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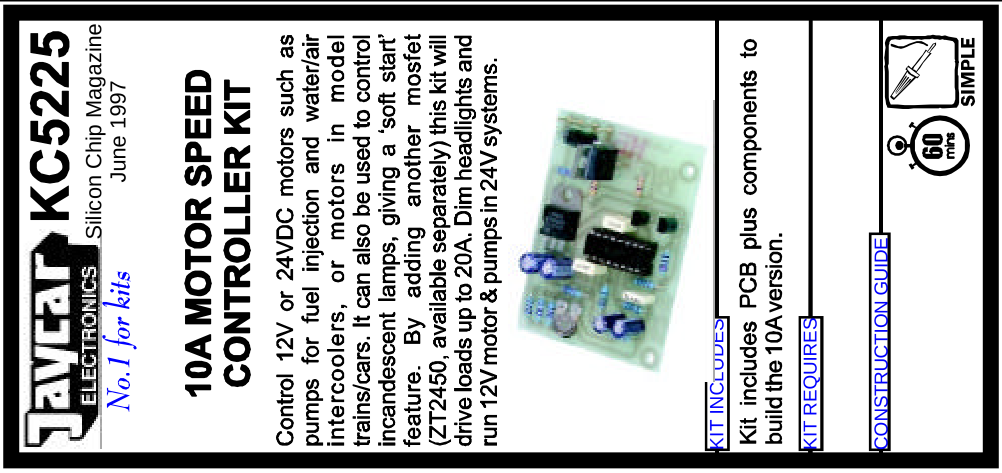
KC5225: 10A DC SPEED CONTROL

Silicon Chip Magazine June 1997 (p26 to p30)

Rev 2.2 **Batch No:**



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- Product Number
- Batch No
- Details of Quality Issue

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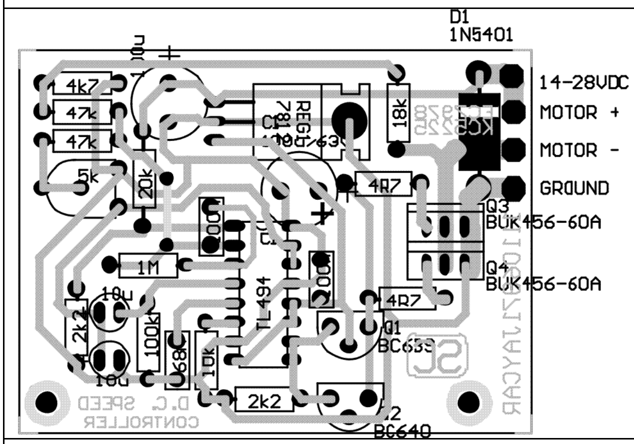
Rev 2.2

Notes and Errata (at time of print):

It is recommended to check the designers/publishers website for further notes and errata since this document was issued, before starting construction.

SC 08/1997
There is a mistake in the text on page 30, third paragraph down. The text states "Make sure that they (the diodes) are connected in the right direction across the motor; ie, anodes to the positive supply line." **The diode(s) should be connected with cathode to the positive supply line, as shown in the circuit and wiring diagrams.**

SC 10/1998
The text on page 30 states that you should be able to measure about +12V at pin 16... of IC1. Pin 16 is grounded - it should refer to pin12.



Jaycar Electronics:
The component spacing for the 2 * 100uF/63V(50V) capacitors on the Pcb is insufficient. Jaycar has substituted one of the capacitors with a 100uF/25V to address this issue. Nevertheless the 2 capacitors will not fit flush onto the pcb.

Jaycar Electronics has revised the Pcb to address the capacitor fitting issue (see left) and to accommodate both 5 & 10mm VR1 trimpots..

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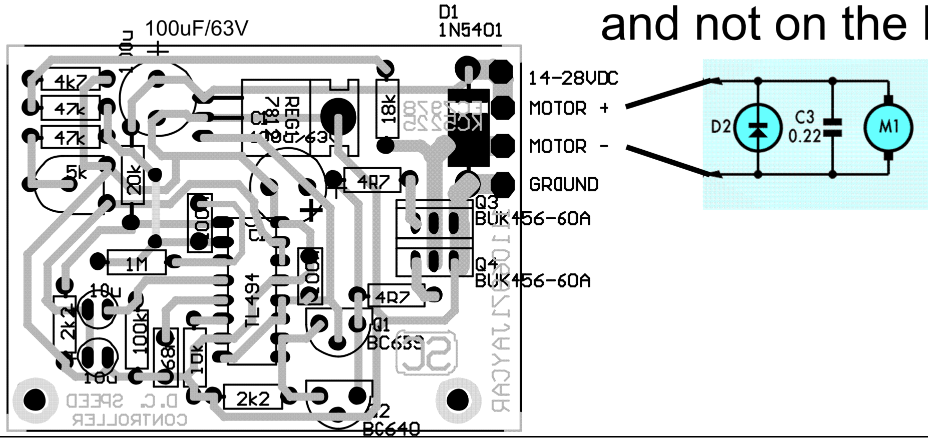
Please note that the PCB has been modified to accommodate 5 & 10mm pitch Vr1 and physical larger size 100uF capacitors.

D2 and C3 mounted across the motor and not on the Pcb.



Possible Substitutions			
Original Part	**Original Part Desc**	**Subst Part**	**Subst. Part Desc.**
~~EC7839~~	~~PCB SC11106971 SPEED CONTR~~	EC7978	PCB (KC5225) SC11106971 REV2 SC06/97
RE6066	10uF 16V Electrolytic	RE6070	10uF 25V Electrolytic
RT4310	5k horizontal trimpot	RT4358	5k horizontal trimpot (piher) and adjust the pins.
Silicon Chip	100uF/50V on the input side of the 12V regulator	RE6150	100uF/63V on the input side of the 12V regulator
Silicon Chip	100uF/50V on the output side of the 12V regulator	RE6130	100/25V used on the output side of the 12V regulator

PARTS LIST

Please note that quantities listed refer to the actual number of items required. When purchasing individual items separately, take pack quantities into account.

[1] *See section about Substitution* [2] **See section about Notes & Errata**

RESISTOR(S)

Cat.#	Qty*	Description	Component Identification And/Or Location
HP1250	4	P.C PIN 0.9MM PKT 50	
RR0580	2	2K2 .5W METFILM 1% PKT 8	Red Red Black Brown Brown
RR0588	1	4K7 .5W METFILM 1% PKT 8	Yellow Purple Black Brown Brown
RR0596	1	10K .5W METFILM 1% PKT 8	Brown Black Black Red Brown
RR0602	1	18K .5W METFILM 1% PKT 8	Brown Gray Black Red Brown

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Rev 2.2

RR0603	1	20K .5W METFILM 1% PKT 8	Red Black Black Red Brown
RR0612	2	47K .5W METFILM 1% PKT 8	Yellow Purple Black Red Brown
RR0620	1	100K .5W METFILM 1% PKT 8	Brown Black Black Orange Brown
RR0644	1	1 M .5W METFILM 1% PKT 8	Brown Black Black Yellow Brown
RR1518	2	4R7 5% 1/4W CARB RES PKT 8	Yellow Purple Gold Gold
RR3274	1	100 OHM 5W W/W RESISTOR	
RT4310	1	5K OHM HORZ MIN T-POT	502

CAPACITOR(S)

Cat.#	Qty*	Description	Component Identification And/Or Location
RE6066	2	10U/16VRB ELECT CAPACITOR	10uF / 16V
RE6140 [2]	**1**	**100U/25VRB ELECT CAPACITOR**	**100uF / 25V** **Output Side of the 12V Regulator, next to the IC**
RE6150	1	100U/63VRB ELECT CAPACITOR	100uF / 63V
RM7115	1	.068UF 68NF 100V MKT POLY	0.068uF / 68n / 683
RM7125	2	.1UF 100NF 100V MKT POLY	0.1uF / u1 / 100n / 104
RM7145	1	.22UF 220NF 100V MKT POLY	0.22uF / u22 / 220n / 224

SEMICONDUCTOR(S)

Cat.#	Qty*	Description	Component Identification And/Or Location
PI6502	1	16 PIN IC SOCKET PCB TIN/G	
ZK8850	1	UA494/ TL494 SWITCHMODE IC	UA494/TL494
ZR1014	1	1N5404 3A 400V DIODE	1N5404
ZR1030 [2]	**1**	**MUR1560/STTA1206D FAST RECOVERY DIODE**	**D2** **MURI 560**
ZT2179	1	BC639 NPN 80V 1A SIG TO92	BC639
ZT2180	1	BC640 PNP 80V 1A SIG TO92	BC640
ZT2450	1	STP60NE06 / BUK456-60 N-CH FET ***	STP60NE06 / BUK45660
ZV1512	1	7812 +12V 1AMP TO-220	7812 / LM340T12

HARDWARE / WIRE(S) / MISCELLANEOUS

Cat.#	Qty*	Description	Component Identification And/Or Location
EC7978 [2]	**1**	**PCB (KC5225) SC11106971 REV2 SC06/97**	**SEE NOTES AND ERRATA**
NS3015	50m	SOLDER 60/40 1MM 1KG RL	

A high-current motor speed control for 12V & 24V systems

This pulse width-modulated 20A speed control can be used for controlling 12V DC motors in cars. Examples are pumps for fuel injection, water/air intercoolers & water injection on modified performance cars. It could also be used for headlight dimming in the daytime & for running 12V motors & pumps in 24V vehicles.

Design by RICK WALTERS

These days, car manufacturers are coming to realise that running pumps full bore all the time is wasteful of the battery/electrical system and also causes premature wear of the fuel pump. A prime example of this is the pump use to pressurise the fuel rail in fuel injection cars. The pump runs continuously, regardless of the fuel demand, and the excess fuel is bled off to the fuel tank to keep the pressure constant.

In the future, most cars will have fuel pumps which are variable speed controlled according to fuel demand. In the meantime, you can do it now with this design, using the car's map sensor output as a measure of fuel demand. However, the exact method for doing this is beyond the scope of this article.

The circuit can control 12V loads up to 20 amps and it uses just two Mosfets to do it.

Other possible applications for this PWM circuit are for control of 12V and 24V motors in model locomotives and cars and in control applications in manufacturing. The circuit has excellent line and speed regulation and uses just one low-cost IC as well as the two Mosfets.

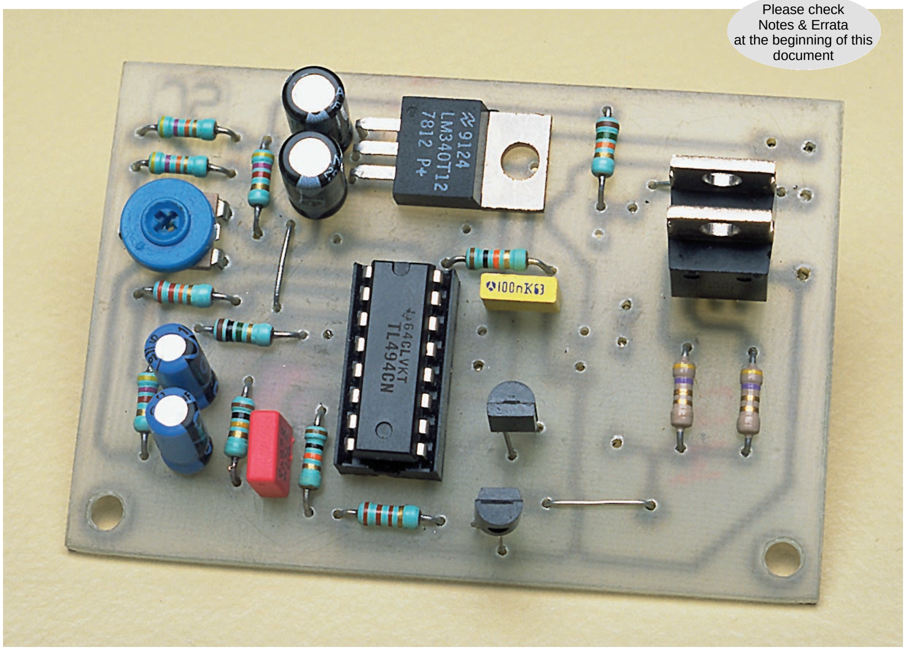
Note: this circuit is not suitable for operating 12V audio equipment in 24V vehicles since its output is pulsed at around 2kHz.

As presented, the circuit incorporates a "soft start" feature which is desirable to reduce inrush currents, particularly if the device is used to control 12V incandescent lamps. However, for some pump applications the soft start may not be wanted and so we'll tell you how to disable it.

We are presenting this project as a standalone PC board. If you want to put it in a case it is a simple matter to install it in a suitable plastic box but that will be up to you. The PC board has all components on it except for a diode (D2) and a capacitor which must be wired across the motor being driven. If the circuit is used to control incandescent lamps, the diode and capacitor are not required.

Circuit description

The heart of the circuit shown in Fig.1 is a TL494 pulse width modulation (PWM) controller. It varies the output voltage fed to the motor by rapidly turning Mosfets Q3 & Q4 on and off. Because the Mosfets are being



This small PC board will provide speed control of 12V or 24V motors drawing up to 20A. Not shown on this prototype board is the input protection diode D1

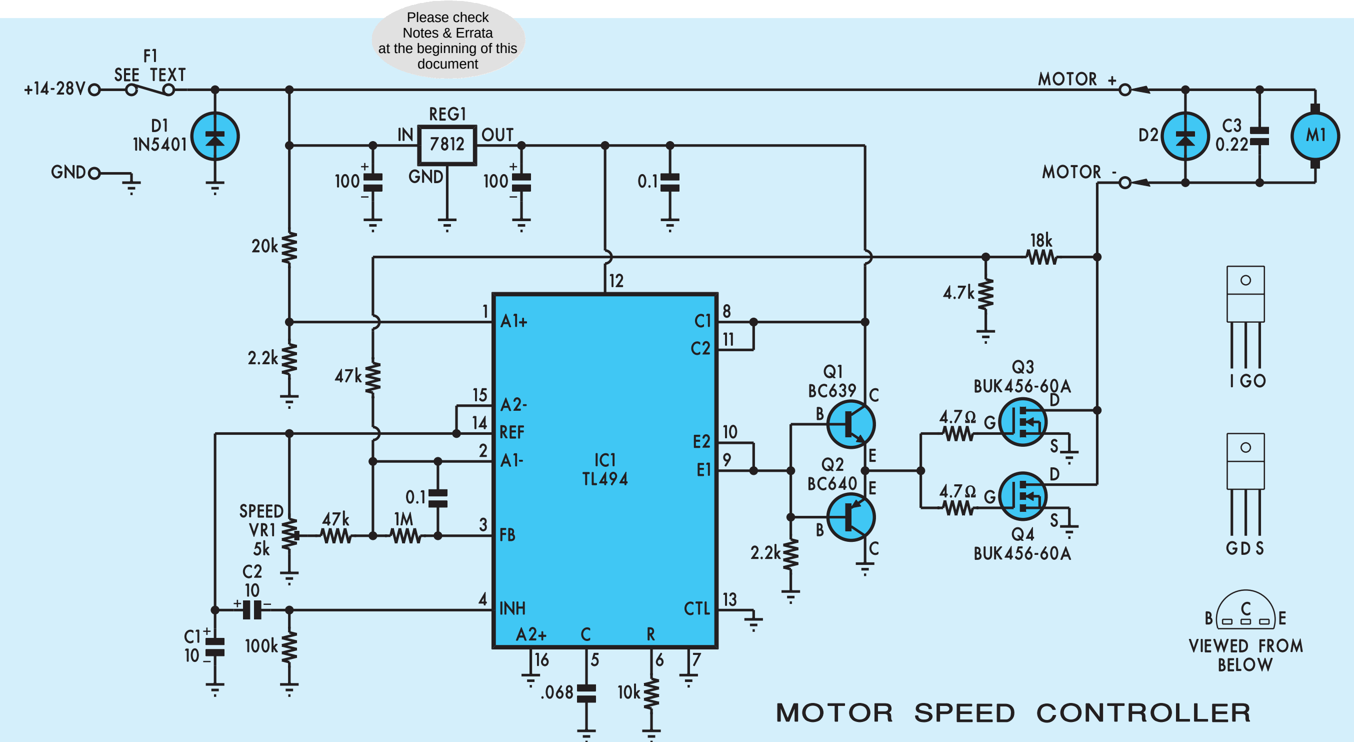


Fig.1: the heart of the circuit is a TL494 pulse width modulation (PWM) controller. It varies the output voltage fed to the motor by rapidly turning Mosfets Q3 & Q4 on and off. Note that diode D2 is essential to the circuit operation.

switched fully on or fully off, they dissipate very little power, even when handling currents as high as 20 amps total. This means that they do not get very hot and no heatsink or very small heatsinks (depending on the output current) are required.

Note that the TL494 is normally used in switchmode power supply applications but it is suitable for virtually any PWM application. Its block diagram is shown in Fig.2. The chip contains the following functions:

- An oscillator, the frequency of which is determined by a capacitor at pin 5 and a resistor at pin 6.
- A stable +5V reference at pin 14.
- A "dead time" comparator with one input driven from the oscillator.
- Two comparators (pins 1, 2, 15 & 16) with their outputs ORed together via diodes (pin 3).
- A PWM comparator with one input from the oscillator and the other from the ORed output of the two comparators.
- A flipflop driven by the dead time and PWM comparators.
- Two 200mA transistors with uncommitted emitters (pins 9 & 10) and collectors (pins 8 & 11), with their bases driven by the outputs of the flipflop.

In simple terms, the TL494 operates as follows. Its oscillator is set to run at 2kHz and it produces a pulse train at its outputs at this frequency. The width of the pulses is varied (ie, pulse width modulated) and the ratio of the "on" time to the "off" time controls the amount of power fed to the load which in this case is the motor.

A fraction of the output voltage is fed to one input of one of the comparators, while the other input is connected to a reference voltage. If the output voltage rises slightly, the comparator input will sense this change and will alter the output on-off ratio and consequently the output voltage. This keeps the voltage at the comparator input equal to the reference voltage.

This is done by reducing the driving pulse on time, reducing the time the switching device is turned on, thereby bringing the output voltage back to the required level. The converse applies for falling output voltages.

Now if we refer to the circuit of Fig.1 again, we see that the TL494 is fed via a 7812 12V regulator. This is not strictly essential for the TL494 since it can operate with a supply ranging from +7V to +40V. However, it is important that the gate drive to Mosfets Q3 & Q4 does not exceed their specifications and so this condition is met with REG1.

In this circuit, the output duty cycle must be able to be controlled over a wide range, from virtually zero up to the maximum of around 90% and so the two internal transistors (C1 pin 8 and C2 pin 11) have their collectors connected to the +12V supply and are used as emitter followers to pull the bases of Q1 & Q2 to +12V. The 2.2kΩ resistor at pins 9 & 10 is the common emitter load and it pulls the bases to ground. Thus, the emitters of Q1 & Q2, together with the gates of Q3 & Q4, swing from 0V to +12V and so the gate drive signal is limited to this voltage.

Q1 & Q2 are included for another reason and that is to rapidly charge and discharge the gate capacitances of the Mosfets each time they turn on and off. This improves the switching action of the Mosfets; ie, it speeds up the turn-on and turn-off times and thereby reduces the power dissipation in the Mosfets.

Soft start

A soft start circuit is incorporated

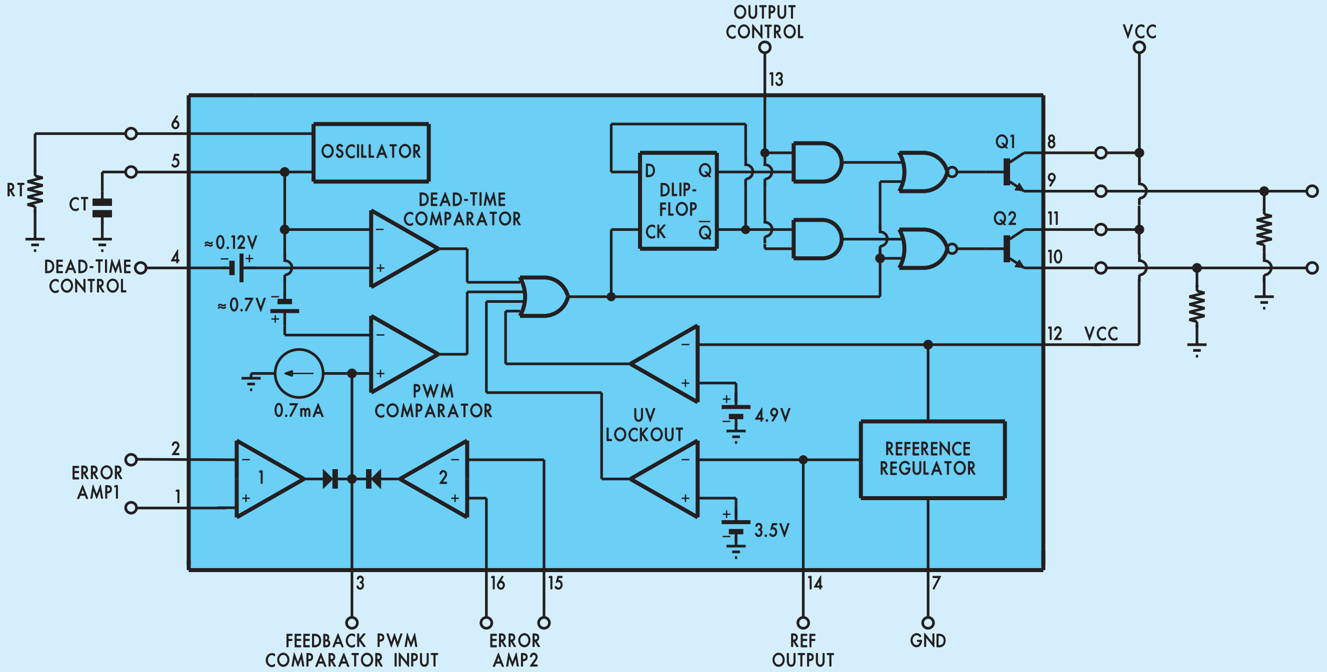


Fig.2: functional block diagram of the TL494. This chip is intended mainly for switchmode power supplies but we have adapted it to control motors and resistive loads.

to reduce surge current into the motor at turn on. When power is first applied, the REF output, pin 14, rapidly charges its associated 10μF capacitor, C1. This pulls the INH(hibit), pin 4, high as the 10μF capacitor (C2) between pins 14 and 4 is initially discharged. While pin 4 pin is high there is no output from pins 9 & 10. As capacitor C2 charges through the 100kΩ resistor the voltage on pin 4 will gradually fall and the output pulse width will increase, giving a smooth rise in the output voltage.

In order to control the output voltage precisely, the TL494 monitors both sides of the motor; ie, the input voltage before the 12V regulator (MOTOR +) and the voltage at the Mosfet Drains (MOTOR -).

The MOTOR+ voltage is fed via the 20kΩ and 2.2kΩ voltage divider resistors to comparator 1, pin 1. The MOTOR- voltage is attenuated by the 18kΩ and 4.7kΩ resistors and fed through a 47kΩ resistor to pin 2. The voltage tapped off the +5V reference by the speed control, VR1, is also fed through a 47kΩ resistor to pin 2.

When the speed control wiper is at minimum setting (ie, 0V), the voltage at the junction of the 18kΩ and 47kΩ resistors will be forced to be twice that on pin 1 of IC1 (nominally 1.4V for +14V input), as the voltage drop across each 47kΩ resistor will be 1.4V. The voltage at the MOTOR- terminal will be about +14V and so the motor will not run.

As VR1 is advanced, the voltage at the MOTOR- terminal will decrease, thereby applying a larger voltage to the motor so it can run.

Normally, the reference voltage on pin 1 of IC1 is fixed and referred to the 5V reference at pin 14. In our case this would not be desirable as the output voltage sensed and regulated by IC1 is between the MOTOR- output and ground (across the 4.7kΩ resistor).

This means that as we vary the supply voltage, the voltage between MOTOR- and ground will be held constant but the voltage across the motor will vary in a direct relation to the voltage change. By connecting the 20kΩ resistor between the input rail and pin 1 of the TL494 we compensate for this.

Protection

Reverse polarity protection is provided by diode D1. It is rated at 3A average but has a one-off surge rating of 200A and will blow the fuse if the leads to the battery are reversed.

Two essential components to the circuit are not mounted on the PC board but are wired directly across the motor itself: D2 and C3. Diode D2 is the most important as it prevents the generation of excessive voltage spikes, each time the Mosfets turn off. D2 must be a fast recovery diode because of the very fast switching of the Mosfets.

The importance of diode D2 and the associated 0.22μF capacitor C3 is demonstrated in the oscilloscope waveforms of Figs.3, 4, 5 & 6. The waveform in Fig.3 shows the circuit driving a resistive load which could be a heater element or an incandescent lamp. Notice that the waveform is a clean pulse with a duty cycle of about 74%. This gives a voltage of about 8.8V across the load.

Now have a look at Fig.4. This shows the circuit set for the same output when driving a motor instead of a resistive load. The scope's vertical sensitivity has been changed to 20V/div instead of 5V/div. Notice the enormous spike voltage amounting to almost 80V peak-to-peak, each time the Mosfets turn off.

This spike voltage is enough to blow the Mosfets because their Drain-Source voltage rating (V_{DS}) is only 60V.

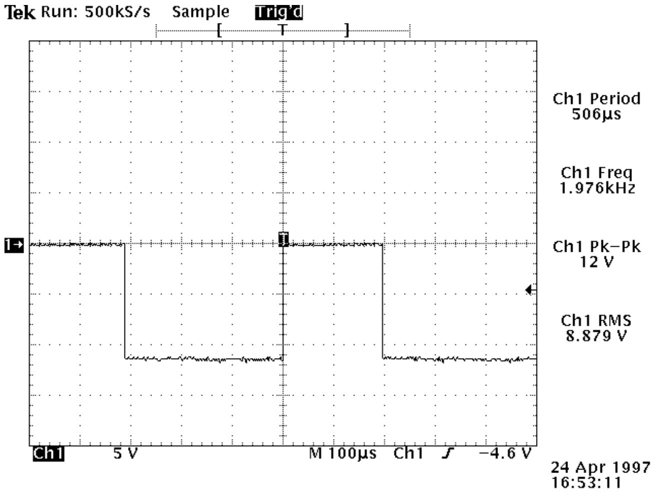


Fig.3: this scope capture shows the waveform across a resistive load which could be a heater element or an incandescent lamp. Notice that the waveform is a clean pulse with a duty cycle of about 74%. This gives a voltage of about 8.8V across the load.

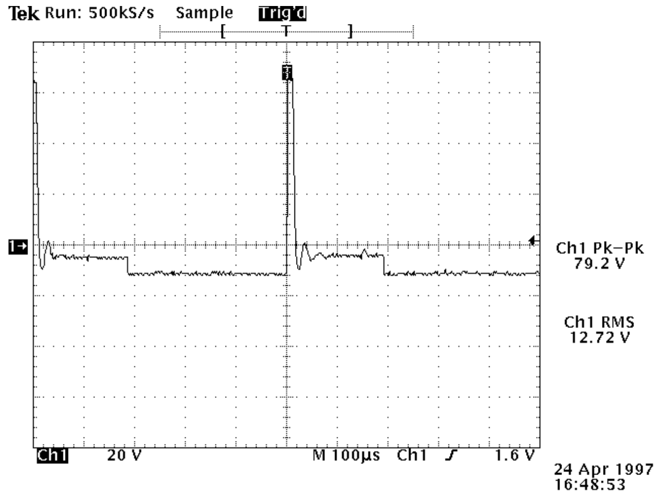


Fig.4: this waveform shows the circuit set for the same output as for Fig.3 but driving a motor instead of a resistive load. The scope's vertical sensitivity has been changed to 20V/div instead of 5V/div. Notice the enormous spike voltage (amounting to almost 80V p-p) each time the Mosfets turn off. This spike voltage is enough to blow the Mosfets because their Drain-Source voltage rating (V_{DS}) is only 60V.

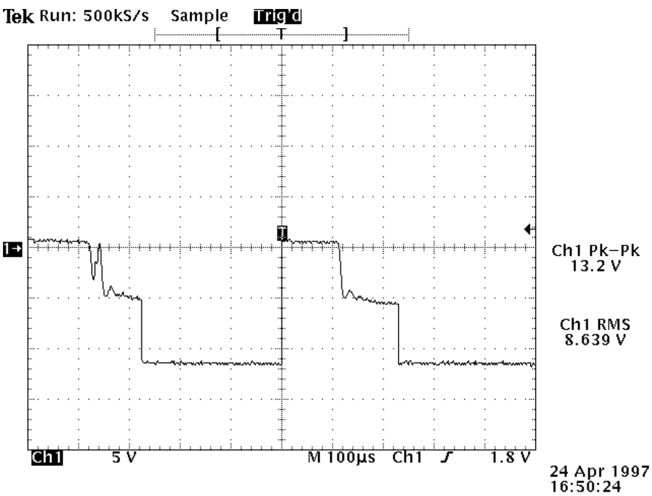


Fig.5: this waveform was produced with the same circuit conditions as for Fig.4 but with D2 connected across the motor to clip the voltage spikes. We now see the motor's back-EMF during the Mosfet off period, showing a value about half of that applied by the control circuit.

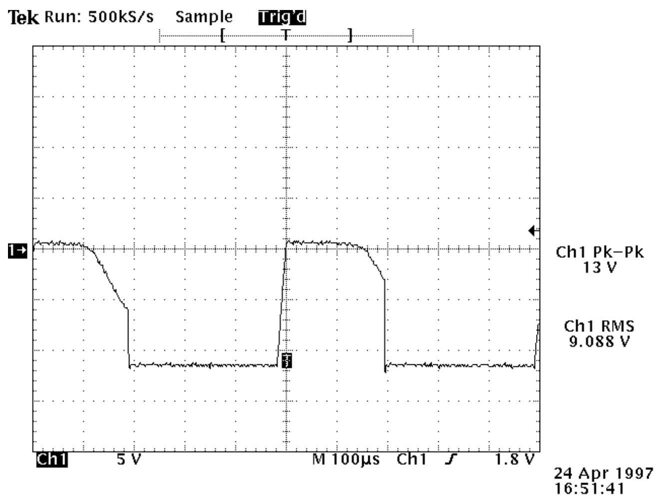


Fig.6: this scope waveform shows the effect when both diode D2 and the 0.22µF capacitor are fitted to the circuit. Note that the capacitor has a filtering effect which acts to remove most of the hash generated by the motor's commutator.

Fig.5 shows the same circuit conditions but with diode D2 connected across the motor to clip the voltage spikes. We now see the motor's back-EMF during the Mosfet "off" period, showing a value about half of that applied by the control circuit.

Finally, Fig.6 shows the effect when both the diode and 0.22µF capacitor are fitted to the circuit. The capacitor has a filtering effect, removing most of the hash generated by the motor's commutator.

The reason that diode D2 and the 0.22µF capacitor C3 are fitted directly across the motor instead of being mounted on the PC board is that this method stops the motor leads from radiating commutator hash which could otherwise interfere with sensitive circuitry elsewhere in the car.

The current rating of diode D2 must suit the rating of the motor. It's not much use connecting a 5A diode across a motor that pulls 20A; it will just blow the diode and then blow the Mosfets.

Finally, also not mounted on the PC board is the in-line input fuse F1. This must also match the rating of the motor.

PC board assembly

The PC board for this design is coded 11106971 and measures 68 x 50mm. It is fairly easy to assemble as it only has a few components on it. Begin by checking the copper pattern against the PC artwork (Fig.8) and repair any defects such as undrilled holes, shorts or open tracks. The component overlay is shown in Fig.7.

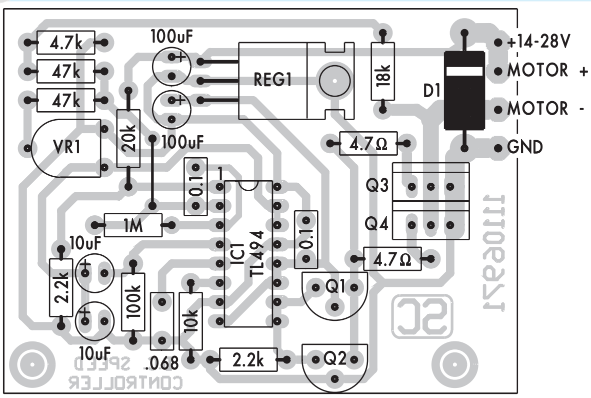


Fig.7: the component overlay for the PC board.

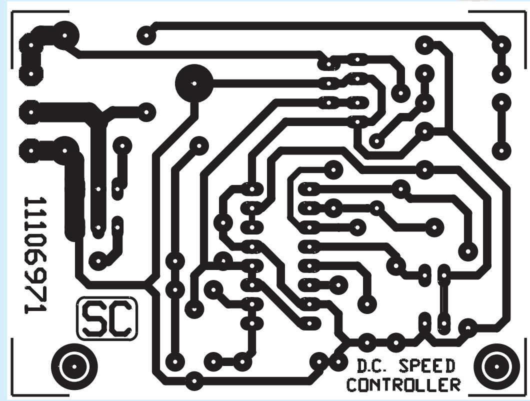


Fig.8: actual size artwork for the PC board.

Fit and solder the resistors, using a cut pigtail from one of them for the one link. This done, fit the IC, REG1 and trimpot VR1, followed by the transistors, capacitors and the Mosfets.

If you intend to operate the controller from a 12V battery and don't intend to draw more than 6A you can use one Mosfet. Provided a small heatsink is fitted you can probably draw up to 10A with one Mosfet. For higher currents, two Mosfets must be used, as shown on the circuit of Fig.1. If you want the full 20A load current, both Mosfets should be fitted with small heatsinks.

Testing

If you are careful with the assembly, it should work first up. Turn VR1 fully clockwise (minimum speed) and solder a resistor of around 100Ω 5W across the motor terminals. If you have a variable power supply, feed 14V to the DC input and ground. If you don't have a power supply you will have to connect the controller directly to a +12V battery.

With the negative meter lead connected to the 0V line, you should be able to measure about +12V on pin 16 and +5V on pin 14 of IC1. The voltage on pin 1 of IC1 should be around +1.4V with 14V input and +1.2V with 12V input. If these values are OK proceed with the following tests.

If you now connect the meter leads across the 100Ω resistor it should read zero volts. Rotate trimpot VR1 slowly anticlockwise and the voltage should increase up to about 12V when fully rotated.

Because IC1 has an internal "dead time" of 10%, the output devices can only be turned on for 90% of the time and the output voltage will never be the same as the input. For 14V input, the maximum output will be about 12.5V.

Be careful not to burn yourself as the 100Ω resistor will become hot at the maximum setting of VR1.

Using the speed controller

As noted above, the rating of the in-line fuse will depend on the load you plan to drive. Obviously a 20A fuse will not protect a 1A motor.

If you don't want the soft-start facility, it can be disabled by omitting capacitor C2. We recommend that the soft-start facility be included for incandescent loads. However, for motor loads, a better approach would be to connect a 1kΩ 1W resistor across the output terminals and then place a switch in series with the motor or whatever load you wish to drive. You then set up the drive voltage you require with trimpot VR1 and use the in-line switch to connect and disconnect the motor.

If resistive or incandescent loads are to be driven, D2 and C3 are not necessary but they must be included when driving any motor, regardless of its current rating.

D2 must be rated to handle a current at least equal to that drawn by the motor. A suitable cheap diode is the MUR1515 which is rated at 150V 15A and should cover most applications. If you want to run a 20A motor, then use two MUR1515s in parallel. Make sure that they are connected in the right direction across the motor; ie, anodes to the positive supply line. If connected the other way around, you will blow the fuse and perhaps the Mosfets too.

C2 should be an MKT polycarbonate capacitor with a rating of at least 100VW. The type of FET used depends on the current drawn by the controlled device. The BUK456-60s specified are readily available and have an "on" resistance of .028Ω.

If you want high currents and 24V operation, the MTP60N06 is a more suitable device. It has an "on" resistance of .01Ω. **SC**

PARTS LIST

1 PC board, code 11106971, 68 x 50mm
1 5kΩ PC trimpot (VR1)

Semiconductors
1 TL494CN switching regulator (IC1)
1 7812 regulator (REG1)1
1 BC639 NPN transistor (Q1)
1 BC640 PNP transistor (Q2)
1 or 2 BUK456-60A/B/H N-channel Mosfets (Q3,Q4)

Capacitors
2 100µF 50VW PC electrolytic
2 10µF 16VW PC electrolytic (C1,C2)
1 0.22µF 100VW MKT polycarbonate (C3)
2 0.1µF MKT polycarbonate
1 .068µF MKT polycarbonate

Resistors (0.25W, 1%)

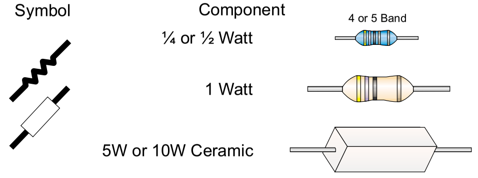
1 1MΩ	1 10kΩ
1 100kΩ	1 4.7kΩ
2 47kΩ	2 2.2kΩ
1 20kΩ	2 4.7Ω
1 18kΩ	1 100Ω 5W (testing)

COMPONENT IDENTIFICATION

This section will help you to match some of the symbols used in schematics (electronic circuit diagrams) to the physical component used in the actual product. You will see the symbol on the left and the component on the right.

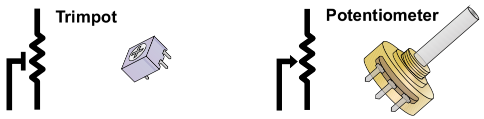
RESISTORS

Symbol | Component



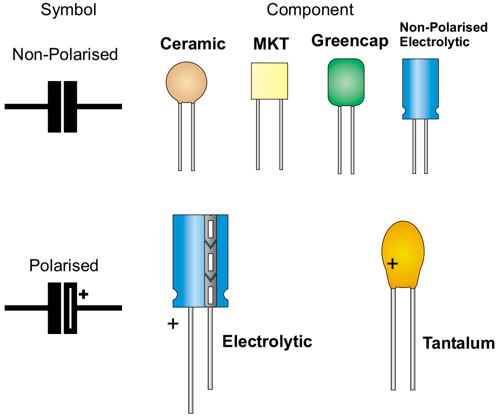
VARIABLE RESISTORS

Symbol | Component | Symbol | Component



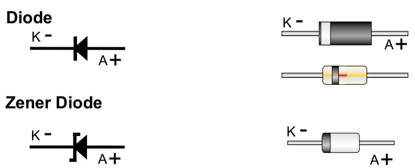
CAPACITORS

Symbol | Component



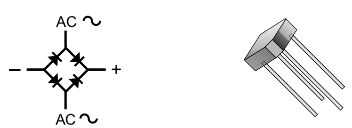
DIODE / ZENER DIODE

Symbol | Component



BRIDGE RECTIFIER

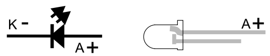
Symbol | Component



COMPONENT IDENTIFICATION

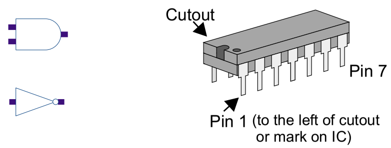
LED's

Symbol | Component



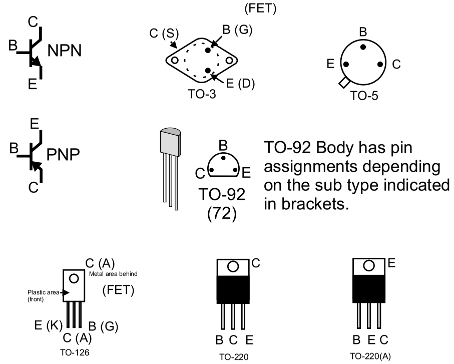
INTEGRATED CIRCUIT (IC)

Symbol (example) | Component

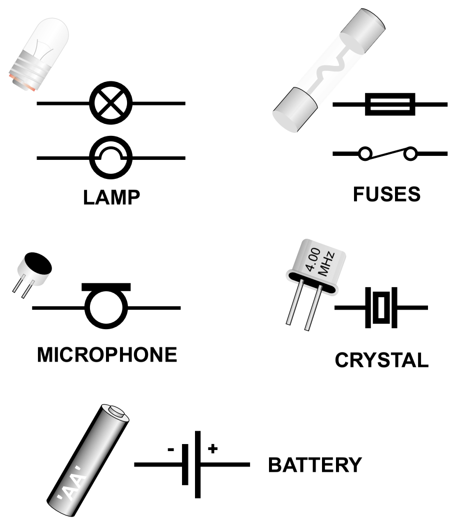


TRANSISTORS

Symbol | Component



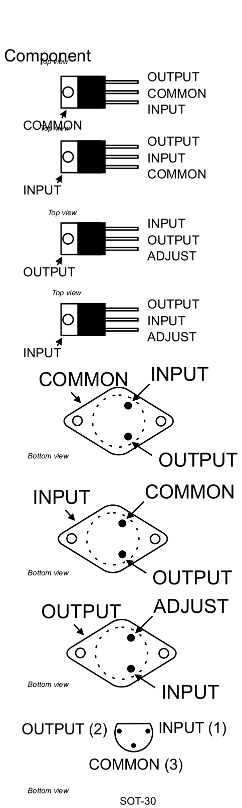
COMPONENT IDENTIFICATION



COMPONENT IDENTIFICATION

VOLTAGE REGULATORS

VOLTAGE REGULATORS



POSITIVE REGULATOR
TO-220 PACKAGE
78XX, LM340, LM2940

NEGATIVE REGULATOR
TO-220 PACKAGE
79XX, LM320

POSITIVE ADJUSTABLE REGULATOR
TO-220 PACKAGE
LM317, LM350

NEGATIVE ADJUSTABLE REGULATOR
TO-220 PACKAGE
LM337

POSITIVE REGULATOR
TO-3 PACKAGE
78XX, LM340

NEGATIVE REGULATOR
TO-3 PACKAGE
79XX, LM320

ADJUSTABLE REGULATOR
TO-3 PACKAGE
LM317, LM350

POSITIVE REGULATOR
TO-92 PACKAGE
78LXX

OHM'S LAW

The most basic law in electronics. The relationship between resistance, voltage and current is determined by Ohm's Law (*). If you know two out of the three values you can work out the third.

V= IxR
I= V/R
R= V/I

The formulas are:

V is Voltage
I is Current in Amps and
R is resistance in Ohms

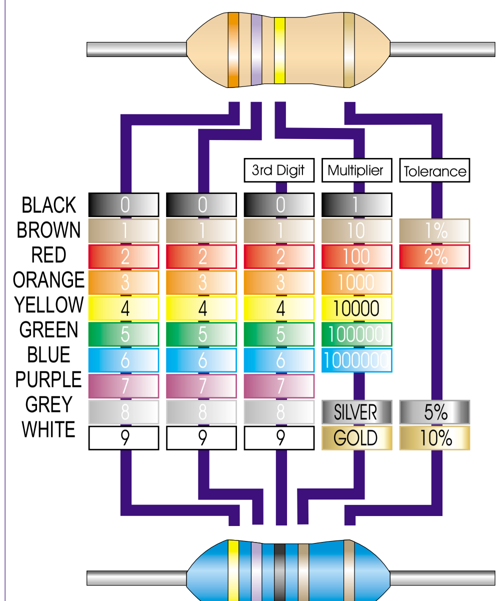
JAYCAR ELECTRONICS

kits@jaycar.com.au

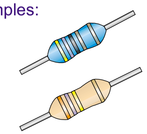
COMPONENT REFERENCE CHART

Ver 1.0 - 23.04.2001

RESISTOR COLOUR CODES



Examples:



(5 BAND)
yellow-purple-black-brown-brown
= 4 - 7 - 0 - 1 - 1% = 4K7 1%

(4 BAND)
orange-purple-yellow-gold
= 3 - 7 - 4 - 10% = 370K 10%

CAPACITOR CODES

Microfarads (u)	Nanofarads (n)	Picofarads (p)	EIA code
-	-	100pF	101
-	0.22nF	220pF	221
0.001uF	1nF	1000pF	102
0.0047uF	4.7nF	4700pF	472
0.01uF	10nF	-	103
0.047uF	47nF	-	473
0.1uF	100nF	-	104
0.47uF	470nF	-	474
1uF	1000nF	-	105

ZENER DIODES (1 WATT UNLESS SPECIFIED)

Part no.	Voltage	Part no.	Voltage
1N4728	3V3	1N4744	15V
1N4729	3V6	1N4745	16V
1N4730	3V9	1N4746	18V
1N4731	4V3	1N4747	20V
1N4732	4V7	1N4748	22V
1N4733	5V1	1N4749	24V
1N4734	5V6	1N4750	27V
1N4735	6V2	1N4751	30V
1N4736	6V8	1N4752	33V
1N4737	7V5	1N4753	36V
1N4738	8V2	1N4754	39V
1N4739	9V1	1N4761	75V
1N4740	10V	1N5349B	12V 5W
1N4741	11V	1N5352N	15V 5W
1N4742	12V	1N5374	75V 5W
1N4743	13V		