Data Conversion Circuits D/A and A/D Converters

Data Conversion Circuits – D/A and A/D Converters

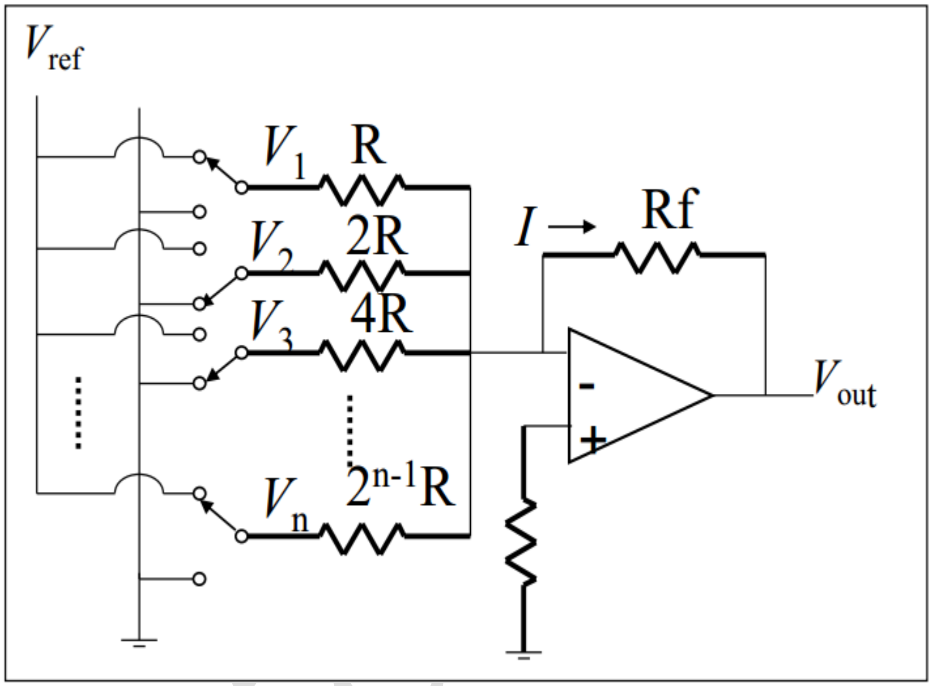
Digital-to-analogue (D/A) and analogue-to-digital (A/D) converters constitute an essential link when digital devices interface with analogue devices, and vice versa. They are important building blocks of any digital system, including both communication and non communication systems, besides having other applications. A D/A converter is important not only because it is needed at the output of most digital systems, where it converts a digital signal into an analogue voltage or current so that it can be fed to a chart recorder, for instance, for measurement purposes, or a servo motor in a control application ;it is also important because it forms an indispensable part of the majority of A/D converter types. An A/D converter, too, has numerous applications. When it comes to transmitting analogue data, it forms an essential interface with a digital communication system where the analogue signal to be transmitted is digitized at the sending end with an A/D converter. It is invariably used in all digital read-out test and measuring equipment. Whether it is a digital multi meter or a digital storage oscilloscope or even a pH meter, an A/D converter is an important and essential component of all of them. In this chapter, we will discuss the operational fundamentals, the major performance specifications, along with their significance, and different types and applications of digital-to-analogue and analogue-to-digital converters, in addition to application-relevant information of some of the popular devices. A large number of solved examples is also included to illustrate the concepts.

- **Digital-to-Analogue Converters**

A D/A converter takes digital data at its input and converts them into analogue voltage or current that is proportional to the weighted sum of digital inputs. In the following paragraphs it is briefly explained how different bits in the digital input data contribute a different quantum to the overall output analogue voltage or current, and also that the LSB has the least and the MSB the highest weight.

Binary Weighted Resistor
Voltages V1through Vn are either V ref if corresponding bit is high or ground if corresponding bit is low

V1is most significant bit
Vn is least significant bit

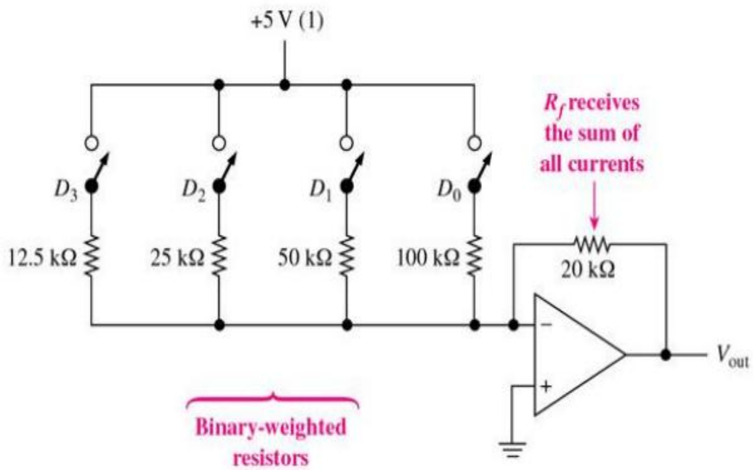


MSB

$$V_{out} = -IR_f = -R_f\left(\frac{V_1}{R} + \frac{V_2}{2R} + \frac{V_3}{4R} + \cdots \frac{V_n}{2^{n-1}R}\right)$$

LSB

1- Binary-Weighted Digital-to-Analog Converters



Digital				Analog
D_3	D_2	D_1	D_0	V_{out} (−V)
0	0	0	0	0
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

Advantages: Simple Construction/Analysis; Fast Conversion

Disadvantages: Requires large range of resistors (2000:1 for 12-bit DAC) with necessary high precision for low resistors; requires low switch resistances in transistors.

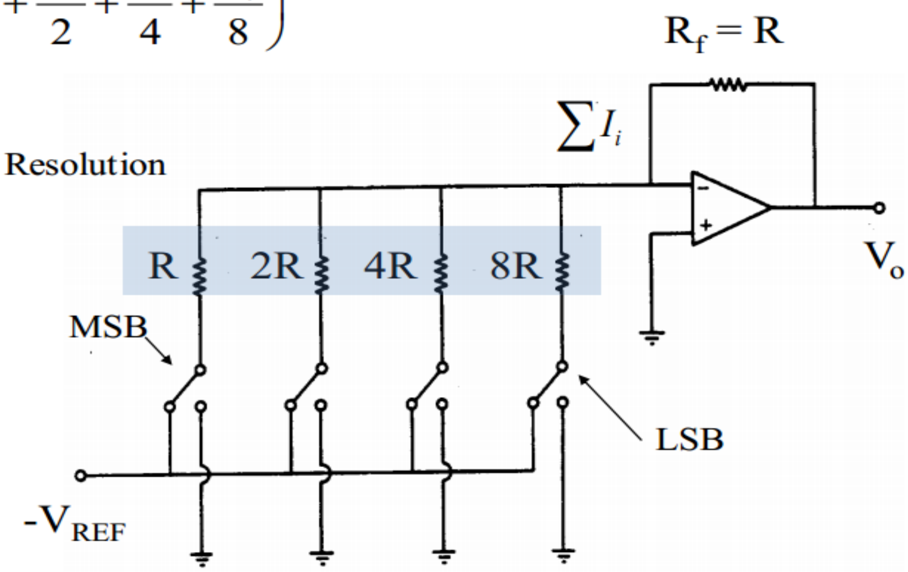
Binary Weighted Resistor

$$\sum I = V_{REF}\left(\frac{B_3}{R} + \frac{B_2}{2R} + \frac{B_1}{4R} + \frac{B_0}{8R}\right)$$

$$V_{OUT} = I \cdot R_f = V_{REF}\left(B_3 + \frac{B_2}{2} + \frac{B_1}{4} + \frac{B_0}{8}\right)$$

$$V_{OUT} = V_{REF}\sum \frac{B_i}{2^{n-i-1}}$$

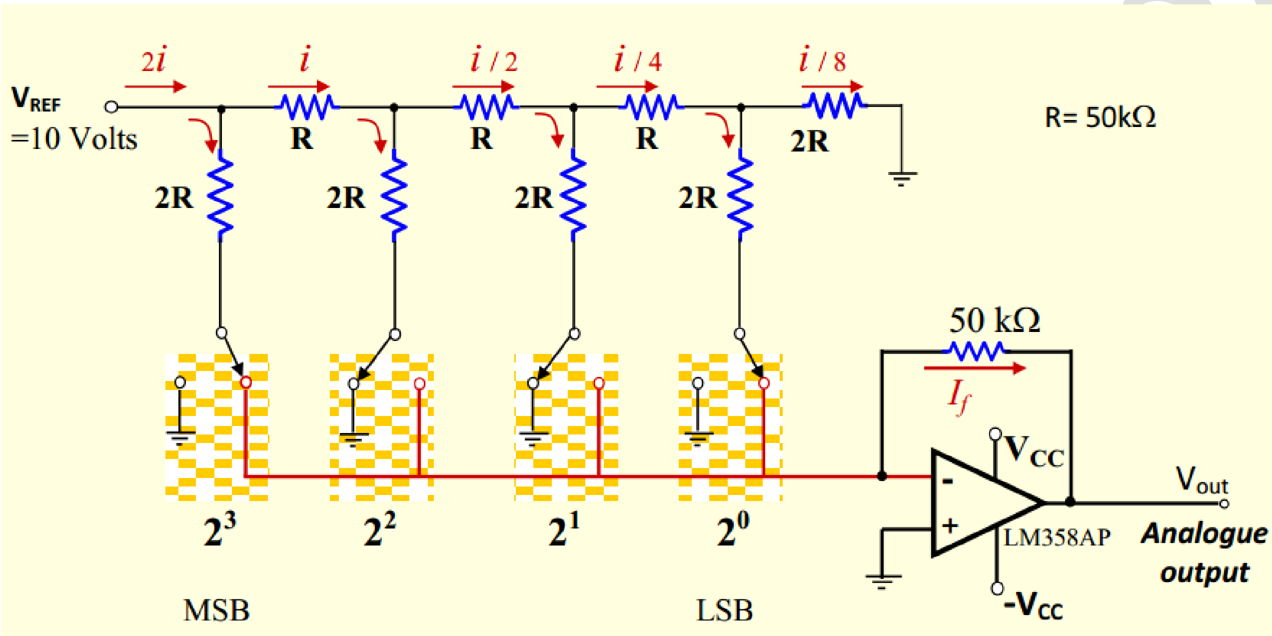
$$= V_{REF} \cdot \text{Digital Value} \cdot \text{Resolution}$$



2- R-2R Ladder

• The less significant the bit, the more resistors the signal muss pass through before reaching the op-amp

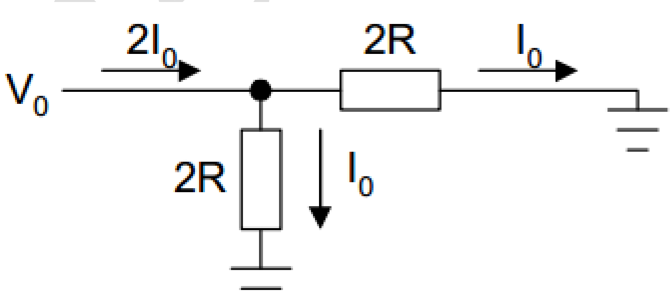
• The current is divided by a factor of 2 at each node



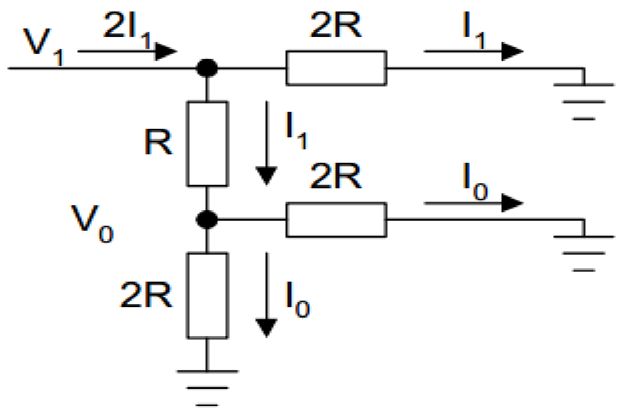
R-2R Ladder

We want to generate currents I0, 2I0, 4I0, …

–Two 2Rresistors in parallel means that the 2Iocurrent will split equally



– The Théven in resistances of the two branches at V1both equal 2Rso the current into this node will split evenly.

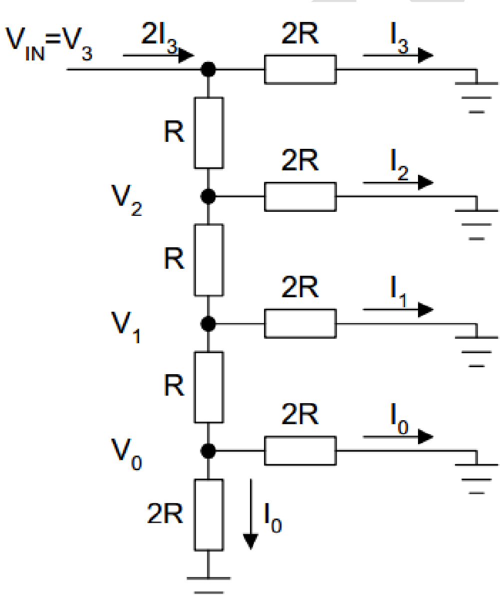


We already know that the current into We already know that the current into node V0is 2I0, so it follows that I1=2Io..

--We can repeat this process indefinitely and, using only two resistor values ,can generate a whole series of currents where In=2nIo.

From the voltage drop across the gp horizontal resistors, we see that

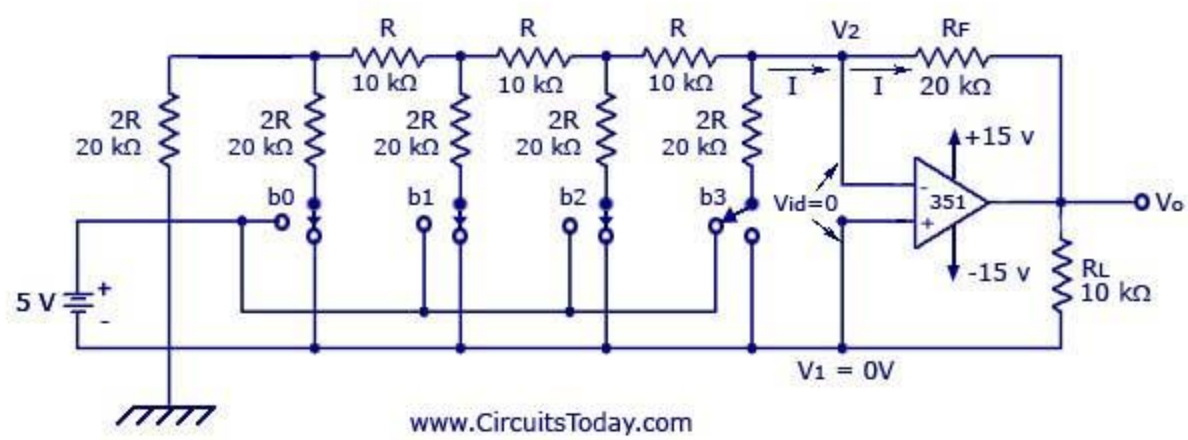
$V_n = 2RI_n = 2^{n+1}RI_0$. For an N-bit ladder the input voltage is therefore $V_{in} = 2^N RI_0 \Rightarrow I_0 = 2^{-N}\, V_{in}/R$.



Advantages / Disadvantages

- **Advantages– R/2nR**
- Fewer Components
- Easy to build for IC's– R/2R
- Greater Stability
- Needs only two values of resistors
- Less reference voltage loading
- **Disadvantages– R/2nR**
- Hard to match resistors
- Stability with temperature change
- Large R more susceptible to noise
- Wide range of reference voltage loading – R/2R
- More parts
- Harder to construct

D/A Converter With R and 2R Resistors



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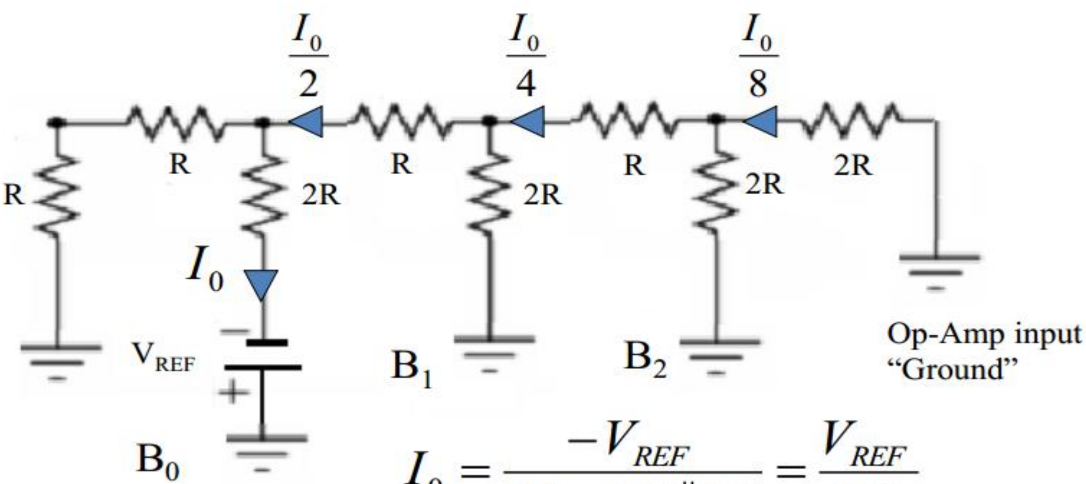
R-2R Ladder

The current is divided by a factor of 2 at each node; Analysis for current from (001)2 shown below



$$I_0 = \frac{-V_{REF}}{2R + 2R \| 2R} = \frac{V_{REF}}{3R}$$

R-2R Ladder: An Example

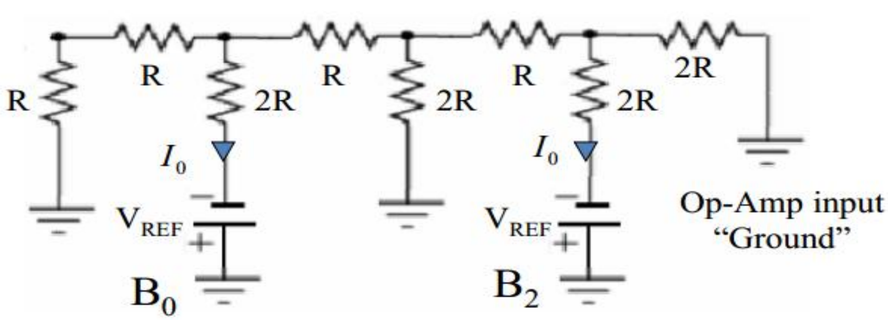
Find the output voltage of the Op-Amp for the following DAC

- Given Values
  - Input = $(101)_2$
  - $V_{REF} = 10$ V
  - R = 2 Ω
  - $R_f = 2R$

$$I_0 = \frac{-V_{REF}}{2R + 2R \| 2R} = \frac{V_{REF}}{3R} = -1.67 \text{ mA}$$

$$I_{op-amp} = \frac{I_0}{8} + \frac{I_0}{2} = -1.04 \text{ mA}$$

$$V_{OUT} = -I_{op-amp} R_f = 4.17 \text{ V}$$



- **Analogue-to-Digital Converters**

What is ADC

- An electronic integrated circuit which transforms a signal from analog (continuous)to digital (discrete) form.
- Analog signals are directly measurable quantities.
- Digital signals only have two states. For digital computer, we refer to binary states, 0and 1.

Types of A/D Converters

- Dual Slope A/D Converter
- Successive Approximation A/D Converter
- Flash A/D Converter
- Delta-Sigma A/D Converter
- Other

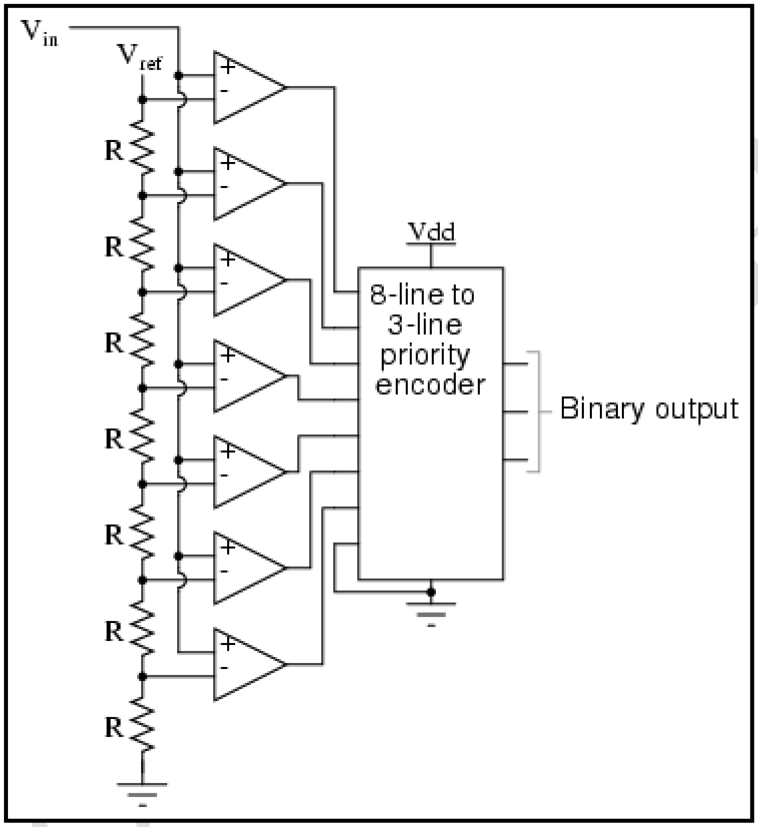
Voltage-to-frequency, staircase ramp or single slope, charge balancing or redistribution, switched capacitor, tracking, and synchro or resolver

Flash A/D Converter

Fundamental Components (For N bit Flash A/D)

- 2N-1 Comparators
- 2N Resistors
- Control Logic

If	Output
$V_{IN} > V_{REF}$	High
$V_{IN} < V_{REF}$	Low



Application of ADC

- ADC are used virtually everywhere where an analog signal has to be processed, stored, or transported in digital form.
- Some examples of ADC usage are digital volt meters, cell phone, thermocouples, and digital oscilloscope.
- Microcontrollers commonly use 8, 10, 12, or16 bit ADCs, our micro controller uses an 8 or 10 bit ADC.