These two slot car controllers will put more zap in their zip

Jonathan Scott

A spare $15 and an idle Saturday afternoon led Jonathan and a few 'assistants' into the labyrinthine maze of the world of slot cars. Your basic slot car set is so basic that Jonathan thought the application of a few engineering and physics degrees, computers, components, electricity and trials would help. These two projects are the result!

WELL, let's not beat about the bush. Slot cars are fun. The genesis of this project was the purchase of a cheap set and the realisation that there was much room for improvement in the whole thing, especially the 'electronics'. Since then, we have built several controllers, purchased an alarming length of track, bought and modified too many controllers and cars, and generally had a load of fun! Here are the fruits of the labours, both in the form of electronic projects and in some discussion of what you can do to get the best performance from even a cheap set of slot cars.

Shortly after the infection set in, the author's household was to be found in a huddle with a couple of computer programmers, another engineer and a couple of PR people. A list was made of all the things that anybody could possibly want out of a given car set, and all the things that could possibly be desired in a controller. Argument ensued. The fearless editor of this magazine would argue for cost effectiveness; another for a no-holds-barred approach. Thursday nights were set aside for the various parties to meet and report ... After preliminary models of controller had been made and *thoroughly* evaluated, it was conceded that all the aims could not be realised in the one type of controller. Hence, two lines were followed and we have the ETI-824 Slot Car Power Supply and the ETI-825 Slot Car Controller. We also have a lot of tips for optimising your set itself, and we trust that these are sufficient to turn a couple or three $15 sets into a first-class slot car racing set-up.

We also present several suggested layouts, and suitable constructs and axioms for the optimisation of your own layouts.

In the course of this research use has been made of calculators, programmable calculators, desktop computers, plotters, engineering degrees, physics degrees, computer science degrees, a mound of components a lot of paper and a *hell* of a lot of electricity — so be warned that one can get pretty involved. Closet racers, prepare for exposure!

If you are not sure that you are a fanatic, the ETI-824 is probably what you require. It is relatively simple to construct, cheap, and easy to get going. It is basically a replacement for whatever you are using to power your set now. It offers operation from ac or dc, car battery, model train transformer, doorbell transformer or a range of typical project transformers or power supplies. It gives independent protected supplies for each lane, adjustable for most car set types available.

If you're after something really exciting, then the ETI-825 is *it*. This is not a project for beginners. It gives independent, protected supplies for each lane. It can operate in voltage and current modes. It has powered braking, controlled overshoot and fuel tank simulation. It has fault and fold warnings, does not load the hand controllers, and can handle a wide range of maximum torques on sets of 4.5 to 12 volt rating. If you are really enthusiastic or you have just blown $100 to $300 on a Scalextric set, this is the one for you.

Slot cars and tracks — a dissertation

In practice, the basic rheostat in series with the track (car) is not at all a bad compromise. For a given control setting the car accelerates fairly rapidly towards a final speed. This is because torque is proportional to current (in the permanent magnet motors used) and current is a maximum when the car is standing still; as the engine RPM increase so does the back emf, or rather the internal emf of the engine, which represents the mechanical power output in the mathematical model of the engine. As this rises, the voltage drop across the control resistance decreases, and so does the current, the torque and the acceleration. (Figure 1.) This gives a very car-like performance for a minimum of parts.

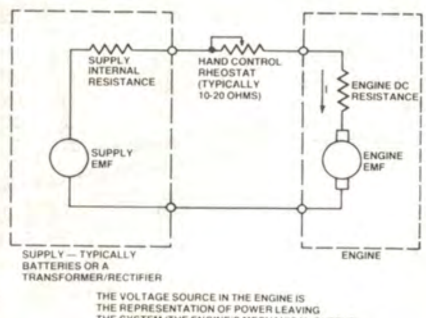


Figure 1. **Circuit model, slot car set.**

The final speed is fixed by the minimum dc path resistance, the available supply voltage and the amount of friction and other losses in the car. Overall performance includes cornering ability, which is affected by the car weighting and wheel

FUN!
FUN!
FUN!

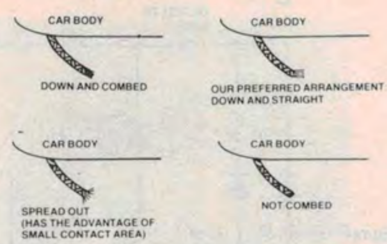


Figure 2. **Arrangements for the contact brushes.**

type and condition. Attention to these factors will effectively 'tune' the car.

If you think you have a car set with one car better than the other, the chances are that checking the above things will reveal a silly fault in one car, and you will end up, after some tinkering, with two improved cars. Let us go through a typical tuning up of a small car, such as those in the $14-$15 sets. We will start at the car and end up at the controller.

Firstly, the wheels. It is important to check that these do not have some wobble or severe out-of-roundness. The tyres should be slightly rough, so that they grip, and fairly flat at the point of contact with the track, so that they do not bounce at all when the wheel rotates quickly. See that the tyre is fitted straight, if you have removable tyres, and that the wheels are squarely mounted on the axles.

Next it is worth opening the car up. Check that the axles and cogs are free of dust and carpet fluff. A very small touch of light machine oil on bearings and cogs is a good idea, though not entirely necessary. DON'T oil the tyres or any exposed bit of the car. See that the cogs mesh neatly and fairly silently. On an expensive car, such as Scalextric, these things should be in order already.

Now let's look at the brushes. These are, in our experience, the most vulnerable point in the car. Brush friction usually accounts for 90% of car performance problems. The brushes should be clean and dust free. There will be some unravelling of the braid. This is good. The ends of the brushes seem to benefit from a bit of 'combing'. This can be done with a small jeweller's screwdriver, a scriber or scalpel. About three to five millimetres of combed braid is nice. Finally, the shape of the brushes is important. There are several ways to bend the brush, and you should experiment to see which is better. We used the down-and-then-straight pattern. (See Figure 2.)

Next, the minimum rheostat resistance is important. Some controllers have such resistive leads that the series resistance never gets below an ohm or two. If you have a protected *voltage* source this is a disadvantage.

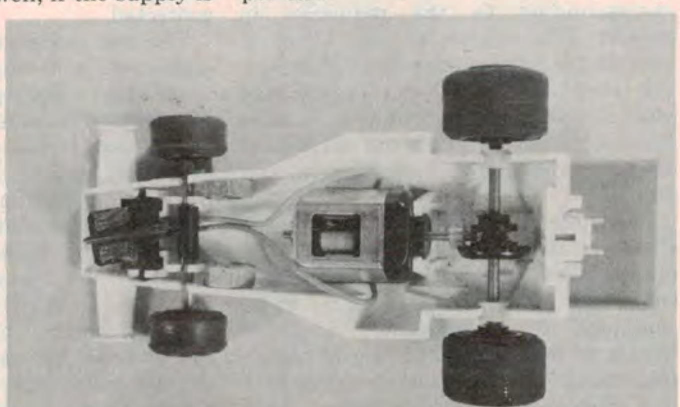
Finally, the supply potential is critical. If it is too high, the control becomes too critical and it is too hard to get just the right amount of power. It cannot be too low, of course, as you would not get anywhere near enough power to realise the maximum speed of which the car is capable without crashing — which takes out all the skill. As well, if the supply is not regulated, one car can interact with the other; the extreme of this is seen when one car suddenly 'shutting down' causes such a surge that the other spins off the track. (It can happen!)

One further factor is worth discussing, with respect to the car: weighting. This is an area where you are going to have to experiment for yourselves. Most cars have spaces inside the plastic shells. Nuts or other pieces of metal can be secured in these spaces with a little Blutac, or similar poster adhesive, to add weight. Weight will reduce the acceleration for a given power, but it will increase wheel adhesion on the road. It will also change the handling, possibly making spinouts more likely, and reduce the period of time required between brush realignments. In our experience, a couple of 2 BA or similar nuts in a small car, near the middle and low down, are quite beneficial if you have adequate power, as with our controllers.

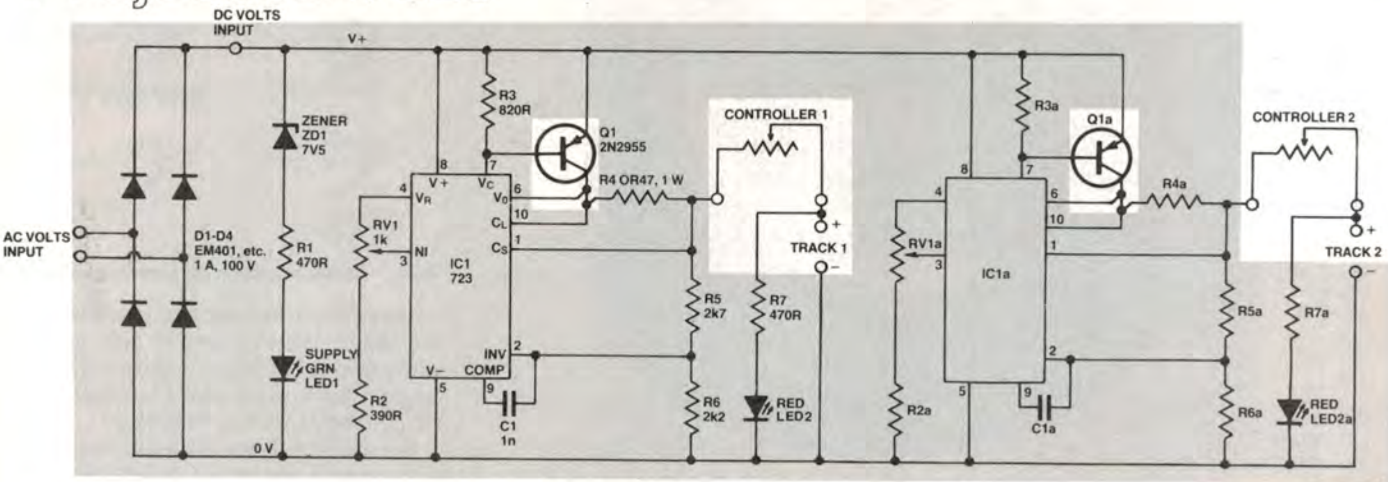
The 824 supply

As we have said, all that is necessary to achieve quite adequate performance is a voltage supply for each car. It needs to be the right voltage, and each car should not interact via the supply with the others. The ETI-824 is this. It is versatile in that it will operate from whatever source of voltage you have available; it simply needs to deliver at least three volts more than the cars need (average) and to be able to supply the maximum current, typically ½ to 1 amp per car. ▶

Plain and simple, the ETI-824 slot car supply.



Example of how to weight a car with two nuts stuck under the body.



HOW IT WORKS — ETI 824

This is basically a crude series voltage regulator, based on the 723 variable regulator IC, that supplies power to the rheostat in the hand controller. The rheostat is in series with the motor in the car, via the track connections. The voltage supplied to the controller and car can be preset anywhere between about 3 V and about 12 V.

The circuit is designed to be powered from a variety of sources — bell transformer, car battery, plugpack, model train transformer or conventional 240 Vac to 15 V/1-2 A transformer — whatever is available. If the source is ac, such as that direct from a transformer secondary, the diode bridge rectifier formed by D1-D4 rectifies this, supplying unfiltered dc to the circuit. These four diodes may be deleted if the unit is run from a dc supply, or they may be left in, provided the dc supply you use exceeds the voltage required by the car by about four volts. Leaving D1-D4 in place has the advantage that the device can be run off ac at any time, and when running it off a dc supply it can be connected either way round as polarity doesn't matter and no possible damage can be occasioned by accidental reverse polarity connection.

To indicate that a supply of sufficient voltage is connected to the circuit, ZD1, R1 and LED1 make a simple indicator. When the supply voltage between the V+ and 0 V rails is high enough to overcome the zener voltage plus the voltage drop across LED1 and R1 at a current of a few milliamps, LED1 will light. You need to produce a minimum of about 10 V between the V+ and 0 V rails. Note that while this is sufficient for the IC regulator circuit to operate, it may not be enough for some slot car sets. For those that require 12 Vdc, at least 14 V between the V+ and 0 V rails will be required. An ac input of up to 24 Vac (RMS) may be used.

Following the rectifier and indicator sections of the circuit is the regulator, which consists of IC1, Q1 and associated components. Each lane in the slot car set should be supplied with a separate regulator circuit to ensure that one lane does not interfere with the operation of the other, especially in the event of a short circuit due to a crash or a fault, etc. Two regulator sections may be run from one rectifier section.

The 723, IC1, controls the base current of Q1 so as to deliver the required voltage to the hand controller, except when the external circuit (controller and car motor, via the track) attempts to draw current above about 1.2 A. In this case, the 723 reduces the voltage supplied to the external circuit to prevent possible damage.

The output voltage is set by RV1. By adjusting this preset control, the voltage delivered to the controller and external circuit may be varied anywhere between about 3 V and about 12 V maximum. This should be adjusted to suit the particular slot car set you are using by setting its position so as to deliver a suitable amount of acceleration to the car when the hand controller is set full on.

LED2 indicates that voltage is reaching the track. This is useful to check correct operation and for detecting shorts on the track.

The 825 controller

For superior performance, the controller can have several 'extras'. This is the ETI-825. Firstly, this gives you *fuel tank simulation*. This means that the control box has a meter which represents fuel in the car. A button 'refuels' the car, provided it is stationary. When it has petrol, you can go again. As the petrol is used up the car gets more acceleration, corresponding to the reduction in weight. The degree of the effect is presettable by a resistor (R107-R207 for the second car). It is rather exaggerated with the value given, but this is more fun. Of course, if you run out of fuel, the car slows down and finally coughs to a stop.

Next, the 825 offers *controlled overshoot*. If the output momentarily exceeds the level that your hand controller commands, the car responds more 'snappily'. This accelerates it a bit harder at first, corresponding to 'dropping the clutch', and brakes hard when it is slowing down corresponding to hard braking. You can even lock up, if you are too hasty!

The controller also informs you if it is folding, such as when the track is short-circuited. In the current mode, it warns of open circuit as well. It does not, in addition, load the hand controller rheostats, as they do not carry the car current. (In some sets the controller handsets get very warm.) It comes with an internal power supply as well. Both controllers are, of course, short-circuit protected.

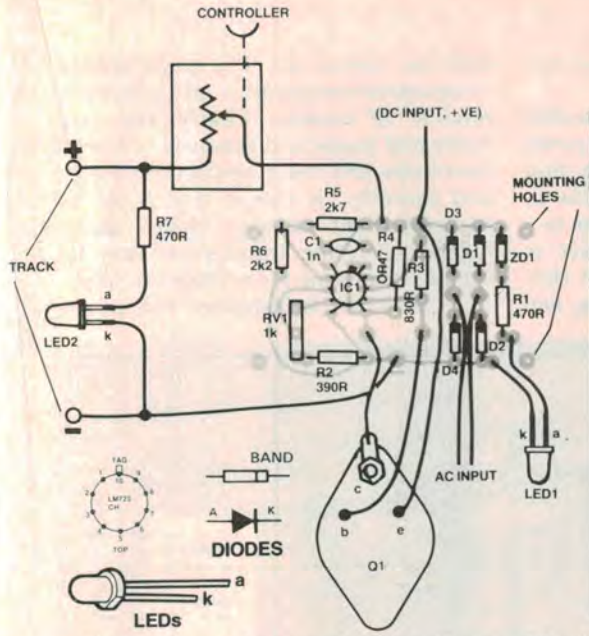
The two modes, current and voltage, each offer their own advantages. Current mode gives torque proportional to control depression, as torque is proportional to current. It has slower take-off and generally sloppier, though perhaps more realistic, operation. It is also more immune to bad contact in the track and brushes, if you are having trouble in that direction. Voltage mode, which we prefer, gives a very tight control, with snappy response from the car; perhaps less realistic, but more fun. It seems to demand more from the drivers, though performance is considerably superior. You can actually get a car to lock up and slide sideways out of a long straight into a corner, and accelerate out of the corner, the car's pin in the slot all the time, which is not a mean feat!

Having set forth the pros and cons, we will proceed into the construction of the two projects, and you may choose the one you feel is appropriate.

Construction ETI-824

Construction of the ETI-824 is relatively straightforward. You will require one pc board for each lane, though some components will not be required on all but the first board. If you have only two lanes, as is likely, you can follow our construction diagrams exactly. Further lanes will simply demand a larger box and a repeat of the wiring up of the first two boards, less ZD1, R1 and LED1.

The first step is to drill the box. We used a jiffy box, primarily because they are the cheapest form of conveniently workable container. If you want it to look particularly good, or it will have to withstand nasty knocks, a diecast aluminium or extruded type of box of sufficient size can be used, but is likely to



PARTS LIST—ETI-824

Resistors .... all ½W, unless noted
R1, R7 .... 470R
R2 .... 390R
R3 .... 820R
R4 .... 0R47, 1W
R5 .... 2k7
R6 .... 2k2
RV1 .... 1k trimpot

Capacitors
C1 .... 1n greencap

Semiconductors
D1-D4 .... 1N4001, EM401, etc. 1A, 100 V
ZD1 .... 7V5, 1 W zener
LED1 .... TIL220G, green
LED2 .... TIL220R, red
IC1 723
Q1 .... 2N2955

Miscellaneous
ETI-824 pc board; jiffy box to suit; terminal block; transformer (if necessary); nuts, bolts, wire etc.
NOTE: The supply circuit is duplicated for the second track. Those components duplicated are designated Q1a, R4a, IC1a, C1a etc.

Price estimate

We estimate the cost of purchasing all the components for this project will be in the range:

$15—$18

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used) etc — whether bought as separate components or made up as a kit.

add 20-50% to the cost. Anyway, if you have our type of box, the front panel doubles as the heatsink.

Drill the 2N2955 mounting holes and the LED mounting holes first. The only other hardware preparation is the holes for the pc board mounting and the holes for the wires and the terminal block to which they lead.

After the drilling is done, assemble the boards. The first should have all components fitted. It is best to include D1 to D4 even if you have a dc supply, as the unit can then not be connected the wrong way around, and can still be used with ac later on if required. Only if the dc is too low to tolerate the diode drops should D1 to D4 be omitted — i.e : below 12 volts average. (Omitting the diodes will let it run on around 10 volts.) It should also be noted that the supply will have to be a bit higher if the car set is a 12 volt type — around 15 volts at least. An 18 Vac transformer is ideal in that situation. Fit all the components on the boards as shown in the overlay, starting with resistors and finishing with the IC. Take care with the IC orientation.

Once the boards are assembled, connect the flying leads as shown in the assembly diagram. The current-limiting resistors for the track LEDs are mounted behind the LEDs themselves, as part of the flying leads. We used an ordinary plastic terminal block as these are cheap and wires will probably not have to be connected and disconnected repeatedly, so that more 'flashy' terminals are not justified.

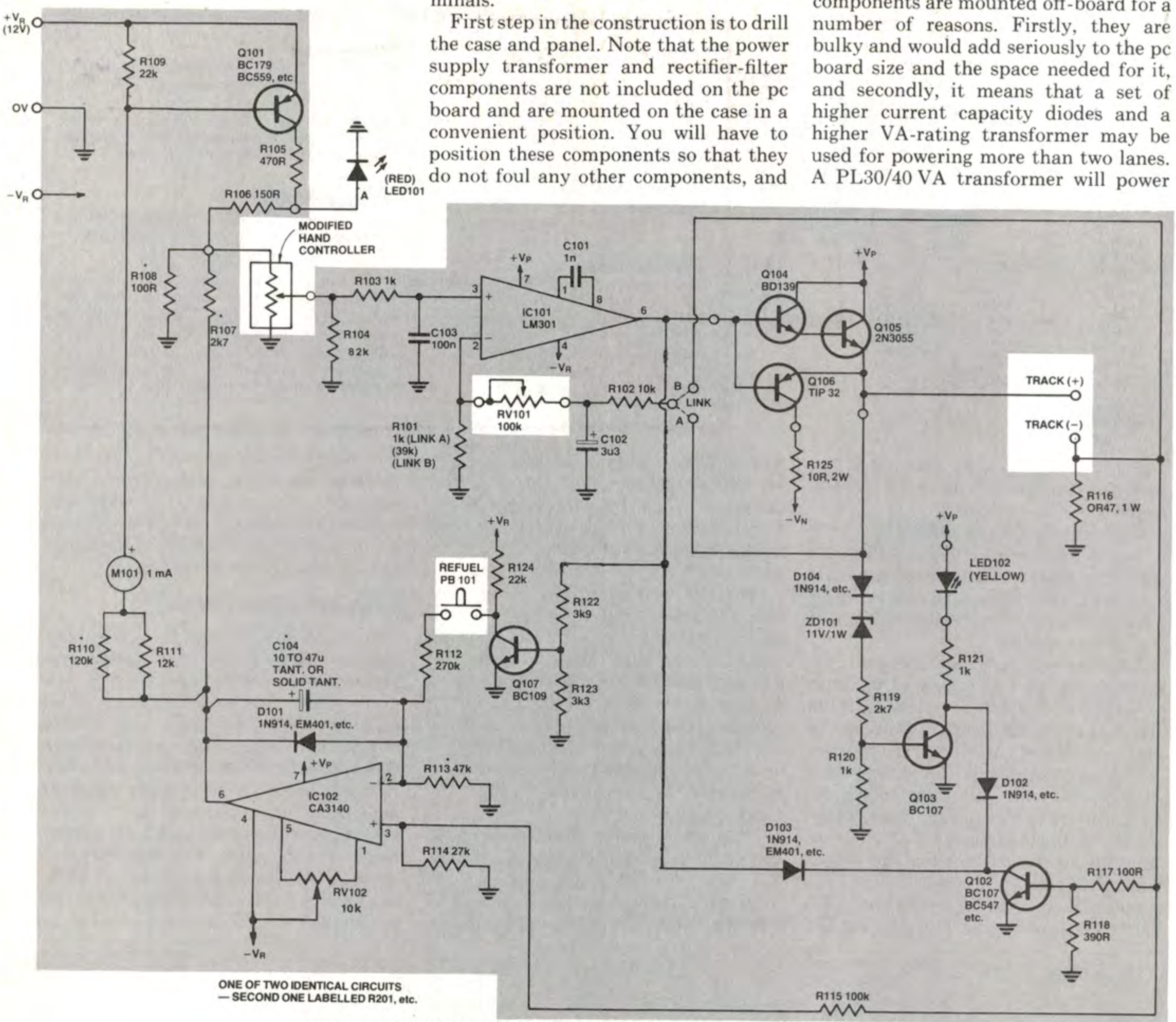
Once the assembly is complete, label the panel and connector appropriately. We used Dymo tape, again in the interests of cost. There is no reason why you should not use paint and Letraset on the panel before assembly, or do a custom job with model paint after assembly, if you should be that way inclined. (Shades of certain panel vans we have seen! Probably more appropriate if your cars are hotrod types.)

Construction ETI-825

Construction of this unit is fairly flexible and will depend somewhat upon how you plan to house the unit. We built two prototypes — one very compactly in an extruded aluminium case from Amtex and one in a large plastic case from Vero (distributed by Warburton and Franki). It is advisable to use a fairly spacious housing as this demands less careful layout and allows easy access for adjustment or debugging. The only requirement for the case is that if you are using our pc board the meters must be spaced horizontally by the required amount, as ▶

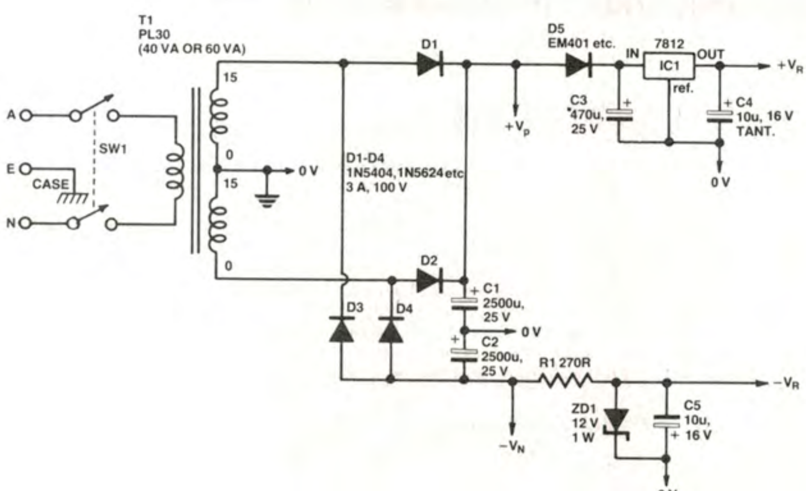
the board mounts on the meter terminals.

First step in the construction is to drill the case and panel. Note that the power supply transformer and rectifier-filter components are not included on the pc board and are mounted on the case in a convenient position. You will have to position these components so that they do not foul any other components, and drill the case to suit. The power supply components are mounted off-board for a number of reasons. Firstly, they are bulky and would add seriously to the pc board size and the space needed for it, and secondly, it means that a set of higher current capacity diodes and a higher VA-rating transformer may be used for powering more than two lanes. A PL30/40 VA transformer will power



ONE OF TWO IDENTICAL CIRCUITS — SECOND ONE LABELLED R201, etc.

*ITEMS ASTERISKED MAY REQUIRE ALTERATION OF VALUE TO SUIT YOUR PARTICULAR REQUIREMENTS — SEE TEXT.



two lanes, a PL30/60 VA will power up to four lanes.

We found it convenient to mount the mains supply terminating block, cable clamp (or clamp-grommet), output terminals and presettable pots (RV101, RV201) on the rear panel of our box. We used ordinary potentiometers for RV101 and RV201, rather than preset types, cut the shafts short and cut a slot in the end of the shafts. To avoid fouling other components, mount the pots so that they are below the height of the transformer.

Next, prepare the front panel. Naturally, drill it first. Locate the meter holes carefully as the pc board determines their spacing (144 mm centre-to-

HOW IT WORKS — ETI-825

The unit comprises a power supply, a control section (involving IC101), a driver circuit (involving Q104, 5 and 6 and associated components), an overload protection and warning circuit (Q102, 3 etc), an 'electronic fuel tank' (Q101 plus IC102 and associated components) and a 'refuel' circuit (Q107 etc).

The circuit has two modes of operation — voltage and current. The mode to be employed is selected by means of a link on the pc board. In the voltage mode, the hand controller sets the voltage delivered to the track (and thus the slot car's motor). In the current mode the hand controller sets the current delivered to the car's motor via the track. In either mode, a potentiometer (RV101) sets the maximum value of the voltage or the current.

POWER SUPPLY

Transformer T1 has two 15V (RMS) secondaries, connected in series. There are two rectifier circuits — one to provide a positive supply rail, the other to provide a negative supply rail. The joining of the two secondaries provides a 0 V connection.

Diodes D1-D2 and capacitor C1 provide a nominal +21V supply rail (+V_P) while D1-D3 and C2 provide a nominal −21V supply rail (−V_N). From these two rails +12V and −12V regulated rails are derived. The +12V rail is achieved by IC1, a three-terminal positive supply regulator (a 7812 or 78L12). This rail is used as a reference for the hand controller and metering circuit. Capacitor C4 ensures high frequency stability for the three-terminal regulator and acts as a supply rail bypass. The −12V rail is derived by a simple zener circuit involving R1 and ZD1. C5 is a supply rail bypass. The negative rail is limited to 12 volts so that the maximum supply voltage limitation of the op-amps, which is about 36 volts, is not exceeded.

CONTROL SECTION

This centres on IC101. A certain current (which we will discuss in detail a little later) is passed through the hand controller resistance. This develops about 200 millivolts drop across it. Thus, when the hand controller is operated, a voltage ranging between 0 and 200 mV is applied to pin 3 of IC101, the precise voltage depending on how far the 'driver' has depressed the controller lever. Capacitor C103 smoothes out any variations — many hand controllers have momentary loss of contact between the wiper and the resistance as the wiper traverses the resistance element. You may need to vary the value of C103 according to how coarse the resistance variation happens to be in your controller. For the inexpensive controllers — which are really quite adequate despite the coarse variation they provide — a value of 470n to 1u (electro) is suitable.

Now, IC101 attempts to drive its output (pin 6) in such a fashion as to induce the same voltage on its inverting input (pin 2) as is on its non-inverting input (pin 3).

In the voltage mode, pin 2 of IC101 is connected via RV101, C102 and associated components to the positive track terminal so that the position of the wiper on the hand control resistance sets the output voltage. In the current mode, pin 2 of IC101 is connected to the end of the 'current sense' resistor (R116) so that current is defined by the position of the wiper on the hand controller resistance.

In either mode, RV101 — which is in series with the negative feedback path — in conjunction with R101, sets the maximum voltage or current delivered to the car's motor via the track. Capacitor C102 induces some 'overshoot' in the feedback which enhances acceleration and braking according to controller movement.

DRIVER

The driver circuit comprises Q104, Q105 and Q106 plus R125. Its function is merely to amplify the current delivered from the output of IC101.

Transistors Q104 and Q105 are connected as a Darlington pair which provides considerable current gain (the Beta of Q105 is multiplied by the Beta of Q104). The output of IC101 (pin 6) swings positive during acceleration (depressing the hand controller lever) and Q104-5 amplify the current, the emitter of Q105 being connected to the track positive terminal. Q106 is reverse biased during this time. During braking, pin 6 of IC101 can go negative (particularly if you 'drop' the hand controller lever). This reverses the voltage delivered to the track or reverses the current flow (depending on which mode you're employing). When this occurs, Q104 and Q105 are reverse biased and Q106 is forward biased — and it amplifies the negative excursions from pin 6 of IC101.

The function of R125 is to protect Q106 against momentary current overload.

PROTECTION

The protection circuit involves Q102, Q103 and associated components. If the voltage output to the track exceeds about 13 volts, ZD101 and D104 conduct, forward biasing the base of Q103. When Q103 turns on, it draws collector current via LED102 and R121. LED102 lights, providing warning of a fault. If the output current exceeds about 1.5 amps the current through R116 (which is in series to the supply to the track) induces a voltage drop across it of about 0.7 volts or so and this forward biases the base of Q102 via R117 and R118. Q102 thus turns on and it draws collector current via D102, R121 and LED102. However, the collector voltage of Q102 will be around a few hundred millivolts and the output of IC101 (pin 6) will be shunted to the 0 V rail via D103 and the collector-emitter junction of Q102.

Thus, you receive a warning of supply overload and the supply, track etc., is protected against overcurrent damage.

FUEL TANK

The 'fuel tank' is simulated by IC102 and associated components. This op-amp is connected as an integrater. A 'full' tank corresponds to 0 V on the output of IC102 (pin 6), an 'empty' tank to about 12 volts. As current flows through the load (car motor), and hence via R116, a voltage is dropped across R116. This voltage is integrated by IC102 which has an RC network (R113-C104) in the feedback loop. As more load current is drawn, pin 6 of IC102 rises towards 12 volts.

The meter, M1, indicates the output voltage of IC102 and is marked like a fuel guage. While the fuel tank is full or partially full, the current through M1 flows via the base of Q101, forward biasing it. Thus, Q101 is held on while this current flows. The collector current of Q101 flows via LED101 (the hand controller and associated resistors). LED101 lights, indicating you have fuel in the tank. When the fuel 'runs out', pin 6 of IC102 is at 12 volts and no current flows through M1 and thus the base of Q101 receives no bias and it turns off. LED101 extinguishes at this stage and no voltage is delivered to the hand controller. IC101 interprets this as if you have the controller set to the rest or off position and no power is supplied to the track. Your car stops . . .

The 'capacity' of the fuel tank is defined by the values of C104 and R113. The values shown give a 'full tank' of about 60 amp-seconds — which corresponds to about 30 rapid laps of a 2½ metre long track in 1/64th scale. The values of C104 and R113 may be varied to suit your taste, as indicated in the table on page 33.

While there is fuel, LED101 is on and its terminal voltage is about 1.7 volts. This voltage permits about 10 mA to flow through the resistance of the hand controller via R105. (Recall we have yet to see what its current is). In addition, R107 permits some current to flow into the controller— generally between 0 and 5 mA — from pin 6 of IC102. This current increases as fuel is 'used up', corresponding to the car getting lighter, and you get more acceleration at any particular hand controller setting as you 'use up' fuel. Resistor R107 defines how much more acceleration is obtained when the car is 'lighter'.

When the fuel runs out and Q101 turns off, the current delivered through R105 to the hand controller plummets and only the 5 mA flowing via R107 is available. This gives a 'soft' end, allowing you to limp to the pits — if you aren't too far away on the track.

The parallel combination of R108 and the hand controller should be around 15 ohms. If your controller has a high resistance, or you want to substitute a 1k wirewound pot, for example, R108 should be derived from the following formula:

$$R108 = \frac{1}{\left(\frac{1}{15} - \frac{1}{R_{controller}}\right)}$$

REFUEL CIRCUIT

'Refuelling' is effected by PB101 and Q107. When the car motor is not drawing power, the output of IC101 (pin 6) is low (less than one volt) and thus Q107, which derives its base bias from pin 6 of IC101, is off. Pressing PB101 connects R112 to the +12 V rail via R124 and IC102 will discharge C104. The output of IC102 (pin 6) will drop to 0 V (which is the 'tank full' condition). Q101 will turn on again and current will be supplied to the hand controller circuit. When you power the car again, the voltage on pin 6 of IC101 will rise, the base of Q107 will be biased on and its collector will draw current via R124. Thus, if you try to 'top up' while the car is in motion, R112 will be virtually connected to the 0 V rail via the collector-emitter junction of Q107 and you won't be able to drive the output of IC102 low. In addition, if you attempt to drive the car while refuelling, the refuelling action will be stopped by the same means.

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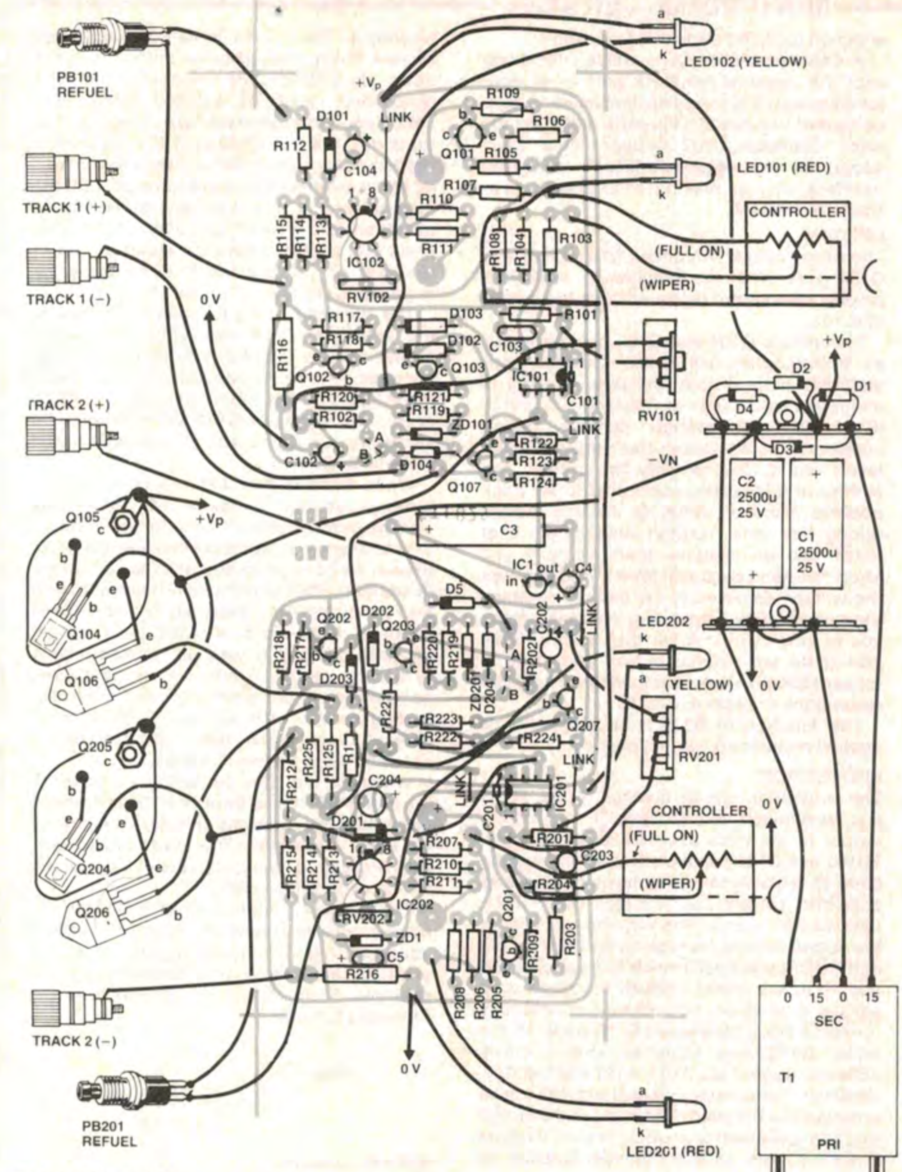
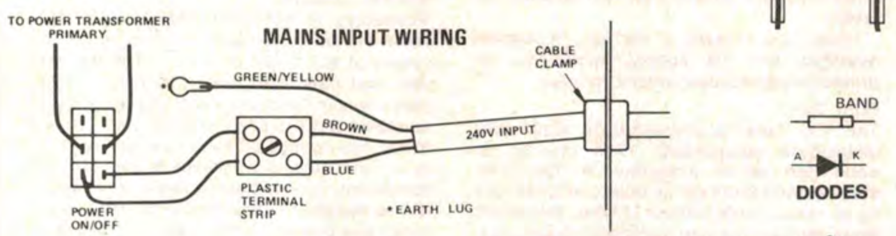
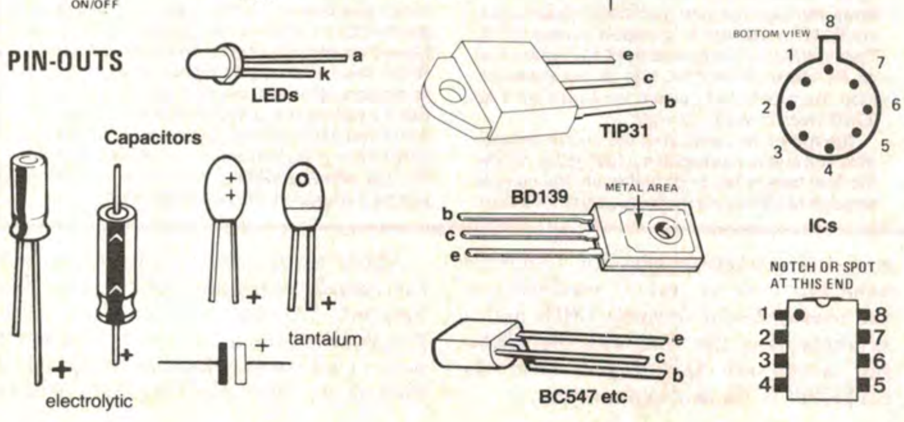
centre). For panel marking we used rub-down lettering on one panel (such as Letraset, Geotype, etc), put directly on the panel after cleaning it, and automotive 'touch-up' paint on the other. Both methods proved satisfactory. In the interests of giving a Spartan, vehicular look we put '?' symbols near the overload/fold warning LEDs and '!' symbols near the fuel warning LEDs, but words are OK if you need the controller to be self-explanatory.

Apply a spray-on lacquer to protect the panel markings. With this job finished, fit the meters, LEDs, etc. Finally, drill the mounting holes for the power transistors, which are mounted off the board. These dissipate little heat so ▶

The pc board artwork for each project appears on page 147.







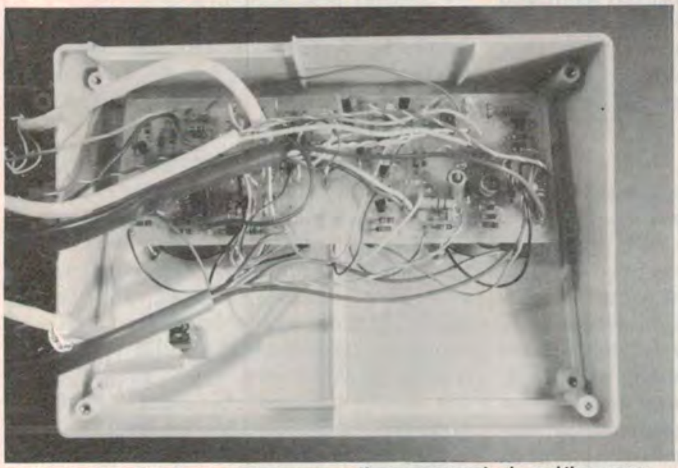
they merely need mechanical support.

The next step is to assemble the components to the pc board. As there are quite a few flying leads, it may pay to use pins for the termination of these to the pc board. Pay attention to all the usual details — orientation of tantalum and electrolytic capacitor, orientation of semiconductors, etc. Choose the components in Table 1 to suit your requirements, according to the instructions given with the Table. When all the components are soldered in place, fit the flying leads to the LEDs and pushbuttons which are mounted on the front panel, along with the meters. These can be secured and the pc board bolted to the meter terminals before the leads to the main case are fitted. Be sure that all flying leads are long enough to allow the box to be fitted together and dismantled without straining the connections. In the controller we assembled in the extruded aluminium case, very long wires were required as the panel has to be slid into position end-wise because it rides in a groove of the extrusion. Long leads can be kept neatly 'loomed' with plastic sleeving slipped over a bunch before one group of ends is terminated.

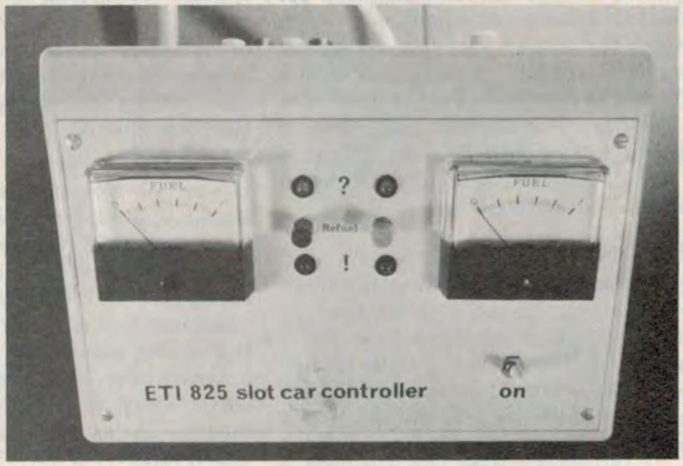
Assemble the transformer, power supply components and potentiometers in the case next and wire them up. Take particular care with the mains wiring. The rectifier components are supported on a tagstrip and we'll leave the wiring details to you for this one.

The final step before testing is to modify the handheld controllers from rheostats to true potentiometers. Open up the case of a controller. You will find that it consists of a short coil of resistance wire, wound on some sort of former, with a wiper contact which moves along the coil according to how far the thumb or finger control is depressed. When fully released, the wiper rests in a position where it does not touch the coil. There will be two wires coming from the hand controller — one leading to the wiper and one from an end of the resistance wire. It is neccesary to have a third contact, connected to the other end of the coil (the end without a connection). Remove the existing wires (some of these have considerable resistance themselves) and fit the two new wires, then the third. These run to the controller unit. Make sure you have plenty of length to play with. Now re-assemble the hand controller, being careful to tie off the wires in the same way the original two were secured.

You should now be ready for a test run.



Inside the ETI-825. The board mounts on the meter terminals and the power supply and other components mount in the cabinet base.



Full frontal view of the ETI-825 'control' panel.

TABLE 1. Component value variations

Component	Nominal Value	Function	How to vary it
C104(C204)	10u	Sets fuel tank capacity, along with C104.	Increase its value to increase fuel tank capacity. E.g: 20u gives double capacity. RANGE: 10 to 47u
R113(R213)	47k	Sets fuel tank capacity, along with C104.	Increase its value to increase fuel tank capacity. RANGE: 10k to 100k
R110(R111)	120k in parallel with 12k.	Calibrates M1 for full scale deflection at 'full tank' status; allows other meter fsd values to be used.	Reduce R110 to increase reading. Choose R110/R111 to give value according to $11.4/I_{fsd}$. This should not need much adjustment if a 1 mA meter is used.
R107	2k7	Sets the variation of engine power remaining fraction of fuel.	Reducing R107 gives a greater gain in power as the fuel 'runs out'. RANGE: 2k2 to 22k.
R108	100R	Sets the effective controller resistance to about 15 ohms.	Choose R108 such that R108 in parallel with the controller resistance gives a combined resistance of 15 ohms.

PARTS LIST—ETI-825

Resistors	all ½W, 5% unless noted
R1	270R
R101	1k (link A), 39k (link B)
R102	10k
R103,120,121	1k
R104	82k
R105	470R
R106	150R
R107	2k7*
R108	100R*
R109,124	22k
R110	120k*
R111	12k
R112	270k
R113	47k*
R114	27k
R115	100k
R116	0R47, 1W
R117	100R
R118	390R
R119	2k7
R122	3k9
R123	3k3
R125	10R, 2W
RV101	100k lin. pot.
RV102	10k

Capacitors

C1	2500u/25 V electro.
C2	2500u/25 V electro.
C3	470u/25 V electro.
C4, C5	10u/16 V tant.
C101	1n greencap
C102	3u3/10 V tant.
C103	100n greencap
C104	10 - 47 u/16 V tant. — preferably solid tant.

Semiconductors

D1-D4	1N5404,1N5624 etc (3A, 100V)
D5,D101,D103	1N4001,EM401, (1A,100V)
D102,D104	1N914, 1N4148
ZD1	12 V, 1 W zener
LED101	TIL220R, red
LED102	TIL220Y, yellow
Q101	BC179, BC559 etc
Q102,103	BC107,BC547 etc
Q104	BD139
Q105	2N3055
Q106	TIP32
Q107	BC109,BC549
IC1	78L12 or 7812
IC101	LM301
IC102	CA3140

Miscellaneous

T1	PL30/40 VA (or 60 VA), Ferguson (2 x 15 V, 1A)
SW1	SPST, 240 Vac rated toggle switch
M101	1 mA meter, MU-45 or similar
PB101	momentary action pushbutton

ETI-825 pc board; case to suit; tagstrips; terminal block; mains cord and plug; clamp grommet; Scotchcal meter scales; nuts, bolts, wire etc.

NOTE: The controller circuit is duplicated for the second track and those parts marked R101, D101, C101, IC101 etc are duplicated, designated R201, D201, C201, IC201 etc for the second controller.

* Components marked with an asterisk may require alteration to suit your particular requirement (see text).

Price estimate

We estimate the cost of purchasing all the components for this project will be in the range;

$60—$70

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used), etc — whether bought as separate components or made up as a kit.

Test run

Make up a simple circle of track. On powering up, the car should work to some degree. If not, stop and recheck. Once it works it is necessary to adjust the presets and so forth. RV102/202 should be adjusted to minimise 'fuel tank' circuit drift in the absence of power being delivered. (These are the integrator offset adjustments.) At this stage it is probably worth assembling the unit and giving it a serious workout. You may find that you want to increase the fuel tank capacity (C104), change from one mode to the other (links A and B) or that the control is rough or jittery. If this latter is the case, then your controller is probably one with *relatively few* turns of resistance wire. This is causing sharp changes in level, to which the electronics respond with excessive overshoot. The cure is to increase C103/203 to, say, 1 µF. This is especially prevalent with the cheap, 6 V operated sets. After you have had a while in the seat, remove the front panel and alter the appropriate components (marked with an asterisk) in order to produce the effects desired. To figure out what these are, consult Table 1.

A note should be included on the correct adjustment of the maximum torque presets, RV101/201. This is much a matter of preference. They should be ▶

Modified hand controller with connection to both ends of resistance wire.

adjusted so that the car does not get ridiculous amounts of power just prior to running out of fuel, but so that the car can just be crashed on full power with a full tank. It is probably also a good idea to set the two channels alike with a multimeter to ensure fairness. (Be sure to have equal amounts of fuel when doing this adjustment!)

The track

When it comes to track, there are three factors worth mentioning which may influence your choice if you have yet to purchase it, before we discuss actual layout. These factors are: range of pieces available, flexibility and width. If you are going to buy the cheap sets, and let's face it, that is the most cost-economical approach, you will have to accept that the track comes in fixed quantities, probably multiples of what it takes to make up one loop or a small figure-8. However, it is so cheap that you can get twelve 45° curves and four straights, not to mention two cars and controllers, and fences, etc, for under $15 in some places in Sydney (e.g.: Paddy's markets, etc). For $30, plus one of our controllers, you can get a really good set-up, and for $45 you get a really *fantastic* set. There is no denying that an expensive brand is better in that you can buy three radii of curvature (for funny bends or up to six lanes) and several lengths of straight, but at $150 or so for a basic figure-eight set, it is not a purchase to be taken lightly. Such sets also have the advantage that they have flexible track which can thus be banked on the curves, but they are on a larger scale and take up more room. The cheap stuff is usually about 102 mm (4″) wide, but if you are lucky you can get it a bit wider, like 110 mm. This is a bit better, as the cars are less likely to interfere with each other on bends, and less likely to foul badly on fences.

In designing a layout, the main problem is not to find a shape which is particularly interesting, but one which is fair, or equal, for both lanes, as well as 'rational'. By rational we mean that the pieces of track fit together into a loop naturally and require no forcing. A layout which has to be pushed out a bit to meet up is not only unaesthetic to the perfectionist mind, but tends to rapidly separate in various places with a bit of use. If you are using the track pieces which come in the cheaper sets you are probably constrained to turn increments of 45°, and straight sections each equal to the centre radius of curvature of the curved sections. If, in addition, you want to use all or almost all of the track available, (and who doesn't?), you are probably constrained to some fixed ratio of curves-to-straights. Even if you are lucky enough to have a range of bits, it is quite challenging to sort out a fair and rational track using all the bits. And besides, who rushes out and gets that quarter straight every time he devises a nice-looking layout that doesn't quite meet up squarely?

Method

If you are not seriously interested in layout analysis and design, you may skip this paragraph; it deals with our mathematical method of thinking out a track set-up. First, let us define some terms. A 'construct' is any group of track sections. It does not necessarily meet up to form a closed loop, but is usually a familiar shape which can be found in common layouts. A rational construct is one which replaces a basic subsection of an oval of track — either a right angle, a single straight section, or a combination of these — and thus, geometrically, introduces an integral multiple (or in some sets of track, a simple rational fraction) of the basic radius of curvature into each axis.

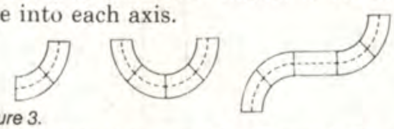


Figure 3.

To explain this, consider Figure 3. The right angle turn introduces a one-unit displacement down and one unit along. The U-bend introduces a two-unit shift down and no shift along. The S-bend introduces three down, and two along. These are all rational constructs in the system of track here — that is, one where straights are exactly one radius of curvature long, as is common. The constructs in Figure 4 are all equivalent to a right angle, and are thus rational.

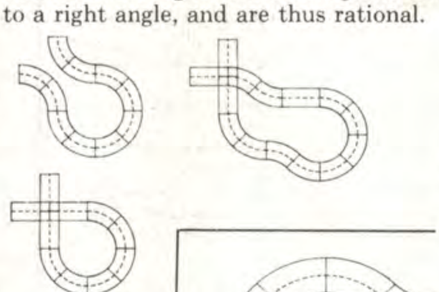


Figure 4.

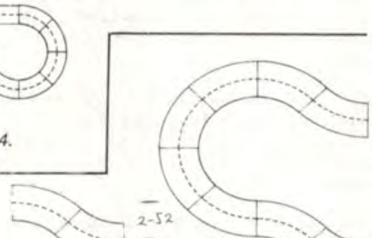


Figure 5.

The zig-zag in Figure 5 is irrational, as it has displacements of $\sqrt{2}$ and $2-\sqrt{2}$ respectively, but the construct next to it is rational, as the zig-zags clearly cancel out.

A layout is said to be *rational* if it fits together *exactly*. For this to happen, there must be no uncancelled irrational constructs. Some constructs favour one lane. For instance, in a plain 180° bend, the outside lane is longer, and thus you might expect it to take longer to negotiate. If there are fences it may be faster, as the car can bounce off them and thus use them to allow greater speed without accident.

Experiment will determine how each construct favours lanes. In our experience, a zig-zag favours the lane first on the outside, especially with fencing. Once you have an idea of each construct and how it favours lanes, you can assemble them into a fair layout. Even though a completely flat layout will inevitably have one lane longer on the outside, it can be made fair by judicious addition of constructs to favour the worse lane — such as zig-zags at the ends of long straights.

It is desirable to avoid bridges, because they are easier to disrupt in moments of excitement as well as harder to achieve with rigid track. It is also a pain to quickly recover a crashed car from the underpass. Flat layouts can be fair, with some thought and understanding of the constructs used.

Finally, let us mention cleaning. Unless rust is rife, abrasive things such as emery paper should be avoided. Cloth soaked with methylated spirit is best for removing crud. After cleaning, light application of machine oil or Vaseline (the latter collects more hair but is better for storage) will reduce crudding and prevent corrosion. The plating on the tracks is sufficient protection until it fails, so just wiping should be enough. Occasionally, the small metal flanges which make contact from track to track should be bent slightly to improve friction and contact.

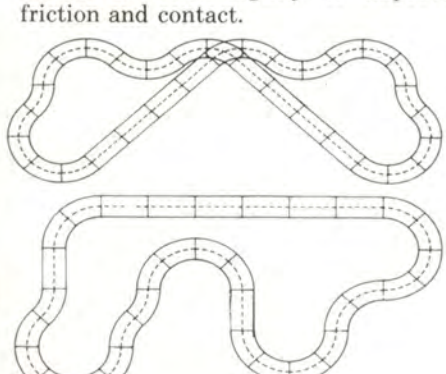


Figure 6.

If you are really getting into it, you can devise a catalogue of constructs. We developed a computer program for checking rationality and a layout plotting routine; we tender a couple of optimal layouts (Figure 6) which use all the track from two cheap figure-eight sets. The analysis and synthesis of track layouts becomes more complex when you have different and more varied pieces available — our examples are of the elementary type, as in cheaper sets. ●