

Introduction

Electronic motor speed controllers first appeared during the 1980s and many were based on dedicated integrated circuits originally designed as a servo controllers. However, with suitable circuit modifications, these ICs could also be used as the basis for a simple electronic speed controller.

Since that time a number of significant events have occurred:-

- The workhorses of many older electronic motor speed controller designs, the tried and tested ZN409 and ZN419 servo amplifier ICs, have been made obsolete.
- MOSFET technology has developed and devices are now available with performance improvements that can be used to good advantage in a speed controller for R/C models.
- The PIC range of microprocessors is readily available and offered at reasonable cost.

Because of these changes it seemed the right time to re-examine the possibilities now available with a view to designing a simple low-cost speed controller using a microprocessor to increase the range of features that may be included and advanced MOSFETs to reduce the parts count.

This Project Article describes an easily constructed, and lightweight, speed controller suitable for use where forward-only control is required. As described later the unit has included in its software a number of safety features along with a few additional features not usually found on controllers at the cheaper end of the market.



Features

- Microprocessor Reliability
- Choice of Output Current Capability
- Software Safety Features
- Choice of Control Law
- Automatic PRF Adjustment
- Small Size and Weight
- Simple to Build and Install

Safety Features

- Start-Up Protection and Arming
- Lost Signal Motor Shut-Down
- Input Signal Pulse Width Validation
- Input Signal Glitch Rejection

Hardware Description

As can be seen from the schematic diagram the controller hardware has no frills and does not include a Battery Eliminator Circuit, or BEC. This has been left out in order to keep the cost and weight to a minimum. It also avoids the potential problems of erratic model behaviour due to the flight-pack being excessively discharged and thus causing the receiver power supply to be unstable.

U1 is a small microprocessor from the popular PIC range, the PIC12C508, and it is this IC that accepts the servo control signal from the receiver and converts it into a pulse width modulated (PWM) signal suitable for driving the MOSFETs. The controller generates a 'low frequency' PWM signal with a period equal to the frame rate of the incoming servo control signal and it is the on/off ratio of the PWM signal that controls the speed of the motor. The motor-off state is produced by an on/off ratio of 0% with motor-fully-on being produced by 100% and values between 0% and 100% giving proportional control of the motor speed.

The MOSFETs used in this design, Q1 and Q2 on the schematic, have been chosen from a range of so-called Logic Level FETs. This title means that compared to previous generations of MOSFETs they may be fully turned on, and hence present the lowest possible on-resistance, by a much lower voltage at the gate terminal. This characteristic, along with the general reduction in on-resistance of the latest offerings, permits the use of only 2 MOSFETs where previously 4 would have been necessary. As a consequence the total input capacitance of the MOSFET set is reduced to a point which allows them to be safely driven directly from a logic style output signal. This design therefore saves the cost, weight and space of 2 MOSFETs and a specialised MOSFET driver IC. Each of the MOSFET gate drive outputs from U1 has a simple resistor network attached whose main function is to ensure that at power up the MOSFETs are kept in the off-state. It also limits the current that can be supplied by the PIC output pin to a safe level. Diode D1 is a fast recovery device and is included to

suppress the back EMF generated by the motor when it is running at less than full speed. The resistor network connected to the input is present to ensure that, should the input be open circuited for any reason, false triggering of the motor does not occur and also to provide a limited degree of protection from large input signals.

The basic unit is designed to work with motors requiring up to 10 amps of continuous operating current but a more powerful version is possible which can be used with motors drawing continuous currents up to 20 amps. The only difference between the two versions being the choice of output MOSFET type.

MOSFET device design compromises usually trade-off high operating voltage against low on-resistance which means that if you can accept a low maximum operating voltage, which R/C modelers usually can, you can obtain remarkably low on-resistances. The devices chosen offer a two-in-parallel on-resistance of 0.007 ohms (10A version) and 0.003 ohms (20A version) with a maximum voltage

Parameter	10 Amp Version			20 Amp Version			Units
	Min	Typ	Max	Min	Typ	Max	
Continuous Motor Current			10			20	Amps
Peak Motor Current (less than 20 seconds)			18			36	Amps
Total MOSFET Power Dissipation at Rated Current		0.7			0.6		Watts
Efficiency at Rated Current		>97			>97		%
Flight Pack Battery Voltage	6.0		15.0	6.0		15.0	Volts
Number of Cells	5		12	5		12	
Controller Operating Voltage (supplied by receiver)	4.5		5.5	4.5		5.5	Volts
Motor Control Switching Frequency		50			50		Hz
Power-Up Arm Time		0.5			0.5		Seconds
Operating Ambient Temperature Range	-20		+40	-20		+40	Deg. C
MOSFET type (2 off per unit)	PHP69N03LT			PHP130N03LT			

Table 1: Specifications

capability of 30V. This very low on-resistance leads both to high efficiency, with typical losses due to the MOSFETs totaling less than 1W, and low running temperatures with a device temperature rise in still air of about 20C, all at full rated output current.

Software Description

After power-up the controlling software immediately ensures that the MOSFETs are switched off thus preventing the motor from turning. It then begins to assess the input signal from the receiver and, having found it suitable, proceeds to provide an output control signal based on the input signal from the receiver. In order for the signal to have been deemed acceptable it must have been such that it would normally produce the motor-off condition and thus, even after the signal validation process is completed, the motor is prevented from rotating. Advancing the stick slightly causes the motor to start.

Although microprocessor based electronic speed controllers are often described as 'proportional' they actually only offer a limited number of discrete speeds. This is because they can only assess the width of the input pulse to a finite resolution and, typically, about 30 actual speeds are provided. In order to achieve a finer degree of motor speed control this unit provides 58 speeds which allows good performance even with non-linear control laws as described below. The controller is designed to operate with the conventionally accepted control sense; i.e. a narrow pulse width produces slow motor speed and wide pulses provide fast speed as shown in Table 2. Note that for safety reasons out-of-range pulse widths

Input Signal Pulse Width	Signal Status	Output Signal
0.000ms < Input < 0.799ms	Error	Motor Fully Off
0.800ms < Input < 1.200ms	Normal	Motor Fully Off
1.201ms < Input < 1.884ms	Normal	Motor Speed Controlled
1.885ms < Input < 2.200ms	Normal	Motor Fully On
2.201ms < Input < ????ms	Error	Motor Fully Off

Table 2: Motor Control Output vs Input Pulse Width

produce an error condition and the motor is shut down.

Software Features

There are a number of useful features built in to the software for this unit and these are described below.

Control Law Selection

The logic level present at pin 5 of the PIC is used to select between the normal 'Linear' law and the special 'Exponential' law. The relationship between the input servo control pulse and the output PWM pulse for both options is shown on the graph in Figure 1. The Linear option is suitable for general use while the Exponential option is ideal for applications where a 'fast start' is needed and/or finer control of motor speed in the upper speed range is required. The selection of control law is made by J2 as follows:-

Not Linked	Linear Control Law
Linked	Exponential Control Law

Automatic PRF Adjustment

Typical R/C systems operate with a 20ms frame rate but, in order to accommodate systems with slightly different rates, this unit will provide the full range of proportional control when operated with systems having frame rates up to 22ms.

Start-Up Protection-Arming

In order to provide safety at

power-up the software switches off the MOSFETs and then examines the input signal and checks its pulse width. It keeps the MOSFETs off until it has 'seen' a continuous stream of pulses, lasting for about half a second, with widths in the range 1.0ms to 1.2ms. If this stream is interrupted by a pulse that does not meet the required specification the 'timer' is reset and the process starts from the beginning again. In this way the chances of unexpected motor rotation while on the ground is minimised.

Input Glitch/Jitter Detection

The software affords protection against the possibility of glitches or jitter causing erratic motor speed. Every input pulse is checked and if it fails to meet specification it is rejected.

Lost Signal Safety Feature

In the event the model flies out of range, and the input signal disappears, the software switches off the MOSFETs until a suitable signal is restored whereupon normal operation resumes automatically. In order to accommodate the possible range of behaviour of receivers under lost signal conditions the software considers any signal present on the input that fails to meet the required specification as invalid and shuts down the motor.

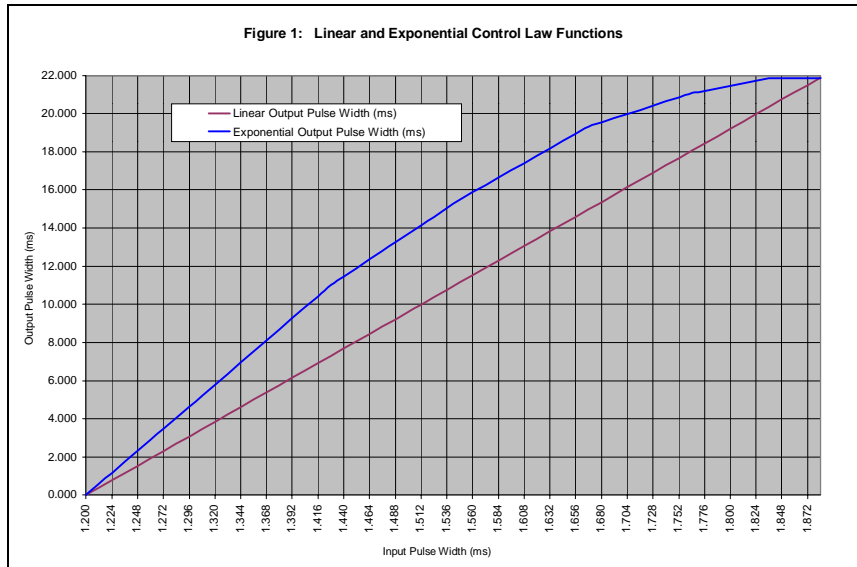
Installing the Unit

Before installing the finished unit in the model it is suggested that the one of the procedures detailed in the later section **Initial Checking and Power-up** is performed.

In order to minimise the losses associated with the high motor currents a little consideration in the placement of the unit is advised. Ideally the speed controller would be mounted close to both the flight-pack and the motor and connected using the shortest possible wires... usually this is not possible and a compromise has to be made.

Consider the following notes:-

1. Use the shortest practicable wiring lengths and good quality connectors.
2. Place the speed controller between the motor and the battery to reduce total wiring lengths.
3. If possible place the unit where an air stream is present...this will help keep the MOSFETs cool.
4. Ensure that the flight-pack isolating connector is readily accessible in the event of an emergency.



Temperature Check

In order to ensure reliable operation of the unit in service it is wise to conduct a test to assess the capability of the unit to handle the particular motor/prop combination envisaged. This can best be done on the bench with the model firmly tethered and the MOSFETs of the speed controller accessible.

Using a fully charged NiCAD pack exercise the speed controller keeping the speed towards the top end of the range. It is under

these conditions that the MOSFETs will dissipate the most power. While performing this test touch the MOSFET tabs every few seconds to establish their temperature and, at worst, they should feel warm. If they become too hot to touch, representing about 60C, then a lower power motor/prop combination should be used.

The current drawn from the battery under these static conditions will be about 25% higher than under the same conditions in flight resulting in higher dissipation in the speed controller. If all is well on the bench there will be a good margin of safety in normal operation.

Performance Tables

Peter Harries has published some useful performance data on the World Wide Web for Speed 400 motors when used with 7 cell battery packs and various propeller types.

The data in the Table 3 is extracted from his web-site. For the complete list visit his web-page; the URL is given at the bottom of Table 3.

Propeller	Current (amps)	Thrust (oz)	RPM	Gearbox Ratio
G 6.0 x 3.0 F	12.0	7.0	12,000	Direct
R 6.0 x 3.5 F	10.5	8.5	13,800	Direct
A 9.5 x 5.0 F	9.0	13.0	6,800	2.33:1
A 9.0 x 6.5 F	11.0	10.0	6,000	2.33:1
A 10.0 x 7.0 F	12.0	13.5	5,700	2.33:1
A 10.5 x 6.0 F	11.0	14.5	5,300	2.33:1
G 11.0 x 8.0 CPF	12.5	16.0	5,000	2.33:1
G 8.0 x 4.0 SP	6.6	10.0	8,300	2.33:1
G 9.0 x 5.0 SP	8.0	12.0	7,200	2.33:1

Key:- A = Aeronaut G = Graupner R = Robbe
F = Folding CP = Camprop SP = Slimprop

Table 3: Speed 400 Motor/Propeller Performance
http://www.image-maker.demon.co.uk/spd_400.htm

Assembly

Assembling the parts onto the PCB is straightforward. However the following components must be inserted in the correct orientation and the following notes may help:-

U1 This component is a CMOS device and should be treated accordingly. It has a semi-circular 'notch' in the end that marks pin 1. The IC should be inserted such that pin 1 connects with the square pad.

Qx The two MOSFETs must be inserted the correct way round. Note on the drawing in Fig1 the 'tab' is shown with an extra line. Fit these components such that the tabs are positioned as indicated and push them vertically down until the wider part of the leads touch the PCB. Owing to the high currents that circulate in a speed controller output stage ensure that the two MOSFETs are soldered with good quality joints.

D1 The method used for the MOSFETs should also be used for this device.

RN The two resistor networks also require to be fitted with the correct orientation. They both have a 'dot' marked on their bodies denoting pin 1. Fit each one such that pin 1 connects with the square pad.

X1 This 3-leaded device is not orientation sensitive and may be fitted either way round.

J1 This 'connector' is not fitted. A suitable servo lead may be used with the free ends stripped and tinned prior to soldering through the PCB noting the order of the connections. This lead is referred to as the 'Input Lead'.

J2 This 'connector' is also not fitted. See the **Software Features** section for more details.

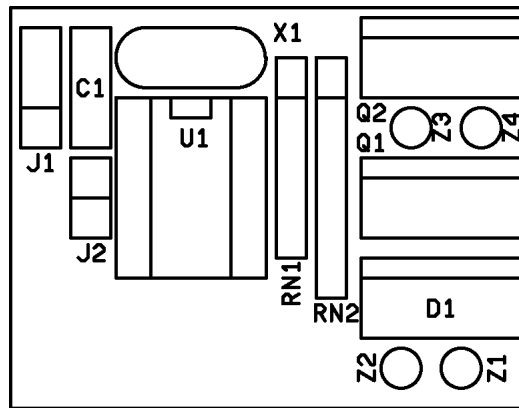


Fig. 1:
Component
Placement
Drawing

Fig. 2:
PCB Copper
Trace Detail
(Underside View)

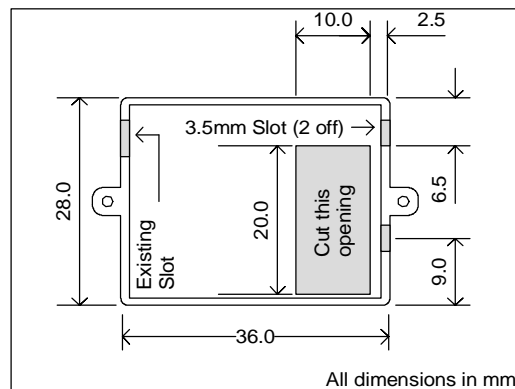
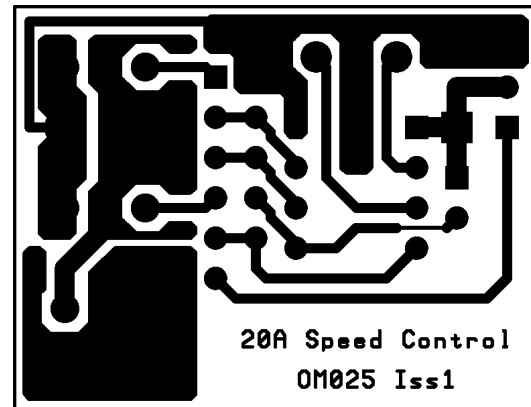
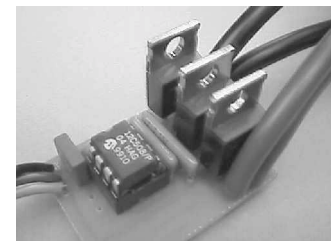


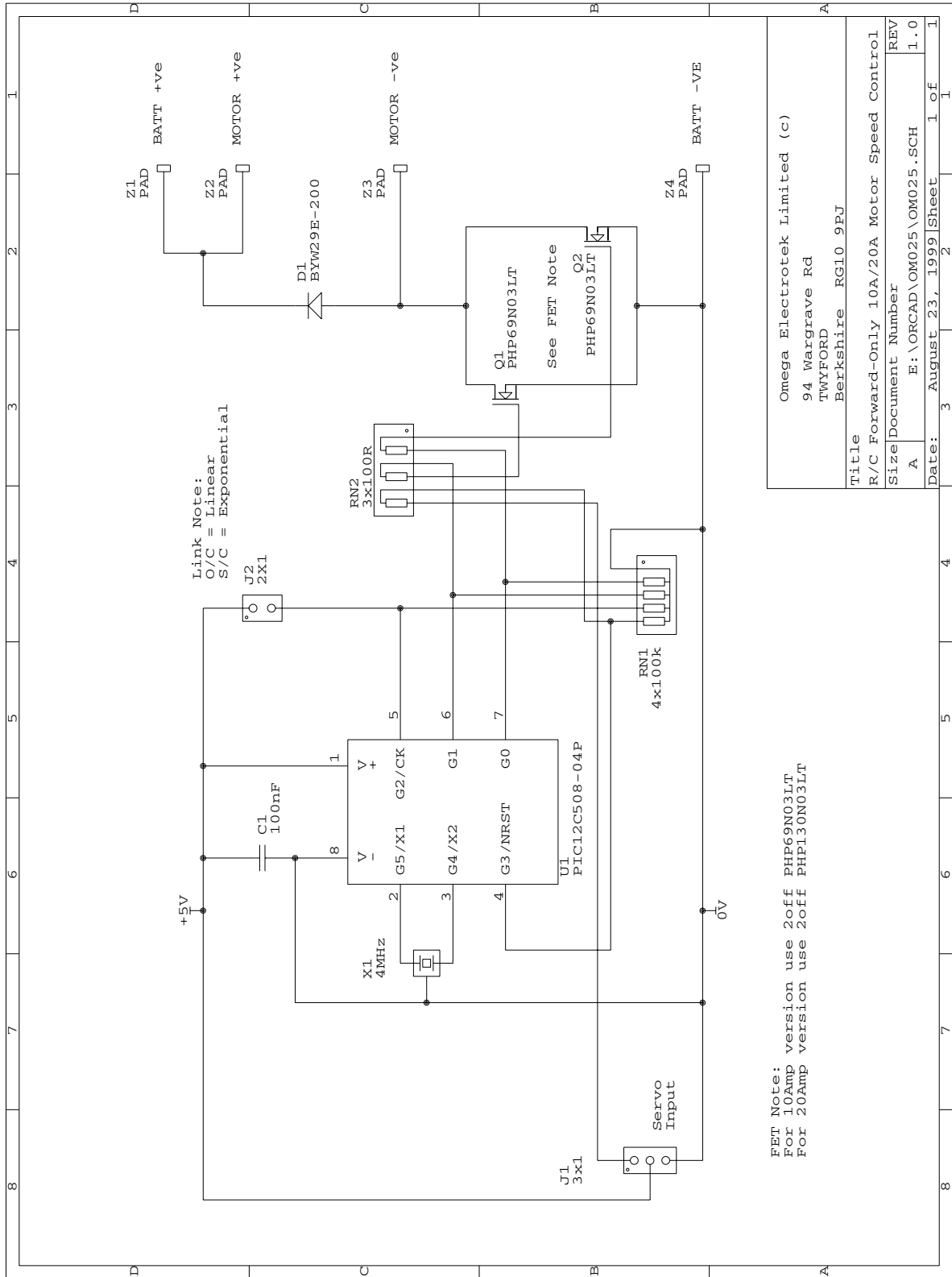
Fig. 3:
JX56L Rework
Drawing
(Underside View)

The 4 wires that carry the motor current should be carefully stripped of the insulation for a distance of about 5mm and soldered to the PCB. Leave the length of each wire long enough to allow easy testing. They can be shortened to the correct length when the unit is being installed in the model.

Fig. 4:
Assembled PCB

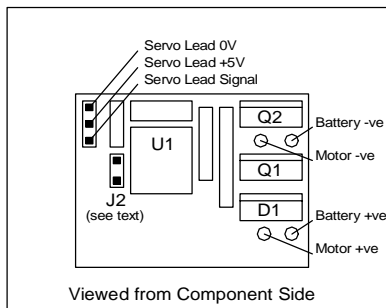


Schematic Diagram



Initial Checking and Power-up

Having carefully checked that all the components and wires are correctly located, orientated and soldered the assembled unit may be tested. Initial testing is best done on the bench and depending on whether you have access to test equipment, either an oscilloscope or multi-meter, or not follow the appropriate procedure. The diagram below shows the locations of the connection points and their functions.



NOTE: There is no reverse polarity protection provided and connecting the unit to a battery with the wrong polarity will probably destroy it.

Oscilloscope Procedure

1. Temporarily replace the motor by connecting a 1kohm resistor across the motor connections.
2. Connect a partially discharged NiCAD pack to the flight-pack connections. This technique may save the MOSFETs and/or wiring in the event of faulty assembly by limiting the available current from the battery. The current required for this phase of the testing is very small and note that NO current should be drawn from the flight-pack at this stage.
3. Connect the 'scope probe ground lead to the flight-pack -ve connection and the

'tip' to the motor -ve connection (a good place for this is the tabs on the MOSFETs). Set the 'scope to display the DC voltage present on the MOSFET drain connections...it should be the equal to the flight-pack terminal voltage.

4. Connect the unit to a receiver using the input lead and power up the receiver.
5. Set the motor control channel to produce the minimum pulse width and hold it for about 1 second. Advancing the stick a little should cause pulses to appear on the 'scope trace. Advancing it all the way should leave the 'scope trace showing a steady 0V. Leave the stick in this position for about 1 second. Bringing the stick back should cause the pulses to re-appear and then finally disappear again with the trace showing the flight-pack voltage. Note that if the Tx is set to produce maximum pulse width at the start of Step 5 no pulses will be seen until after the 1 second wait at 'full throttle'. Pulses will appear on the way down.
6. If everything is satisfactory so far the NiCADs can be replaced with a charged set and a motor connected across the motor connections. Repeating Step 5 should produce controlled motor rotation. Check that the the MOSFET and diode tabs remain cool while performing this test. This completes the pre-installation testing.

Oscillographs of some typical waveforms taken from this project and also additional technical information are contained in the Technical Note 'How it Works - The Electronic Motor Speed

Controller', - Technical Note MECTN001.PDF.

Multi-meter Procedure

1. Perform Steps 1 and 2 as per the Oscilloscope Procedure above.
2. Set the meter to a range suitable for displaying the flight-pack voltage and connect the meter -ve lead to the flight-pack -ve connection and the +ve lead to the motor -ve connection.
3. Connect the unit to a receiver using the input lead and power up the receiver.
4. Perform Step 5 as per the Oscilloscope Procedure above noting that instead of pulses the multi-meter reading should begin to fall until the stick is nearly fully advanced when the reading should read less than 0.1V DC. Bringing the stick back should cause the reading to rise again toward the NiCAD terminal voltage.
5. Perform Step 6 as per the Oscilloscope Procedure above.

No Equipment Procedure

1. Connect a suitable motor across the motor connections.
2. Connect a partially discharged NiCAD pack to the flight-pack connections as described in Step 2 of the Oscilloscope Procedure.
3. Connect the unit to a receiver and power up.
4. Perform Step 5 of the Oscilloscope Procedure above and check that the motor speed ramps up, as the stick is advanced, and back down again to rest when the stick is returned to the 'motor stopped' position.
5. Perform Step 6 as per the Oscilloscope Procedure above.

This completes the testing procedure and, in order to secure the Input Lead connections, a blob of Araldite may be applied around the wires on the component side of the PCB to increase the mechanical strength. Information concerning installation in the model may be found in the **Installing the Unit** section above.

Components

Complete kits of the components required to build this project are available from the Model Electronics Company. Alternatively just the PCB and the pre-programmed microprocessor may be purchased and the remaining parts obtained from other sources using the Parts List table as a guide.

For those people not wishing to undertake the assembly of the PCB this is available pre-assembled and tested. Please see the price list for details.

Item	Manufacturer	Specification or Part Number
C1	N/A	100nF 63V 10%
D1	Philips Semiconductors	BYW29E-200
RN1	Bourns	100k 0.2W 5%
RN2	Bourns	100R 0.2W 5%
U1	Pre-Programmed	PIC12C508-04P
X1	Murata	CST4.00MGW
Q1, 2 (10A)	Philips Semiconductors	PHP69N03LT
Q1, 2 (20A)	Philips Semiconductors	PHP130N03LT

Table 4: Parts List

Note that where manufacturers part numbers are given their continued accuracy cannot be guaranteed

Notes

This Project Article is issued by :-

The Model Electronics Company
68 Kentsford Road
Grange-over-Sands
Cumbria LA11 7BB

For information on placing an order for this project please see our price list which gives details of prices and payment methods. The price list may be obtained from the address above or from our web-site.

<http://www.omegaco.demon.co.uk/mechome.htm>

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