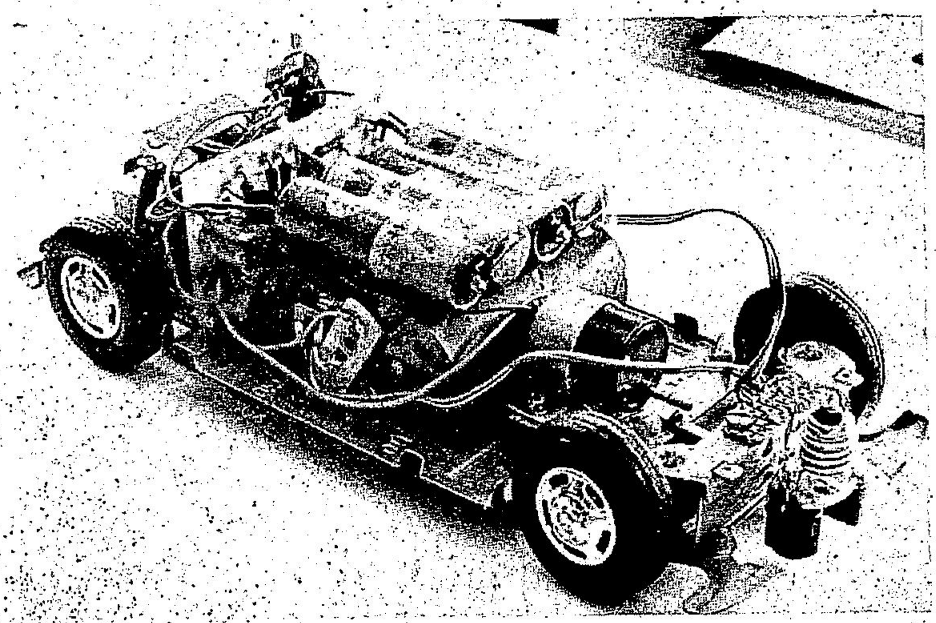
White Line Follower

This toy car will follow a track around — but there's always the danger of spinning off!



THE IDEA OF A SLOT CAR that doesn't need a slot is not new — in fact, sophisticated systems based on inductive loops have been used in large factories for some years. This project is at the other end of the complexity scale, and uses a simple light/photocell combination to follow a white line. The electronics involved make up a simple feedback control system — as soon as one photocell sees more light than the other, the differential amplifier applies a correcting voltage to the steering servomotor and so the model steers itself back on to the line.

We are not sure whether to class this project as a toy or as a serious experimental project. Certainly, the basic project makes a great toy, but there is tremendous scope for experimenting and 'tuning' the control circuitry. Like all control systems, this one displays a characteristic called 'damping' — if the system is overdamped, the car will steer sluggishly and will have difficulty following anything except the smoothest curves. If the control circuitry is underdamped, the car will oscillate from side to side on curves — this may also be set off by small deviations on the straights.

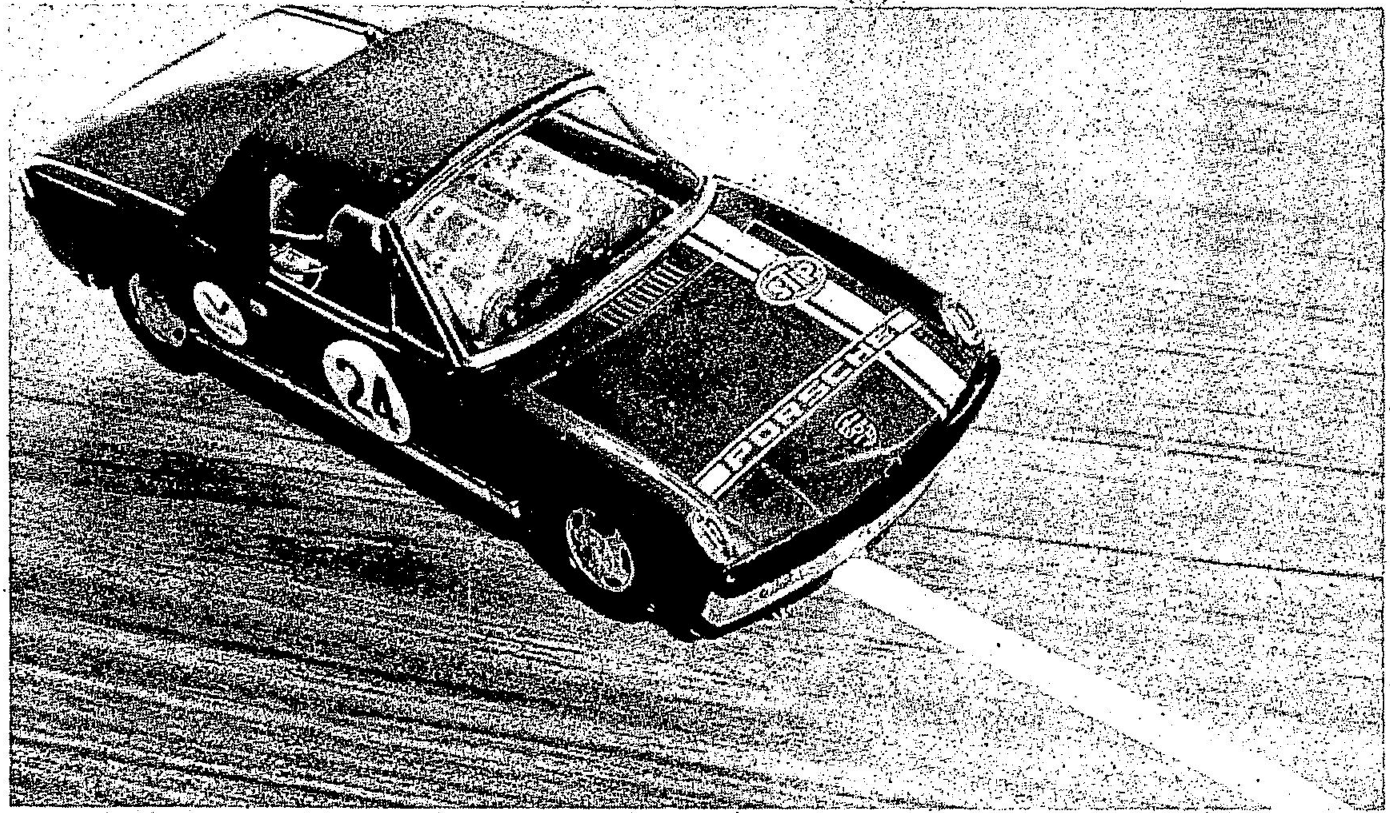
The ideal situation is to have a 'critically damped' system, which has just the right combination of characteristics to respond quickly on curves without oversteering. This can be achieved by theoretical analysis, using techniques like Nyquist's Criterion, but it's more fun to tune by trial and error. The damping is a factor of the photocell spacing, the amplifier gain and the servomotor characteristics.

You can have a lot of fun racing these cars, especially since there is quite a bit of scope for tinkering and tuning them. The layout of your race track should include both smooth and tight curves — you may have problems with figure-8's that cross at anything but right angles.

CONSTRUCTION

Construction of the mechanical side we must leave to the individual reader. The car we used was purchased from Woolworth's and already had steerable front wheels, which saved a lot of work in designing and building, although for the enthusiast a plastic kit would be a good start.

The motor for the steering should operate on 1.5 V reliably and has to be geared down. The motor we used had an internal 15:1 gearbox and the steering



arms were driven by a piece of fishing line wrapped around the shaft (see photo). This is only one possible method — we leave the final choice to you.

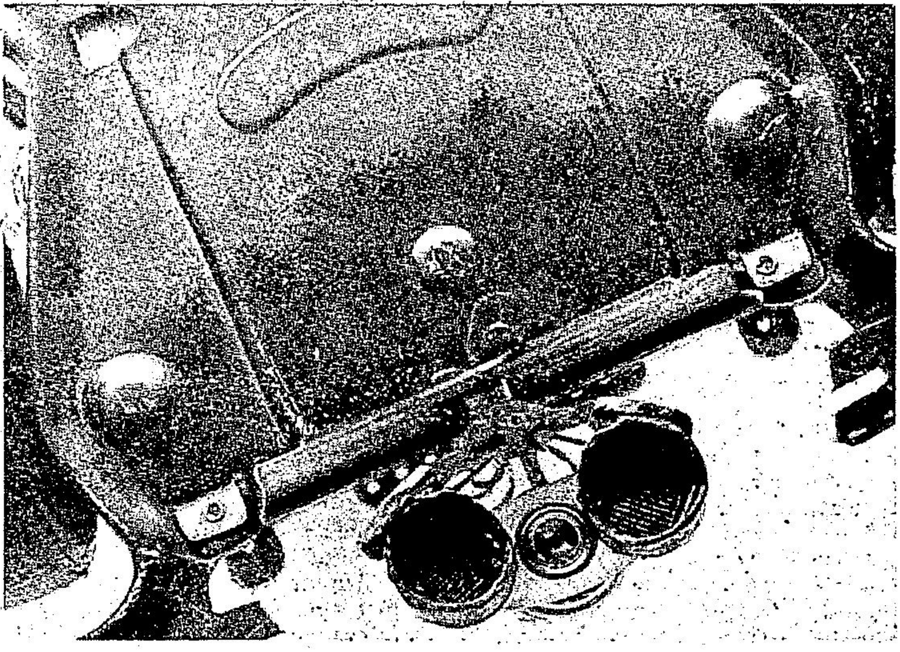
The sensors should be mounted in front of the wheels and should move with them so that when the wheels turn to the right, the sensor also moves to the right and vice versa.

The LDRs were housed in short lengths (about 10 mm) of cardboard tube to act as a shield and were spaced about 15 mm apart (we used a 12 mm wide line) with the bulb mounted between them.

Electrically the components can be built onto the PC board described which can be mounted somewhere in the car. We used separate batteries for the electronics and ran the bulb off the main batteries, to keep the electronics supply more constant.

EXPERIMENTING

Using different motors/gear ratios some changes to the electronics will probably be found necessary. These would mainly involve C1, R1 and R10. Increasing R10 or reducing R1 increases the DC gain, while increasing C1 increases the dynamic damping to reduce overshoot. Track width may also be experimented with as well as LDR spacing.



Underneath view of the photo resistors and the light bulb.

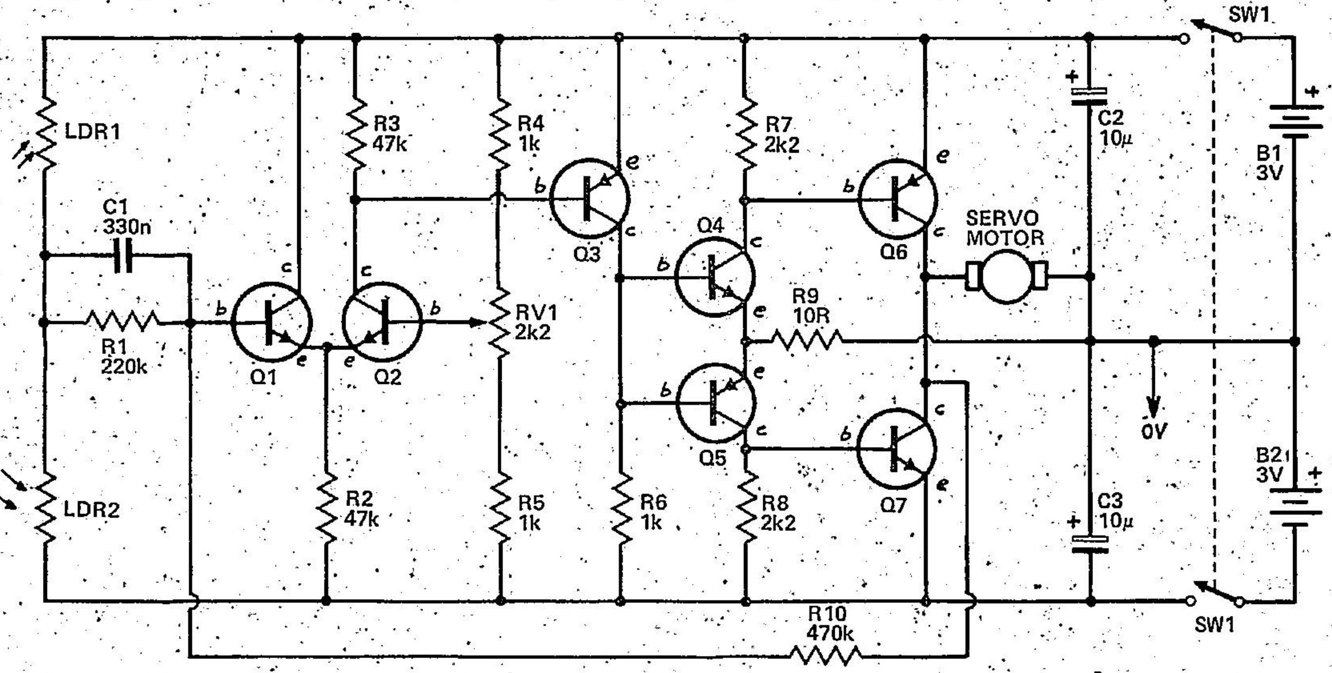
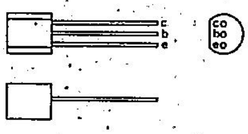
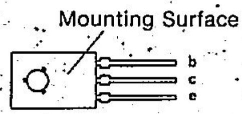


Fig. 1. The circuit diagram of the electronics.



MPS 6515



TIP29, TIP30

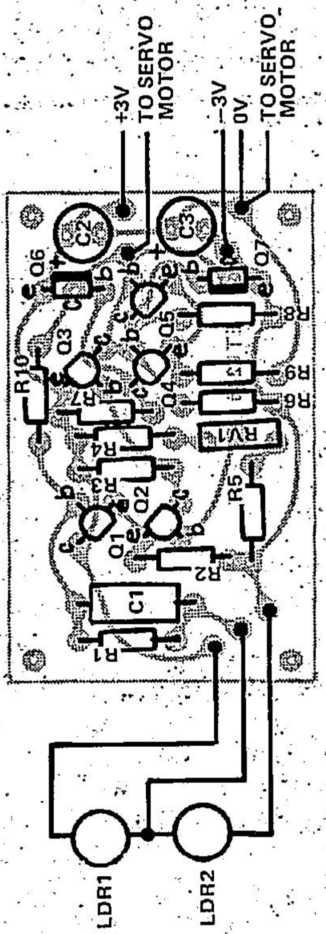


Fig. 2. Component overlay.

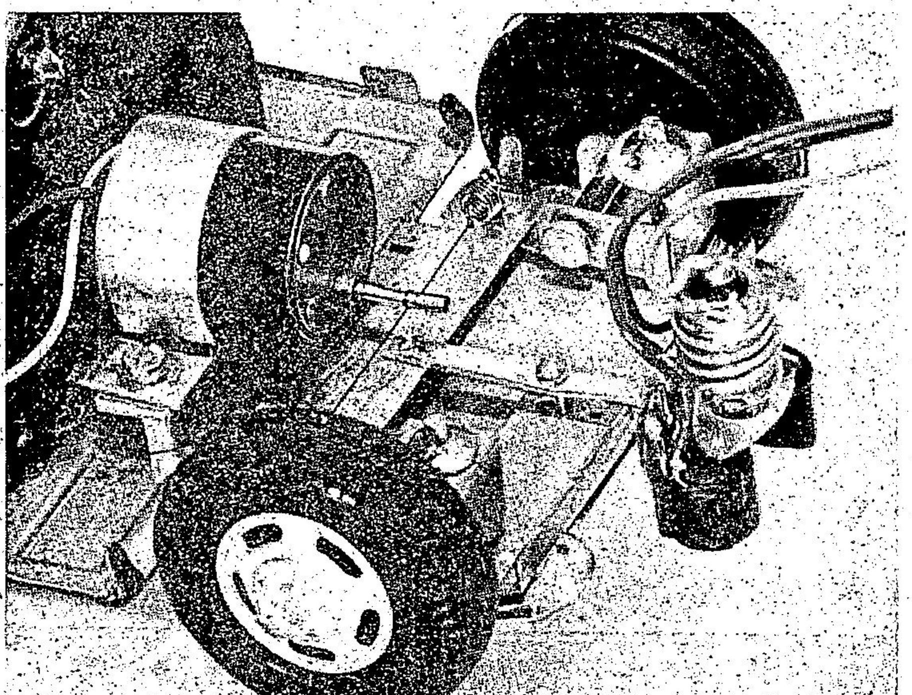
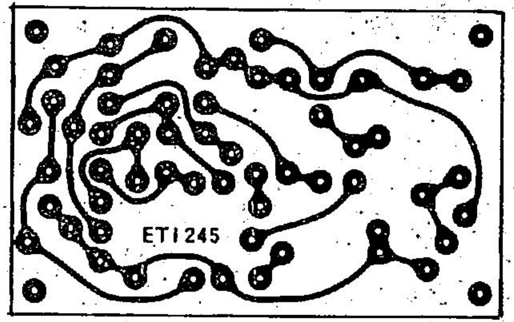


Photo showing the mechanical side of the project.

White Line Follower



PARTS LIST

RESISTORS all ½W, 5%
- R1 . . . . . 220k
- R2,3 . . . . 47k
- R4–R6. . . 1k
- R7,8 . . . . 2k2
- R9 . . . . . 10R
- R10. . . . . 470k

LIGHT DEPENDENT RESISTORS
- LDR1,2 . . . Philips 8-731-03 or similar

POTENTIOMETERS
- RV1 . . . . 2k2 Trim

CAPACITORS
- *C1. . . . . . 330n polyester
- C2,3 . . . . 10µ 10V electrolytic

SEMICONDUCTORS
- Q1,2 . . . . MPS6515
- Q3 . . . . . 2N3905
- Q4 . . . . . MPS6515
- Q5 . . . . . 2N3905
- Q6 . . . . . TIP30C
- Q7 . . . . . TIP29C

MISCELLANEOUS
- PC Board ETI 245
- 3V bulb
- *servo motor and gears
- toy car
- 2 pole toggle switch

*see text

HOW IT WORKS

The sensor used to look for the white line is a pair of light dependent resistors (LDRs) which are aimed at either side of the line so that each sees half white half dark. The line is illuminated by a bulb to ensure that the LDRs have a relatively low resistance. If the car is moved off the centre line one LDR will see more 'white' and its resistance will fall. The two LDRs are connected in series across the supply voltage and so the voltage at the junction will vary as the car moves in relation to the line.

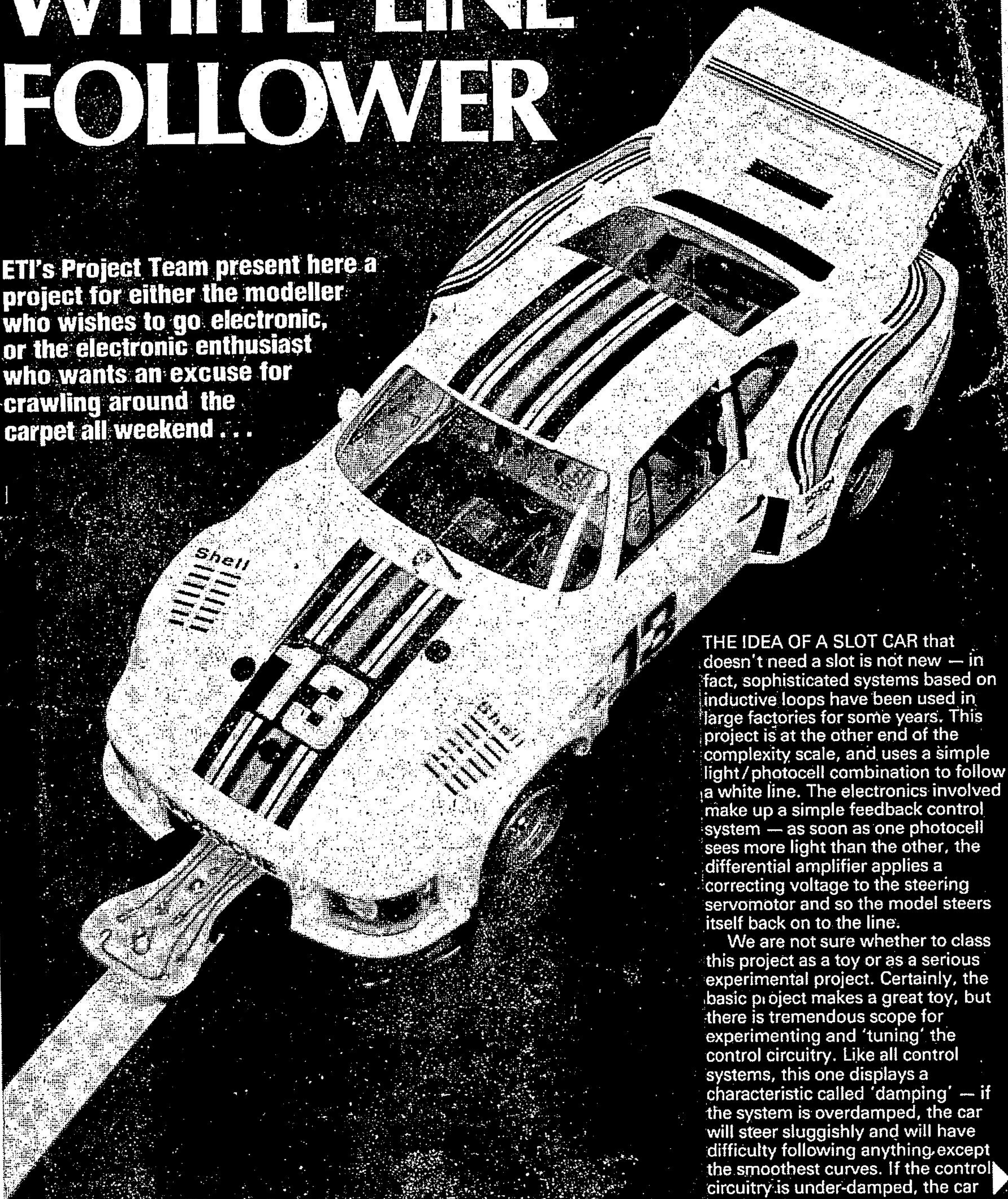
This voltage is compared with that set on RV1 by Q1 and Q2, the error signal driving the servo motor in the correct direction to try to eliminate the error. Negative feedback is provided by R10 to reduce the 'open loop gain', and dynamic feedback is provided by C1 which is used to reduce overshoot.

When designing the mechanical side of the car's steering mechanism, provision should be made to somehow move the sensors with the front wheels to provide additional negative feedback.

The motor used in the prototype was an expensive one (about \$40) with an internal 15:1 gearbox. While a motor of this quality is probably not justified a reasonably good motor and reduction gear is necessary, as the cheap (50c) motor we tried didn't seem to like starting on 1.5 V.

WHITE LINE FOLLOWER

ETI's Project Team present here a project for either the modeller who wishes to go electronic, or the electronic enthusiast who wants an excuse for crawling around the carpet all weekend . . .



THE IDEA OF A SLOT CAR that doesn't need a slot is not new — in fact, sophisticated systems based on inductive loops have been used in large factories for some years. This project is at the other end of the complexity scale, and uses a simple light/photocell combination to follow a white line. The electronics involved make up a simple feedback control system — as soon as one photocell sees more light than the other, the differential amplifier applies a correcting voltage to the steering servomotor and so the model steers itself back on to the line.

We are not sure whether to class this project as a toy or as a serious experimental project. Certainly, the basic project makes a great toy, but there is tremendous scope for experimenting and 'tuning' the control circuitry. Like all control systems, this one displays a characteristic called 'damping' — if the system is overdamped, the car will steer sluggishly and will have difficulty following anything except the smoothest curves. If the control circuitry is under-damped, the car

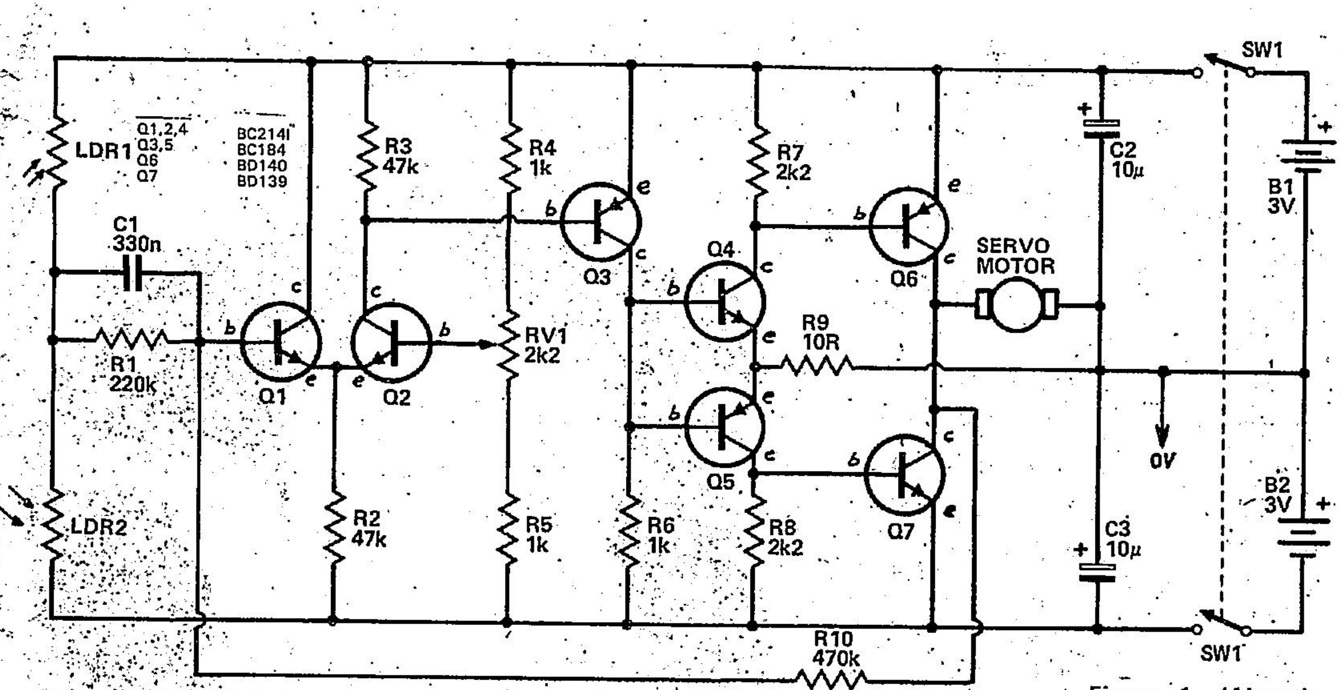


Figure 1. (Above) Circuit diagram of the white line follower unit.

HOW IT WORKS

The sensor used to look for the white line is a pair of light dependent resistors (LDRs) which are aimed at either side of the line so that each sees half white half dark. The line is illuminated by a bulb to ensure that the LDRs have a relatively low resistance. If the car is moved off the centre line one LDR will see more 'white' and its resistance will fall. The two LDRs are connected in series across the supply voltage and so the voltage at the junction will vary as the car moves in relation to the line.

This voltage is compared with that set on RV1 by Q1 and Q2, the error signal driving the servo motor in the correct direction to try to eliminate the error. Negative feedback is provided by R10 to reduce the 'open loop gain', and dynamic feedback is provided by C1 which is used to reduce overshoot.

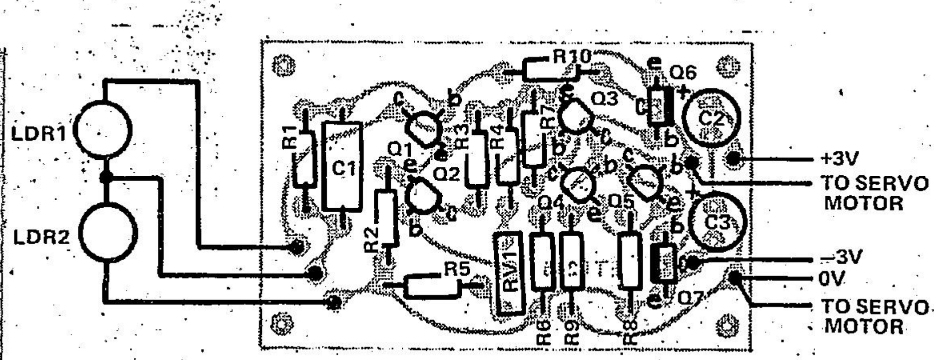


Figure 2. Component overlay. See text for details of mounting the board and servo motors within the model.

will oscillate from side to side on curves — this may also be set-off by small deviations on the straights.

The ideal situation is to have a 'critically damped' system, which has just the right combination of characteristics to respond quickly on curves without oversteering. This can be achieved by theoretical analysis, using techniques like Nyquist's Criterion, but it's more fun to tune by trial and error. The damping is a factor of the photocell spacing, the amplifier gain and the servomotor characteristics.

You can have a lot of fun racing these cars, especially since there is quite a bit of scope for tinkering and tuning them. The layout of your race track should include both smooth and tight curves — you may have problems with figure-8's that cross at anything but right angles. And of course you can time races with your ETI stopwatch!

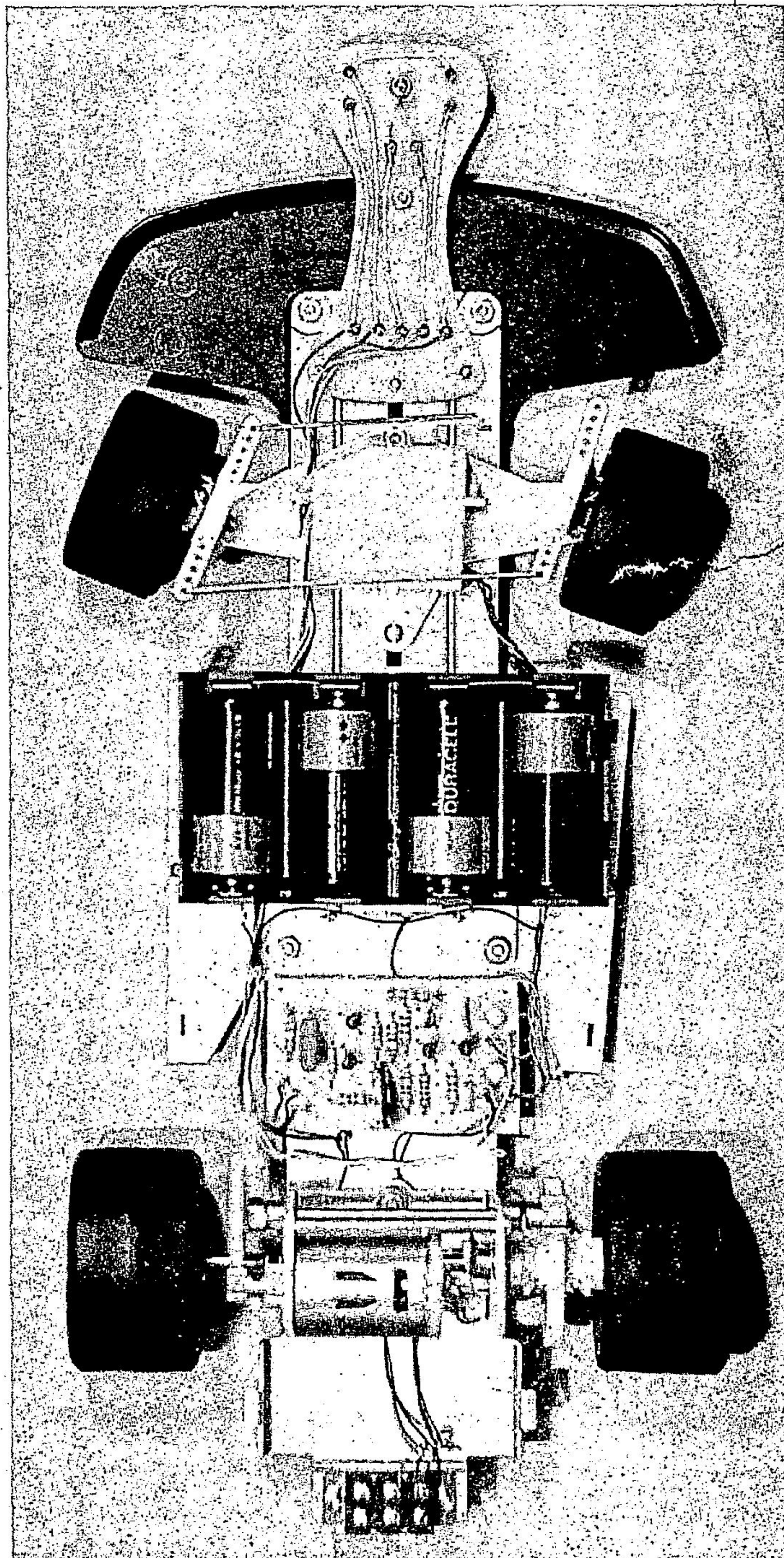
Construction

The mechanical side of constructing the car we must leave to the individual reader. As we were more interested in the electronics side of the project we tended to take short cuts as far as the mechanics go. The car we used was a Tamiya Porsche 935 Turbo, a model specifically designed for radio control applications but ideal for our application. No doubt the model enthusiasts amongst you will know of many other models that would prove suitable.

We cheated with the steering mechanism as well by using a commercial servo motor stripped of its electronics to provide control of ▶

PARTS LIST

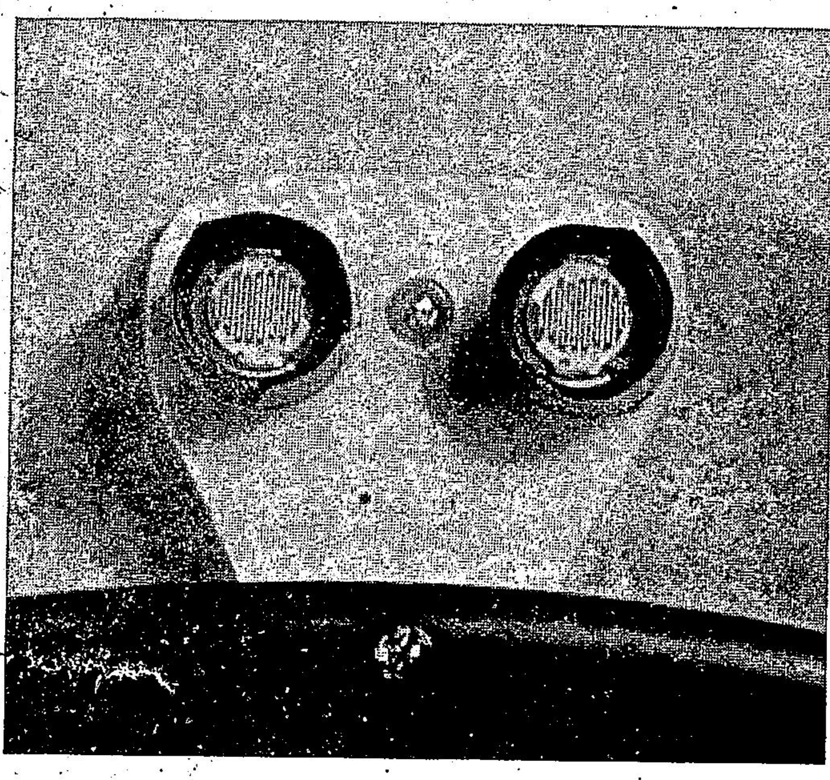
RESISTORS	
R1	220k
R2,3	47k
R4,5,6	1k
R7,8	2k2
R9	10R
R10	470k
LIGHT DEPENDENT RESISTORS	
LDR1,2	ORP12
POTENTIOMETER	
RV1	2k2 min vert
CAPACITORS	
C1	330u Polyester
C2,3	10u 10 V Electrolytic
SEMICONDUCTORS	
Q1,2,4	BC214
Q3,5	BC184
Q6	BD140
Q7	BD139
MISCELLANEOUS	
PCB as pattern, 3V bulb, 2-pole on/off switch, servo motor and car (see text)	



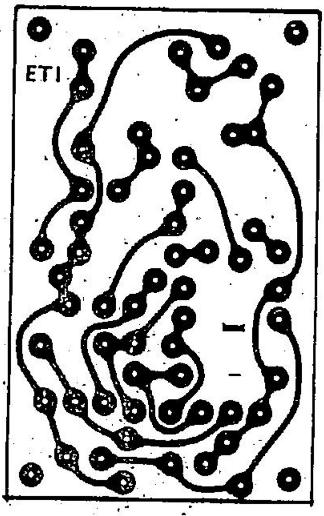
On the right the Porsche with its lid off. The PCB is mounted behind the drive motor, which is sitting between the rear wheels. The servo is sited between the front wheels, and the board upon which we put the LDRs and bulb can be seen on the front of the chassis.

BUYLINES

Purchasing the electronic components should prove straightforward. The mechanical parts are, as we say in the main text, a matter for the individual constructor.



Above: the eyes of the animal. The bulb lies right between the LDRs. On the right: the foil pattern for the white line follower circuit, shown full size.



the steering. Again for those with a mechanical bent, a standard model motor (one that will operate reliably on 1.5V) driving the front wheels via suitable links is probably the best bet.

Ideally the sensors should be mounted in front of the wheels and should move with them so that when the wheels turn to the right the sensor does likewise and visa versa (another test of mechanical ingenuity).

The LDRs were housed in short lengths (about 10 mm) of cardboard tube to act as a shield and were spaced about 15mm apart (we used a 12 mm wide line) with the bulb mounted between them.

Electrically the components can be built onto the PC board described which can be mounted somewhere in the car. We used separate batteries for the electronics and ran the bulb off the main batteries, to keep the electronics supply more constant.

Experimenting

Using different motors/gear ratios some changes to the electronics will probably be found necessary. These would mainly involve C1, R1 and R10. Increasing R10 or reducing R1 increases the DC gain, while increasing C1 increases the dynamic damping to reduce overshoot. Track width may also be experimented with as well as LDR spacing. ETI