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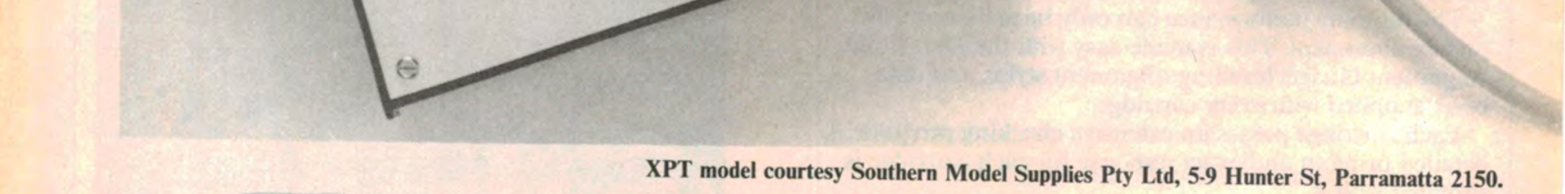
Pulse-power train controller

Here is an up-to-the-minute train controller offering all the most desirable features including inertia, full overload protection and walk-around throttle. We feel it is the best controller available, regardless of cost.

by LEO SIMPSON & JOHN CLARKE

Apart from electronics itself, few hobbies can match the long term satisfaction enjoyed by keen model railway enthusiasts. Of course if you are involved in both model railways and electronics you have the best of both worlds. The model railway enthusiast with an electronics background is able to provide many of the circuits which do so

XPT model courtesy Southern Model Supplies Pty Ltd, 5-9 Hunter St, Parramatta 2150.



much to add realism to model railway operation.

This applies particularly to our new *Railmaster* Train Controller which offers a wide range of operating features but with emphasis on ease of use. With this train controller you'll not only find that the trains operate more reliably but they also operate more realistically. And the *Railmaster* is very easy to drive.

Witness the operation of a real train such as a diesel loco with a long rake of loaded goods wagons. It starts off very slowly and almost imperceptibly accelerates its heavy load up to speed. Once up to speed, which may only be 40km/h or so, it will then maintain that rate consistently until the brakes are called upon. Braking is no sudden matter either. It takes a lot of track, maybe as much as a kilometre, to bring a heavy goods train to a halt.

Ask a model railway enthusiast to duplicate this and he will probably shake his head. With most controllers it is no easy task to reliably produce realistically smooth stops and starts and jerk-free and stall-free slow running. That is where this new controller excels.

The new controller includes a circuit which causes the model to operate as if it had the sizeable inertia of a real train. Winding the throttle up to maximum causes the model to move off very slowly without jerking or momentarily stalling. Acceleration is then smooth and progressive. Similarly, winding the throttle back causes the model train to lose speed slowly, gradually coming to a complete stop.

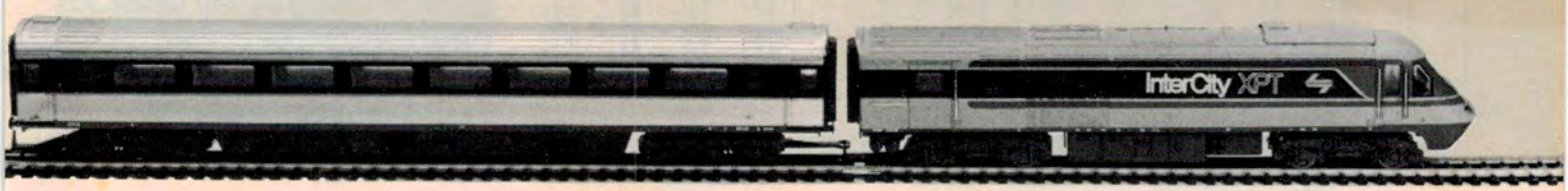
The amount of simulated inertia is variable. A long goods train can be made to accelerate much more slowly than a loco running without any load. Or, if you like, you turn the inertia off.

But simulated inertia is only part of the appeal of this new circuit. It also has two features to give enhanced low speed running. First, it works on the pulse width modulation principle and second, it monitors the speed of the loco motor and varies the drive voltage to compensate for speed variations.

Before we go into the way in which the controller actually provides these benefits let us look at the other features of the controller. They are as follows:

- Full short circuit protection including audible and visible short circuit indicators.
- Power and track monitor indicators.
- Provision for walkaround throttle.
- Adequate power for double and triple heading of locos.
- Fixed 12VDC and 15VAC for lighting and accessories.

Let's discuss these additional features. The comprehensive short circuit protection is provided for a number of reasons. Short circuits in model train layouts may often be hard to detect — often it is thought that something is wrong with the loco if it is not moving but the reason may well be an



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inadvertent short circuit elsewhere in the track.

In any case, if children are to use a train controller it must be short-circuit proof. They will often short out the tracks from sheer devilment, just to stop the train or to see the sparks fly!

Our new *Railmaster* controller can not only withstand short-circuits indefinitely, but also has a loud buzzer and a LED indicator to draw attention to the short circuit in no uncertain terms. This is desirable because many locos will briefly short out the supply as they cross the points. This is a problem of compatibility between rails and wheels and often causes jerky running which would otherwise be blamed on the loco or controller.

Even the briefest of short circuits will cause the buzzer to sound and the LED to flash. So even if you are deaf the short circuits will be brought to your attention. Once you become aware of momentary short circuits as the train goes around the track you can remedy them and get better overall operation.

Other LED indicators are provided for power and track voltage. The track voltage LED gives a good indication of the average voltage actually being applied to the track which is handy if you are having trouble with a particular locomotive.

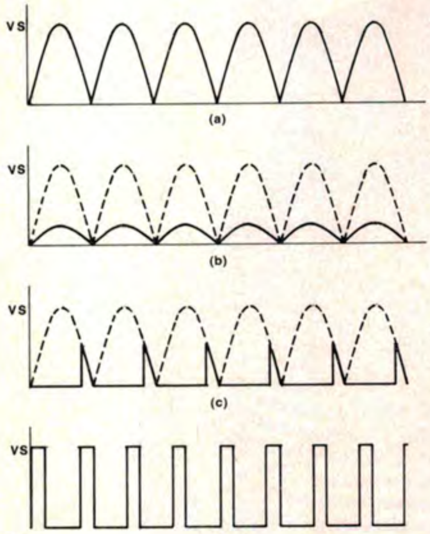


FIG. 1

Fig.1: (A) full-wave rectified sinewave; (b) transistor controller output; (c) thyristor controller output; (d) pulse controller output.

Walkaround throttle

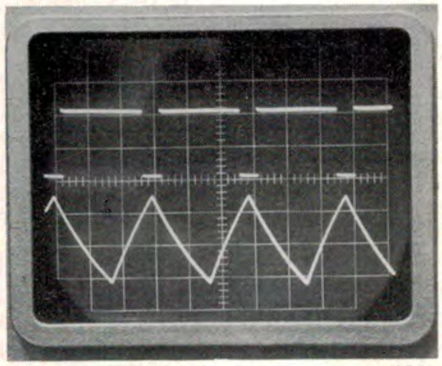
What's a walkaround throttle? It's a throttle you can walk around with. It's fun to be able to follow a train around a layout, controlling it as you go. This new controller circuit has provision for such a walkaround throttle which includes a forward/reverse switch. If you have a large layout you could install sockets at several points so that the control lead is not unnecessarily long.

A local/remote switch on the Train Controller selects either the main controller or the walkaround throttle function.

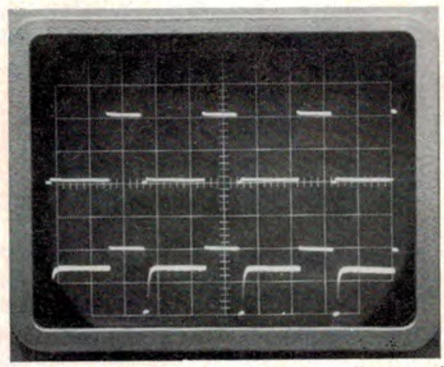
A walkaround throttle is particularly handy when you are carrying out fiddly shunting manoeuvres. (In fact, railway modellers often refer to their shunting yards as fiddle yards).

Power output

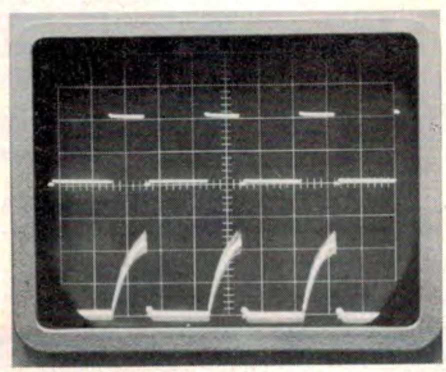
How many locos can the Controller power at the same time? Railway modellers often wish to double-head or even triple-head locos to pull long trains. The answer to the question depends on the locos. If they have inbuilt lighting or smoke generators then two locos is probably the limit before the short-circuit indicator will sound. If the locos do not



Upper trace: output voltage at pin 1, IC2a; 10V/div. Lower trace: ramp voltage at pin 6, IC2b; 1V/div. Timebase: 2ms/div.



Upper trace: output voltage at collector of Q2. Lower trace: voltage across loco motor. Both traces 10V/div; 2ms/div.



Upper trace: output voltage at collector of Q2; 10V/div. Lower trace: loco current across 0.1Ω sense resistor; 50mA/div.

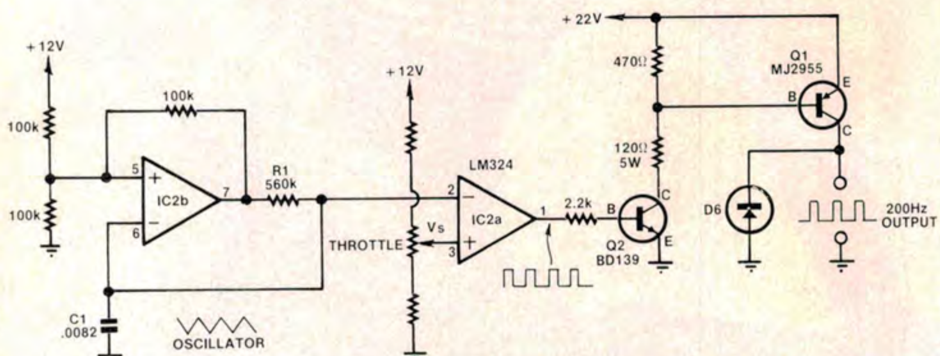


Fig. 2

Fig.2: basic train controller circuit. IC2b works as a triangle wave generator while comparator IC2a delivers square wave pulses to buffer stage Q2 and Q1.

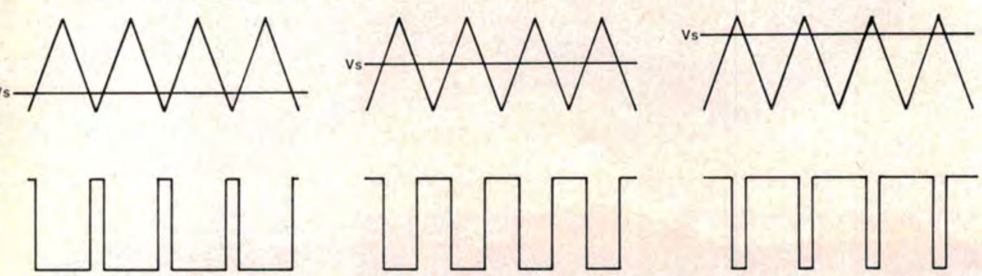


FIG. 3 (a) (b) (c)

Fig.3: how the output of comparator IC2a varies. The control voltage (VC) is set by the throttle and compared with the triangular waveform from the oscillator.

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have lighting or smoke, three can be powered.

As an additional feature the controller has fixed 12VDC and 15VAC outputs which can be used for powering point motor circuits and layout lighting. However, we should make the proviso that if these outputs are heavily loaded the controller capacity will be correspondingly reduced. This is fixed by the transformer rating which is 30VA.

Pulse width modulation

Over the years a number of electronic circuits have been devised to overcome the difficulties of slow speed running referred to earlier. These have included thyristor and transistor controllers.

Although these are a big improvement on simple rheostat (variable resistor) controllers they still leave a lot to be desired when it comes to starting and slow speed running. This is because they use the voltage waveform derived from a full wave rectifier and low voltage transformer, from the 50Hz mains supply. This waveform is depicted in Fig. 1(a) as a typical full-wave rectified sinewave.

Fig. 1(b) shows the output of a typical transistorised controller at a low speed setting and Fig. 1(c) shows the output of a thyristor controller for the same low speed setting. It can be seen that the peak voltage of both waveforms is quite low and would be inadequate where there are problems of contact resistance.

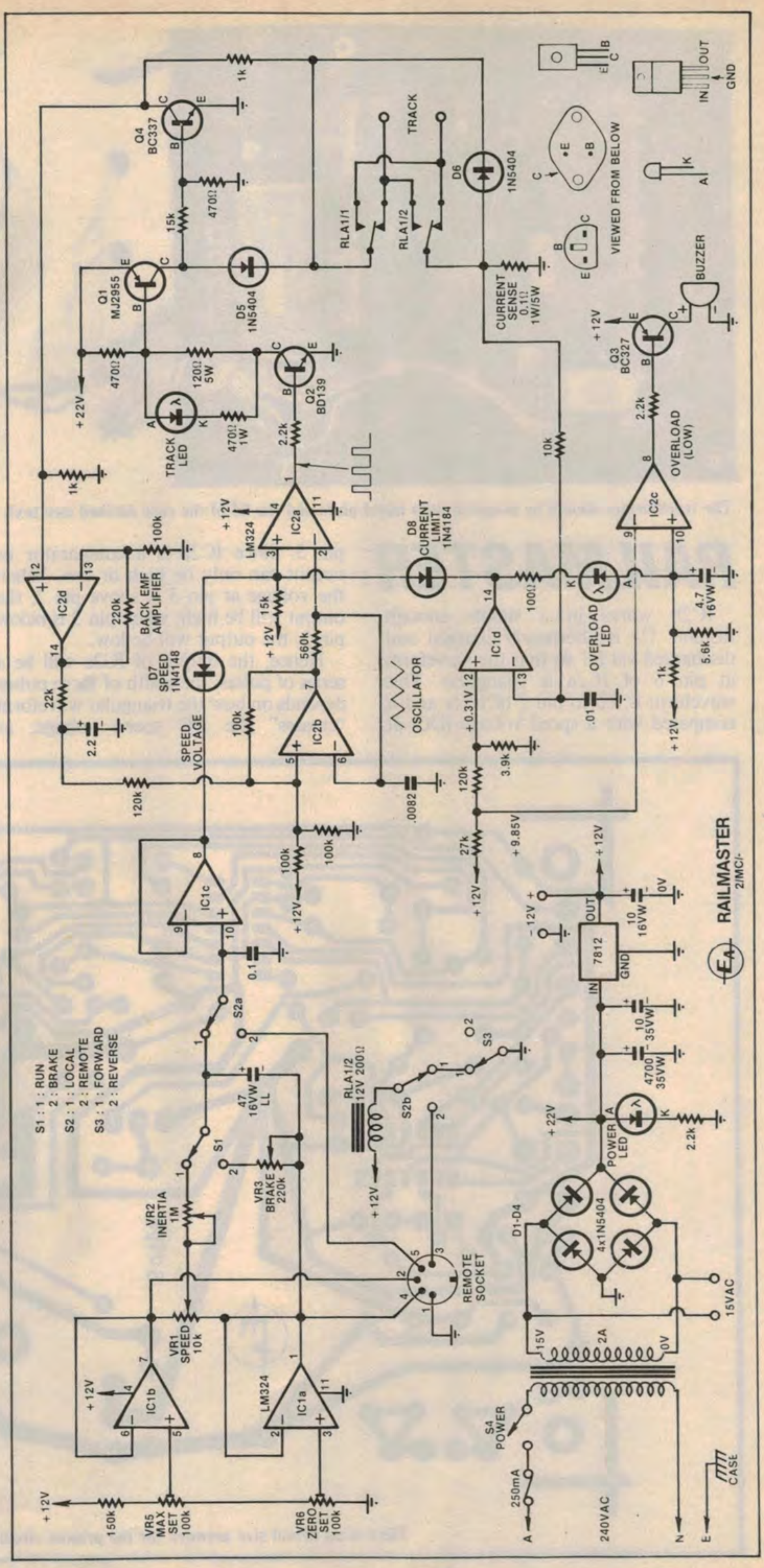
The solution is to supply the loco with the full voltage output regardless of the speed setting; the idea is to feed a series of pulses to the loco and vary the width of the pulses to vary the power delivered. The waveform is depicted in Fig. 1(d).

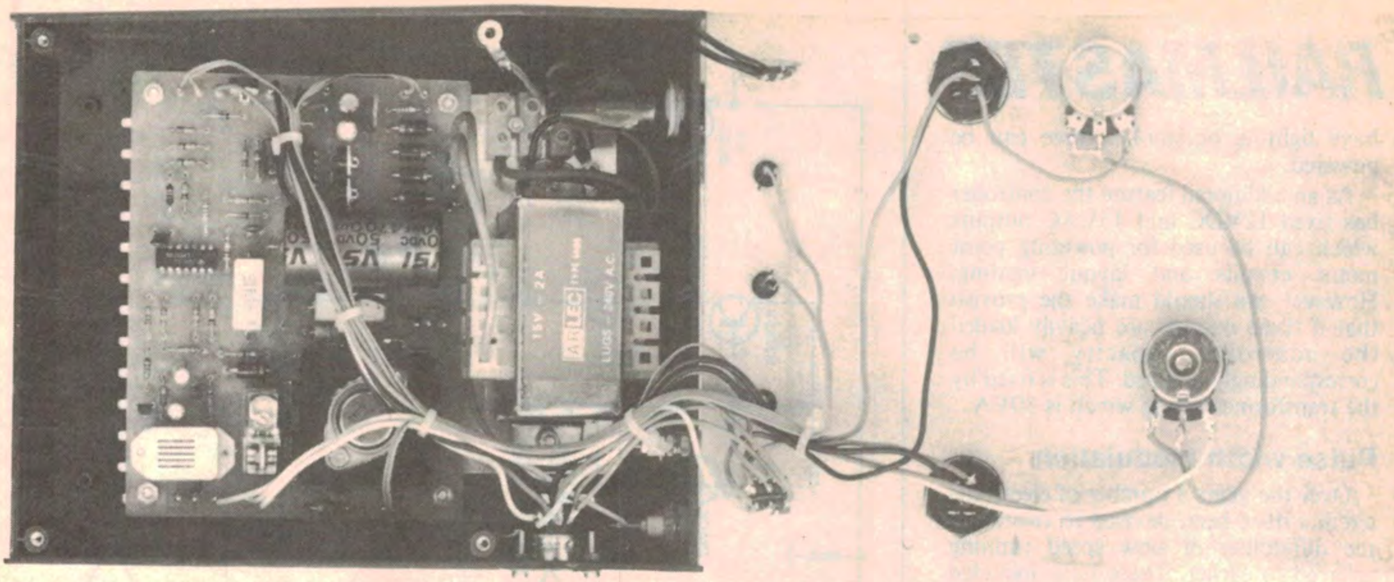
The advantage of a pulse width modulation circuit is that, even at low power settings, the voltage applied to the track is high. In this circuit, the track voltage is about 20 volts DC, depending on the load conditions. Such a high voltage is better able to overcome contact resistance and thus give much better low speed running.

Nor is the frequency of the pulses set by the 50Hz mains supply. Instead it is set at about 200Hz which gives much smoother operation with most motors.

Operating principles

Rather than try and glean the operating principles from the complete circuit, let us extract the core components instead. These are depicted in Fig. 2 and comprise IC2a and IC2b. IC2b is an op amp wired as a Schmitt trigger oscillator while IC2a is wired as a comparator.





The transformer should be mounted on a metal plate and the lid of the case earthed (see text, page 49).

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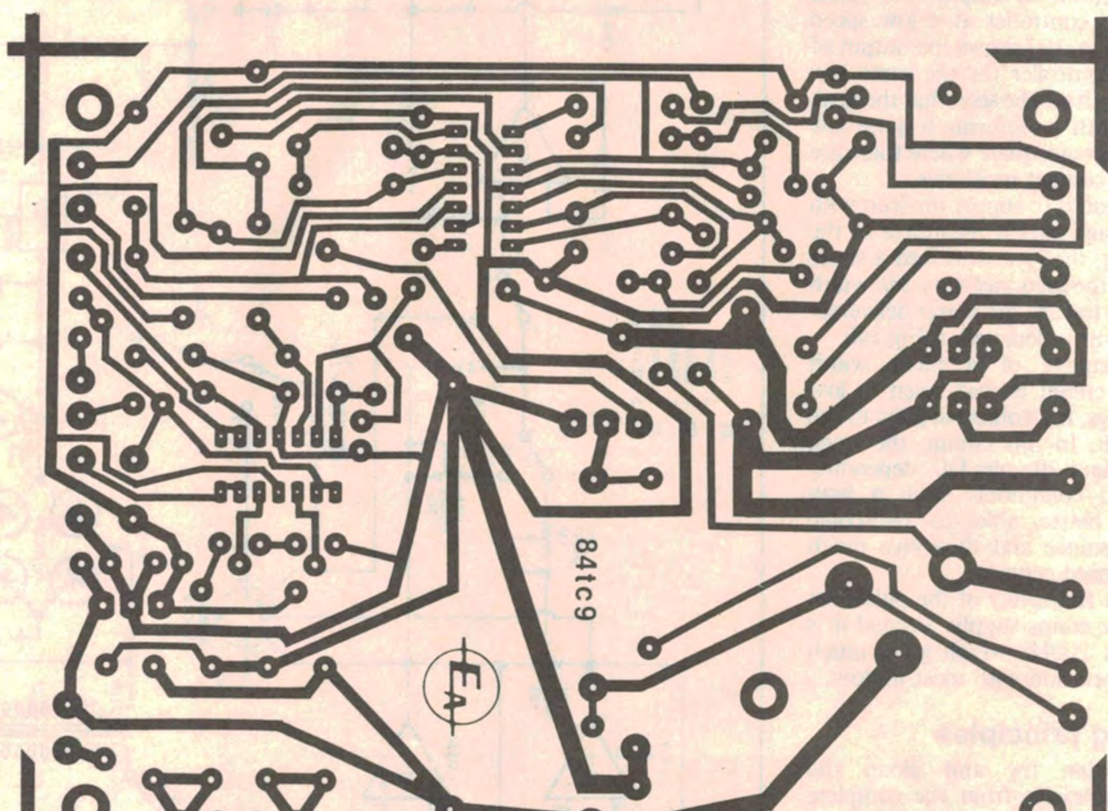
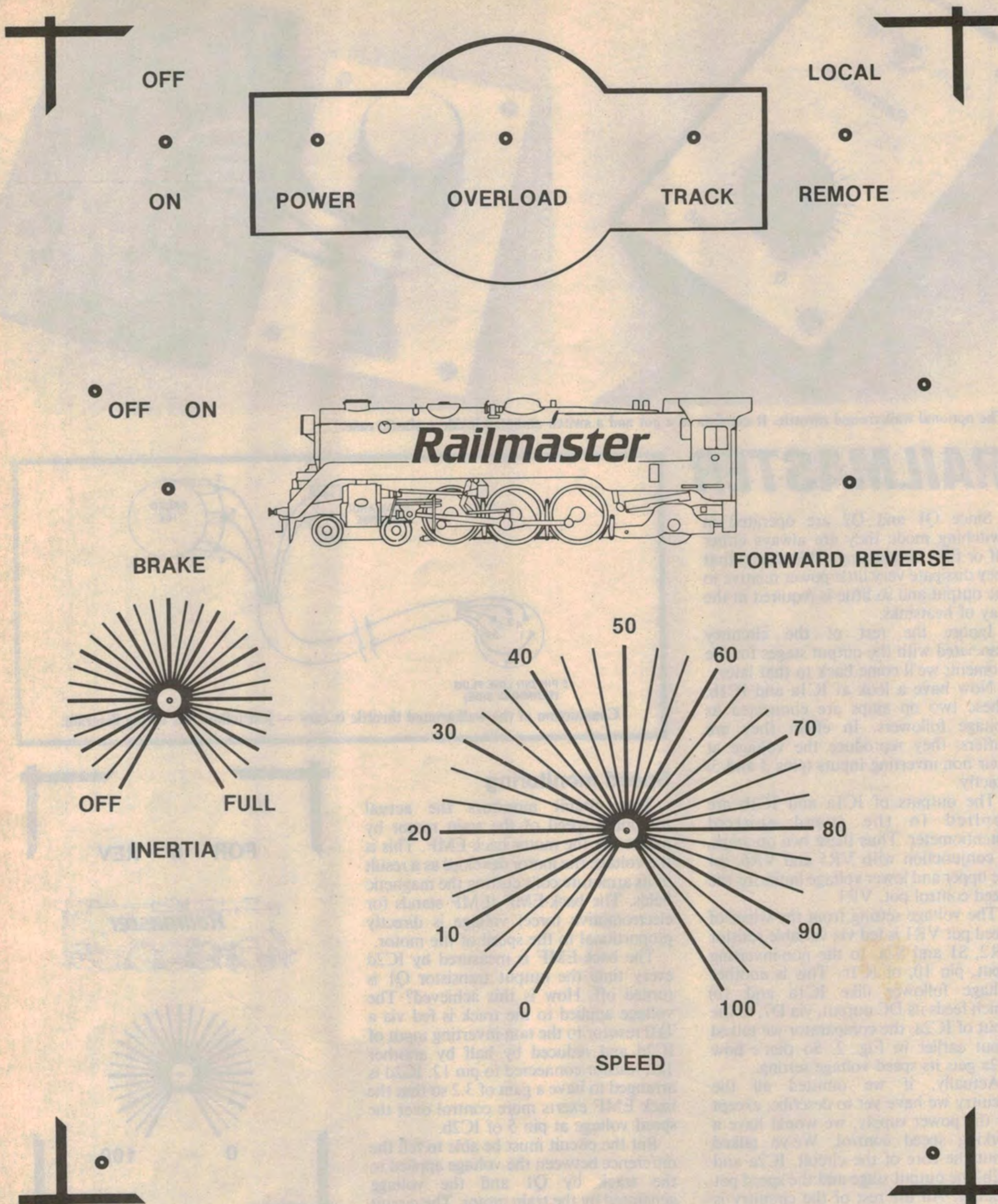
IC2b works in a simple enough fashion. C1 is alternately charged and discharged via R1 so that the waveform at pin 6 of IC2a is triangular. This waveform is fed to pin 2 of IC2a and is compared with a speed voltage (DC) at pin 3. Since IC2a is a comparator its output can only be high or low. When the voltage at pin 3 is above pin 2, the output will be high; when pin 3 is below pin 2, the output will be low.

Hence, the output of IC2a will be a series of pulses; the width of these pulses depends on how the triangular waveform "crosses" the DC speed voltage, as shown in Fig. 3. Therefore, when the speed voltage fed to pin 3 is high, the output is high most of the time and we get wide pulses. When the speed voltage is low, we get narrow pulses. These pulses are fed to the motor via a transistor buffer stage Q1 and Q2.

D6 protects Q1 against the nasty spikes generated by the train motor each



Here is an actual size artwork for the printed circuit board.

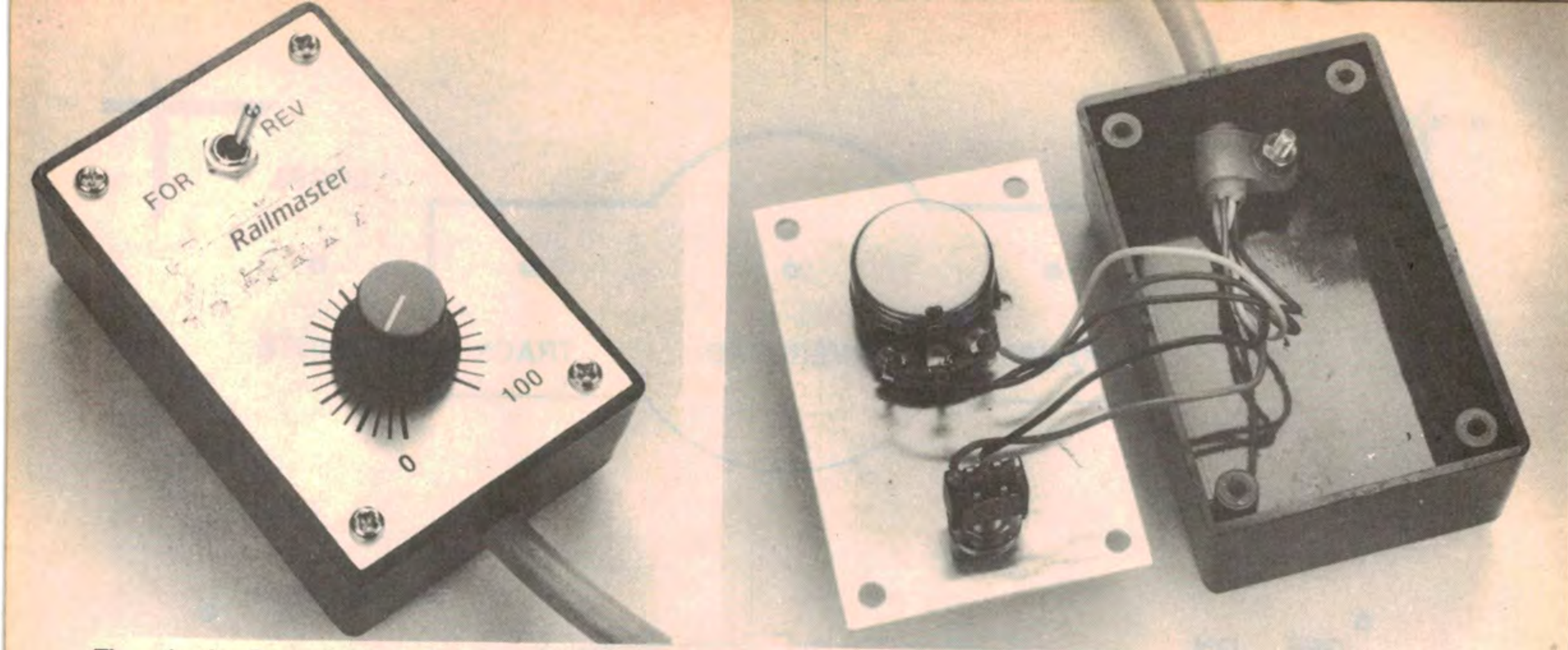


Actual size front-panel artwork. Ready-made PCBs and panels are available from parts retailers.

time Q1 is turned off. These spikes are clamped by D6 to the 0V rail.

Relating all this to the main circuit diagram may seem a big jump but don't be overawed. IC2a and 2b are slap bang in the middle of the circuit diagram, performing the same function.

The output of IC2b is fed via a 2.2kΩ resistor to Q2 which is turned on or off by the voltage pulses. In turn, it turns Q1 on or off. So the voltage pulses are fed from the collector of Q1, via D5 and the relay, directly to the rails and eventually to the train motor. Q1 and Q2 can be regarded as a switching power amplifier.



The optional walkaround throttle. It consists of a pot and a switch mounted inside a plastic case.

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Since Q1 and Q2 are operated in switching mode they are always either off or fully conducting. This means that they dissipate very little power relative to the output and so little is required in the way of heatsinks.

Ignore the rest of the circuitry associated with the output stages for the moment; we'll come back to that later.

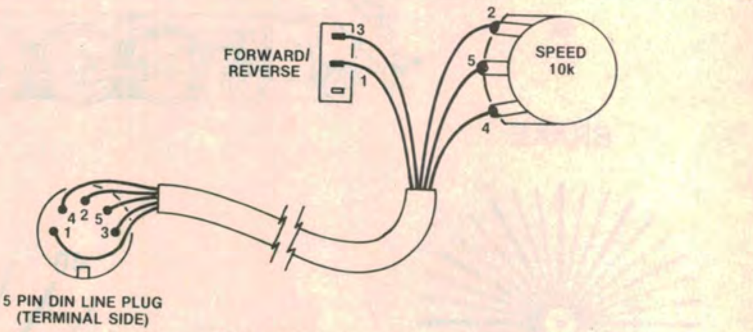
Now have a look at IC1a and IC1b. These two op amps are connected as voltage followers. In effect they are buffers; they reproduce the voltage at their non-inverting inputs (pins 3 and 5) exactly.

The outputs of IC1a and IC1b are applied to the speed control potentiometer. Thus these two op amps, in conjunction with VR5 and VR6, set the upper and lower voltage limits for the speed control pot, VR1.

The voltage setting from the wiper of speed pot VR1 is fed via variable resistor VR2, S1 and S2a, to the non-inverting input, pin 10, of IC1c. This is another voltage follower (like IC1a and 1b) which feeds its DC output, via D7, to the input of IC2a, the comparator we talked about earlier in Fig. 2. So that's how IC2a gets its speed voltage setting.

Actually, if we omitted all the circuitry we have yet to describe, except for the power supply, we would have a working speed control. We've talked about the core of the circuit, IC2a and IC2b, the output stage and the speed pot circuitry. All the rest of the circuitry is really gilding the lily, but it makes it work a lot better.

A LED connected across the 120Ω collector load resistor for Q2 gives a visible indication of the voltage being applied. It is quite progressive in effect and a useful feature of the controller.



Constuction of the walkaround throttle is easy — just follow this wiring diagram.

Speed monitoring

This circuit monitors the actual rotational speed of the train motor by measuring the motor back-EMF. This is the voltage the motor develops as a result of its armature coils cutting the magnetic fields. The back-EMF (EMF stands for electromotive force) voltage is directly proportional to the speed of the motor.

The back-EMF is measured by IC2d every time the output transistor Q1 is turned off. How is this achieved? The voltage applied to the track is fed via a 1kΩ resistor to the non-inverting input of IC2d and reduced by half by another 1kΩ resistor connected to pin 12. IC2d is arranged to have a gain of 3.2 so that the back EMF exerts more control over the speed voltage at pin 5 of IC2b.

But the circuit must be able to tell the difference between the voltage applied to the track by Q1 and the voltage generated by the train motor. The circuit achieves this by turning Q4 on whenever Q1 is on. This means that whenever Q1 is applying voltage to the track, Q4 is turned hard on and thereby prevents any voltage being fed to the input of IC2d.

Diode D5 is required to isolate the collector of Q1 from the train load. If D5 was not included, Q4 would be turned on by the motor back-EMF and thus defeat its purpose. The result of Q4 turning on

This artwork for the walkaround throttle fits a standard UB5 zippy box (28 x 54 x 83mm).

Continued on page 47

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whenever Q1 turns on is that the output of IC2d is a pulse waveform. This is filtered to produce pure DC by a 22kΩ resistor and 2.2μF capacitor.

This DC voltage is then fed to the non-inverting input, pin 5, of IC2b, to effectively raise its DC reference voltage level. This has the effect of raising the overall DC level of the triangular voltage waveform at the output of IC2b, pin 7. When this "raised" triangular waveform is fed to the comparator, IC2a, the effect is to reduce the pulse width output.

So that is how the circuit provides good speed regulation. It measures the back-EMF of the motor; if the speed is tending to rise the pulse width output will be reduced and so bring the speed back to the desired setting.

Short circuit protection

As already mentioned, there are several short-circuit protection features. Two op amps are involved: IC1d and IC2c, both wired as comparators.

The current pulses drawn by the motor are sensed by the 0.1Ω/5W resistor connected to the anode of D6. These pulses are fed to IC1d via a 10kΩ resistor and filtered by a .01μF capacitor to obtain a small DC voltage at pin 13.

This voltage is compared with the voltage appearing at pin 12 of IC1d. Normally, pin 12 will be above pin 13 and the output of IC1d will be high and so nothing will happen. But if an overload occurs, large pulses will occur across the 0.1Ω/5W resistor. This will develop a relatively large voltage at pin 13 and so the output of IC1d will suddenly go low. This does several things:

First, D8 conducts and pulls down the reference voltage on pin 3 of IC2a. This greatly reduces the output pulse width and thereby prevents very large short-circuit currents from flowing. Note that this does not totally remove the output from the track — it reduces it.

Second, IC1d turns on the overload LED which also discharges the capacitor at pin 10 of IC2c. This causes the output of IC2c to go low and turn on Q3 which energisers the buzzer, a piezolectric device with inbuilt circuitry.

Inertia and braking

Now let's return to the speed control potentiometer and associated circuitry. Inertia is provided by VR2, a 1MΩ pot wired as a variable resistor. Depending on the setting of VR2, the voltage from the speed pot VR1 will build up gradually on the 47μF capacitor and so too will the speed voltage from IC1c which is fed to IC2a.

Braking is provided by VR3 and S1. When S1 is switched into circuit, VR3 discharges the 47μF capacitor at a rate dependant on its setting.

Note the use of a relay to provide the forward and reverse function. If it were not for the need for a walkaround throttle, the relay could be replaced by a double-pole double-throw switch (DPDT) of suitable current rating. Since a relay is used, there are two forward/reverse switches, S3 on the main control console and a remote SPST (single-pole, single throw) switch in the walkaround throttle. One or other of these switches is selected by S2b.

> We estimate the current cost of parts for this project to be
>
> **$75 – $80**
>
> This includes sales tax.

Walkaround throttle

The walkaround throttle or handheld speed control is brought into circuit by the double pole switch S2 (local/remote). S2a switches out the inbuilt speed controls (ie, VR1, VR2 etc) and switches in the external speed control which may be a simple pot like VR1 or may duplicate the entire inertia and braking features.

Note that if more than one walkaround throttle socket is required on the layout they can be simply wired in parallel.

Power supply

The power supply uses a mains transformer with a 15V/2A secondary to drive a bridge rectifier and 4700μF filter capacitor. This provides about 20 to 22VDC, depending on the total load, and this unregulated DC is fed to the output stage Q1 and to a three-terminal 12V regulator. The 12V DC feeds all the circuitry with the exception of Q1.

Op amp peculiarities

Before leaving the circuit description we should point out a feature of the op amps used, the LM324 quad types. This quad op amp has been used for several reasons. First, its inputs can be connected directly to the negative supply rail. This feature is used in the current sensing amplifier IC1d and in the back-EMF amplifier, IC2d.

Second, when operated as a comparator, the output of the op amp

PARTS LIST

1 PCB, code 84tc9, 107 × 140mm
1 Scotchcal front panel, 216 × 166mm
1 console box 170 × 214 × 32 × 82mm (W × D × HF × HR)
1 mains transformer, 15VAC at 2A, Arlec 5504 or equivalent
1 relay, 12V/200ΩDPDT 5A contacts (DSE Cat No. S-7130)
2 paddle switches (DSE S1393)
1 SPDT mains toggle switch
1 DPDT toggle switch
1 3AG panel mount fuse holder and 250mA fuse
6 binding post terminals, 2 green, two white, 1 black and 1 red
1 3-way mains terminal block
1 1-metre length of mains cord and plug
1 mains cord grommet
1 mains cord clamp
1 mini buzzer
1 heatsink, 50mm square × 25mm high drilled for TO-3
1 6-pin panel mount DIN socket
2 knobs
2 solder lugs
4 6mm standoffs
1 piece of aluminium sheet, 120 × 60mm
25 PC stakes

Semiconductors
3 5mm red LEDs plus bezels
2 LM324 quad op amps
1 7812 3-terminal positive 12V regulator
6 1N5404 3A rectifier diodes
2 1N914, 1N4148 diodes
1 MJ2955 PNP power transistor
1 BD139 NPN transistor
1 BC327 PNP transistor
1 BC337 NPN transistor

Capacitors
1 4700μF/35VW axial electrolytic
1 47μF/16VW RBLL (low leakage) electrolytic
1 10μF/35VW PC electrolytic
1 10μF/16VW PC electrolytic
1 4.7μF/16VW PC electrolytic
1 2.2μF PC electrolytic
1 0.1μF metallised polyester
1 .01μF metallised polyester
1 .0082 metallised polyester

Resistors (¼W, 5% unless stated)
1 × 560kΩ, 1 × 220kΩ, 1 × 150kΩ, 2 × 120kΩ, 4 × 100kΩ, 1 × 27kΩ, 1 × 22kΩ, 2 × 15kΩ, 1 × 10kΩ, 1 × 5.6kΩ, 1 × 3.9kΩ, 2 × 2.2kΩ, 3 × 1kΩ, 2 × 470Ω, 1 470Ω 1W, 1 × 120Ω 5W, 1 100Ω, 1 × 0.1Ω 5W, 1 × 1MΩ linear potentiometer, 1 × 10kΩ wirewound potentiometer, 1 × 220kΩ miniature vertical trim pot, 2 × 100kΩ miniature vertical trimpots,

Miscellaneous
Screws, nuts, heatshrink, tubing, solder, assorted hook-up wire.

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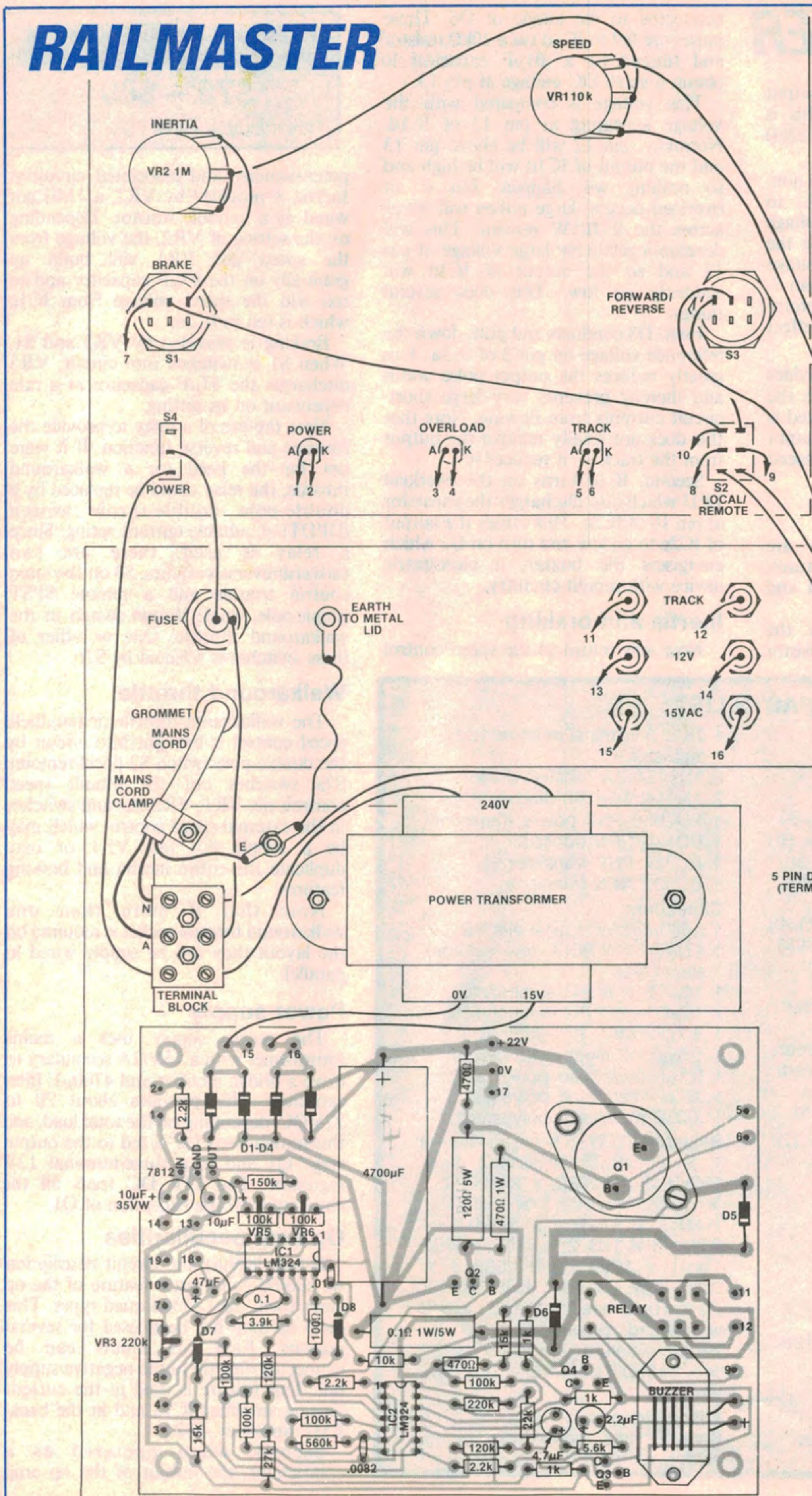

Parts overlay and wiring diagram for the Railmaster train controller. Take care with the mains wiring.

will go to either rail potential. This feature is used in the overload buzzer driver, IC2c and in the driver for Q2, IC2a.

Myths of pulse power

Some rail modelling enthusiasts are not keen on the concept of "pulse power". They claim that it makes motors run hot and can lead to burnouts. In theory this is right but in practice it does not matter.

The torque developed by a permanent magnet motor is directly proportional to the average current whereas the heat dissipation in the motor is proportional to the RMS current. On this basis, the amount of heat produced at a given speed setting on a pulse DC supply will be higher than for the same speed setting from a pure DC supply.

However, virtually all commercial train controllers do not use pure DC. They use rectified but unfiltered DC. So the difference in motor power dissipation between an unfiltered DC supply and this pulse-width modulated supply is small. Nor is there any likelihood of motor burnout unless the gear system is binding. Under this latter condition there is a danger of motor burnout even with a pure DC supply.

Do not apply full power to a loco which is stalled. (Sometimes the gears do bind). This would invite a motor burnout.

Some commercial train controllers have had a "pulse power" feature whereby the motor is fed with half-wave rectified DC. This is a crude system whereby the peak voltage applied to the motor is higher for a given setting than for a full-wave rectified DC. This system also makes the motor and gearbox very noisy.

The Railmaster pulsed output will become audible with some locos but this depends on the quality and amount of wear in the motor and gearbox train. Sometimes the loco can be adjusted to minimise this noise which is really only evident at low speed settings.

Construction

The Railmaster controller is housed in an attractive sloping front case with aluminium lid. We have produced artwork for the lid which features a representation of one of the most popular steam locos, the NSW "Pacific" class C.38. Lest readers in other states feel disgruntled, we should point out that all Australian states had Pacific class locos at some time during the steam era.

The console case is available in blue, grey or black and measures 170mm wide and 214mm deep. It is available from Jaycar stores.

All the circuitry, with the exception of switches, potentiometers and LEDs, is accommodated on a printed circuit board measuring 107 x 140mm and coded 84tc9.

No special procedure need be followed when assembling the PC board although we suggest that small components be installed first. Leave the larger components such as the 4700μF filter capacitor, buzzer, relay, power transistor and heatsink till last.

Note carefully the orientation of diodes, transistors, electrolytic capacitors and semiconductors when they are being installed. Note that D5 and D6 should be 1N5404 types, to give a generous current rating.

The two wirewound 5W resistors should be raised slightly off the PC board to avoid the possibility of charring if they are overheated. Normally this should not happen.

The buzzer may be secured by two small self-tapping screws or with double-sided adhesive tape.

No heatsink is required for the three-terminal regulator if it is merely used to power the internal circuitry of the controller. If additional load is connected, a flag heatsink may be required.

We suggest the use of PC stakes to make the job of connecting leads to the board easy.

The MJ2955 must be fitted with a heatsink. We used a multiple-finned type which is supplied ready drilled for TO-3 transistors. No mica washer is required but heatsink compound should be smeared on the transistor mounting surface before assembling.

When the PC board is completely assembled, your attention can be turned to the console box. This should be drilled to take all the hardware before the components are installed. Similarly, the Scotchcal panel, if used, should be attached to the lid before the panel is drilled.

The three LEDs were affixed to the panel using bezel mounts made for the purpose. The large paddle switches are available from Dick Smith Electronics (Cat No. S-1393). We used a red paddle for the brake switch and a white paddle for the forward/reverse switch. They have the advantage that they are easy to mount, requiring a round hole with a small locating notch.

We used a wirewound pot for the main throttle control. This has a smaller "dead band" than carbon pots and thus gives a more progressive control action.

The transformer should be mounted on a metal plate measuring about 120 × 60mm. The three-core power flex should be brought through a grommetted hole in the rear of the console and secured with a suitable cord clamp. The active and neutral wires should be terminated in a three-way terminal block, as per the wiring diagram. The mains earth wire should be connected to the metal plate mentioned above and the case lid.

Sleeving should be pushed over the mains fuseholder after wiring it. This prevents accidental contact with the mains while the unit is being worked on. All the rest of the wiring details can be obtained from the accompanying wiring diagram.

Setting up

When the assembly has been finished and double-checked you are ready to apply power but don't, whatever you do, connect a train at this stage.

Check all the voltages shown on the circuit diagram and verify that they are in the right ball park, ie, within ±10% of marked values.

Now advance the throttle fully clockwise and adjust VR5 to give a DC voltage reading (using an analog or digital multimeter) across the output terminals of no more than 12V DC. Note that this is actually a pulsed DC waveform with a peak value of about 20V DC.

Now rotate the throttle anticlockwise and check that the output voltage decreases progressively towards zero. The actual zero setting can be adjusted by VR6. This should be adjusted so that, with the throttle at minimum setting, there is a very slight voltage of, say, 0.5V DC. This value can be decided finally when you run trains with the controller.

All the other controller features should be checked, including the short circuit protection. Even on brief short circuits the buzzer should sound and the overload LED should light.

Note that the buzzer will sound briefly at switch-on because of the charging time for the 4.7μF capacitor at pin 10 of IC2c.

As an audible check on the operation of the Railmaster you can listen to its output via a loudspeaker and a 100Ω resistor. Do not connect the loudspeaker directly across the output otherwise you will be deafened by the racket. You will also run the risk of damaging the voice coil.

At low throttle settings the speaker should give out a "thin, spiky" sound which becomes louder and more mellow as the throttle is advanced.

Now connect the unit to the track of your layout and run your trains to your heart's content.