

Simple Auto-Reverser – Technical Details

Introduction

The circuit schematic of the Simple Auto-Reverser (SAR) is shown in [1] on the next page, followed by a brief description of how everything operates and fits together.

Power Supply

Power for the SAR is supplied from the DCC track output of your command station or booster which is normally set at between 14 and 16 volts. The DCC AC output is rectified by diode bridge BR1 to supply voltage regulator VR1 which, in turn, supplies +5 volts to the voltage comparator IC1, the delay timer IC2, and to the dual D-type flip-flop IC3.

The overall current consumption of the SAR is around 35 mA. Although this current is well within the capabilities of a low-power voltage regulator (such as a 78L05), in the worst case VR1 has to drop around 11 volts, leading to a power dissipation approaching 400mW which would result in a 78L05 in a TO92 package getting very hot. Hence the use of a 7805 regulator in a TO220 package with a metal tab which just gets slightly warm.

Following VR1 is the bulk reservoir capacitor C2 which ensures that the +5 volt supply is maintained for the SAR operational circuitry during any dips in DCC input voltage. Such dips, due to short circuits across the track gaps at the entrance and exit of the reversing track section, are used to trigger SAR operation.

Short-Circuit Detection and Consequent Actions

When the metal wheels of a locomotive bridge the track gap when entering a reversing section with the opposite DCC phase on the rails a short-circuit across the DCC supply occurs. As well as generating a current surge, this short circuit also causes the voltage applied to the track to collapse towards zero. This significant dip in track voltage is passed from the output of BR1 via R3 to the positive input of voltage comparator IC1.

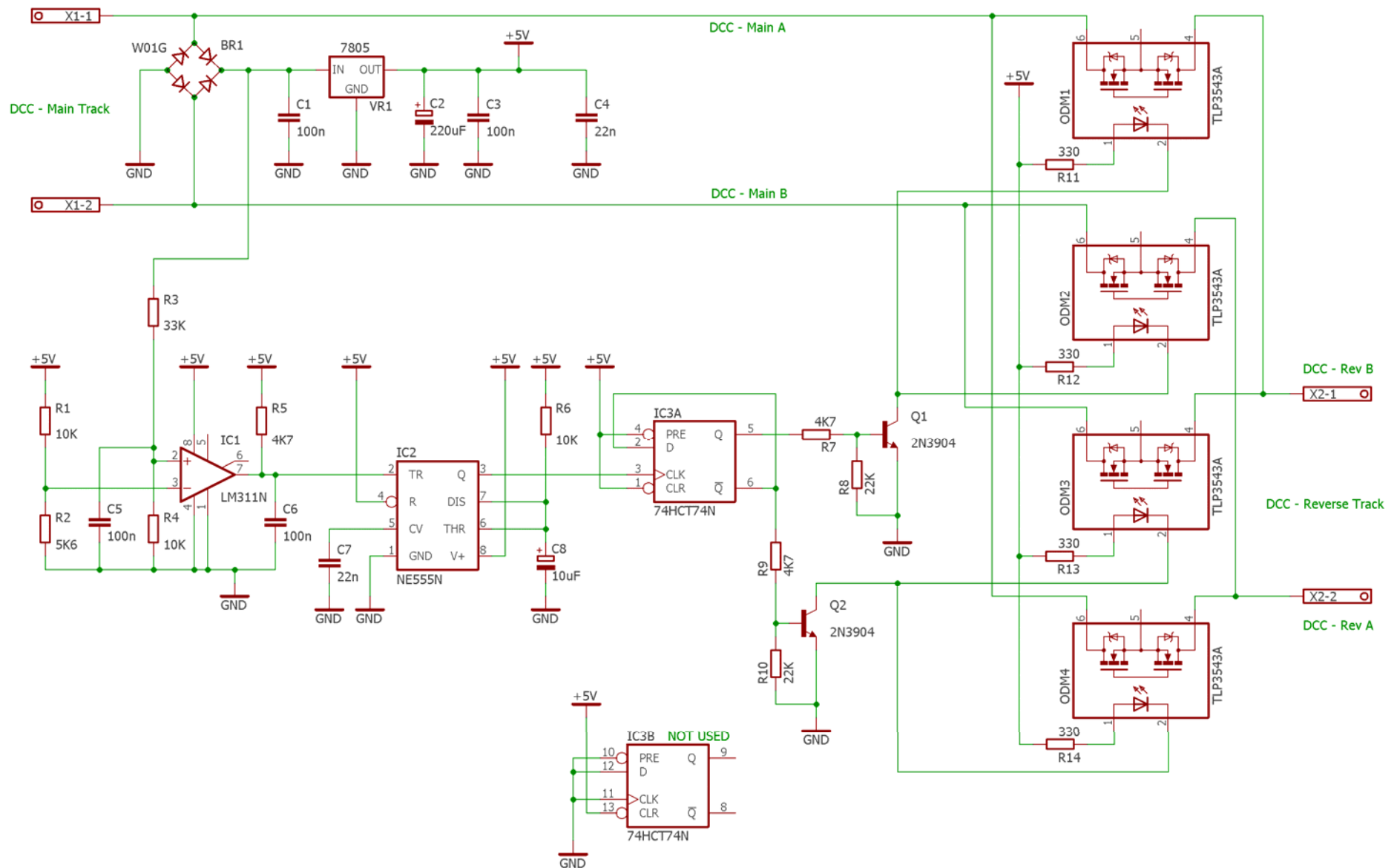
Normally, the IC1 positive input will be held at between +2.8 to +3.2 volts which is above the reference voltage of +1.8 volts at the IC1 negative input, set by resistors R1 and R2, so that the output of IC1 is held high at +5 volts.

When the dip in DCC voltage occurs, it will drop the voltage at the IC1 positive input. When this falls below +1.8 volts, it activates the comparator and causes the IC1 output to fall to GND (0 volts). This negative-going edge then triggers the precision timer IC2 which is configured as a monostable with a period of around 100msec, set by capacitor C8 and resistor R6. As a consequence, there is a positive-going transition at the output of IC2 from GND to +5 volts, which is passed to the CLK input of flip-flop IC3A.

Any further voltage transitions at the IC2 TR input (as a result of 'contact bounce' from the loco wheels bridging the track gap) have no effect on the IC2 output level during the set monostable (delay) period. Capacitors C5, C6 and C7 act as low-pass filters to reduce the effect of any random noise (voltage transients) on this part of the circuitry from the input DCC track supply.

The Q and Q/ outputs of the D-type flip-flop IC3A are always in opposite states. If Q is at +5 volts then Q/ will be at GND, and *vice versa*. When there is a positive transition at the IC3A CLK input (from the output of IC2) the state of the D input is transferred to the Q output. Since the D input is connected to the Q/ output, the Q output assumes the previous state of the Q/ output, ie. the Q and Q/ outputs each 'flip' to the opposite state they were in before the CLK transition arrived.

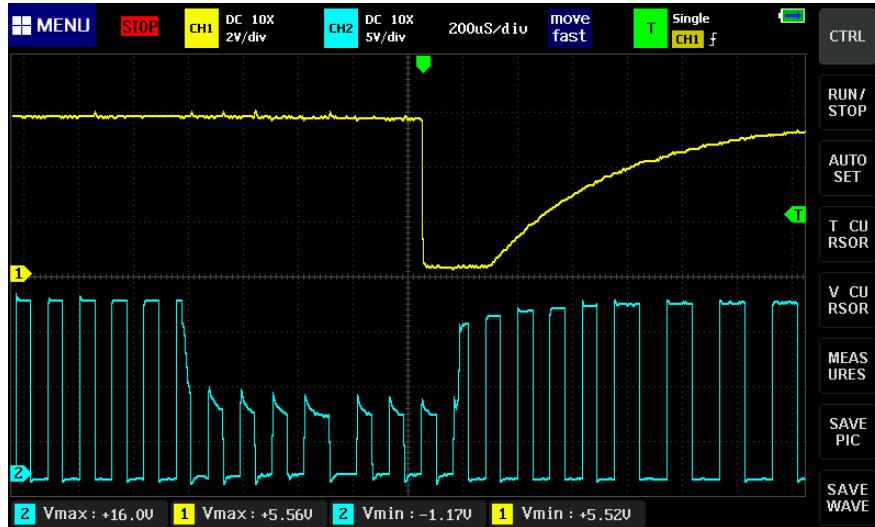
The Q and Q/ outputs of IC3A directly control the phase of the DCC output from the SAR via transistors Q1 and Q2 and the dual-FET photorelay devices ODM1 through ODM4.



1. Simple Auto-Reverser – Circuit Schematic

Switching Event Timing

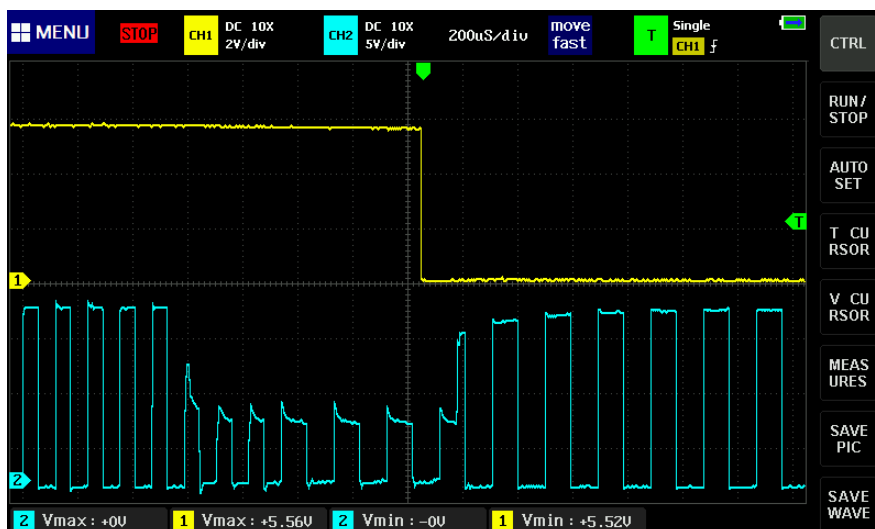
When the locomotive bridges the track gap at the entrance to the reversing section, the immediate dip in the track DCC voltage is sensed by the voltage comparator IC1 via bridge BR1 and resistor R3. The output of IC1 falls from +5V to GND as soon as capacitor C5 discharges via resistor R4 to a voltage below the threshold set by resistors R1 and R2, which takes around 800usec as shown by the top (yellow) trace of the oscilloscope screenshot in [2] below. The lower (blue) trace shows the state of the input DCC-Main-A –



2. Triggering of IC1 output following dip in DCC input voltage

The transition at IC1 output triggers monostable IC2 and flip-flop IC3A, as described previously. As soon as IC3A changes the output DCC phase to remove the track short circuit, the voltage at the non-inverting input of IC1 rises as C5 is recharged via R3 until it is again above the threshold level (taking about 300usec), then allowing the output of IC1 to return to +5V with a time constant set by R5 and C6, as shown above.

Once triggered, the output of IC3A remains in a stable state, setting the output DCC phase as required, as shown by the top trace (yellow) in the oscilloscope screenshot in [3] below. The lower trace (blue) shows the mainline DCC voltage recovering from the short-circuit in about 500usec –



3. Stable IC3A output setting the required output DCC phase

DCC Output and Phase Control

When the Q output of IC3A is high (+5V) transistor Q1 is switched on via resistor R7. This brings its collector to near GND and draws current through the input photodiodes of ODM1 and ODM2, allowing the latter devices to conduct.

Transistor Q2, at the same time, is switched off since its base is connected via R9 to the IC3A Q/ output which will be at GND. Hence, no current is drawn through the photodiodes of ODM3 and ODM4, maintaining this pair of devices as non-conductive.

Conversely, when IC3A is 'flipped' by a positive transition on its CLK input as described in the previous section, transistor Q2 will be switched on and transistor Q1 will be switched off. The states of all four ODM devices will then change, leaving ODM1 and ODM2 non-conductive and ODM3 and ODM4 conductive.

When ODM3 and ODM4 conduct, the DCC Main-In A terminal is connected to the Rev-Out A terminal (via ODM4) and the Main-In B terminal is connected to the Rev-Out B terminal (via ODM3). The result is that the DCC output is 'in-phase' with the DCC input.

On the other hand, when ODM1 and ODM2 conduct, the DCC Main-In A terminal is connected to the Rev-Out B terminal (via ODM1) and the Main-In B terminal is connected to the Rev-Out A terminal (via ODM2). Hence the DCC output is 'out-of-phase' with the DCC input.

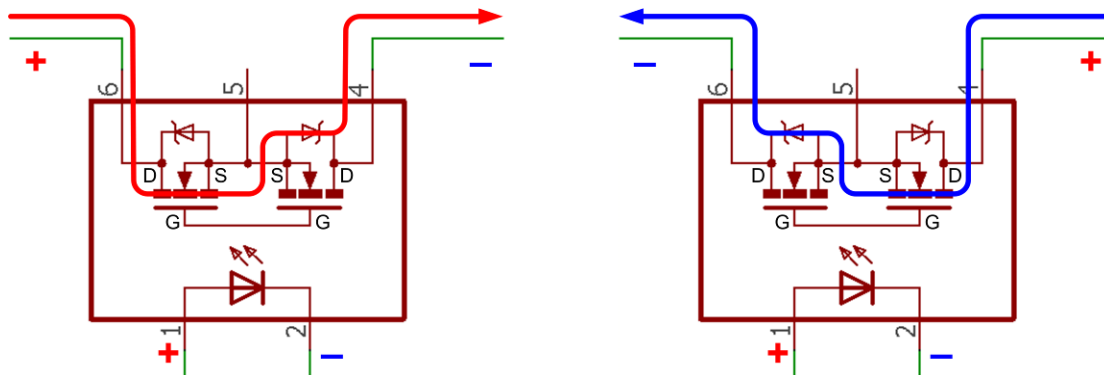
The overall result is that whenever the SAR is triggered by a short-circuit at a track gap, the Rev-Out DCC phase changes to the opposite state, which is what we require of an auto-reverser.

Dual-FET Photorelay Operation

Each of the photorelay chips (ODM1-ODM2) contains a pair of back-to-back N-channel power MOSFETs (metal-oxide-silicon field effect transistors), with their source terminals connected together. Using a pair of MOSFETs in this way allows the device to switch an AC load such as DCC where the polarity of the input line alternates between positive and negative at a frequency of around 6kHz.

The photorelay chip contains some internal circuitry which activates the gates of the MOSFETs whenever it is illuminated by a photodiode contained within the package. Using optical coupling in this way allows the relatively high DCC voltage of the switched power line to be completely isolated from the low-voltage control circuitry (IC1-IC3) driving the photodiode.

The key to the device's operation is that a MOSFET only conducts when its drain is positive with respect to its source, even when the gate is active. Hence, in the left part of diagram [4], with the DCC input line positive, the lefthand MOSFET will conduct whereas the righthand one will not, despite being nominally switched on. However, the internal construction of MOSFETs leads to them having what is known as a 'body diode' which allows current to flow past the device when the drain is reverse-biased – so that current flows through both MOSFETs following the path indicated by the red line.



4. Conduction paths depending on DCC input line polarity

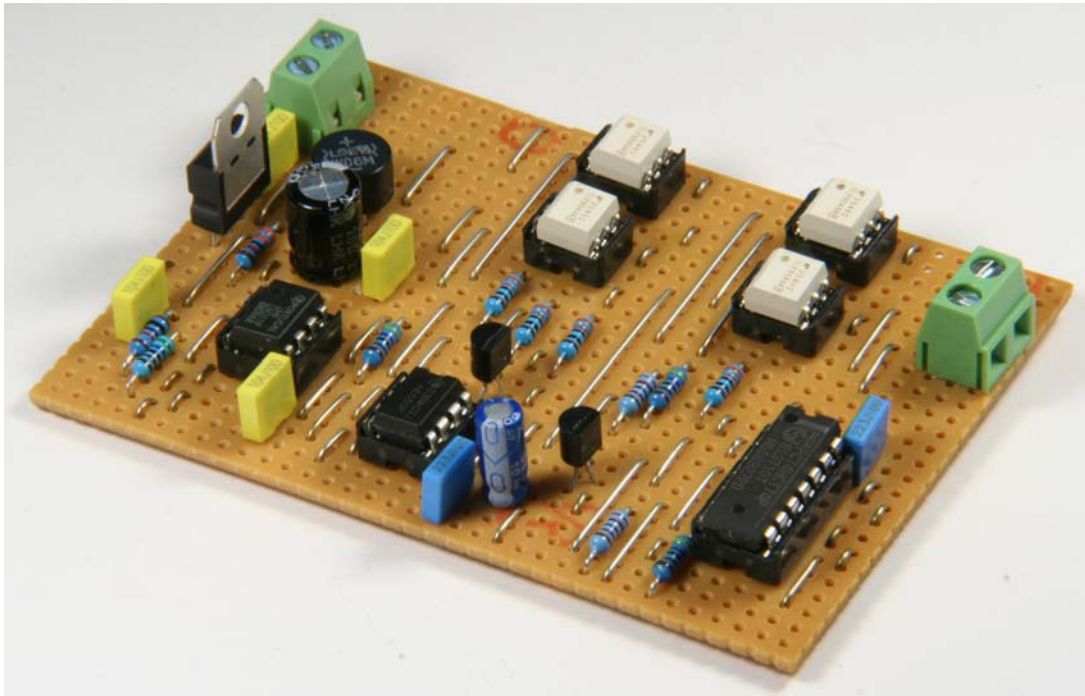
When the DCC input line changes to negative, as in the right part of diagram [2], the lefthand MOSFET switches on to conduct the track current while the righthand one is off but allows the current to flow through its body diode, following the blue line.

When the photodiode is switched off, deactivating the internal gate circuitry, both MOSFETs will switch off so that no current flows through the MOSFETs themselves. Current cannot flow through the body diodes either in this situation, since they are connected in opposite directions, hence DCC power to the output line is completely removed.

Note that, due to the very low resistance of the MOSFETs when switched on (typically 0.02 ohm), they do not dissipate appreciable power even when carrying high currents. Even when carrying a maximum current of 5A (definitely not recommended for continuous operation), dissipation would only be around 500mW which is within the absolute maximum package capability of 700mW.

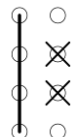
Building the Simple Auto-Reverser on Stripboard

Although it requires a bit more work than using a ready-made printed circuit board, it is perfectly possible to build the Simple Auto-Reverser on stripboard. The diagrams [6] and [7] on the following pages show the component placement, plus the top-side wires connecting various copper strip sections together and the necessary breaks in the copper strips, using a piece of stripboard of size 3.6" by 2.6" (35 by 25 holes), as shown in [5] below. Here, all the chips were mounted in sockets so that they could be re-used on a PCB, but there is no reason they cannot be soldered directly in place.

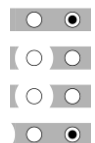


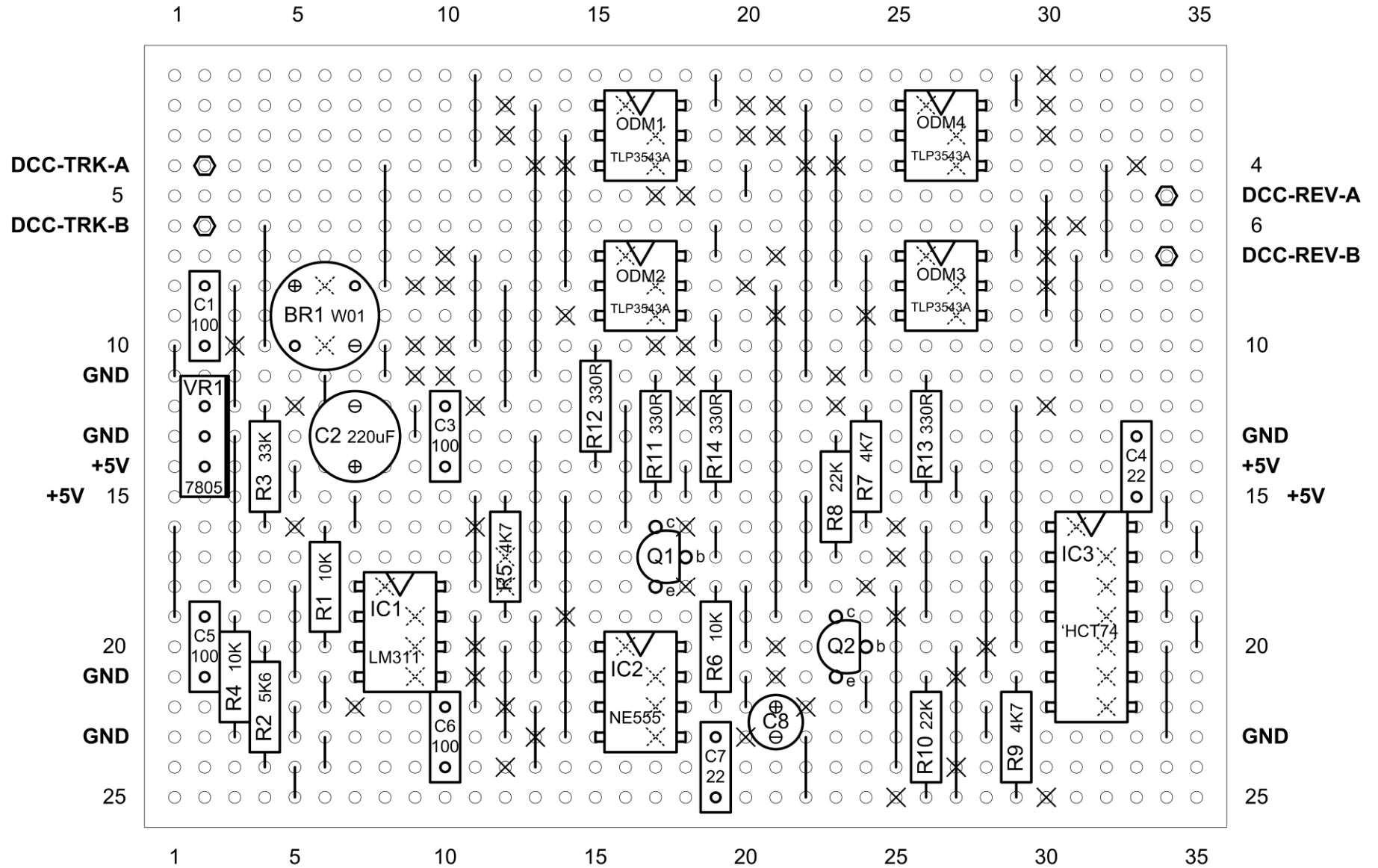
5. Simple Auto-Reverser on stripboard

In the component placement diagram the vertical lines represent 22AWG tinned copper wires and the crosses indicate where there is a break in the copper strip on the underside, as indicated in the small extract from diagram [6] on the right –

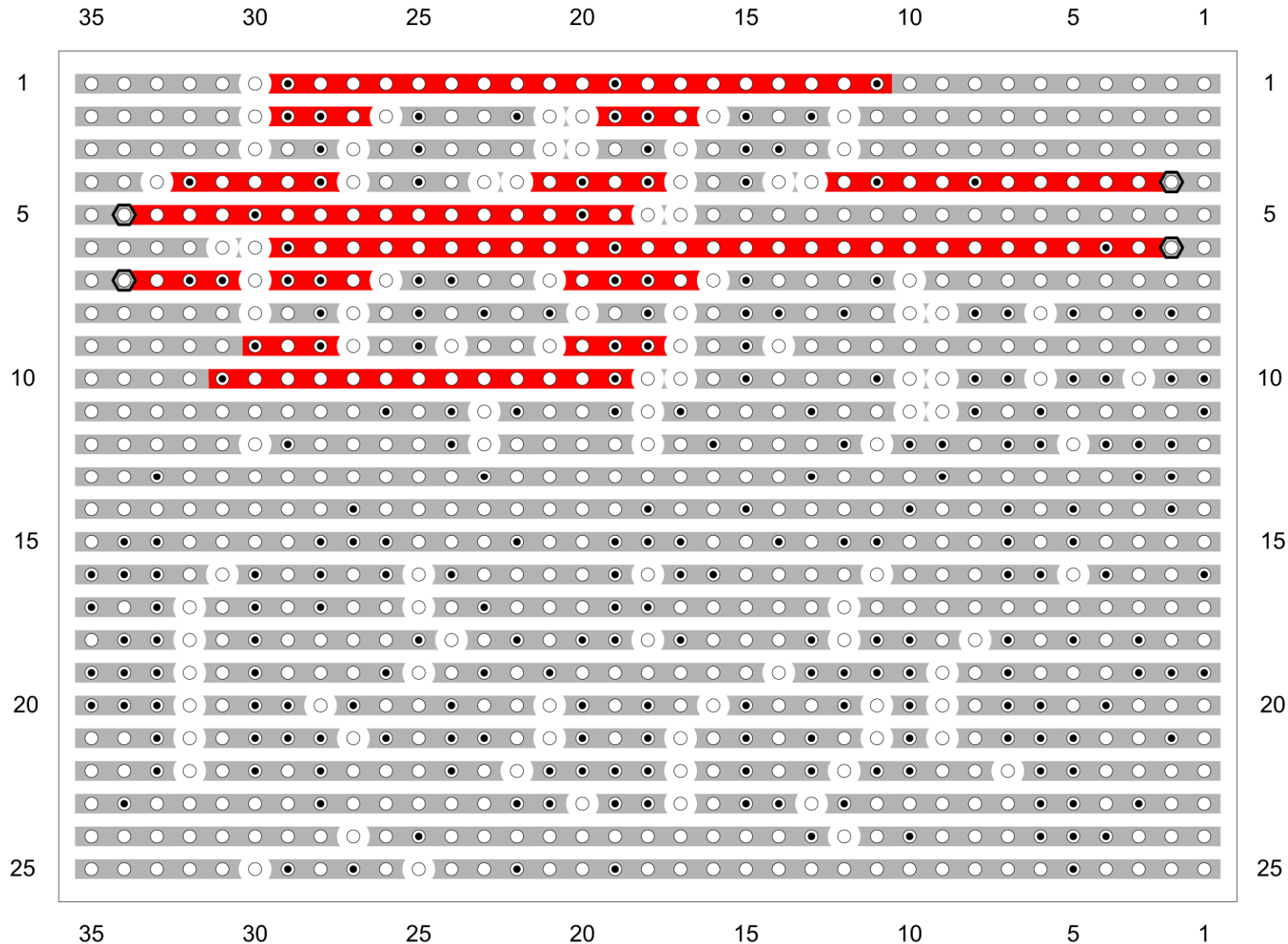


Similarly, in diagram [7] the white circles represent track breaks and the black dots show where connections are made to components or wires on the top side, as indicated in the small extract from diagram [7] on the right (showing the corresponding board area) – track breaks are made using either a proprietary tool or an appropriately-sized twist drill bit. –



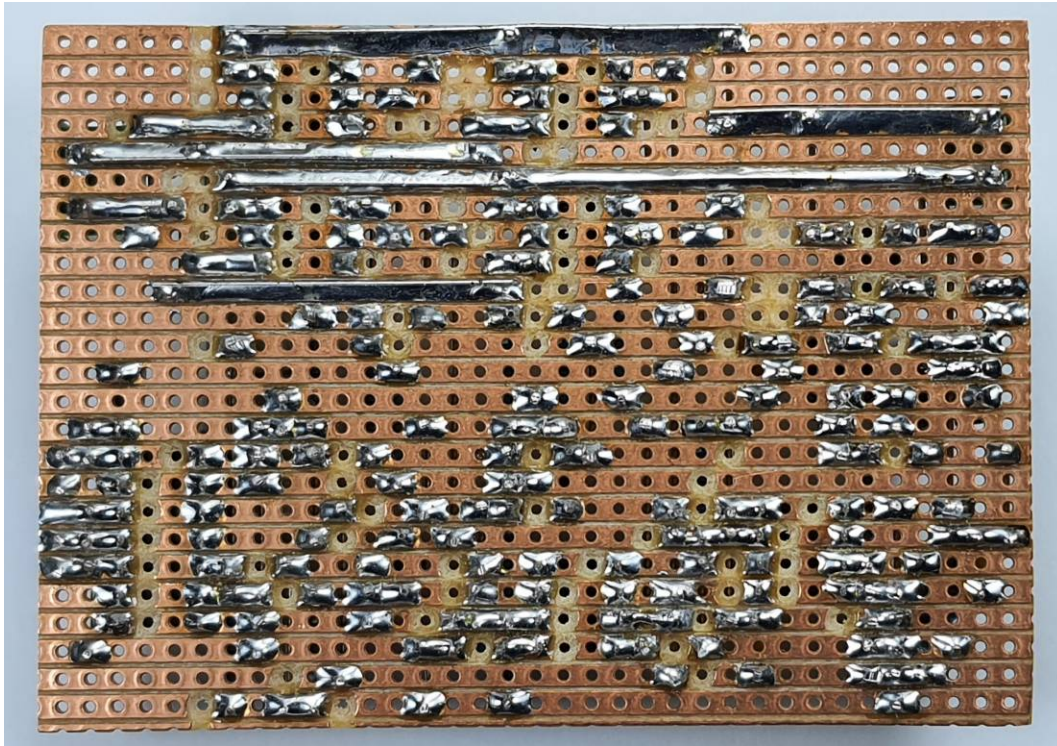


Simple Auto-Reverser – Technical Details



7. Simple Auto-Reverser – Underside showing track breaks and component connections – with high-current tracks highlighted in red

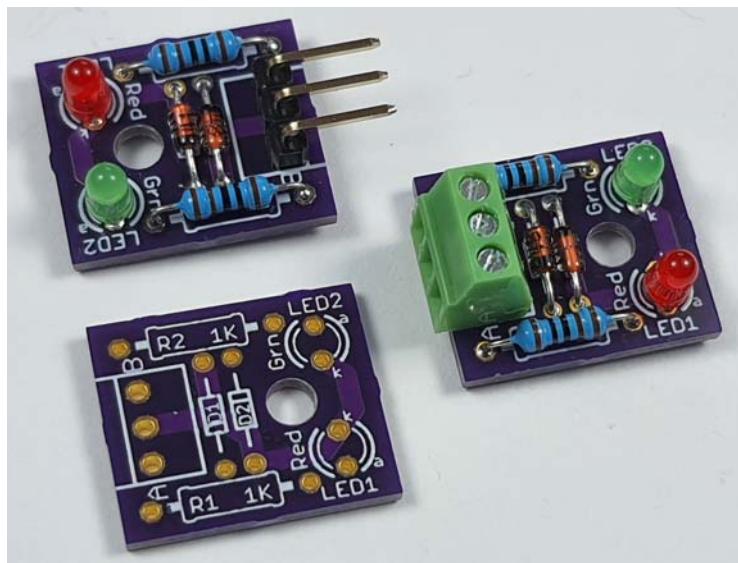
Note that, as the copper strips do not have a great current-carrying capacity, it is recommended that you solder lengths of 22AWG tinned copper wire along those strips shown in red in diagram [7]. Where the relevant piece of track is short, it is sufficient simply to apply extra solder to the track between the component connection points. A photograph showing these enhanced track strips is shown in [8] below.



8. Simple Auto-Reverser – Stripboard underside showing high-current tracks

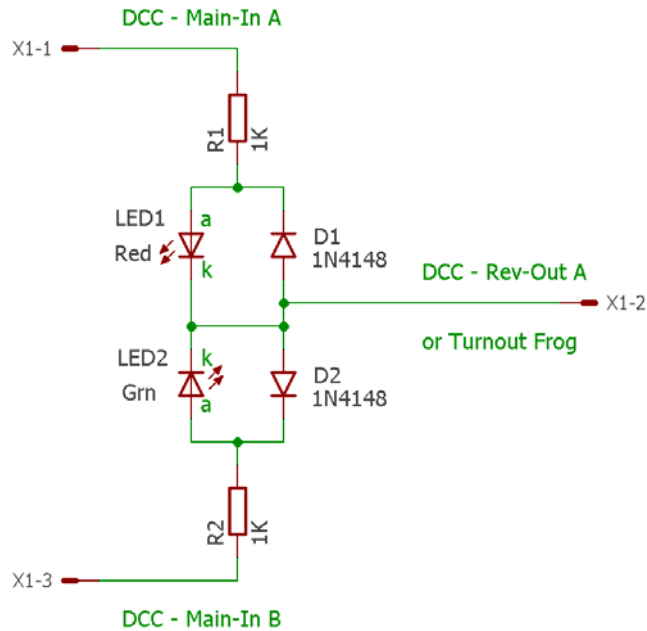
DCC Phase Indicator

As shown being used in the video clip which accompanied the main project article, the DCC Phase Indicator was originally developed to indicate the state of turnouts with 'live' (power-switched) frogs but can just as easily be used to indicate the DCC phase of a reversing section.



9. DCC phase indicator boards

The circuit schematic of the DCC Phase Indicator (DPI) is shown in [10] below –



10. DCC Phase Indicator – Circuit Schematic

When used as a turnout position indicator, the outer pair of terminals (X1-1 and X1-3) are connected to the main track and the centre terminal (X1-2) to the turnout frog so that when the turnout is set straight the green LED lights, and when it is set diverging the red LED is lit.

To indicate the DCC phase of a reversing section, connect the X1-1 and X1-3 terminals to the main track A and B rails, and the X1-2 terminal to the A rail of the reversing section on the other side of the track gap. When the reversing section rails are in-phase with the main track rails, X1-1 and X1-2 will always be at the same voltage, so no voltage is present across R1, LED1 and D1 and LED1 (red) will not be lit. The full DCC voltage will, however, appear across R2, LED2 and D2 so that the green LED lights. Note that the DCC voltage continually reverses polarity so that LED2 only lights when X1-3 is positive with respect to X1-2. When the polarity is reversed, LED2 would be damaged by the full DCC negative voltage, but D2 conducts instead, so restricting the reverse voltage across LED2 to a safe 0.7V.

Conversely, when the reversing section rails are out-of-phase with the main track, there is voltage between X1-1 and X1-2 (but not between X1-2 and X1-3) so that the Red LED lights.

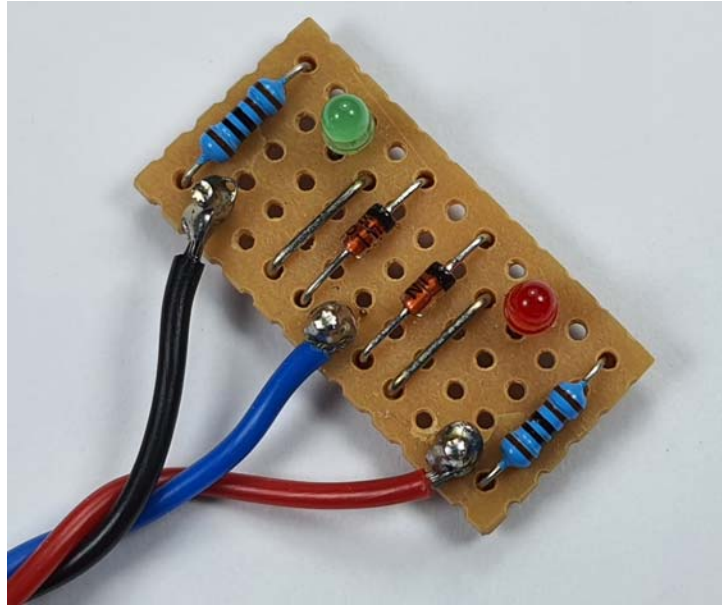
If you would like to build some phase/turnout indicators for yourself, then you can obtain a set of three PCBs from OSH Park at a cost of \$2.10, as you can see if you follow the link https://oshpark.com/shared_projects/VnZRD1NU.

Again, if you would like to use an alternative PCB supplier, you can download a .zip file with the full set of Gerber files from my own website at www.a-train-systems.co.uk/sar-download.

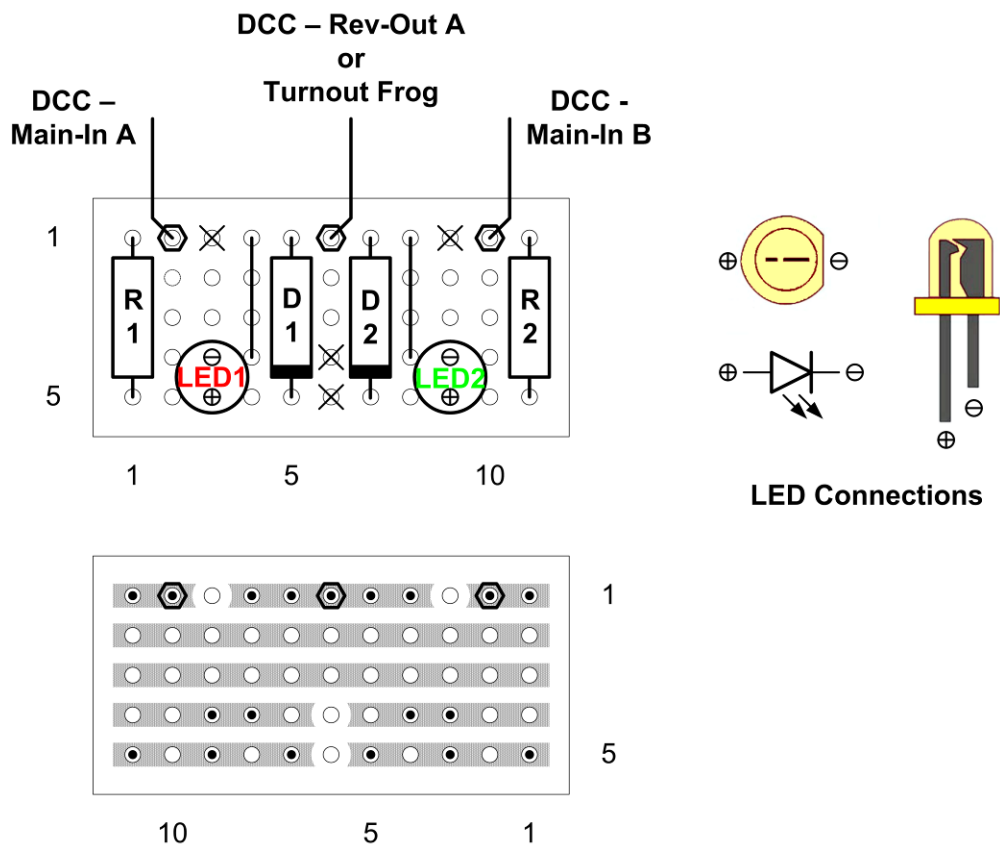
The components required are two 1K resistors (metal film, 0.25 Watt), two diodes such as type 1N4148, and two 3mm LEDs, one red and one green. Fit the diodes with their striped ends as shown on the PCB, and the LEDs with their negative (short) leads towards the centre of the PCB in the holes marked 'k', as shown in [9].

You have the choice of fitting either a 3-pin header (for connection using a standard servo connector lead) or a 3-way 0.1" terminal block to use individual wires – or you can simply solder wires directly to the PCB.

If you want to build a DCC Phase Indicator on stripboard rather than on the available PCB, as shown in [11] then just follow the details shown in [12] below –



11. DCC phase indicator on stripboard



12. DCC Phase Indicator – Stripboard details