Imperial College London

Topic 10

Amplification and Amplifiers

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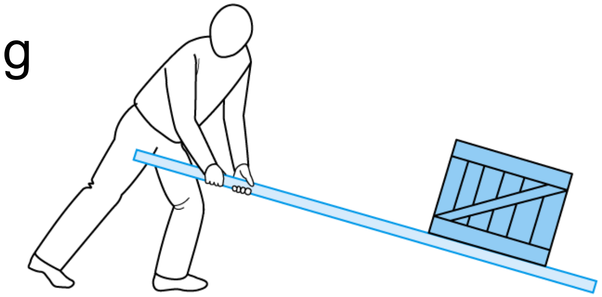
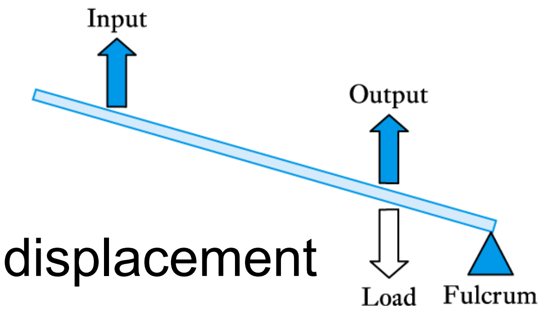
The Idea of amplification

- Amplification is one of the most common processing functions
- **Amplification** means making things bigger
- **Attenuation** means making things smaller
- There are many non-electronic forms of amplification

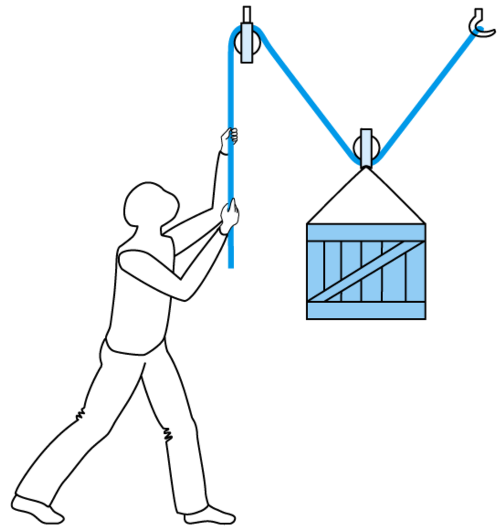




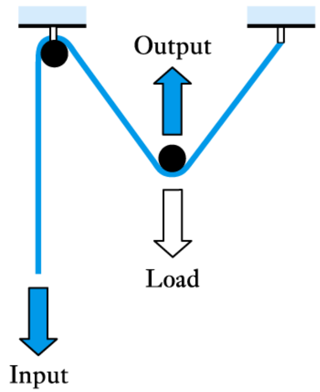
- **Non-electronic amplifiers: Levers**
  - Example shown on the right is a force *amplifier*, but a displacement *attenuator*
  - Reversing the position of the input and output would produce a force *attenuator* but a displacement *amplifier*
  - This is an example of a **non-inverting amplifier** (since the input and output are in the same direction)

Another example of amplification

- **Non-electronic amplifiers**
  - **Pulleys**
    - Example shown here is a force *amplifier*, but a displacement *attenuator*
    - This is an example of an **inverting amplifier** (since the input and output displacements are in opposite directions) but other pulley arrangements can be non-inverting



- **Passive and active amplifiers**
  - Levers and pulleys are examples of **passive amplifiers** since they have no external energy source
    - ➢ In such amplifiers the power delivered at the output must be less than (or equal to) that absorbed at the input
  - Some amplifiers are not passive but are **active amplifiers** in that they have an external source of power
    - ➢ In such amplifiers the output can deliver more power than is absorbed at the input



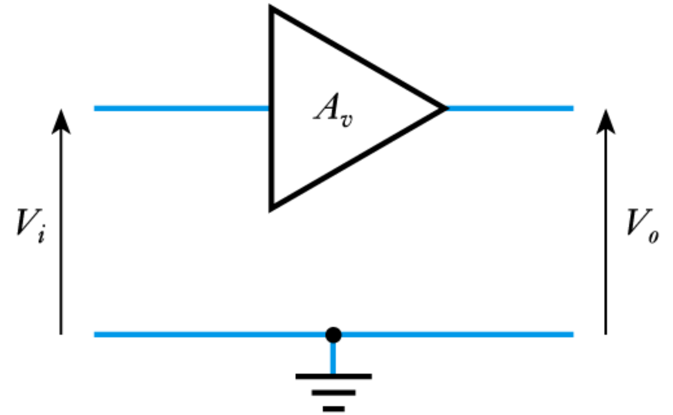
Electronic Amplifiers

- We will concentrate on *active* electronic amplifiers
  - take power from a power supply
  - amplification described by gain

$$\text{Voltage Gain } (A_v) = \frac{V_o}{V_i} \text{ or } 20\log_{10}\frac{V_o}{V_i}\text{ dB}$$

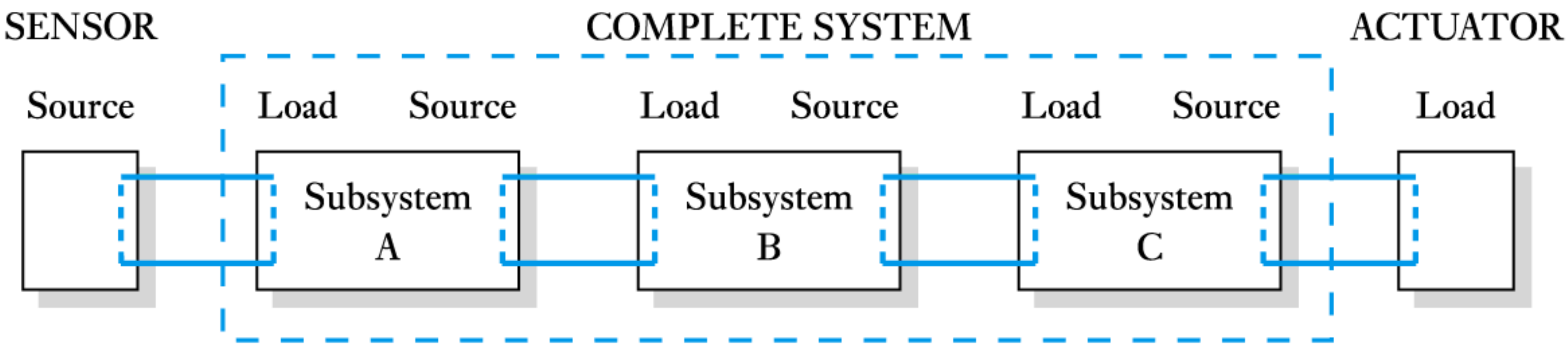
$$\text{Current Gain } (A_i) = \frac{I_o}{I_i} \text{ or } 20\log_{10}\frac{I_o}{I_i}\text{ dB}$$

$$\text{Power Gain } (A_p) = \frac{P_o}{P_i} \text{ or } 10\log_{10}\frac{P_o}{P_i}\text{ dB}$$



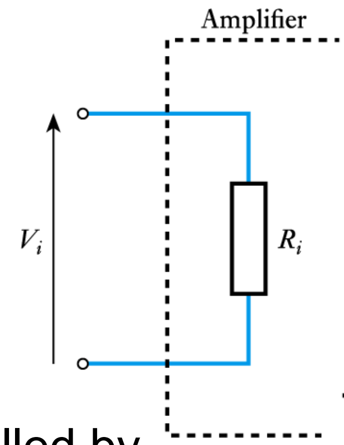
Sources and Loads

- An *ideal* voltage amplifier would produce an output determined only by the input voltage and its gain.
  - irrespective of the nature of the source and the load
  - in real amplifiers this is not the case
  - the output voltage is affected by **loading**

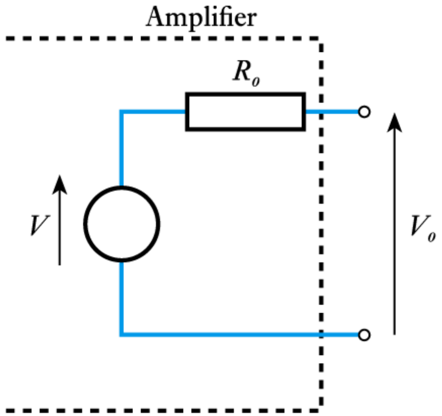


Modelling Sources and Loads

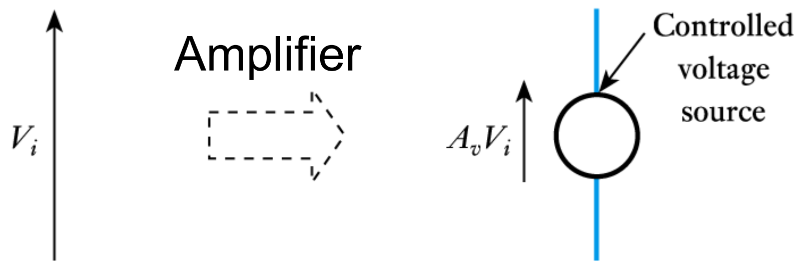
- **Modelling the input of an amplifier**
  - the input can often be adequately modelled by a simple resistor
  - the **input resistance**



- **Modelling the output of an amplifier**
  - Similarly, the output of an amplifier can be modelled by an ideal voltage source and an output resistance.
  - This is an example of a **Thévenin equivalent circuit**

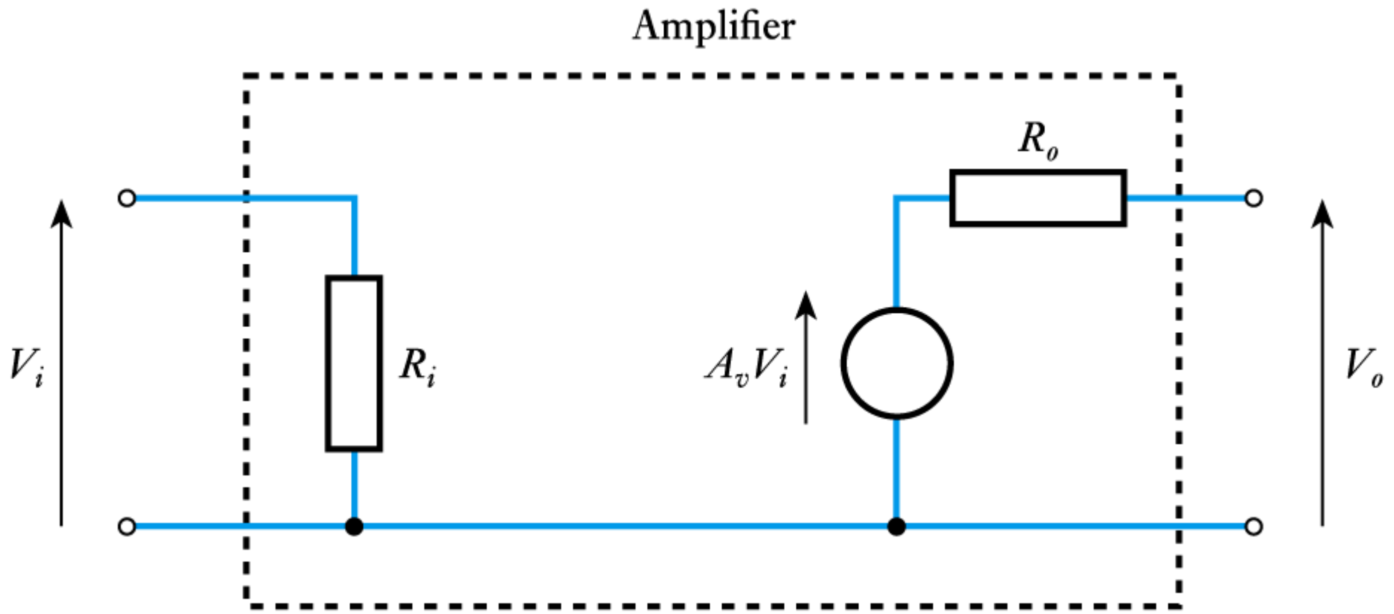


- **Modelling the gain of an amplifier**
  - can be modelled by a controlled voltage source
  - the voltage produced by the source is determined by the input voltage to the circuit



Equivalent circuit of an amplifier

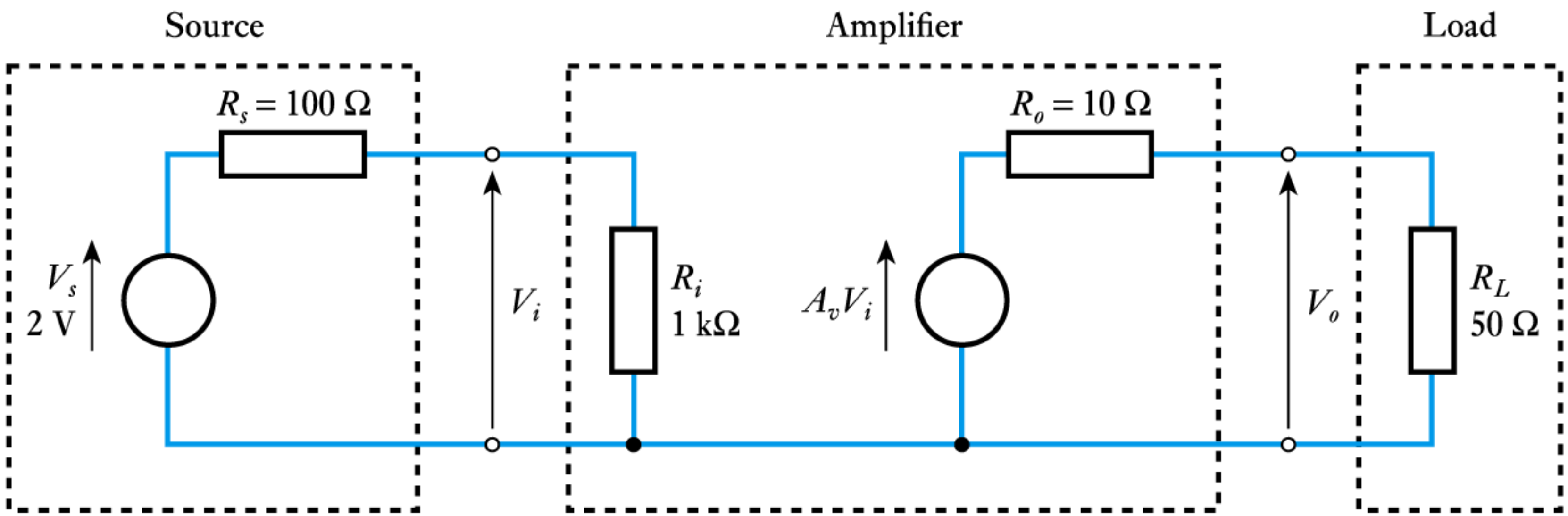
- We can put together the models for input, output and gain, to form a model of the entire amplifier as shown here



An example (1)

- An amplifier has a voltage gain of 10, an input resistance of 1 kΩ and an output resistance of 10 Ω.
- The amplifier is connected to a sensor that produces a voltage of 2 V and has an output resistance of 100 Ω, and to a load of 50 Ω.
- What will be the output voltage of the amplifier (that is, the voltage across the load resistance)?

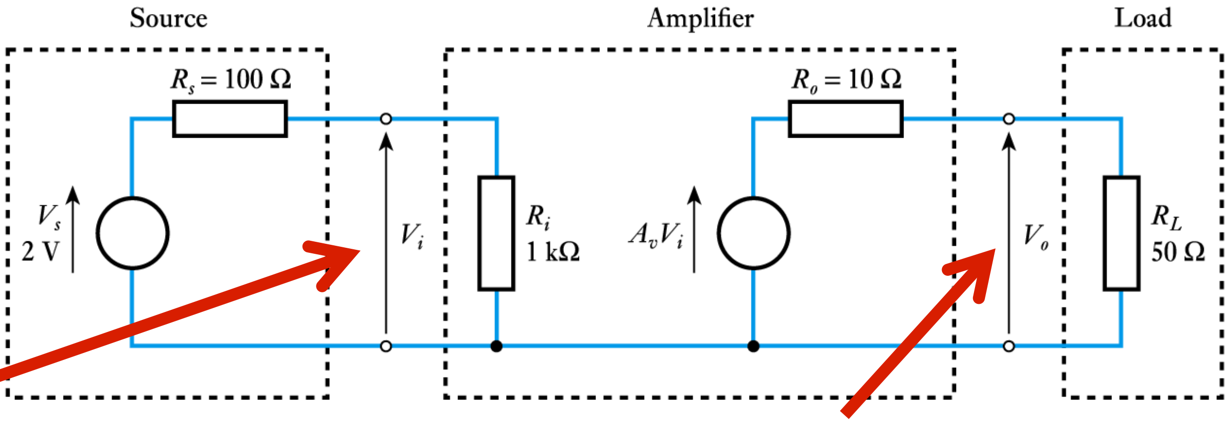
- We start by constructing an equivalent circuit of the amplifier, the source and the load:



An example (2)

- From this we calculate the output voltage:

$$V_i = \frac{R_i}{R_s + R_i} V_s$$
$$= \frac{1\ \text{k}\Omega}{100\ \Omega + 1\ \text{k}\Omega} \times 2\ \text{V} = 1.82\ \text{V}$$



$$V_o = A_v V_i \frac{R_L}{R_o + R_L}$$
$$= 10\ V_i \frac{50\ \Omega}{10\ \Omega + 50\ \Omega}$$
$$= 10 \times 1.82 \frac{50\ \Omega}{10\ \Omega + 50\ \Omega} = 15.2\ \text{V}$$

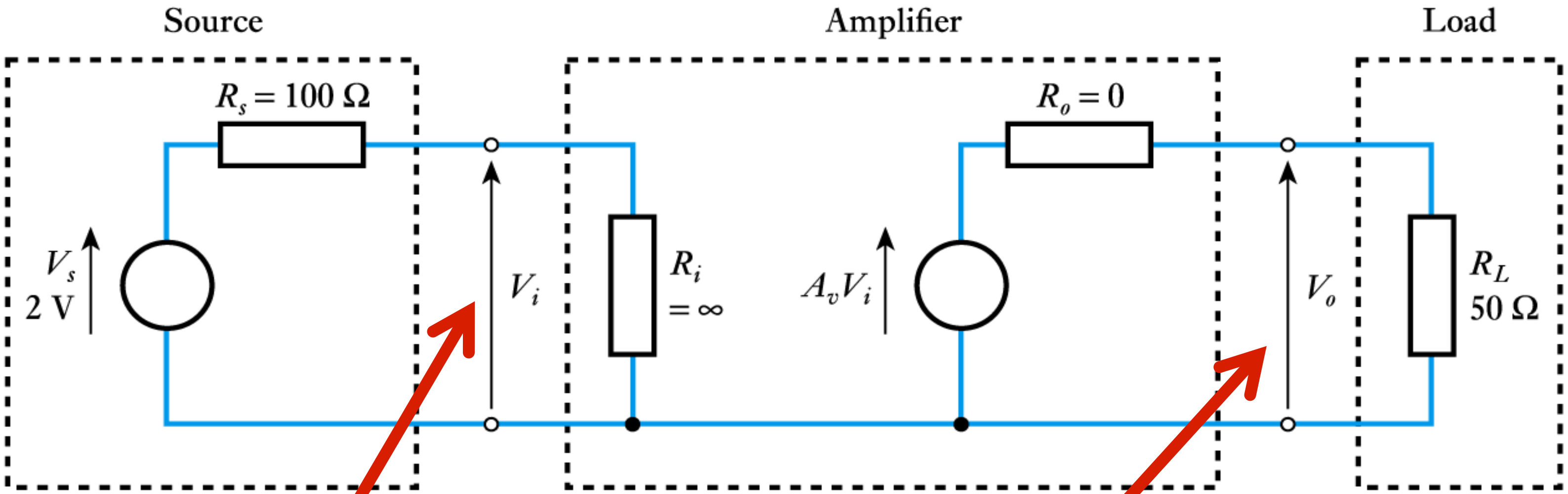
- Although the amplifier has a gain of 10 when it is NOT connected to anything, when used in the system, the actual gain is:

$$\text{Voltage Gain } (A_V) = \frac{V_O}{V_i} = \frac{15.2}{1.82} = 8.35$$

- The reduction of the voltage gain is due to **loading effects**.
- The original gain of the amplifier in isolation was 10. It is the **unloaded** gain.

An ideal voltage amplifier

- An **ideal voltage amplifier** would not suffer from loading
  - it would have $R_i = \infty$ and $R_o = 0$



- If $R_i = \infty$, then

$$\frac{R_i}{R_S + R_i} \approx \frac{R_i}{R_i} = 1$$

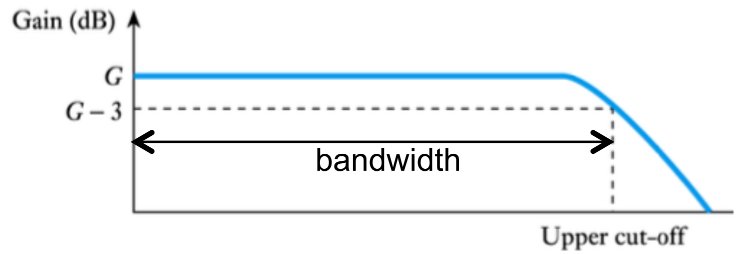
- and,

$$V_i = \frac{R_i}{R_s + R_i} V_s \approx V_s = 2\ \mathrm{V}$$

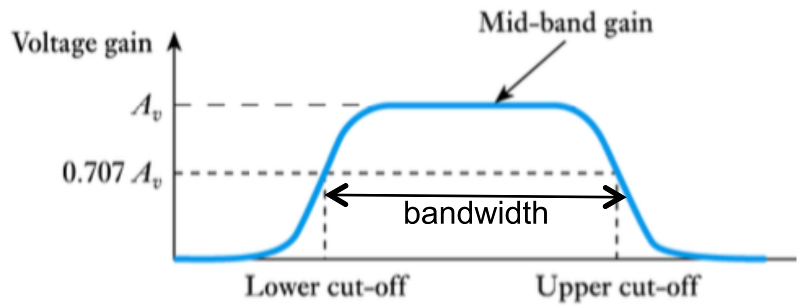
$$V_o = A_v V_i \frac{R_L}{R_o + R_L} = 10\ V_i \frac{50\ \Omega}{0\ \Omega + 50\ \Omega} = 10 \times 2 \frac{50\ \Omega}{50\ \Omega} = 20\ \mathrm{V}$$

Frequency response and bandwidth of Amplifier

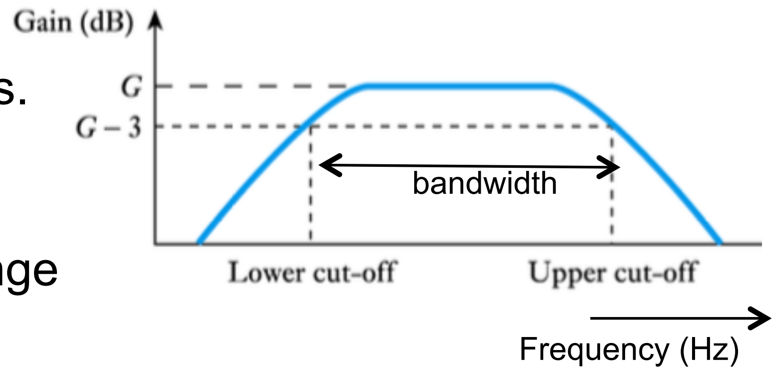
- All real amplifiers have limits to the range of frequencies over which they can be used.
- The gain of a circuit in its normal operating range is termed its **mid-band gain**.



- The gain of all amplifiers falls at high frequencies.
  - Characteristic defined by the **half-power point.**
  - Gain falls to **1/√2 = 0.707** (**-3dB**) times the mid-band gain.
  - This occurs at the **cut-off (or corner) frequency.**



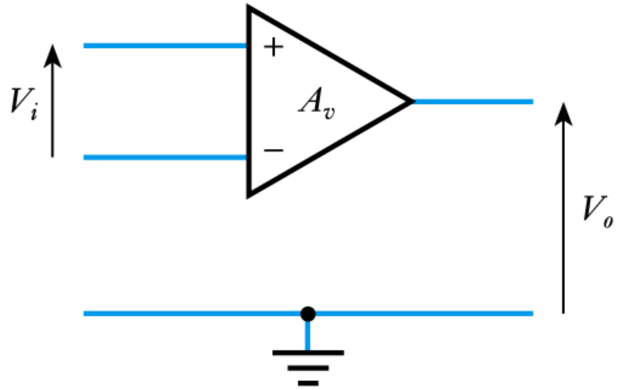
- In some amplifiers gain also falls at low frequencies.
  - These are **AC coupled amplifiers**



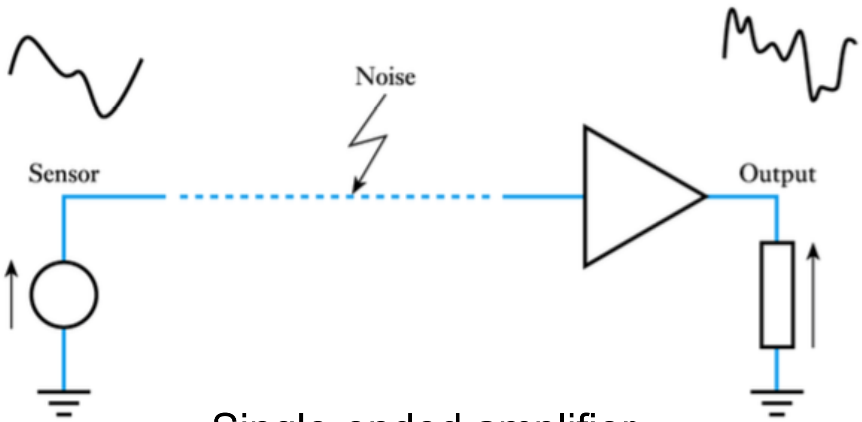
- The **bandwidth** of the amplifier is the frequency range up to the -3dB point (or cut-off frequencies)

Differential amplifiers

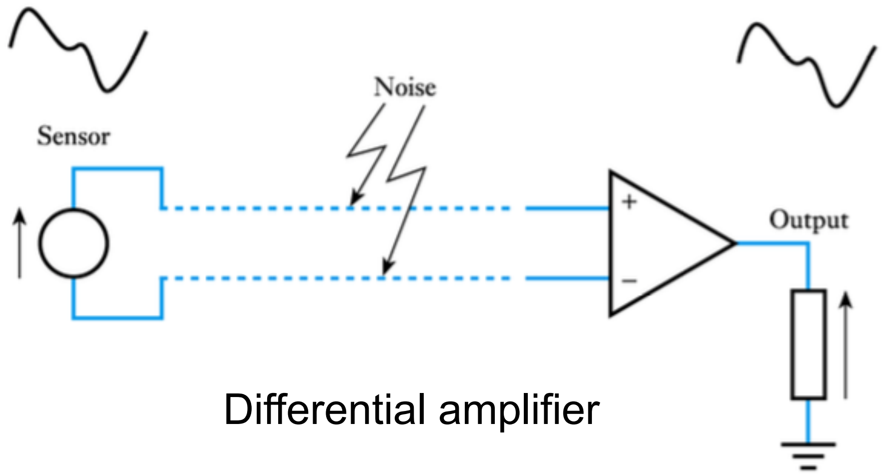
- Differential amplifiers have two inputs and amplify the voltage difference between them.
  - Inputs are called the **non-inverting input** (labelled +) and the **inverting input** (labelled –)



- An example of the use of a differential amplifier:



Single-ended amplifier



Differential amplifier

Equivalent circuit of a differential amplifier

- In Lab 3, we will be using a common differential amplifier called **operational amplifier** (OpAmp).
- The equivalent circuit of such a differential amplifier is: