ECEN202 2024

Analogue to digital and Digital to Analog Conversion.

Lecture 1

A-D/D-A

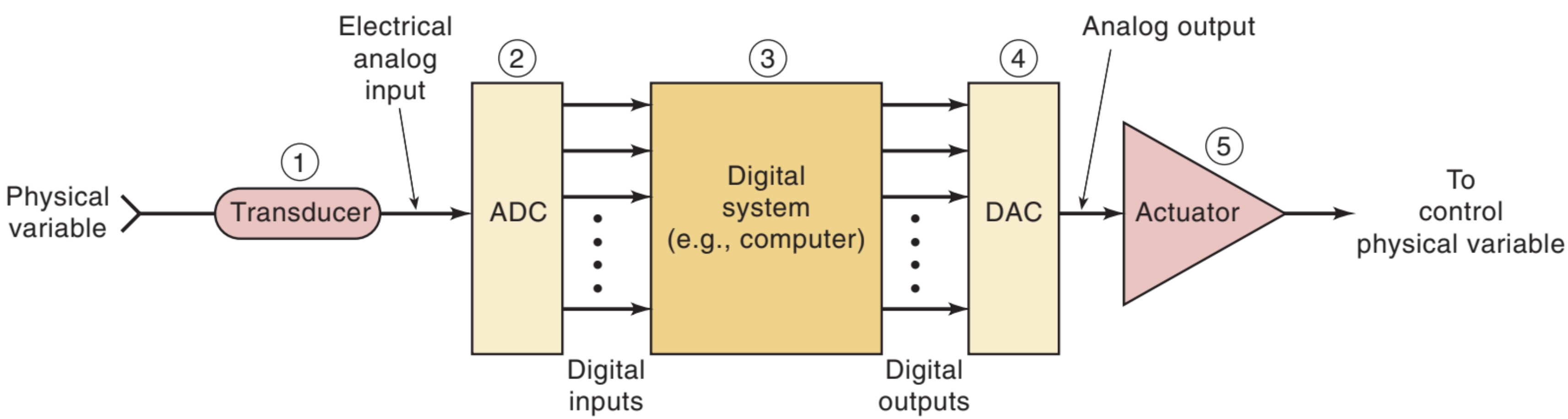
- Conversion between analogue and digital signals is common. The following aspects will be examined:
  - DAC and ADC
  - Different conversion methods
  - Sampling
  - Analogue multiplexing
  - Analogue interfacing

Interfacing With the Analog World

- A review of the difference between digital and analog quantities
  - Digital quantities – values can take on one of several discrete values. Discrete
  - Analog quantities – values can take on an infinite number of values. Continuous.

Interfacing With the Analog World

- Transducer
- ADC
- Computer
- DAC
- Actuator



Digital to Analog Conversion

- The conversion process:

–Digital code is converted to a voltage or current proportional to the digital code

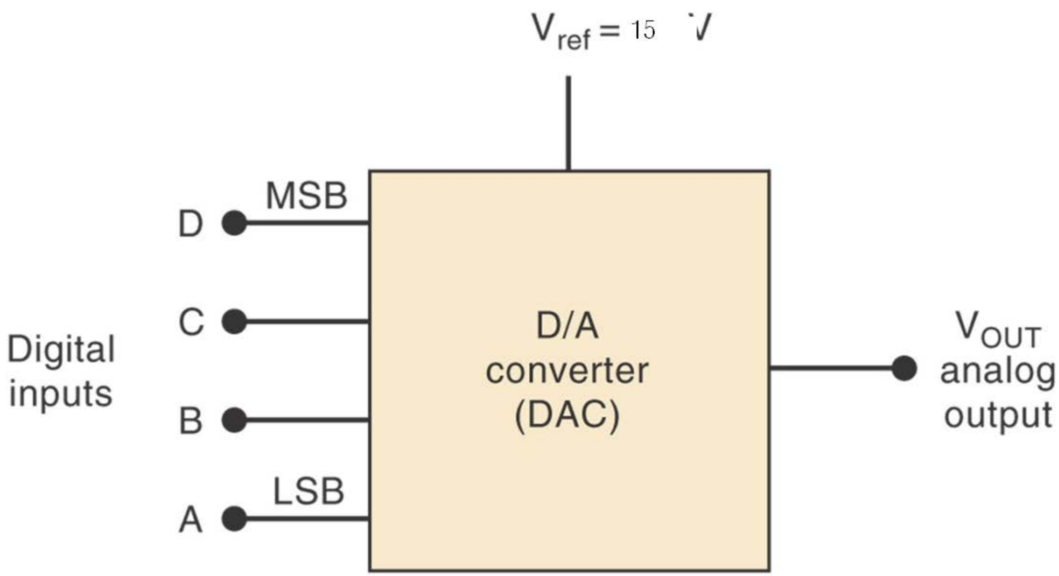
– Voltage reference used to determine the full scale O/P.

– Analog O/P = K x digital I/P
where K is the proportionality factor

– "Pseudo analog" as O/P cannot take on continuous values

–Bipolar DAC's: Use 2's compliment to represent negative voltages

Four-bit DAC with voltage output.



D	C	B	A	V_{OUT}	
0	0	0	0	0	Volts
0	0	0	1	1	
0	0	1	0	2	
0	0	1	1	3	
0	1	0	0	4	
0	1	0	1	5	
0	1	1	0	6	
0	1	1	1	7	
1	0	0	0	8	
1	0	0	1	9	
1	0	1	0	10	
1	0	1	1	11	
1	1	0	0	12	
1	1	0	1	13	
1	1	1	0	14	
1	1	1	1	15	Volts

(b)

Problem 1: A 5-bit DAC has a current O/P. For a digital I/P of 10100 an O/P current of 10 mA is produced. What is:

(i) I_{out} for a digital I/P of 11101 ?

(ii) The full scale O/P ?

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(ii) The full scale O/P ?

Answer:

(i) 10100_2 is decimal 20_{10} .

Thus K = 10mA/20 = 0.5mA

So for $11101_2 = 29_{10}$ we have O/P = 29 x 0.5mA = 14.5 mA

(ii) Thus full scale O/P: 11111 = 31_{10}

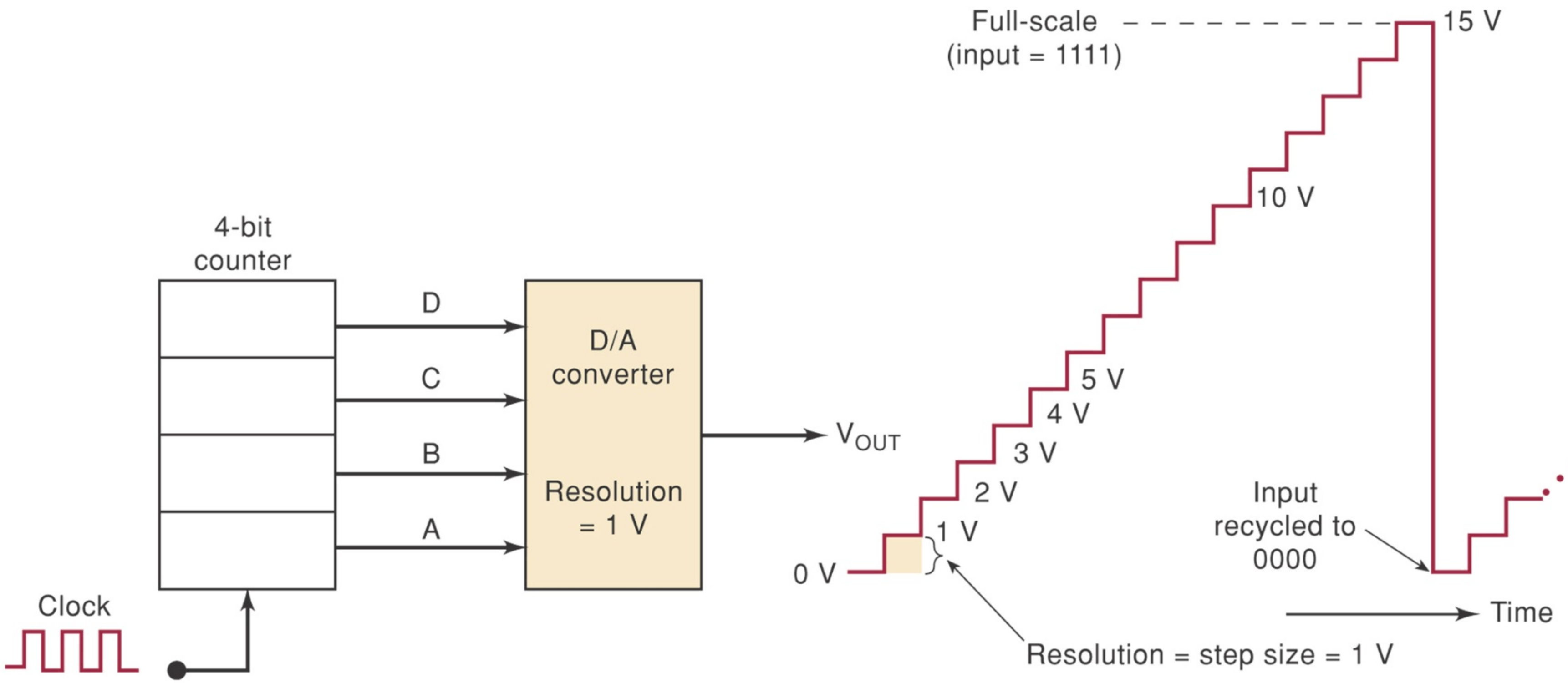
Thus O/P = 31 x 0.5 mA = 15.5 mA.

Resolution (Step size)

The smallest change that can happen in the analog output as a result of change in the digital input.

The resolution is always equal to the weight of the LSB and is also referred to as the ***step size*** because it is the amount that V_{OUT} will change as the digital input value is changed from one step to the next.

Output waveforms of a DAC as inputs are provided by a binary counter



Resolution

Difference in O/P voltage caused by a single code bit change on the I/P.

$$\text{Resolution} = \frac{\text{Full scale analog output}}{2^n - 1}$$

$$= K$$

Percentage Resolution

Often useful to express resolution as a % of the full scale output:

% Resolution = Step Size/Full Scale x 100%

E.g.: 1V step/15 V Full scale x 100% = 6.67%

Questions ?

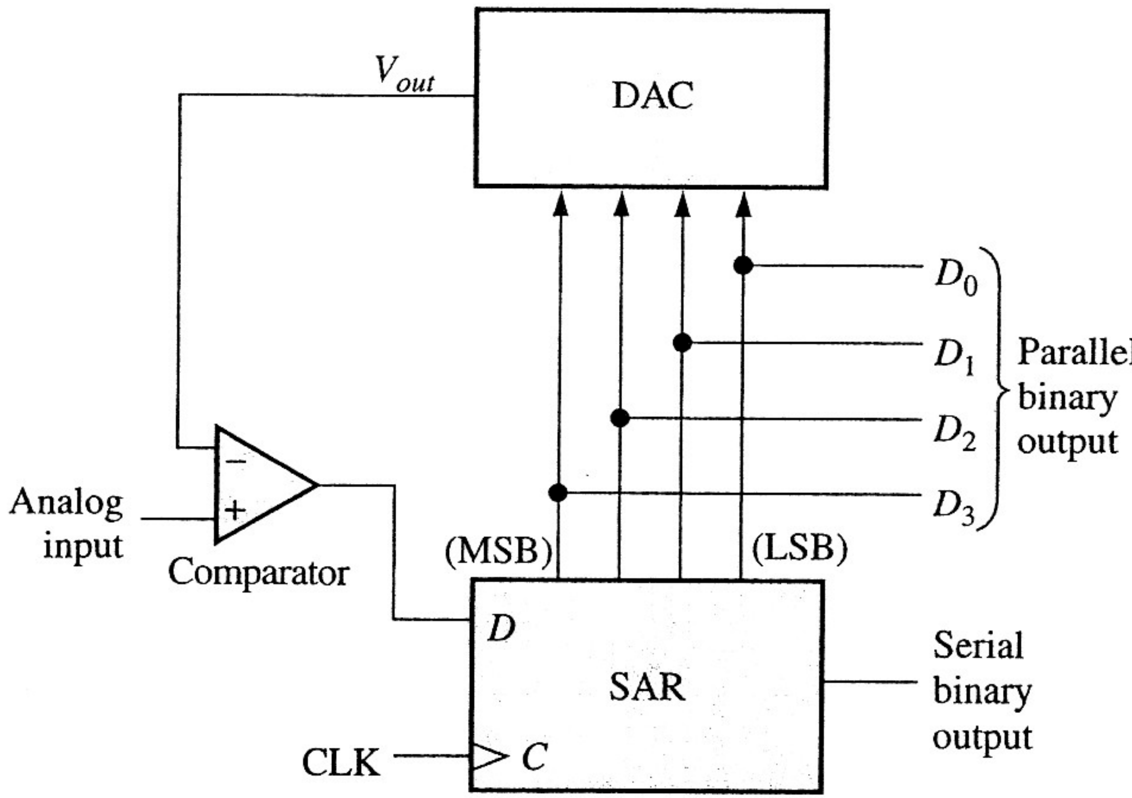
A. How do we construct a digital to analog converter ?

B. How do we use them in practice ?

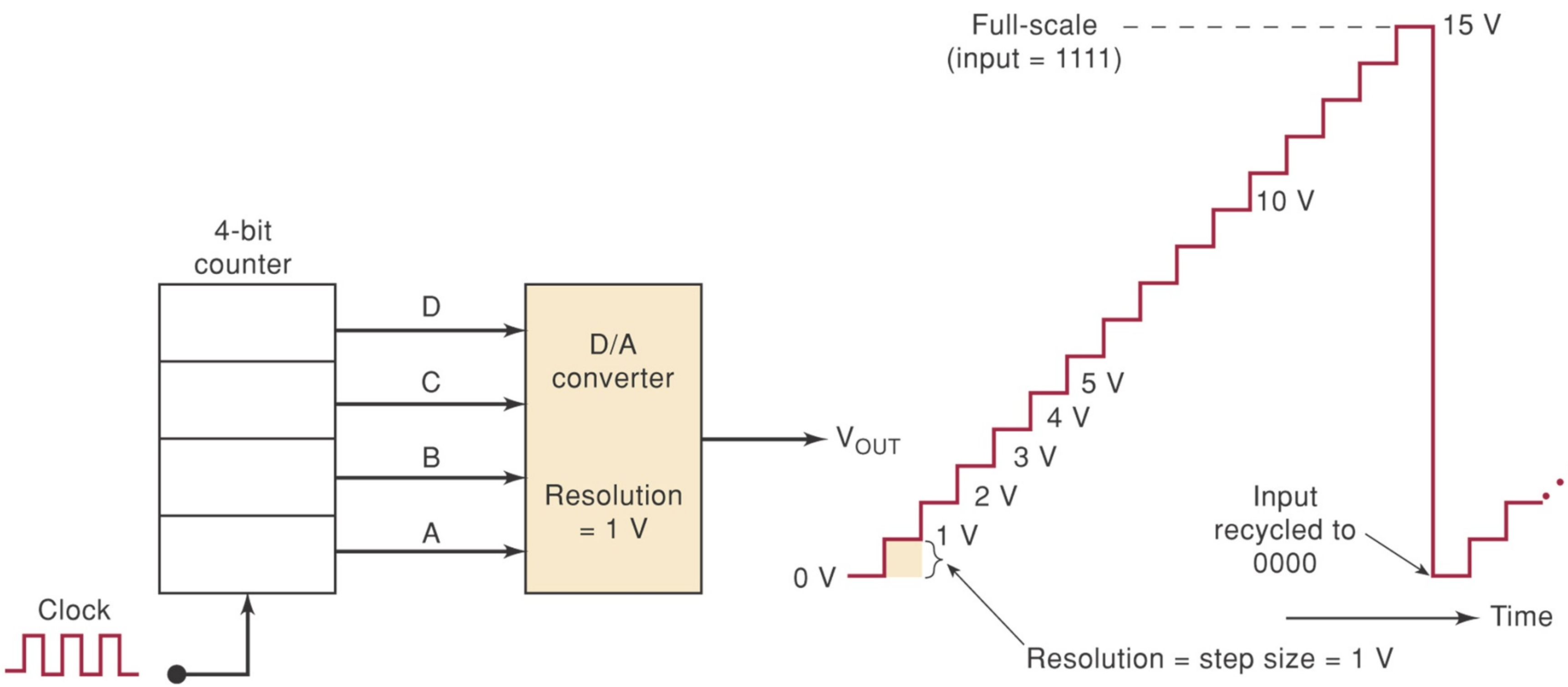
C. What are they useful for ?

What are they useful for ?

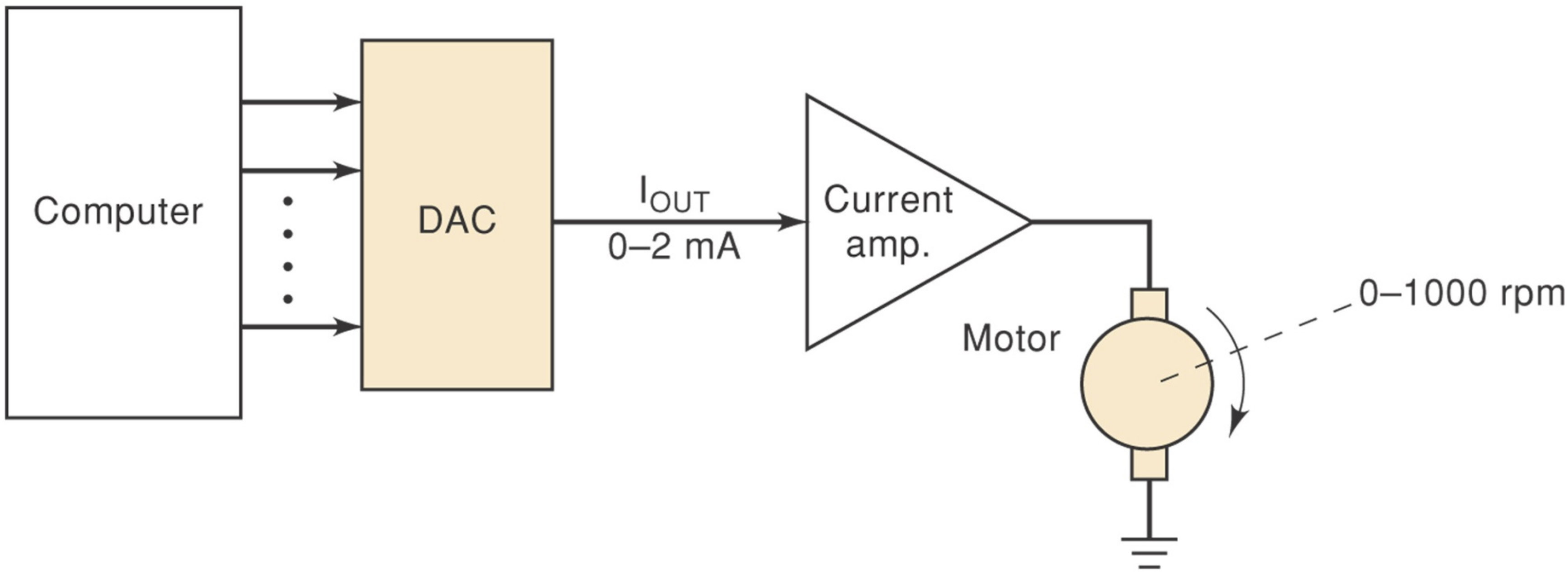
1. Essential part of many A/D converters – e.g. SAC



2. Digital waveform generators.



3. Control current/voltage output to drive a transducer or process.

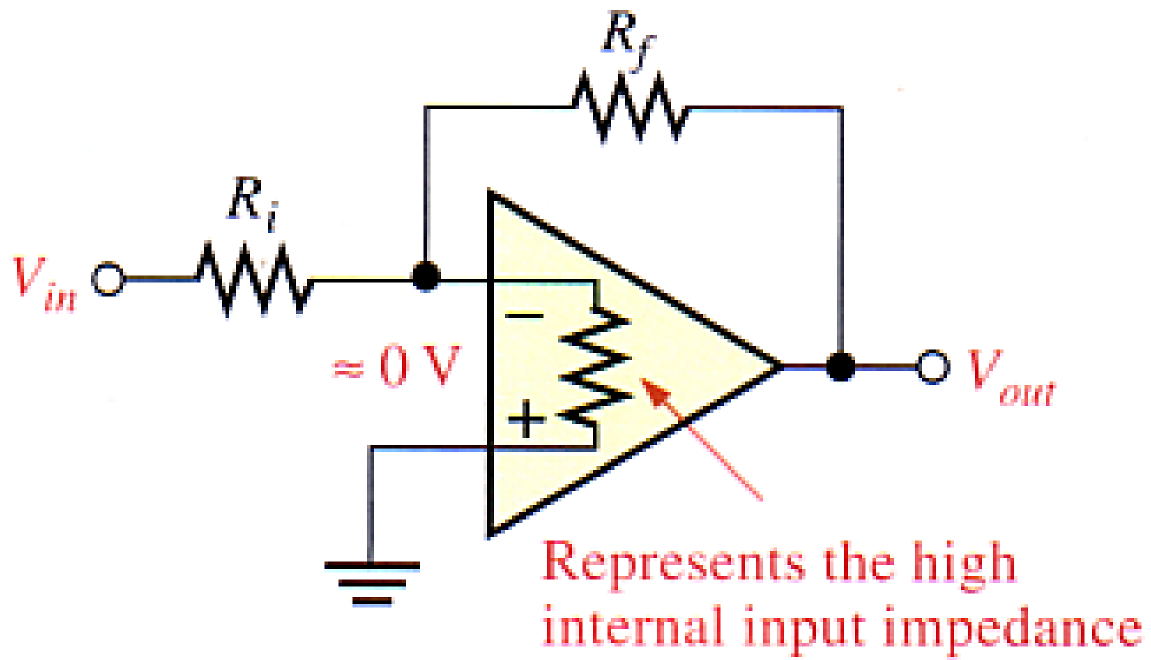


A computer controlling the speed of a motor. The 0- to 2-mA analog current from the DAC is amplified to produce motor speeds from 0 to 1000 rpm (revolutions per minute). How many bits should be used if the computer is to be able to produce a motor speed that is within 2 rpm of the desired speed?

Using nine bits, how close to 326 rpm can the motor speed be adjusted?

Basic Construction of a Digital to Analog Converter

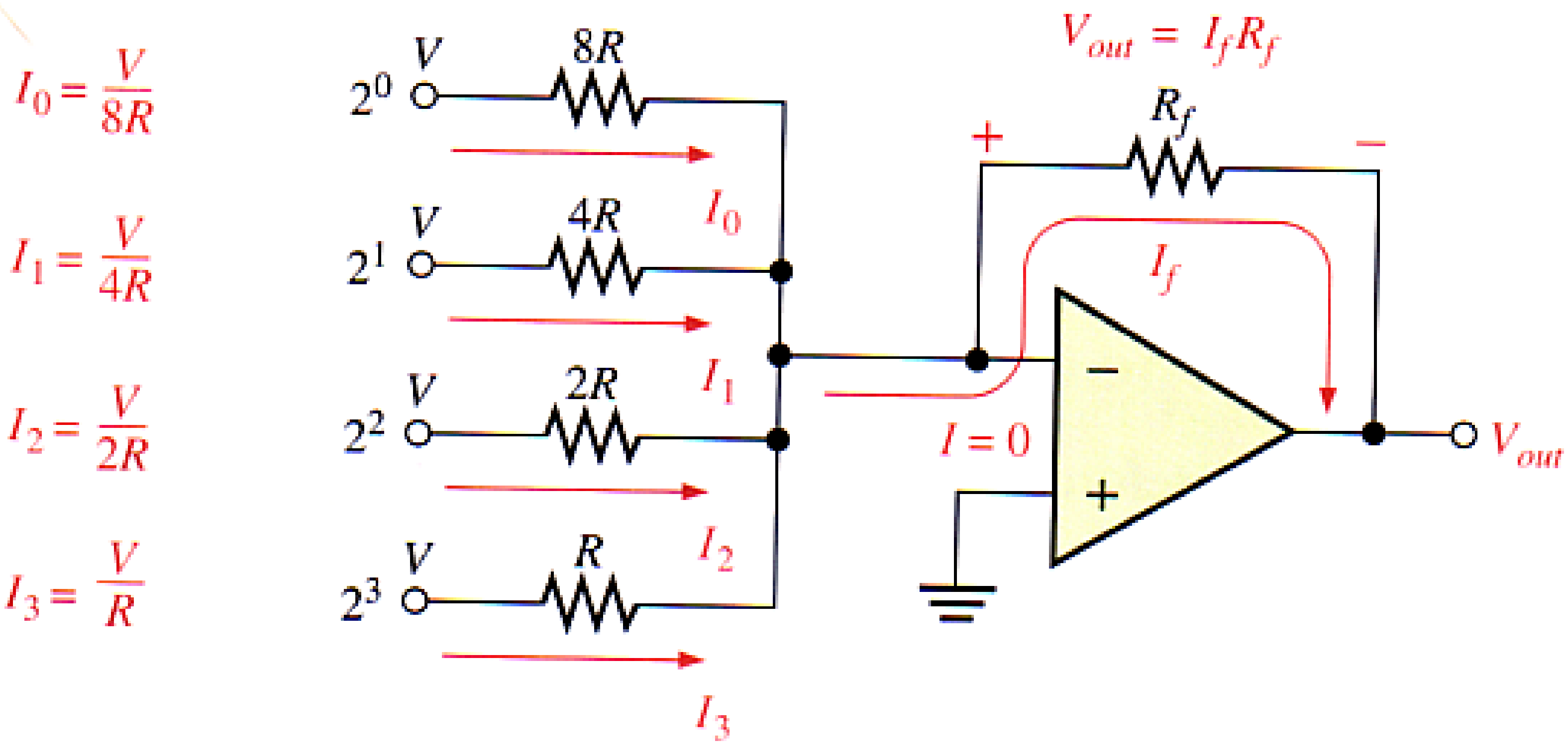
Consider the Op-amp as an inverting amplifier:



(b) Op-amp as an inverting amplifier with gain of R_f/R_i

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}$$

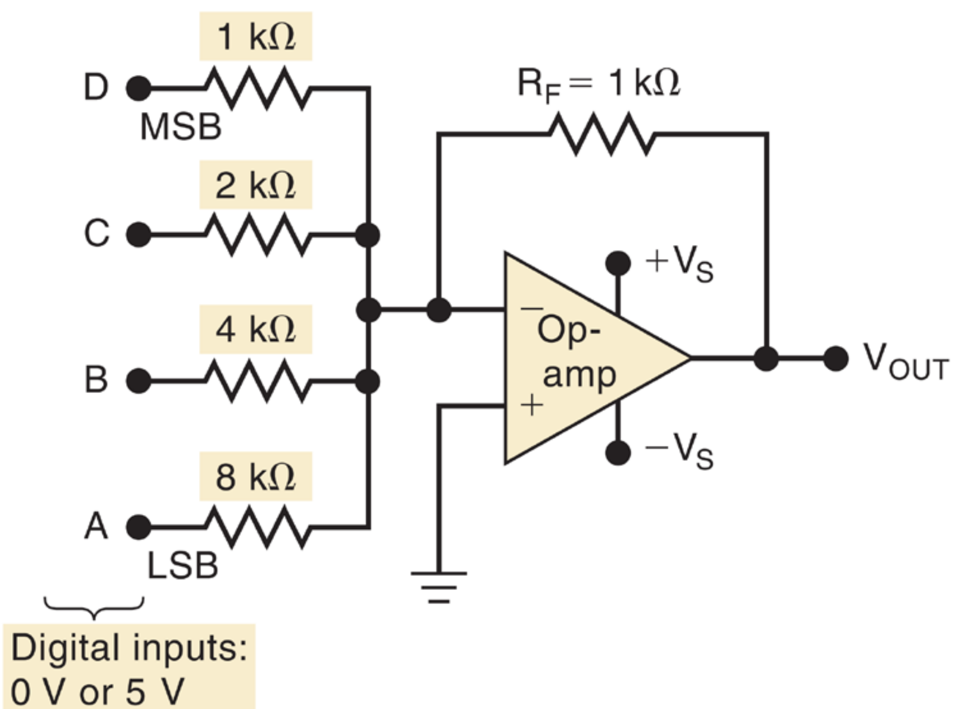
A binary weighted input D/A converter circuit



$$V_{out} = I_f R_f = \left(\frac{V}{8R} + \frac{V}{4R} + \frac{V}{2R} + \frac{V}{R}\right) R_f$$

D/A Converter Circuitry

- A summing operational amplifier with a resolution of .625 V



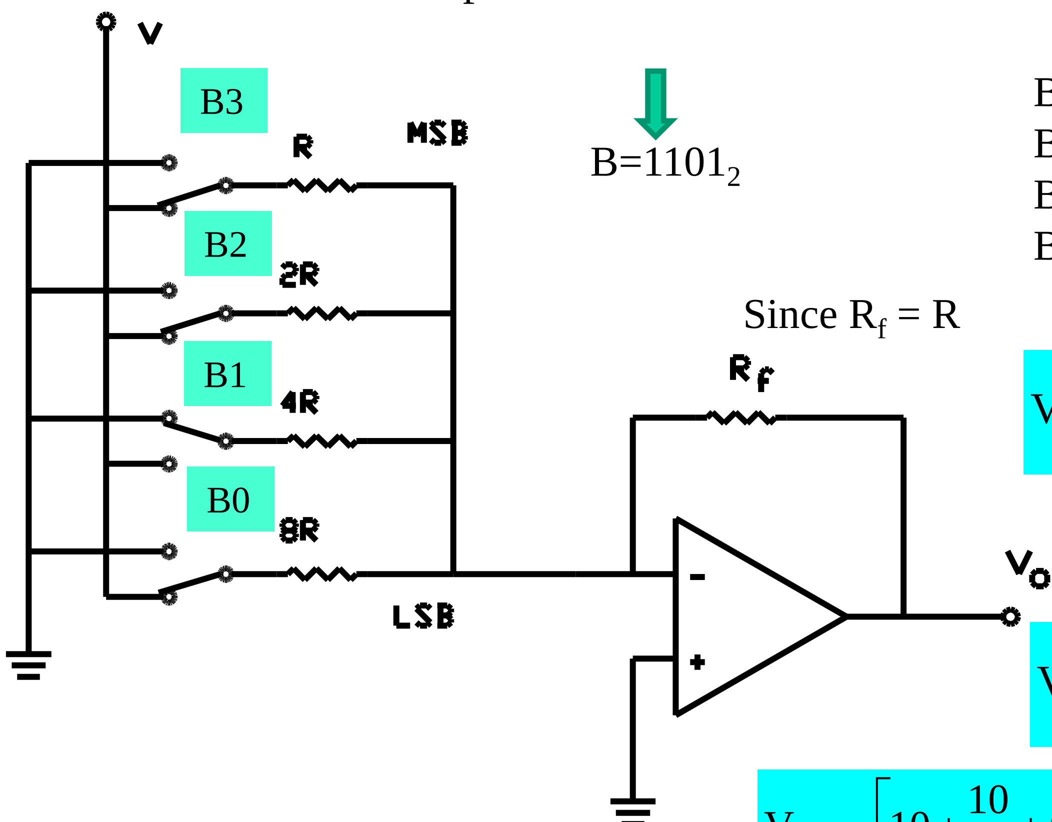
Input code

D	C	B	A	V_{OUT} (volts)
0	0	0	0	0
0	0	0	1	−0.625 ← LSB
0	0	1	0	−1.250
0	0	1	1	−1.875
0	1	0	0	−2.500
0	1	0	1	−3.125
0	1	1	0	−3.750
0	1	1	1	−4.375
1	0	0	0	−5.000
1	0	0	1	−5.625
1	0	1	0	−6.250
1	0	1	1	−6.875
1	1	0	0	−7.500
1	1	0	1	−8.125
1	1	1	0	−8.750
1	1	1	1	−9.375 ← Full-scale

Binary Weighted DAC Example

- Example: For the binary-weighted resistor DAC below find the output when the input word is 1101_2 V = 10 Vdc, R_f = R

n=4



$B=1101_2$

B3=1 MSB
B2=1
B1=0
B0=1 LSB

Since $R_f = R$

$$V_o = -R \cdot \left[\frac{B3 \cdot V}{2^{1-1}R} + \frac{B2 \cdot V}{2^{2-1}R} + \frac{B1 \cdot V}{2^{3-1}R} + \frac{B0 \cdot V}{2^{4-1}R} \right]$$

$$V_o = -\frac{R}{R} \cdot \left[\frac{1 \cdot V}{2^0} + \frac{1 \cdot V}{2^1} + \frac{0 \cdot V}{2^2} + \frac{1 \cdot V}{2^3} \right]$$

$$V_o = -1 \cdot \left[\frac{1 \cdot 10}{2^0} + \frac{1 \cdot 10}{2^1} + \frac{0 \cdot 10}{2^2} + \frac{1 \cdot 10}{2^3} \right]$$

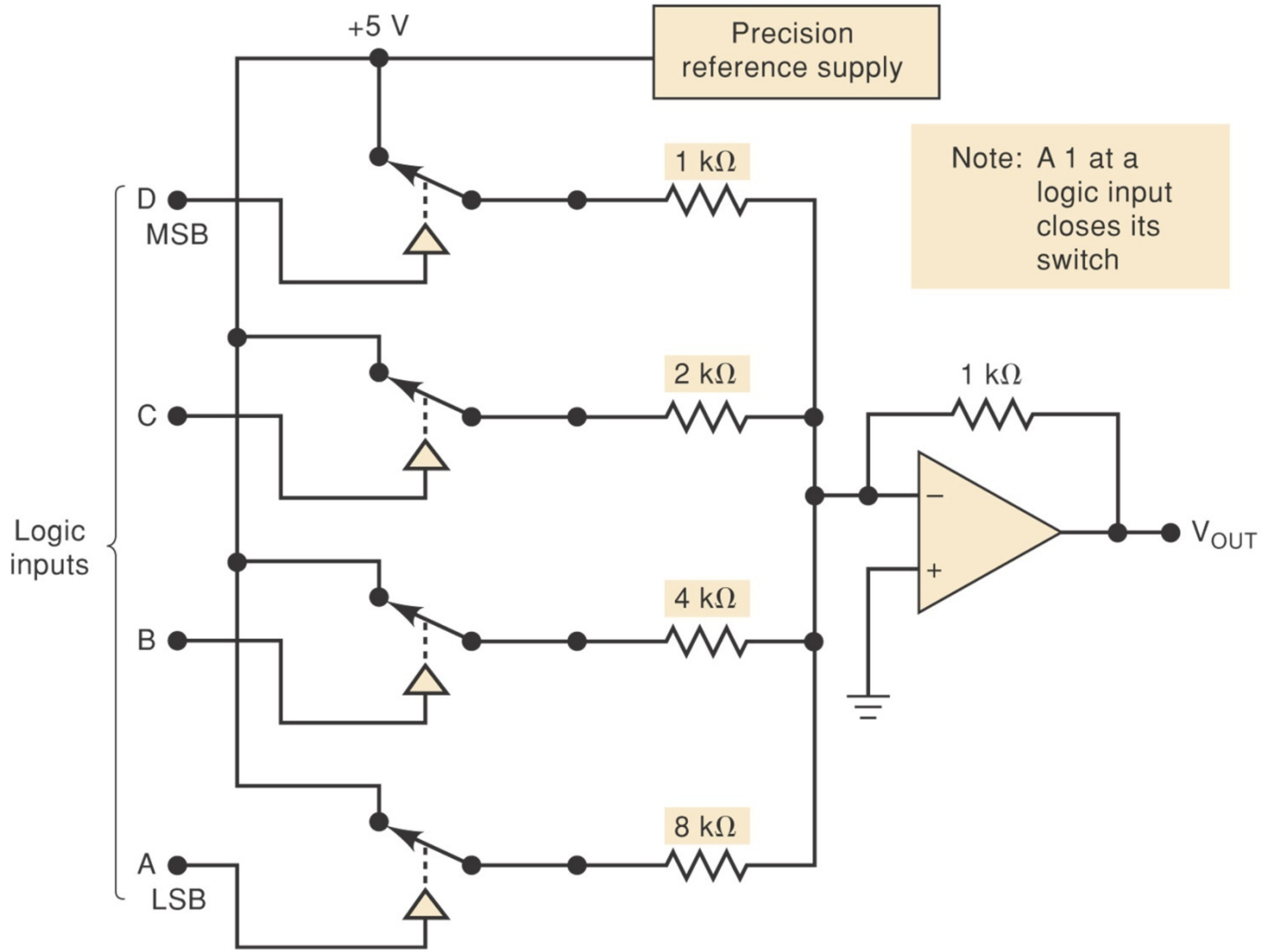
$$V_o = -\left[10 + \frac{10}{2} + 0 + \frac{10}{8} \right] = -[10 + 5 + 1.25] = -16.25$$

Precision of the O/P voltage depends on:

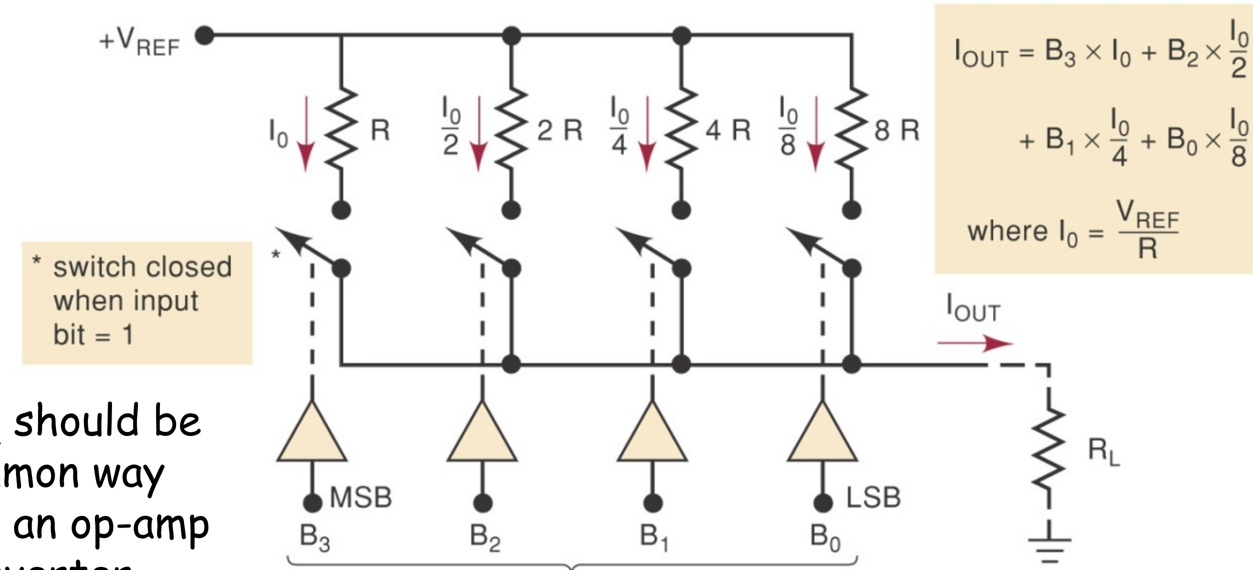
1) Precision of the resistors – can be made very accurate by trimming (But wide range needed !)
2) Precision of the I/P voltages. Need better precision than typical digital voltages. Use digital signals to select a precision voltage supply

Need additional circuitry

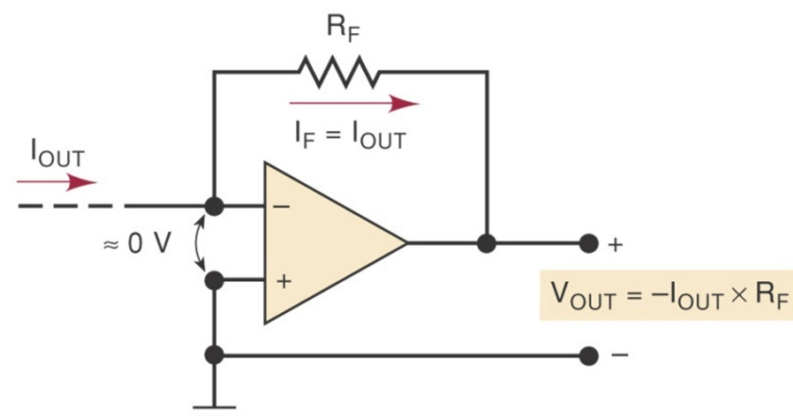
Complete four-bit DAC including a precision reference supply.



(a) Basic current-output DAC; (b) connected to an op-amp current-to-voltage converter.



(a)



(b)

For I_{OUT} to be accurate, R_L should be a short to ground. One common way to accomplish this is to use an op-amp as a current-to-voltage converter. Here, the I_{OUT} from the DAC is connected to the op-amp's "-" input, which is *virtually at ground*. The op-amp negative feedback forces a current equal to I_{OUT} to flow through R_F to produce $V_{OUT} = - I_{OUT} \times RF$. Thus, V_{OUT} will be an analog voltage that is proportional to the binary input to the DAC. This analog output can drive a wide range of loads without being loaded down.

Problem 1: Assume that V_{REF} = 10 V and R = 10 k Ω
Determine the resolution and the full-scale output for this DAC. Assume that RL is much smaller than R.

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Solution: $I_0 = V_{REF} / R = 1$ mA. This is the weight of the MSB. The other three currents will be 0.5, 0.25, and 0.125 mA. The LSB is 0.125 mA, which is also the resolution.

The full-scale output will occur when the binary inputs are all HIGH so that each current switch is closed and

$I_{OUT} = 1 + 0.5 + 0.25 + 0.125 = 1.875$ mA

Note that the output current is proportional to V_{REF}. If V_{REF} is increased or decreased, the resolution and the full-scale output will change proportionally.