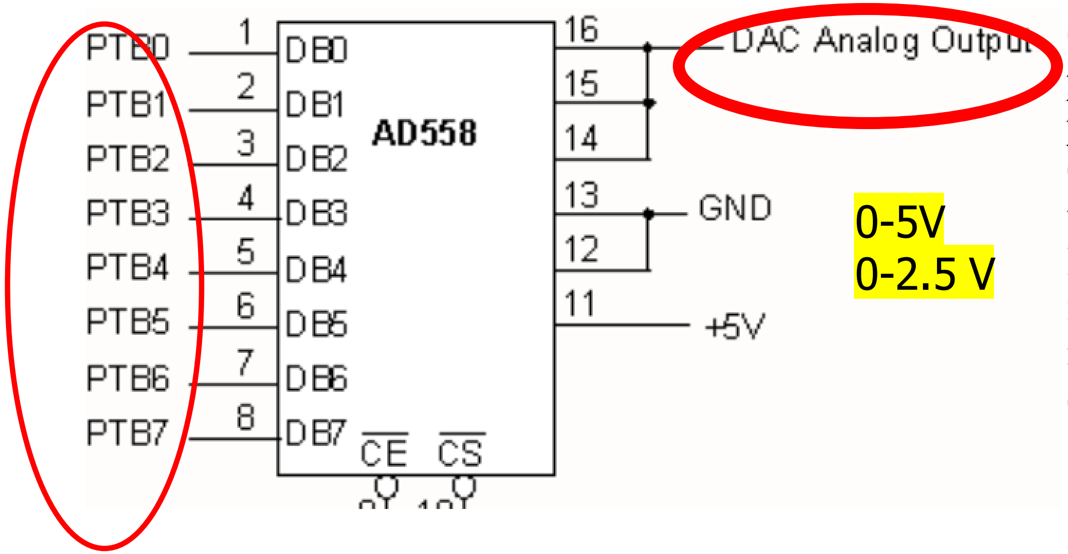
Develop a general expression for V_{out}

$$V_{OUT} = (b_{N-1} \cdot 2^{N-1} + b_{N-2} \cdot 2^{N-2} + \cdots + b_1 \cdot 2^1 + b_0 \cdot 2^0) \cdot \frac{V_{REF}}{2^N}$$

Digital to Analog Converter (DAC)

- R-2R Ladder DAC is widely used
  - It's a programmable summing amplifier
    - The smallest change in voltage (the 'resolution') that can be output by the DAC is determined by the number of bits:
      - Resolution = $V_{ref} / 2^N$, where N is the number of bits
        - Given V_{ref} = 5 V, and a 10-bit DAC, what is the smallest change in voltage that the DAC can output?

Problem 1 - Digital-to-Analog Converter



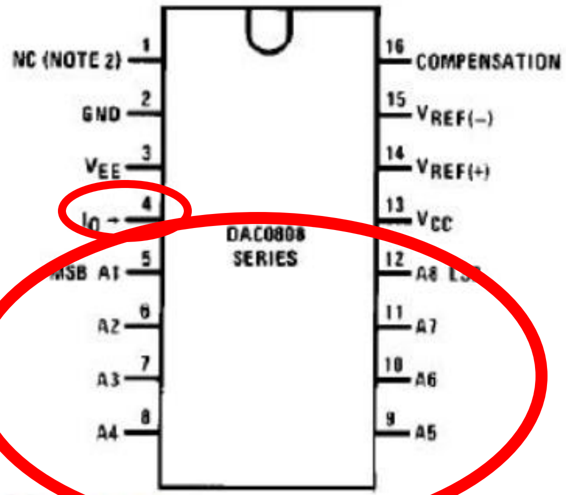
(a) Interface the AD558 8-bit DAC to a parallel port as shown. Write a simple program to exercise the DAC as follows. Generate a saw-tooth ramp by outputting the values from 0 to 255 in a continuous loop. Determine the period and frequency of the output waveform. What information does this reveal about the execution time of your program?

One Channel 0-10V DAC I2C Digital To Analog Converter

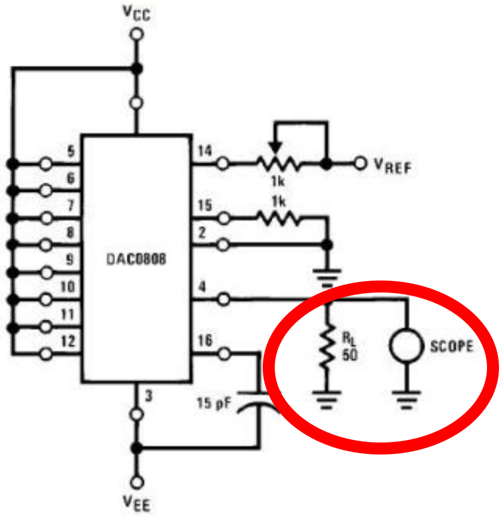
CPU---Micro ====== Analog ==== command Analog actuator– motor driver/ servo motor driver– proportional valve --- induction motor diver ,....

مشخصات آی سی DAC0808:

Dual-In-Line Package



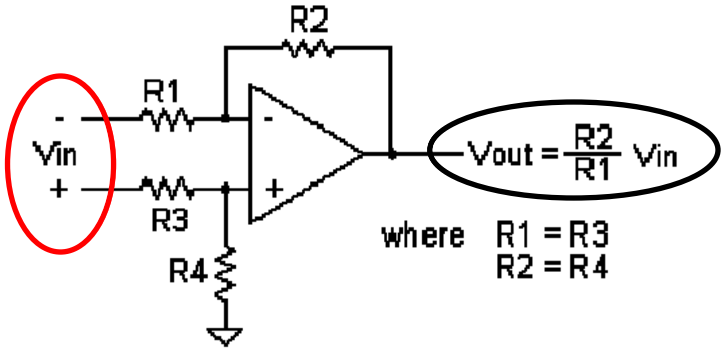
Test Circuits (Continued)



Features

- Relative accuracy: ±0.19% error maximum (DAC0808)
- Full scale current match: ±1 LSB typ
- 7 and 6-bit accuracy available (DAC0807, DAC0806)
- Fast settling time: 150 ns typ
- Noninverting digital inputs are TTL and CMOS compatible
- High speed multiplying input slew rate: 8 mA/μs
- Power supply voltage range: ±4.5V to ±18V
- Low power consumption: 33 mW @ ±5V

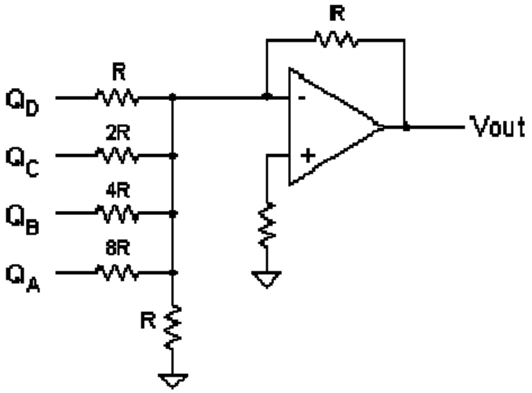
Differential Amplifier



This is the basic circuit from which all others can be derived. All op-amps are designed to amplify the voltage difference between the **non-inverting** (+) and **inverting** (-) **inputs** while ignoring any **common-mode** signal that may be common to both. The ability to reject the common signal while amplifying the differential input is called the **common-mode rejection ratio** (CMRR).

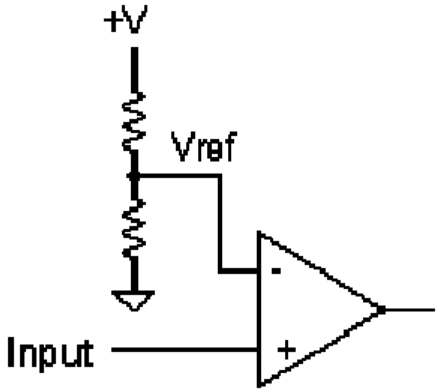
Lots of negative feed-back is used to control the voltage gain of the amplifier.

Summing Amplifier



Recall the simple DAC circuit in Chapter 7, Problem 8. By adding an op-amp to the circuit any loading effect on the resistor network is virtually eliminated.

Voltage Comparator



An analog or voltage comparator compares two input voltages and determines which is higher or lower. Since the voltage gain is infinite the output voltage could have only one of two values, equal to the negative or positive supply rail. Thus an input signal with a continuous analog range is converted to a digital signal. This is a 1-bit ADC.

Sampling Theorem

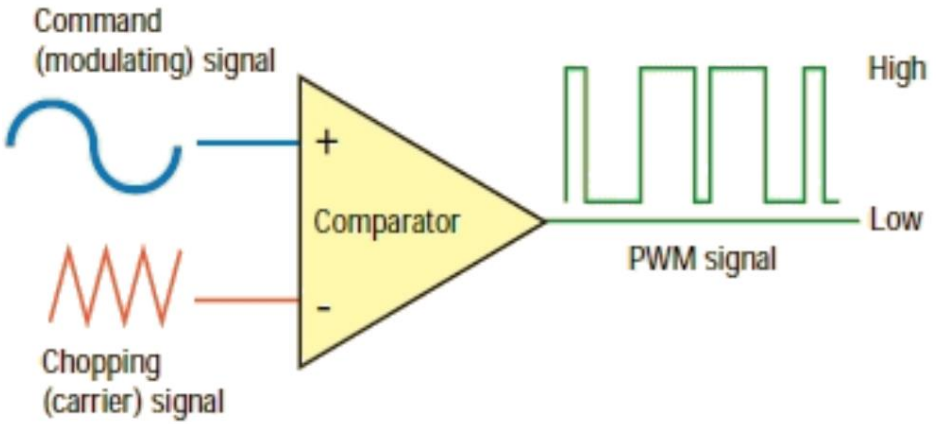
When an analog waveform is sampled, the voltage signal which is continuous in both amplitude and time is digitized. This digitization process results in quantization effects in both domains which lead to important consequences. In the amplitude domain, the resolution is determined by the number of bits of the ADC. Thus an 8-bit ADC can digitize the input signal into 255 voltage steps, equivalent to a precision of 0.4%. The following table shows the effects of various number of ADC bits.

No. of ADC bits	No. of Steps	Precision
8	255	0.4 %
10	1023	0.01 %
12	4095	0.02 %
14	16383	0.006 %
16	65535	0.0015 %

DAC: Digital to Analog Conversion

❑PWM (Pulse Width Modulation)

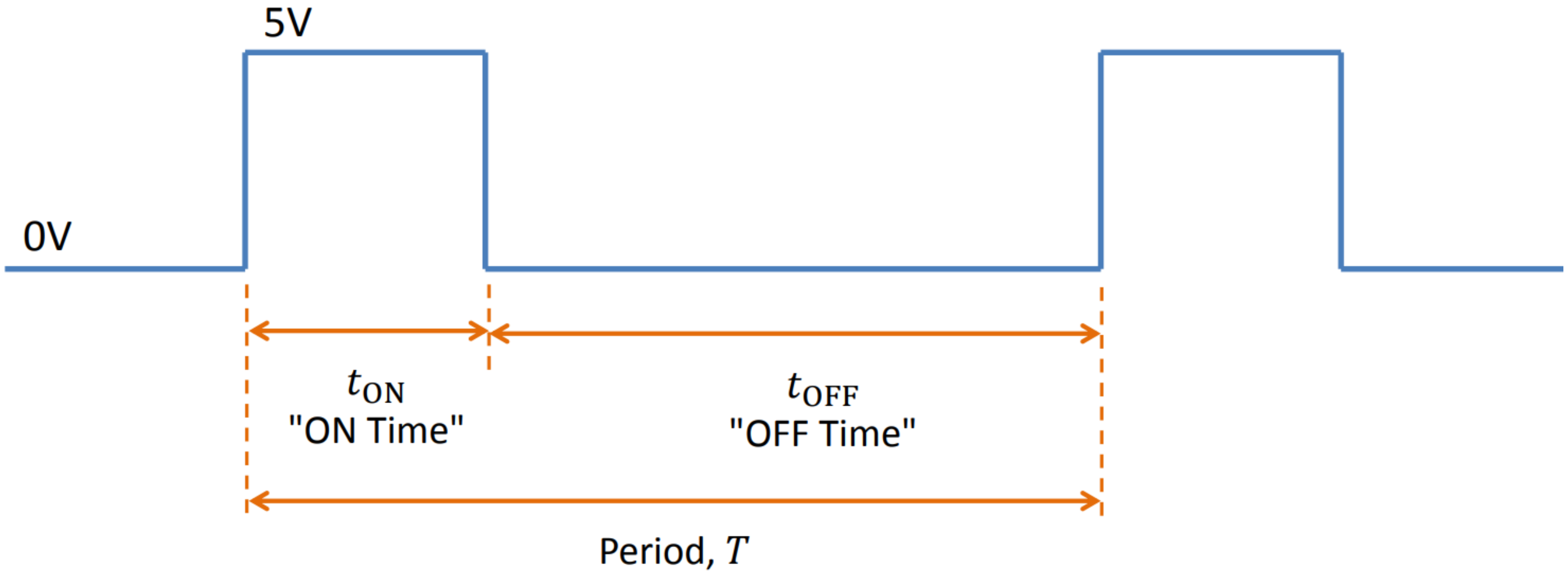
- ❑ Rectangular Pulse Wave
- ❑ Duty Cycle controls average voltage
- ❑ Very high frequency content
- ❑ Need a low pass filter to remove the sharp transitions at edges of the pulses
- ❑ About 90% efficiency



PWM (Pulse Width Modulation)

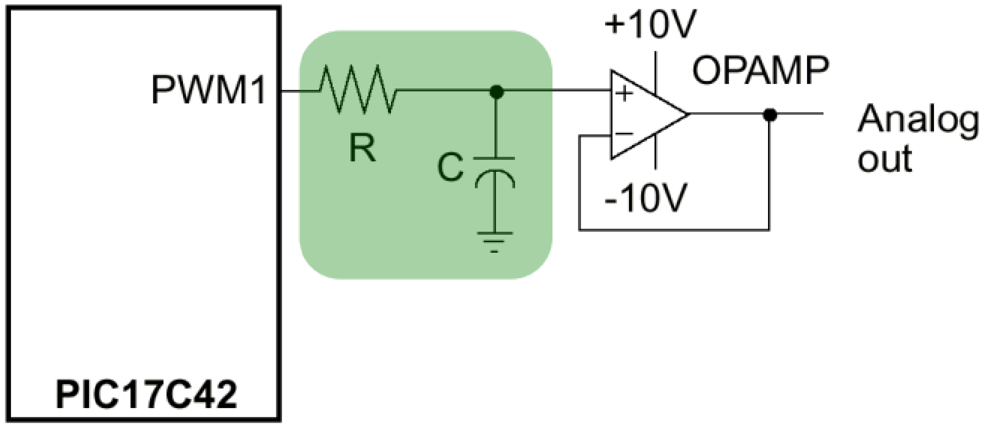
Duty Cycle = $t_{ON}/T \Rightarrow$ 0 – 100%

Frequency (rad/sec) = 1/T



PWM (Pulse Width Modulation)

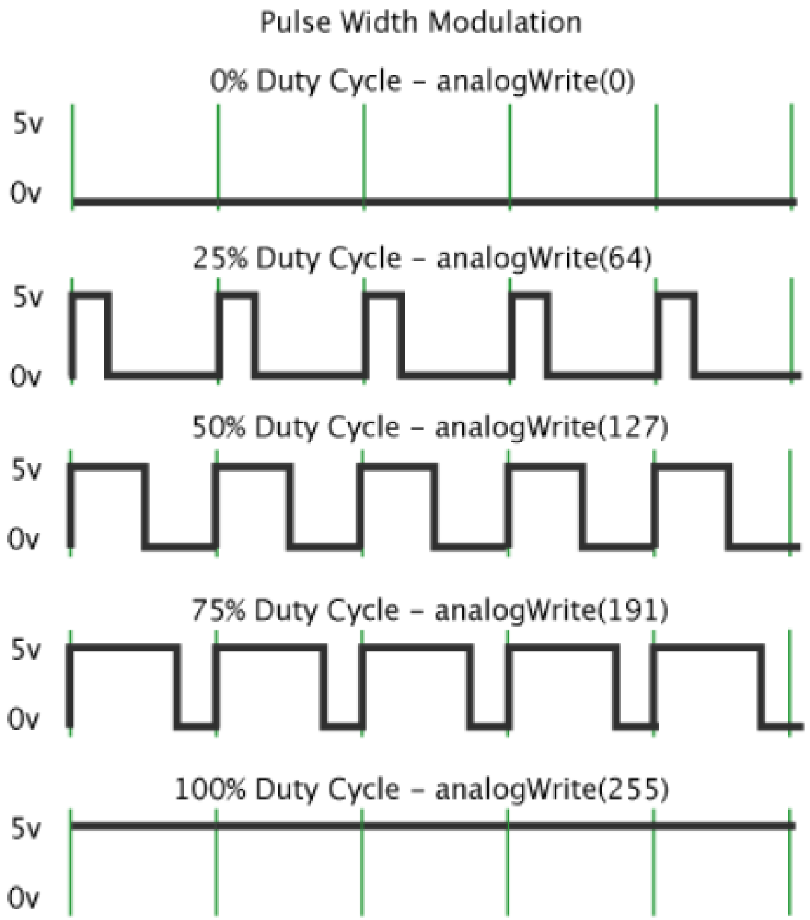
- Low pass filtering the PWM signal can produce an analog signal whose magnitude is proportional to the pulse width of the PWM signal.
- For Motor/ Motion control, Motor/ Motion system will act as the low pass filter
- Unipolar output
- Best suited when an analog output is needed but does not require a high resolution DAC



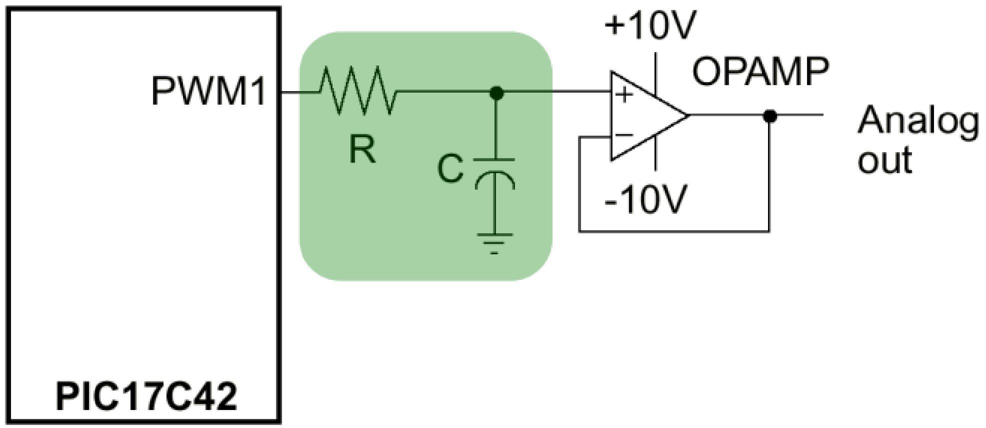
PWM (Pulse Width Modulation)

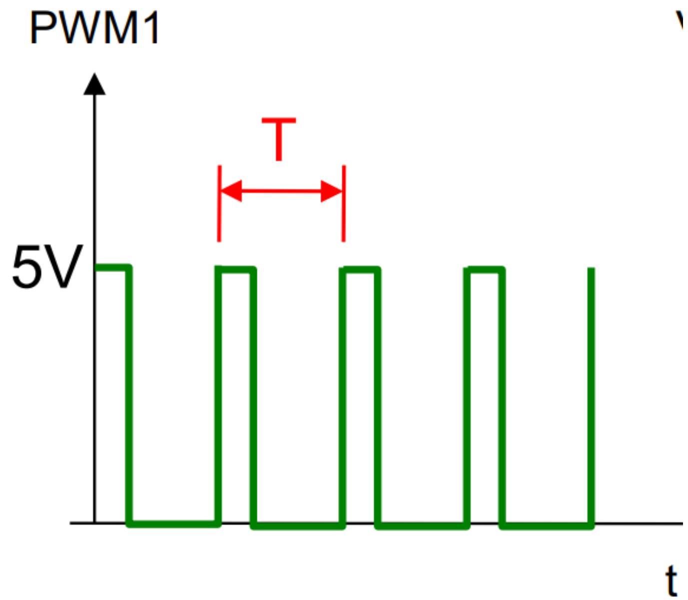
8 bit resolution:
100% / 255 → 0.39% per step
5V/255 → 19.6 mV per step

Arduino default PWM frequency:
Pin 5,6 : 976 Hz
Pin 3,9,10,11 : 488 Hz



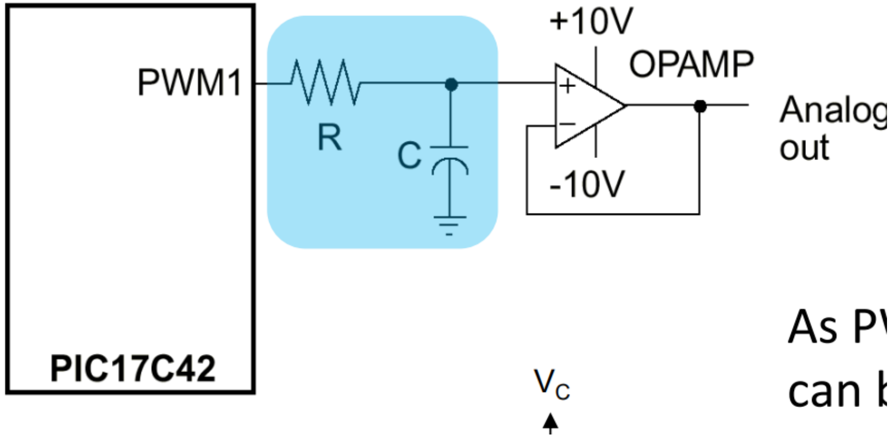
PWM (Pulse Width Modulation)

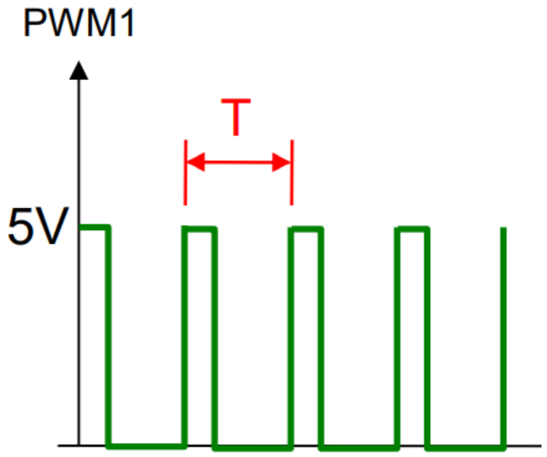




25% Duty Cycle

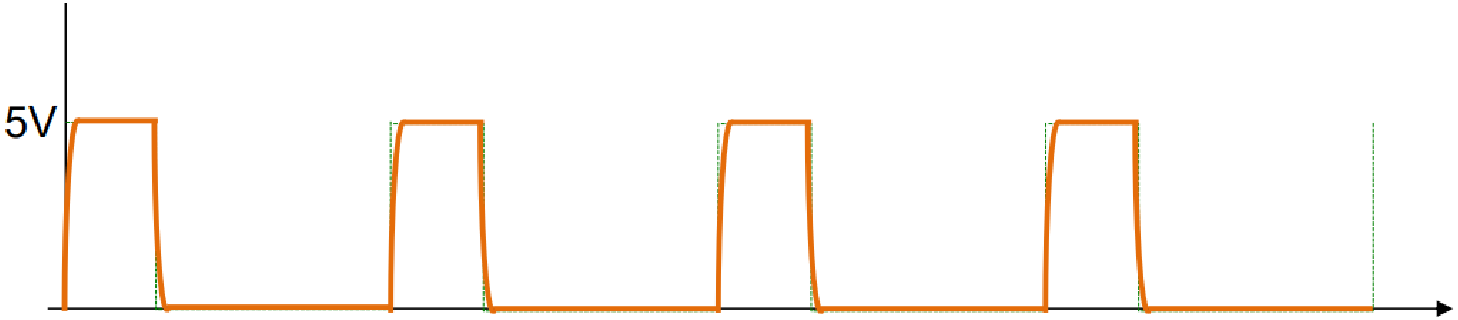
As PWM frequency increases, capacitor can barely charge and discharge fully



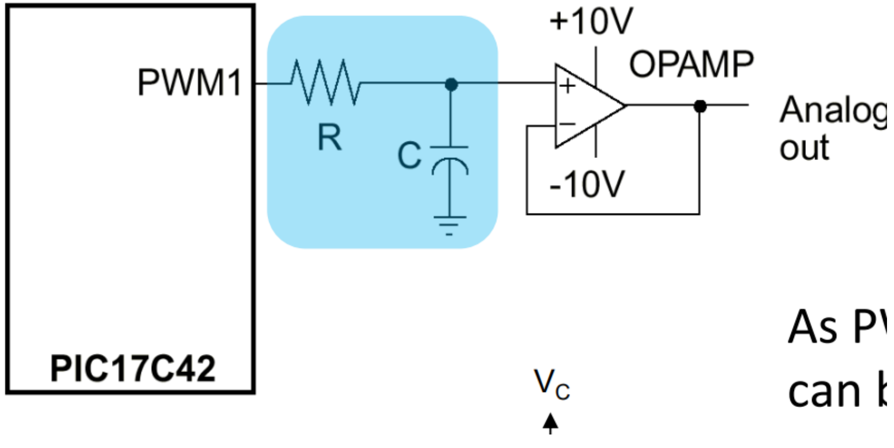


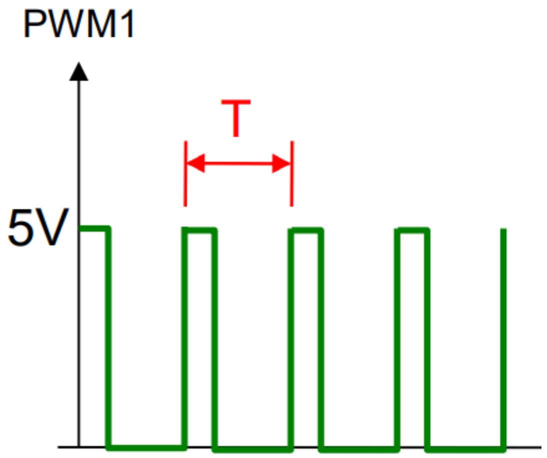
25% Duty Cycle

At low PWM frequency, capacitor can fully charge and discharge.

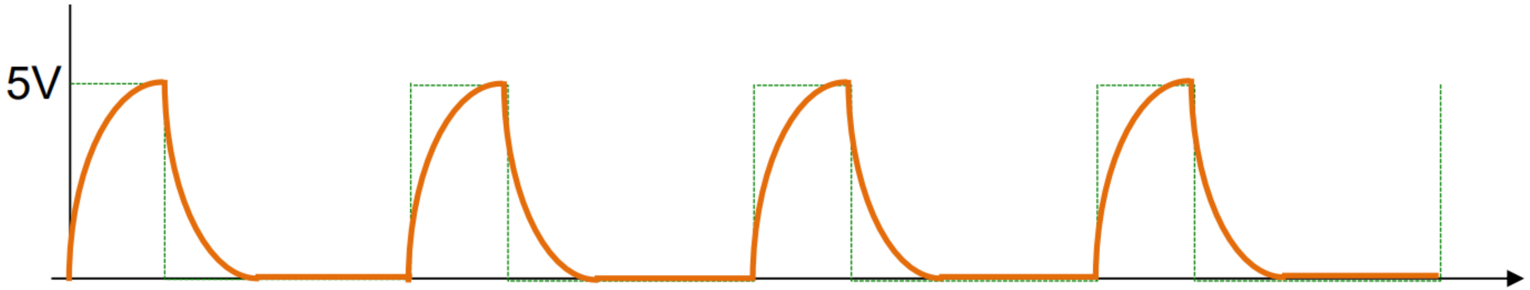


As PWM frequency increases, capacitor can barely charge and discharge fully

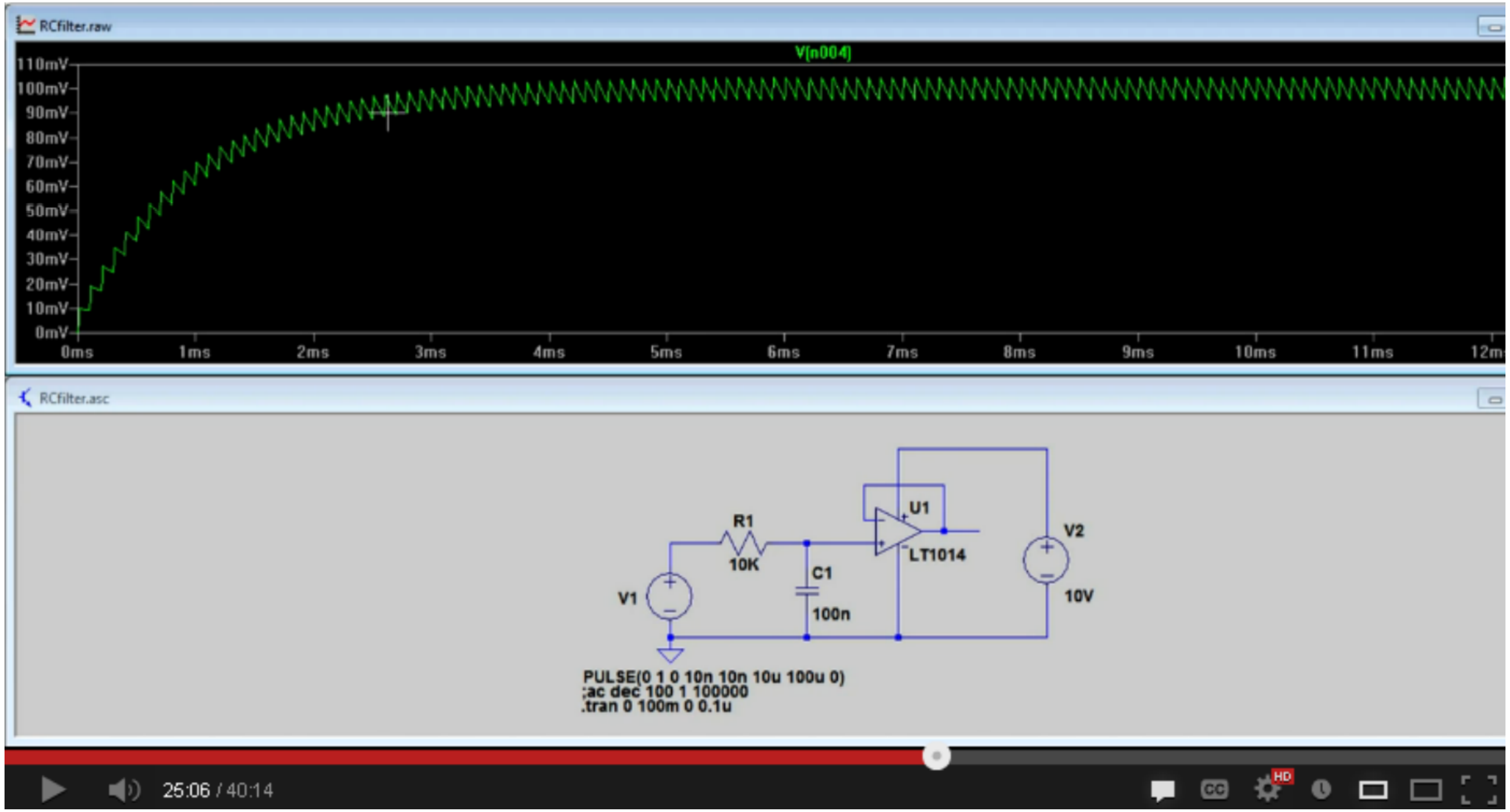




25% Duty Cycle



PWM (Pulse Width Modulation)



http://www.youtube.com/watch?v=YaRDbw38x7Q

Thank You For Your Attention!

Any Question?