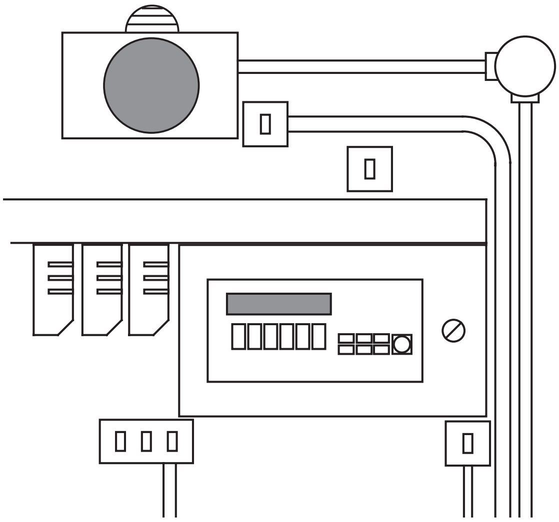
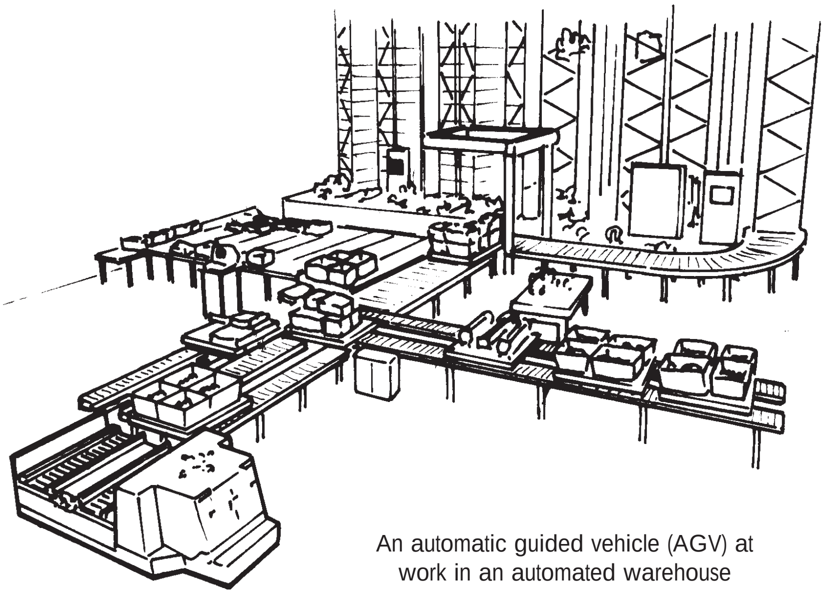
MONITORING AND CONTROL SYSTEMS

Electronic monitoring and alarm systems have become increasingly sophisticated over the last decade. This is partly due to new sensor technology, fail-safe design requirements, and generally the increasing expectations of consumers. For example, in the past many alarm systems - especially domestic ones - used a simple circuit board that would 'latch' on an alarm sound such as a bell if a momentary switch contact was made or broken.



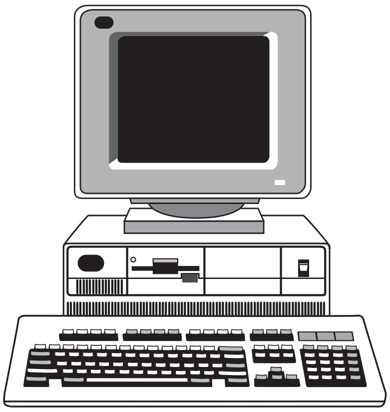
Today it is expected that most alarms will do far more than this, and many are designed as integrated alarm and process monitoring systems - especially in industrial environments.



An automatic guided vehicle (AGV) at work in an automated warehouse

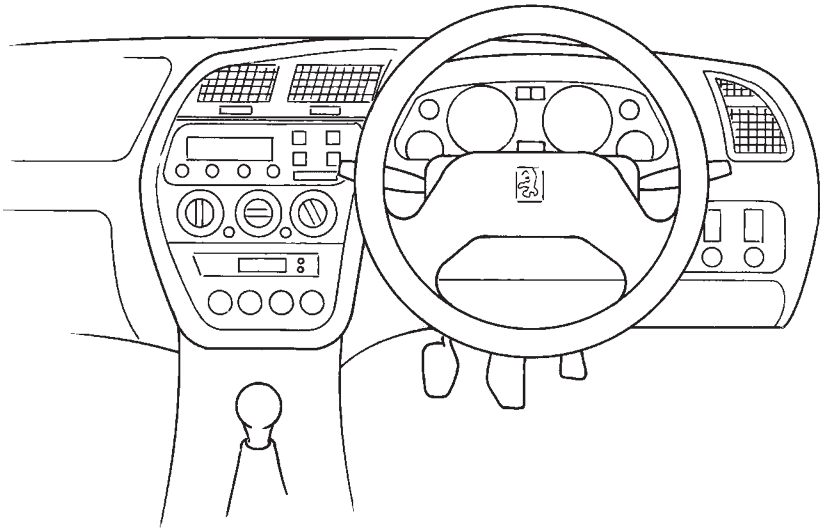
Many alarm and monitoring systems use an electronic *scanning* principle to enable a central operator or alarm user to look at the status of doors (open or closed), fluid levels (high or low), safety guards (positioned or not), temperature (above or below an optimum point), voltage level etc. (In a complex industrial environment, many of these functions are often combined in a single system.) In a scanning system, a centralised controller 'interrogates' a range of sensors - usually at high speed. If one of several sensors shows up a warning condition, this is shown up more or less instantaneously by the controller if the scanning speed is high enough.

A similar scanning principle is used in electronic keyboards such as those for computers where it is not possible to connect all individual keys into the central processor. Instead, each key of the keyboard is scanned sequentially at very high speed - several thousand times a second. Because even the fastest keyboard user is relatively slow keying in information, the machine always recognises when a particular key is pressed.

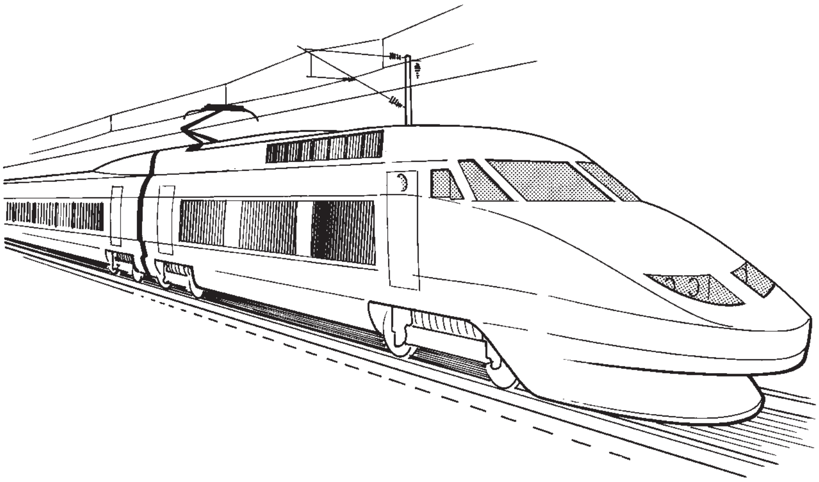


DESIGN OPPORTUNITIES

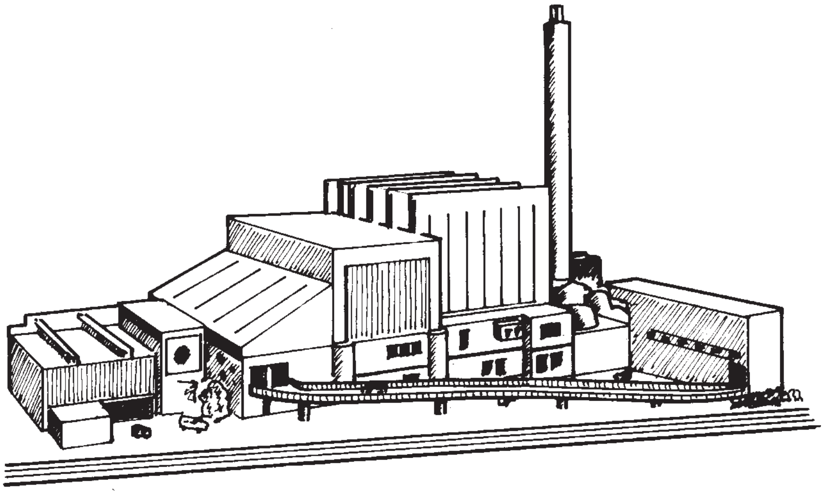
There are countless situations where combined monitoring and alarm systems are used. Any means of modern transport involves such systems; examples include cars (look at the instruments on the dashboard) and the high-speed Channel Tunnel trains (which door is not properly closed ?).



This is not even to mention the complex signalling and control systems used for transport networks such as railways.



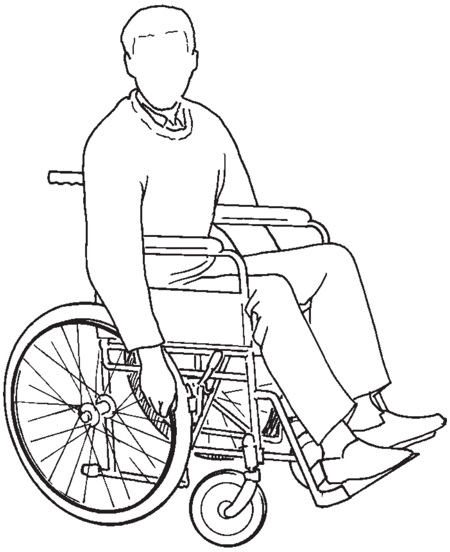
Most industrial operations involve extensive monitoring of premises and equipment which becomes increasingly important as advances in automation steadily reduce the number of people directly overseeing operations or processes. Systems monitoring and control is one of the most important aspects of modern power station design - especially nuclear power stations which require several levels of failsafe protection.



There are likely to be many local contexts where some form of monitoring and control is needed and where the scanning principle can be usefully applied. Examples include the following:

- A combined alarm and monitoring system for domestic or industrial premises capable of locating a possible system fault or point of entry at the time the alarm sounds.

- An immobile disabled person requiring a means of monitoring events such as a doorbell sounding - and making an appropriate response. (Note: the scanning principle is already widely used to enable disabled people to select and control things from an electronic 'menu'.)



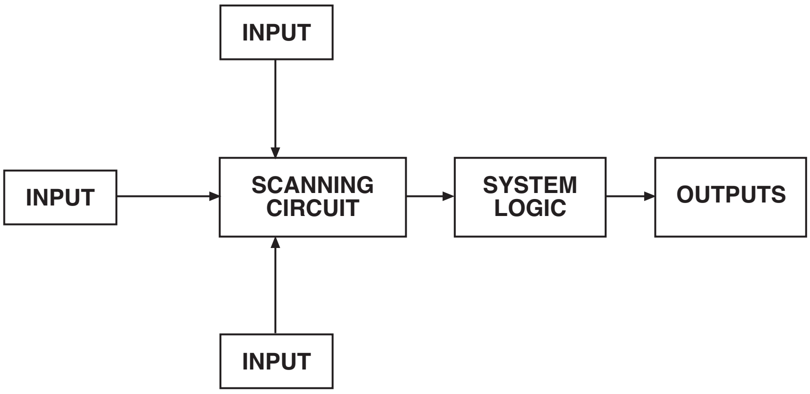
DESIGN SPECIFICATION

When a brief has been agreed on, it is necessary to draw up a design specification. This is a detailed description of what a system would be like, what it will do and who will use it. It is very important in the case of monitoring and control systems to recognise and take into account the full range of inputs and to decide on the range of response options required. If the context in which you wish to work is large, complex or both , you might design and produce only part of the system to prove your ideas.

ELECTRONIC SCANNING, MONITORING AND CONTROL

For a basic scanning, monitoring and control system, we can list four main requirements:

- inputs - e.g. transducers and sensors
- scanning circuit
- system logic
- output(s)

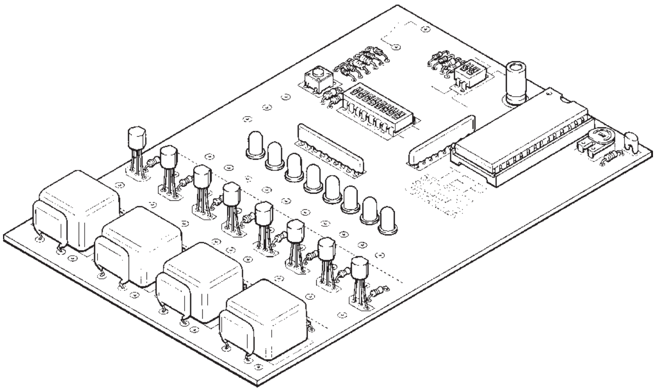


These may be linked together as a series of 'building blocks'. (Note: systems designers often 'sketch' their thoughts using *informal* styles of block diagram. It is a straightforward way of visualising something that would otherwise be quite abstract.)

The following notes provide ideas for the two central parts of the system: scanning circuit and system logic

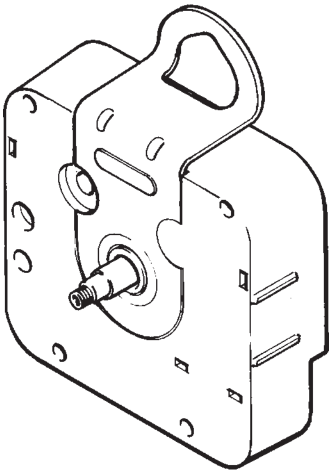
ELECTRONIC SCANNING

For a basic scanning system, the first requirement is a means of high speed sequential switching. This can be achieved, for example, using the TEP 'Bit by Bit' controller or the PLC chip (See study files 3 and 4). For a dedicated circuit, an alternative is to use an electronic clock driving a decade counter.

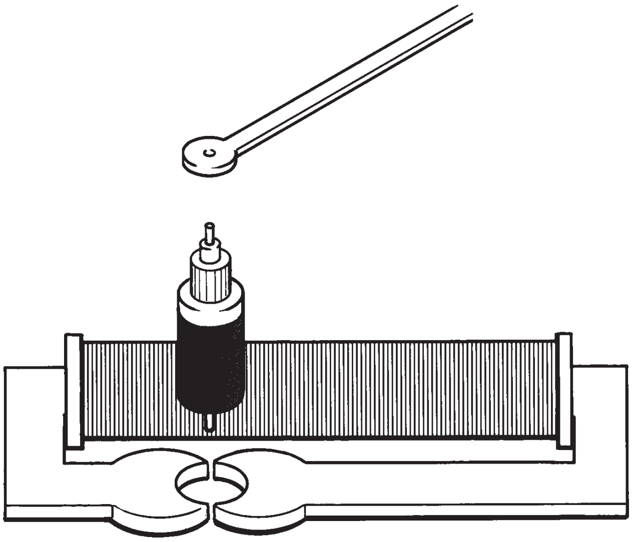


1. The clock

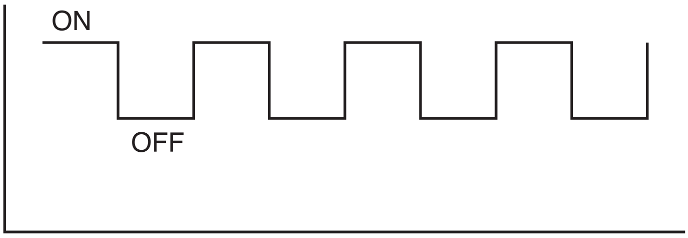
An electronic clock provides a regular series of pulses - usually at very high speed. Quartz crystal clock movements used in most analogue-display clocks use an electronic clock circuit running at very high speed.



The pulses from this clock are divided by a second circuit to provide a pulse every second. This powers a tiny stepper motor to turn the seconds hand from which the minute and hour hands are mechanically geared down. A quartz crystal - which is often larger than the electronic circuit - is connected to regulate the 'beating' of the electronic clock. The crystal has a high resonant frequency which the clock locks onto. The crystal is the equivalent of the pendulum or balance wheel in an older type of mechanical clock.



The series of pulses created by an electronic clock can be thought of as a rapid switching 'on' and 'off' - which we normally describe as switching between logic states 1 ('on') and '0' ('off'). The pulse train from such a clock can be represented graphically as a square wave. It is possible to create this train of pulses by simply opening and closing a mechanical switch - but this would be neither accurate nor very rapid !

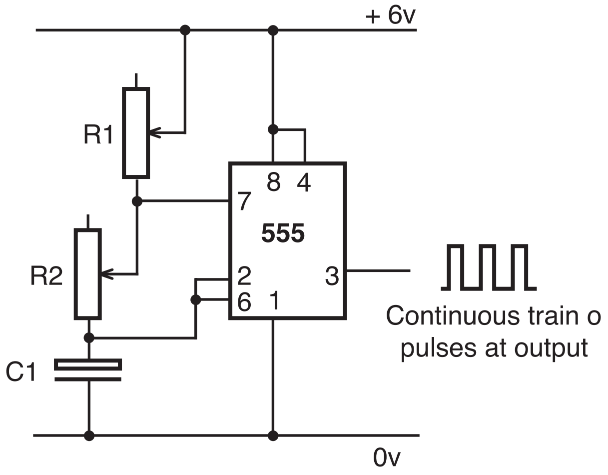


Designers use a variety of 'standard' circuits to produce the square wave pulse train. Two of the most common are the 555 timer used in its astable mode and the principle of connecting two logic gates with a few external components.

USING A 555 TIMER AS A CLOCK

The 555 is a general purpose timer I.C. that can be used in one of two modes, either **astable** or **monostable**.

Astable mode - The device will supply a continuous train of pulses at its output. The frequency and duration of the pulses is set by a network of two resistors and one capacitor (R_1, R_2, C_1).



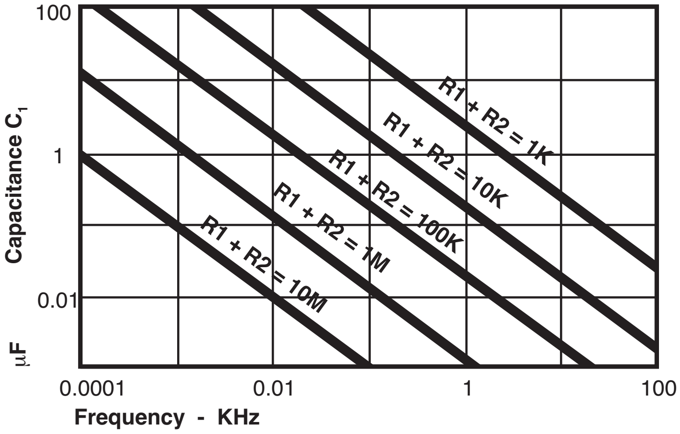
Continuous train o pulses at output

It is possible to calculate the frequency and duration of the pulses using the following formulas:

$$\text{pulse duration} = 0.693\,(R_1+R_2)C_1$$

$$\text{frequency} = \frac{1}{(R_1+2R_2)C_1}$$

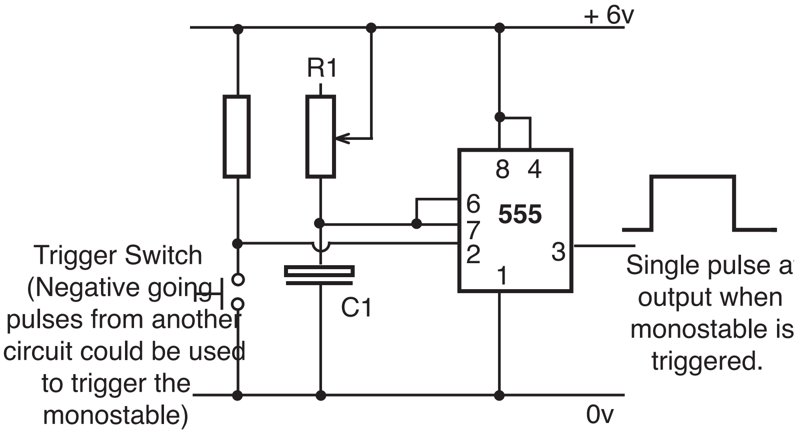
It can be easier, though, to use a table, or series chart, to look up the **very approximate** starting values for R_1, R_2 and C_1.



Simply select the desired frequency on the horizontal axis, draw a line from this point up the graph until you intersect with one of the diagonal resistance lines. This gives you the value for $R_1 + R_2$.

Then draw a horizontal line across from this intersection point to the capacitance values on the vertical axis. This gives you a value for C_1.

Monostable mode - The output from the device will switch from low to high when it is triggered. (Low = 0 volts, high = supply voltage.) The output will stay high for an amount of time that is set by the resistor capacitor network of R_1 and C_1. Once this time has passed the output will go low again. It will stay low until the device is triggered again.

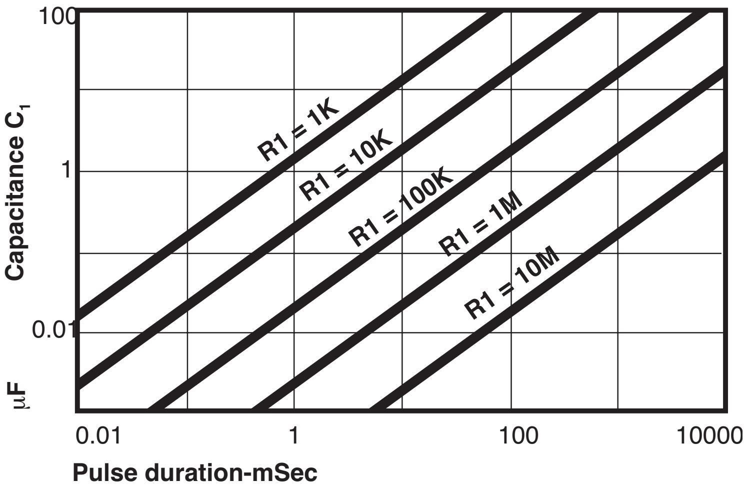


The monostable is triggered by pulling pin 2 down from the supply voltage to 0 volts. This can be done using a switch or by another control circuit.

The duration of the output pulse can be calculated by using the formula:

$$\text{Pulse duration} = 1.1\ R_1C_1$$

Again you can use a series chart to find the values of R_1 and C_1.

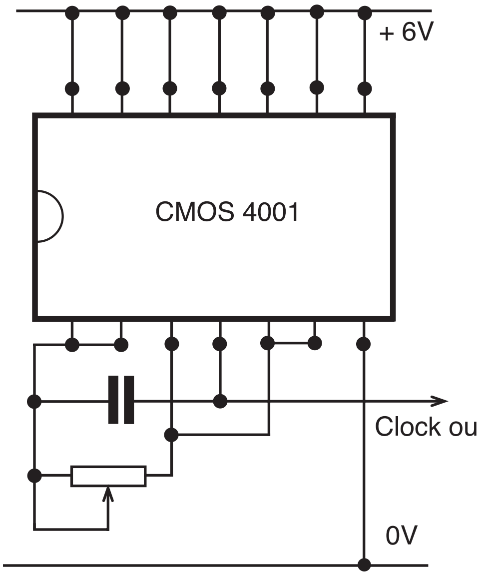


Select the desired pulse duration from the horizontal axis. Draw a line up the graph until you intersect with one of the diagonal resistance lines. This gives you the value for R_1. Draw a line across from the intersection point towards the capacitance values on the vertical axis. This gives you the value for C_1.

USING LOGIC GATES AS A CLOCK

There are several well known ‘formula’ circuits for using logic gates to create a clock. A common one uses a pair of invert or NOT gates and a capacitor and resistor to set the frequency. In the diagram shown, a pair of NOR gates have their inputs wired together to give NOT gates and these in turn are connected so that the output of the second gate switches regularly between logic 1 and logic O - i.e. effectively switches ON and OFF like the 555 timer output. The speed is determined by the values of the capacitor or resistor. Increasing the value of *either* capacitor or resistor reduces the speed of the clock. As an example, the following values will give a clock speed of approximately 0.5 - 100 Hz.

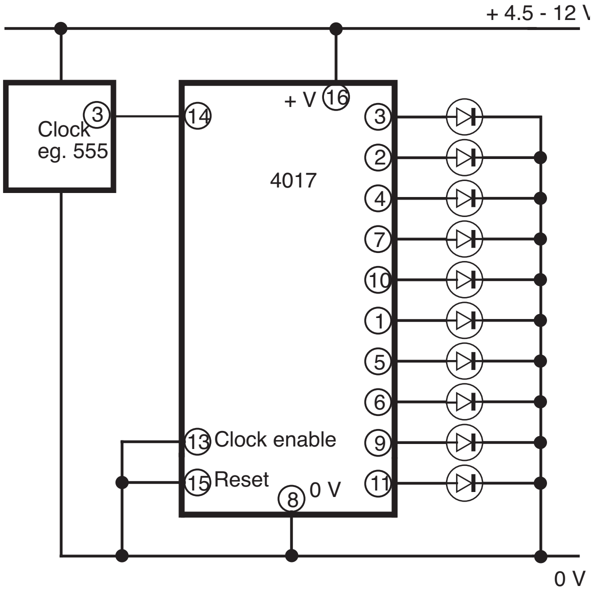
• Resistor 5m • Capacitor 47µF



It is normal to use a variable resistor for clock speed adjustment - usually a pre-set type that can be easily mounted onto a circuit board.

2. Decade Counter

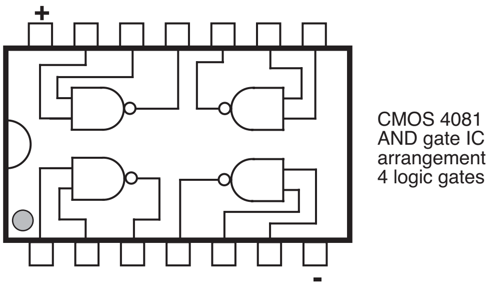
Sequential switching can be achieved with a device called a *decade counter*. This has a clock input to drive it and 10 outputs. When a decade counter such as CMOS 4017 is connected to a clock - e.g. the 555 timer - each of its ten outputs goes to logic 1 in turn and the others remain at logic O. If you connected LEDs to each of the outputs, you would see the first LED lighting up, then the next - and so on. If the LEDs were arranged in a straight line and the clock set to a higher speed, the effect would be to see a ripple of light passing through the LEDs. (This circuit is sometimes used for visual effects.)



IMPORTANT: In normal operation, the clock enable and reset pins of 4017 should be connected to 0 v.

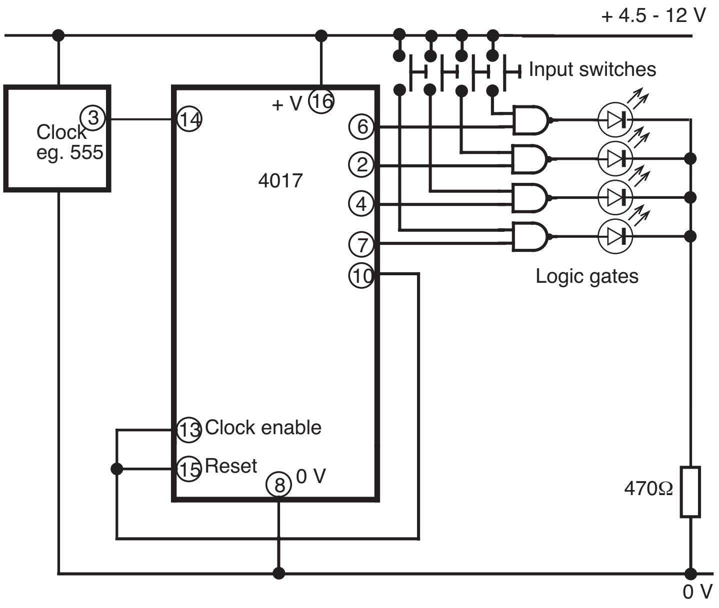
Systems Logic

Combining the clock and decade counter provides a facility for scanning. To make use of it, we need to add *logic* to the system. This is readily available in the form of self-contained logic gate circuits - usually several to a chip.



A logic gate has two or more inputs and one output. A set of rules, expressed in a truth table, determines the state of the output (logic 1 or logic 0) from the input conditions. A dual-input AND gate, for example, requires both inputs to be at logic 1 before the output goes to logic 1. Any other combination of input conditions keeps the output at logic 0.
(See study file 16.)

Let us assume that in an alarm or monitoring system there are 4 sensor switches.

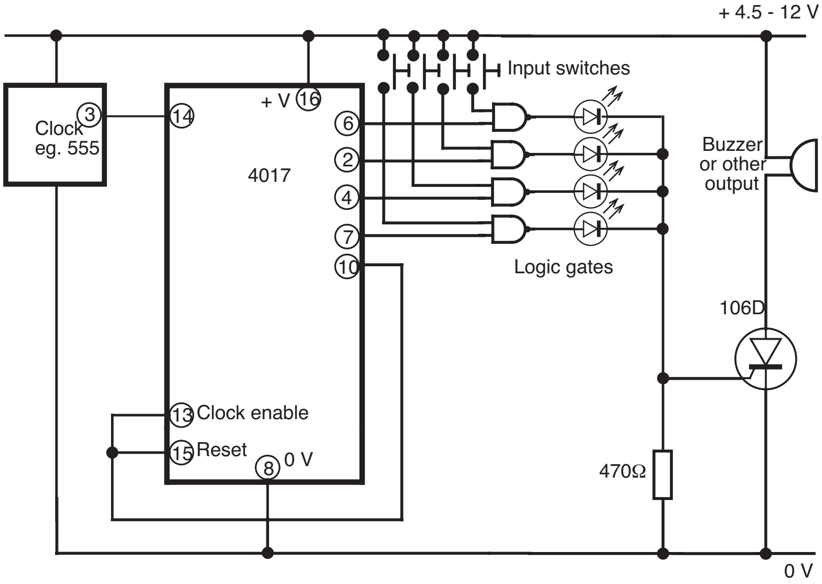


While each remains open, the condition it represents is 'normal'. If one of these switches is closed, we want a central operator to identify at a glance which sensor switch is affected. One method of achieving this is as follows:

Each of the first four outputs of a 4017 decade counter are connected to one input of a dual-input AND gate. The other input of each AND gate is connected to the sensor switch. The output of each AND gate is connected to the Ov rail by an LED and resistor. When a sensor switch is closed **and only when** the appropriate decade counter output is at logic 1 will the LED light up. If the clock is set to a high enough speed, the LED concerned will appear to be lit up all the time - but at a lower brightness. This is because when four outputs are scanned, any one LED will only be turned on for a quarter of the time. (You can compensate safely for this by using a lower than normal value LED protection resistor.) If two sensor switches are closed, two LEDs will come on - and so on.

You can experiment with scanning speeds to find an optimum value. It will need to be in excess of 24 Hz to eliminate any flicker effect. This is the speed at which film frames are changed and the lowest speed at which *persistence of vision* deceives us into thinking that a light source is continuous.

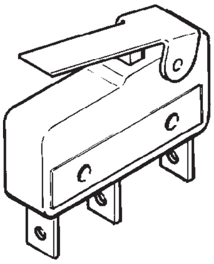
Any AND gate output in the system can also trigger an audible alarm. Many alarm systems use a thyristor to provide for latching. This enables an audible or visual signal to persist after the original cause - e.g. the momentary closing of a switch - has ceased. A common thyristor is 106D which has a current switching capability of 3 amps. It can be compared to a small power transistor as shown. When a small trigger current is supplied to the gate of the thyristor, the device 'turns on' and will pass a relatively high current anode to cathode. Unlike a transistor, whose collector to emitter current is proportional to base current, the thyristor latches or stays conducting after triggering. The easiest way to reset the thyristor is temporarily to interrupt its supply. The scanning circuit with thyristor added now provides the basis for a complete alarm and monitoring system.

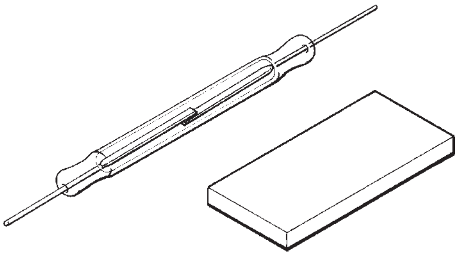


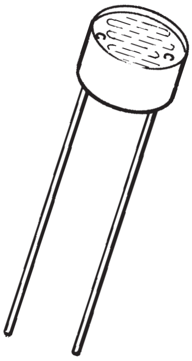
AND gates can be added, if required, to all ten outputs of the decade counter. Additional AND gates or alternative kinds of logic gate can also be added to provide a range of different functions.
See Technology Study File 16.

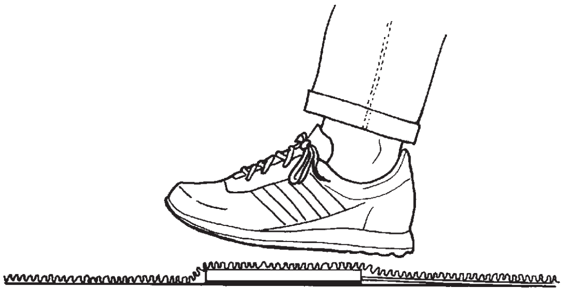
INPUTS AND OUTPUTS

Many alarm systems use reed switches, micro switches and mat switches as inputs. These are all reliable mechanical devices. Other possible inputs include sensors whose resistance changes accordingly to an environmental change - e.g., thermistor (temperature); Light dependent resistor (light); parallel probes (moisture conductivity).

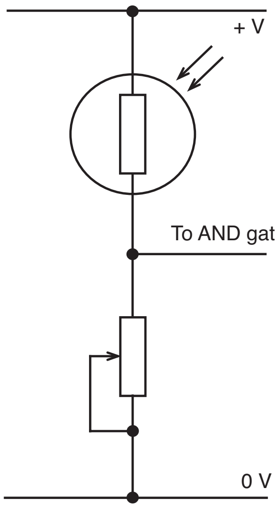








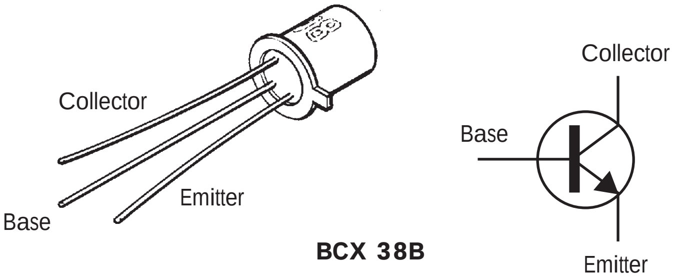
It would normally be necessary to incorporate these in the system as part of a potential divider circuit so that the changing condition is converted into a changing voltage.



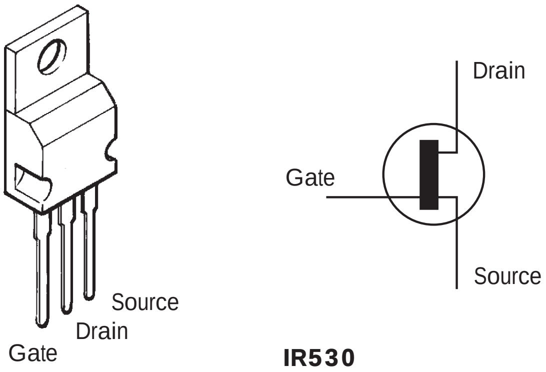
A CMOS AND gate input 'sees' a voltage more than half of its supply voltage as logic 1 and less than half the supply voltage as logic 0. The only real problem is that the voltage change might be very slow around this transition point. One way of sharpening the response from this kind sensor is to add a *schmitt trigger* - readily and cheaply available on a chip.

See Technology Study File 17

The 106D thyristor is capable of driving higher current loads directly - e.g. small motors, filament bulb - or it can be used for energising a relay coil. Alternative (non-latching) buffers are the Darling pair transistor BCX38B, capable of switching up to 800mA, and the IR530 power MOSFET, capable of switching up to 15A.



BCX 38B



IR530

It should be remembered that an input switch or sensor condition might provide a momentary signal only. This would set off a thyristor-based alarm, but not keep the signal LED energised. Where this is essential, you must consider building in more than one latch.