Cambridge

A2 Level

Physics

CODE: (9702)

Chapter 25

Chapter 25: Electronics

Components of an electronic sensing system

In its basic form, an electronic sensor may be represented as a sensing device, a processor that provides an output voltage, and an output device (Figure 25.2).

Figure 25.2 Block diagram of an electronic sensor.

The sensing device is sometimes called a **transducer**. A transducer changes energy from one form into another. A microphone is an obvious example, as it changes sound into electrical energy

Piezo-electric transducers

Some crystals such as quartz produce an electric field when a force is applied and the shape of the crystal changes. This is known as the piezo-electric effect.

When a sound wave hits one side of the sheet, the compressions and rarefactions cause the pressure to increase and decrease. The crystal changes shape in response to these pressure changes and a small voltage is created across the connections. Figure 25.3 shows the symbol for a microphone

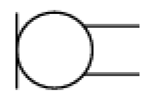

Figure 25.3 The symbol for a microphone.

The light-dependent resistor (LDR)

A light-dependent resistor (LDR) is made of a high resistance semiconductor. If light falling on the LDR is of high enough frequency, photons are absorbed by the semiconductor. As some photons are absorbed, electrons are released from atoms in the semiconductor.

The voltage of the supply is shared between the two resistors in proportion to their resistance, so as the light level changes and the LDR's resistance changes, so does the voltage across each of the resistors.

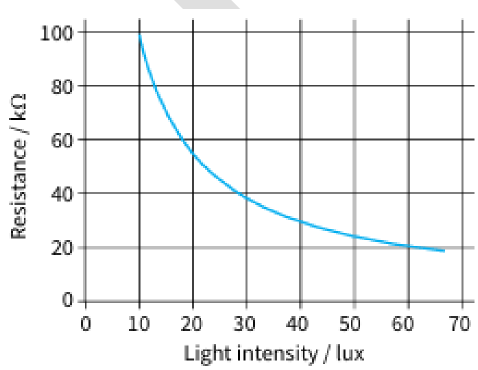

Figure 25.4 Resistance plotted against light intensity for an LDR.

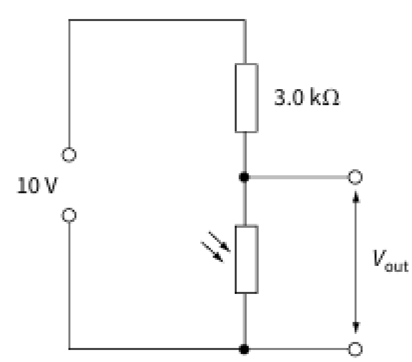

Figure 25.5 An LDR used in a sensor.

The metal-wire strain gauge

A strain gauge takes advantage of the change in resistance of a metal wire as its length and cross-sectional area change. When stretched, a metal wire becomes narrower and longer; both these changes increase the electrical resistance. When compressed, a metal wire becomes shorter and wider; as long as it does not buckle, these changes decrease its electrical resistance.

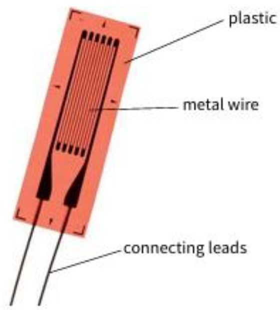

Figure 25.7 A metal-wire strain gauge.

The operational amplifier (op-amp)

Operational amplifiers (op-amps) are among the most widely used electronic devices today, being used in a vast array of consumer, industrial and scientific devices. The amplifier is the basic building block of many electronic systems. The electrical output from the musicians in the concert shown in Figure 25.14 must be amplified before it can be passed to the loudspeakers and turned into sound.

One approach is to use an amplifier with a very high gain and then provide an external circuit which reduces the gain but ensures that the overall gain is the same for signals of a greater range of frequencies. Such a device is the **operational amplifier (op-amp).**

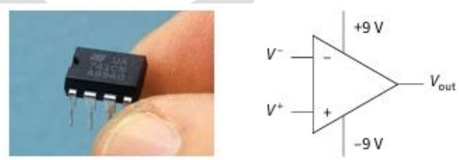

Figure 25.15 An operational amplifier and its symbol.

When the output voltage reaches either supply voltage, the highest or lowest value that it can achieve, the amplifier is said to be saturated.

The open-loop voltage gain G_0 is given by:

$$G_0 = \frac{\text{output voltage}}{\text{input voltage}}$$

For the op-amp in Figure 25.15 the open-loop voltage gain is given by:

$$G_0 = \frac{V_{out}}{(V^+ - V^-)}$$

The properties of an ideal op-amp

The ideal op-amp has the following properties.

Infinite open-loop voltage gain

This means that when an op-amp is used on its own, with no feedback loop, then a small input signal will be amplified to an 'infinite' output signal. Clearly this is not physically possible (the output cannot exceed the supply voltage) and at its maximum output the amplifier is saturated with output value +Vs or −Vs.

Infinite input resistance (or impedance)

The input to an op-amp is a voltage. If, for example, a piezo-electric microphone is connected to the op-amp, then the microphone is acting as the voltage supply. It acts just like an electrical battery but the voltage it produces changes with time. Any voltage supply has an internal resistance. You may remember that one of the effects of this is to reduce the terminal p.d. when a current is supplied.

Zero output resistance (or impedance)

The output from an op-amp is a voltage. The op-amp is itself acting as a voltage supply to the next part of a circuit. An ideal op-amp has zero output resistance and so it acts just like an electrical battery with zero internal resistance. This means that there will be no 'lost volts' when current is supplied by the op-amp. An actual op-amp typically has an output resistance of around 75 Ω. Infinite bandwidth

Infinite slew rate

An ideal op-amp should change the output instantaneously as the input is changed. The slew rate of the op-amp is the factor that affects this time delay. An infinite slew rate means there is no time delay.

Zero noise contribution

Any signal includes a small amount of noise. The ideal op-amp does not produce any noise itself, although it will amplify any noise that is present in its input.

The op-amp as a comparator

The op-amp shown in Figure 25.16 is connected to two power supplies. One battery of 9 V is connected between the zero volt line and the +9 V positive supply terminal of the op-amp and the other between the zero volt line and the negative power supply terminal. These batteries are not shown.

Negative feedback

What happens when the op-amp in Figure 25.17 is connected to a heater which warms the air around the thermistor?

The op-amp senses when the room is cold and switches on the heater. The heater then warms the room and this information is fed back to the thermistor, which then senses that the room is now warm enough and switches off the heater. This process is known as **feedback** and keeps the room at a reasonably constant temperature.

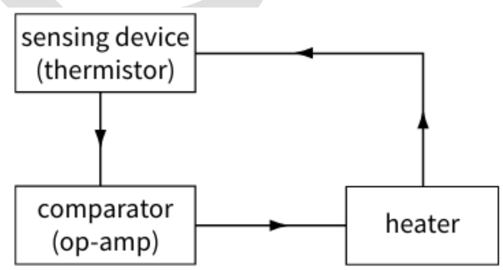

Figure 25.18 Feedback keeping temperature constant

The effect is shown in Figure 25.18.
Another advantage is that it does not matter whether the frequency of the input signal is high or low; the gain is the same. So the output signal is exactly the same as the input signal and there is no distortion. This is only true when the open-loop voltage gain is high. At very high frequencies the open-loop voltage gain falls and eventually the closed-loop gain falls. The **bandwidth**, the range of frequencies for which the gain is constant, is increased by using negative feedback.

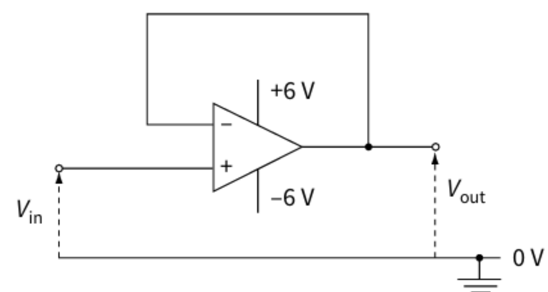

Figure 25.19 An op-amp with the output connected to the inverting input.

The inverting amplifier

The inverting amplifier shown in Figure 25.20 uses negative feedback, but not all of the output voltage is fed back to the inverting input (−). When an op-amp is connected as an inverting amplifier:

■ ■ the non-inverting input (+) is connected to the 0 V line

■ ■ part of the output voltage (or signal) is connected to the inverting input (−)

■ ■ the input voltage (or signal) is connected to the inverting input. To understand how the inverting amplifier works, you need to understand the concept of the **virtual earth approximation**. In this **approximation** the potential at the inverting input (−) is very close to 0 V. Why is this true? T here are two steps in the argument:

- The op-amp multiplies the difference in potential between the inverting and non-inverting inputs, V^- and V^+, to produce the output voltage V_{out}. Because the open-loop voltage gain is very high, the difference between V^- and V^+ must be almost zero.
- The non-inverting input (+) is connected to the zero volt line so $V^+ = 0$. Thus V^- must be close to zero and the inverting input (–) is almost at earth potential.

Point P is known as a **virtual earth**.

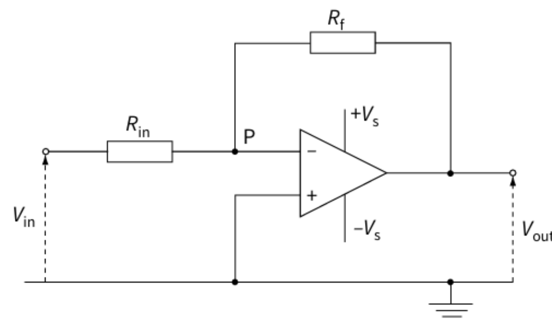

Figure 25.20 An inverting amplifier.

The non-inverting amplifier

Figure 25.21 shows the circuit for a non-inverting amplifier. The input voltage is applied to the non-inverting input; part of the output voltage is fed back to the inverting input.

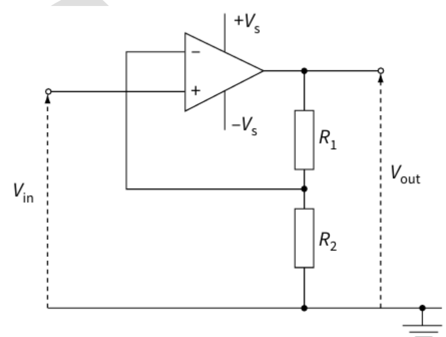

Figure 25.21 A non-inverting amplifier.

Output devices

The output voltage of an op-amp may be used to operate a device according to the changing input voltage. We will now look at three types of output device.

The relay

Although the output resistance of an op-amp is low, a typical op-amp can only provide a maximum output current of 25 mA. The maximum voltage output from an op-amp is also limited to the supply voltage, typically 15 V. To switch on larger currents and larger voltages the op amp is connected to a relay

The **relay** is just an electromagnetic switch operated by a small current in the coil. Notice that there are two circuits, one to the coil and one involving the switch contacts A1 and A2. When a small current passes through the coil of the relay in Figure 25.22, the iron core attracts a movable arm and the contacts connected to A1 and A2 close, completing the second circuit.

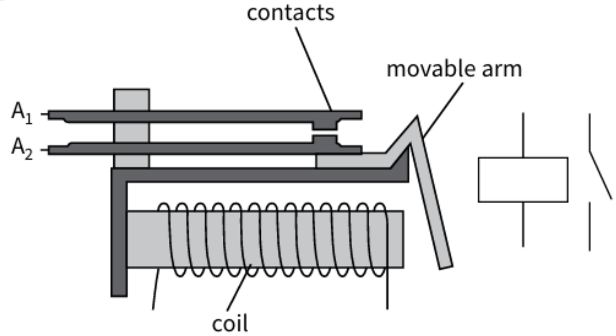

Figure 25.22 A relay and its circuit symbol.

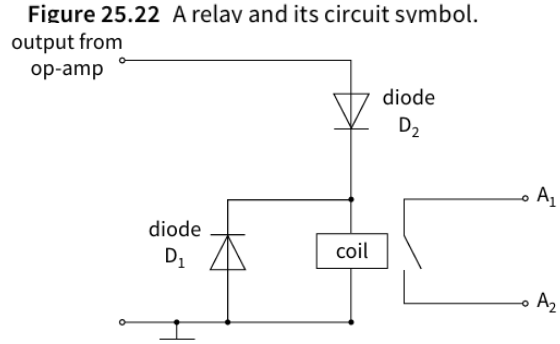

Figure 25.23 The output of an op-amp connected to a relay.

The light-emitting diode (LED)

T he light-emitting diode is a very convenient device to attach to the output of an op-amp. LEDs come in several different colours and only require a current of about 20 mA to produce a reasonable light output. When placed on the output of the op-amp they readily show the state of that output, whether it is positive, negative or zero.

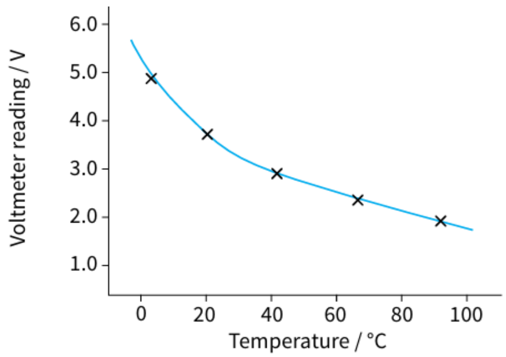

Figure 25.25 A calibration curve relates the output voltage of an op-amp to the variable it is being used to measure.

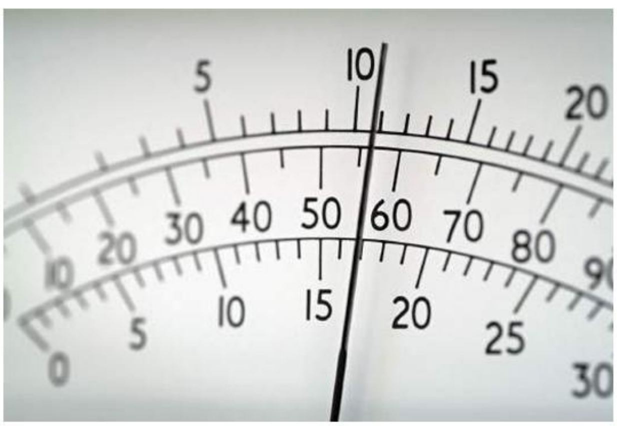

Figure 25.26 Linear and non-linear scales.

The top scale is non-linear and might be the value of the physical quantity being measured. Care is needed when reading a non-linear scale when the pointer is between the markings.

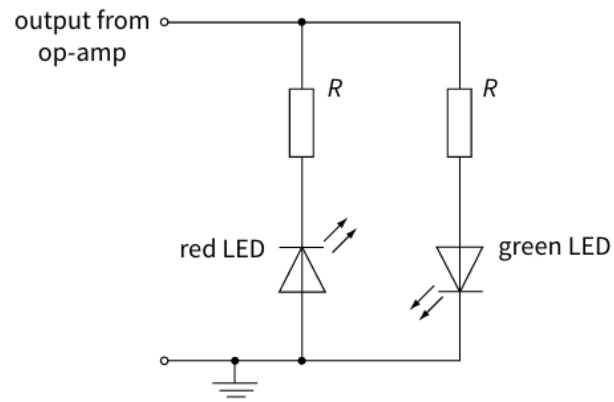

Figure 25.24 LEDs connected to the output of an op-amp.