Lecture 3 – Actuator drives and Sensor outputs

Dr. Aftab M. Hussain,

Assistant Professor, PATRIoT Lab, CVEST

Actuator drive

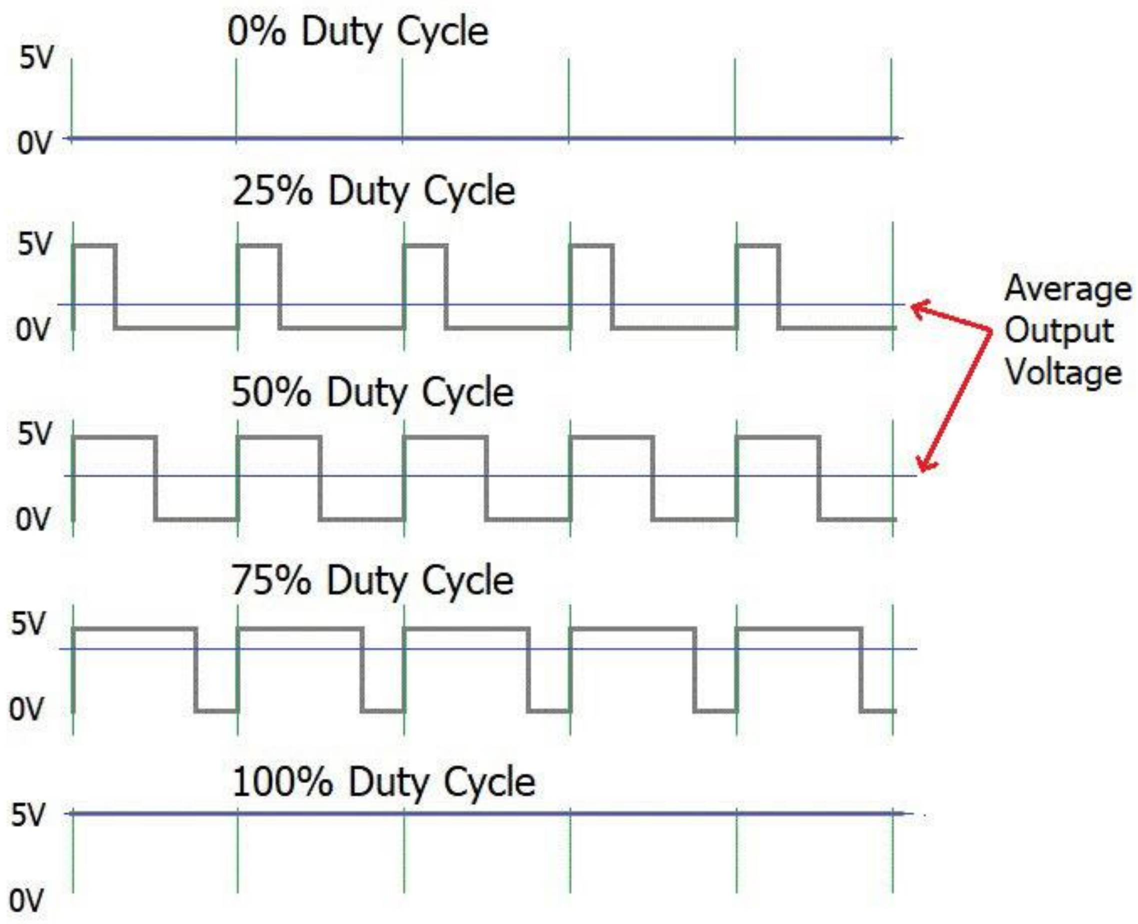
- There are many types of actuators:
  - Mechanical (electromagnetic drives)
  - Thermal (heating coil)
  - Optical (LED)
  - Acoustic (speaker)

- Most of these require an analog input voltage to control the intensity of actuation

- This analog signal needs to be obtained using an analog output pin (with a built-in DAC) or an external DAC

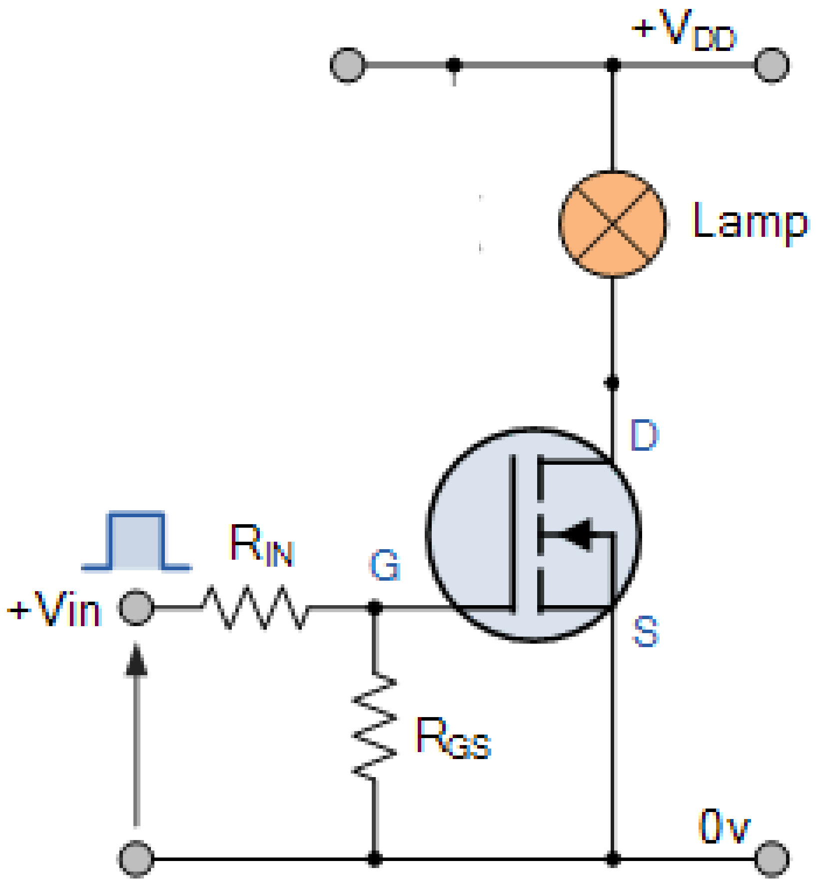
Actuator drive - PWM

- A very common way of skipping the DAC and getting “analog looking” voltage from digital output pins is the PWM method
- The output voltage is cycled from logic-0 to 1 at a very high rate with a particular duty cycle at a particular frequency
- This gives the illusion of the output being analog, say if this output is connected to an LED, the output intensity is perceived as the average of the PWM over time
- Arduino has no DAC, only PWM!



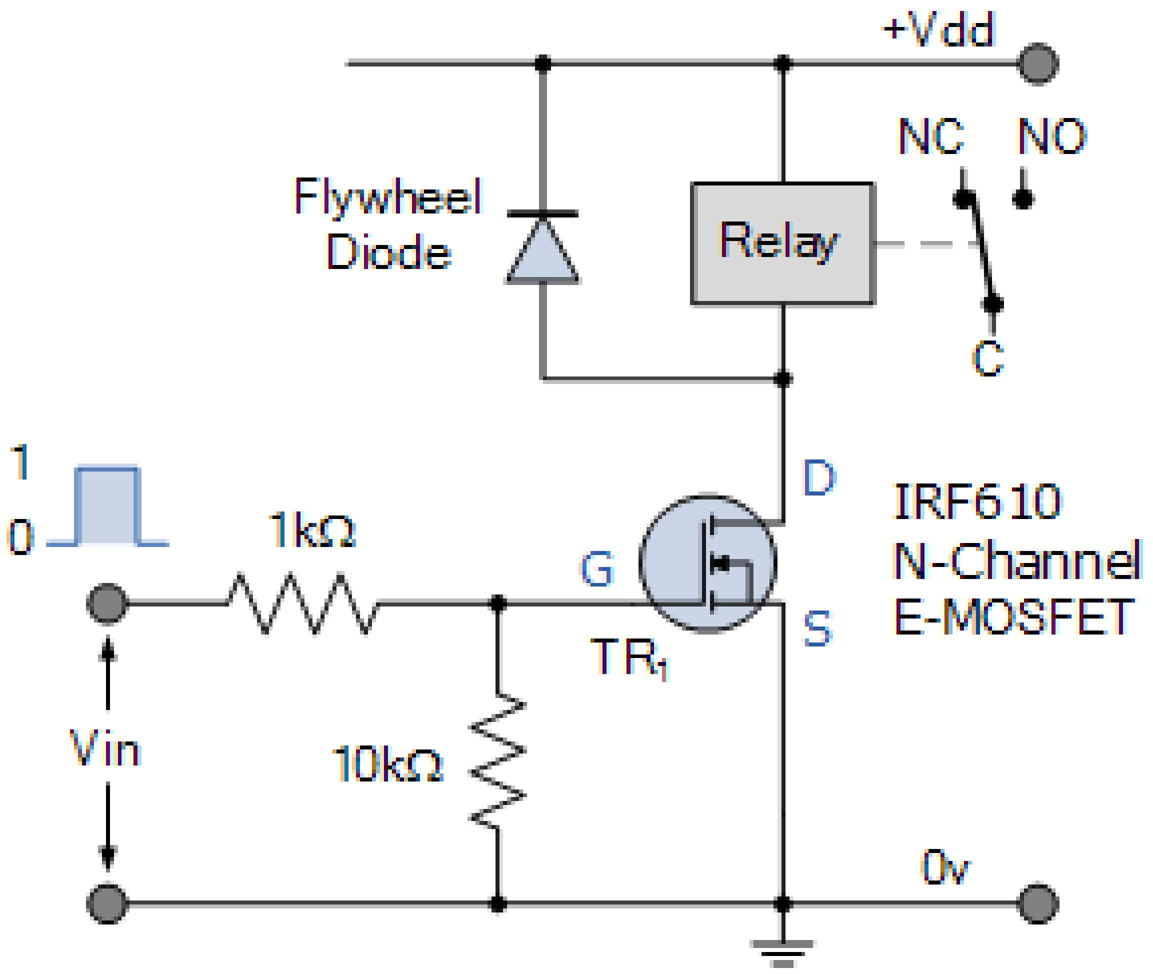
Actuator drive – loading effect

- A common problem with controlling certain peripherals with controllers is the loading effect
- If an actuator is to be driven with controller output, the current supplied by the controller output pin should be sufficient to drive it
- If it is not, the best way is to connect the actuator to a sufficient power source through a switch (transistor) and drive the using the controller output



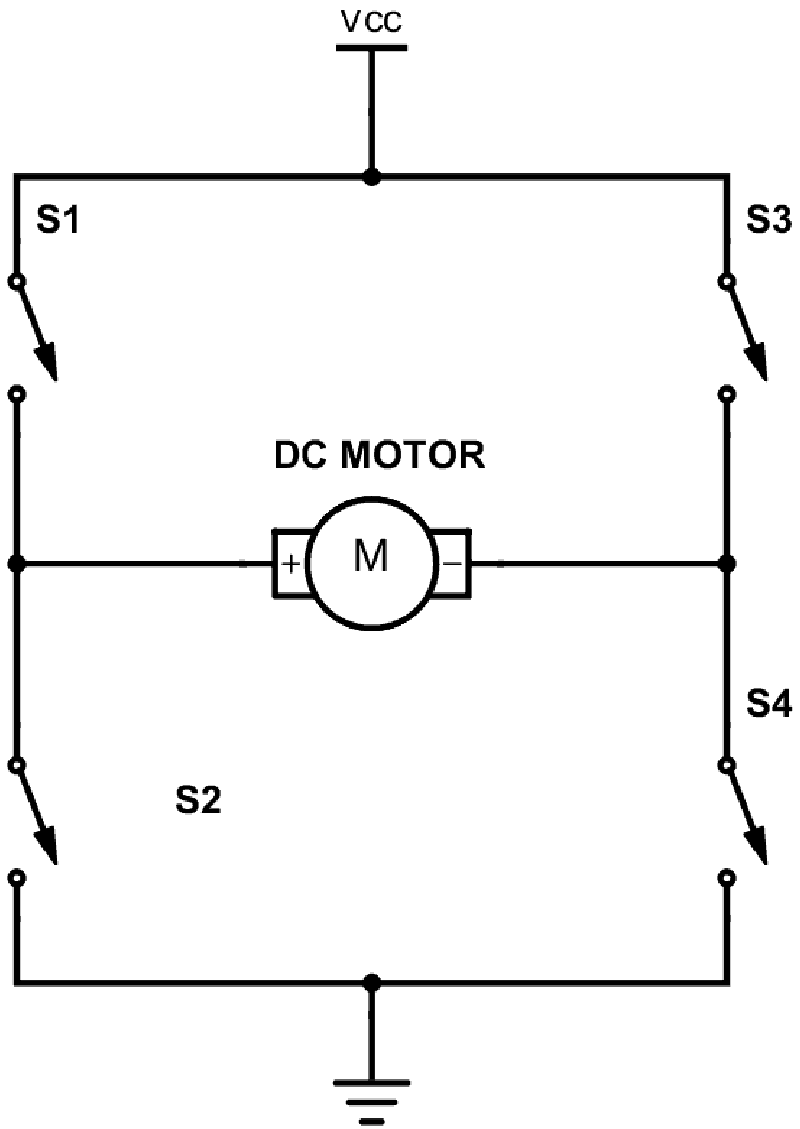
Actuator drive – loading loading effect

- In case of very large loads, a single stage of transistor switching may not be enough
- A common example is driving an AC load (say a light bulb) using a controller
- In this case, a relay is used as a switch to drive the power side using signal from the control side
- However, the power needed to switch the relay is often times more than the controller can provide, so we need a transistor circuit to power the relay



Actuator drive – H bridge

- A transistor switch is great to drive a motor forward, however, if the same supply is to be used to drive it in reverse, an H-bridge circuit is needed
- When S1 and S4 are closed and other two are open, the motor moves in forward direction
- When S2 and S3 are closed and other two are open, the motor moves in reverse
- The switches are generally realized using transistors
- When S1 and S3 or S2 and S4 are closed, the motor brakes (same voltage at the terminals)
- In other cases, the motor coasts



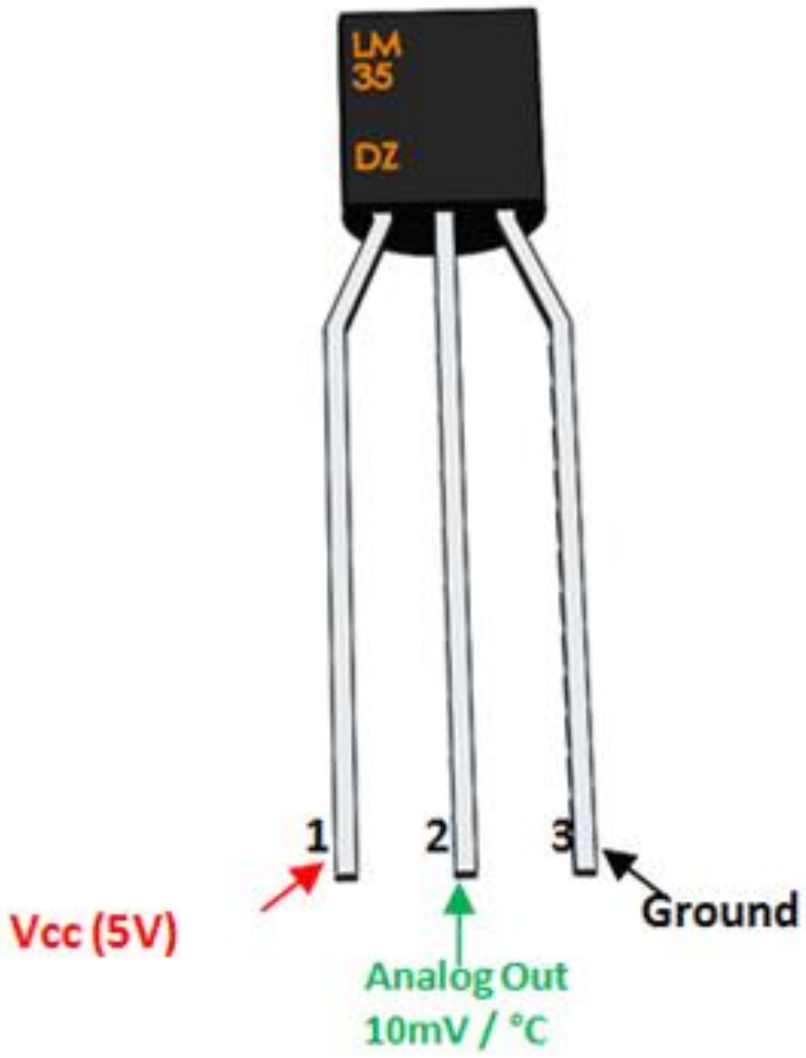
Sensors outputs

Dr. Aftab M. Hussain,

Assistant Professor, PATRIoT Lab, CVEST

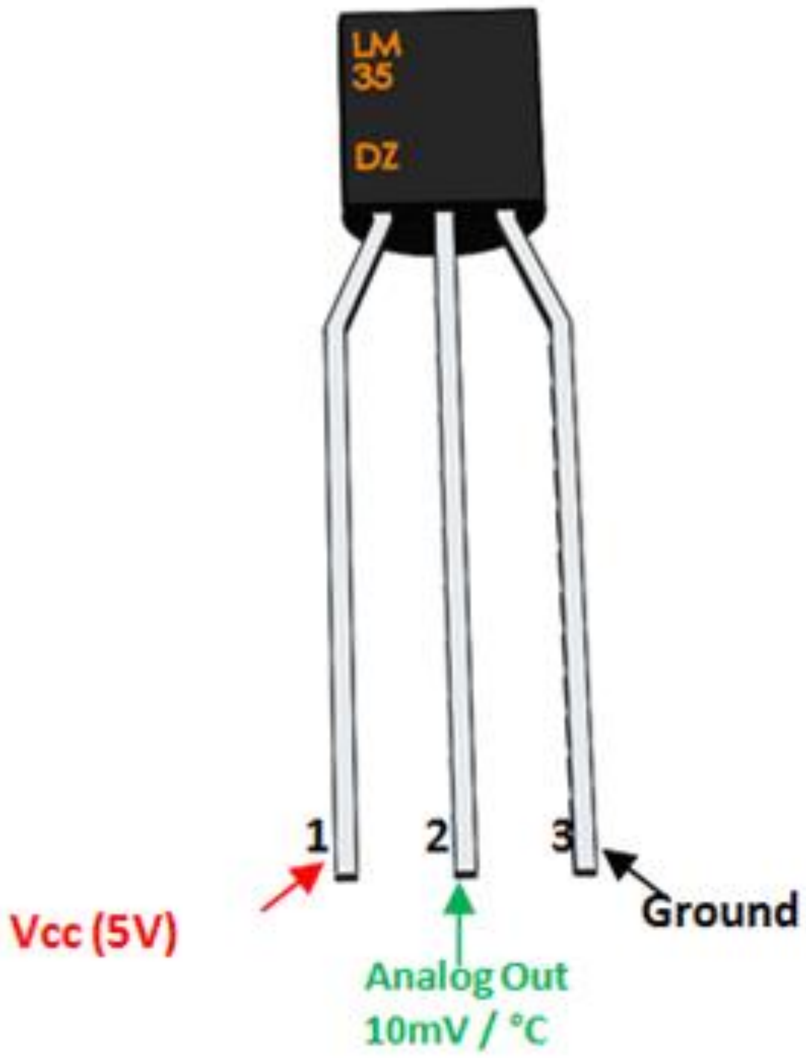
Sensor outputs – Analog

- Analog output is the simplest form of output for a sensor
- It has two pins – the analog output and the ground
- The analog output can be fed directly to some controllers that have a built-in analog to digital convertor (like Arduino), in other cases, an external ADC is required (like Raspberry pi)
- NodeMCU has one “analog read” pin



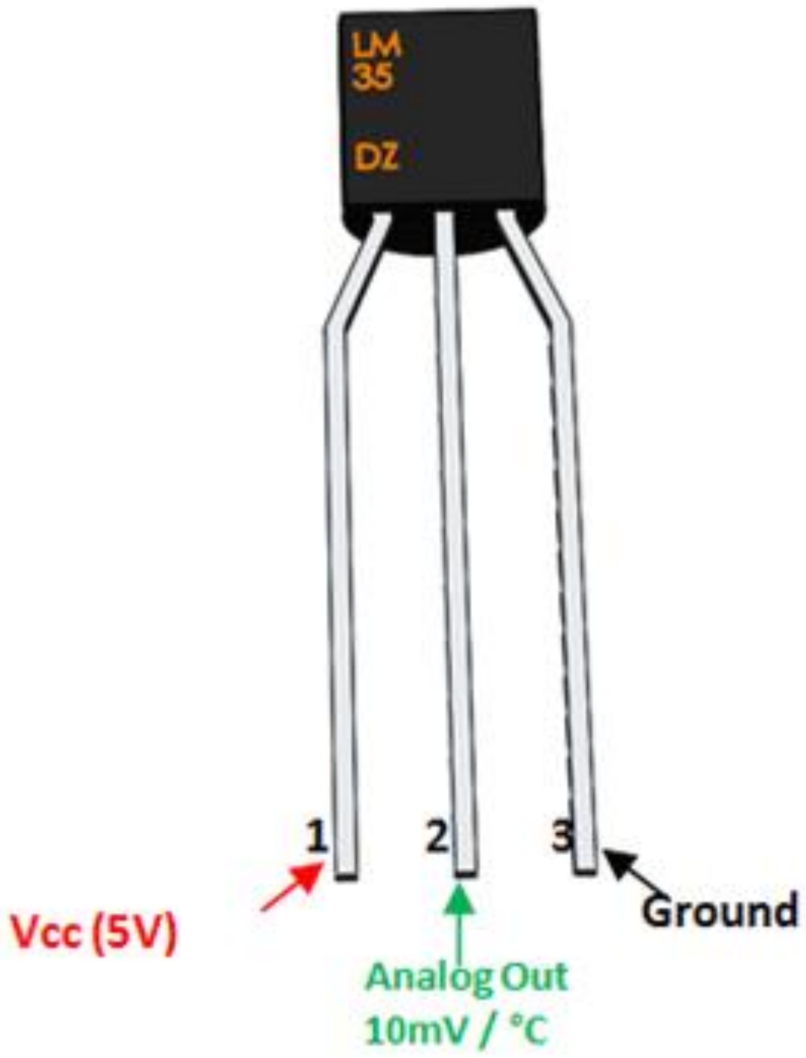
Sensor outputs – Analog

- Selecting an ADC can be tricky – because analog signals are continuous in time as well as amplitude, and there digital counterparts are discrete in both
- In time axis, the “discreteness” is measured by sampling rate (generally in ksps or Msps)
- In voltage axis, the “discreteness” is measured in the output bits



Sensor outputs – Analog

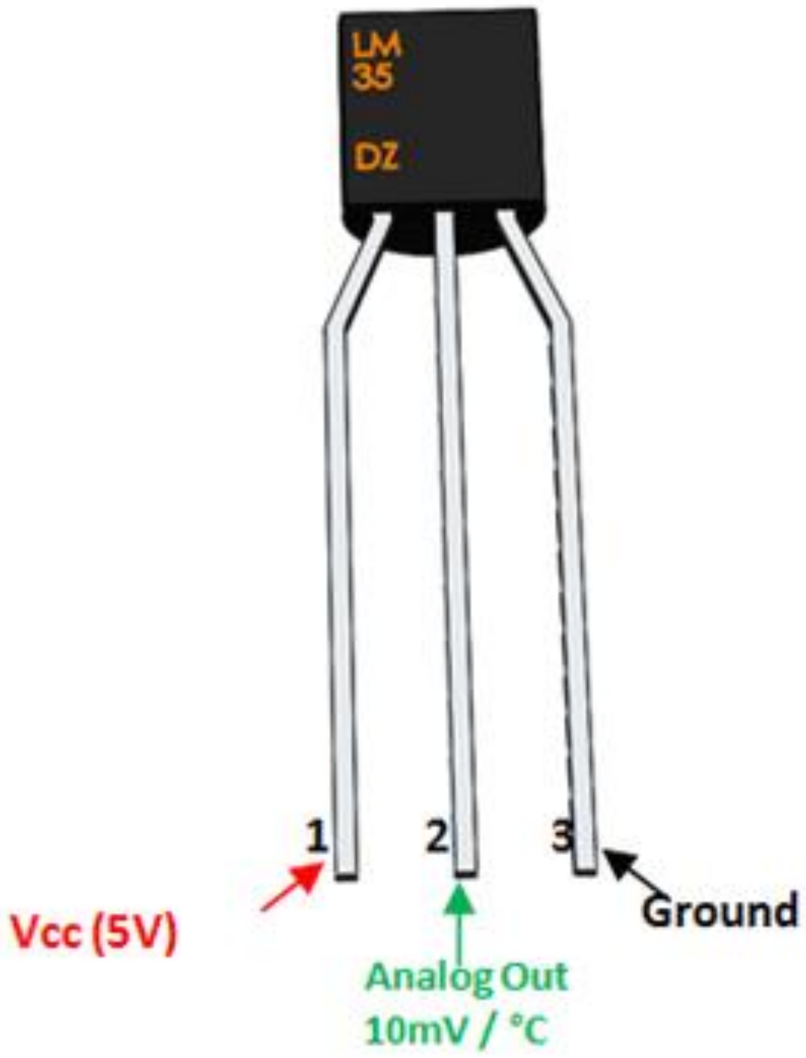
- Example: a 10-bit ADC can output a maximum of 1024 levels, so for a 5 V range, the difference in successive samples is ~5 mV
- Clearly, more bits and higher sampling frequency is ideal
- However, these are competing goals because more bits take more time to process reducing the sampling rate



Sensor outputs – Analog

- Advantages:
  - Simple implementation with an onboard ADC (single wire)
  - Continuous output – so can be on demand
  - Infinite resolution

- Problems
  - Needs an ADC
  - Very susceptible to noise
  - The “loading” effect



Need of ADCs and DACs

- We know that sensor outputs (e.g., a voltage measured with a thermocouple or a speech signal recorded with a microphone) are analog quantities, varying continuously with time
- However most of the processing, storage and happens in digital format
- An ADC (Analog-to-Digital Converter) is used to convert an analog signal to the digital format
- The reverse conversion (from digital to analog) is also required (mostly for actuator operation)
- For example, music stored in a DVD in digital format must be converted to an analog voltage for playing out on a speaker
- A DAC (Digital-to-Analog Converter) is used to convert a digital signal to the analog format

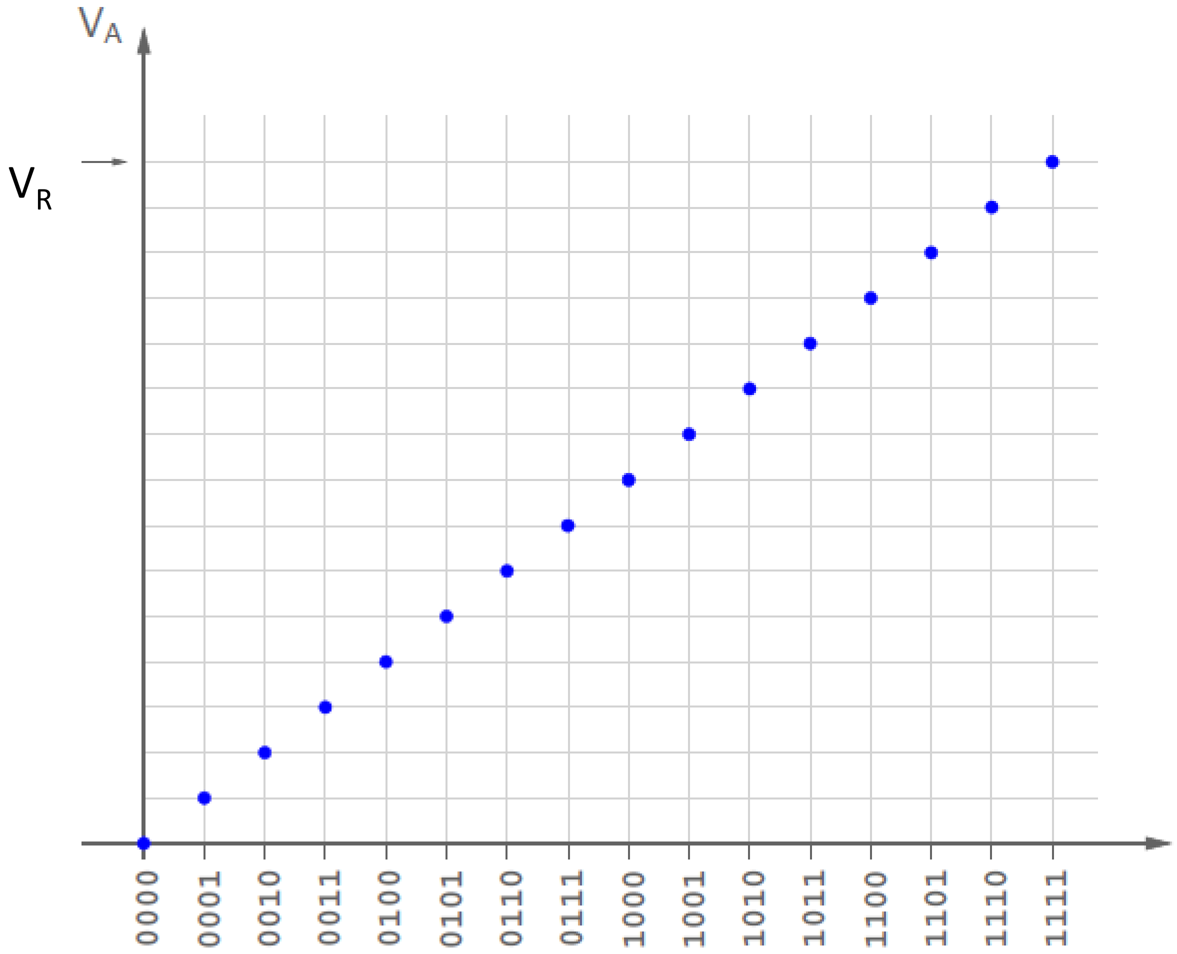
DAC

- A DAC is a circuit that takes digital signal and provides a corresponding analog output
- For a four bit DAC with input $A_3A_2A_1A_0$, the output voltage is:

$$V_A = \frac{V_R}{15}[(8\,A_3 + 4\,A_2 + 2\,A_1 + A_0)]$$

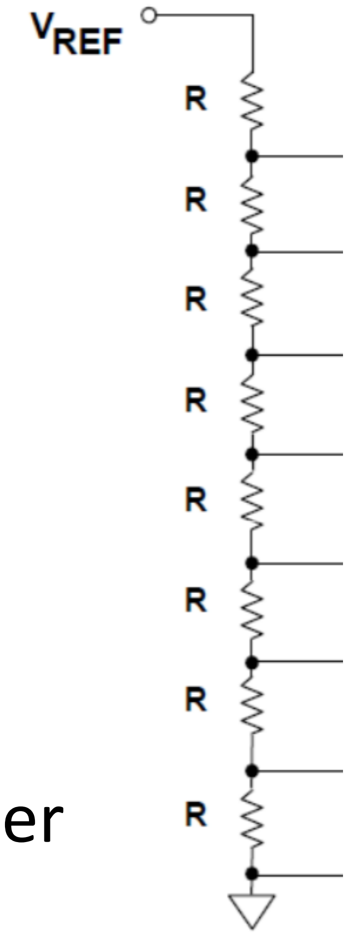
- In general, the output is:

$$V_A = \frac{V_R}{2^n - 1}\sum_{k=0}^{n-1} A_k\,2^k$$



DAC – Kelvin divider

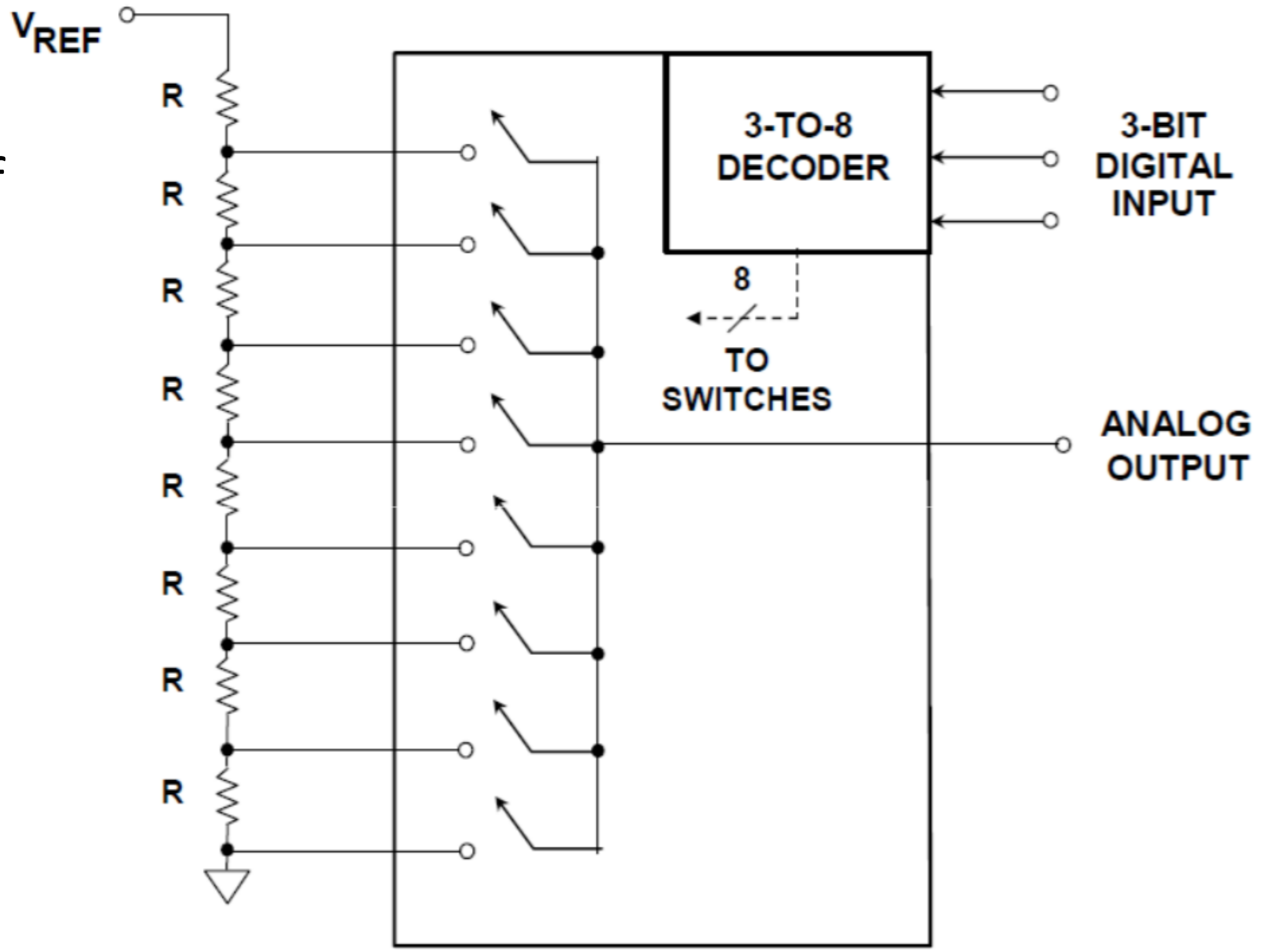
- The most intuitive way of implementing a DAC is using the Kelvin divider
- In this case, we use 2^n resistors of equal values in series with the reference voltage
- The voltage is thus divided into 2^n equal intervals
- The output is then tapped from an appropriate position using a decoder circuit in conjunction with 2^n switches



DAC – Kelvin- divider

- Advantages:
  - Simple design
  - It is configurable to non-linear DACs if specific step size is required for particular applications

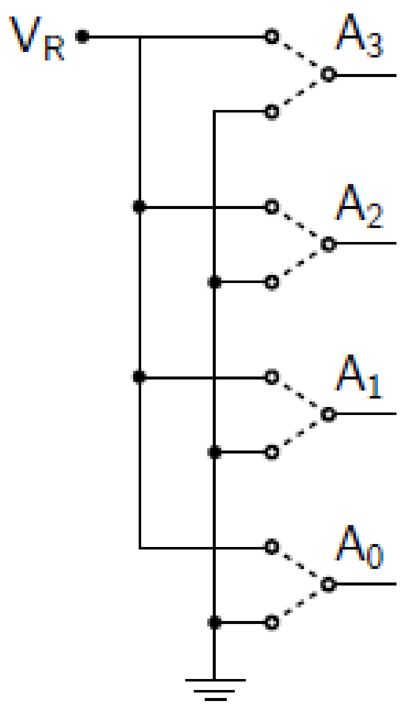
- Disadvantages
  - 2^n switches and resistors can explode exponentially
  - Large power consumption
  - Decoding circuit can become complicated for large values of n



DAC – Weighted resistors

- We can connect the input signals to switches such that the V_R appears at a terminal if the input is high
- Such a connection can be used in conjunction with resistors of specific value to obtain the analog voltage
- If the input bit A_k is 1, the terminal gets connected to V_R ; else, it gets connected to ground
- Thus,

$$I_k = \frac{A_k V_R - 0}{R_k} = \frac{A_k V_R}{R_k}$$



DAC – Weighted resistors

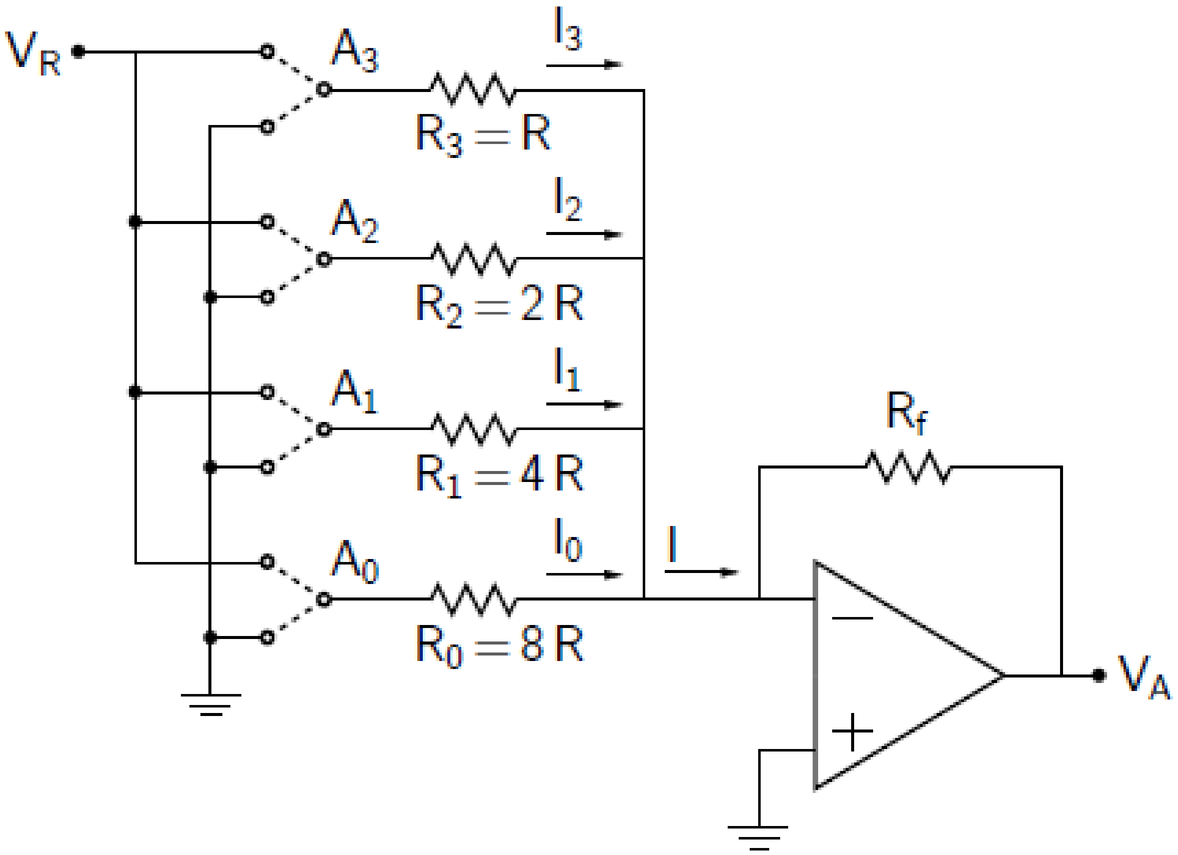
- From the non-inverting opamp, we have:

$$V_A = -R_f I = -R_f \sum_{k=0}^{n-1} \frac{A_k V_R}{R_k}$$

- If we use $R_k = \frac{2^{n-1}R}{2^k}$:

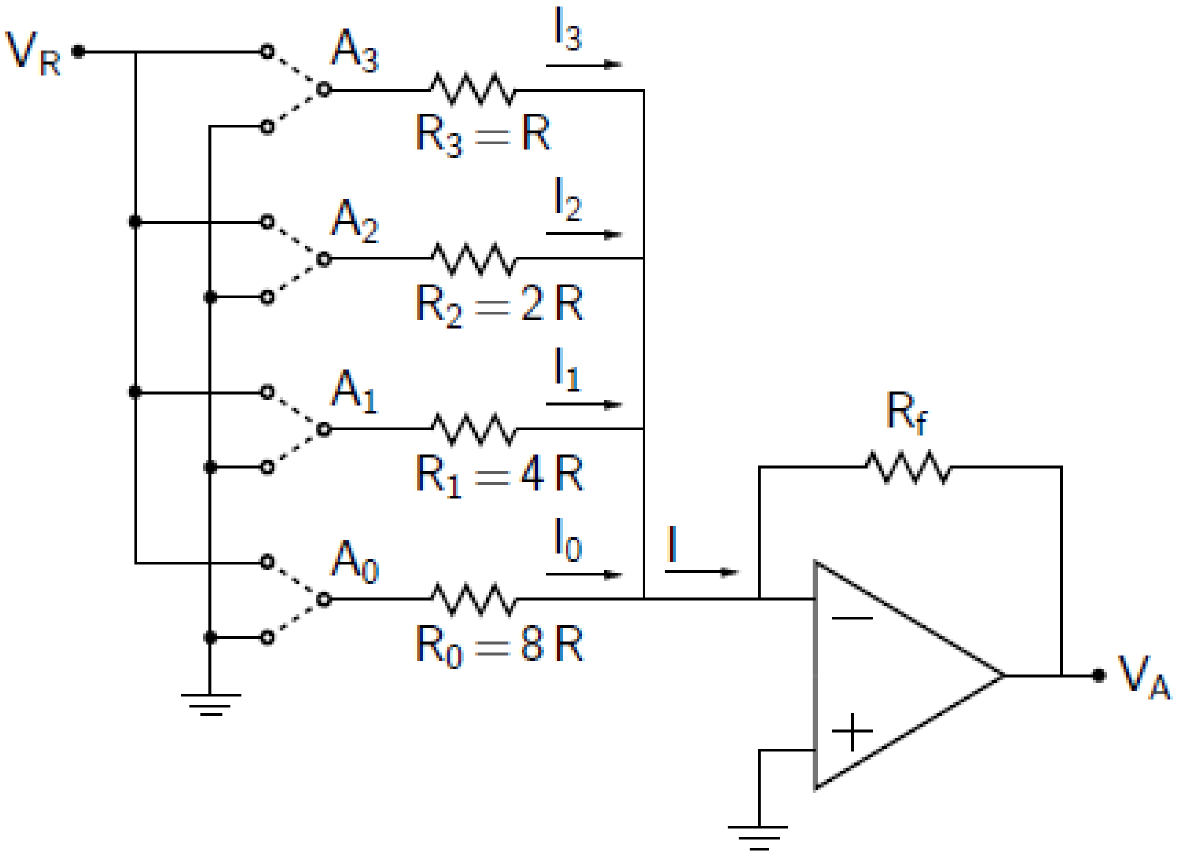
$$V_A = -R_f I = -\left(\frac{R_f}{R}\right)\frac{V_R}{2^{n-1}} \sum_{k=0}^{n-1} A_k 2^k$$

- Thus, with only n resistors and n switches, the circuit can be made
- R_f can be used to introduce additional gain



DAC – Weighted resistors

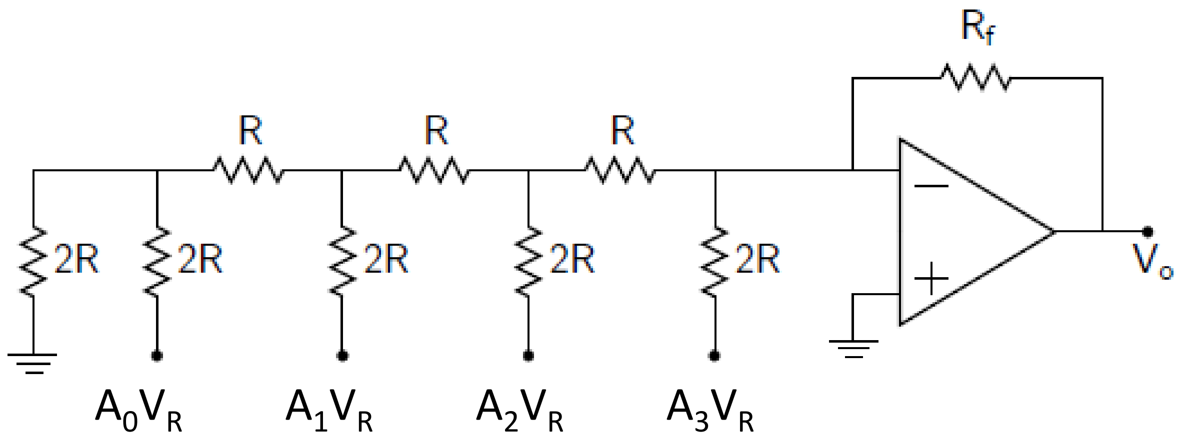
- Advantages:
  - n resistors and 2n switches
  - Current is only drawn when input is applied, no static power consumption
  - The R_f value can be varied to obtain a gain along with D to A conversion



- Problems:
  - Hard to find resistors of exact values such as R, 2R… 16R, 32R etc.

DAC – R-2R ladder

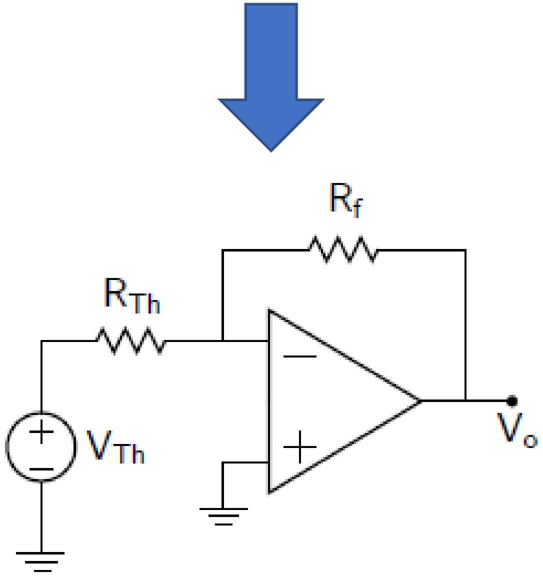
- The R-2R ladder circuit consists of the input voltage applied to a resistance network made of resistors of values R and 2R as shown



- The output can be thought of as an Thevenin equivalent circuit with,

$$R_{th} = R$$

$$V_{th} = \frac{V_R}{16}(A_3 2^3 + A_2 2^2 + A_1 2^1 + A_0)$$



- Thus,

$$V_0 = -\left(\frac{R_f}{R}\right)\frac{V_R}{16}(A_3 2^3 + A_2 2^2 + A_1 2^1 + A_0)$$

DAC – R-2R ladder

- Advantages:
  - Does not require resistors of specific values
  - Can be made using only 2n resistors and 2n switches
  - No static power consumption

- Due to its many advantages, R-2R ladder is often used in fabricating commercial DACs