Relevant Information

Interconnection of systems and sub-systems

I Development of Electronics Technology

Electrical engineering focuses on the flow of electric current within metals / electrical appliances, such as generators and motors. Electronics deals with the science of the movement of electric charges in substances, vacuum and semiconductors.

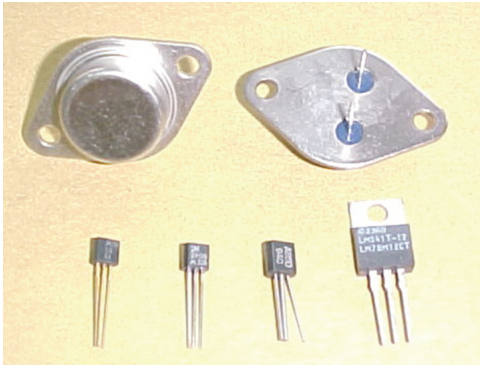
1. Development of Electronics Technology

Around the eighteenth century, scientists have acquired concrete results in their researches on electricity and magnetism. They published theories about electromagnetism, put forward theories about the existence of electric charges and discovered the existence of electrons, laying the foundations of the development of electronics technology.

Vacuum tubes

a. The Age of Vacuum Tubes

Vacuum tubes – vacuum containers in which electrodes are sealed for controlling the flow of electrons – were invented in the mid-nineteenth century. They are used in early radios, televisions and computers. They have a number of shortcomings including their bulky size, high cost, large power consumption, high working voltage, requiring preheating to function, poor reliability and easily damaged filament. Today, however, due to their special sound quality, a lot of audio systems are still using them.



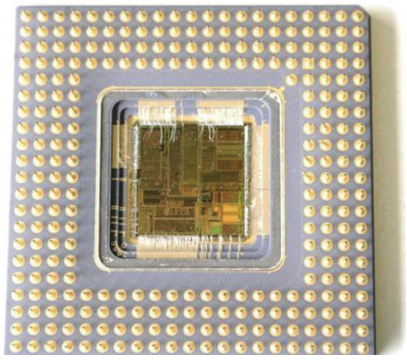
Transistors

b. The Age of Transistors

In the mid-twentieth century, transistors made of semiconductors with three terminals were invented. They have a lot of advantages including small size, light weight, low working voltage, cheap, low power consumption, not requiring preheating to function, not easily damaged, excellent performance and high reliability. Transistor radios, record players and video recorders appeared successively. They changed from huge household appliances to battery-powered, portable devices, which are still being used today.

c. The Age of Integrated Circuits

In 1961, the first integrated circuit (IC) containing less than 100 chips was launched. Soon after then, small-scale ICs with a few hundred chips gradually developed to medium-scale and large-scale ICs that contained thousands of chips. These ICs have ever-growing advantages such as even smaller size, even lighter weight, lower working voltage, lower price, lower power consumption, more durable, better performance and even higher reliability.



An IC is a complete circuit installed on a chip

When very-large-scale ICs are developed, many of them are used to manufacture microcomputers. Thus, this period is also called the **age of microcomputers**. Products are becoming increasingly miniaturised.

ICs in different packages

Bulky vacuum tube audio systems are made into personal portable audio systems

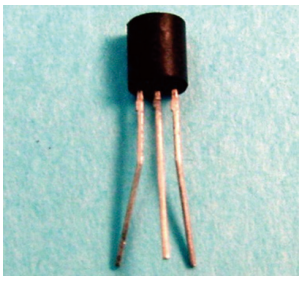
2. Semiconductor and Transistor

Conductors such as copper have high electrical conductivity while insulators such as plastics are a great obstacle to the flow of electric current. Semiconductors have electrical conductivity lying between those of conductors and insulators.

Semiconductors usually refer to metalloids including silicon, germanium, arsenic, gallium and tellurium, which contain holes of positive charges. Semiconductors can be used to manufacture various electronic components, ranging from diodes (e.g. light emitting diodes (LEDs) and rectifiers), solar batteries, transistors to ICs.

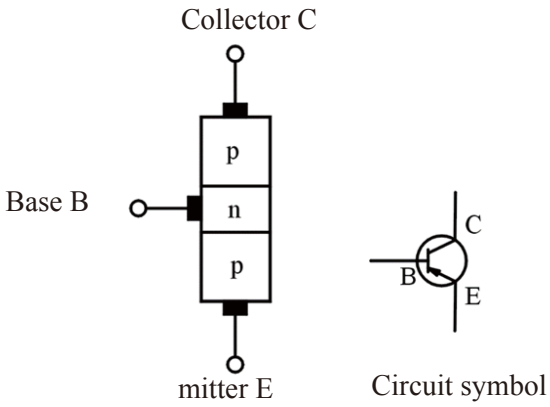
a. Functions of Transistors

A transistor is formed by three p-type and n-type conductors, which can be arranged in p-n-p or n-p-n order. They are known as PNP-type and NPN-type transistors respectively. There are many uses of transistors, such as for switching on/off electronic circuits, amplifying electric currents and amplifying voltages.

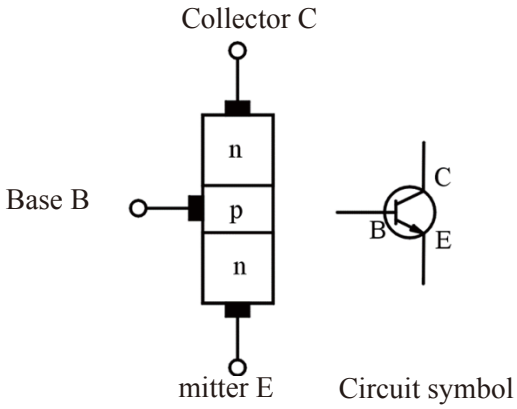


i) Switch

A transistor has three poles: base (B), collector (C) and emitter (E). The symbols for representing the two types of transistors are different. The one for a PNP transistor contains an arrow pointing at its base while the one for an NPN transistor contains an arrow pointing away from its base. Since it is simpler to mass produce NPN transistors than PNP transistors, we will focus the following discussion on the former.

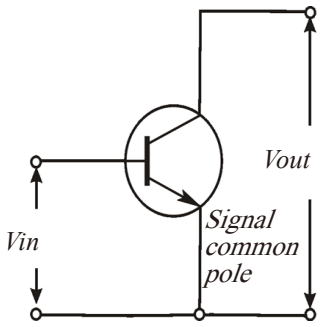


PNP-type transistor



NPN-type transistor

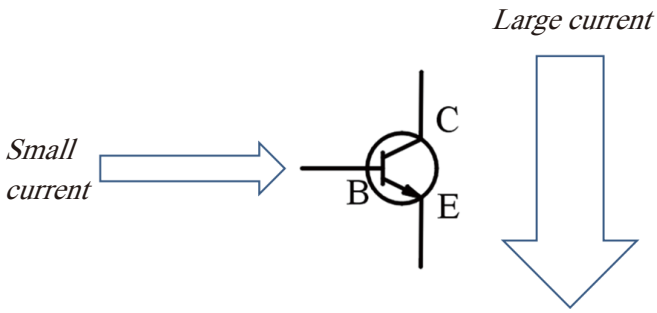
There are many ways to connect a transistor circuit. Shown on the right is a common emitter circuit, in which the emitter of an NPN transistor is connected to both its base and collector. In this kind of circuit, the base-emitter voltage is the input voltage V_{in} and the collector-emitter voltage is the output voltage V_{out}. For the transistor to function properly, the input voltage V_{in} must be higher than the cut-off voltage V_{BE}(ON) (about 0.7V), or else the transistor will stay in the cut-off state and will not conduct electricity.



Common emitter circuit

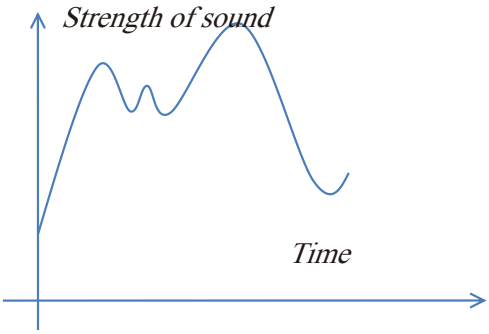
ii) Amplification

When the input voltage Vin at the base of an NPN transistor is about 0.7V, its collector-emitter will 'open up a passage' for a large current to pass through, even if there is only a small current entering the base.

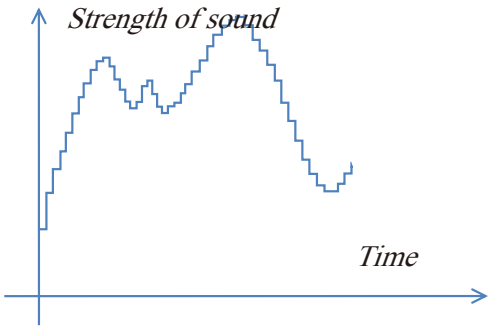


b. Analogue-to-Digital Converter

The strengths of signals of sound and light will change at times. The pop music that someone finds very pleasant may be intolerable noises for another person. The strength of signals during a period of time can be represented in an analogue manner. However, a computer cannot comprehend these signals directly. They must first be digitised and converted to digital signals for a computer to process them.

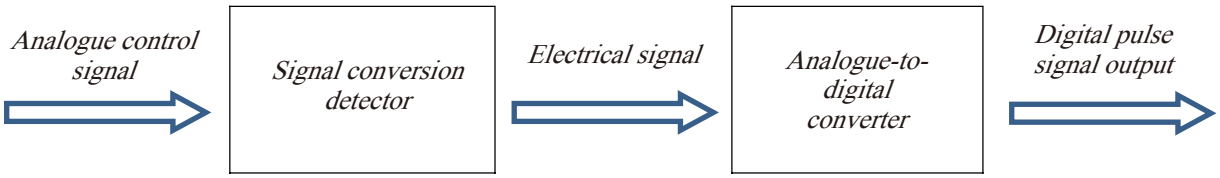


Analogue signal



Digital signal

An analogue-to-digital converter (ADC) converts the analogue signals obtained from its electronic sensor to digital signals before the signals are further processed or transmitted. Its working principle is shown below. Conversely, a digital-to-analogue converter (DAC) transforms digital signals to analogue signals.



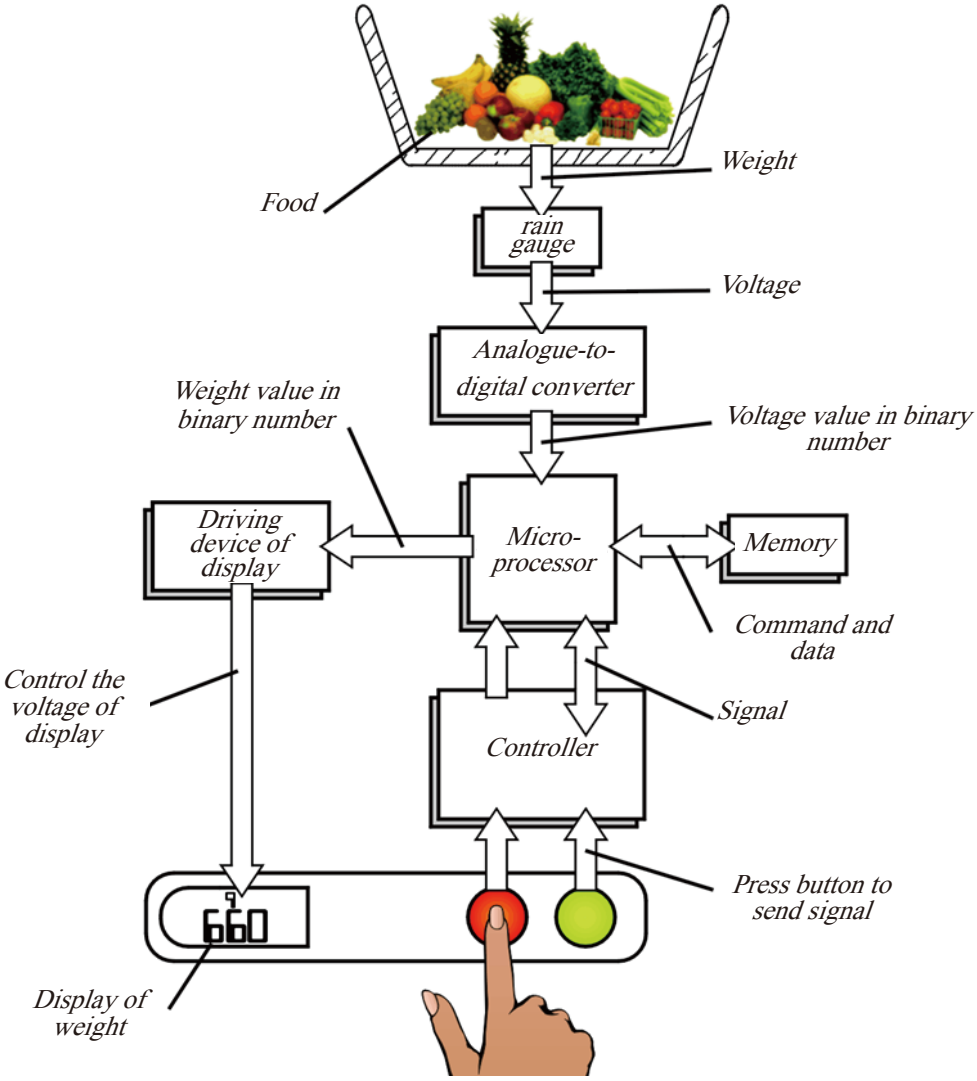
Working principle of an analogue-to-digital converter

Advantages of Digital Signals

The signals obtained by an electronic sensor are usually analogue ones. When an analogue signal is transmitted to a distant position or is being processed multiple times, due to the resistance of a transmission wire, its voltage will attenuate, thus causing transmission errors. A digital signal consists of two values only, high and low. Its values will not easily alter after transmission and is therefore suitable for multiple processing or transmission.

Example:

The following figure shows an example of an analogue-to-digital conversion. In the figure, the microprocessor of the electronic scale can continuously execute some commands. Analogue signals (weights of food) are sent to the strain gauge. The analogue-to-digital converter constantly converts the data received to digital signals '1' and '0', which are then transformed to decimal numbers. The weight readings are then displayed on the screen.



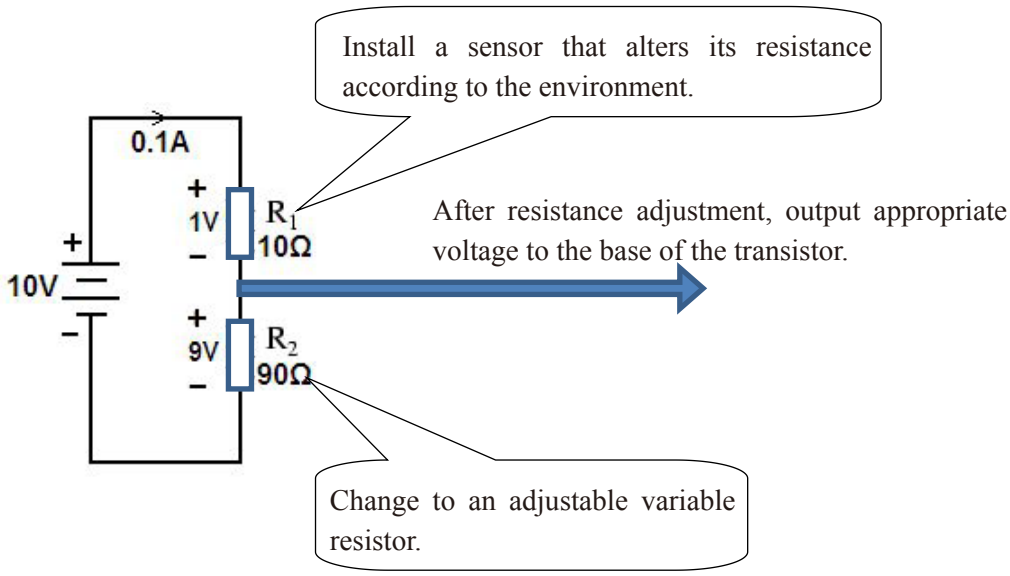
Operation flowchart of an electronic scale

List three household or daily life electronic products that have applied the use of digital signals. What are the strengths of these digital products as compared to their analogue counterparts?

c. Applications of Transistors

If we can control the input voltage *Vin* at the base B of an NPN transistor to vary between values larger and smaller than 0.7V, then we can make use of the transistor. However, common batteries have fixed voltages. In this situation, we need to apply voltage division mentioned in Teaching Material 4. In a voltage divider circuit, the ratio of individual resistance to total resistance is the same as the ratio of individual voltage drop to total supply voltage. This is known as the voltage divider formula.

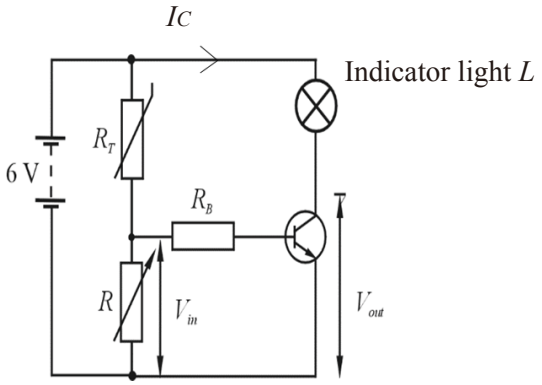
By installing a sensor that will alter its resistance according to the environment, coupling with a suitable variable resistor, we can output appropriate voltage to the base of the transistor. Control can then be realised.



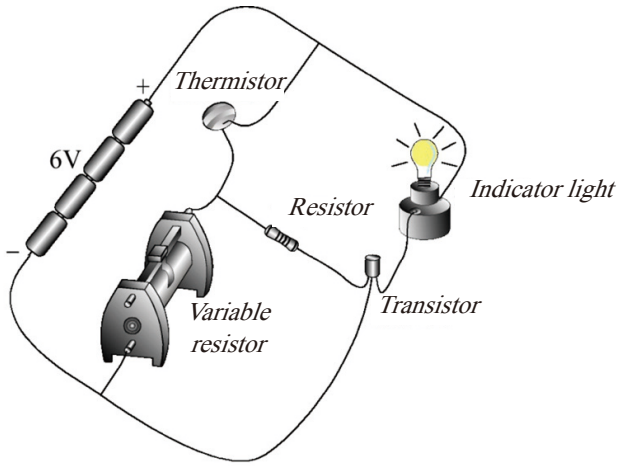
Example:

(i) Temperature-sensitive Switch

The following diagram illustrates a circuit of a simple temperature-sensitive switch, in which the transistor acts as the switch. At a lower temperature, the thermistor (R_T) has greater resistance, leading to a smaller *Vin* potential difference across variable resistor *R*. When *Vin* is smaller than 0.7V, the transistor will remain in a cut-off state and the output voltage will be 6V, that is I_C equals 0. As a result, the indicator light *L* will not turn on as there is no current passing through.



(a)Circuit of a temperature-sensitive switch



(b)Pictorial diagram of a circuit of a temperature-sensitive switch

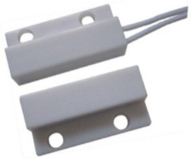
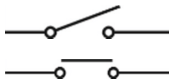
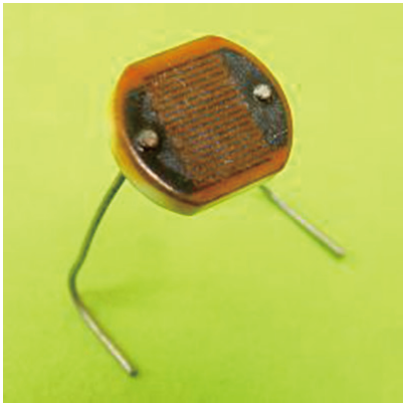
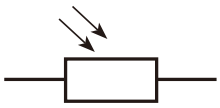
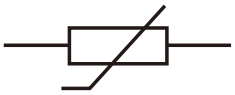
When the temperature rises, R_T will decrease and thus the potential difference *Vin* across *R* will increase. As the value of *Vin* increases to about 0.7V, the output voltage *Vout* will decrease to about 0, i.e. I_C becomes maximum (saturated). Current can then flow from the collector to the emitter of the transistor, causing the indicator light *L* to light up. This circuit can be used in a fire alarm system. Variable resistor *R* can be used to adjust the temperature that will set off the alarm.

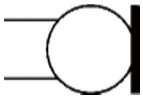
(ii) Other Sensor Switches

If we replace the thermistor of the above circuit to another sensor whose resistance also varies according to the environment, coupling with the setting of resistance of the variable resistor, we can obtain a range of different sensor switches. Apparently, the output devices should also be changed to other desired components. In the following, let's take a look at some common input, control and output components.

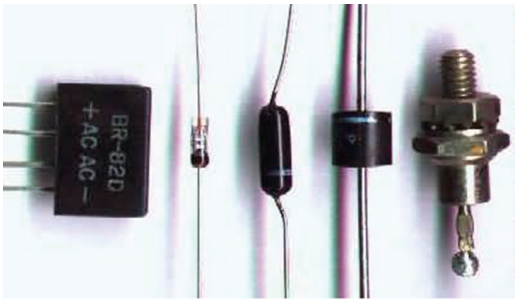
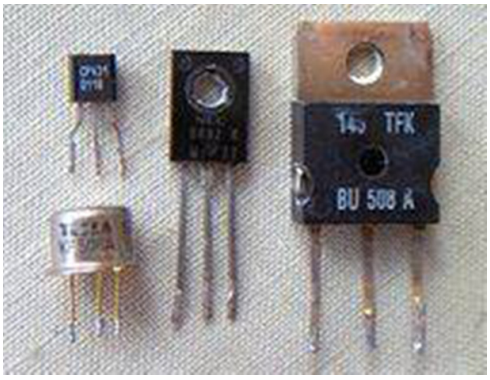
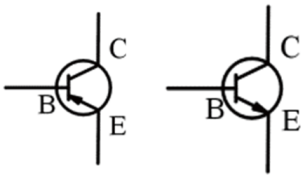
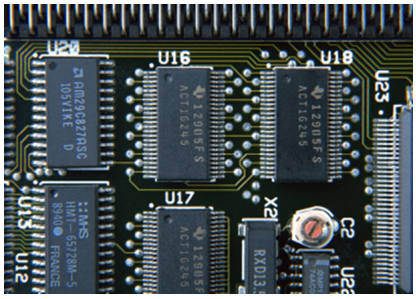
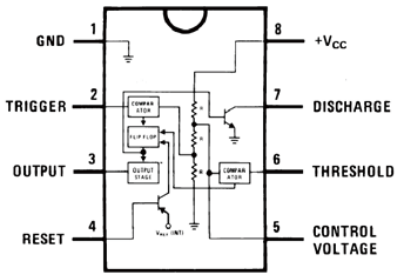
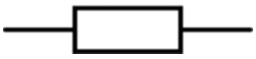
II Common Electronic Components

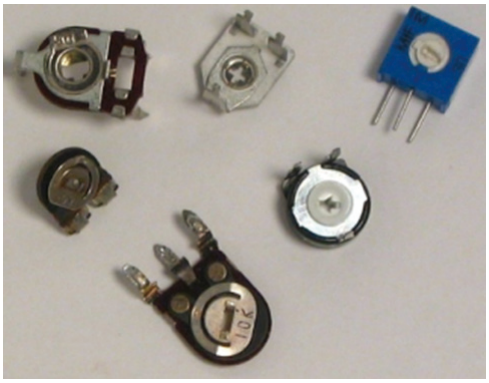
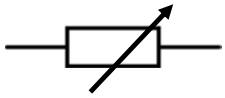
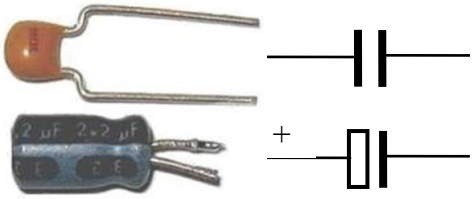
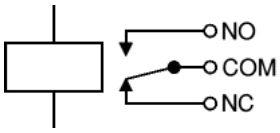
1. Common Input components

Small switch Switch with indicator light Micro switch  Magnetic switch	The main function of a **switch** is to enable or interrupt the flow of an electric current. It can also be used to switch circuits. 
	A **light sensor** is a kind of variable resistor. Its resistance varies with the intensity of the surrounding light. Light sensors are commonly used in automatic traffic lights, infrared detectors, etc. 
	A **thermistor** is kind of resistor that detects the variation of temperatures. Its resistance varies according to the temperatures. Thermistors are most commonly used in temperature monitoring systems for central processing unit (CPU) and fire monitoring systems. 

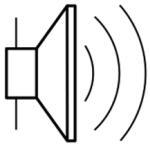
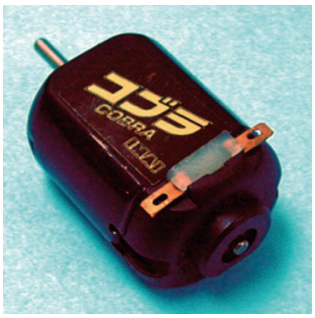
	A **humidity sensor** has two electrodes. The resistance between the two electrodes reflects the humidity of the environment. Humidity sensors are commonly used for detecting the humidity of soil so as to control humidification devices such as automatic sprinklers. They can also be used to control automatic rain cover devices.
	A **microphone** is a kind of electro-acoustic transducer, which converts sound to electronic signals. Microphones can be used in a wide range of applications including phones and karaoke systems. 

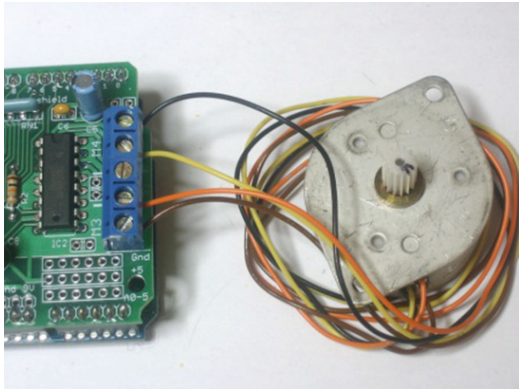
2. Common Processing Components

	A **diode** restricts the flow direction of electric current. It allows a single flow direction and prohibits the flow in the opposition direction.
	A **transistor** is a semiconductor device. There are many uses of transistors, such as switching on/off electronic circuits, amplifying electric currents and amplifying voltages. 
	An **integrated circuit (IC)** is a micro-electronic circuit. Sophisticated high-tech methods, such as photo etching, are used to engrave a large amount of electronic components onto a small piece of chip (usually made of silicon), which is then sealed in a small plastic case, exposing only the pins.  LM555 Timer
	A **resistor** is a two-terminal electrical or electronic part. It can produce a voltage drop between terminals, resisting the flow of electric current. 

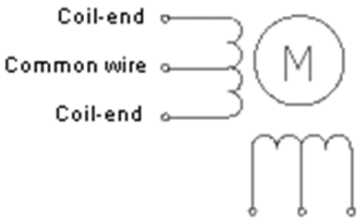
	A **potentiometer** is a kind of variable resistor, which can be used as a voltage divider. Potentiometers are most commonly used as audio control devices (volume controllers of radios and televisions). 
	A **capacitor** can store the energy between two tightly placed metal plates. When an electric current is applied to a capacitor, electric charges will be built on each of the metal plates. Capacitors can be used as devices for storing energy and time control. 
	A **relay** is an electrically operated switch. For example, connecting a 12V-battery circuit to a coil can be used to control a 220V a.c. circuit. Relays are usually used for isolation purposes. 

3. Common Output Components

	When a forward current flows through a **light emitting diode (LED)**, the LED will light up. An LED is also a kind of diode. LEDs can be arranged in different ways to produce seven-section displays and array displays.
	A **speaker** is a kind of electro-acoustic transducer. It converts electronic signals to sound, allowing people within a certain distance to hear the sound. 
	A **buzzer** is similar to a speaker, which uses electro-acoustic signals to produce sound. The only difference between the two is that a piezo-electric buzzer is driven by voltage while a speaker is driven by the current generated from a coil.
	A **motor** can convert electrical energy to magnetic energy and kinetic energy. Motors are used in a wide range of household appliances such as fans, air conditioners, washing machines and hairdryers.



A **stepper motor** makes use of the electric current flowing towards its coil to rotate in specific steps, so as to control the motor's position and speed precisely. Stepper motors are applied in computer printers and floppy disk drives.



III Electronic-control Circuits

In the design of an electronic-control circuit, we must first understand the characteristics of each electronic-control component. Then, according to the basic design processes, we can set up the circuit by connecting the various electronic components.

Design Example

Situation

In the following, we will take a simple street lighting system as an example to illustrate the basic processes for designing an electronic-control circuit. The lighting system turns the lights on and off according to time, so that the lights will light up at nights and go off in the mornings regularly. However, although the ambient light is insufficient in the mornings of winters or rainy days, the lights still will not turn on.

Street being illuminated by lighting

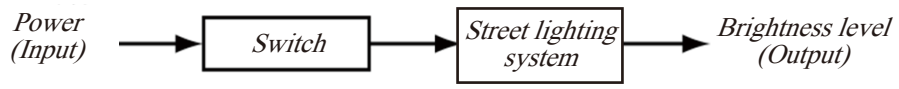
Design Brief

To avoid the above-mentioned drawback, the automatic switching of the lighting system should depend on the level of brightness instead.

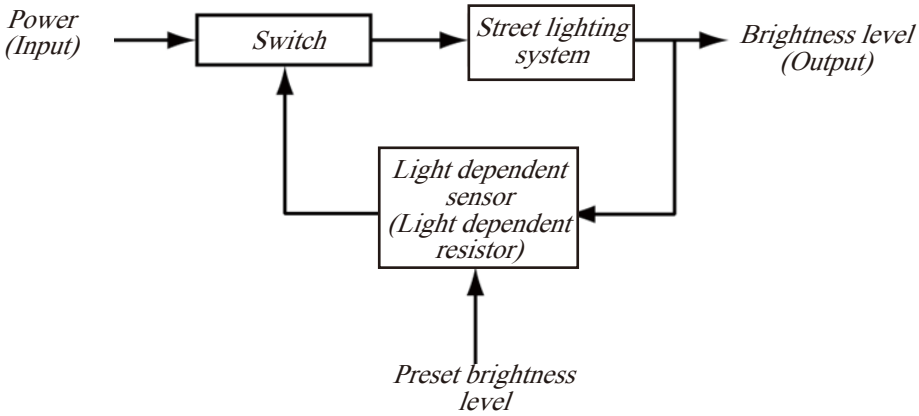
Design Specifications

The following figures show the block diagrams of the original simple street lighting system and the suggested improvement of the system. The latter relies on a light dependent sensor (e.g. a light dependent resistor) to detect the brightness level of the streets to provide appropriate feedback for controlling the ON/OFF of street lights.

Original design:
Control the lights according to time
(open - loop design)



Suggested design improvement:
Control the lights automatically
(closed - loop design)

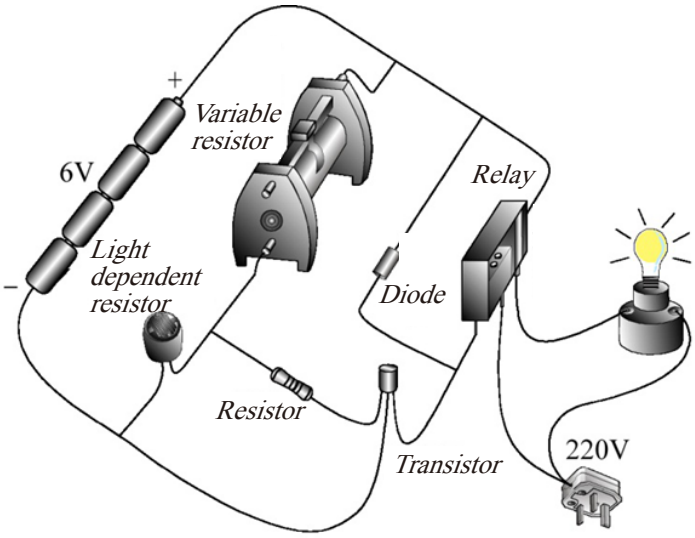


Information Collection

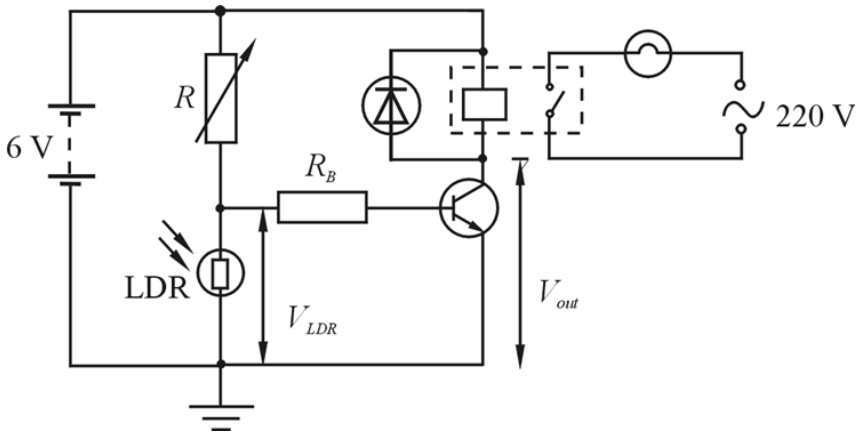
As the electronic-control system uses light dependent resistors and high-voltage switches, we should refer to information regarding light dependent resistors, transistor switches, relays and control circuits.

Solution

The following figure shows a circuit that uses a transistor to control a light dependent switch. The circuit uses a relay to switch on/off the street lightings. The resistance of the variable resistor is set at about 200 k.



(a) Pictorial diagram of a light dependent switch circuit



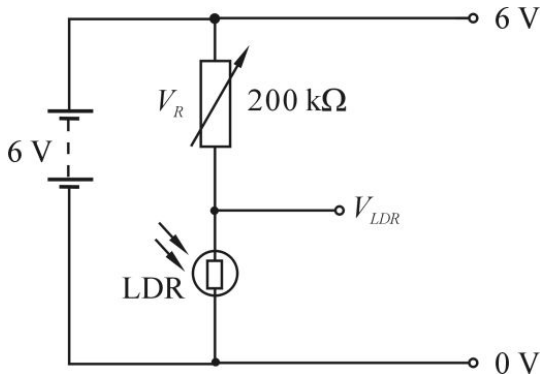
(b) Light dependent switch circuit

Situation 1

When the light dependent resistor is illuminated, its resistance is very low (about 9 k) and the potential difference across it, V_{LDR}, is:

$$V_{LDR} = \frac{9}{9+200} \times 6 = 0.258 \text{ V}$$

As a result, the potential difference across it is lower than the cut-off voltage of the transistor (about 0.7V). The transistor will remain in the cut-off state and no current will pass through the collector. The output voltage *Vout* equals 6V, causing the switch of the relay to remain open. Thus, the street lighting will not be switched on.



The variable resistor and the light dependent resistor in the light dependent switch circuit act like a voltage divider.

Situation 2

When the light dependent resistor is put in a dark place, its resistance becomes very high (about 600 k). Therefore, the potential difference across it, V_{LDR}, will exceed the cut-off voltage of the transistor:

$$V_{LDR} = \frac{600}{600+200} \times 6 = 4.5 \text{ V}$$

The collector current will flow through the transistor, causing the output voltage *Vout* to reduce to near zero. This will make the switch of the relay to connect with the circuit of the street lighting so that the lighting switches on. A diode is connected in parallel with the relay to prevent huge induced electromotive force generated by the coil when switching on and off the relay to damage the transistor. By adjusting the resistance *R* of the variable resistor, the lighting can be set to activate at a brighter or darker circumstances.

Realisation, Testing and Evaluation

When a solution is made, we can test by connecting the above light dependent switch circuit to a light bulb to see if it works and then figure out other details, such as the adjustment of the variable resistor *R*. Then we can evaluate the performance of this electronic-control system and propose ways for improvement. It must be reminded that one must pay attention to safety when connecting the circuit.

The light bulb is connected to 220V mains supply, beware of electric shock!!

Lesson Activity: Circuit Design

We have discussed the basic operation of control circuits and introduced various input, processing and output components. Now let's try to apply them to solve some problems.

Problem 1:

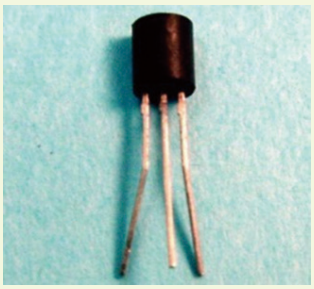
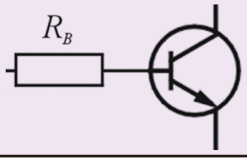
Design a circuit that will deliver a warning signal when **the temperature drops below a certain temperature.**

Solution:

Design a circuit that will deliver a warning signal when the temperature drops below a certain temperature. (*In this problem, the solution is already provided.*)

Input	Process	Output
Require a component that can detect a low temperature.	Require to convert the input of low temperature detection to an output signal.	Require to deliver a warning when a signal is received.

Component Selection:

Input	Process	Output
	 Transistor (with protective resistor)	
Symbol:	Symbol: 	Symbol:

Complete Circuit: *(Refer to page 7)*

Problem 2:

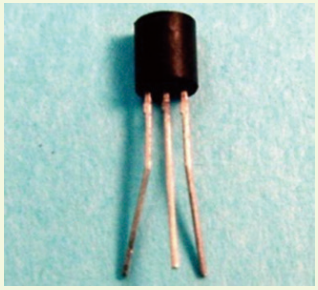
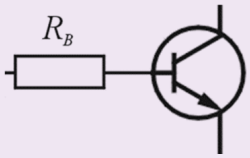
Design a circuit that will deliver a warning signal when the **indoor temperature is too high**.

Solution:

Design a circuit that will deliver a warning signal when the indoor temperature is too high.

Input	Process	Output

Component Selection:

Input	Process	Output
	 Transistor (with protective resistor)	
Symbol:	Symbol: 	Symbol:

Complete Circuit:

Problem 3:

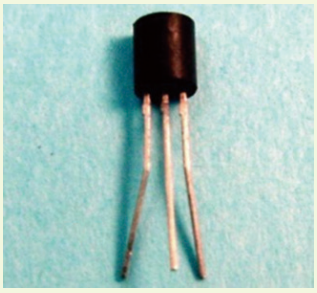
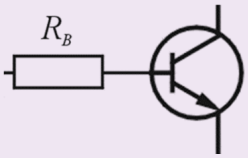
Design a circuit that will deliver a warning signal when the soil **humidity is insufficient**.

Solution:

Design a circuit that will deliver a warning signal when the soil humidity is insufficient.

Input	Process	Output

Component Selection:

Input	Process	Output
	 Transistor (with protective resistor)	
Symbol:	Symbol: 	Symbol:

Complete Circuit:

Problem 4:

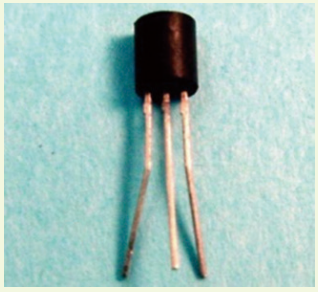
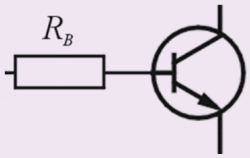
Chi Ming keeps some fishes in a fish tank. The water in the tank will reduce naturally due to evaporation. Design a circuit that will deliver a warning signal when the **water level falls** below a specific point.

Solution:

Design a circuit that will deliver a warning signal when the water level falls below a specific point.

Input	Process	Output

Component Selection:

Input	Process	Output
	 Transistor (with protective resistor)	
Symbol:	Symbol: 	Symbol:

Complete Circuit:

Problem 5:

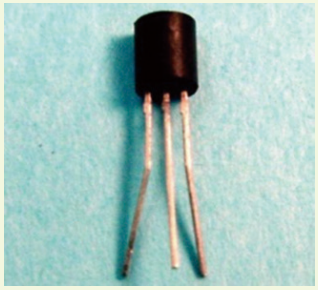
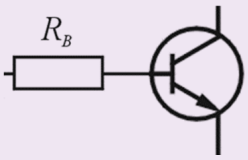
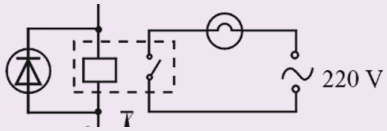
An elderly couple find it troublesome to turn on the lights when it gets dark. Design a circuit that will **turn on the lights** for them when it **gets dark.**

Solution:

Design a circuit that will turn on the lights when it gets dark.

Input	Process	Output

Component Selection:

Input	Process	Output
	 Transistor (with protective resistor)	As the output voltage and current are high, power needs to be supplied through a relay
Symbol:	Symbol: 	Symbol: 

Complete Circuit: *(Refer to page 18)*

Problem 6:

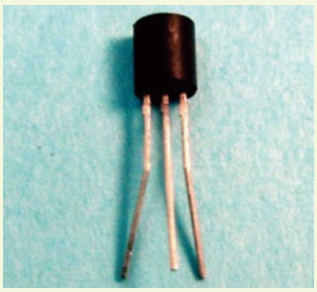
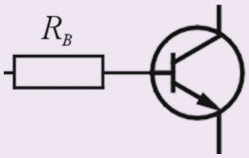
Mrs Chan, who lives in a village house, has a new born baby. To avoid waking the baby when he is asleep in the room, she will close the door when doing housework. She would like to have a device that will deliver her a warning signal when the baby wakes up and cries.

Solution:

Design a circuit that will deliver a warning signal when a baby cries.

Input	Process	Output

Component Selection:

Input	Process	Output
	 Transistor (with protective resistor)	
Symbol:	Symbol: 	Symbol:

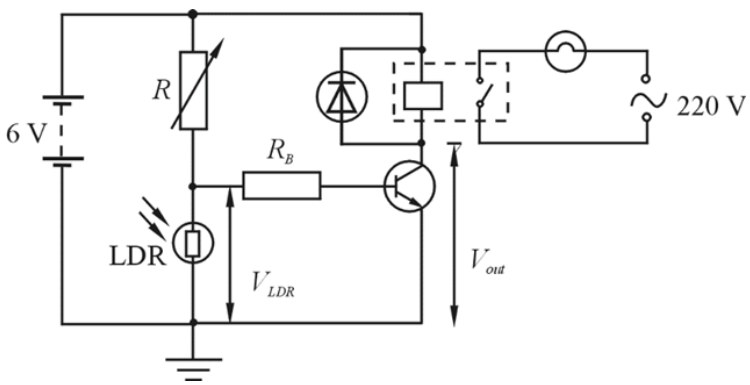
Complete Circuit:

IV Circuit Diagram and Printed Circuit Board

1. Circuit Diagram

A circuit diagram is a simplified graphical representation of a circuit. It uses simple symbols to form the circuit, with the symbols connecting to each other. A circuit diagram shows how the electronic components of a circuit are interconnected (however, when the physical electronic components are placed on a real circuit board, their positions may vary due to their sizes, shapes, pin positions, etc.). Circuit diagrams are applied in circuit design, wiring planning of print circuit boards, and maintenance of electrical appliances and electronic equipment.

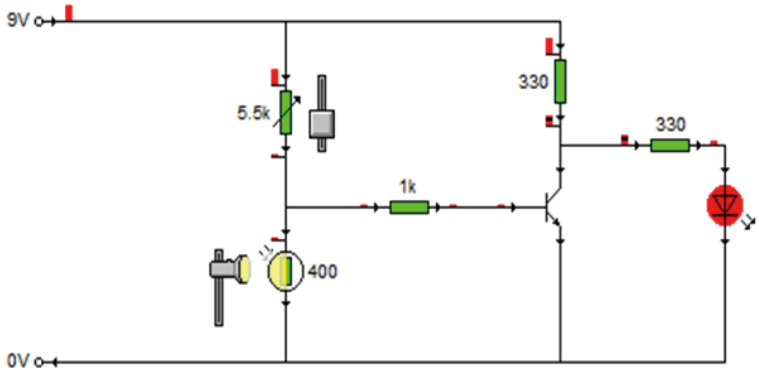
For the above-mentioned light dependent switch circuit, its design will begin with a circuit diagram like the following during the design stage.

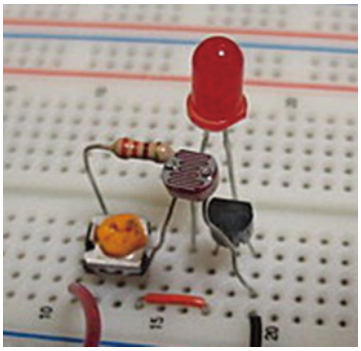


Circuit diagram of a light dependent switch

2. Simulation Testing

Apart from professional software, students can download trial version of software from the Internet such as Crocodile Clips (Yenka) for simulation testing of circuits (home use only and with time limit). (For safety, the following circuit connects an LED in series with a resistor to substitute the relay and 220V mains light bulb.)



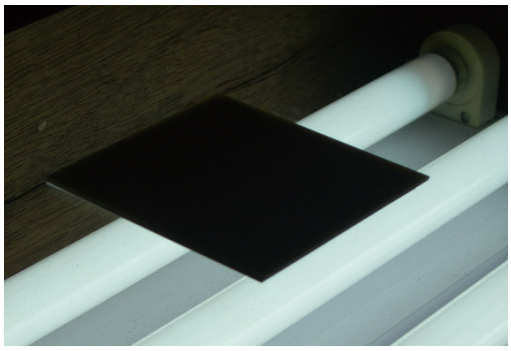


3. Breadboard Testing

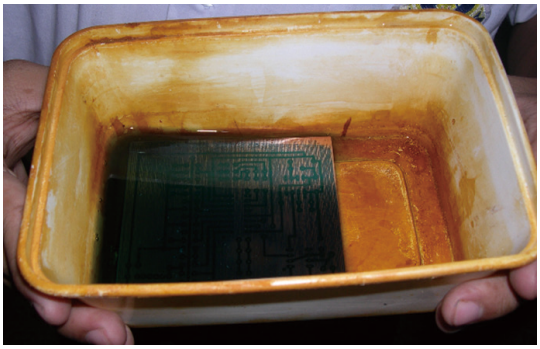
Students can also insert components onto a breadboard for testing a circuit.

4. Printed Circuit Board

A **printed circuit board (PCB) or printed wiring board (PWB)** mechanically supports and electrically connects electronic components using conductive tracks. Traditional PCBs use etch-resistant inks to print the circuit wiring and patterns, and are thus called printed circuit boards or printed wiring boards. As current electronic products are becoming more miniaturised and sophisticated, most PCBs nowadays are produced through applying an etch-resistant coating onto the circuit boards, followed by developing and etching to produce the required circuit boards. The circuit boards have developed from single-sided to double-sided and multi-layer to handle complex circuits.

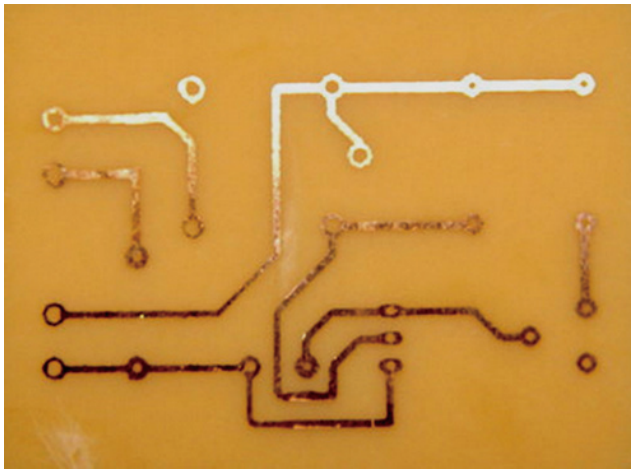


Exposing for developing



Etching

The design of a PCB is based on a circuit diagram, with the aim to realise the desired circuit functions. A PCB design mainly refers to the design of its layout, which needs to take into account factors including the electronic components, metal wiring, vias, external connection arrangement, electromagnetic protection, cooling and noise level. Well-designed circuit board wiring can save production cost, as well as achieve good circuit and cooling performance. Simple circuit board layouts can be designed manually; complex wiring designs, however, are usually done with the aid of computer software.



PCB of a light dependent switch circuit

When a PCB is ready, we can insert and solder electronic components onto it. Testing can be performed after the connections are checked and found to be correct.

V Glossary of Terms

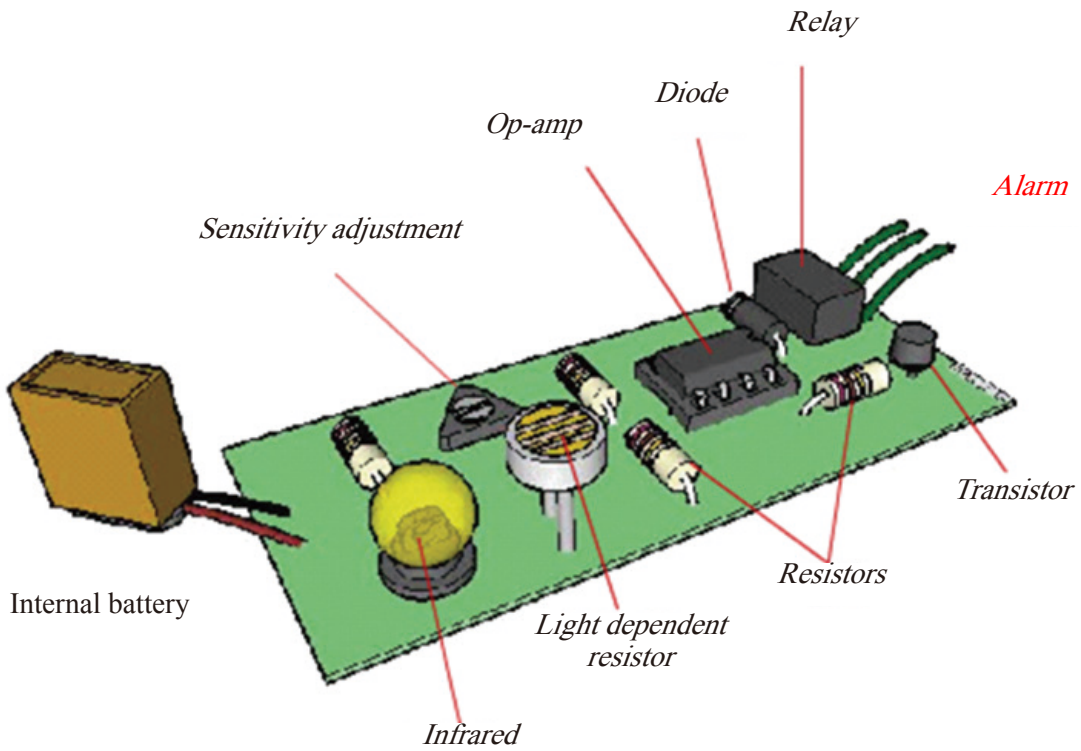
Electrical engineering	電機工程		Moisture sensor	濕度感應器
Electronic engineering	電子工程		Microphone	麥克風
Vacuum tube	真空管		Diode	二極管
Transistor	晶體管		Resistor	電阻器
Integrated circuits	集成電路		Variable resistor	可變電阻器
Base	基極		Capacitor	電容器
Collector	集電極		Relay	繼電器
Emitter	射電極		Light-emitting diodes (LED)	發光二極管
Analogue signal	類比信號		Speaker	揚聲器
Digital signal	數碼信號		Buzzer	蜂鳴器
Converter	轉換器		Motor	電動機/馬達
Switch	開關掣		Stepper motor	步進馬達
Micro switch	微動開關		Circuit diagram	電路圖
Light dependent resistor	光敏電阻器		Printed circuit board (PCB)	印刷電路板
Thermistor	熱敏電阻器			

VI Interactive Information

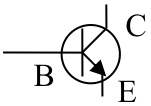
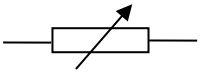
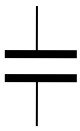
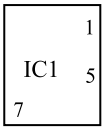
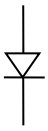
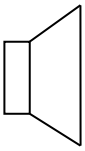
	Website	Content
1.	http://www.yenka.com/	Computer modelling tools
2.	http://www.technologystudent.com/elec1/elecex.htm	Learning materials with animations

Exercise

1. In the following diagram, label each input component with an I, processing component with a P and output component with an O.



2. Put down the names or symbols of the electronic components in the following table.

Component	*Symbol*
	
	
Resistor	
	
Light dependent resistor	
	
	
Light-emitting diode	
Motor	
	

Project Activity – Electronic-control (Environment Model)

Project Activity Guidelines

1. Objectives

a. Using electronic kits, solder to make a sensor switch circuit (light or heat sensitive).
b. Using the sensor switch circuit, make an environment model with simulated automation.
c. Try to manage a project.

2. On completion of the design project, students should be able to

a. get familiar with simple electronic components and their characteristics;
b. master basic soldering skills;
c. apply electronic circuiting on a model; and
d. make considerations from different perspectives.

3. Activity Outline

Two in a group, design and make an environment model with simulated automation.

Name of group: _____

Group members:

（1）：_____（ ） （2）：_____（ ）

4. Recommended Time

15 teaching periods × 40 minutes (total 600 minutes)

5. Required Materials and Tools

a. Light dependent (or heat sensitive) switch circuit kits (or a breadboard with appropriate electronic components)
b. Materials for making the model such as plastic sheets, cardboard, wood strips and straws

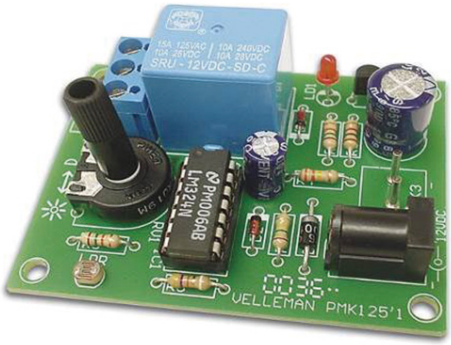
6. Activity Content

Before making, students are advised to carry out the project activity in Teaching Material 4 in order to familiarise themselves with basic soldering skills.

(a) Sensor Switch Circuit

Purchase sensor switch circuit kits for soldering, or purchase a breadboard with the addition of appropriate electronic components for self-making the circuit.

Light dependent switch circuit with the use of a transistor



Light dependent switch circuit with the use of an operational amplifier

References on electronic circuit kits:

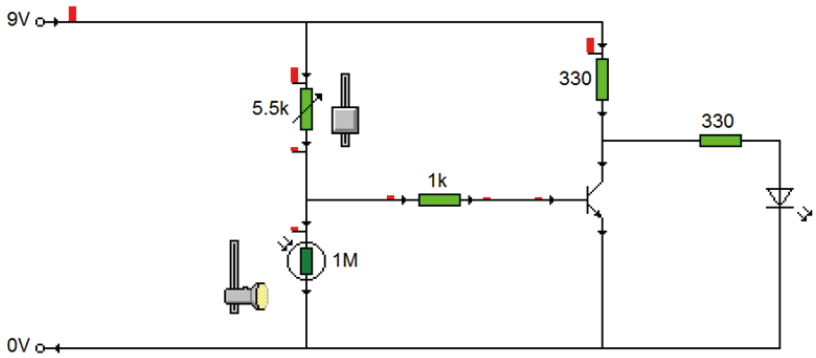
http://www.comebetter.com.hk/

http://www.robotzone.com.hk/index.php?option=com_virtuemart&Itemid=154

http://ectechnic.com/diy/elect/component.htm

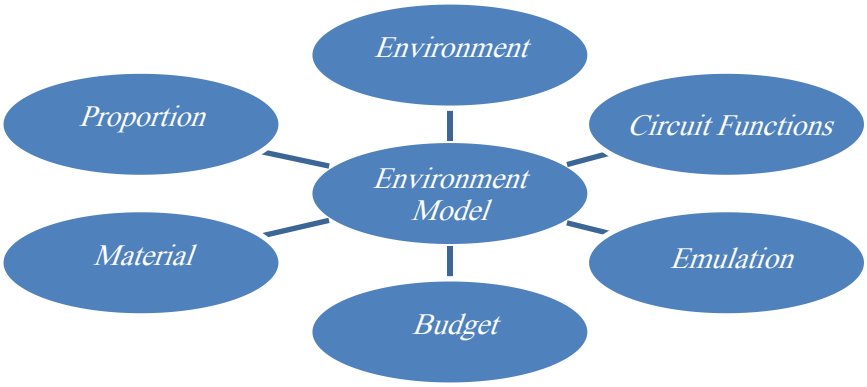
http://www.wecl.com.hk/weclub/DIY_parts.pdf

Or use the term 'light dependent sensor kits' (光敏傳感器套件) to search on websites such as Taobao.com.



For reference: A circuit made using self-purchased electronic components

(b) Considerations of Environment Model



When designing and making the environment model, we should consider the following:

(i) What environment are we simulating?
(ii) What is the function of the sensor circuit in the environment model?
(iii) How can the model be made like the real environment?
(iv) What are the scale and size of the model?
(v) What materials are used to make the model?
(vi) What is the budget of the production of the model?

(c) Development of Design Concepts

(i) Prepare the production schedule.
(ii) Observe the surroundings to find automatic operated facilities.
(iii) Observe the surroundings to find the environments which you wish to be automatic operated.
(iv) Identify environments that are automatic operated according to brightness level or temperature.
(v) What difficulties you expect to encounter when modelling the ideal environment?
(vi) How to overcome these difficulties?
(vii) One of the team members focusing on the design processes while the other one focusing on the production processes, study the consideration factors described in the Lesson Activity of Teaching Material 6.
(viii) Carry out the design processes.
(ix) Draft three initial designs.
(x) Choose the most appropriate design and further develop it.
(xi) Prepare the budget.