Construction Project:

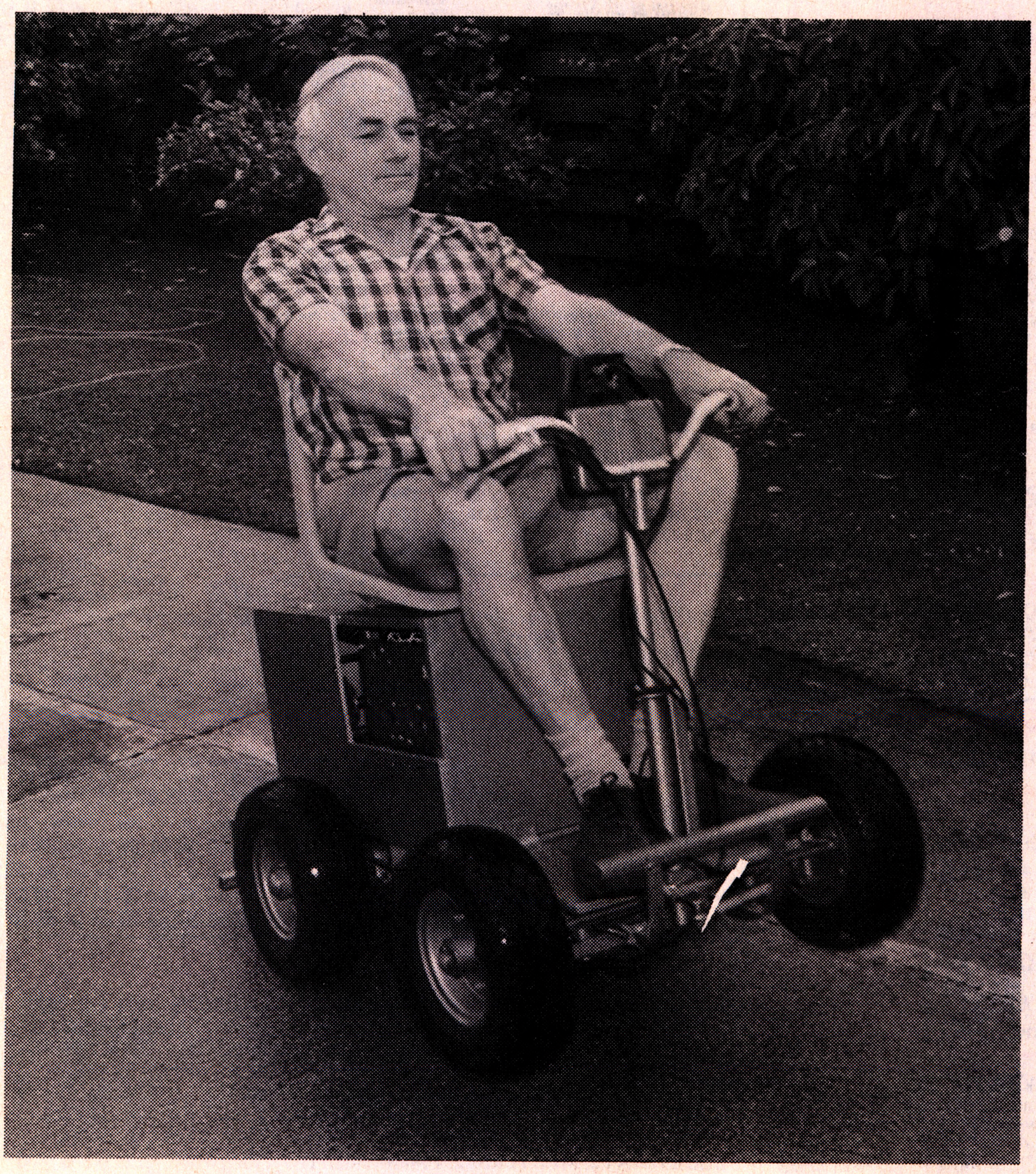
5KW DC MOTOR SPEED CONTROLLER

Here's a relatively simple, but reliable electronic speed controller for DC motors running from voltages up to 50V. The author developed it to control the motor of an electric wheelchair, but it could be used to control any similar kind of motor. The design can also be scaled up or down, to suit larger or smaller motors.

by RON BADMAN, ZL1AI

When a colleague recently built a *high* powered wheelchair for his handicapped wife to negotiate their beachhouse property, I agreed to provide the motor speed control electronics for it. This article describes the simple and inexpensive DC motor speed controller which resulted, and which will comfortably handle up to five kilowatts using chopper techniques. The total cost of parts used in the controller itself is about A$35.

The wheelchair concerned is a four wheeled machine, with drive to the rear wheels via a high mounted differential and chain drives. The steering uses handlebars coupled to tie rods on the front wheels. Power was provided by four aircraft type gel cell batteries, giving 50 volts at a very high current capability.



After first trying a 50 volt shunt wound motor which proved to have insufficient power, the motor selected (because it was available) was a 32 volt compound wound DC motor measuring some six inches in diameter by 10 inches long. It was labelled '1/4 horsepower', which seemed rather light for its size. We tested it at both 36 volts and at 50 volts and it proved to have more than sufficient power for the job. It had a stall current in the region of 100 amps.

Design approach

I decided to use a pulse width modulated drive to the motor, with a variable on/off ratio for speed control. Using this technique I could see no difficulty retaining the full 50 volt battery. Electric motor ratings are *average* ratings and can be exceeded substantially for short periods, provided the motor temperature remains within reasonable limits — provided also that the commutator can handle the current, and that the shaft can handle the torque.

In normal running, the wheelchair motor is operating well within its ratings, but still has the capacity to provide emergency power when required, by exceeding the (average) motor ratings for short periods.

After considering all sorts of speed regulating techniques, and discussing these with the wheelchair owner, we concluded that a simple accelerator control without speed regulation was all that was required. (i.e., the system you have in a normal motor vehicle). I decided to start by using the ubiquitous 555 timer, in a simple astable circuit capable of varying the on/off ratio from 1% to 99% with a single potentiometer. This circuit

in fact did the job so well that I have used it unchanged in the final unit.

I chose power MOSFETs as the control elements because of the ease of driving them at high currents, and because they can be paralleled so easily, unlike bipolar transistors. I settled on the IRF640, an N-channel enhancement mode MOSFET with ratings of 18 amps continuous, 72 amps peak, and 200 volts maximum. The leads on the FETs looked so thin that I wondered how on earth they would handle these currents, but of course they did.

Each FET has an ON resistance at maximum current of 0.18 ohm, with +10 volts on the gate. I used six of these in the controller, so it will handle 108 amps continuous and 432 amps peak. The total resistance is 0.03 ohms, giving a voltage drop of 0.7 volt at 20 amps or 3.0V at 108 amps.

The circuit

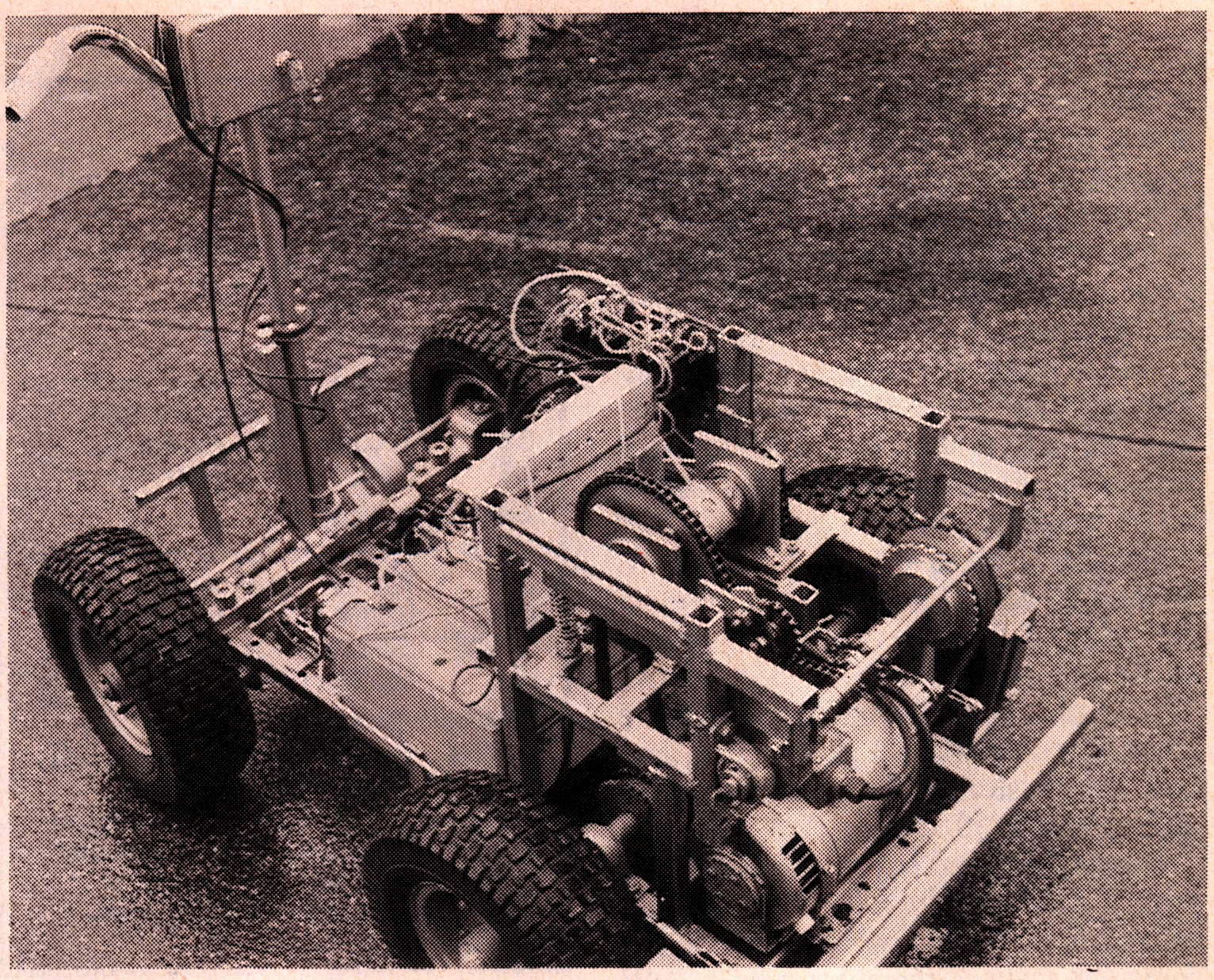
The circuit is shown in Fig.1. The speed control element RV1 is a 50k slider potentiometer, coupled to a foot activated accelerator pedal.

Capacitor C1 charges through R1, the upper section of RV1 and D1, until the voltage on pin 6 of the 555 reaches 2/3 of the pin 8 voltage. Pin 7 then pulls down to ground, and C1 discharges through D2, R2, and the lower section of RV1 until pin 2 of the 555 reaches 1/3 of the pin 8 voltage. Pin 7 then floats, and the recharge cycle starts anew. So the charging is controlled by the upper part of RV1, whereas the discharge is controlled by the lower part. Thus moving RV1 changes the on/off ratio over a very wide range, while leaving the total period (and hence the frequency) constant. The 555 drives the MOSFETs directly, with a 10 volt square wave. (10 volts is required to drive them fully on.) The 555 and MOSFETs chop the current at approximately 100Hz.

I experimented with the effect on torque of changing the frequency, and tried a circuit which increased the frequency as the pulse width increased, but found no improvement over the constant frequency. In fact, at higher frequencies the motor can emit considerable noise, whereas at 100Hz it is almost silent.

The rectifier bridge D4 - D7 is used to protect the MOSFETs and to absorb the inductive EMF from the motor when the current is interrupted. The BR358 bridge with its diodes paralleled as shown makes an inexpensive pair of diodes which can handle 100 amps peak. Two single diodes of suitable rating could of course be used.

The IRF640 MOSFETs actually have their own in-built diodes, so that strictly speaking the lower diodes on the bridge are not needed. However I feel that they provide good protection for the MOSFETs, at little cost.

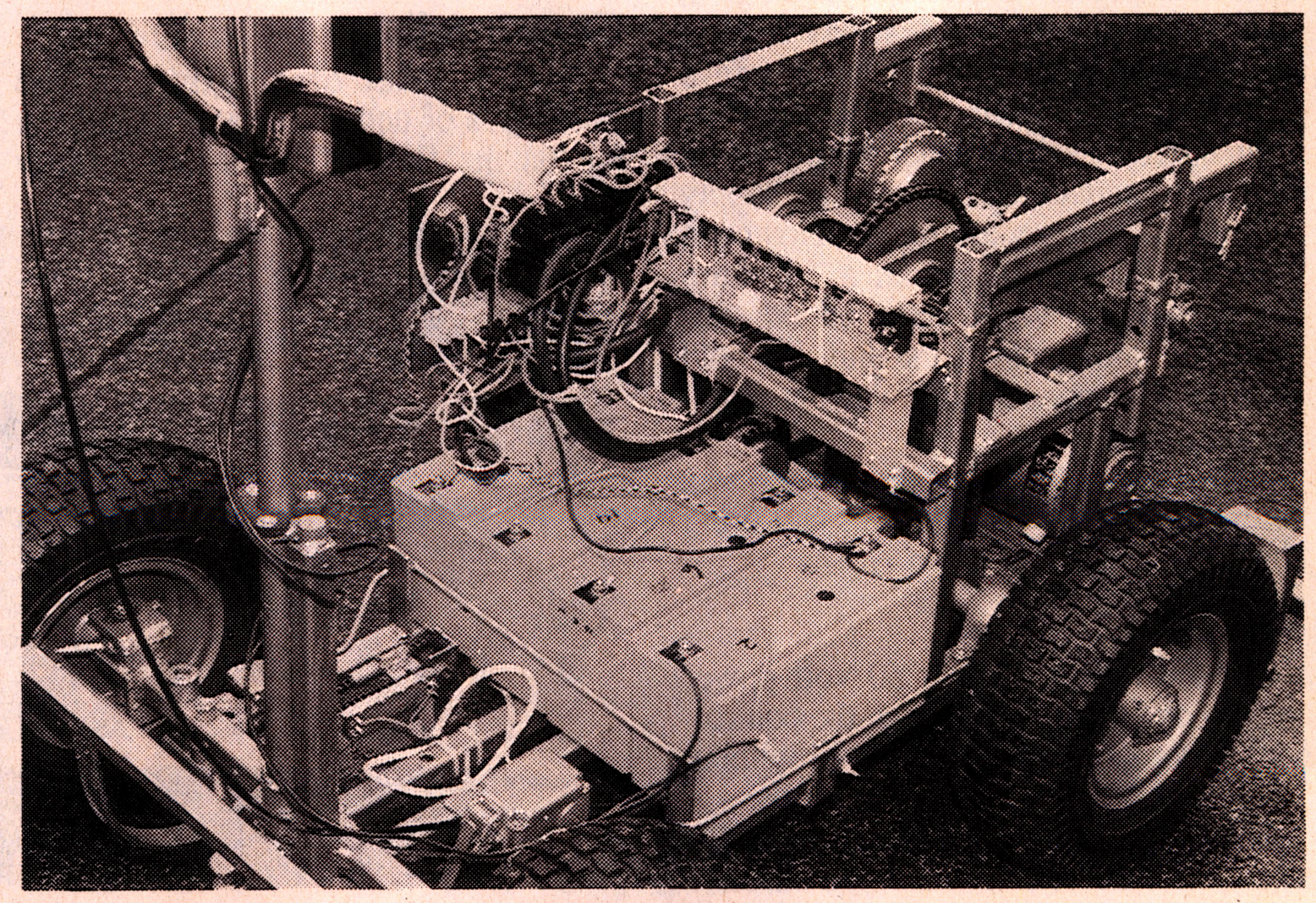


The electric wheelchair for which the author designed the speed controller described in this article, with its covers removed. The motor and drive system are mounted under the seat, with the controller module at top front.

The 10V supply

I found it more difficult than I had expected to obtain 10 volts for the 555 pulse generator. I could not use a three terminal regulator, because of their voltage limitations. Even the LM317HV, rated at 60 volts, would have been marginal, as the batteries on full charge run to some 55 volts and this voltage appears across the regulator upon switch on.

I therefore decided to use an emitter follower transistor, with its base voltage fixed by a zener diode, a technique I had used often in the days before three terminal regulators. For some reason, this circuit did not want to work with the chair controller, and promptly blew a piece off the regulator transistor. I



Another view of the wheelchair with covers removed, showing the batteries and giving a better view of the controller and fuse panel.

5KW DC Motor Speed Controller

retaliated, after a lot of thought, with some heavier components and some bypass capacitors, to avoid any possibility of oscillation.

The controller, in a fresh offensive, blew a lead off the transistor and a track off the board!

At this stage, I decided that a more intrinsically safe 10 volt regulator was required, .and I therefore settled on a simple zener diode regulator with a series resistor.

Now I wanted to test the chair with 24, 36, and 50 volts. I therefore had to select the value of the series resistor to supply sufficient current for the 555 (about 12mA) plus a small current through the zener (I chose 12mA) at 24 volts, and both the resistor and the zener had to be able to handle 50 volts applied.

Thus R3 worked out at 630 ohms, and with a 50V supply it would dissipate some 2.5 watts, and the zener diode D3 some 0.6 watts. I therefore used a 10W resistor and a 5W zener in the prototype. You may prefer to select R3 to suit the voltage used, and so minimise heating. Determine the value from the formula:

R = 33 x (V-10)

where V is the supply voltage you intend to use. Then use the nearest preferred value, e.g., if you wish to use 24 volts, the calculated value of R is 462 ohms, so you use a 470 ohm resistor.

Reversing

I made no provision for reversing the motor electronically. Being compound wound, I could not reverse the shunt field winding to reverse the motor as it would then oppose the series field. I could have placed the armature in a bridge rectifier circuit, so that the armature current was always in the same direction, and then reversed the supply voltage to reverse the motor. However, this would have required a 100-amp bridge, which would have added substantially to the cost of the unit. It would also have dropped several volts at maximum current.

The simple and practical approach was to cut the wires to the brushes and bring them out to a reversing relay.

The trial...

On the bench, with a 50 volt power supply and a 330 watt motor, the controller worked perfectly first time, without R4-R11, C5 or the dissipative beads.

However, when I installed it on the chair, with 50 volts of battery, a different motor, and long leads between motor and controller, some of the MOSFETs suddenly grew hot when the accelerator potentiometer was opened.

PARTS LIST

Resistors

R1,2,4-10	1k 1/4W
R31	1.2k 5W (see text)
R11	18 ohms 1/2W
RV1	50k linear pot

Capacitors

C1	0.22uF metallised polyester
C2	0.1uF metallised polyester
C3	1000uF 16VW electrolytic
C5	0.27uF metallised polyester

Semiconductors

D1,D2	1N4148 silicon diode
D3	10V 1W zener diode
D4-D7	BR358 rectifier bridge
Q1-Q5	IRF640 power MOSFET
IC1	555 timer

Miscellaneous

B1-B14 Ferrite RF suppression beads, Philips type 020-15460

PC board, 58 x 205mm, code 94msc10; 270mm length of aluminium U channel extrusion, 76 x 38 x 4mm; length of 1.6mm copper wire; nuts, bolts, lock-washers etc.

After fitting the additional components, a smooth control was achieved with no heating. Gradually working up to full power, I found that some minutes were required before any warmth at all could be felt in the MOSFETs or heatsink. The motor itself showed no sign of warmth after some 30 minutes of running the chair, including some heavy current use.

You may not need the dissipative beads, but I think it is a good precaution to include them.

Construction

With a total dissipation in the MOSFETs of under 20 watts when driving on the flat, I figured that a fairly simple heatsink would suffice. I decided to line the MOSFETs up side by side inside a 270mm length of 76 x 38 x 4.7mm 'U' channel of aluminium, with the 555 circuitry at one end of the channel, and all components mounted inside the channel for mechanical protection.

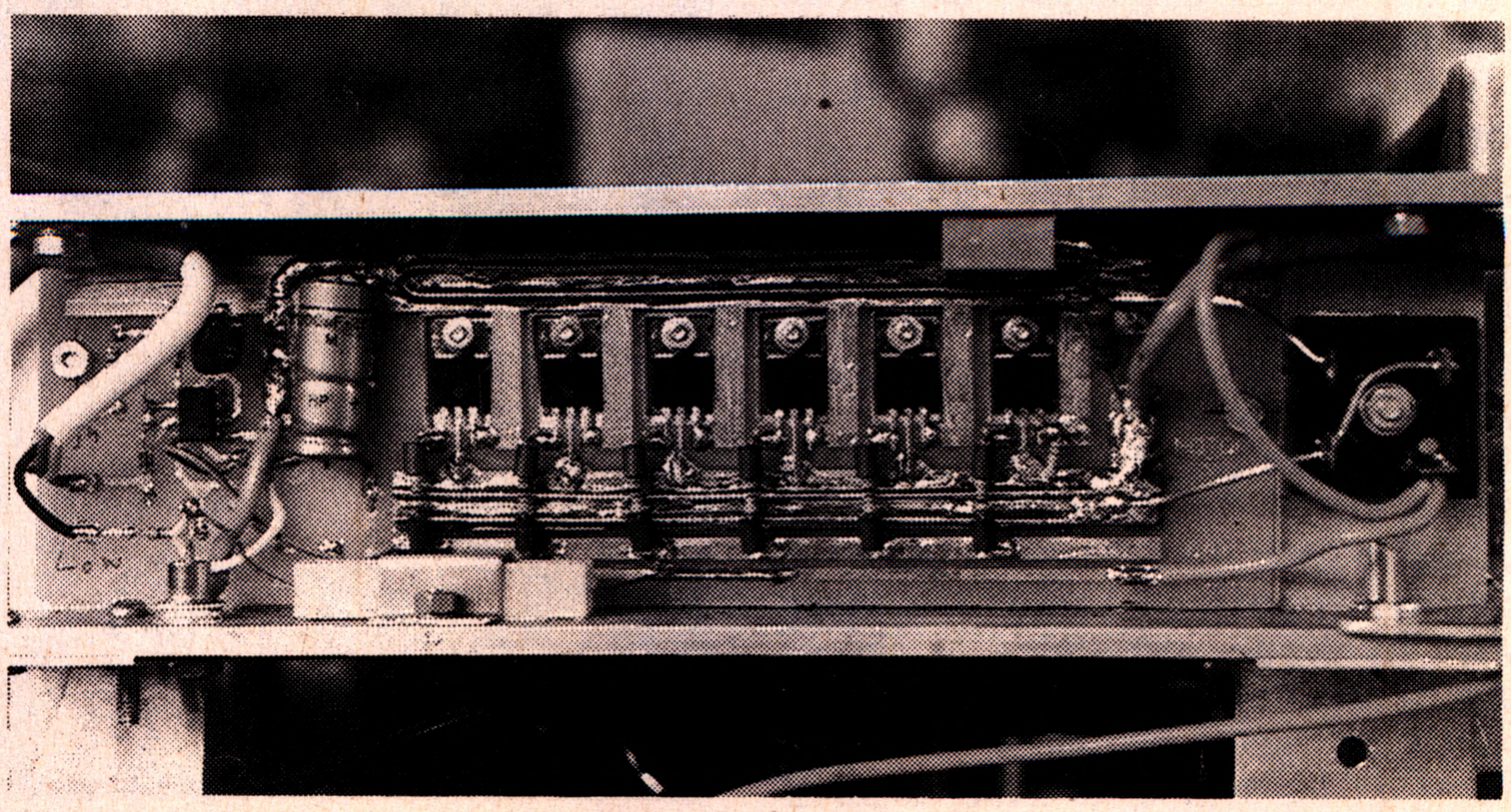
Now to carry 100 amps the main PCB tracks must be some 10mm wide, and this posed problems in laying out the board. If I mounted the MOSFETs vertically on one edge of the board, as is commonly done, their leads would not reach both tracks.

Also, because of the currents involved, I wanted to keep the leads short, rather than extend them.

I overcame these problems by running the main current carrying tracks one on each side of the FETs, and cutting rectangular holes in the PCB so that the FETs could lay flat on the aluminium surface (with insulation of course). The next difficulty was to solder the FETs in place accurately under the board so that when it was turned over and mated to the channel, the FETs would line up correctly with their mounting holes.

At this point I had the idea of making the PC board upside down, with all components on the copper side. This had several advantages: the PCB could be laid (track side up) flat on the channel without spacers, and the FETs then bolted to the channel with their leads sitting against the tracks, ready for soldering. It also meant that FETs could be replaced easily if required, without removing the PCB. All other components I surface mounted.

I used normal components, but mounted them on top of the board, bending the component leads and pins at right angles, to give good soldered connections. Because they were added later, C5 and R10 are not mounted on the board,



A close up view of the author's prototype controller — built before resistor R3 and the 10V zener diode were allowed for on the board.

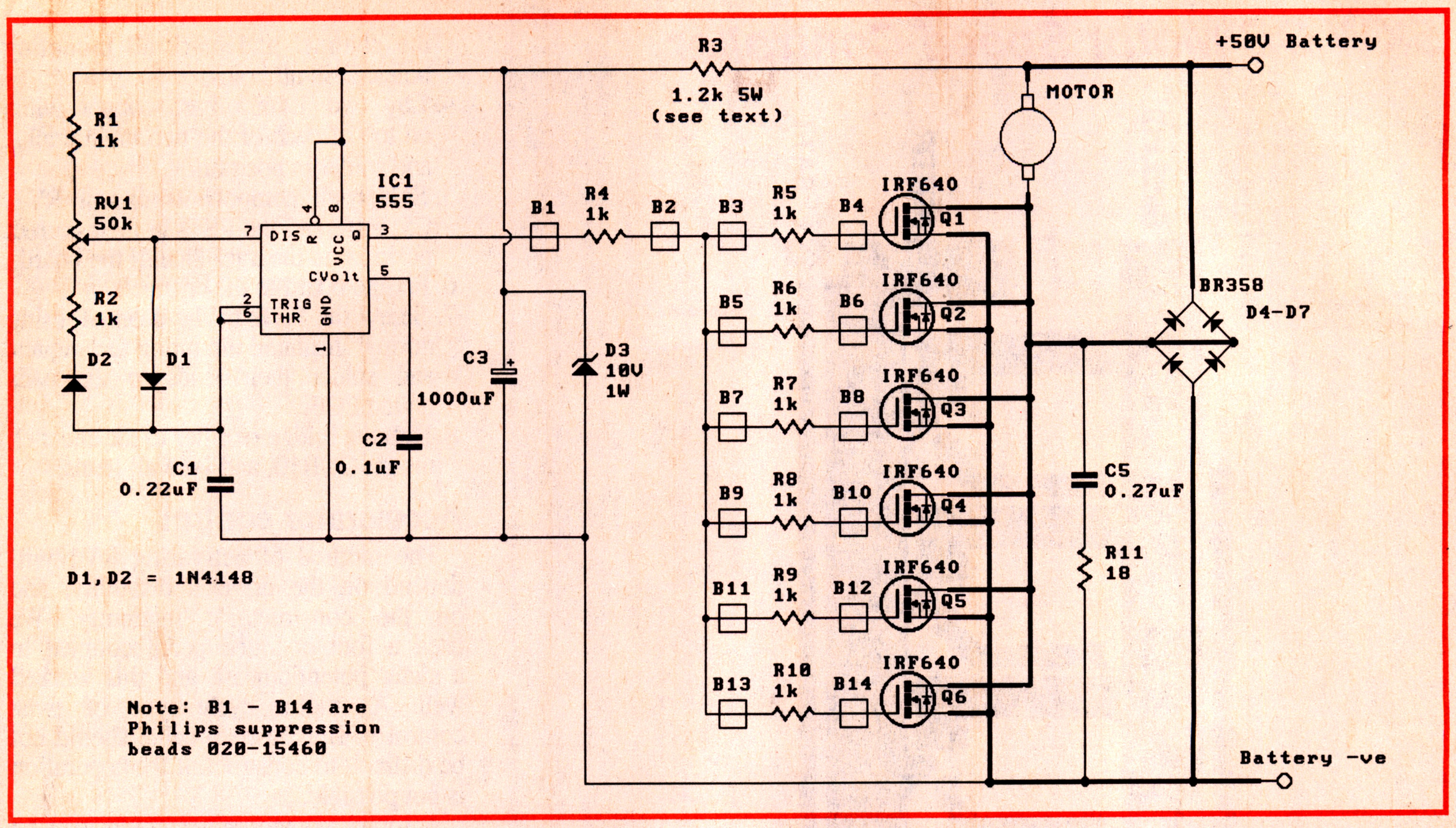


Fig.1: As you can see from the schematic, the circuit of the controller is surprisingly simple. A 555 timer chip is used to generate a 100Hz squarewave of adjustable duty cycle, and this is used for pulse-width control of six IRF 640 power MOSFETs in parallel, switching the motor current. Stopper resistors and ferrite beads are used to ensure stability.

but were wired separately, using an insulated tie point fixed to the U channel. The rectifier bridge D4-D7 is fixed to the U channel, just clear of the end of the board, to provide heat sinking.

After selecting the track widths to handle the expected currents, I decided I would like an added safety margin while experimenting, so I laid two strands of 1.6mm bare copper wire on the main tracks, and soldered them in position.

This is easy to do with the 'upside down' PCB, and it also prevents the PCB from acting as a fuse in the event of a short circuit. You should, of course, use a circuit breaker or fuse in the main supply lead to protect the controller and motor against accidental shorts.

The PCB artwork is shown full size in Fig.2, and the component layout in Fig.3. Because the component leads do not go through the board, there are no component mounting holes in the PCB. I initially mounted R3/D3 on the side of the U channel for cooling, but after revising the value of R3 as described earlier, I modified the PC board to accommodate these two components.

I did not revise the PCB after adding C5/R10, hence these remain mounted on tag strips.

You could, if you wish, extend the board to accommodate these latter components. I have included photos of the prototype, to show the general method of construction, but bear in mind that the PCB layout has been revised since the photos were taken.

Assembling the unit

Here are some points to note in connection with assembling the controller, in the recommended sequence:

1. Make sure the PCB has cut-outs in it for mounting the FETs. If it does not, you will have to drill holes of about 10 mm diameter, and then use a nibbling tool or file to shape the holes so that the FETs will fit through them.
2. Drill mounting screw holes in the PCB for screwing it to the channel.
3. Lay the PCB and FETs in position on

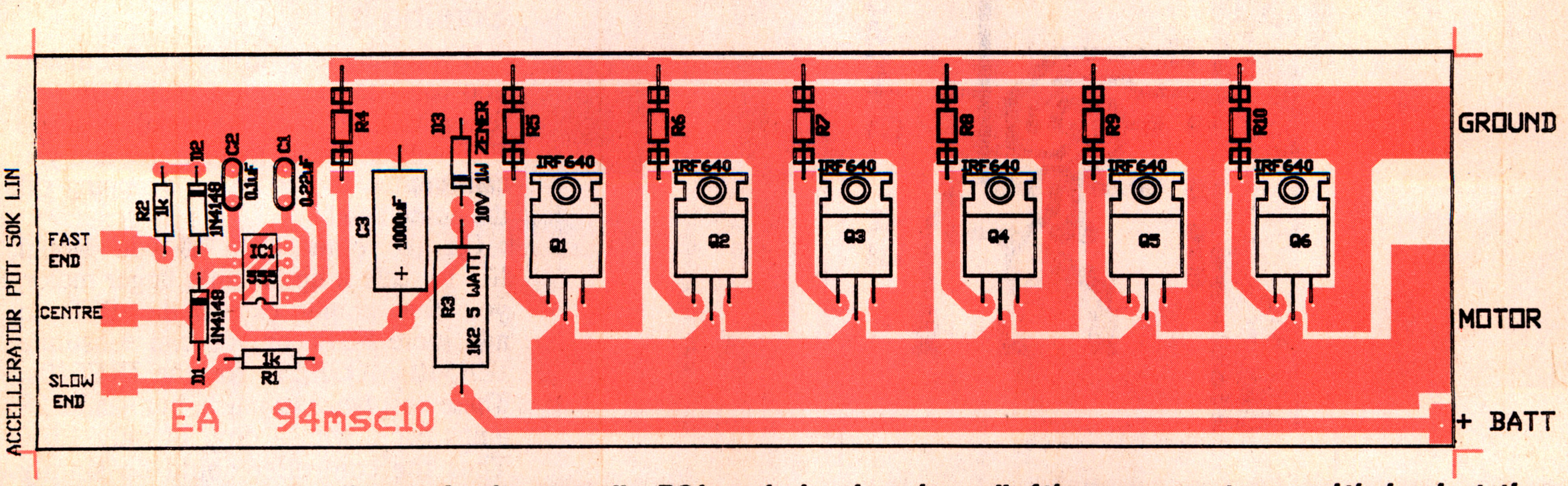


Fig.2: Here is the overlay diagram for the controller PC board, showing where all of the components go and their orientation. Snubber components C5 and R11 are mounted off the board, as is the BR358 rectifier bridge and control pot RV1.

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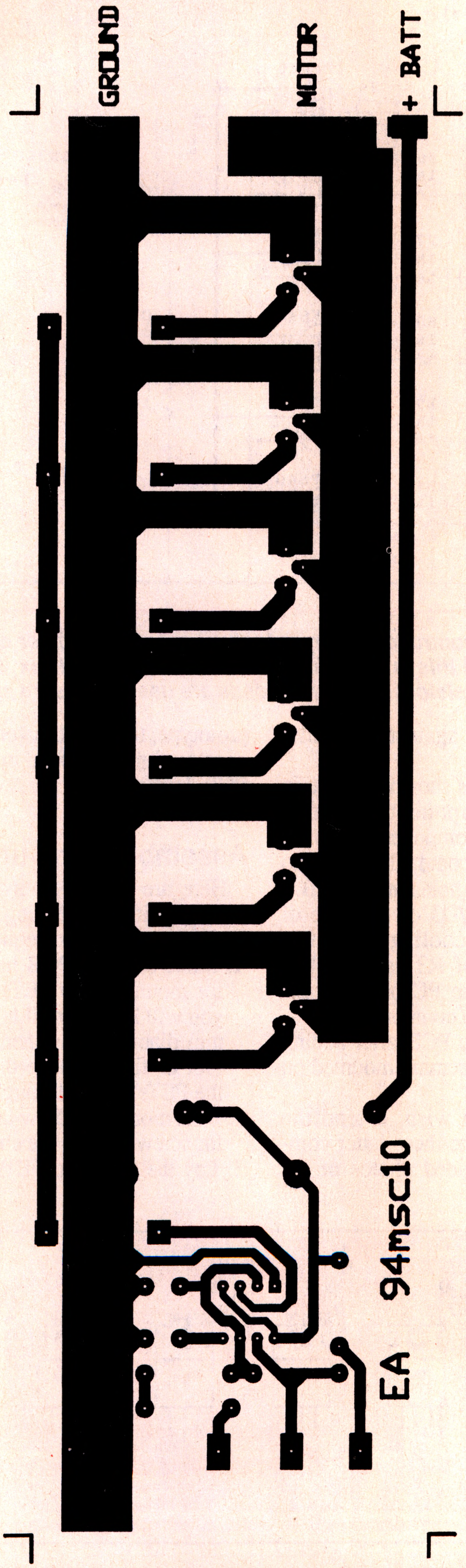

Fig.3: The artwork for the controller PC board, reproduced actual size for those who wish to etch their own boards.

the channel and mark all mounting holes. Drill all holes.

4. Lay two 1.4mm bare copper wires on top of each of the two main tracks, and solder in position.
5. Solder all components except RV1, C5, R10, and the FETs in their correct position on the track side of the board.
6. Fix the board to the channel.
7. Screw the FETs to the channel, using normal insulated mounting techniques, and solder their leads to the pads on the PCB.
8. Bolt the bridge rectifier to the channel, mount C5/R10, and wire all items.

Accelerator control

The method of activating RV1 will depend on the driver's disability, and on the constructor's ingenuity. We used a foot operated pedal coupled to a slider potentiometer, and this worked well. A motor cycle type of twist control with a Bowden cable should not be difficult to construct, if foot operation is not possible.

A rotary potentiometer could also be used, but I think the linkages would be a little more complex than for the slider type.

Performance

Control is very smooth. The chair can inch away, or if the pedal is floored, it will do 'wheelies' — lifting the front wheels clear of the ground.

At walking speed on level ground, the motor draws some 5A, and at jogging speed about 10A, rising to 25A on a hill and 45 - 100A on a steep ramp, or to lift the wheels over a substantial obstacle.

In normal use, (with dissipation in the MOSFETs under 20 watts) the heatsink runs cold. At maximum current of 100A, dissipation rises to about 300 watts, but as such use is rare and of short duration, little heating results.

Scaling it

If you want to control a smaller motor, you can use the same circuit, but with fewer MOSFETs on the board. A single FET will do for up to 18 amps, and you can shorten the board by chopping off the unused end.

On the other hand if you would like to scale it up to suit a larger motor, you can simply extend the PCB to add more FETs, or you can substitute IRF540 MOSFETs for the IRF640s. These cost twice as much, but handle 28 amps each, with a drop of only 1.6V. Thus the controller could be simply upgraded to handle 168 amps by changing the FETs... ❖