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

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

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

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

![Equivalent circuit of an amplifier](image-url)
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:
From this we calculate the output voltage:

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

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

\[ V_o = A_v V_i \frac{R_L}{R_o + R_L} = 10 V_i \frac{50 \text{ } \Omega}{10 \text{ } \Omega + 50 \text{ } \Omega} \]

\[ = 10 \times 1.82 \frac{50 \text{ } \Omega}{10 \text{ } \Omega + 50 \text{ } \Omega} = 15.2 \text{ V} \]

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,

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

$$V_o = A_v V_i \frac{R_L}{R_o + R_L}$$

$$= 10 V_i \frac{50 \Omega}{0 \Omega + 50 \Omega}$$

$$= 10 \times 2 \frac{50 \Omega}{50 \Omega} = 20 \text{ V}$$
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 $1/\sqrt{2} = 0.707$ (-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:
In Lab 3, we will be using a common differential amplifier called **operational amplifier** (OpAmp).

The equivalent circuit of such a differential amplifier is: