Digital Electronics: Electronics, Devices and Circuits

Interfacing to the ‘Analogue World’

Introduction

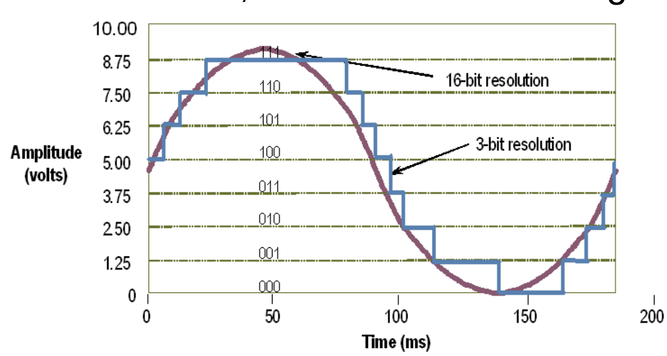
- Digital electronic systems often need to interface to the ‘analogue’ real world. For example:
  - To convert an analogue audio signal to a digital format we need an analogue to digital converter (ADC)
  - Similarly to convert a digitally represented signal into an analogue signal we need to use a digital to analogue converter (DAC)
- ADCs and DACs are implemented in various ways depending upon factors such as conversion speed, resolution and power consumption

Analogue to Digital Conversion

- ADC is a 2 stage process:
  - Regular sampling to convert the continuous time analogue signal into a signal that is discrete in time, i.e., it only exists at multiples of the sample time T. Thus x(t) can be represented as x(0), x(T), x(2T), x(3T)….
  - These sample values can still take continuous amplitude values, hence the next step is to represent them using only discrete values in the amplitude domain. To do this the samples are quantised in amplitude, i.e., they are constrained to take one of only M possible amplitude values
  - Each of these discrete amplitude levels is represented by an n-bit binary code
  - Thus in an n-bit ADC, there are $M=2^n$ quantisation levels

Analogue to Digital Conversion

- Thus the ADC process introduces 'quantisation error' owing to the finite number of possible amplitude levels that can be represented
- The greater is the number of quantisation levels (i.e., 'bits' in the ADC), the lower will be the quantisation error, but at the cost of a higher bit rate



Analogue to Digital Conversion

- In addition, the sample rate (1/T) must be at least twice the highest frequency in the analogue signal being sampled – known as the Nyquist rate
- To ensure this happens, the analogue signal is often passed through a low pass filter that will remove frequencies above a specified maximum
- If the Nyquist rate is not satisfied, the sampled signal will be subject to 'alias distortion' that cannot be removed and will be present in the reconstructed analogue signal

Analogue to Digital Conversion

- The ADC also requires that the input signal suits its specified amplitude range. Usually, the ADC has a range covering several Volts, while the signal from the transducer can be of the order of mV
- Consequently, amplification (a voltage gain>1) of the analogue signal is usually required before being input to the ADC
- If not, the digitised signal will have poor quality (i.e., a low signal to quantisation noise ratio)
- Operational amplifier based 'Gain blocks' in front of the ADC are often used since they have predictable performance and are straightforward to use

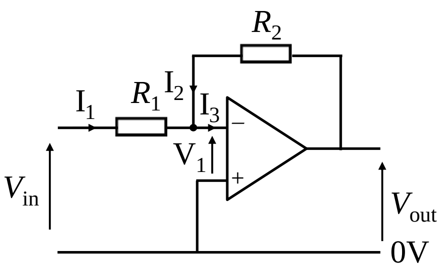
Digital to Analogue Conversion

- A DAC is used to convert the digitised sample values back to an analogue signal.
- A low pass filter (one that removes high frequencies) usually follows the DAC to yield a smooth continuous time signal
- Operational amplifier based buffer amplifiers are also often used following the DAC to prevent the load (e.g., transducers such as headphones) affecting the operation of the DAC

Operational Amplifier Circuits

- Operational amplifiers (or ‘Op-Amps) have 2 inputs (known as inverting (-) and non-inverting (+)) and a single output
- They can be configured to implement gain blocks (i.e., amplifiers) and many other functions, e.g., filters, summing blocks
- We will now look at several common op-amp based amplifier configurations, specifically inverting, non-inverting and unity gain buffer
- We will assume the use of ‘ideal’ op-amps, i.e., infinite input resistance (zero input current) and infinite gain.

Inverting Amplifier



$I_1 + I_2 - I_3 = 0$

Now, $I_3 = 0$ since the input resistance of the op amp is ∞, so

$I_1 = -I_2$

$V_{in} - I_1 R_1 - V_1 = 0$ and

$V_1 + I_2 R_2 - V_{out} = 0$

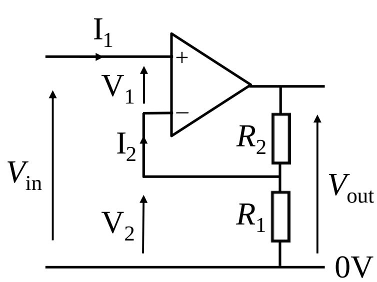
Now, $V_1 = 0$ since the op-amp has ∞ gain (virtual earth assumption)

$V_{in} = I_1 R_1$ and $V_{out} = I_2 R_2 = -I_1 R_2$

So, $I_1 = -\dfrac{V_{out}}{R_2}$

Yielding, $V_{in} = -\dfrac{V_{out} R_1}{R_2}$ Voltage gain, $\dfrac{V_{out}}{V_{in}} = -\dfrac{R_2}{R_1}$

Non-Inverting Amplifier



Now, $I_1 = I_2 = 0$ since the input resistance of the op amp is ∞, so

$V_2 = V_{out} \dfrac{R_1}{R_1 + R_2}$

$V_{in} - V_1 - V_2 = 0$

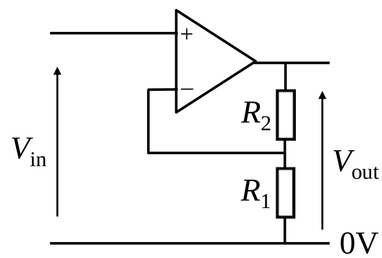
Now, $V_1 = 0$ since the op-amp has ∞ gain (virtual earth assumption)

$V_2 = V_{in}$

So, $V_{in} = V_{out} \dfrac{R_1}{R_1 + R_2}$

Yielding, $\dfrac{V_{out}}{V_{in}} = \dfrac{R_1 + R_2}{R_1}$ Voltage gain, $\dfrac{V_{out}}{V_{in}} = 1 + \dfrac{R_2}{R_1}$

Buffer Amplifier (Unity Gain)

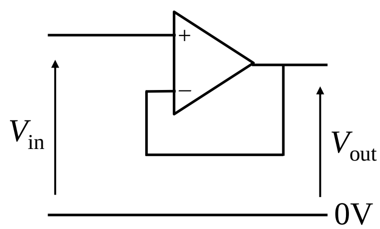


We know the voltage gain for the non-inverting amplifier is,

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$$

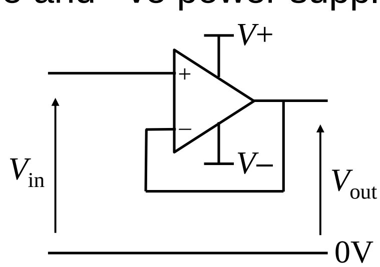
Now, if we let $R_2 = 0$ (a short circuit) and $R_1 = \infty$ (open circuit) then

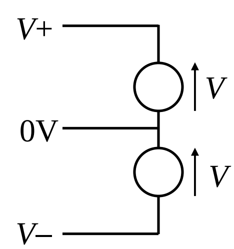
$$\frac{V_{out}}{V_{in}} = 1$$



Op-Amp Power Supplies

- Usually, op-amps use split power supplies, i.e., +ve and –ve power supply connections





- This permits input signals having both +ve and –ve excursions to be amplified
- This can be inconvenient for battery powered equipment. However, if the input signal is for e.g., always +ve, the V– rail can removed i.e., set to 0V

Op-Amp Applications

- As mentioned, op-amps can be used in many other common analogue signal processing tasks, for example:
  - Filters: circuits that can manipulate the frequency content of signals
  - Mathematical functions, e.g., integrators and differentiators
  - Comparators and triggers, i.e., thresholding devices
- A ‘cookbook’ of useful such applications can be found in ‘The Art of Electronics’ by Horowitz and Hill