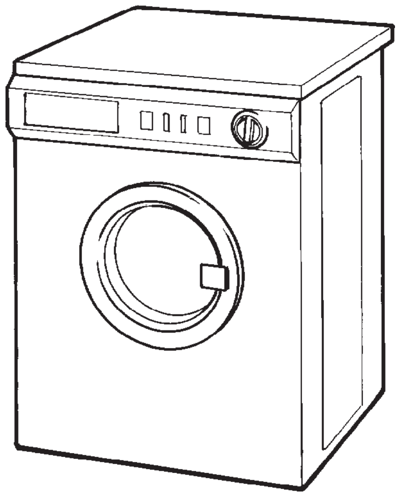
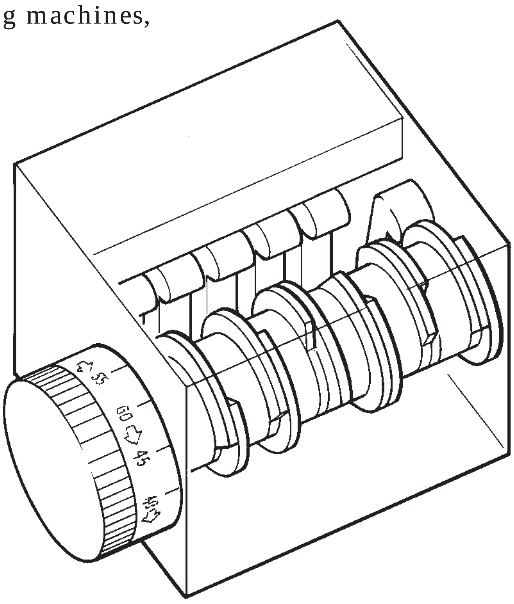
ELECTRONIC 'CAM' TIMER

Modern consumer products such as washing machines require *process* control systems. A washing machine, for example, uses a simple *continuous* control system to regulate the temperature of the water and a *sequential* control system to start and stop the wash drum motor (at different speeds) and open and close solenoid valves at correct times in the washing sequence.

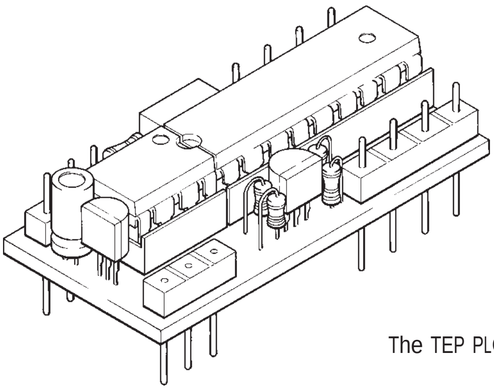


In many modern washing machines, the process control is accomplished by a cam timer. This is a motor-driven switch which is opens and closes switches mechanically. The motor turns a shaft very slowly and a series of cams along the shaft operate one or more switches.
See Technology Study files 10 and 14



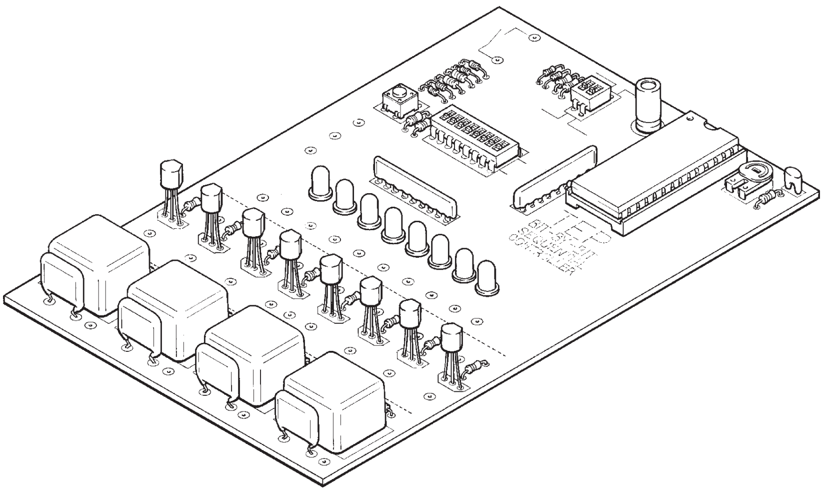
Cam switches are generally reliable but can only be programmed by changing cams along the rotating shaft. Programming a washing machine by one of these switches really means turning the shaft around manually (with the knob at the front of the machine) so that the sequence of operations can begin in different places along the pre-programmed cam switch cycle.

Cam switches are being replaced increasingly by electronic controllers which have no moving parts. Some of these controllers, like the TEP PLC chip, are based on a microprocessor and are often described as 'computers on a chip'.



The TEP PLC chip

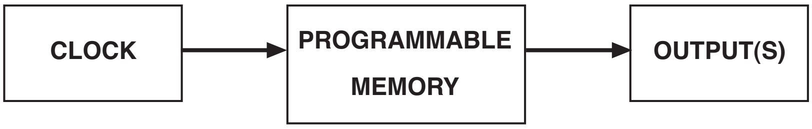
They contain all the elements of a basic computer and may be pre-programmed by a PC to perform a variety of control functions. The TEP 'Bit by Bit' controller is an example of an 8 output sequential controller which, in principle, could control a washing machine.
See Technology Study Files 4 and 5



The sequential switching action of most cam timers can be carried out electronically using circuits designed specifically for the purpose. An electronic 'cam' timer requires three basic 'building blocks':

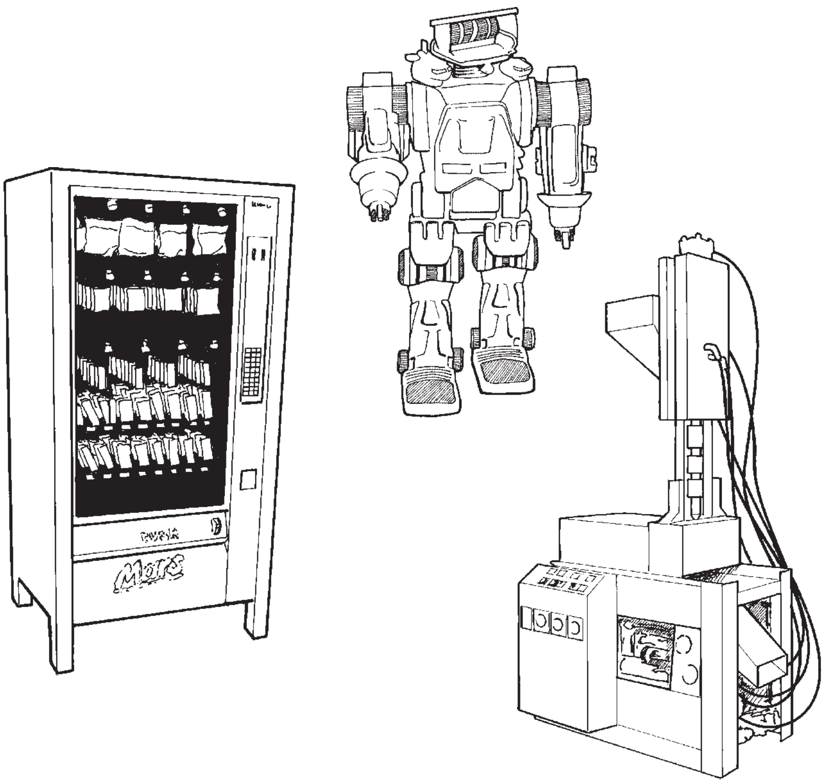
- a clock to regulate the speed of sequential switching - taking the place of the motor driving the cam shaft;
- a programmable memory - taking the place of the cams;
- one or more output buffers - taking the place of the cam-operated switches.

We can represent these three elements in a block diagram.



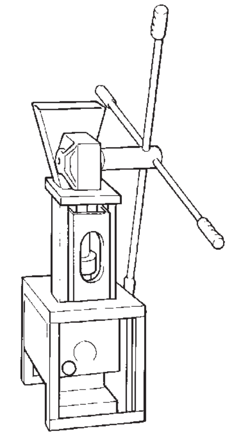
Design Opportunities

There are many situations where sequential timers are needed. Vending machines, toys and injection moulding machines are diverse examples of their uses. It is widely believed that many products relying on older *electromechanical* cam timers could benefit from upgrading to an electronic system which is potentially cheaper, reliable, and potentially more flexible.

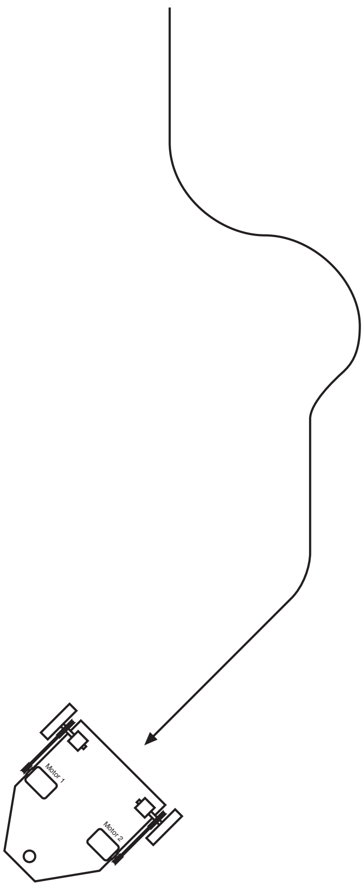


There are likely to be many local industrial, domestic or commercial contexts where the type of electronic sequential controller described in this unit could be used. Existing examples include the following:

- A small injection moulding machine whose moving parts are driven by pneumatic rams. The controller actuates a number of solenoid valves that control the ram movements in a programmed sequence.

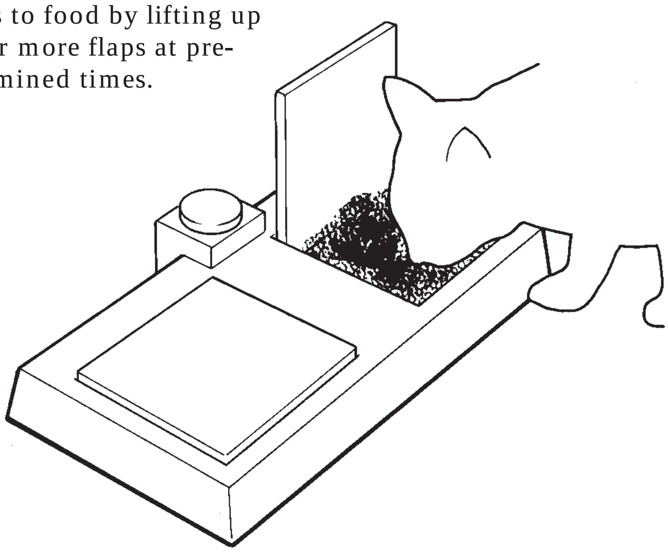


- A range of toys that can be programmed for a sequence of different movements. A buggy, for example, that steers by using two drive motors which are switched on and off in predetermined sequence.



1	on	on						
2	on	on						
3	on	on						
4	on	off						
5	on	off						
6	off	on						
7	off	on						
8	off	on						
9	on	off						
10	on	on						
11	on	on						
12	on	on						
13	off	on						
14	on	on						
15	on	on						
16	on	on						
	↓ m1	↓ m2						

- A pet feeder which controls access to food by lifting up one or more flaps at pre-determined times.

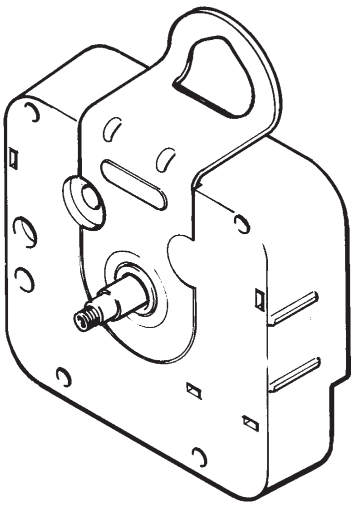


Design Specification

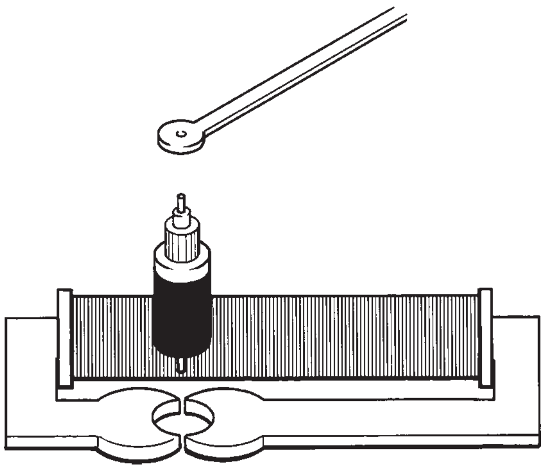
When a brief has been agreed on, it is necessary to draw up a design specification. This is a detailed description of what a product or system using a sequential timer would be like, what it will do and who will use it. The type of sequential timer described below can drive several outputs (equivalent to the cams in a cam timer) with up to 10 programmed steps for each output (although this can be extended). The circuit principle described has the advantage of simplicity but it will not be suitable for all sequential timing situations. You should read the following text carefully before finalising your specification.

Designing and Building an Electronic 'Cam' Timer.

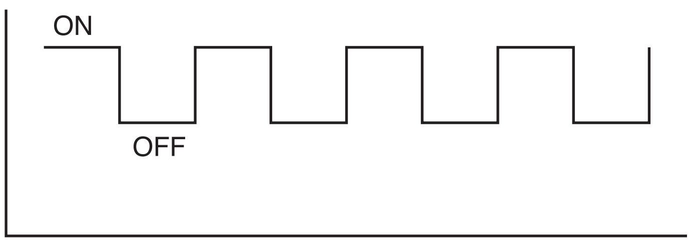
1. The clock.
An electronic clock provides a regular series of pulses - usually at very high speed. Quartz crystal clock movements used in most analogue-display clocks use an electronic clock circuit running at very high speed.



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. 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’ - or switching between logic states logic 1 and logic 0. 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 !

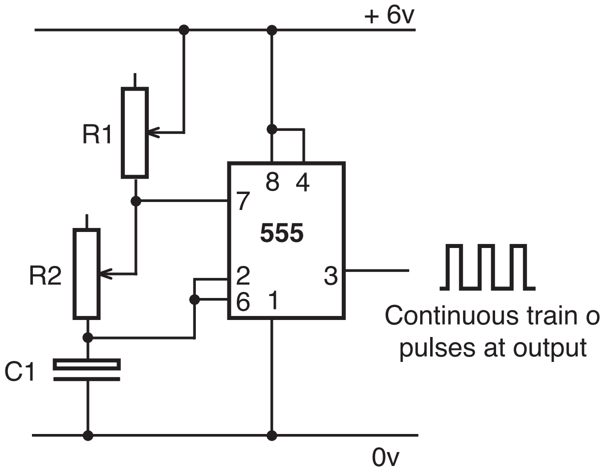


Designers use a variety of ‘standard’ circuits to produce the square wave pulse train. Two of the most common are the 555 timer used in its astable mode and the principle of connecting two logic gates with a few external components.

USING A 555 TIMER

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).

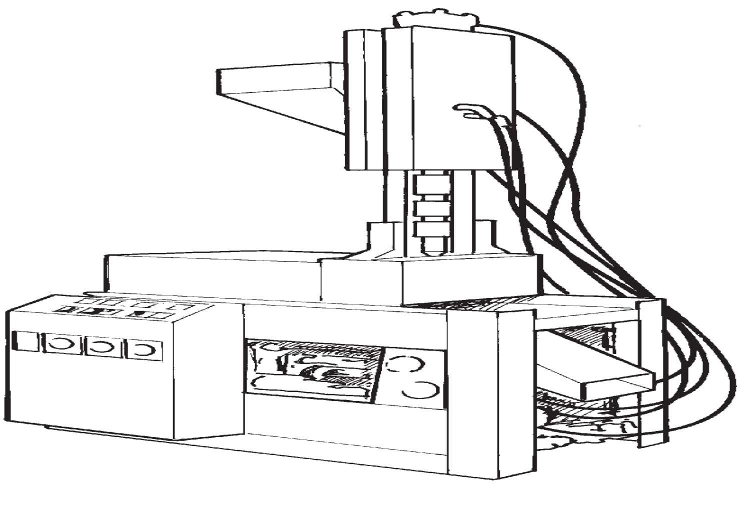


It is possible to calculate the frequency and duration of the pulses using the following formulas:

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

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

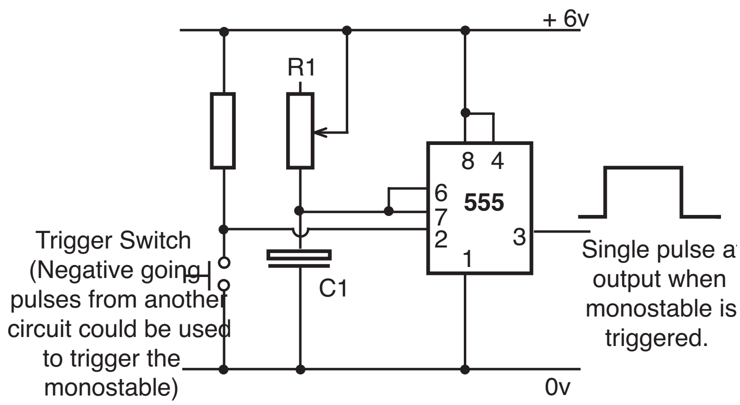
It can be easier, though, to use a table, or series chart, to look up the **very approximate** starting values for R_1, R_2 and C_1.



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.

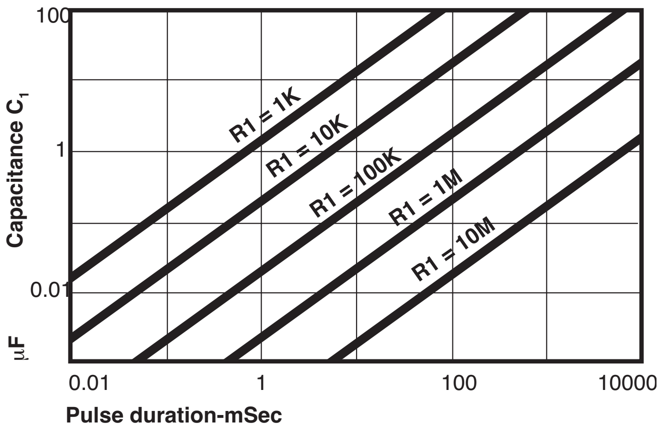


The monostable is triggered by pulling pin 2 down from the supply voltage to 0 volts. This can be done using a switch or by another control circuit.

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

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

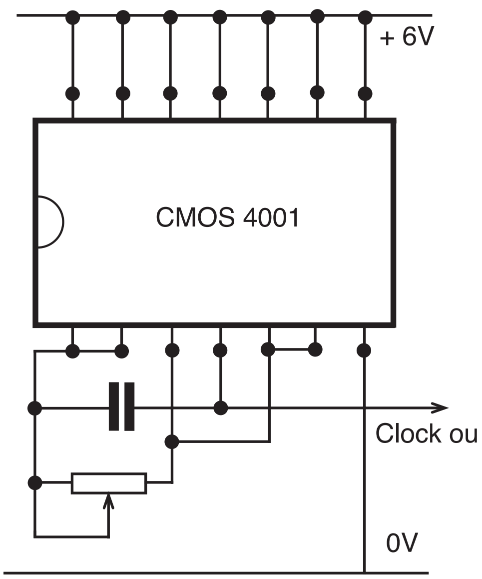
Again you can use a series chart to find the values of R_1 and C_1.



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

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.

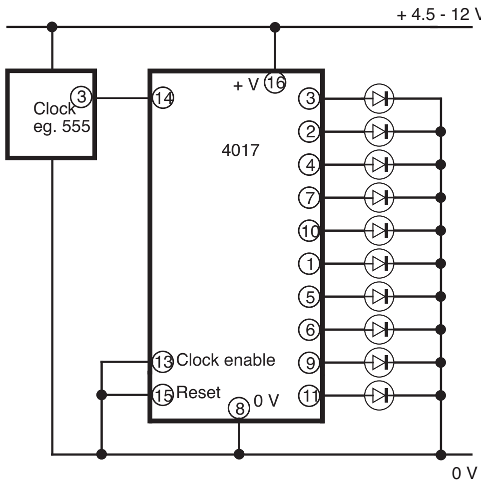


• Resistor 5m • Capacitor 47μF

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.

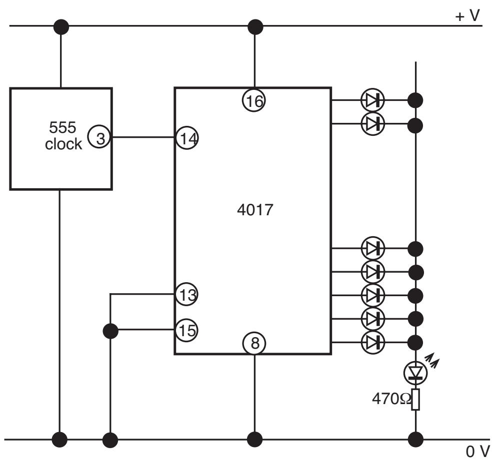
TIMER SEQUENCING

A typical cam timer uses cams profiled to turn a switch on and off several times during a single revolution. This sequencing function can be provided electronically using a *decade counter* chip such as the CMOS 4017. When this 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.)

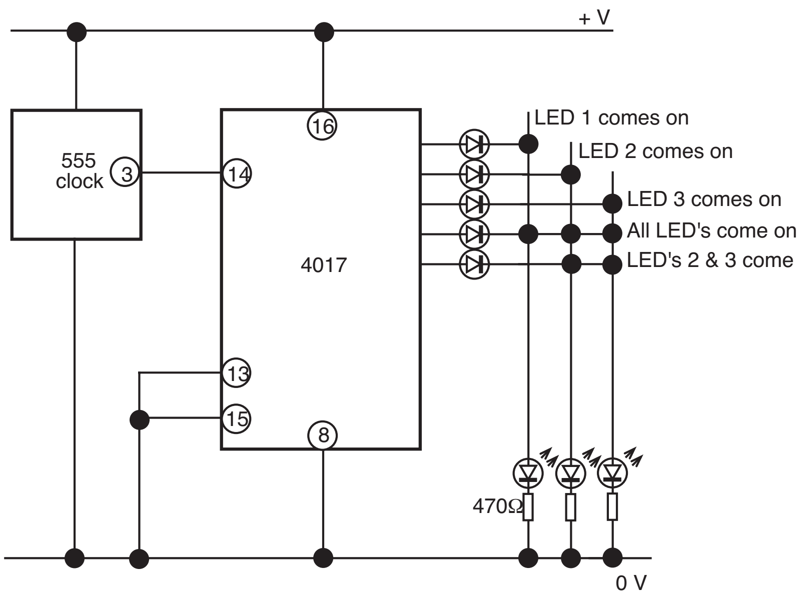


TIMER MEMORY

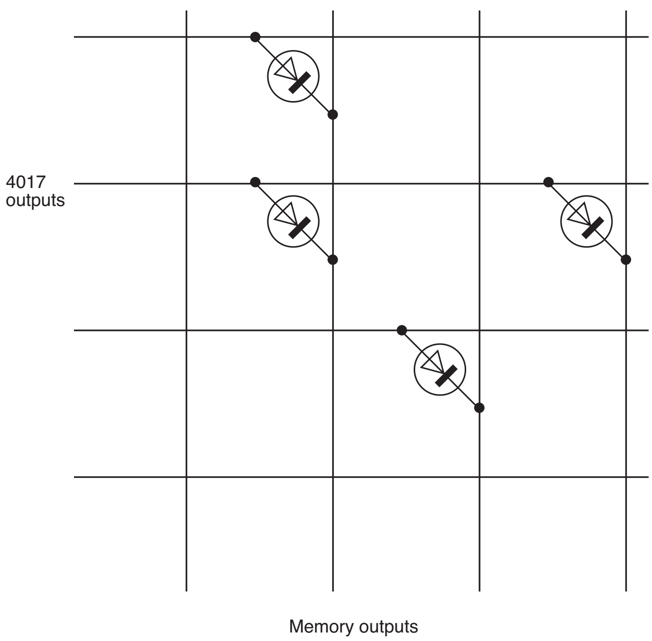
The outputs from the decade counter can be programmed over the ten step cycle by connecting (or not connecting) each one to a single LED by means of diode links. This is shown in the diagram. If the clock is running at a speed of 1 Hz, the LED will be energised for the first two seconds, then it will be off for three seconds and then it will come on for five seconds - and the cycle will repeat. It is necessary to use diode links because when one output is at logic 1 all the others are at logic O and if they are connected direct, there will simply be a short circuit.



The LED in this example is equivalent to *one* of the cam switch outputs More than one LED output can be programmed by connecting or leaving diode links to additional output lines. The diagram shows how, in principle, three LEDs (or more) can be controlled by linking across from the decade counter outputs.

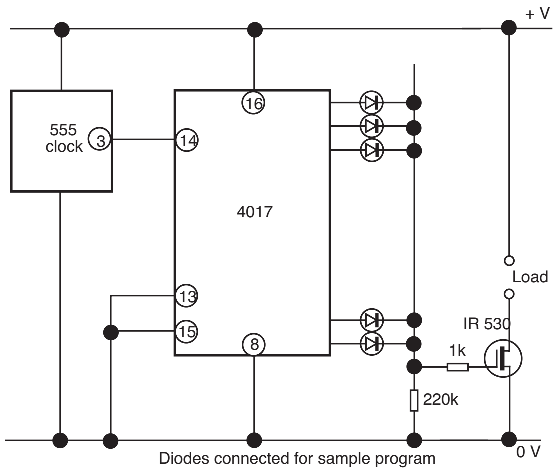


This arrangement of diodes is called a *diode matrix* and is usually represented as series of links within a matrix of horizontal and vertical lines. Note: in practice each 4017 can really only source enough current to drive one LED brightly.



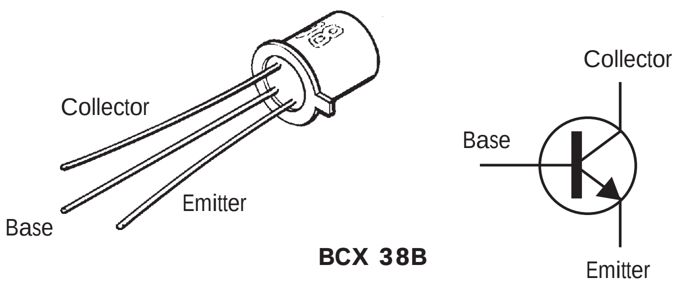
Outputs

In practice, a single output from a 4017 decade counter is not designed to source current for two or more LEDs at the same time and it will certainly not be capable of switching heavier loads. In a practical controller, each vertical output line requires an output *buffer*. This is normally a transistor or a transistor plus relay. BCX38B is a Darlington pair device capable of switching up to 800mA.

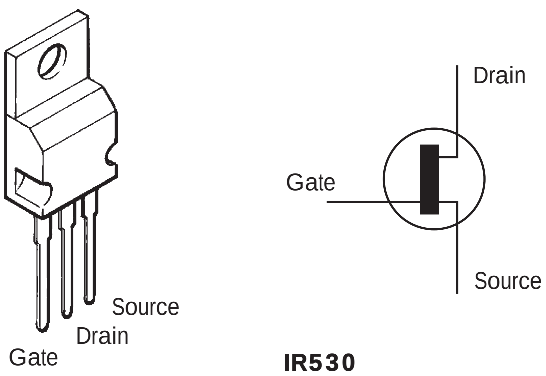


Diodes connected for sample program

IR530 is a power MOS FET device capable of switching up to 15A. It has the added advantage that its *gate* is voltage controlled and it is, effectively, just 'looking' for a logic state to switch it on or off. Unlike a bipolar type transistor (e.g. BC108) it does not draw any base current and switches behave more like a mechanical switch with a very low *drain* to *source* ‘on’ resistance.



BCX 38B



IR530

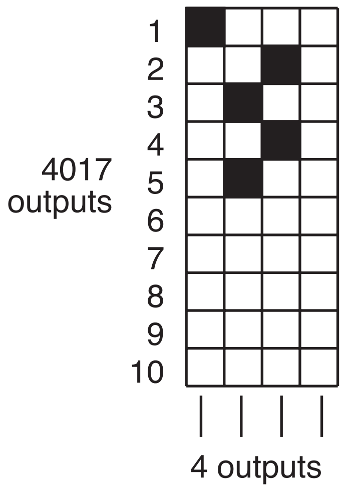
PUTTING IT ALL TOGETHER

A practical circuit for an electronic 'cam' timer - excluding details of the 555 timer clock - is shown below. In practice, the pin-outs of the 4017 are not in a straight line but if required, this can be achieved by careful routing of the PCB tracks.

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

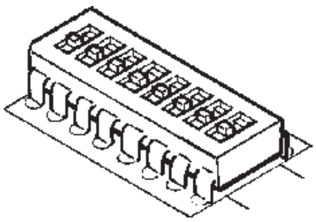
PROGRAMMING THE SEQUENTIAL TIMER

A simple paper grid can be used to assist in programming the timer; in the example shown, a cell is simply blocked in to show the 'on' state or left blank for 'off'. The output part of the PCB is designed accordingly and the diode memory *hard wired* in by soldering on the diode links.

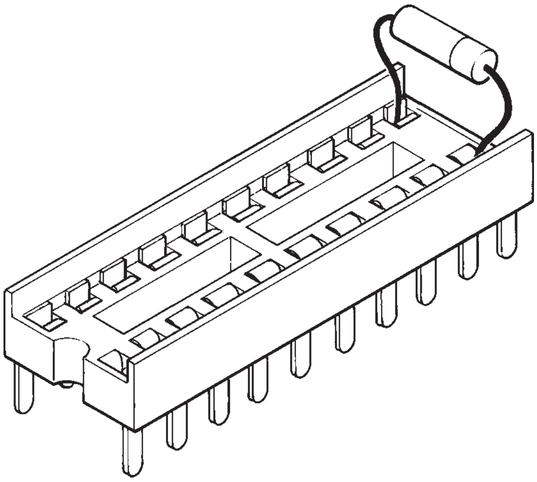


The disadvantage of hard wiring is that the timer becomes dedicated to only one programme. Alternative methods are to:

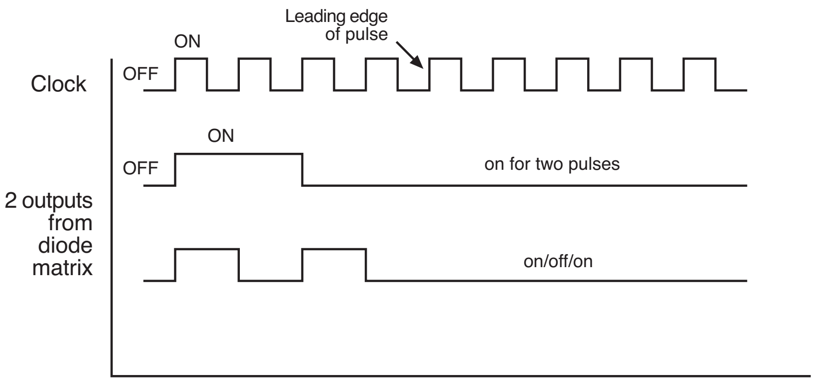
- insert a block of 10 DIP switches between the outputs and 10 diodes. The switches can then be set to make or break any diode link.



- insert a DIL socket between the 4017 outputs and the output rail. Diode links can be inserted or withdrawn as required.

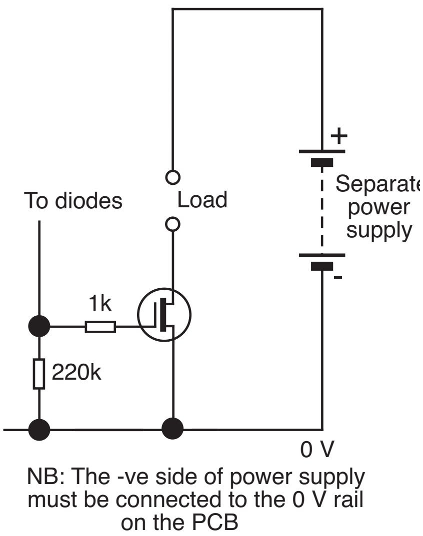


The output sequence of the timer, *as well as internal circuit events,* are normally shown using a *timing diagram*. In the example timing diagram for the sequential timer, the square wave at the top is the train of clock pulses and each output is represented 'on' (higher line) or 'off' (lower line) below. You will note that the 4017 decade counter is triggered by the *leading edge* of each clock pulse.



Reliable Operation of the Sequential Timer

The power supply of the timer may also be used for output loads such as motors or lamps. In practice, it is better to use a separate supply both to avoid sudden loads (which momentarily reduce supply voltage and possibly interfere with the operation of the chip) and run down a battery if used. Where the same supply is used for both the control board and load(s) then small capacitors (e.g., 0.22μF) should be connected as close as possible to the power supply pins of both the 555 and the 4017.



In addition - or sometimes even if a separate supply is used - it may be necessary to suppress loads against electromagnetic interference. Small DC motors are a notorious source of interference which can affect the operation of the chips. This problem can normally be cured by connecting both a 10μF electrolytic and a O.22μF ceramic capacitor in parallel across the motor terminals.