Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 22: Electronic Circuits and Devices

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Operational Amplifiers

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INTRODUCTION

Determine the operational characteristics of amplifier circuits

- Power amplifiers: class A, B and AB.
- Operational amplifiers: inverting, non-inverting, differential, summing, integrator, differentiator, comparator, instrumentation, Schmitt trigger, active filters.
- Gain, bandwidth, frequency response, input and output impedance.
- Distortion and noise.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

1.1 Power Amplifiers

The main purpose of power amplifiers is to enhance the magnitude of the signal that is put into it (i.e. speaker systems amplifying the audio signal to make the song louder). A typical loudspeaker will have a low impedance ($\sim 7\Omega$), and so will need to be able to supply high peak currents to operate the low impedance speaker.

Amplifiers are divided into specific classes, depending on their amplification signal, demonstrated by Fig.1.1. There are many amplifier classes that are available to technicians, but this unit will cover just three: A, B and AB. These amplifiers, and class C, produce analogue signal outputs, whereas other amplifiers (D, E, F, G, S, T) are known as switching amplifiers and will only have digital signal outputs.

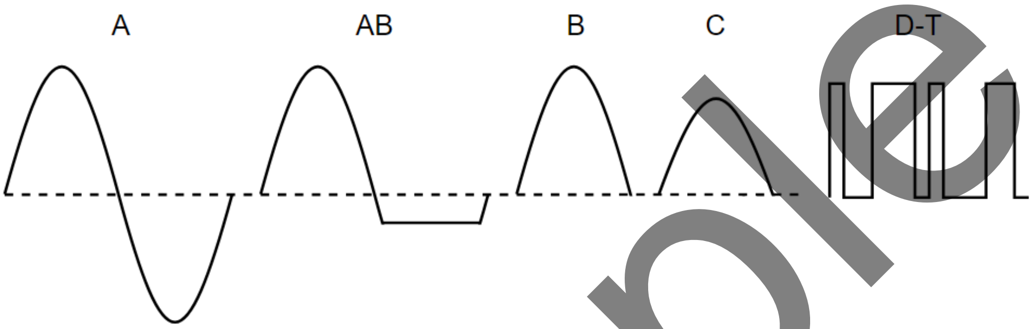

Fig.1.1: Outputs of amplifier classes

1.1.1 Class A Amplifiers

These amplifiers are the one of the simplest, and therefore the most common. The schematic of a class A amplifier is shown in Fig.1.2 and uses a common emitter configuration while for both halves of the waveform.

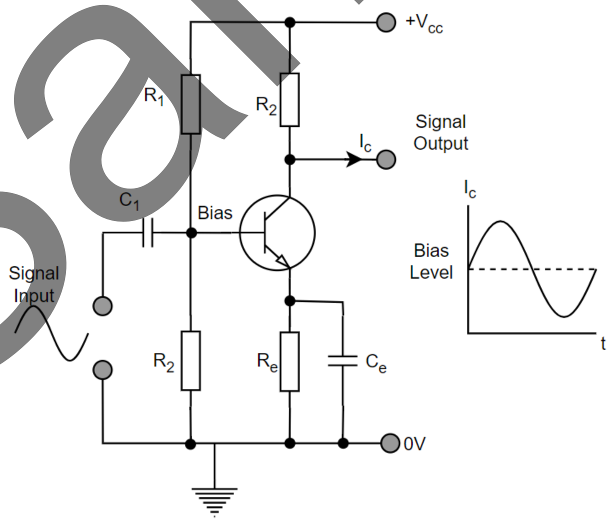

Fig.1.2: Class A amplifier schematic

As you can see by the schematic, the transistor will always have a current flowing through it and so the system will never turn off, even if there is no signal input. With this in mind, class A amplifiers are very inefficient, and generate a lot of heat even when there is no signal to be amplified. They are however, the most accurate amplifiers with low signal distortion.

1.1.2 Class B Amplifiers

Class B amplifiers were developed as a solution improve the efficiency and heat loss present in class A amplifiers. The simplest of class B amplifiers consists of two complimentary transistors that processes one half of the waveform each and create a "push-pull" arrangement. A schematic for a simple class B amplifier. A circuit diagram of a class B amplifier is shown in Fig.1.3.

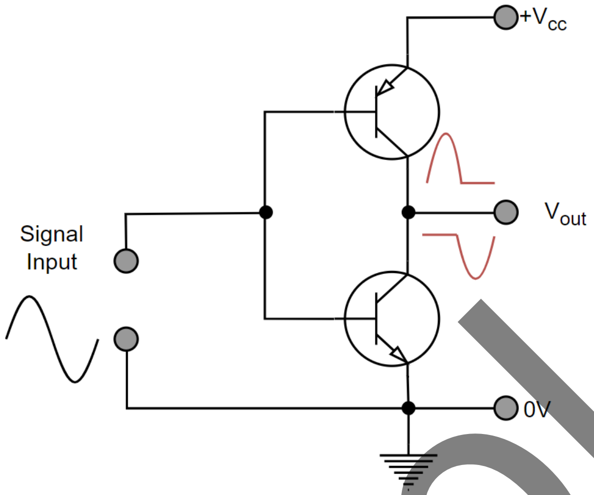

Fig.1.3: Class B Amplifier

When there is no input signal, then the gates of the transistors are not active, meaning that no current can flow between $+V_{CC}$ and $0V$, thus improving the overall efficiency of the system. V_{out} is shown in Fig.1.4. You will notice that this is *not* a perfect sine wave. Transistors have a dead band of input voltages between $\pm 0.7V$, so between these voltages, there is a "crossover distortion" because the transistor is not active.

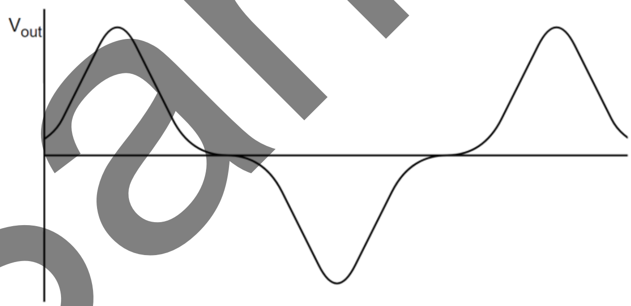

Fig.1.4: An output signal of a sine wave in a class B amplifier, exhibiting crossover distortion

1.1.3 Class AB Amplifier

In order to reduce the crossover distortion, class AB amplifiers were developed, essentially a hybrid of the class A and the class B. The class AB amplifiers introduce a small bias on each transistor, so that they are still switched on between $\pm 0.7V$, and eliminate the distortion exhibited by the class B. The AB amplifier is most commonly used in audio power amplification. By introducing a bias into the system, the transistors are active for more than half of the signal. Since the transistors are active for more of the cycle than they are in class B, they are less efficient, but still more efficient than having a class A in place. Fig.1.5 shows a circuit diagram of a class AB amplifier.

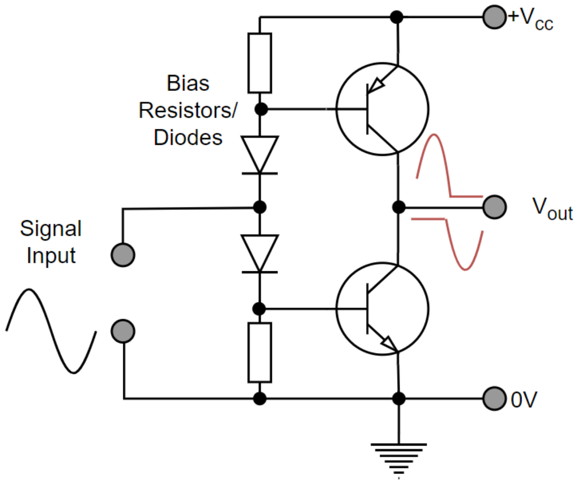

Fig.1.5: Class AB amplifier

1.1.4 The Ideal Amplifier

As with any aspect of engineering, the goal of a system is to be as closer to perfect as is physically possible. The characteristics of the ideal amplifier are:

- Infinite Bandwidth
- Infinite gain available
- Easily controllable gain
- Linear with no distortion
- Cheap
- Easy to convert functionality
- No Noise

While ideal does not exist, the closest we have at the moment is the Operational-Amplifier (Op-Amp), they are cheap to manufacture and have excellent performance characteristics. They are linear devices and can be used for mathematical operations, which will be discussed further in Section 1.4. The Op-Amp has two inputs: inverting and non-inverting, one output, and with a voltage across the internal circuitry that powers the electronics. A diagram of an Op-Amp can be seen in Fig.1.6, this is the drawing that is used to simplify circuit diagrams. The inner workings of an Op-Amp are complex, and in practice they are shaped just like any other integrated circuit.

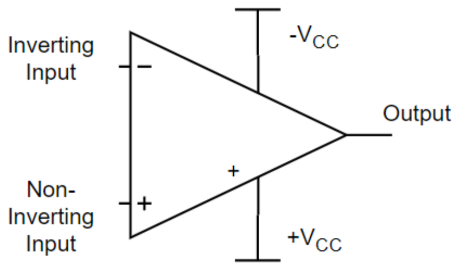

Fig.1.6: Op-Amp diagram.

1.2 Characteristics of Op-Amps

1.2.1 Impedance

The impedance is the ratio of voltage to current (essentially the resistance). ***For an ideal Op-Amp the input impedance is infinite***. Infinite input impedance implies no loading of sources connected to the input terminals of the Op-Amp, but realistically the impedance is not infinite and there will be some leakage current.

For an ideal Op-Amp the output impedance is zero. This makes sense because ideally, we would like the device to deliver high currents without reducing the output voltage. Typical values for actual devices are around 75Ω. Check device datasheets for actual values.

1.2.2 Bias

Although the ideal Op-Amp is assumed to have infinite input impedance and therefore zero current flowing into the input terminals, there is some current drawn in practical devices. The input currents to the Op-Amp are averaged to produce a figure for the input bias current***. An ideal Op-Amp will therefore have zero input bias current***.

The offset bias is the difference between the two input bias currents. Since the ideal Op-Amp has zero input bias current, it can also be stated that: ***The ideal Op-Amp has zero offset bias***.

Changes in temperature can cause Op-Amp parameters to "drift". Bias current is particularly susceptible to drift with temperature. ***An ideal Op-Amp will have zero drift***.

1.2.3 Voltage Gain

The voltage gain (A_V) is the ratio of output voltage to the input voltage, expressed by Eq.1.1. The gain will vary on the configuration of the Op-Amp circuitry. ***For an open loop (no feedback resistor) ideal Op-Amp the voltage gain is infinity***.

$$\frac{V_{OUT}}{V_{IN}} = A_V \qquad \text{(Eq.1.1)}$$

1.2.4 Common Mode Rejection Ratio (CMRR)

Consider the two test circuits in Fig.1.7. The first circuit measures the differential voltage gain (A_D) of the Op-Amp. There is a separate signal presented to each of the Op-Amp inputs. An ideal Op-Amp should give an infinite differential voltage gain (i.e. maximum voltage at the output). The second circuit has the inputs shorted (common) so this will measure the common-mode voltage gain (A_{CM}) of the Op-Amp. An ideal Op-Amp will give zero voltage for this test.