6

D/A AND A/D CONVERTERS (DATA CONVERTERS)

In This Chapter

6.1 DATA CONVERTERS

Signals in the real world are analogous e.g.,— light, sound etc. So real world signals must be converted into digital using a circuit called as analog to digital converter, before they can be manipulated by digital equipment.

e.g.,— when we scan a picture with a scanner, what scanner is doing is an analog to digital conversion. It is taking the analog information provided by the picture (light) and converting it into digital.

When we record our voice or use a VOIP solution on our computer, we are using an analog to digital converter to convert our voice, which is analog, into digital information.

Digital information is not only restricted to computers. When we talk on the phone e.g., our voice is converted into digital (at the central office switch: If we use an analog line or at our home, if we use a digital line like ISDN or DSL). Since our voice is analog and the communication between the phone switches is done digitaly.

When an audio CD is recorded at a studio, once again analog to digital is taking place, converting sounds into digital numbers that will be stored on the disc.

Whenever we need the analog signal back, the opposite conversion-digital to analog converter) which is done by a circuit called DAC (Digital to analog converter) is needed. When we play audio CD, what the CD player is doing is reading digital information stored on the disc and converting it back to analog. So we can hear the music.

When we are talking on the phone, a digital to analog conversion is also taking place (at the central office switch: Analog line, or at our home, if we use a digital line like ISDN or DSL). So we can hear what the other party is saying.

But why digital? There are some basic reasons to use digital signals instead of analog—

(*i*) **Noise**—As analog signals can assume any value, hence noise in interpreted as being part of the original signal.

e.g.,— when we listen to a LP (Long Playing) recording, we hear noise, because the needle is analog and thus don't know the difference from the music originally recorded from the noise inserted by dust or cracks. Digital systems on the other can only understand two numbers i.e., 0 & 1. Anything different from that is discarded. That's why we don't hear any unwanted noise when listening to an audio CD, even if we played it thousands times before.

(*ii*) **Data compression capability:** Since the digital counter part of an analog signal is just a bunch of numbers, there numbers can be compressed, just like we would compress a word like using WinZip to shrink down file size e.g., compression can be done to save storage space or bandwidth.

Data counters convert one form of data to another form of data.

Types of Data converters

1. Digital to Analog Converter (D/A converter)
2. Analog to Digital Converter (A/D Converter)

Digital to Analog Converter

It converts digital data into its equivalent analog data.

Use of analog data : To drive motors/other analog devices.

Analog to Digital Converter

It convertes analog data into its equivalent digital data.

Use of digital data : For easy processing.

D/A Converter (DAC)

Digital/Binary data → Analog data (Voltage/Current)

Block diagram

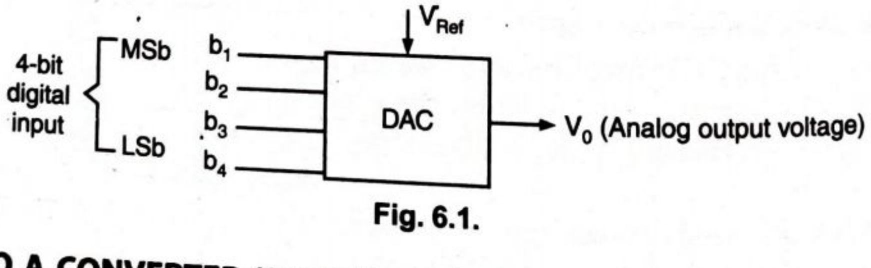

Fig. 6.1.

6.2. D TO A CONVERTER (DIGITAL TO ANALOG CONVERTER (DAC)

Definition :

D/A conversion is a process of taking a value represented in digital code e.g., binary data and converting it into a voltage or current which is proportional to the digital value.

Block Diagram of DAC

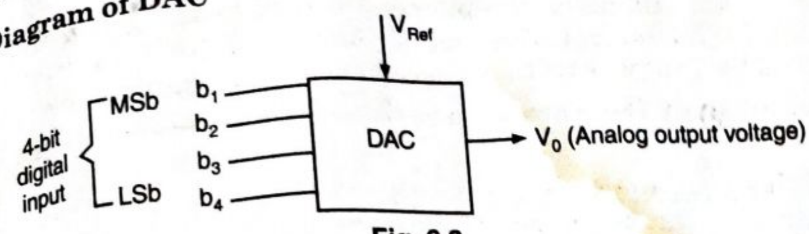

Fig. 6.2

DAC takes binary data and V_{Ref} as input and converts it to analog output voltage V_O.

Mathematically we can represent:

$$V_0 = k\, V_{Ref}\left[b_1 + \frac{b_2}{2} + \frac{b_3}{4} + \frac{b_4}{8}\right] \quad ...(1)$$

where V_0 – Analog output voltage

V_{Ref} – Reference input voltage

$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix}$ – 4 bits of binary input : b_1 – MSb

: b_4 – LSb

b_1, b_2, b_3, b_4 can take value either 1 or 0.

Let's take $k = 0.5$ and $V_{Ref} = 10$ V. Now, for different combinations of $b_1\, b_2\, b_3\, b_4$, we find output voltage V_0.

b_1	b_2	b_3	b_4	V_0
0	0	0	0	0V
0	0	0	1	$V_0 = 0.5 \times 10\left[\frac{1}{8}\right] = \frac{5}{8} = 0.625$ V
0	0	1	0	$V_0 = 0.5 \times 10\left[\frac{1}{4}\right] = \frac{5}{4} = 1.25$ V
0	0	1	1	$V_0 = 0.5 \times 10\left[\frac{1}{4} + \frac{1}{8}\right] = 5\left[\frac{2+1}{8}\right] = \frac{15}{8} = 1.875$ V
0	1	0	0	$V_0 = 0.5 \times 10\left[\frac{1}{2}\right] = 2.5$ V
0	1	0	1	$V_0 = 0.5 \times 10\left[\frac{1}{2} + \frac{1}{8}\right] = 5\left[\frac{4+1}{8}\right] = 3.125$ V
0	1	1	0	$V_0 = 0.5 \times 10\left[\frac{1}{2} + \frac{1}{4}\right] = 5\left[\frac{2+1}{4}\right] = 3.75$ V
0	1	1	1	$V_0 = 0.5 \times 10\left[\frac{1}{2} + \frac{1}{4} + \frac{1}{8}\right] = 5\left[\frac{4+2+1}{8}\right] = 4.375$ V

1 0 0 0	$V_0 = 0.5 \times 10\,[1] = 5\text{ V}$
1 0 0 1	$V_0 = 0.5 \times 10\left[1+\frac{1}{8}\right] = 5\left[\frac{9}{8}\right] = 5.625\text{ V}$
1 0 1 1	$V_0 = 0.5 \times 10\left[1+\frac{1}{4}+\frac{1}{8}\right] = 5\left[\frac{8+2+1}{8}\right] = 6.875\text{ V}$
1 1 0 1	$V_0 = 0.5 \times 10\left[1+\frac{1}{2}\right] = 5\left(\frac{3}{2}\right) = 7.5\text{ V}$
1 1 0 1	$V_0 = 0.5 \times 10\left[1+\frac{1}{2}+\frac{1}{8}\right] = 5\left[\frac{8+4+1}{8}\right] = 8.125\text{ V}$
1 1 1 0	$V_0 = 0.5 \times 10\left[1+\frac{1}{2}+\frac{1}{4}\right] = 5\left[\frac{4+2+1}{4}\right] = 8.15\text{ V}$
1 1 1 1	$V_0 = 0.5 \times 10\left[1+\frac{1}{2}+\frac{1}{4}+\frac{1}{8}\right] = 5\left[\frac{8+4+2+1}{8}\right] = 9.375\text{ V}$

$$0 + 0.625\text{V} = 0.625\text{ V} + 0.625\text{ V} = 1.25\text{ V} + 0.625\text{ V} = 1.875\text{ V} + 0.625\text{ V} = 2.5\text{ V}$$
$$2.5\text{ V} + 0.625\text{ V} = 3.125\text{ V} + 0.625\text{ V} = 3.75\text{ V} + 0.625\text{ V} = 4.375\text{ V} + 0.625\text{ V} = 5\text{ V}$$
$$5\text{ V} + 0.625\text{ V} = 5.625\text{ V} + 0.625\text{ V} = 6.25\text{ V} + 0.625\text{ V} = 6.875\text{ V}$$
$$6.875\text{ V} + 0.625\text{ V} = 7.5\text{ V} + 0.625\text{ V} = 8.125\text{ V} + 0.625\text{ V} = 8.75\text{ V} + 0.625 = 9.375\text{ V}$$

We have seen that: Between two successive levels, difference is 0.625 V which is called as resolution.

Resolution—Change of analog output caused by change of input of 1 bit i.e., 0.625 V.

Hence, resolution is voltage increment between adjacent upper levels.

Transfer characteristics of 3 bit DAC—

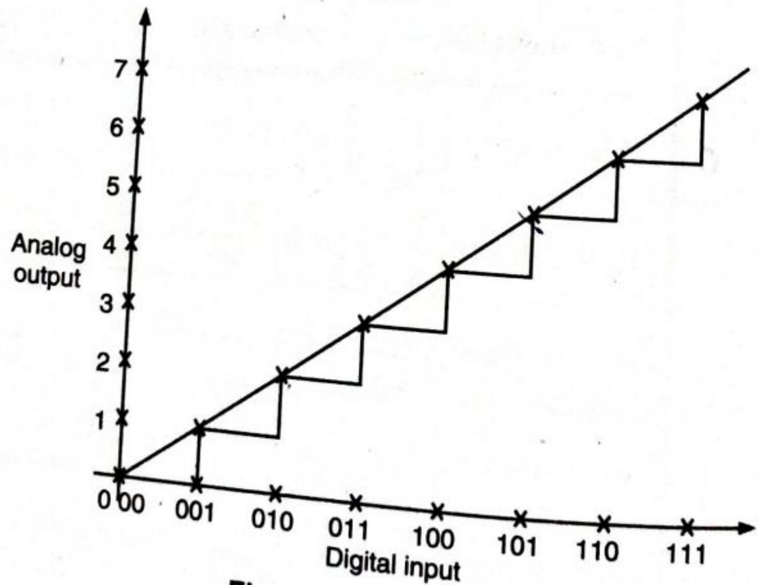

Fig. 6.3. Digital input

Ideally transfer curve is observed as linear. But, practically transfer curve is found to be Non linear.

6.3. SPECIFICATION OF DAC OR GOVERNING CHARACTERISTICS OF DAC

"These characteristics play an important role to determine the stability and accuracy of analog output." Characteristics are specified as—

(1) Accuracy
(2) Monotonicity
(3) Resolution
(4) Offset voltage
(5) Settling time
(6) Temperature Sensitivity

(1) Accuracy

"It measures how much obtained analog output voltage is close to expected theoretical output". e.g. Accuracy of ± 1% : It indicates that if Ideal/Theoretical analog output voltage is 100 V. Then it is said to be accurate if it lies in the range of 99-101V.

(2) Monotonicity:

"A D/A converter is said to be monotonic if it gives an analog output voltage which increases linearly and offcourse regularly with regular increments of digital input signal."

Let's take a block diagram of 3 bit DAC.

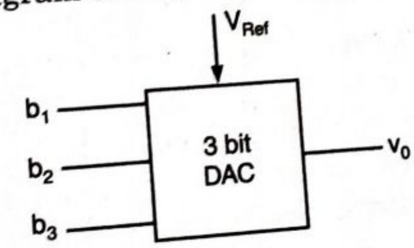

Fig. 6.4.

Output voltage obtained should be a perfect staircase waveform with steps equally spaced and of same amplitude. We can observe this by drawing transfer characteristics of 3 bit DAC:

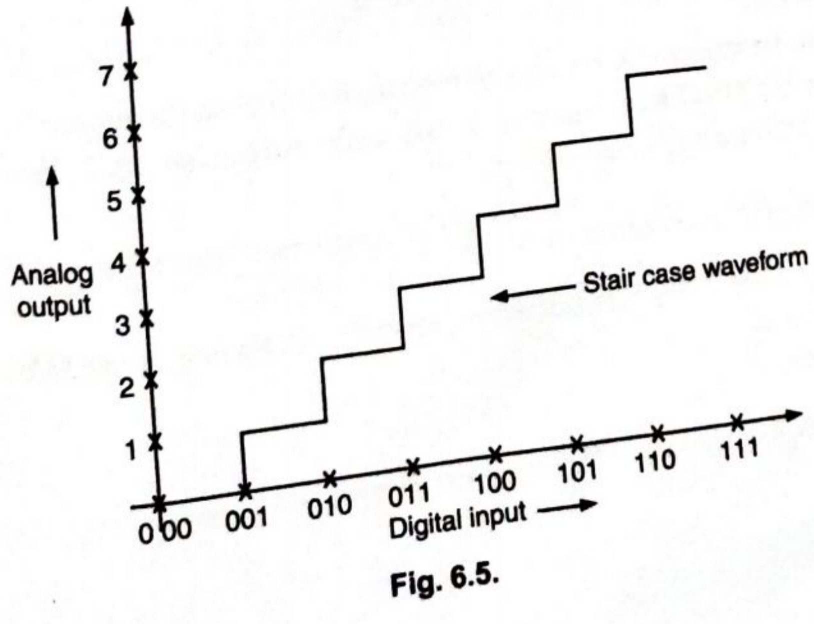

Fig. 6.5.

Perfect staircase waveform indicates monotonicity is maintained otherwise if steps are missing or have varying amplitude, it means monotonicity is not maintained and DAC is said to be defective.

(3) Resolution:

"Change in analog output caused by change in digital input of 1 bit is called as resolution. e.g.,—Let's take a 4 bit DAC. Digital Input bits are b_1, b_2, b_3 and b_4 and obtained analog output voltage is V_0.

b_1	b_2	b_3	b_4	$V_0(V)$
0	0	0	0	$0V$
0	0	0	1	$1V$
0	0	1	0	$2V$
0	0	1	1	$3V$
0	1	0	0	$4V$
0	1	0	1	$5V$
0	1	1	0	$6V$
0	1	1	1	$7V$
1	0	0	0	$8V$
1	0	0	1	$9V$
1	0	1	0	$10V$
1	0	1	1	$11V$
1	1	0	0	$12V$
1	1	0	1	$13V$
1	1	1	0	$14V$
1	1	1	1	$15V$

In the drawn table, we observe that resolution obtained here is 1 V.

Resolution is always equal to weight of LSb and is also known as step size.

Generally resolution is expressed as—

"Amount of voltage increment per step"

Otherwise:

"Resolution is expressed as a percentage of full scale output".

e.g.,— 4 bit DAC has maximum full scale output as 15 V. We need to find out its resolution and % resolution.

$$\text{Resolution (step size)} = \frac{\text{Full scale output (maximum output)}}{\text{No. of steps}}$$

For *n* bit DAC: Number of steps are $2^n - 1$. Hence, 4 bit DAC require 15 steps to progress.

In this way:

$$\text{Resolution} = \frac{15\text{ V}}{15} = 1\text{ V}$$

Hence step size = 1 V

Now % resolution can be found as—

$$\% \text{ resolution} = \frac{\text{Step size}}{\text{Full scale output}} \times 100 = \frac{\left(\dfrac{\text{Full scale output}}{\text{No. of steps}}\right)}{\text{Full scale output}} \times 100$$

$$= \frac{1\text{ V}}{15\text{ V}} \times 100 = \frac{1}{\text{No. of steps}} \times 100$$

$$= 6.67\% = \frac{1}{2^n - 1} \times 100$$

Q: For 3 bit DAC, full scale output voltage is 10 V. Find out step size and percentage resolution.

Answer: Step size $= \dfrac{10}{7} = 1.42$ V

% resolution $= \dfrac{1}{7} \times 100 = 14.2\%$

Q: For 4 bit DAC, full scale output voltage is 10 V. Find out step size and percentage resolution.

Answer: Step size $= \dfrac{10}{2^{10} - 1} = 9.8$ mV

% Resolution = 0.0978%

(4) Offset Voltage

Ideally output of a digital to analog converter will come cut 0V if binary inputs are all zeros. But practically, there will be a very small output voltage called as offset voltage.

(5) Settling Time

"Time taken by DAC to produce an output to settle within $\pm \frac{1}{2}$ (Weight of LSb) or $\pm \frac{1}{2}$ (Resolution) or $\pm \frac{1}{2}$ (LSb) of its final value due to change in digital input.

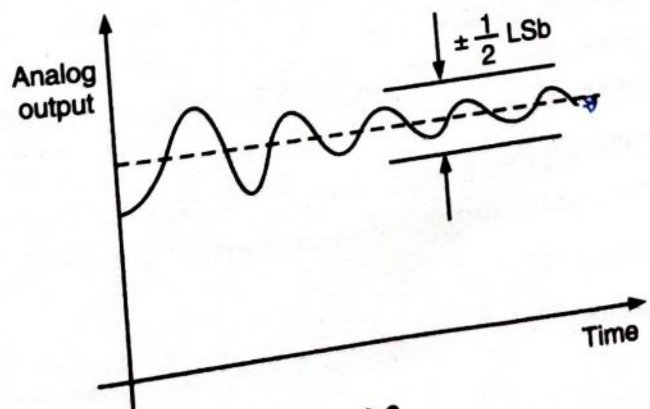

Fig. 6.6.