Electronics for Model Railways

Chapter 20

Semiconductors and ICs

By Davy Dick

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In memory of Margaret

Contents

Semiconductors and ICs

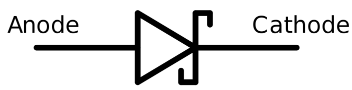
There are many, many types of semiconductor devices and they can be found in all but the simplest of household, industrial, military and medical electronic objects.
This chapter only covers the most common ones used in model railways. This is only an introduction to these components, as they are very wide in their scope and there is a lot of detailed information out there. Fortunately, we can do a lot with them without having to delve too deeply into their inner workings.
This chapter only gives a flavour of these semiconductors, highlighting some of their main features. They are fascinating, offering unlimited opportunities for model railways.

Diode

We looked at the diode in Chapter 1. The usual silicon diode (e.g. the 1N4001) is ideal for most rectification purposes. However, it less suitable for rectifying higher frequencies.
It has a forward voltage of around 0.6V to 0.7V resulting in a small loss of voltage.
Worse though, is the time it takes to recover from conducting back to non-conducting. This *'reverse recovery time'* could last as long as several milliseconds. This is not a problem a lower frequencies but results in significant loss of efficiency at higher frequencies.

Schottky diode

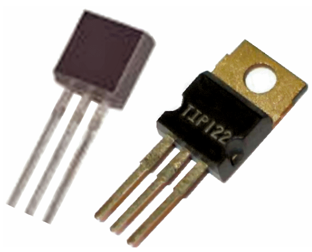
The Schottky diode is of a different construction which minimises these problems. Its forward voltage is around 150mV to 450mV and it has zero recovery time.
It can found in DCC circuits which operate at fast switching speeds.



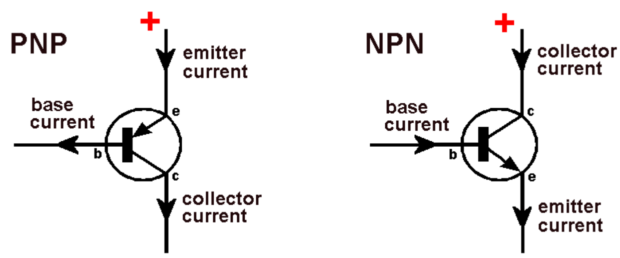
Transistors

These are available in a range of shapes and sizes, using different materials and providing different functions and different power handling capabilities.
They are generally used in two ways:
As an amplifier, to boost small audio or radio-frequency signals.
As an electronic switch, to control LEDs, relays, etc.

As the images show, they have three wire leads. In most transistors, these are called the emitter, base and collector.
Although other types are used, we will first examine the most common types of transistor – those known as PNP and NPN types.
The difference lies in their physical construction.
A PNP type has a layer of n-type semiconductor that is sandwiched between two layers of p-type semiconductor.
The NPN type is more common nowadays and it has a layer of p-type semiconductor that is sandwiched between two layers of n-type semiconductor.



The illustration shows the symbols for the two types. It also shows how current flows through them.
With a PNP type, the collector is taken to 0V while the emitter is taken to the positive



supply. This is the reverse for NPN types; the emitter is taken to 0V.
In both cases, the base connection can be thought of as a tap that regulates the amount of current flowing between the other two connections (another type of transistor, the FET, even calls the connections the 'source', the 'gate' and the 'drain').

The PNP transistor

Applying a voltage across the emitter and collector produces a current flow between them when the base is held at 0V. If you now gradually increase the voltage between the base and emitter, the current flow will be reduced until it completely stops (known as *'cutoff'*).
Conversely, decreasing the voltage across the base/emitter junction, increases the flow of current between the emitter and collector.

The NPN transistor

Applying a voltage between the emitter and collector produces no current flow when the base held to 0V.
If you now gradually increase the voltage between the base and emitter, the current flow will be increased until it reaches the maximum that is possible with that transistor (see below).
Conversely, decreasing the voltage across the base/emitter junction, decreases the flow of current between the emitter and collector until it eventually stops.

Gain and saturation

There is a direct relationship between the input current and the output current of a transistor and this is called its *'gain'*.
For example, a BC547 transistor (an NPN type) has a maximum current gain of 800. So, a current of 1uA (one microamp) flowing from base to collector should result in a current flow of 800uA from collector to emitter. Similarly, a 2uA base/emitter current should result in a 1.6mA collector/emitter current and a 10uA base/emitter current should result in an 8mA collector/emitter current.
This current amplification cannot carry on indefinitely, as the BC547 can only handle a maximum current of 100mA from collector to emitter.
Once the transistor reaches the 100mA flow, any further increase in base/emitter current has no further effect on the output current. This stage is known as *'saturation'*.

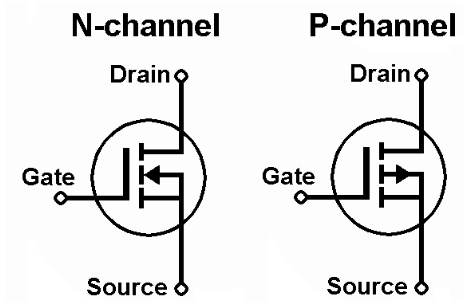
The larger power transistor shown in the above picture is a TIP122 and is an NPN type with a gain of 1000 and a maximum current of 5A. So, a 1mA base/emitter current should result in a maximum of 1A collector/emitter current. As with other power transistors, its collector is bonded to a metal plate to allow a heat sink to be fitted to transfer away heat when high currents are being drawn.

Note

The arrows in the above illustration show the flow of 'conventional current' (see chapter 1) which thought that current flowed from a positive potential to a negative potential. In fact, actual current comprises a flow of electrons which is attracted to a positive potential (the opposite of the directions shown in the arrows). As long as you are aware of the distinction, you will not be puzzled when different diagrams and explanations describe current flow differently.

MOSFETs

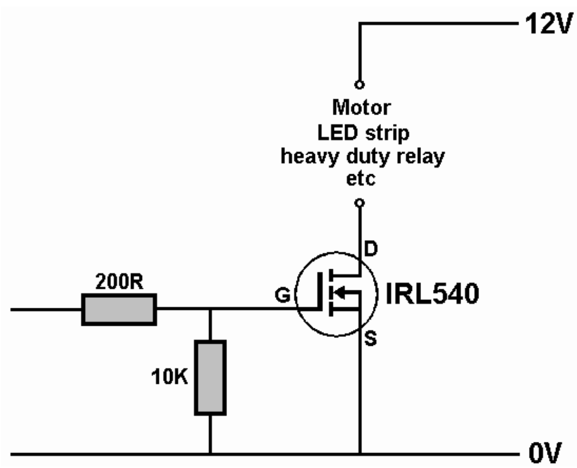
MOSFET stands for *Metal-Oxide Semiconductor Field-Effect Transistor,* which is quite a mouthful. The first part describes its make-up and the second part how it operates.
Like bipolar transistors, MOSFETs have three connections.
They are known as the *'Gate'*, *'Drain'* and *'Source'* instead of the *'Base'*, *'Collector'* and *'Emitter'* connections in a bipolar transistor.



Unlike bipolar transistors, MOSFETs are voltage controlled. The field-effect transistor is a type of transistor which uses an electric field to control the flow of current. Whereas the bipolar transistors use a base-emitter current to control output current, the FET has almost no gate-source current flow.
Applying a voltage to the gate generates an electrical field and this controls the current flow through the channel between the source and the drain.
They are often used in powerful audio amplifiers but we can use them as power switches.

Choosing a MOSFET

MOSFETs are available as N or P channel, depletion mode or enhancement mode, and standard or logic-level.
N channel, enhancement mode, logic-level MOSFETs are best suited for our purposes.
Enhancement mode MOSFETs allow current to flow from source to drain when a positive voltage is applied to the gate. Many MOSFETs (e.g. the IRF range) are designed to only allow current flow when the gate is at 10V or more.
However, many circuits that might be connected to the drain (e.g. PIC and Arduino-based modules) have outputs that only rise from 0V to +5V.
In these cases, we would use the IRL series of MOSFETs (the 'L' indicates a logic-level gate drive). An IRL type MOSFET will turn fully on with an input of +5V.



The diagram shows a heavy-duty switch using an IRL540 MOSFET (an N channel enhancement mode transistor). Any DC load can be connected between the drain and the positive supply and the IRL540 can output a whopping maximum of 28A (with a heatsink).
The transistor is turned on when +5V is presented to the gate, although the input could be PWM (pule width modulated) to control a motor's speed, etc.
The 200 Ohm resistor is there to protect the attached circuit should the MOSFET fail and to limit any instantaneous high current when the transistor is first switched on (the gate can be highly capacitive and produce a brief current surge). The 10k Ohm ensure the gate turns off when Gate signal is removed.

Note

If you a connect an inductive load (e,g, motor, relay, solenoid,etc.) connect a flyback diode across the device..

Further reading

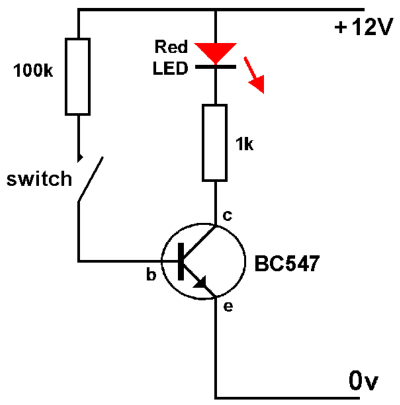
That was only a brief outline of the transistor's main characteristics. If you want to know more about transistors, here are a few places to look:

www.electronics-tutorials.com/basics/transistors.htm
https//electroicsclub.info/tranistors.htm
www.rason.org/Projects/transwit/transwit.htm
www.electronics-tutorials.ws/transistor/tran_4.html
www.electronics-tutorials.ws/transistor/tran_6.html

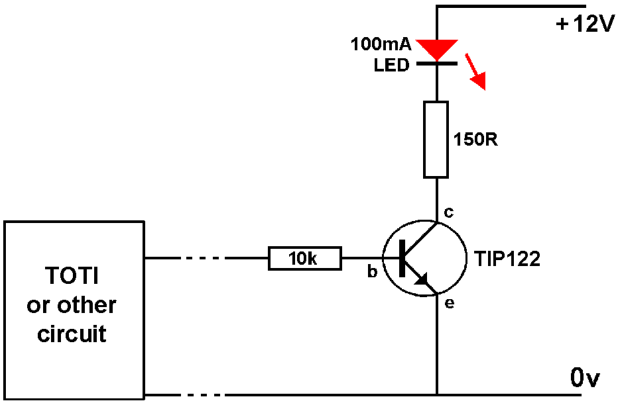
Practical examples

Here are some example circuits which might further explain how transistors work.

Single LED



This circuit uses an NPN transistor, with its emitter taken to 0V and in this configuration acts as an electronic switch.
The 1k resistor limits the current through the LED (and also through the collector-emitter junction). As shown, no emitter/collector current will flow and the LED will be unlit.
If we now throw the switch, conventional current flows from +12V through the 100k resistor and through the base-emitter junction. The 100k resistor is used to limit the maximum base-emitter current.
The smaller current through the base-emitter junction results in a much greater current through the collector-emitter junction and the LED will light.

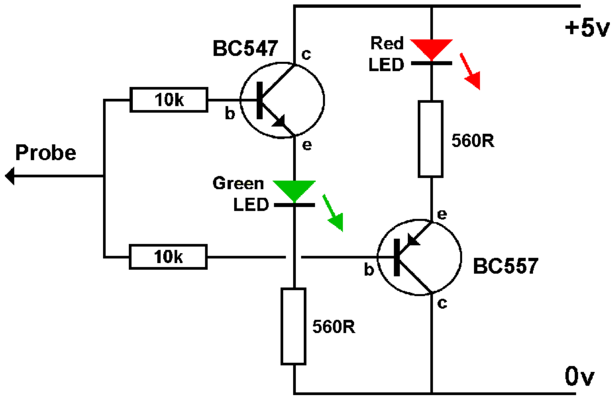


This circuit is used to illuminate a much brighter 100mA LED and uses a TIP122 power NPN transistor. The 150 ohm resistor limits the maximum collector current.
The output from a TOTI (Train On Track Indicator) or other electronic module is unlikely to be able to provide the larger current requirements of this high-current LED.
This is solved by using a power transistor switch like the one shown.
In this case, the output of the other device is used to produce the TIP122's base-emitter current. Once again, the smaller base-emitter current results in a much greater collector-emitter current.

Logic probe

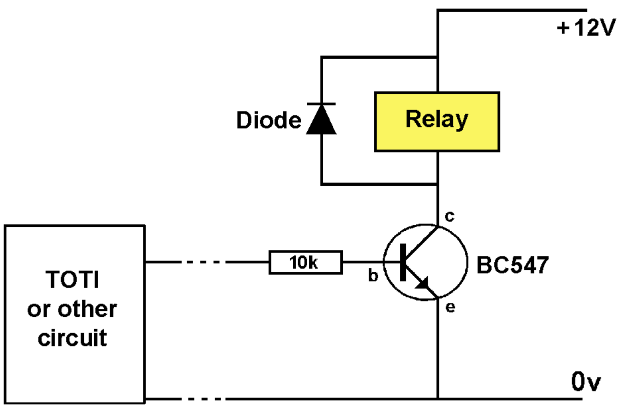
Many modellers own multimeters, which are extremely useful tools for testing and fault-finding on layouts and on electronic modules. The ability to read different voltage levels helps trace bad joints, etc.

But, when dealing with modules that work on digital inputs and outputs, you only want to know whether a particular point in your circuit is at +5v or at 0v.
That is where a logic tester is handy.
This circuit works by connecting it to the +5v and 0v of the module you are checking. Then you touch any point in the circuit with the probe. If +5v is on that point, a green LED lights up. If there is 0v at that point, the red LED lights up. All other voltages, or points not connected to anything, either keep the LEDs unlit or dimly lit.



The BC547 is an NPN type and current flows from its collector to emitter when its base is at a higher voltage than its emitter. The BC557 is a PNP and allows current to flow from its emitter to collector when its base is at a lower voltage than its emitter. That's why the red LED lights on 0V while the green LED lights on 5V.

Relay
Some relays operate with a relatively small current. Others require a transistor to act as a current amplifier to switch the relay. You have to check the manufacturer's specifications.
In this circuit, the relay resistance is 250 ohms, therefore requiring 48mA to operate it. The BC547 provides the required current amplification.
As mentioned in a previous chapter, the diode prevents any back EMF from damaging the transistor when the relay is switched off.

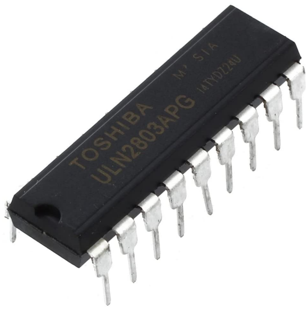


Transistor arrays
There are occasions when you want to control multiple devices with transistor switches (e.g. groups of LEDs, sets of relays, stepper motors, etc.). Rather than using multiple transistors, you can use a transistor array to save space and tidy your board.
Transistor arrays are just multiple transistors in one package. Each input pin on the package controls its own corresponding output pin. For example, applying a high (usually +5V) to an input pin makes its output pin go low (0V).

They are mostly described as *'high current Darlington transistor arrays'*. This just means that there are two transistors for each output. The first transistor amplifies the current and the second amplifies further. This is very useful as most other modules are not capable of switching high currents and need to use high current amplifiers.

The outputs are *'open-collector'* which means that the output needs to have a load connected between its output pin and the positive supply. The transistor's collector (or drain in MOSFETs) is not connected to anything internally and needs the load to allow current to flow from emitter (or MOSFET source) to the positive supply.

ULN2803



The ULN2803A is a high-voltage, high-current Darlington transistor array, consisting of eight NPN Darlington pairs.
It has 18 pins, 8 inputs, 8 outputs and a 0V and positive supply pin.
It has two rows of pins and pins 9 and 10 are connected to the power supply.
The other pins are arranged in pairs with the input pin facing across from the output pin. So, pin1 is the input pin that controls output pin 18, pin 2 controls output pin 17 and so on.
The drivers have *'open collector'* outputs. which means that they require a load to be connected to their outputs to see the expected voltage changes.

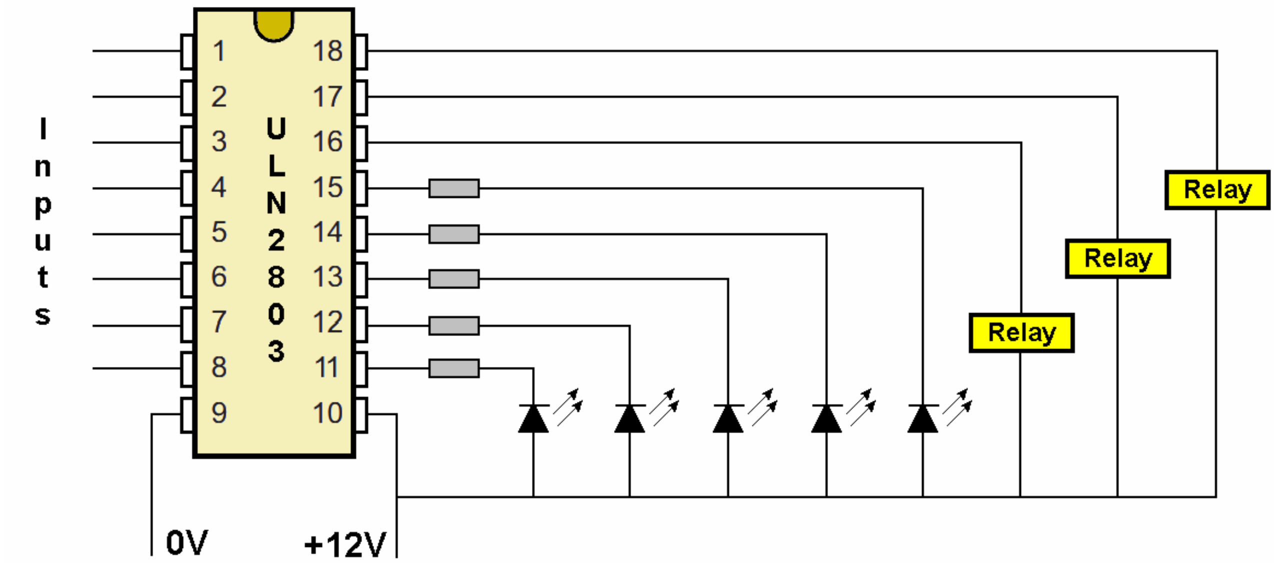
The supply can be up to 50V, although we would mostly be using it at 12V or less. Each output is capable of supplying 500mA. However, that does *not* mean that the ULN2803 can simultaneously drive all 8 outputs at 500mA, as it would overload and burn out the chip. In practice, you could drive four outputs at 300mA each, or seven outputs at just under 200mA each.
Since the inputs to the ULN2803 can handle PWM inputs, you can still drive all eight outputs at 500mA each – if you drive all inputs with a duty cycle of just under 25%.
These are only limitations if all outputs are having to simultaneously control devices with heavy current demands.

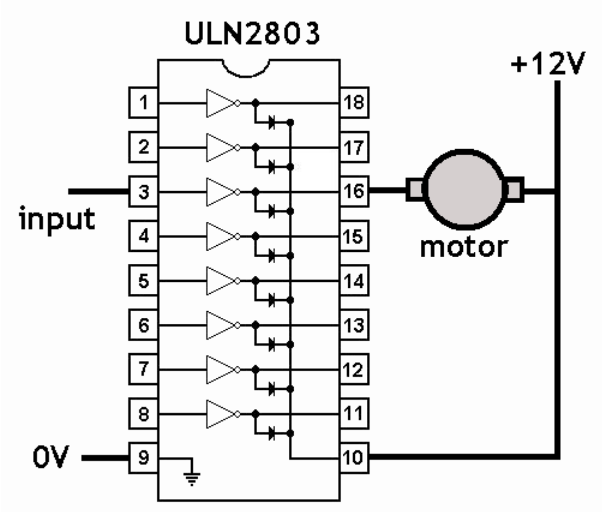
The outputs are *'inverted'*, which means that each output pin is always at the opposite polarity to its corresponding input pin.

When pin1 goes high, it makes pin 18 go low.
When pin 1 goes low, it makes pin 18 go high.

The same applies to all of the drivers. So when pin 8 goes high, it makes pin 11 go low, and vice versa.

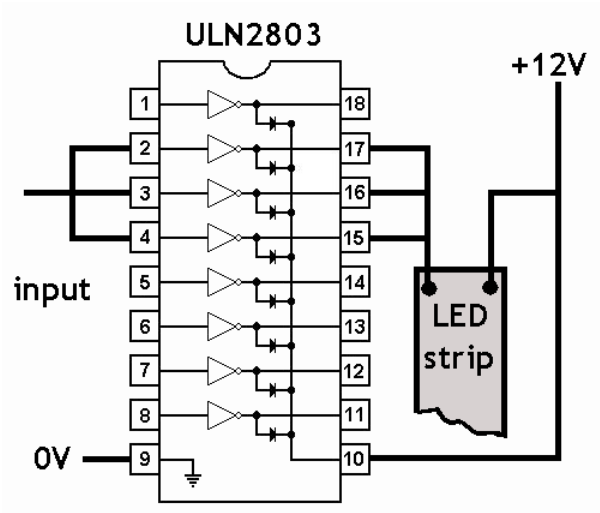
This illustration shows five LEDs and three relays being controlled through this single device.

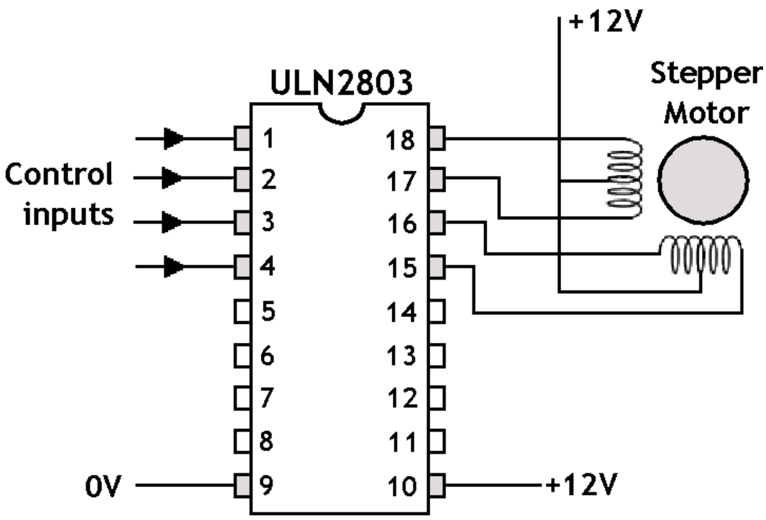




Here is an example of controlling a motor.
When pin 3 goes high, pin 16 goes low and the motor turns.
Inside the chip there are clamp diodes for each output pin. This allows inductive loads such as motors and relays to be connected without additional external flyback diodes.
Each input pin has an internal 2k7 resistor between the pin and the transistor base and can be controlled directly from a TTL or 5V CMOS

Here is an example of controlling a 12V LED strip.
Each output has a maximum rating of 500mA but a full 5m LED strip can be in excess of 1A.
The ULN2803 allows you to use the output pairs in parallel.
In this example, pins 2, 3, and 4 are all commoned together so that one input change operates all three power transistors.
Similarly, pins 16, 17 and 18 are commoned so that the combined current capacity has been increased to 1.5A.



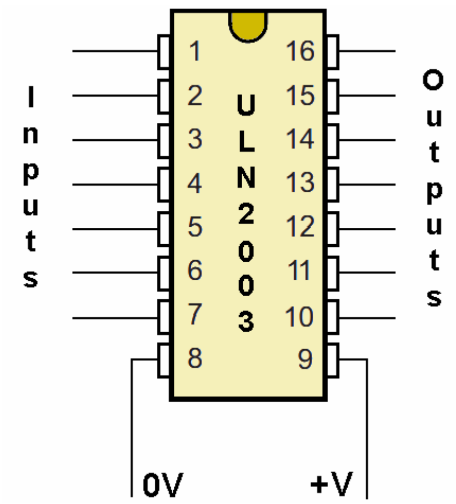


In this example, four of the power transistors are being used to control a Unipolar stepper motor. This type of stepper motor has four coils. Power is applied to each coil in turn and the motor spindle rotates by a small amount each time.

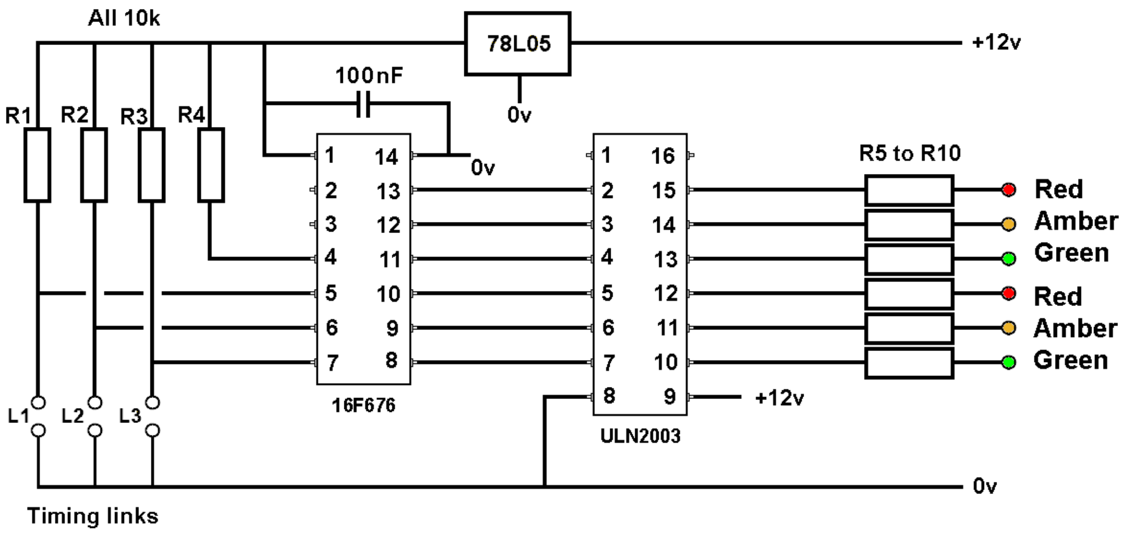
The internal transistors are only used to switch the high currents involved.
Their inputs are switched in a sequence that is controlled by a PIC chip, an Arduino or other such controller.

ULN2003

The ULN2003 device is very similar to the ULN2803. Since it only has seven sets of drivers, the chip has 16 pins compared to the 18 pins used by the ULN2803.
Like its larger brother, the ULN2003 has its inputs pins facing their corresponding output pins; a very hand layout when designing circuit layouts.
So, pin1 controls output pin16, etc.
Its outputs are also inverted and it has similar voltage and current handling capabilities to the ULN2803.
Although these chips have built-in back emf protection, some manufacturers recommend using additional external protection measures.

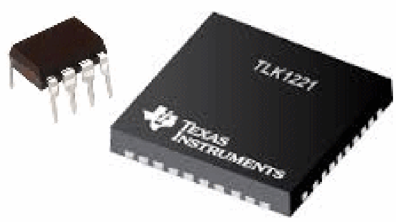


Here is an example of its us in our traffic lights kit.



Integrated Circuits

These are often simply referred to as *'ICs'*.
As the description implies, it is a single electronic component that carries out a task that would normally require multiple individual components. The semiconductor layers inside the chip are created in such a way that they carry out the functions of multiple transistors, diodes, capacitors, resistors, etc. - all integrated within a single small casing.



With the advent of ICs, large boards jam packed with components were replaced by much smaller, more efficient, lower current, cheaper devices. Just how far this process has gone can be demonstrated by the 'brains' of a humble Xbox 1 computer which uses 5 billion transistors – all built in to a device the size of an After Eight mint! An iPhone 10 has 4.3 billion and a NVIDIA GeForce GTX 1080 Ti GPU has 12 billion!
A simple IC may have only 6 pins to connect to the outside world, while complex ICs may have 80 external pins.

There is a huge range of ICs and each one is designed to carry out a particular function or set of functions. Their internal workings are pre-set at manufacture to carry out specific tasks and these cannot be altered, although their performance can often be tweaked using external components.

Examples include:

Voltage regulators – to ensure a constant fixed supply voltage output, regardless of most input voltage fluctuations and changing current demands.

Timers – to create timed pulses for scale time clocks, control brightness of LEDs, control servo movements, control loco motors using PWM (pulse width modulation).

Amplifiers – to boost the level of audio or radio signals, or act as current amplifiers for switching or control purposes.

Converters - to convert digital values to analogue values (and vice-versa), to convert voltage levels into frequencies.

Logic – to implement simple switching decisions (e.g. the output only changes to low when all its inputs are set to low) or more complex logic operations (e.g. using only 4 input lines to change the output level of any one of 16 output lines).

Display drivers – to control bar graph displays, 7-segment LEDs and LCD displays.

Remote control encoders/decoders – to control toys, televisions, garage openers, etc.

Memory chips – to store data for later use (e.g. in digital cameras, audio players, etc.) or to store applications while being run in computers.

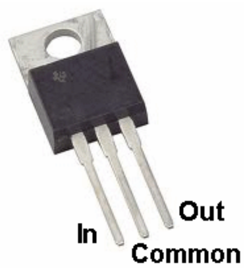
Motor drivers – to handle DC motors, stepper motors and servo motors.

All of these IC chips are connected to devices or components in the outside world. Sometimes the components are connected in order to adjust performance (within the range allowed by the IC). For example, the settings of a timing chip are set by the choice of external timing components.
In other instances, the IC acts on external stimuli (e.g. a remote control encoder) or controls other circuits (e.g. a voltage regulator).

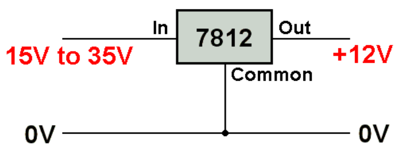
Practical examples

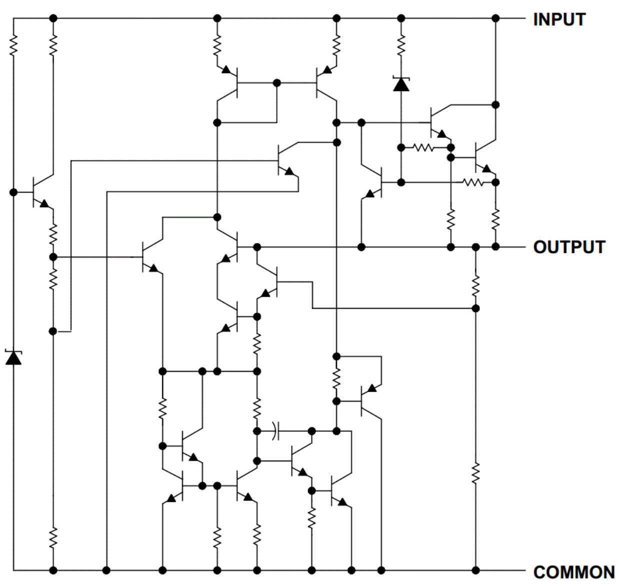
Here are some typical examples of integrated circuits.

Voltage regulators



Chapter 1 looked at power supplies and voltage regulation. One of the simplest ICs is the voltage regulator. It has only three pins. The one shown in the illustration is a 7812, which means that it produce a steady 12V output, at up to 1.5A, even when the voltage at its input varies from 15V DC up to 35V DC.
The 7812 has an internal voltage loss of 2.5V, so needs a minimum of 14.5V DC input to ensure a smooth regulated output.





Its case, and common pin, are bonded to a metal plate to which can be bolted a heat sink. This is necessary when dropping large voltages at high currents, to prevent the IC overheating.
When used in a circuit for this purpose, it would also normally have smoothing capacitors fitted.

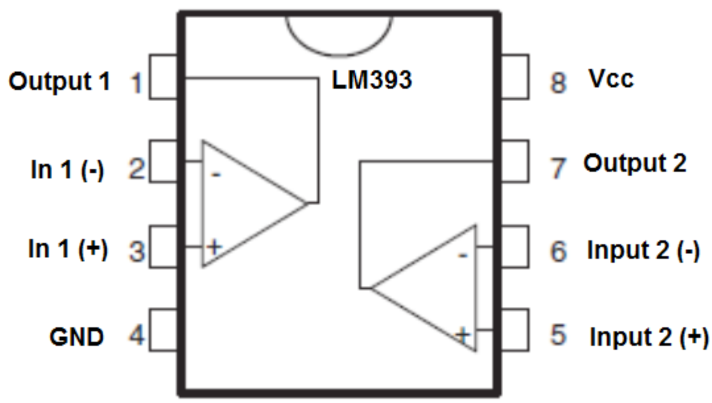
The circuit is reproduced to demonstrate that even a simple IC can be complex inside. The 7812 has over 40 internal 'components', including 17 transistors. Other varieties produce outputs of 3.3V, 5V, 6V, 9V, etc.

Comparators

A comparator chip contains one or more high-gain '*differential amplifiers*'. These compare the voltage difference between two analogue inputs to decide on whether its digital output should go high or low.

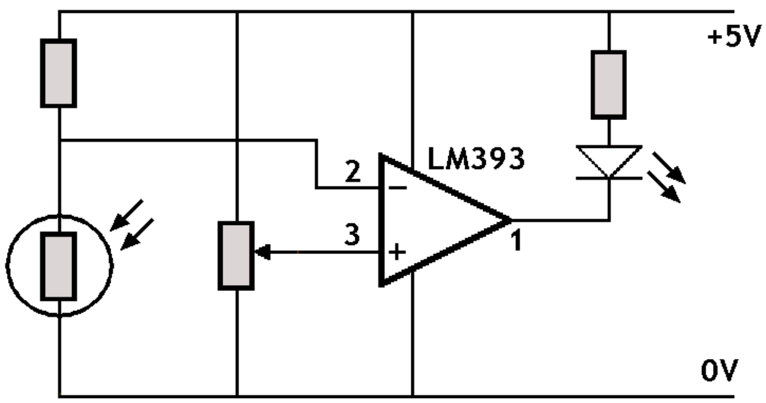
This image shows a LM393 chip which house two independent identical circuits.

Pin 2 is known as the inverting input, while pin 3 is called the non-inverting input.



If the voltage at the inverting input is higher than at the non inverting input, the output turns on (i.e. goes low).
If the voltage at the inverting input is lower than at the non inverting input, the output is off.

This is a LM393 chip used in a circuit for a basic night light.



The voltage on input 2 depends on the voltage at the junction of the resistor and the light

dependent resistor (LDR). The two act as a voltage divider and the resulting voltage is passed to pin 2.
The resistance of the LDR changes based on the amount of light that strikes its surface.
In the daytime, the resistance of the LDR is low, bringing down the voltage at the junction and making the voltage at pin 2 low.
In dark conditions, the resistance of the LDR is high, increasing the voltage on pin 2.

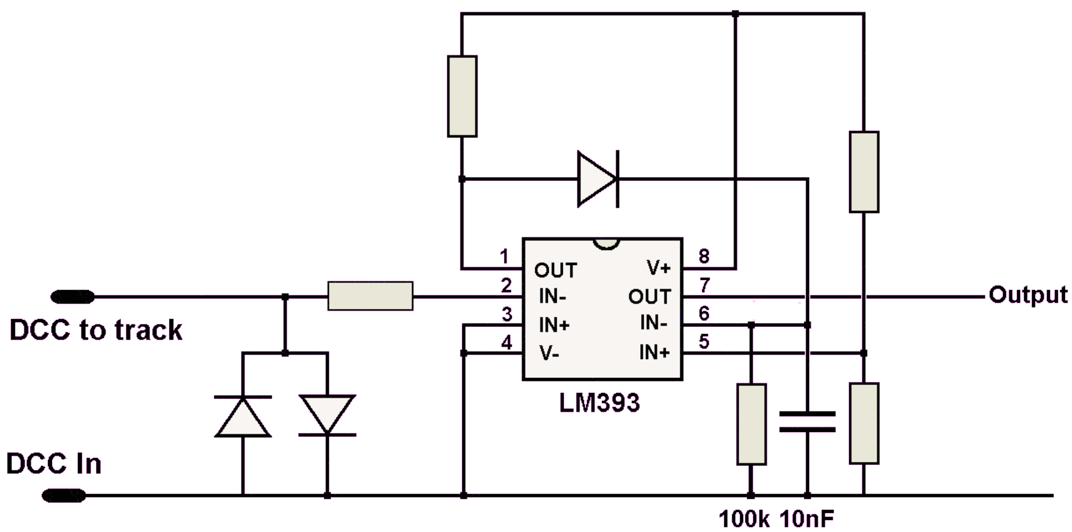
So, the voltage level on pin2 varies with the amount of light on it.
You can also alter the reference voltage on pin 3 by turning the variable resistor and this will set the level at which the output will trip.

During the day, the voltage on pin2 is lower than that on pin 3 so the output remains high.
As it gets darker, the voltage on pin 2 increases until it is greater than that on pin3. When that happens, the output on pin 1 goes to 0V and the LED illuminates.

If we replace the LDR input with a heat sensor, we have a basic thermostat, or we can use the circuit detect an object overheating. We could also amend to detect water levels, sound levels or an other changing analogue value.

The night light example only uses one of the differential amplifiers.

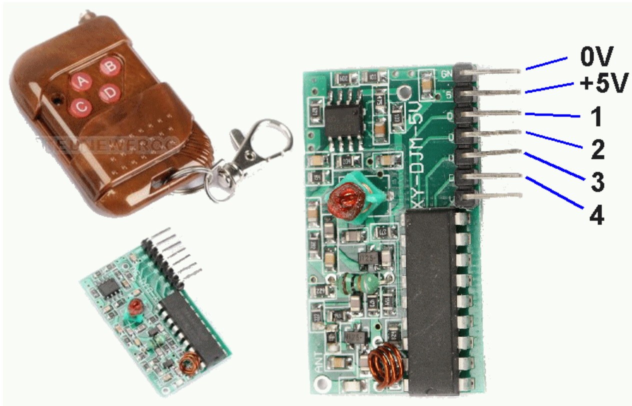
This is the circuit for a DCC track occupancy detector and it uses both differential amplifiers.



Pin 4 is permanently held at 0V. When a loco enters a section of track, the DCC voltage develops voltages pulses across the diodes and this is passed to pin 2. With every pulse that takes pin 2 high, pin 1 goes low, so there is a constant stream of pulses on pin 1 (as long as the loco remains in that track section).
Pin 5 is connected to a voltage divider that maintains a voltage on it that is half the supply voltage.
The pulses from pin 1 gradually charge up the voltage on the 10nF capacitor, until pin 6 is at a greater voltage on pin 5. At this point, the output pin 7 goes low.
It will stay in this condition until the loco leaves the track section. The 10nF capacitor then discharges through the 100k resistor.

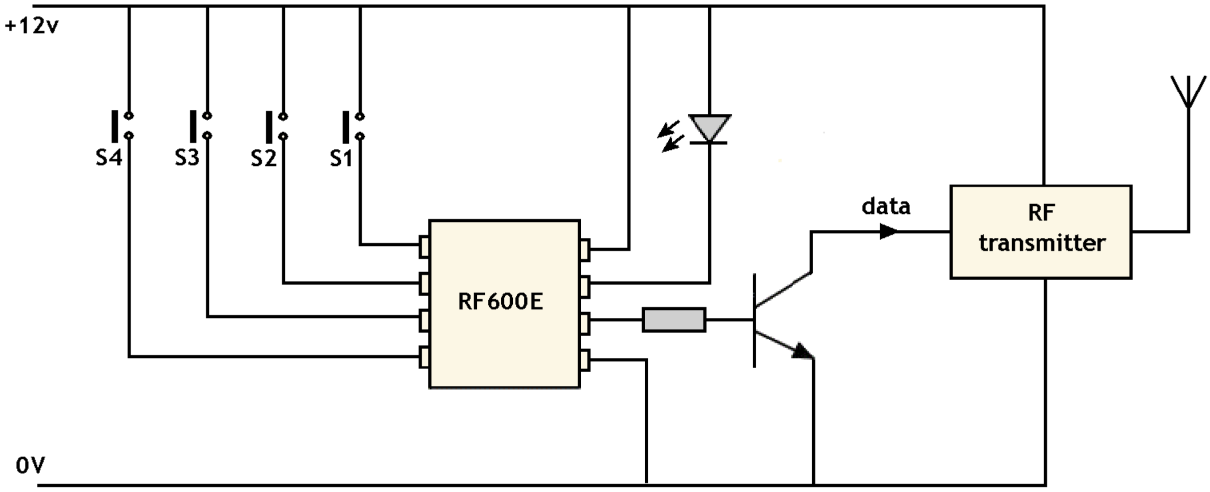
4-channel wireless remote control

This is similar to the key fob you use to open garage doors, etc. This particular model has four buttons on the transmitter and has four matching output pins on the receiver module. Holding down button A on the transmitter changes the state of output pin 1 on the receiver, and so on.

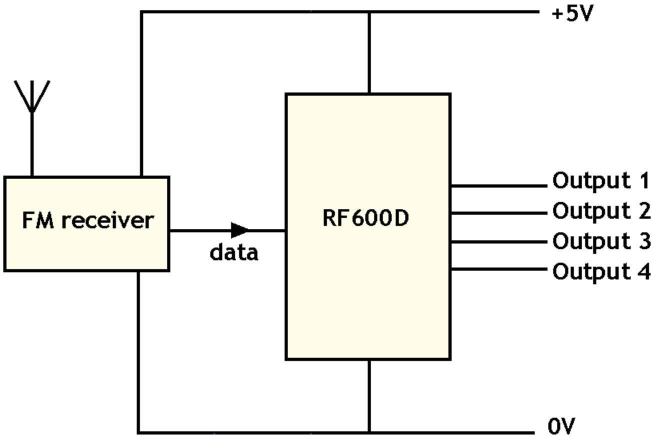


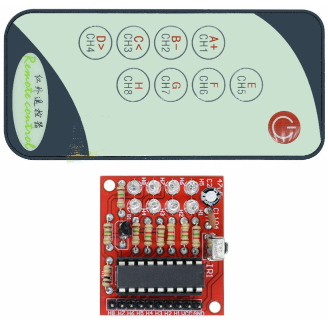
We have an exhibition layout that features a building on fire,complete with fire effects and animations. It also has sound effects. The fire engine sound is particularly piercing and we wanted to avoid annoying ourselves and other exhibitors with regular bursts of sound. Using this remote, we can bring on the animated sequence whenever we want, switching it on during busy times and leaving it off during quiet times.

The transmitter uses an RF600E encoder chip that responds to a button press by sending out a particular coded sequence. This is then sent to an RF transmitter module.



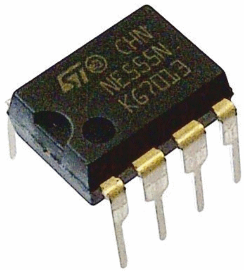
At the receiving end, the receiver module passes the sequence to a RF600D decoder chip. This translates the sequence into a change of output on the corresponding pin. The encoder and decoder ICs are dedicated to a single function each. Like many other ICs, they are designed for a single purpose use.





Other similar versions are available, such as this eight channel system.

The 555



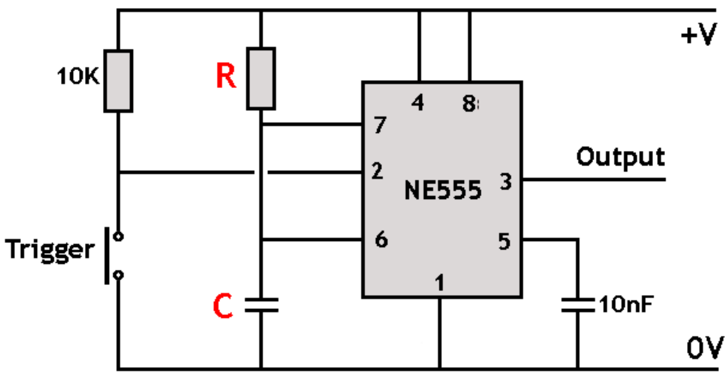
This little integrated circuit has been around since 1971 and is still in widespread use today Billions have been manufactured.
It is a comparatively simple IC with only 25 transistors, 2 diodes and about 16 resistors.   It is named 555 because it uses three 5K resistors to create its internal voltage divider reference.
However, it is quite versatile and can be configured in one of three operating modes:

- Monostable
- Bistable
- Astable

Its supply voltage can be anywhere between 4.5V and 16V, which means it will work happily with both 5V and 12V supplies.   Its output can handle up to 200mA.
A full functional description of the 555 can be found in Technical Bulletin G25/1 on the MERG website.

Monostable mode

As the name implies, in this mode the 555 output has only one stable state.
You can make it temporarily change state but it will revert to its stable state after a time.
This is sometimes described as a *'one-shot'.*
Pin 2 is known as the *'trigger'* pin and the 555 activates when the trigger pin is taken low (below 1/3 of the supply voltage).



In this example, the trigger pin is taken low by pressing a push-button, but the pin could be connected to any device whose output goes sufficiently low.
So, for example, if a module detects a problem its output could trigger the 555 to sound an alarm for a fixed period.
When the trigger pin goes low, the *'output'* pin (pin 3) is taken high.
The capacitor **C** starts to charge up through resistor R until the voltage across the capacitor reaches 2/3 of the supply voltage.
Pin 6, the *'threshold'* pin, responds by bringing the output back to low.
Pin 7, the *'discharge'* pin then discharges the capacitor, ready for any future button press.

The pulse duration (the 'time period') is determined by the values of **C** and R. The bigger the resistor and capacitor values, the longer the delay.
There is a useful calculator at:

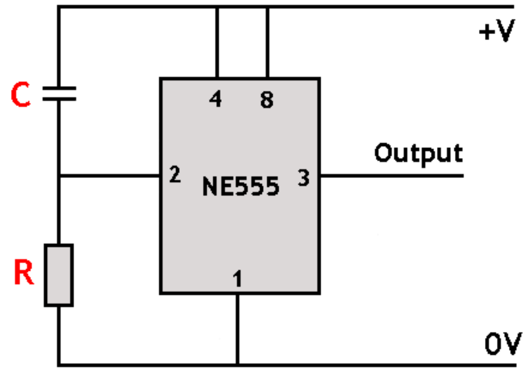
www.allaboutcircuits.com/tools/555-timer-monostable-circuit/

Delay before turn on

The above circuit changes its output state when its trigger was brought low by some external means (i.e. a human finger or another electronic module).
There may be times when you want to have a delay period when the circuit's power is switched on.

You may want to power up different sections of a layout in a phased manner, to prevent the power supply experiencing surges, or to to prevent servo kick by applying the servo voltage after the servo controller has settled down.

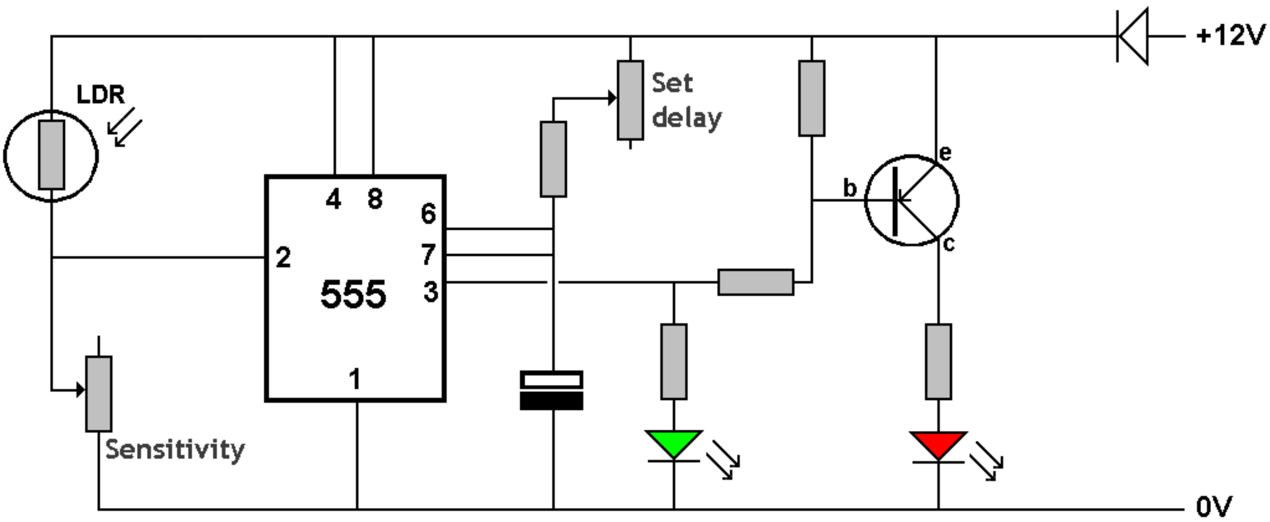
In this circuit, the trigger pin is high on switch on, as the capacitor has still to charge up. Therefore the output remains low.
As the capacitor charges up, the voltage on the trigger pin decreases.
When the voltage at pin 2 gets below 1/3 of the supply voltage, the trigger pin activate the 555 circuitry and the the output pin goes high and stays high.



Note

The first circuit brought the output high for a period before reverting to low.
The second circuit held the output low for a period before reverting to high.

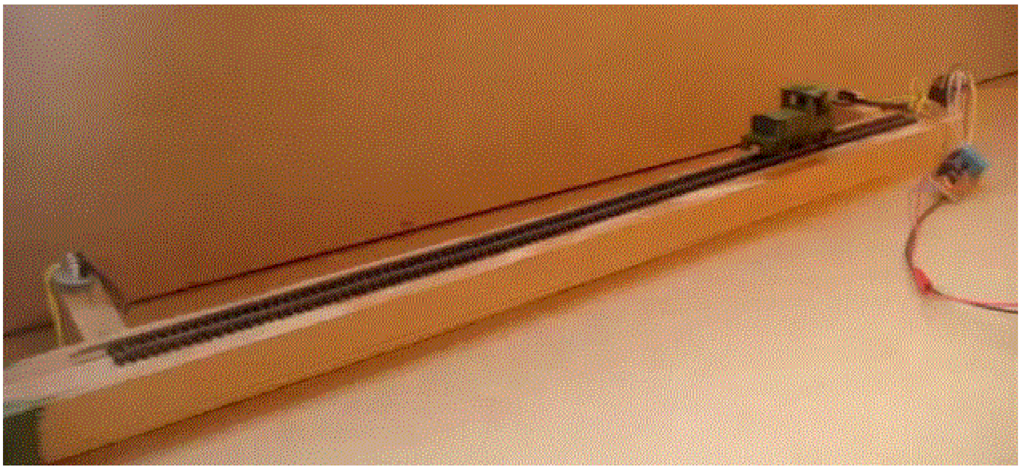
This circuit also uses the 555's monostable mode.
A club layout has an up line and a down line. Each line has signal lights that are currently operated by switches. The operators usually forget to throw the switches, resulting in trains running through red lights.
This circuit uses a light-dependent resistor (LDR) to detect the approaching train and automatically turn the lights to green for a period until the train passed. The delay in switching back to red is adjustable. The output pin goes to a green LED and to a red LED via a transistor. When the output pin is high, the green LED illuminates and the red LED is extinguished. After the delay period ends, the output pin goes low, resulting in the RED illuminating and the green LED extinguishing.



Bistable mode

In this mode, also known as a *'flip-flop',* there are two stable states.
It has two inputs. When pin 2 is taken low, the output pin goes high.
When pin 4, the *'reset'* pin is taken low, the output pin goes low.
The output voltage is determined by which input pin you last took down low.

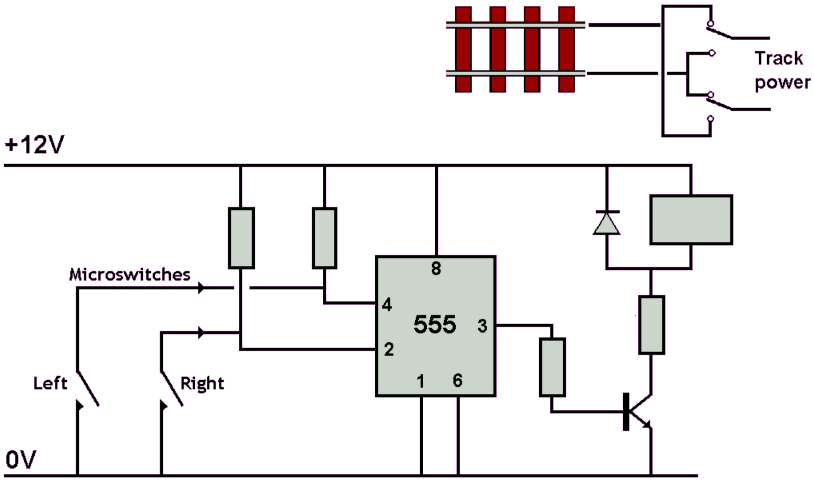
In this example it is being used to warm up locos before placing them on a layout.



A microswitch is fitted at each end of the track, with extended paddles added so that they span the track.
When the loco reaches one of the end, it operates that microswitch

The 555's output is used to switch a relay on and off and its switch contacts reverse the track polarity each time.

If the relay is a low current type it can be connected directly between pin3 and the supply. Otherwise, a transistor is used to act as a current amplifier.



Astable mode

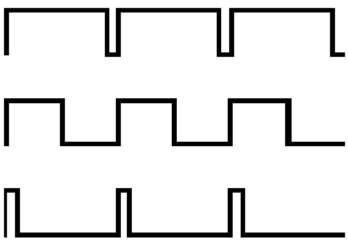
In this mode, the 555's output has no stable state; it is continually switching its output between high and low.
You control its operation by the values of resistors and capacitor that connect to pins 2, 6 and 7. These control two characteristics of the oscillating output:

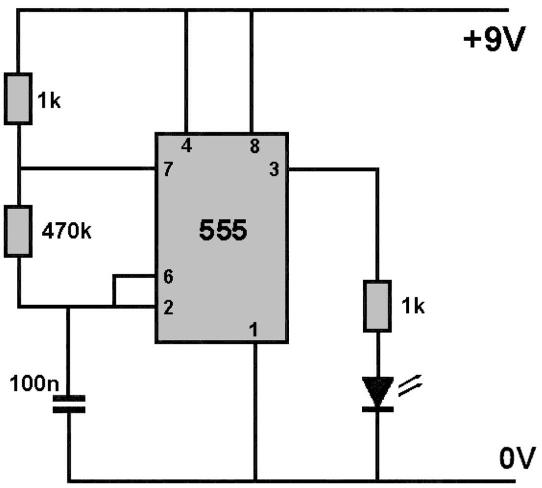
Frequency

This describes how often the output goes high.   It is measured in complete cycles per second. This ranges from low frequencies up to audio frequencies and well beyond.

Mark/space ratio

This measures the relative times that the output is high (mark) compared to low (space). The top waveform in this illustration has a large mark/space ratio (90/10), as the pulse is on for much longer than it is off.   In the middle waveform, there is a 50/50 ratio. In the lower waveform, the on time is much shorter than the off time so it has a low mark/space ratio (10/90).



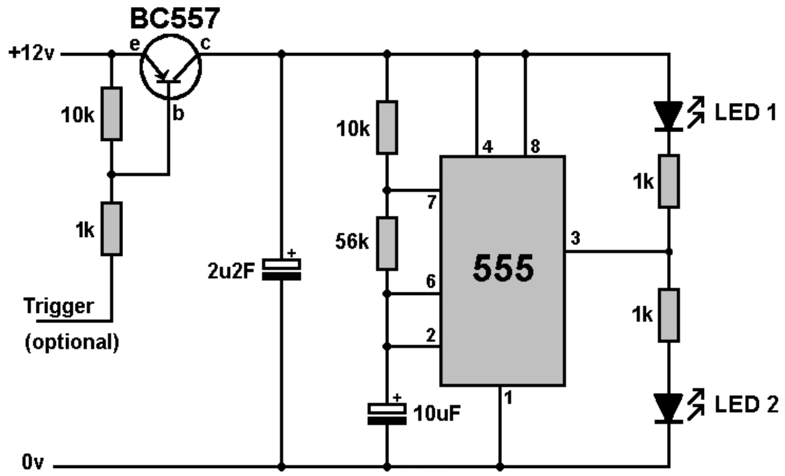


Because we can vary the mark/space ratio, we can create circuits where the 555 lights a LED with a 50/50 ratio or just lights it for a short time every so often.

This circuit will flash a single LED.

We could replace the LED with an piezo transducer to create an audible warning device. Most piezo devices have a resonant frequency around 3kHz and this would create the loudest sound.

This is a circuit for a dual LED flasher.
Tthe LEDs flash alternately.
The 555 chip is configured as an astable oscillator with its output (pin 3) swinging between high and low voltages.
When pin 3's voltage is high, LED 2 illuminates while LED 1 remains unlit.
When pin 3's voltages drops to 0V, LED 1 is illuminated and LED 2 is extinguished.



This continually repeats, at a rate set by 10uF capacitor and the 10k and 56k resistors.

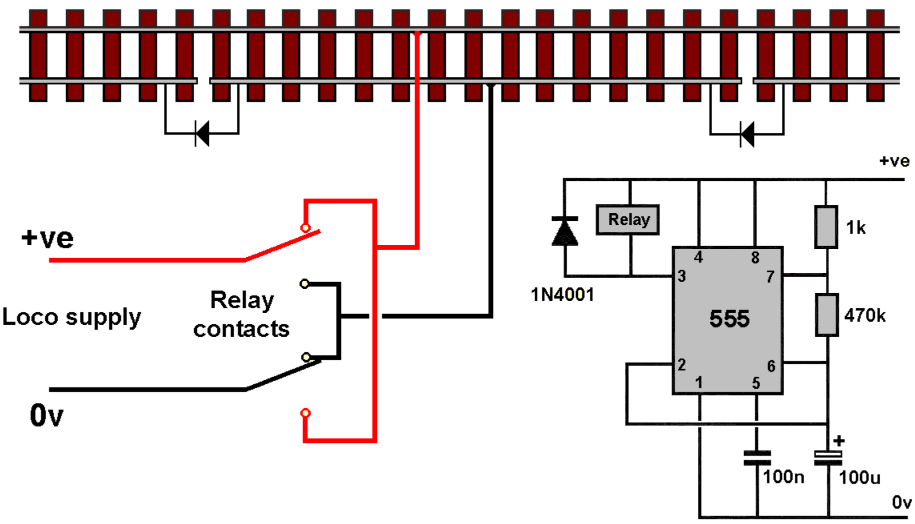
Possible uses include pickup trucks, emergency vehicles, Belisha beacons for crossings, etc.

When used with a barrier crossing, you need the flashing to be switchable, only working when the gates are lowered. The transistor. when fitted, acts as a switch. Inputs to the trigger could come any track occupancy detector (MERG have a range of types).

If you want the LEDs to continually flash (e.g. as in pedestrian crossings), do not use the transistor and its two associated resistors.

Shuttle

The bistable example used microswitches to continually move a loco back and forth along a length of track. There was no delay at either end.
This astable circuit has no external inputs and uses a long delay (approx 30 seconds) between each reversal of the track polarity.

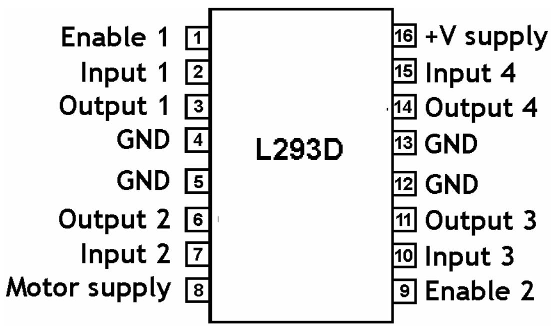


You can apply formulae to calculate the frequency and also the mark/space ratio for any given set of components.
It is much easier just to use an online calculator such as this:
www.daycounter.com/Calculators/NE555-Calculator.phtml
For more details on 555 timers, read John Matthew's article in the Winter 2006/7 Journal, or look at
http://talkingelectronics.com/projects/50%20-%20555%20Circuits/50%20-%20555%20Circuits.html

Controllable motors

To be fully controllable, a motor has to be be able to run both forward and reverse, able to be be switched on and off, and also have its speed altered.
Electronic circuits can be designed for these tasks. You can build a circuit using multiple transistors, etc. However, there is no need as there are integrated circuits that combine these features in a single chip. Indeed, some chips can handle two motors.

One such examples is the L293D *'Quad Half H-Bridge Motor Driver'* chip.
The L293D can handle 600mA continuously, or double that for short periods).
The *'Quad'* in the chip title indicates that the chip contains four identical drivers, each with its own input pin and output pin. There are two such circuits on each side of the chip.

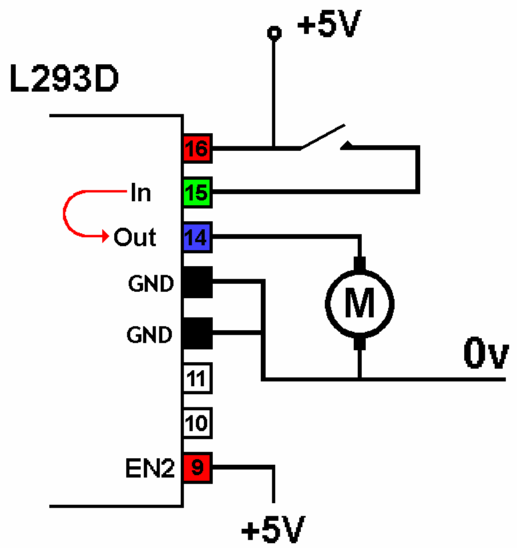


- Pins 2, 7, 10 and 15 are input pins
- Pins 3, 6, 11 and 14 are output pins.
- Pin 16 is connected to the +5V supply.
- Pins 4, 5, 12 and 13 are connected to the 0V of the supply.
- Pin 8 is connected to the voltage supply for the motor, which may be different from the +5V supply for the chip (e.g. it might be connected to +12V to run a 12V motor). It supports from 4.5V to a maximum input of 36V.
- Pin 1 is the *'Enable'* pin for the pair of left-hand drivers, while pin 9 is the enable pin for the right-hand drivers.

The enable pins can be switched externally, where bringing it down to 0V stops the drivers from working. If this is not needed, the pins can be permanently connected to +5V. They can also be fed with a PWM signal to control the motor speed. See the chapter on Loco Controllers for a description of PWM.

The voltage on the input pins controls the voltage on their matching output pins.
So, for example, taking pin 15 high makes output pin 14 go high (to the voltage on the motor supply pin), while taking pin 10 high makes output pin 11 go high. This way, the chip could be used to control four separate motors.

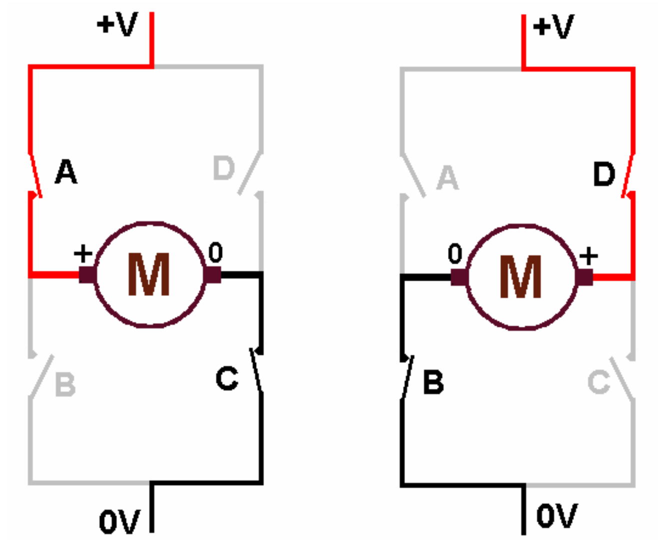
This illustration shows a single motor being operate by its own switch. Taking pin 15 high results in the output pin 14 going high. The motor turns.
Removing the +5V from pin 15 results in pin 14 going low. The motor stops.



Although the diagram shows a switch, pin 15 could be switched by a push-button, relay contacts or from the output of another module.

Although they can be switched on and off separately, the motor is unable to be reversed.

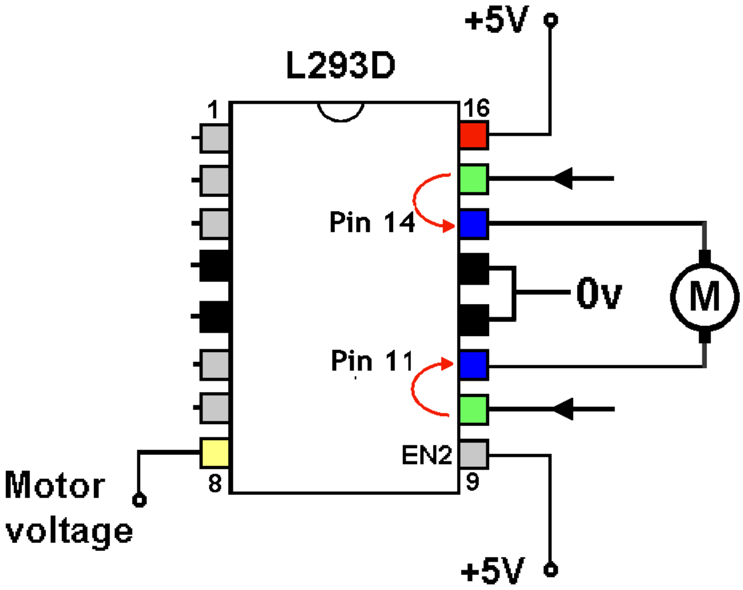
That is where the *'H-Bridge'* mode in the chip's title can be utilised.
This illustration shows the operation of an H-bridge circuit, using conventional switches.



When switches A and C are closed, the motor has a positive potential on its left hand connection and 0v on it other connection. The motor will turn in one direction.
If we now open switches A and C, and close switches B and D, the voltage across the motor is reversed and the motor turns in the opposite direction.

An H-bridge can be constructed from four power transistors or even relay contacts, each carrying out the functions of the four switches in the above circuit.

Better still, the L293D can be wired to provide two separate H-bridge circuits.
In the following example, if we switch pin 11 high and pin 14 low the motor will rotate in one direction. Reversing the polarity of these two output pins will rotate the motor in the opposite direction.
If the two controlling inputs pins 10 and 15 are both at supply voltage or both at zero volts, there is no potential difference across the motor and it will not rotate.



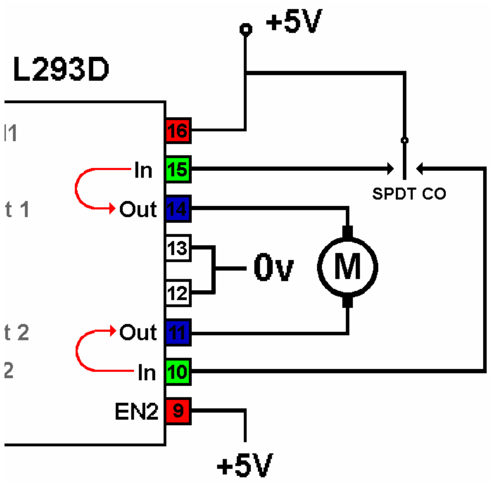
The table below summarises the options:

Enable	Pin 10	Pin 15	Result
High	Low	High	Rotate one direction
High	High	Low	Rotate other direction
High	High	High	Fast motor stop
High	Low	Low	Fast motor stop
Low	X	X	Free-running motor stop

The X indicates that it does not matter whether the pin is High or Low.
There are two motor stopped modes, free running stop and braked stop.
With the '*Enable*' pin high the motor will brake to a stop, with a low it will free run.

Switching an H-bridge

As can be seen from the above table, we need two inputs to control an H-bridge circuit, allowing us to have forward, reverse and stop.
This example circuit uses a SPDT CO switch to handle the inputs. It has three positions, including a centre-off position.
When the switch is left in the middle position, neither pin has a high voltage and the motor is stopped.
Throwing the switch to the left brings pin 15 high (pin 14 goes high) and the motor rotates.
Throwing the switch in the other direction, brings pin 10 high (pin 11 goes high) and the motor rotates in the opposite direction.

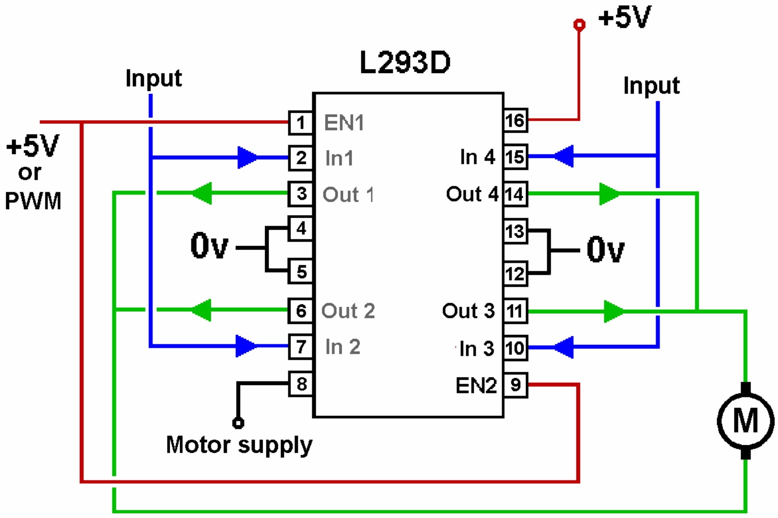


Although a switch is shown, it could be replaced by relay contacts, a pair of pushbuttons, or the outputs from other modules.

Notes

- Although the examples show the input and output pins on the right hand side of the chip, the identical sets of pins are available on the left hand side inputs and outputs.
- Make sure you buy the L293D and not the other variations of this chip, as the 'D' indicates that the chip contains internal clamp diodes to allow it to work with inductive loads.
- **Make sure that the output pins never short to 0V or to the supply or the chip will be damaged.**

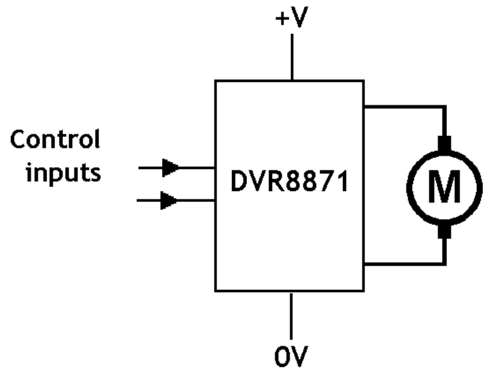
If you need to switch even greater currents, you can parallel the inputs and outputs of both bridges, as shown in this illustration. This doubles the output handling capacity of the L293D to 1.2A.
The blue lines show the inputs on each side being connected together.
The green lines show the outputs of each side being connected together.
The enable pins are also connected together and taken to +5V, or to a PWM signal if required.



If you only need to control a single DC motor, an alternative is the DVR8871.
It has the following extra benefits over the L293D

- Greater maximum motor voltage (from 6.5V to 45V)
- Higher current handling (2A with 3.6A peak)
- No need for separate logic and motor supplies
- No need for an enable pin

Like the L293D, it is an H-bridge driver and uses two inputs to control motor direction.
With both inputs low, the motor free runs to a stop,
It also supports PWM speed control.



On the downside, it only handles one motor and is quite a bit more expensive than the L294D.

If you like simplicity or have to control a motor that is either high voltage or heavy current, this is the best choice.

Final note

Although the L293D or the DVR8871 can be controlled by switches, their inputs are intended to be controlled by a microprocessor (e.g. a PIC chip or an Arduino).