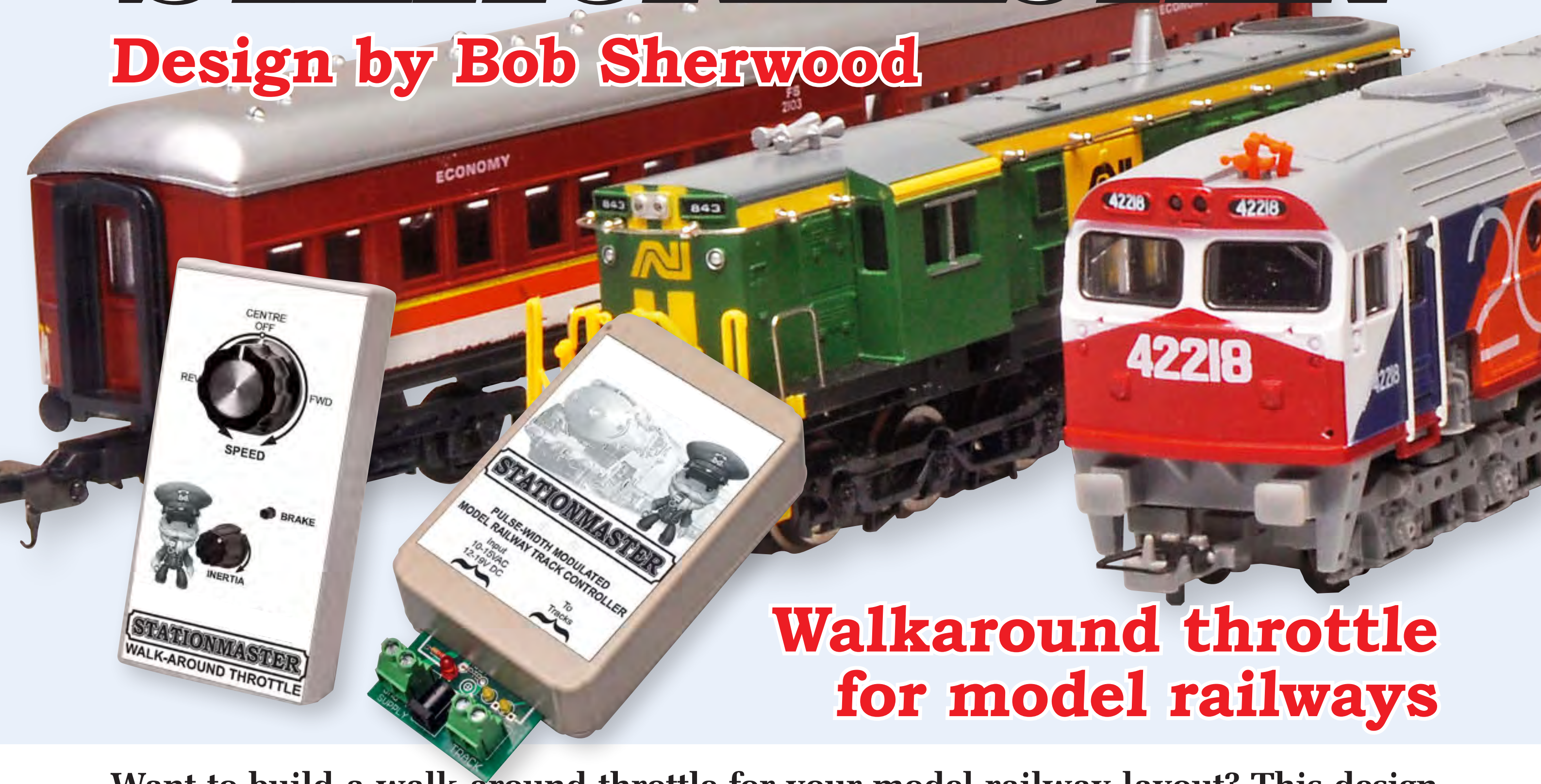
STATIONMASTER

Design by Bob Sherwood



Walkaround throttle for model railways

Want to build a walk-around throttle for your model railway layout? This design is easy to build, yet provides useful features such as adjustable inertia, emergency braking and PWM control. It features a separate hand controller which you can plug into various sockets around your layout.

While Digital Command Control (DCC) is the bee's knees for large model railway layouts, a simple walk-around throttle is all you need for smaller layouts. And of course, there is nothing to stop you using this controller on a large layout, as well.

The benefit of a speed controller with a hand-held walk-around controller is that you can plug it into sockets at various points around your layout. This *Stationmaster* design by Bob Sherwood uses cheap, readily available Telecom-style RJ sockets and plugs. Your layout can have one socket or many, depending on how many you want, and you can use standard flat or curly leads.

Chances are you already have a spare AC or DC power supply that would be suitable to run the *Stationmaster*. Anything from 12V DC or 10VAC at 1A up to 25V DC or 18VAC at 5A would do the job. 1A will be plenty for a single locomotive, but if you're planning to run several on the same tracks, you will need at least two or three amps.

If you already have a train controller but it's a variable DC output type, you will want to upgrade to the *Stationmaster* because as you have probably noticed, any time the locomotive hits a dirty section of track at a low DC voltage, it tends to slow down, lurch or even stop. That's much less of an issue with PWM (pulse width modulation) drive because you will be applying higher peak voltages to the track.

The PWM voltage is applied to the track by an H-bridge IC. The operation of an H-bridge is shown in Fig.1, and four possible switch conditions are shown. Here we are showing the H-bridge as comprising four switches, although in the *Stationmaster* they are of course N-channel MOSFETs.

Fig.1(a) shows the default state with all switches off. In this state the motor is not connected to anything, and so if the locomotive is moving, it will continue to move but will slow down naturally due to friction in the wheels, gearing and motor. If the locomotive is not moving, it would be possible to push it along the track and it may roll down a steep grade on its own.

In Fig.1(b), switches S1a and S2b are closed. One end of the motor is connected to the positive supply and the other end to ground, so the motor is driven in one direction. In Fig.1(c), the opposite pair of switches is closed, and so the motor drive polarity is reversed and the motor will rotate in the opposite direction.

Features and specifications

- Walkaround hand controller
- Controls: forward/reverse, speed, inertia (momentum), emergency brake
- Indicators: power on, forward/reverse drive, track voltage indicators
- Short-circuit protection
- Output current: up to 3.5A; adjustable current limit
- Supply voltage: 12-25V DC, 10-18VAC
- Quiescent current: 20mA
- PWM frequency: ~8kHz

In Fig.1(d), switches S1b and S2b are closed, and so the motor is effectively shorted out. This will provide significant braking. If the locomotive is moving, it will quickly come to a halt and if it is stationary, it will be difficult to move and will not roll down a steep grade. If the opposite set of switches were closed (ie, S1a and S2a), the effect would be the same.

All four switches plus the control logic and gate drive circuitry in the *Stationmaster* are integrated into a single IC, a Texas Instruments DRV8871 H-bridge. One important feature of this IC is that it contains protection logic to prevent the wrong pair of switches from being closed, resulting in the power supply being shorted out.

Speed control is achieved by switching rapidly between the configuration of Fig.1(a) and either of Fig.1(b) or Fig.1(c), depending on the direction of travel.

The more time the H-bridge spends in the state of Fig.1(a), the lower the locomotive speed. With a PWM control scheme, the rate at which the H-bridge alternates between these configurations is fixed and speed is controlled by how much time it spends in the two states. The percentage of the time where voltage is applied to the tracks is known as the duty cycle; a higher duty cycle results in a higher speed.

Circuit description

The complete *Stationmaster* circuit is shown in Fig.2; it consists of two main sections. On the left is the PWM waveform generation circuitry and on the right, the DRV8871 H-bridge IC and associated components, to provide the high-current drive to the locomotive tracks.

The PWM-generation circuitry is based on IC1, a TL084 and IC2, an MC14584 hex schmitt trigger inverter. Two of the op amp stages, IC1a and IC2b, combine to form an ~8kHz triangle-wave generator. IC1b is configured as an integrator, with its pin 5 non-inverting input connected to a 2.5V half-supply rail derived from the 5V rail via two 220Ω resistors and a 1µF filter capacitor.

When its pin 6 inverting input is above 2.5V, the output voltage at pin 7 drops at a constant rate, whereas when the pin 6 input is below 2.5V, the output voltage at pin 7 rises at the same rate. Op amp stage IC1a is configured as a comparator with hysteresis, and its output is low when its pin 3 input is below 2.5V and high when its input is above 2.5V.

This input is fed via a divider from the output of IC1b, with the other end of the divider connected to its pin 1 output. So essentially, this completes the feedback path causing IC1b to oscillate, as well as defining the amplitude of the triangle wave it produces, by the ratio of the 1kΩ and 3.3kΩ resistors.

When output pin 1 of IC1a is low, at say 0.9V, output pin 7 of IC1b will need to rise above 3V in order to switch the output of IC1a high. You can confirm this by calculating the voltage at pin 3 (in the middle of the divider): ((3V × 3.3kΩ) + (0.9V × 1kΩ)) ÷ (3.3kΩ + 1kΩ) = 2.51V. Similarly, when output pin 1 of IC1a is high, at say 4.05V, output pin 7 of IC1b will need to fall below 2V in order to switch the output of IC1a low; ((2V × 3.3kΩ) + (4.05V × 1kΩ)) ÷ (3.3kΩ + 1kΩ) = 2.48V.

So these will be the approximate maximum and minimum voltages of the triangular waveform at output pin 7 of IC1b, with a maximum of around 3V, a minimum of around 2V and thus a peak-to-peak voltage of around 1V.

The actual waveforms produced by the prototype are shown in the oscilloscope grab of Fig.3. The waveform at pin 1 of IC1a is the green trace, while that at pin 7 of IC1b is the blue trace. As you can see from the measurements at the bottom of the screen, the actual peak-to-peak voltage of the triangle wave is 880mV and the frequency is 9.43kHz (the actual frequency will vary depending on circuit tolerances, but it is not critical).

The triangular wave is converted into a variable-duty-cycle PWM signal by comparing its amplitude to that of a DC control signal, which varies somewhere between its minimum and maximum voltages. The higher the control signal voltage, the higher the PWM duty cycle. However, the situation is complicated by the fact that we need to be able to drive the locomotive in either direction and that we also need a 'dead band' when the speed pot is set somewhere around the middle, where there is no drive at all.

This situation is handled by using two comparators along with two triangle waveforms that have slightly different DC levels. The other two stages of op amp IC1 – ie, IC1c and IC1d – are used for these comparators, and the waveform from the pin 7 output of IC1b is coupled to two of their inputs (pins 9 and 12) via 100nF capacitors. The DC bias for these two pins is provided by a resistor network across the 5V supply comprising two 47kΩ fixed resistors, an 18kΩ resistor and 20kΩ trimpot (VR1) which is connected as a rheostat (ie, variable resistor).

Thus, input pin 9 of IC1c has a DC level between 2.84V and 3.22V, while input pin 12 of IC1d has a DC level between 1.78V and 2.16V, depending on the setting of VR1. The average of these two voltages will be very close to the 2.5V half-supply rail. The further apart these two voltages are, the larger the 'dead band' will be, allowing the speed control potentiometer to be rotated over a larger part of its range without any drive to the locomotive.

This adjustment is necessary to allow for variations in the amplitude of the triangle waveform; VR1 is adjusted until the waveforms no longer overlap, so that there is no drive to the locomotive tracks with the speed pot in its central position.

Also, there's no guarantee that when its speed pot is in its half-way position, it will necessarily be at exactly half its nominal resistance value. Indeed, if using a pot with a central detent, it would be very annoying if the loco slowly moved in one direction or the other. So the dead band needs to be so that the loco tracks get no drive with the speed pot at its half-way point.

The two DC-biased triangle waveforms can also be seen in Fig.3, with pin 9 of IC1c in yellow and pin 12 of

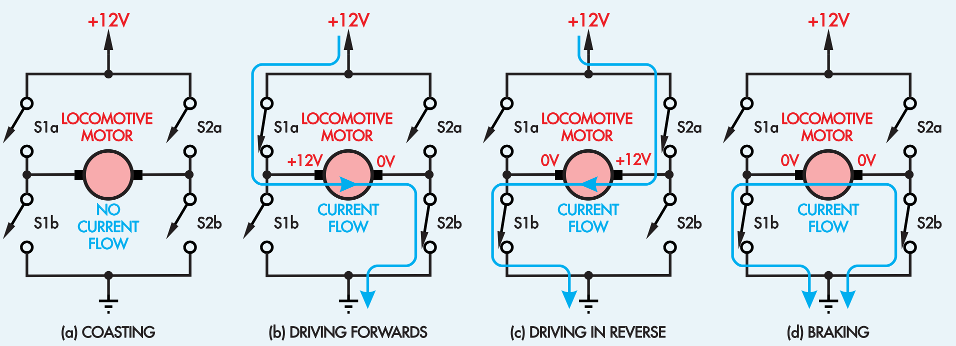


Fig.1: four of the five possible configurations of an H-bridge (the fifth is not used in our application). The voltage across the motor and the current flow path is shown, assuming a nominal 12V DC supply. In case (d), the current flow direction depends on the direction of motor rotation at the time of braking. The switches are usually discrete MOSFETs (they may also be internal to an IC) as in the *Stationmaster*.

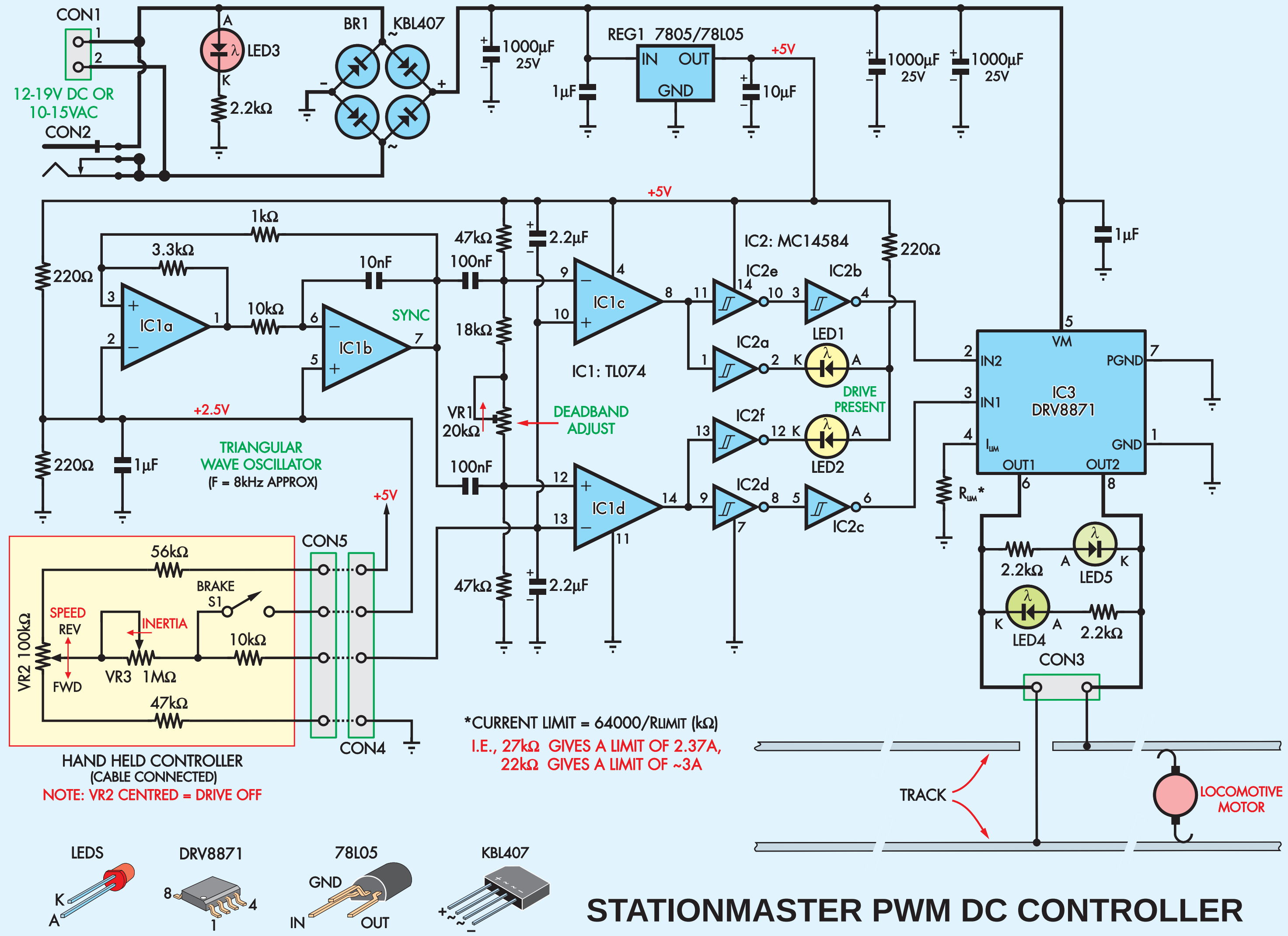


Fig.2: the complete circuit diagram for the *Stationmaster*, with the hand controller circuitry shown in the box at lower left. IC1a and IC1b generate a triangle waveform at around 8kHz, and IC1c and IC1d compare this to the control signal from speed pot VR2. The outputs of IC1c and IC1d are PWM signals which are squared up by schmitt trigger inverter IC2 and fed to H-bridge IC3 to drive the tracks.

IC1d in mauve. As you can see, VR1 has been adjusted so that the minimum voltage of pin 9 is above the maximum voltage of pin 12.

Speed, inertia and brake controls

The speed, inertia and brake controls consist of two pots and a momentary switch, and are usually mounted in the separate hand controller unit which is attached to the main board by a telephone cable.

Normally, a two-metre cable is about right; however, you can use a longer or shorter cable if necessary. There are provisions to mount these controls inside the main unit; however, we won't go into details about that option since we think most people will want to use the hand controller for walk-around operation.

The controls are shown at lower left in the circuit of Fig.2. Speed control pot VR2 is effectively connected across the 5V supply with padding resistors at either end to limit the voltage at its wiper so that it varies over an appropriate range to go from full speed in the forward direction to full speed in reverse, without too much of a dead zone at either end.

The inertia potentiometer is wired as a rheostat (variable resistor) and is in series with the return signal from the speed pot's wiper. The other end of the inertia pot is fed to a pair of 2.2µF capacitors on the main board, via a 10kΩ fixed resistor, so the higher a resistance the inertia pot is set to, the more slowly the voltage across these 2.2µF capacitors change. This simulates a locomotive with more inertia (mass), so its speed will change more slowly when the speed pot is rotated.

Brake switch S1 bypasses both the speed and inertia pots and connects the 2.5V mid-rail supply directly to the 10kΩ capacitor, which rapidly charges/discharges the 2.2µF capacitors on the main board until the locomotive has stopped and it will remain stopped until the brake switch is released; if the speed pot is at its midpoint after the brake is released, the loco will not move off again.

Note that braking is not instant, as this may cause the locomotive(s) to derail, but it will stop the loco(s) significantly faster than simply winding the speed pot back to its central position.

Track drive

The output of op amp (comparator) IC1c goes high when the speed control signal at its pin 10 non-inverting input is above the triangle waveform at its pin 9 inverting input. Thus, its output duty cycle increases with clockwise rotation of the speed pot.

Similarly, the output of op amp (comparator) IC1d goes high when the speed control signal at its pin 13 inverting input is lower than the triangle waveform at its pin 12 non-inverting input. Thus, its output duty cycle increases with anti-clockwise rotation of the speed pot.

As stated earlier, VR1 is adjusted so that the output of both comparators remain constantly low with the speed pot at its halfway point. This condition is shown in the scope grab

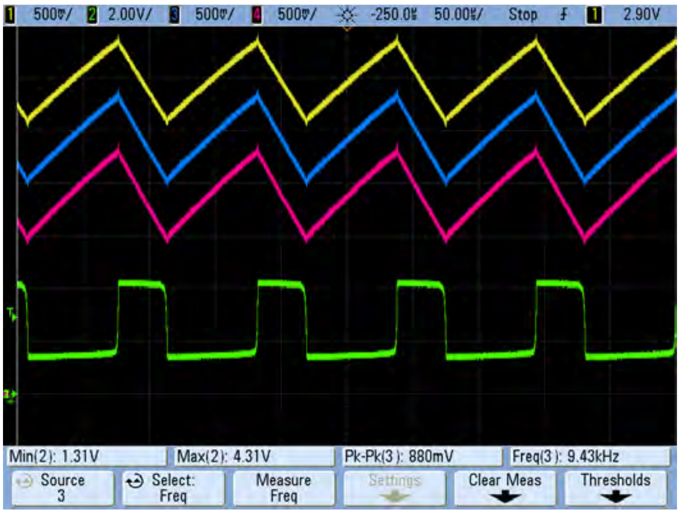


Fig.3 the blue trace is the triangle waveform at pin 7 of IC1b. It has a frequency of 9.43kHz and an amplitude of 880mV peak-to-peak. The yellow and mauve traces are the DC-shifted versions of this waveform at pins 10 and 13 of IC1 respectively. The green trace shows the pulse applied to pin 6 of IC1b which is in-phase with the triangle waveform and has a maximum voltage of 4.31V and minimum of 1.31V, limited by the drive capability of the op amp.

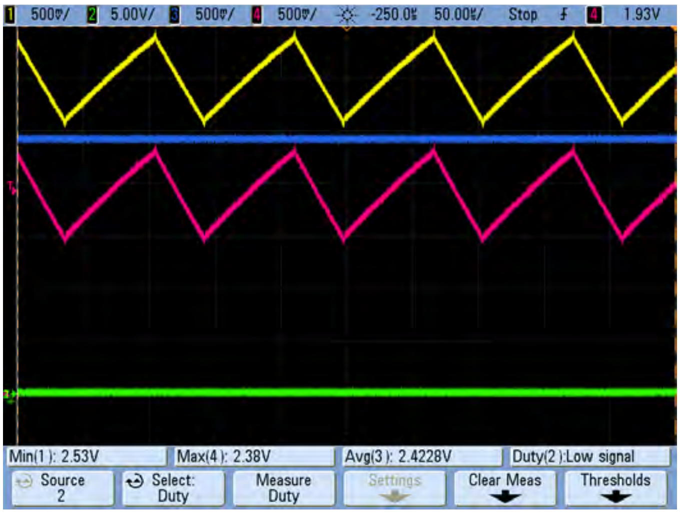


Fig.4 (right): the same voltages from pins 10 and 13 of IC1 are shown here but the blue trace now shows the reference voltage from speed pot VR2. Since it is below the yellow trace and above the mauve trace, no drive is applied to the tracks and the PWM output at pin 4 of IC2b, shown in green, is a flat line (ie, there is no PWM signal to tracks).

of Fig.4. The blue trace is the reference voltage from speed pot VR2. Since it is below the yellow trace and above the mauve trace, no drive is applied to the tracks and the PWM output at pin 4 of IC2b, shown in green, is a flat line.

Drive from both op amps (comparators) is fed to four of the six schmitt trigger inverter stages of IC2. IC2a and IC2f invert these signals and then drive LED1 and LED2, which have a common 220Ω current-limiting resistor. Hence, as the locomotive moves faster in the forward direction, LED1 lights up brighter (as it has a higher duty cycle) and similarly, the brightness of LED2 indicates the drive speed in the reverse direction.

The remaining four inverter stages are wired up in two series pairs, effectively forming buffers to square up the signals from IC1c and IC1d, and pass them to the inputs of integrated H-bridge IC3.

With IN1 and IN2 (pins 3 and 2) of IC3 both low, there is no output drive. With IN1 high, OUT1 (pin 6) is driven high while OUT2 (pin 8) is driven low. With IN2 high, OUT1 is driven low while OUT2 is driven high, reversing

Parts List

1 double-sided PCB available from the *EPE PCB Service*, coded 09103171, 143.5 × 50.5mm
1 flange mount ABS box, 125 × 80 × 35mm
1 panel label, 50 × 92mm
1 20kΩ single-turn horizontal PCB-mount trimpot (VR1)
2 No.4 × 5mm self-tapping screws
2 2-way 6.35mm PCB-mount terminal blocks (CON1,CON3)
1 PCB-mount DC socket, 2.1mm or 2.5mm ID (CON2)
1 6P4C RJ14 low-profile PCB-mount modular socket (CON4)
2 14-pin DIL sockets (optional)
10 PCB stakes (optional)

Semiconductors
1 TL074 quad JFET-input op amp (IC1)
1 MC14584 hex schmitt trigger inverter (IC2)
1 DRV8871 H-bridge IC (IC3)
1 78L05 100mA 5V linear regulator (REG1)
1 400V 4/6A vertical PCB-mount bridge rectifier (BR1)
2 3mm yellow LEDs (LED1,LED2)
1 3mm red LED (LED3)
2 3mm green LEDs (LED4,LED5)

Capacitors
3 1000µF 25V low-ESR electrolytic capacitors
1 10µF 6V tag tantalum capacitor
2 2.2µF 50V multi-layer ceramic capacitors
2 1µF 50V multi-layer ceramic capacitors
1 1µF 25V X7R SMD ceramic capacitor, 2012/0805 size
2 100nF 50V multi-layer ceramic capacitors
1 10nF 50V MKT capacitor

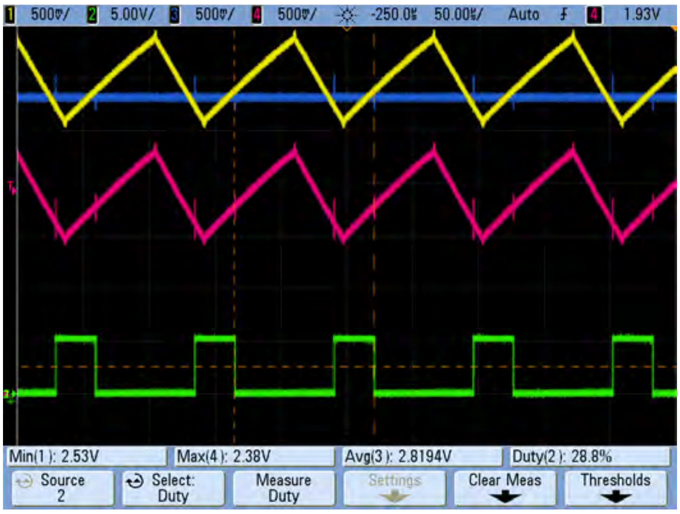
Resistors (all 0.25W, 1%)

2 10MΩ	2 47kΩ	1 22kΩ	1 18kΩ
1 10kΩ	1 3.3kΩ	3 2.2kΩ	1 1kW
3 220W			

Additional parts for hand controller

1 PCB available from the *EPE PCB Service*, coded 09103172, 98 × 40.5mm
1 light grey ABS instrument case, 160 × 60 × 30mm
1 panel label, 51 × 94mm
1 6P4C RJ14 low-profile PCB-mount modular socket (CON5)
1 PCB-mount tactile switch with 22mm long actuator (S1)
1 100kΩ 16mm potentiometer with centre detent (VR2)
1 1MΩ 9mm vertical PCB-mount potentiometer (VR3)
1 button cap (for S1)
1 33mm black 1/4-inch shaft knob with white marker (for VR2)
1 11mm black 18 tooth spline plastic knob (for VR3)
4 No.4 × 5mm self-tapping screws
8 M3 nylon hex nuts
3 50mm lengths of light duty hookup wire
1 2m RJ14 to RJ14 telephone cable

Resistors (all 0.25W, 1%)
1 56kΩ 1 47kΩ 1 10kΩ



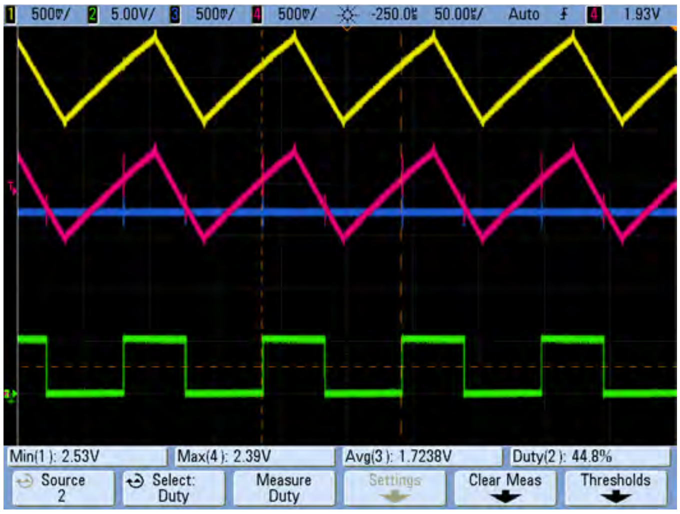


Fig.5 (left): the same traces as in Fig.4, but now the speed pot has been rotated clockwise, increasing the reference voltage (shown in blue). When the yellow waveform is below the blue reference voltage, the PWM output at pin 4 of IC2b, shown in green, increases to 5V and it drops back to 0V when the yellow and blue waveforms cross again. Thus, as the speed pot is rotated further clockwise, the PWM pulses at pin 2 of IC3 (IN2) increase in duty cycle.

Fig.6 (right): now speed pot VR2 has been rotated anti-clockwise past its centre position, so the reference voltage, shown in blue, has now dropped low enough to intersect with the mauve waveform. The green trace now shows output pin 6 of IC2c, which feeds input IN1 (pin 3) of IC3. Note that the positive edge of the PWM pulses is now delayed compared to the crossing point, due to the limited bandwidth of op amp IC1; however, the speed pot can still be used to adjust the PWM duty cycle.

the locomotive. And with IN1 and IN2 both high at the same time, both outputs are driven low to provide motor braking; however, that feature is not used in this circuit.

PWM output waveforms

We previously referred to the scope waveforms of Fig.3 and Fig.4, with the latter showing the condition where the speed control pot VR2 is centred, so there is no output at pin 2 of IC3 (IN2, green), nor at pin 3 (IN1, not shown).

In Fig.5, we have rotated VR2 partway clockwise and this has caused the control voltage (blue trace) to rise to 2.82V. As a result, pulses now appear at pin 2 of IC3 (IN2, green) with a duty cycle of 28.8%. You can see that the leading edges of these pulses correspond to the point where the yellow trace dips below the blue trace and the trailing edges are where they cross over again, so the higher the blue (control) voltage, the greater the applied duty cycle will be.

Fig.6 shows the situation with VR2 rotated anti-clockwise from its central detent, reducing the control voltage (blue trace) to 1.72V. The green trace now shows the voltage at pin 3 of IC3 (IN1) which has a duty cycle of 44.8% and the edges correspond to the points where the blue and mauve traces intersect.

H-bridge IC details

The internal block diagram of the DRV8871 IC is shown in Fig.7. It has four internal N-channel MOSFETs with parallel diodes that form the H-bridge which drives the motor; the circuit blocks to control the MOSFETs' gates; the charge pump to generate the required high-side and low-side gate drive voltages; and the various control and protection units within.

This IC has a current-limiting facility which both protects it from damage and also helps the unit withstand accidental short circuits across the track, as will inevitably happen on any model layout, particularly when a locomotive is derailed. The maximum output current depends on the value of R_{LIM} which connects between the I_{LIM} pin and ground. The IC is rated for up to 3.6A peak, so a current limit of around 3A, as set by R_{LIM} = 22kΩ is quite safe.

Should IC3 overheat due to extended high current delivery, it will automatically shut down until it has cooled sufficiently and then resume operation. IC3 also has an internal 'dead time' delay to prevent cross-conduction of its internal MOSFETs, which means that the driving circuitry can change the state of inputs IN1 and IN2 at any time without any chance of damaging the IC.

Referring back to Fig.2, IC3 also has an SMD ceramic 1µF bypass capacitor to help stabilise the output voltage and provide a relatively clean square wave for driving the motor. Note that IC3 has integral diodes between each output and the two supply rails, to

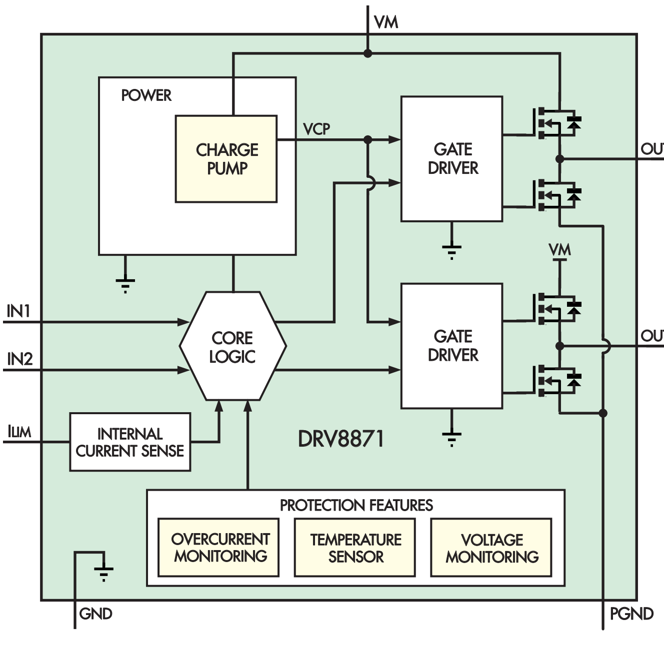
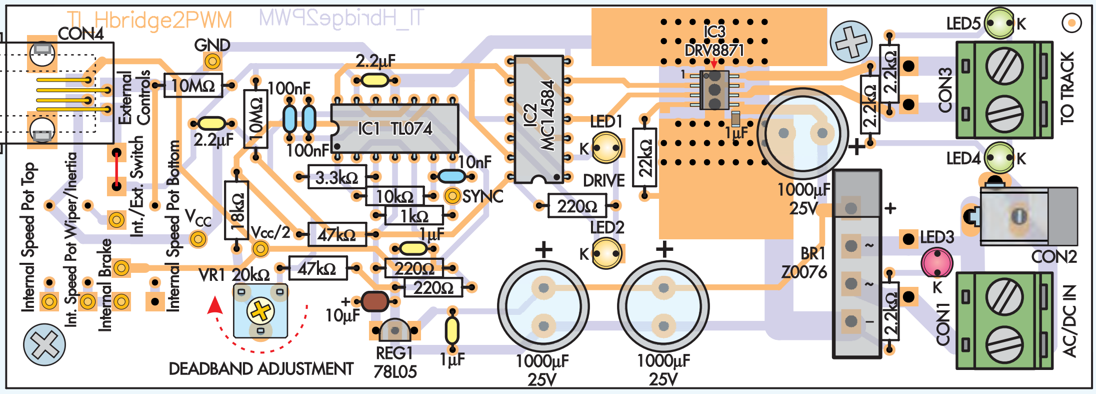


Fig.7: internal block diagram for the DRV8871 H-bridge IC. The internal MOSFETs are shown at upper-right; you can see the similarity in their connections to Fig.1. The IC also contains the boost circuitry to produce the required high and low-side drive signals to the MOSFET gates, control logic to prevent cross-conduction, plus current and temperature sensing and shutdown.



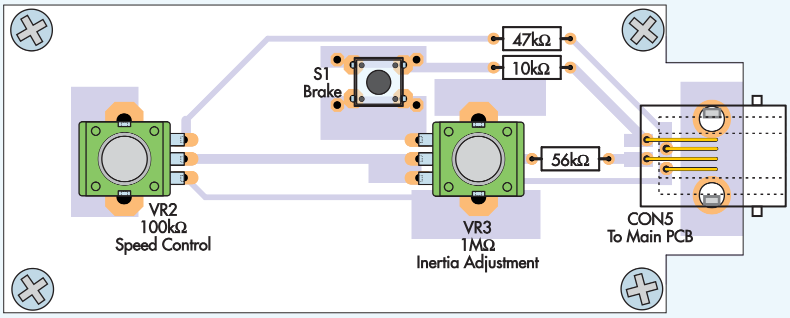


Fig.8: PCB overlays for the main PCB and hand controller PCB. Follow these to build the two boards. There are only two SMD components, IC3 and its 1µF bypass capacitor, both on the main board. The empty component positions in the lower left corner of the main board are there to allow the controls to be mounted in the same box as the main board and are left out if built with the hand controller, as shown here. Don't forget to install the wire link in place of the internal/external switch.

clamp any inductive spikes from the locomotive motor(s). It is purpose-designed for driving motors.

LED4 and LED5 are connected across the track outputs in opposite directions with 2.2kΩ current-limiting resistors and so normally echo the brightness of LED1 and LED2 respectively. However, if there is a short across the track, LED1/LED2 will still light, while LED4/LED5 will be off or dim. Note that LED4 and LED5 are located near the output terminal and are visible with the lid on the case.

Power supply

The power supply is quite simple and accepts either 10-15VAC or 12-19V DC. Actually, all the components should survive with a supply as high as 25V DC or 18VAC, should you wish to push it close to its limiting values.

LED3 is connected directly across the inputs and so will light solidly with a DC input or flicker with reduced brightness at 50Hz with an AC input. Either CON1, a 2-way terminal block, or CON2, a DC barrel connector can be used. We suggest you stick with the terminal block if your power supply is rated at more than 2A.

The input supply is rectified by bridge rectifier BR1 and this means that with a DC supply, the polarity of the connection is not important. The output of the rectifier is filtered with two parallel 1000µF capacitors, smoothing any ripples in the DC and also providing AC-to-DC conversion if required (in combination with BR1). The resulting DC is fed straight to the motor controller IC (IC3) and also to the input of 5V regulator REG1.

REG1 has a 1µF input bypass capacitor and 10µF tantalum output filter capacitor, and supplies IC2, IC3 and the two divider networks.

Construction

The *Stationmaster* is built on two PCBs. The main board is coded 09103171, measures 143.5 × 50.5mm and hosts most of the components. The hand controller board is coded 09103172, measures 98 × 40.5mm and is fitted with the components shown in the yellow box in Fig.2. Both of these boards are available from the *EPE PCB Service*.

Use the overlay diagrams in Fig.8 as a guide to construction, which is quite straightforward. The only slightly tricky component is IC3, which is only available in a surface-mount package, so start by soldering this. It has the additional twist that the underside of the IC features a metal pad which needs to be soldered to the PCB to provide sufficient heatsinking.

If you have a hot air rework station, all you need to do is apply a thin layer of solder paste to the central pad and eight pins for IC3, drop the IC in place (ensuring its pin 1 dot is oriented as shown in Fig.8) and then gently heat the IC until all the solder reflows. You can check that the solder underneath the IC has melted properly by examining it from the underside of the board through the three large vias positioned under IC3, once the board has cooled sufficiently.

If you don't have a hot air tool, we suggest you place a thin layer of solder paste (or at a pinch, flux paste) on the central pad for IC3, then position it as explained above and tack solder one of the eight pins using a regular soldering iron.

Check that the IC is sitting flat on the board and properly positioned over its pads, and then solder the remaining pins. Next, refresh the first pin which was tack-soldered. If any bridges form between its leads, clean them up using solder wick.

You can then flip the board over and melt some solder into the three large vias under the IC. Leave the iron in contact with this pad for a few seconds to ensure that the new solder remains molten and sufficient heat conducts through to the other side of the board to reflow the solder paste. That should do the trick and you can then remove any excess solder on the underside pad using a solder sucker or some solder wick.

There are also two small sets of SMD pads on either side of IC3, and the one to lower right is for the 1µF bypass capacitor. This is pretty easy to solder, simply tack solder one end, wait for the solder to cool, solder the other end (being careful to ensure the solder flows onto both the PCB pad and the end of the capacitor) and then apply fresh solder to the first joint.

Through-hole parts

With IC3 in place, the rest is pretty straightforward. Fit the 15 small resistors in the locations shown in Fig.8. It's a good idea to check the values with a

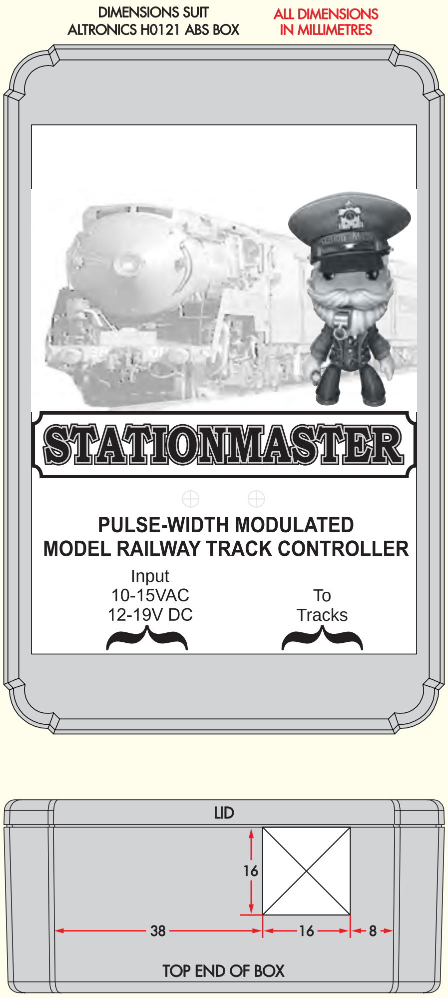


Fig.9: drilling and cutting diagrams for the main box. The top panel drilling template can also be used as the panel label.

DMM before fitting as the colour bands can be hard to identify accurately.

If you are using IC sockets, now is a good time to install them, making sure to orient the notches as shown in the overlay diagram. Otherwise, solder the other two ICs directly to the PCB, but be careful to make sure that you don't get them mixed up and that the pin 1 dot goes in the location shown.

Next, install all the small capacitors. The values are indicated on the overlay diagram. The capacitors of 1µF and above have a polarity (+) indicator, but do note that only the 10µF capacitor is actually polarised and this should have a matching + sign printed on its body, which must be lined up with that on the PCB.

LEDs 3-5 can now be fitted, taking care to orient them with the flat side of the lens/shorter lead (cathode) to the right/bottom of the board, where indicated with 'K' on the PCB overlay. These are pushed all the way down onto the PCB before being soldered and the leads trimmed.

You can now fit the PCB stakes if you want to; however, it isn't necessary and you can simply probe these pads with DMM leads if you want to troubleshoot the circuit.

Now mount trimpot VR1 and regulator REG1. You will need to crank REG1's leads to fit the solder pads, and make sure it goes in the right way around, with its flat face towards the nearest edge of the PCB. Note that a 7805 regulator can be used instead, and in this case, its metal tab faces the edge of the PCB.

Next on the list are DC connector CON2 and RJ12 connector CON4, both of which should be pushed all the way down onto the PCB before you solder their pins. You can then follow with terminal blocks CON1 and CON3, which must be fitted with their wire entry holes towards the right edge of the board.

Next, fit BR1, with its chamfered corner towards the top edge of the board. It should also have a + sign on the body of the device which you can line up with the polarity marker on the PCB. The three 1000µF capacitors can go in next, being careful to ensure that the longer (+) lead goes through the pad marked + in each case.

Now install LED1 and LED2. If you want these to be visible through the panel label on the lid of the box, fit them with the bottom of each lens 21mm above the top surface of the PCB.

However, these are really only necessary for diagnostic purposes, so you could just solder them flat on the PCB like the others. As before, the cathode side (shorter lead) is indicated in the overlay with a 'K', and this should line up with the flat side of the lens.

The main PCB is now complete and you can move on to building the hand controller.

Hand controller assembly

There aren't many components on this board. First, solder the three small resistors in place, then fit the RJ12 connector in the same manner as you did for the main board. Having done that, solder S1 and VR3 in place after making sure they have been pushed down fully onto the PCB.

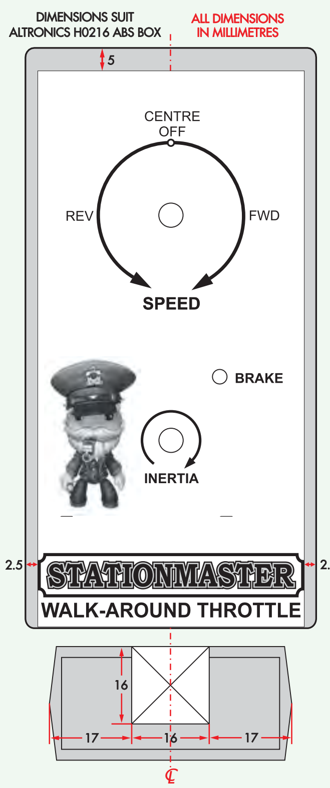
For VR2, you can use a similar pot to VR3; however, it's better if you use the 16mm pot with centre detent, as specified in the parts list. In this case, the pot is be mounted on the case and attached to the PCB via three short (~50mm) flying leads. Refer to the photo above right to see how the wiring is done.

Completing the hand controller

The next step is to prepare the two cases to accept the boards. For the hand controller, this is simply a matter of drilling three holes in the lid for the two pots and pushbutton shaft to poke through.

You can download the panel label artwork from the *EPE* website and use this as a drilling template; or copy Fig.10. The hole for the 9mm pot should be drilled to 7mm, and 8mm for the 16mm potentiometer. Ideally, you should also drill a 3mm hole for the latter pot's locking tab, although you can simply snap this off (but then you will need to do its nut up tight to stop it rotating).

Having done that, print and affix the panel label (see the link below Fig.10 for suggestions on how to do this) and cut out the holes with a sharp hobby knife; there's no need to make a hole for the pot's locking tab, as this will not protrude through the case.



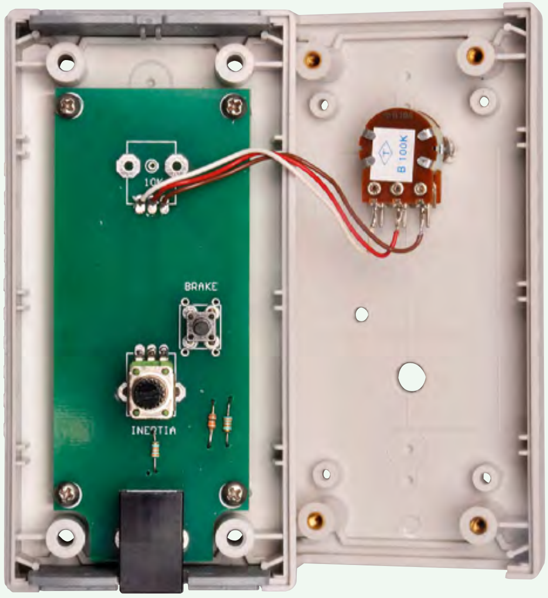


Fig.10: drilling and cutting diagrams for the hand controller. As with the main box, the top panel drilling template can also be used as the panel label.

If you want to make your own label for either of the cases we have a short description on our website on printing A4-sized synthetic sticky labels here: www.siliconchip.com.au/Help/FrontPanels

Now cut and/or file a rectangular hole in the case end panel, as shown in Fig.10. You can then insert this into the appropriate slots and affix the hand controller PCB to the integral posts in the bottom of the case using four small self-tapping screws. Note though that you need to place two M3 nylon nuts on top of each of these posts before inserting the screws; these act as spacers to get the modular socket to just the right height.

It's then simply a matter of inserting the other end panel into the case, placing the lid on top, using the four supplied screws to join the two halves of the case together and then attaching the two knobs and the button cap for S1. The knob for VR3 and the button cap for S1 are simply pressed on and held by friction (note that you will need to use the grub screw to attach the knob for VR2).

Completing the main unit

Now to complete the main unit. First, you need to cut or file down the rim around the lid of the case so that when you attach the PCB later, the part which projects out the side will not be fouled by this rim. See the photo adjacent to Fig.9 for details.

Having done that, the next step is to make the cut-out for the modular socket in the side of the case. Fig.9 shows the detail. The only remaining holes that need to be made are for LED1 and LED2, assuming you've decided to install them with long leads so that they can be seen with the lid on. The positions for these 3mm holes are shown in Fig.9.

Now affix the panel label, using the same technique as for the hand controller, making sure the 'Motor Drive Present' text goes just below the two holes if you have drilled them. The label should be oriented so that the logo is near the cut-out for the modular socket.

Then attach the PCB to the lid using two short self-tapping screws and check that the two halves of the case fit together properly and the top of the LED lenses poke through the hole (if you've made them).

But before you actually put the case together, we need to do some testing and adjustment.

Test and set up

Plug the hand controller into the main board using a 4-wire telephone cable and centre the speed pot while the inertia pot should be fully anti-clockwise. Adjust trimpot VR1 on the main board to be fully clockwise.

Apply power to the main board via CON1 or CON2 and check that LED3 lights. The other LEDs should be off. If any of the other LEDs light up, switch off and check for faults. Using IC3's ground plane as the 0V reference, check for 4.5-5.5V at the V_{CC} test point and half that at the $V_{CC}/2$ test point. If you have a frequency meter, measure the frequency at the SYNC test point. It should be in the range of 8-10kHz.

Measure the AC voltage across the terminals of CON3. You should get 0V. Now slowly rotate VR1 anti-clockwise until LED1 and/or LED2 light up, then back off slightly until both LED1 and LED2 are off. Check again that you have 0V at CON3.

You can now slowly rotate speed pot VR2 in one direction. If rotating clockwise, LED1 and LED4 should both light up and get brighter as you turn the pot further. If rotating anti-clockwise, LED2 and LED5 should both light up and get brighter as you turn the pot further.

Now rotate the inertia pot clockwise and the above should still hold true, but you should notice that the rate of change of LED brightness has been reduced. With the speed pot fully at one stop, hold down brake switch S1 and check that LED1, LED2, LED4 and LED5 all switch off in fairly short order and return to their previous states once you release it.

As a final test, you can hook up the CON3 terminals to a pair of train tracks and check you can control the speed and direction of a locomotive on those tracks as expected. If it moves in the opposite direction to what you intend, simply swap the connections at CON3.

Final assembly and usage

Now that you've confirmed it's working, you can join the two halves of the box with the supplied screws and integrate the controller into your layout.

Note that pressing and holding the brake button will bring everything to a halt very quickly; practice will allow you to tap S1 to slow a locomotive, which will return to set speed when you release it.

If you do need to use S1 for emergency braking, remember to set speed potentiometer VR2 to its central position (easy if you've used a pot with centre detent) before releasing S1 in order to prevent the locomotive from moving again when S1 is released.

RJ12 adaptors can be purchased and placed along a loom cabled around the layout so that the hand control can be unplugged and moved to a different location as you operate.

The speed set at the time of unplugging will be maintained for a period and will slowly diminish over time until control is re-established, which might cause a rapid return to the former speed. It's best to set the inertia control fairly high before plugging the controller back in to avoid this.