



Triac-based for *ultra-smooth* control!

BY JOHN CLARKE

Full-Wave, 10A Universal

This relatively simple but highly effective Triac-based circuit gives smooth, full range speed control for electric drills, lawn edgers, circular saws, routers or any other appliance with universal motors (ie, brush-type), rated up to 10A.

Most SCR or Triac-based speed controllers usually have very poor low-speed control and won't let the motor reach full speed. This speed limitation comes about because these circuits can only switch on every second half-wave of the 230VAC mains voltage. This means that they can only feed a maximum voltage of about 160VAC to the motor.

These limitations are demonstrated in the waveforms shown in Scope1 and Scope2, which come from the Half-Wave Speed Controller published in February 2009.

Up till now it has been very difficult to design a Triac-based circuit which would give smooth control over a wide range of speeds.

Nor was it is easy to provide good speed regulation which means that the motor speed is less likely to vary if the loading changes.

But our new Full Wave Uni-

versal Motor Speed Controller provides much improved speed control because it not only uses a microcontroller to provide more precise phase control of the Triac but it also employs current feedback.

This is not our first full range speed control for universal motors. Our last design was featured in the February and March 2014 issues. See www.siliconchip.com.au/Series/195

This had a complex circuit that rectified the 230VAC mains and used a rugged IGBT (insulated gate bipolar transistor) to rapidly switch the pulsating DC waveform at 980Hz.

At low speeds, very narrow pulses are applied to the motor while at full speed the IGBT is continually on. This technique is referred to as pulse width modulation (PWM).

That design is still valid but due to its complexity, it also meant that it was (and still is), large and expensive.

Our new Triac-based design

Features

- Full wave motor control
- Full speed range
- 220VAC to 250VAC 50Hz/60Hz
- For "universal" motors (ie, series motors with brushes)
- 10A 230VAC or similar nameplate rating
- Soft start



Motor Speed Controller

also offers impressive performance but it is less complex and less costly. The Triac is phase-controlled and works similarly to a leading edge light dimmer (more on phase control later).

The 600V 40A Triac is also arguably more rugged than the IGBT used in the 2014 design. For an explanation of leading and trailing edge dimmer operation, see our article in the July 2017 issue (www.siliconchip.com.au/Article/10712)

By the way, our new circuit offers much better speed control than our Mk2 phase controller from February 2009 which used the same BTA41 Triac. See www.siliconchip.com.au/Article/1339

Soft start

A particularly attractive feature of this new design is “soft start”. This means that regardless of speed setting, the motor speed will smoothly build up to the setting and thereby avoid any sudden kicks – an all-too-common reason for users presenting at hospital casualty rooms!

The new Speed Controller can be used with a 220 to 250VAC mains supply, at 50Hz or 60Hz. This means that it can be used in any country that has a 220VAC or above. However, it is not directly suitable for use with a 110VAC mains supply; that would require some component changes.

Why do you need speed control?

Most power tools will do a better job if they have a speed control. For example, electric drills should be slowed down when using larger drill bits. This is particularly the case

when drilling sheet metal; using too fast a speed will result in a triangular hole.

Similarly, it is useful to be able to slow down routers, jigsaws and even circular saws when cutting some materials, particularly plastics, as many plastics will melt rather than be cut if the speed is too high.

The same comments apply to sanding and polishing tools and even electric lawn trimmers, where they are less likely to snap their lines when slowed down.

Even if you do not want a reduced motor speed, the soft start feature of this Speed Control is handy when using large power tools such as circular saws and routers which can otherwise give a substantial kick if started at full voltage. (Some modern power tools, such as electric chainsaws, have this feature built-in).

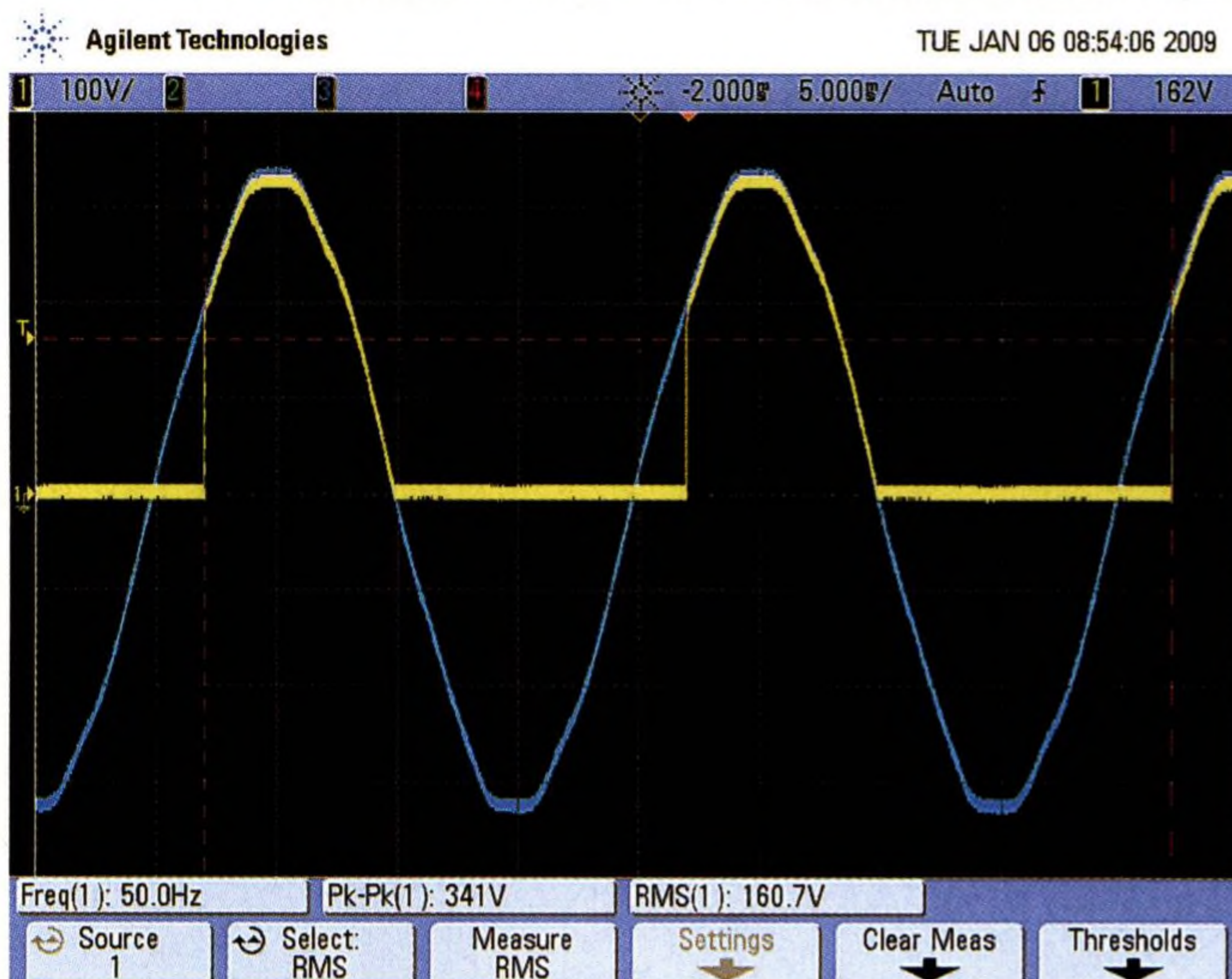
Phase control

Before we continue, we should explain what we mean by phase control that is used in this new design.

As you know, the mains AC voltage is a sinewave. It starts at zero, rises to a peak, falls back to zero, then does the same thing with the opposite polarity. This repeats 50 times each second for 50Hz mains and 60 times per second for 60Hz mains.

We vary the speed of a motor by varying the time during each half cycle when power is applied: feed power very early in the cycle and it runs fast; delay applying power until much later in the cycle and it runs slowly.

These half-wave control waveforms are taken from our February 2009 Drill Speed Controller, for comparison with the new one . . .



Scope1: the controller is set for maximum output with resistive load. The yellow waveform is essentially a half-wave rectified sine wave with a value of 161V RMS (70% of the blue 230V mains waveform) and a peak value of 341V.



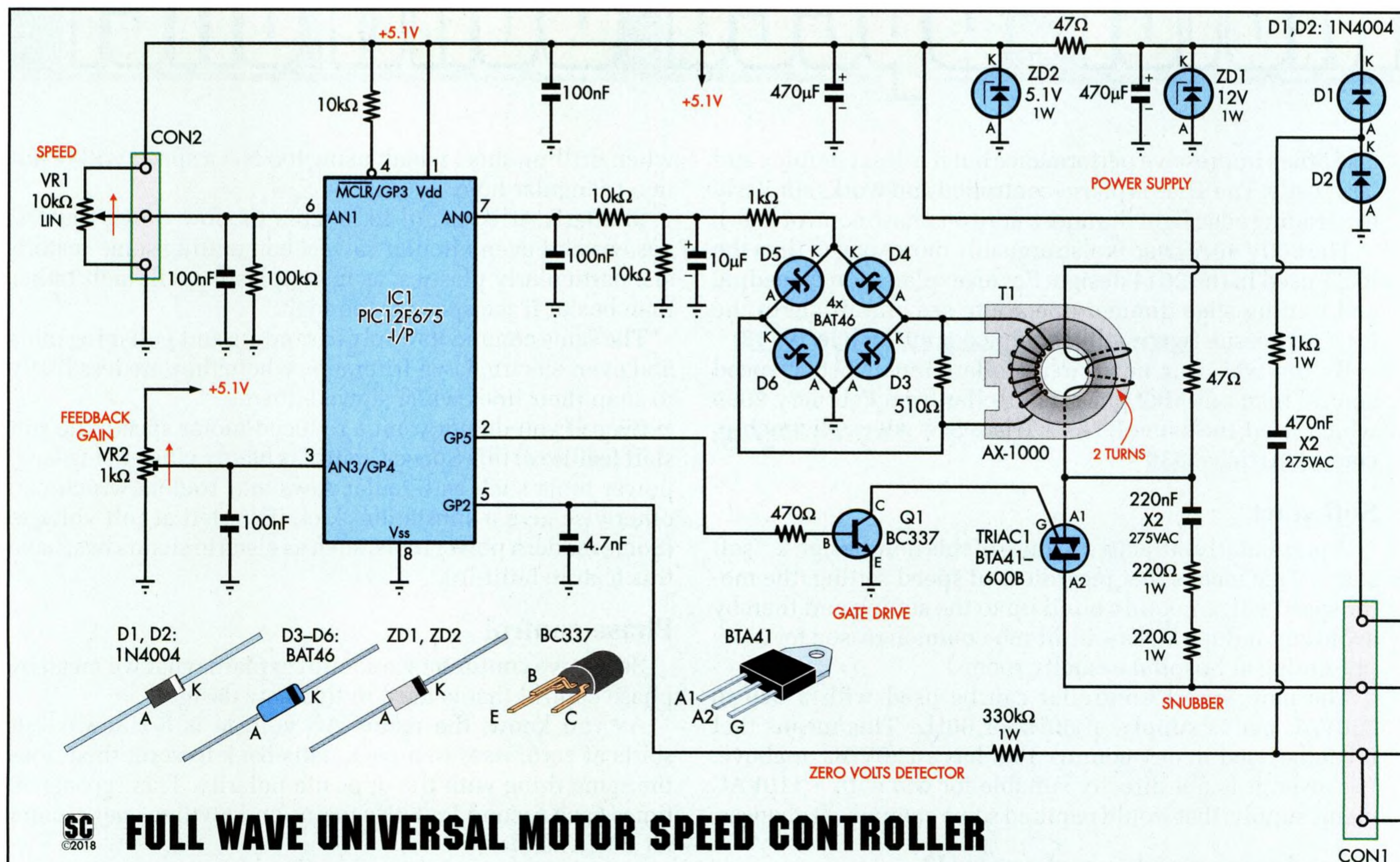
Scope2: the Speed Controller set for maximum output when driving an electric drill. There is considerable hash at the beginning of each positive half-cycle, caused by interaction between the drill's commutator and the Triac.

Phase control employs either an SCR (silicon controlled rectifier) for half-wave control or a Triac to provide full wave control, as used in "leading edge" dimmers.

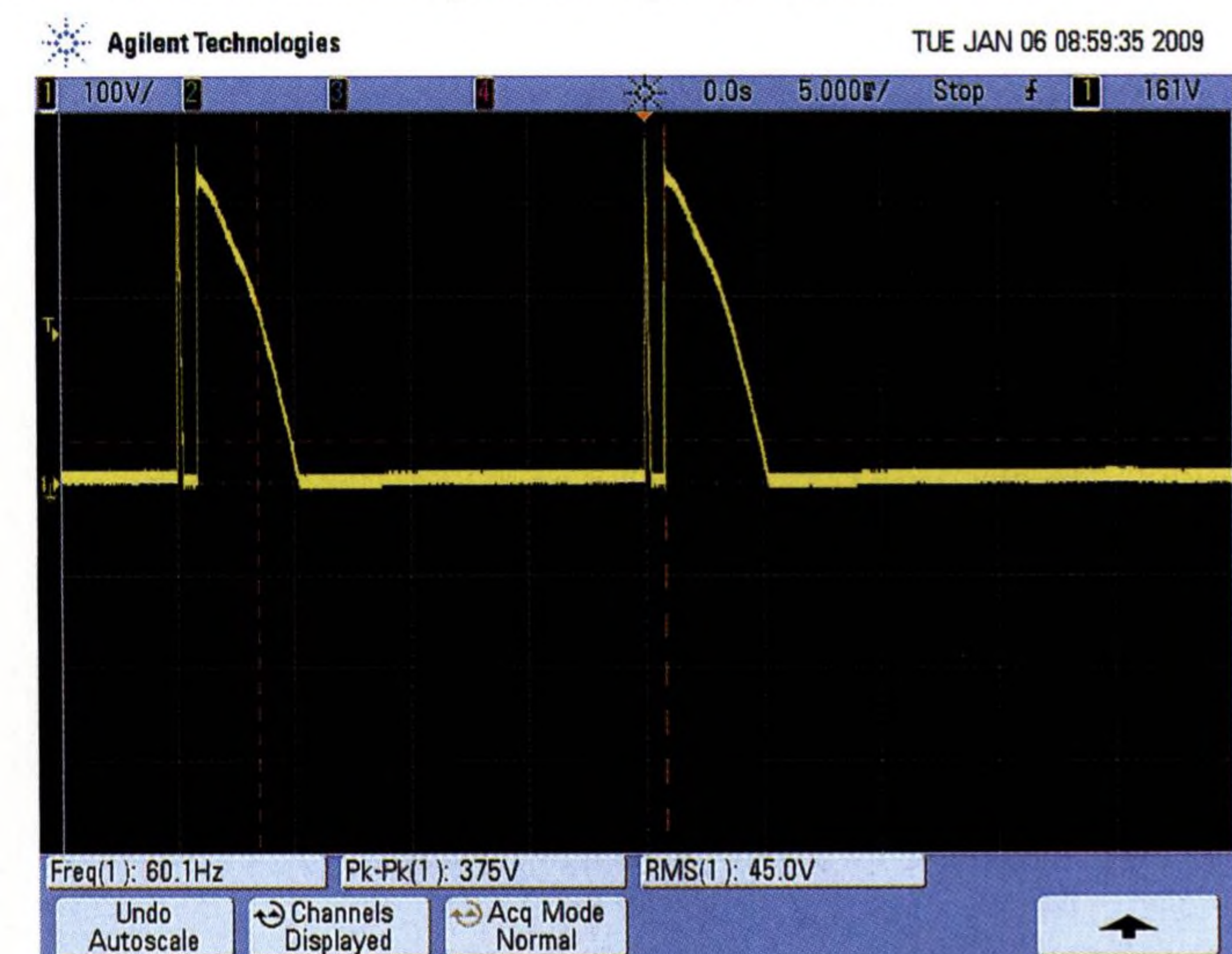
Half wave control means that only one side of the mains waveform (the positive or the negative) is applied to the motor.

These devices are turned on by a

trigger pulse applied to their gate electrodes and the term "phase control" comes about because the timing of the trigger pulses is varied with respect to the phase of the mains sinewave.



in fact, there is no comparison in performance!



Scope3: now set for a lower speed from the electric drill, the Triac is on for a shorter time and the RMS value of the waveform is considerably reduced to 45V. Note the frequency error caused by hash on the waveform.

Speed regulation

For a motor to have good low speed performance, the speed control circuit should compensate for any drop in motor speed as the load increases, by increasing power to the motor. Many simple SCR speed controllers rely upon

the fact that a motor produces a back-EMF (electromotive force) which is proportional to its speed.

The circuit compensates for a drop in back-EMF by triggering the SCR earlier in the mains half-cycle and so applying more voltage to the motor.

In practice though, the back-EMF generated by most appliance motors is quite weak while the SCR is not conducting.

This is partly because there is no field current and the generation of voltage is only due to remnant magnetism in the motor core.

Furthermore, any back-EMF that is produced tends to be too late after

the end of each half-cycle to have a worthwhile effect on the circuit triggering in the next half-cycle.

Our new Speed Control uses a different method to provide good speed regulation. It monitors the motor current to sense motor speed. If it senses a drop in speed, it increases the effective voltage to the motor.

From the general discussion above you can assume that our new design is significantly different to the February 2009 controller and although both use the same Triac.

The 2009 design uses the Triac as an SCR and the control to the motor is only half-wave.

Our new design uses the Triac to apply AC to the motor and it is triggered in both half-cycles of the mains waveform.

Unfortunately, the triggering requirements for correct operation with an inductive load such as a motor cannot be provided by a simple circuit.

In fact, the Triac must have multiple triggering pulses in each half-cycle and their timing is very critical. The only solution is to use a microcontroller.

So let's have a look at the full circuit in Fig.1.

Circuit description

The key components are the Triac and the PIC12F675 microcontroller, IC1. IC1 monitors the speed potentiometer, VR1 at pin 6. It also monitors feedback gain potentiometer VR2, at pin 3, the current feedback via current transformer T1, at pin 7 and the mains waveform via a 330kΩ resistor at pin 5.

In response to all those parameters, IC1 produces a series of pulses and these drive the NPN transistor Q1 and thence the gate of the Triac.

The Triac gate current flows via the 47Ω resistor connected between the 5.1V supply and the Triac's A1 terminal, then out through the gate and to circuit ground via Q1 (ie, the gate current is negative).

This method of connection places the 47Ω resistor between the 230VAC mains supply and the 5.1V supply which runs the PIC microcontroller. This arrangement has been used to avoid Triac switching noise getting into the 5.1V supply which can cause latch-up of the microcontroller.

Snubber network

A snubber network comprising two 220Ω 1W resistors in series and a 220nF 275VAC X2-rated capacitor connected between the A1 and A2 terminals of the Triac. This network is there avoid rapid changes in voltage being applied to the Triac which would otherwise it turn on (dV/dt switching) when it is supposed to be off.

These rapid changes in voltage can occur then power is first applied or can come from voltage transients generated by the inductance of the motor being controlled, each time the Triac turns off. In effect, the snubber network acts to damp transients and reduce their amplitude.

The DC supply for the microcontroller is derived directly from the 230VAC mains supply via a 470nF 275VAC X2 rated capacitor in series with a 1kΩ 1W resistor. The capacitor's impedance limits the average current drawn from the mains while the 1kΩ resistor limits the surge current when power is first applied.

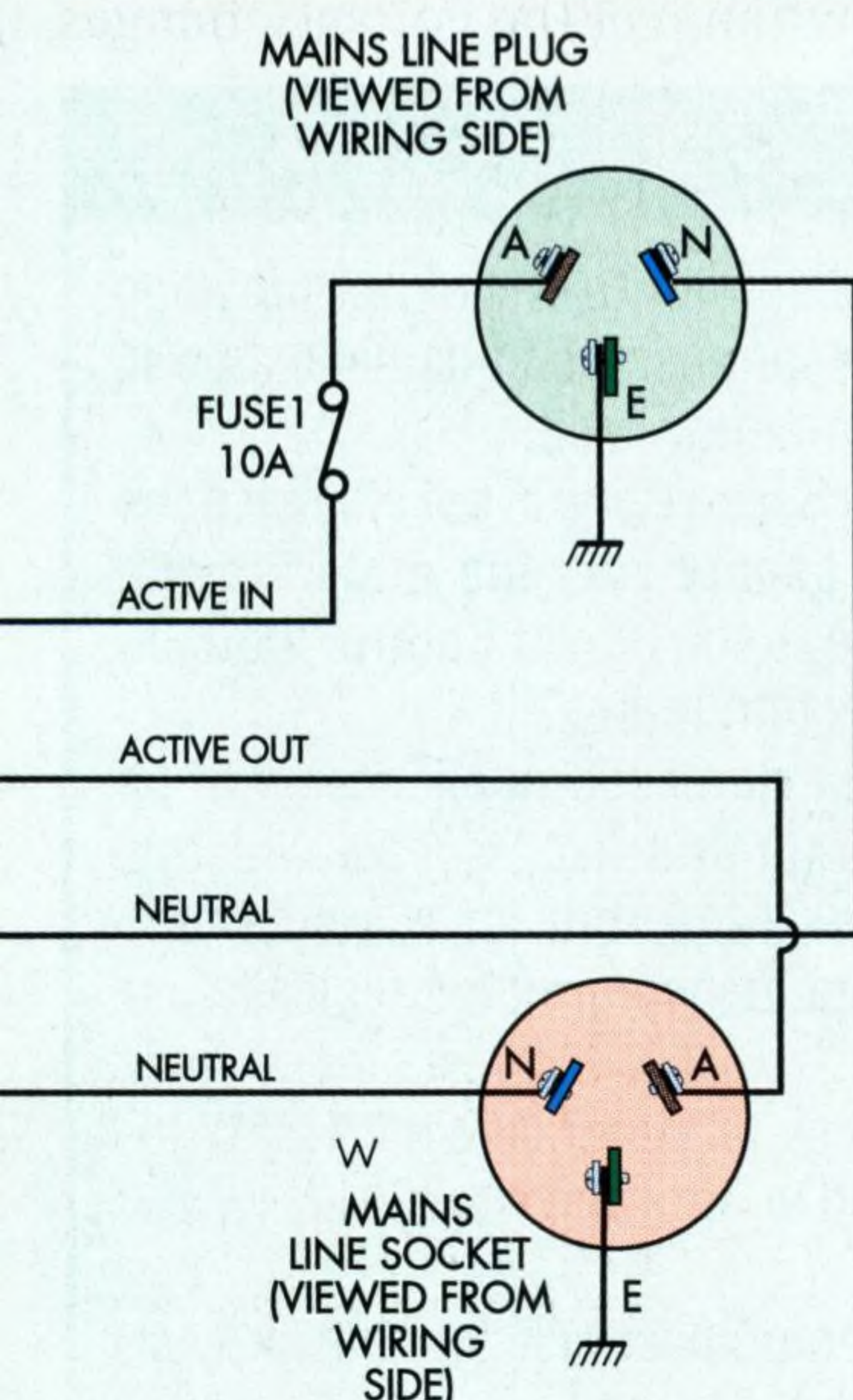
It works in the following way. When the Neutral line is positive with respect to the Active line, current flows via the 470nF capacitor and diode D1 to the 470μF capacitor to

WARNING!

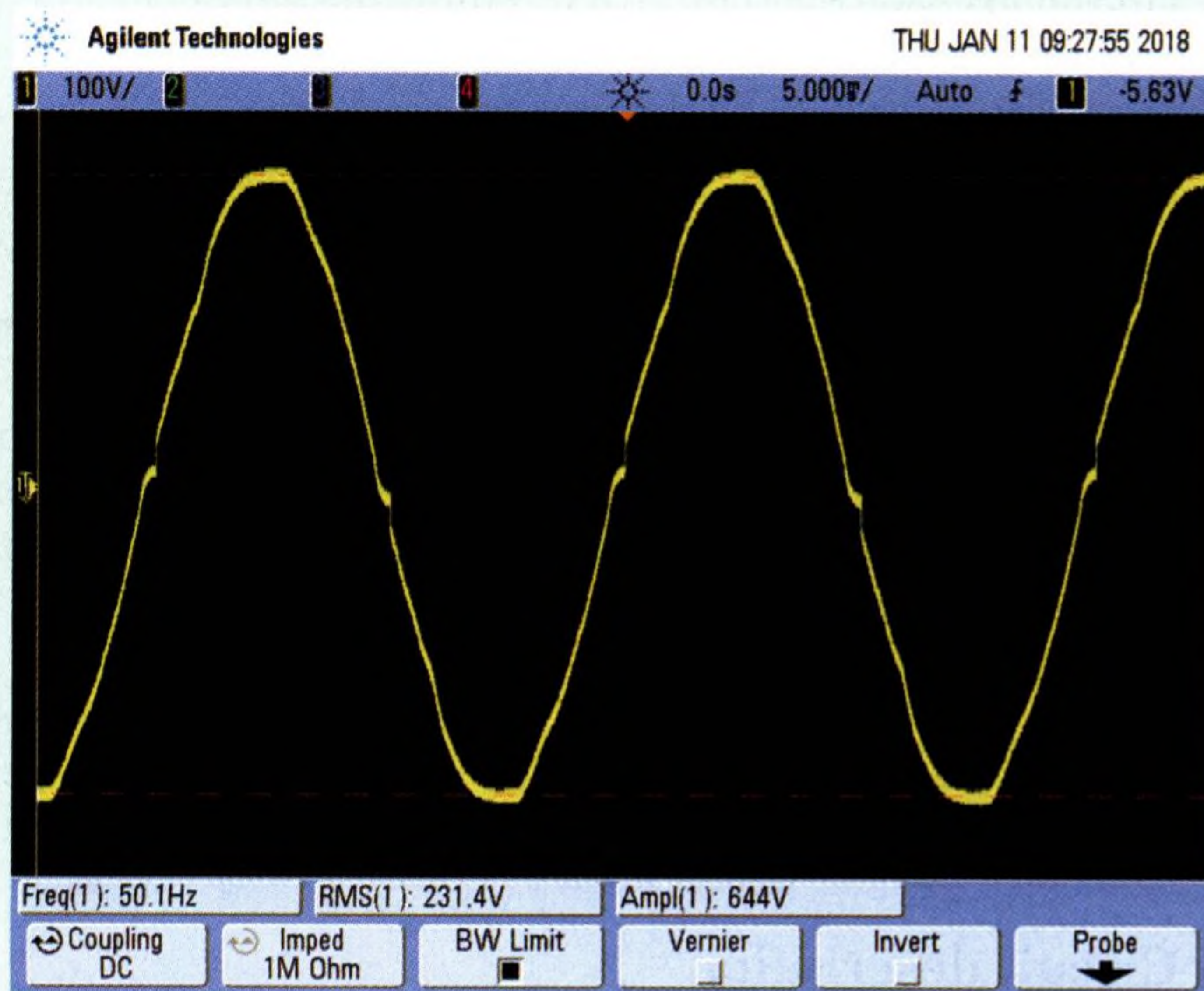
(1) This Speed Controller circuit operates directly from the 230VAC mains supply and contact with live components is potentially lethal.

(2) This circuit is not suitable for use with induction motors.

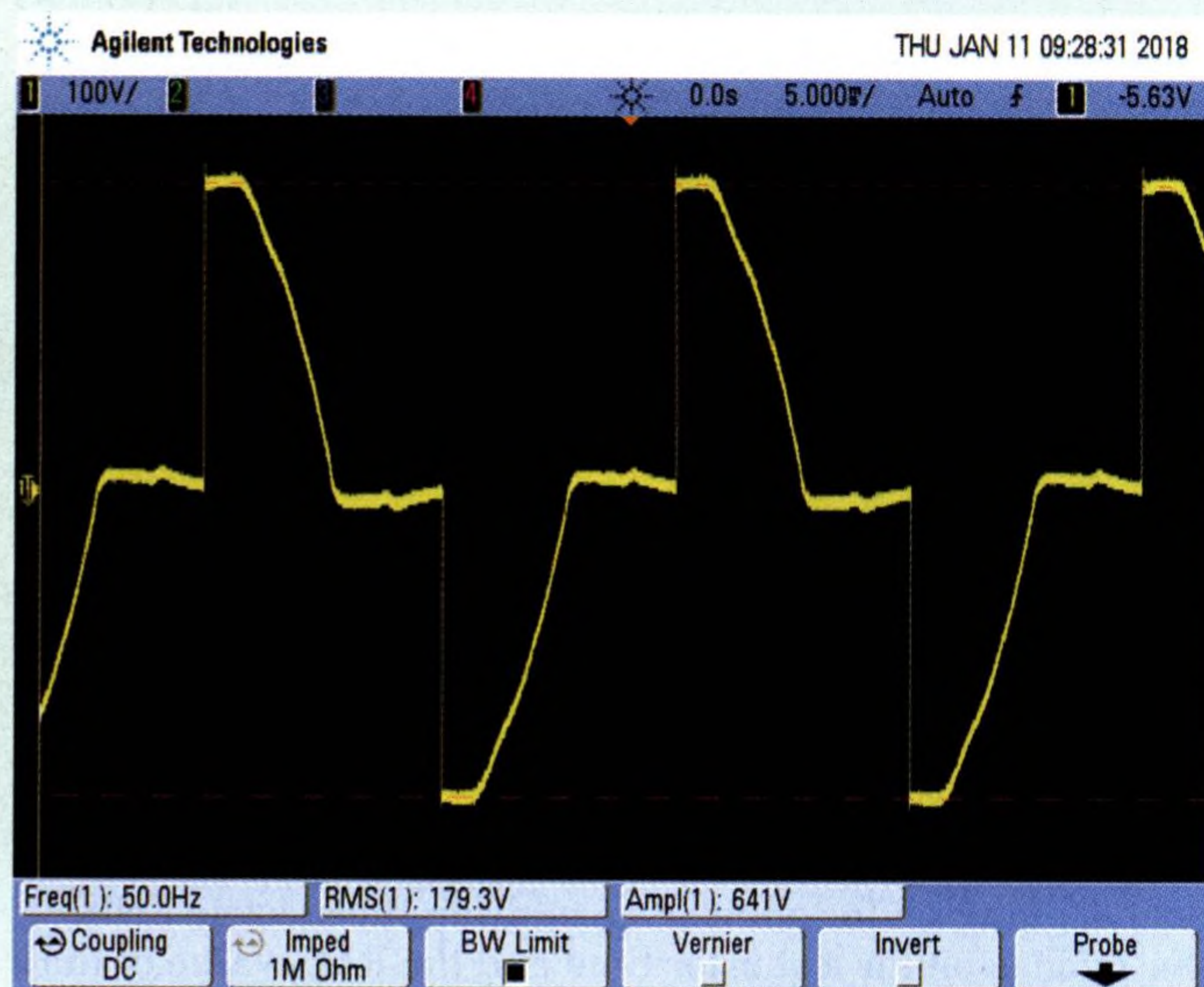
(3) Power tools with inbuilt fans must not be operated at low speeds for long periods, otherwise they may overheat.



DRILL SPEED CONTROLLER PERFORMANCE WAVEFORMS



Scope4: this shows the waveform at maximum output. There is only a very short period (<0.4ms) at the beginning of each half-cycle when the Triac is off.



Scope5: here the output is set to about half, corresponding to an RMS voltage about 180V.

Scope 4, 5 and 6 are all with an incandescent lamp load.

charge it up. On negative half-cycles, the current through the 470nF capacitor is reversed via diode D2.

Zener diode ZD1 limits the voltage across the 470µF capacitor to 12V and that supply then feeds a second 470µF capacitor via a 47Ω resistor and its voltage is limited to 5.1V by zener diode ZD2. This is the supply for the microcontroller, IC1.

IC1 has its $\overline{\text{MCLR}}$ input (pin 4) tied to the 5.1V supply via a 10kΩ resistor and this provides a master clear (reset) for IC1 when power is applied. The main 5.1V supply for IC1 is decoupled with a 100nF capacitor.

VR1 is the speed potentiometer and it is connected across the 5.1V supply with the wiper connected to the pin 6, AN1 input. IC1 converts the voltage set by VR1 into a digital value using its internal analog to digital converter. The 100kΩ resistor from the wiper to ground holds the AN1 input at 0V, setting motor speed to zero should VR1's

wiper go open-circuit.

Trimpot VR2 is also connected across the 5.1V supply and has its wiper monitored by the AN3 input of IC1 at pin 3. This voltage sets the gain of the feedback to maintain motor speed load. It is also converted to a digital value within IC1.

The 100nF capacitors at the wiper of VR1 and VR2 are there to provide a low source impedance for the analog to digital converter sample and hold input.

Mains synchronisation

Since the timing of the Triac's trigger pulses are so critical to its correct operation, IC1 needs to monitor the mains voltage. This is done by the GP2 input of IC1, at pin 5. This monitors the mains Neutral via a 330kΩ resistor and the signal is filtered with a 4.7nF capacitor.

An interrupt in IC1 occurs whenever the voltage changes

What motors can be controlled?

We've noted elsewhere in this article that this controller suits the vast majority of power tools and appliances. These generally use universal motors and are series-wound motors with brushes. Incidentally, they're called universal motors because they can operate on both AC and DC.

You cannot use this Speed Control with any appliance which has an electronic speed control built in, whether part of the trigger mechanism or with a separate speed dial.

This does not apply to tools such as electric drills which provide a choice of two speeds via inbuilt reduction gears.

What about induction motors?

We have strongly warned against using any of our previous AC speed controls with induction motors, for two reasons.

First, the output of our previous designs is variable unfiltered DC – and that will not run an induction motor, which requires a variable supply frequency for its speed to be varied.

Second, connecting an induction motor to any of our previous speed controls usually resulted in serious circuit damage as well possibly burning out the induction motor itself.

That won't happen with this new Speed Control **but since it does not vary the mains frequency it cannot vary the motor speed.** You are unlikely to do any damage to the Speed Control though.

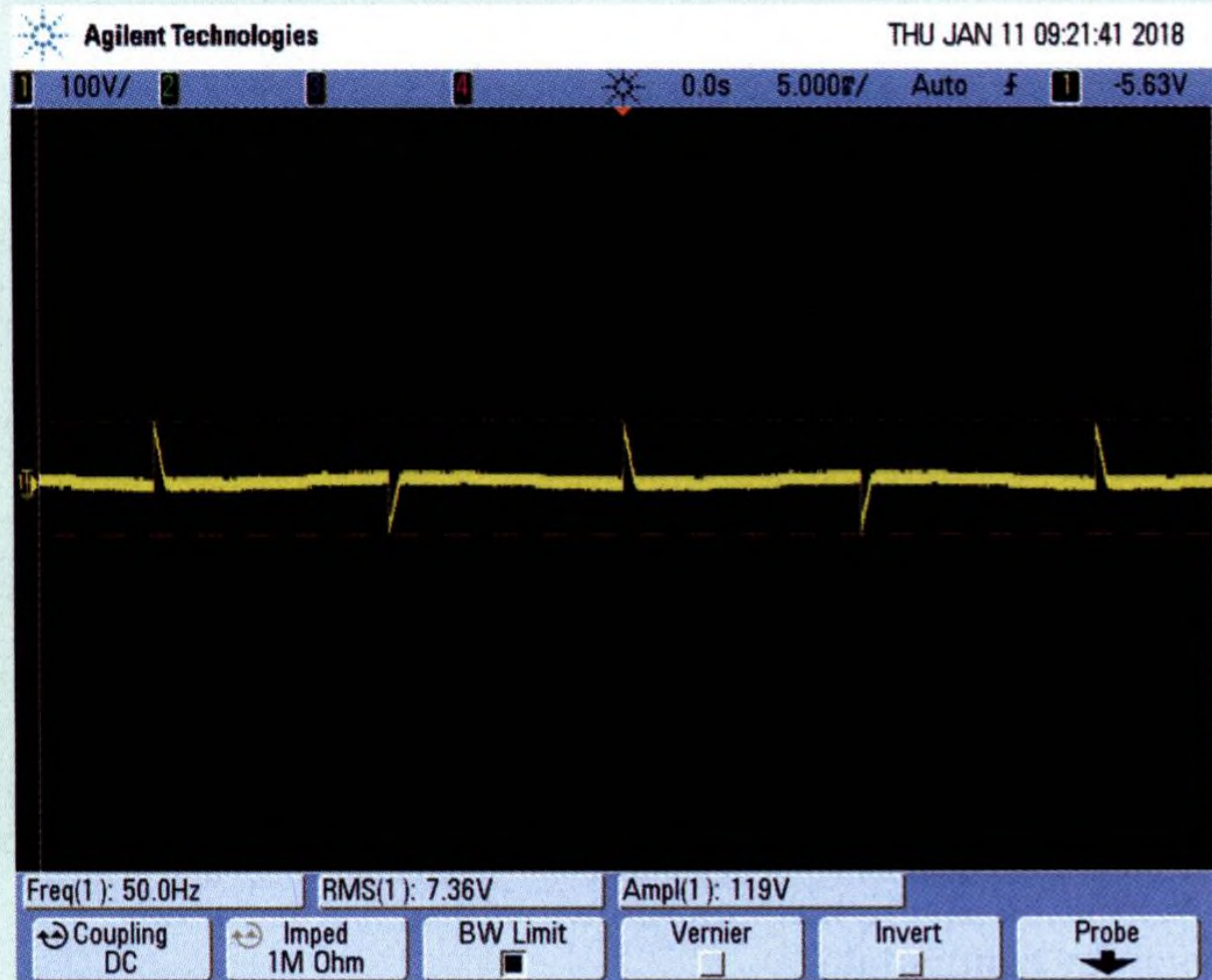
So how do you identify an induction motor?

Most induction motors used in domestic appliances will be 2-pole or 4-pole and always operate at a fixed speed, which is typically 2850 rpm for a 2-pole or 1440 rpm for a 4-pole unit. The speed will be on the nameplate. Bench grinders typically use 2-pole induction motors.

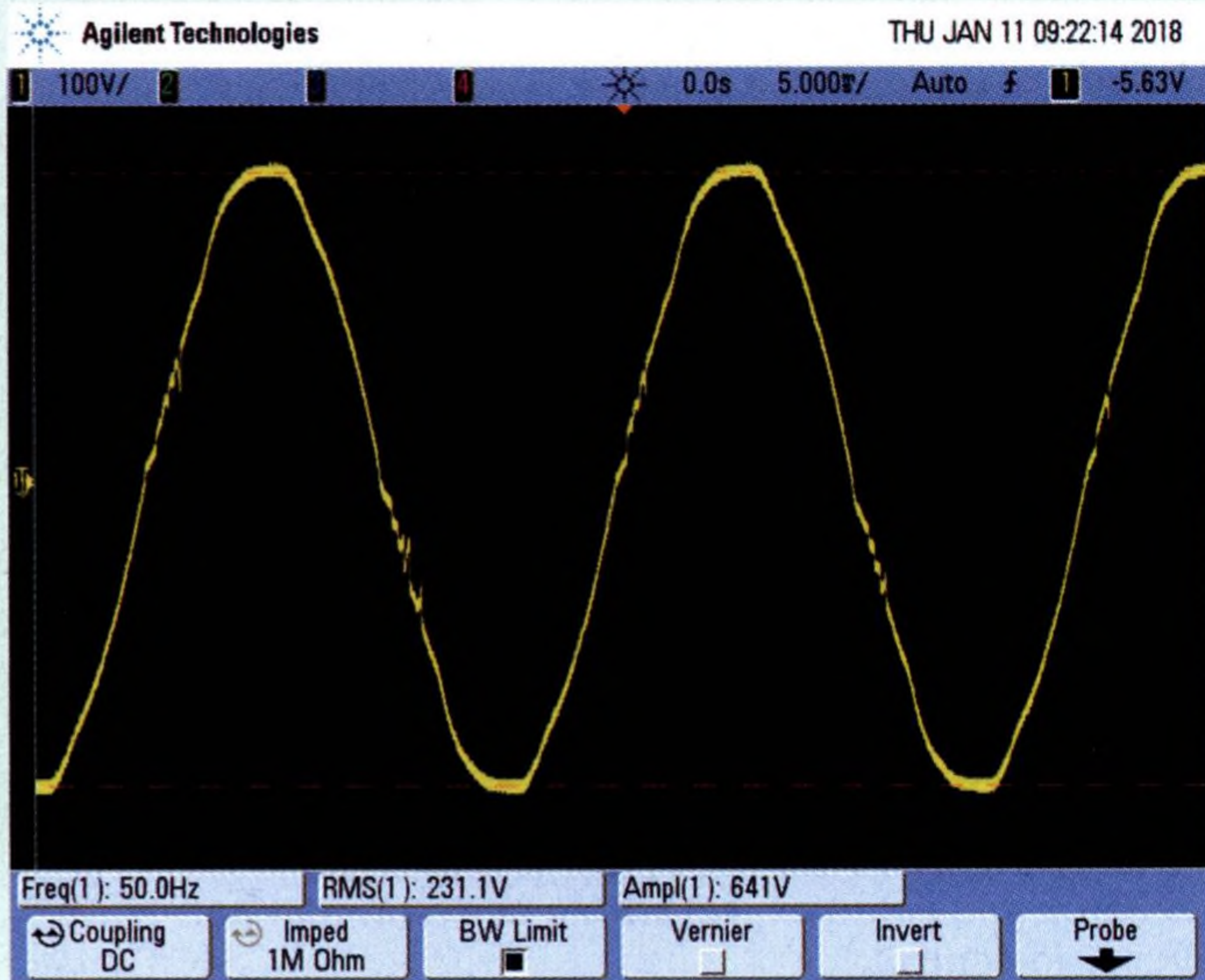
If you do need to control this type of motor, use the 1.5kW Induction Motor Controller published in April and May 2012. (www.siliconchip.com.au/Series/25).

Note that there are important modifications for that project, published in December 2012.

This series of scope grabs (and those overleaf) shows the Triac Speed controller working with a 150 watt incandescent lamp load and a Bosch 500W 2-speed drill. In each case, the connection to the output of the speed controller is made via a 100:1 probe. The waveforms are identical to those taken with a fully isolated differential probe.



Scope6: the output is set to the minimum whereby the Triac is still firing. The RMS voltage is 7.36V and the lamp filament is not even glowing.



Scope7: here the output is set to maximum but the load is the 500W drill. The hash on the waveform is due to the motor's commutator.

from a high (around 4V) to a low level (around 1V) and also from a low to a high.

That interrupt level occurs when the mains voltage swings through zero volts in either direction. The interrupt tells IC1 that the voltage of the mains has just passed through 0V.

That allows IC1 to synchronise gate triggering with the mains waveform. Note that the 4.7nF capacitor at pin 2 introduces a phase lag (delay), but this is compensated for within IC1's software.

Current feedback

By now, you are probably wondering about the function of transformer T1 and the associated bridge rectifier. This is used to monitor the load current through the Triac. T1 is a current transformer comprising a ferrite toroid with a 2-turn primary winding in series with the Triac. The secondary winding has 1000 turns and it is loaded with a 510Ω resistor.

With this loading, the transformer produces a voltage of 800mV per amp of load current which is the current through the motor being controlled.

This voltage is fed to the bridge rectifier consisting of four schottky diodes and the resulting DC is filtered with a 10µF capacitor.

The 1kΩ series resistor provides the attack time for the resulting current feedback signal while the 10kΩ resistor provides the decay, discharging the capacitor over time.

The current feedback signal is monitored at the AN0 input at pin 7 and the associated 10kΩ resistor and 100nF capacitor provide extra filtering, as well as limiting any current into the internal protection diodes at pin 7.

So transformer T1 provides the current feedback signal for IC1 which gives motor speed regulation and trimpot VR2 is gain control for that function. You set VR2 to give the optimum speed regulation for the power tool you are controlling.

Construction

With the exception of VR1 (the speed control potentiometer), the Full Wave Universal Motor Speed Controller is constructed entirely on a double-sided, plated-through PCB (printed circuit board) coded 10102181 and measuring 103 x 81mm.

This is mounted inside a diecast box measuring 119 x 94 x 34mm.

Follow the overlay diagram shown in Fig.2.

Assembly can begin by installing the resistors. The resistor colour codes are shown in a table but you should also double-check each resistor using a digital multimeter.

Following this, fit the diodes, which must be orientated as shown. Be careful: there are several different diode types – 1N4004 for D1 and D2 and BAT46 for D3 to D6; zener diodes are a 12V 1W type (1N4742) for ZD1 and a 5.1V 1W type (1N4733) for ZD2.

If you get any of these mixed up, the circuit will not operate.

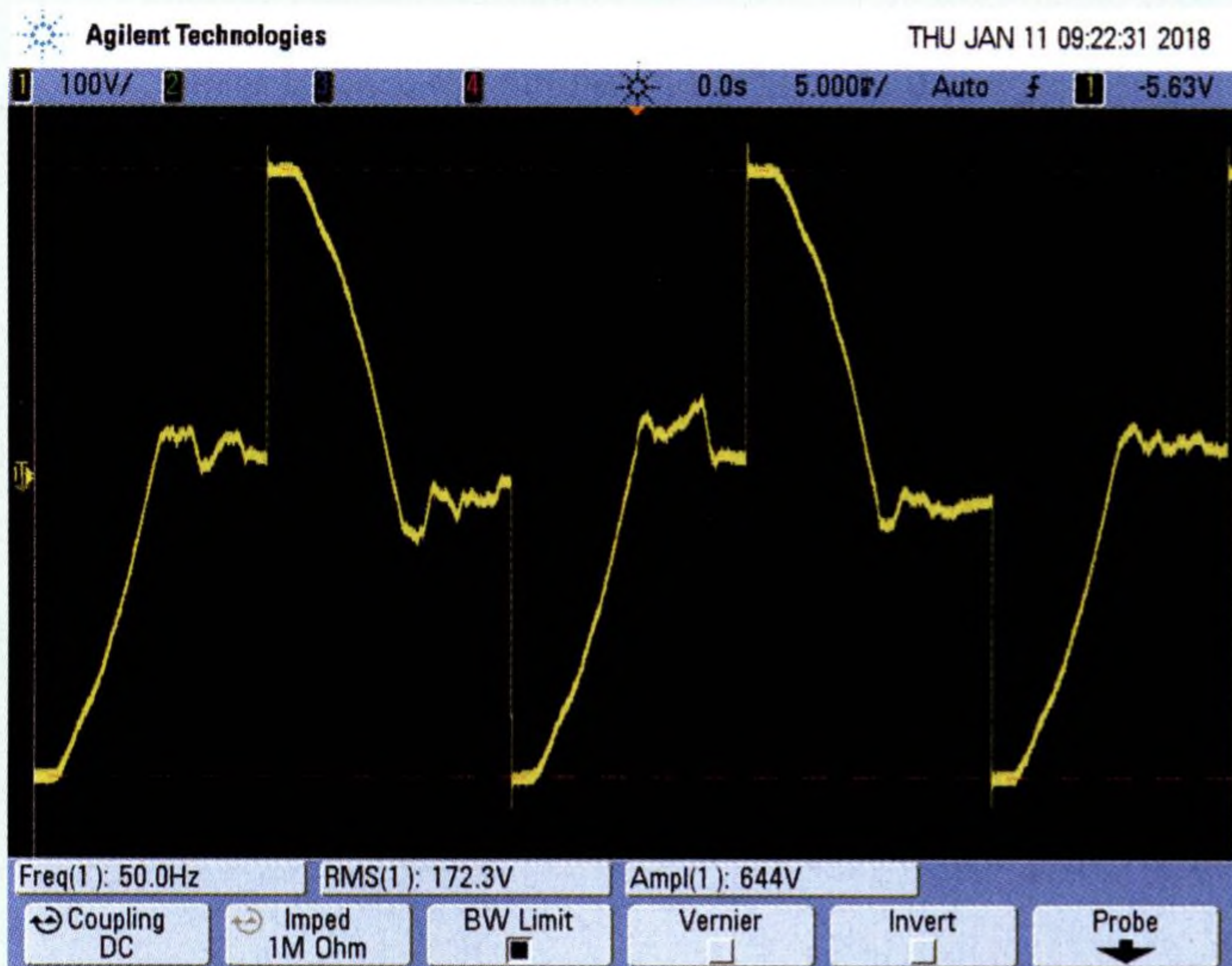
IC1 is mounted on an 8-pin DIL socket so install this socket now, taking care to orientate it correctly, with the notch facing towards the top of the PCB.

Leave IC1 out for the time being though – we'll fit it later on. Q1 can be installed now.

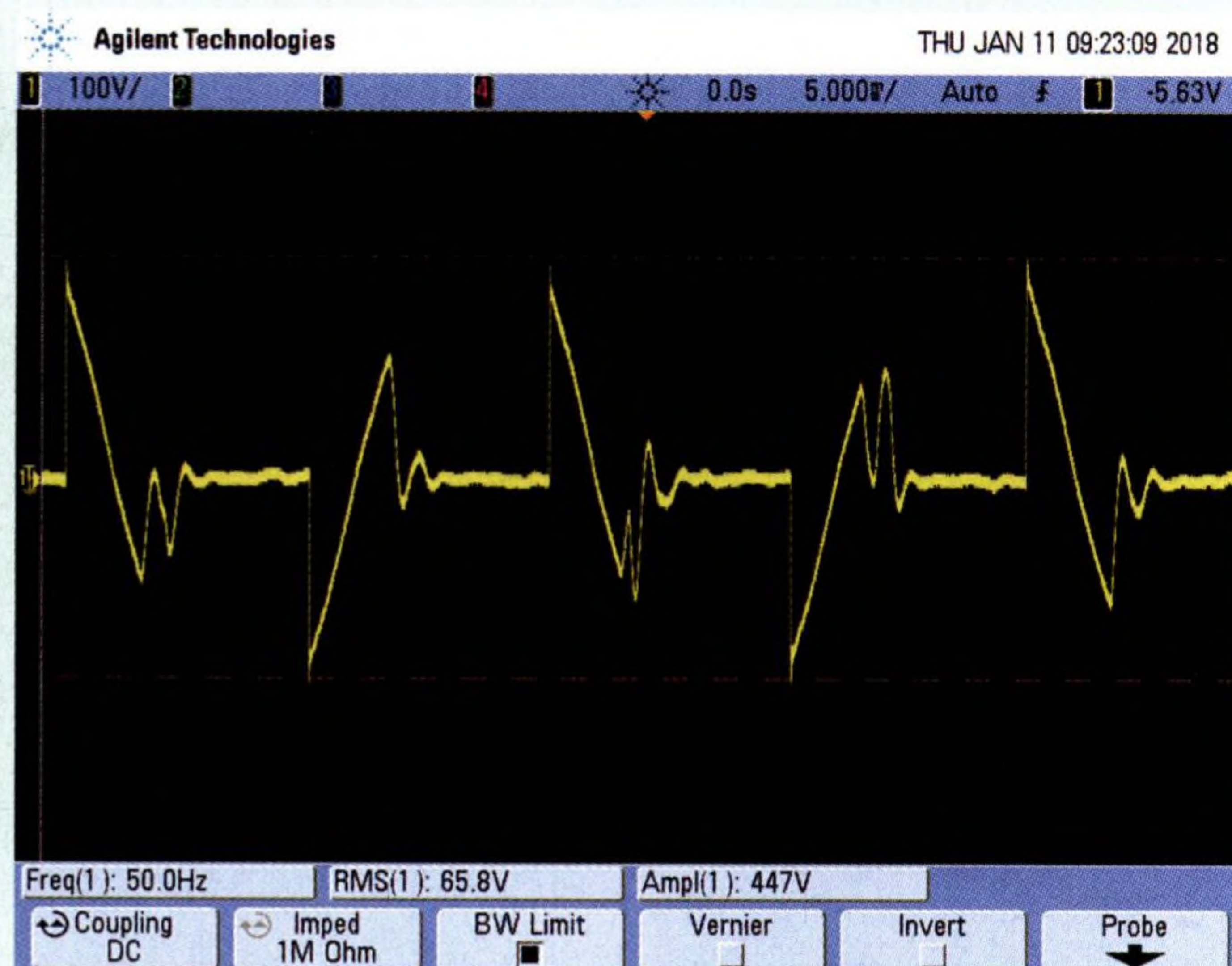
Capacitors are placed next. The MKT capacitors and the polypropylene types usually use a code for the value. These are all shown in the capacitor code table. By contrast, electrolytic capacitors are almost always marked with their value (in µF) along with their polarity (usually the negative lead is marked with a stripe). They must be inserted with the polarity shown.

The screw terminals are next. The 3-way terminal block for CON2 is installed with the lead entries toward the lower edge of the PCB.

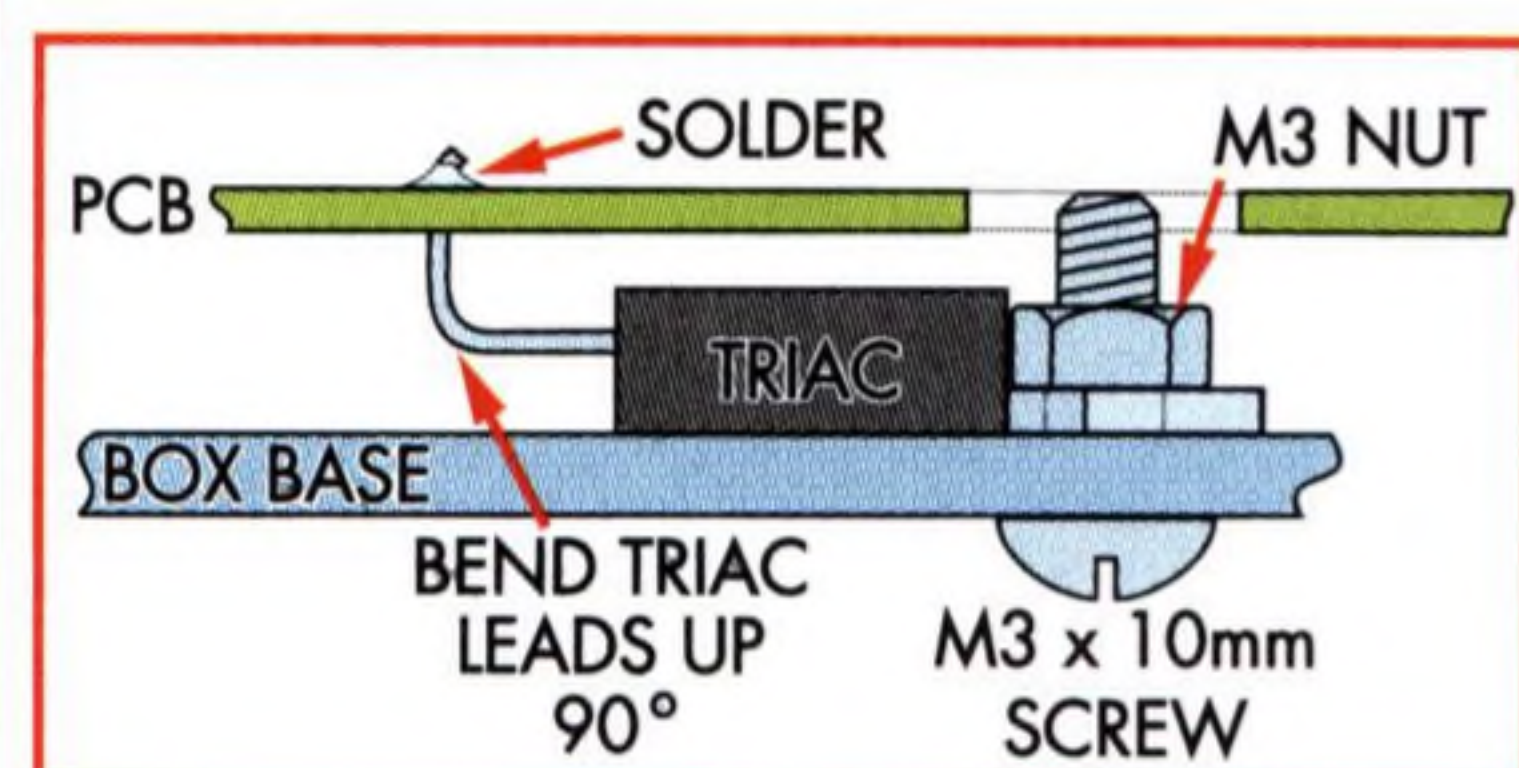
Finally (for now), install the current transformer, T1. It does not matter which way it is oriented. The Triac is fitted later.



Scope8: the output is set to about half with the 500W drill as a load. The RMS voltage is just less than 180V, the maximum you could expect with a conventional half-wave SCR speed control.



Scope9: here the output is set to the minimum that will give useful smooth low speed running from the drill. Again, the severe hash on the waveform is due to the motor's commutator.

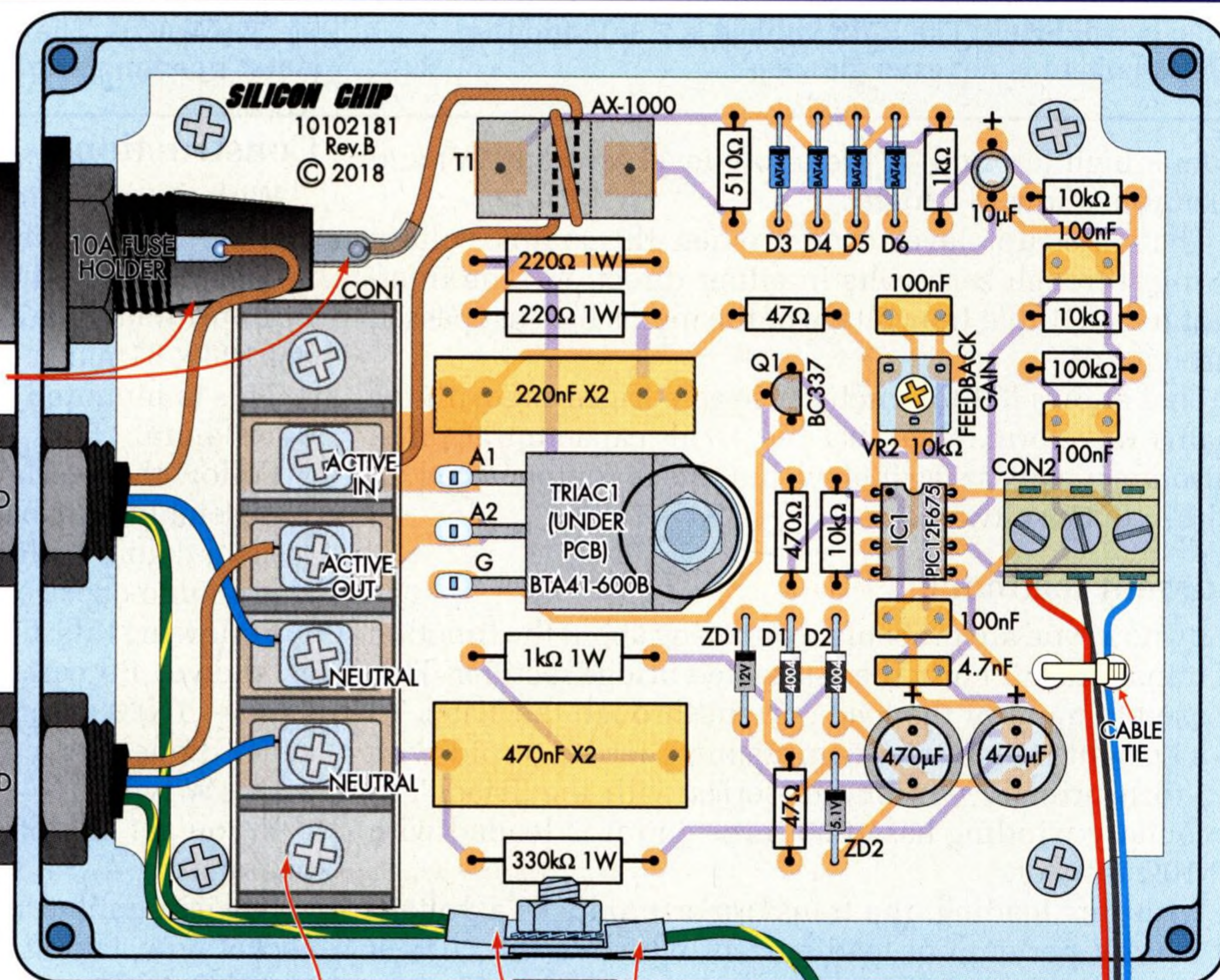


COVER FUSE HOLDER SOLDER JOINTS WITH HEATSHRINK TUBING

TO MAINS PLUG

SUPER GLUE GLAND NUT THREADS

TO MAINS SOCKET



CLEAR SHROUD OVER TERMINAL BLOCK

M4 SCREW, STAR WASHER AND NUT

EARTH LUG EYELETS

EARTH LUG, M4 SCREW, STAR WASHER & NUT

CABLE TIE

(INSIDE OF BOX LID)

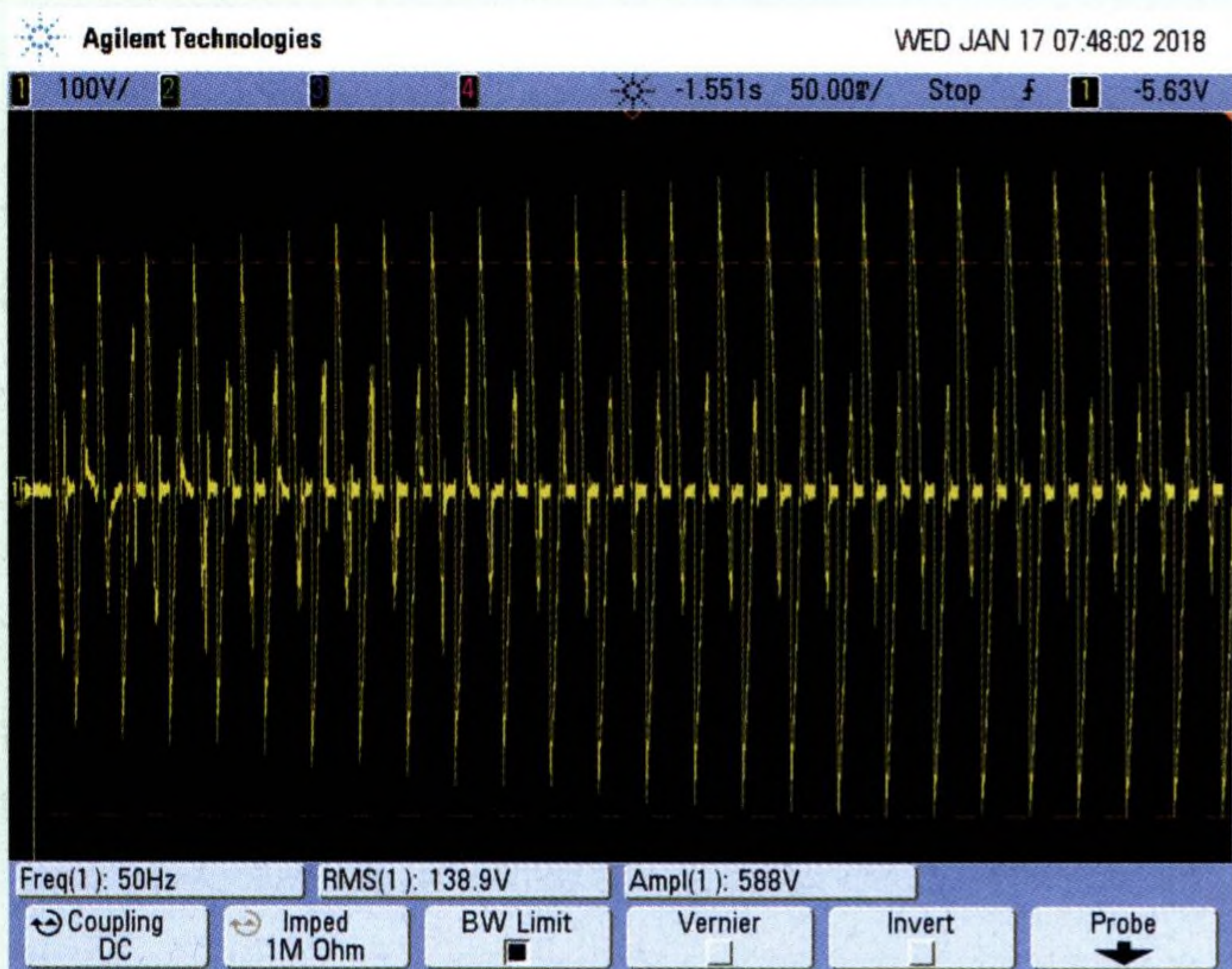
COVER JOINTS IN HEATSHRINK TUBING

7.5A MAINS RATED WIRES

SPEED POTENTIOMETER (VR1)

CABLE TIE

Fig.2: this combined component overlay and wiring diagram shows where everything goes and the inter-connections required. The Triac is secured to the bottom of the case (ie, underneath the PCB) with a 3mm screw and nut – the oversize hole in the PCB helps with tightening the nut. Its leads are bent up 90° and then soldered to the top side of the PCB once fitted (the holes in the PCB are all plated-through) – see the inset diagram above. Ensure all screws/nuts/etc are tightened really well and all soldered joints are exemplary!



Scope10: the ramp-up of the Triac triggering angle during soft startup. The full ramp-up takes more than one second.

Drilling the case

Further construction requires drilling holes in the diecast enclosure. A template is shown in Fig.4 for the end and side panel drilling details. The lid requires a 9.5mm diameter hole for potentiometer VR1 and a 4mm hole for the earth screw hole.

The PCB is mounted on the base of the case using M3 tapped spacers that are 6.3mm (or 8mm) long. Holes are required for these mounting holes on the base of the case.

The CON1 screw terminal end of the PCB sits further away from the end of the box compared to the other end. This allows space for the cable gland nuts. Position the PCB in the case to use as a template and mark out the hole positions and drill out to 3mm.

Attach the 8 or 6.3mm long spacers to the PCB. Then bend the triac leads up at 90° 4mm from the body of the triac. Insert the leads into the PCB from the underside. If you are using 6.3mm spacers, the underside pigtail leads from the components must be cut short to prevent close contact with the base of the case. They should be trimmed anyway regardless of the spacer length.

The PCB can be secured to the case with screws from the underside into the tapped spacers. Mark out the triac mounting hole position on the base of the case.

Remove the PCB again and drill out to 4mm. Clean away any metal swarf and slightly chamfer the hole edges. Re-attach the PCB and adjust the Triac lead height so the metal tab sits flush onto the flat surface.

Secure the Triac with the M3 screw and nut. The metal tab is internally isolated from the leads and so does not require any further insulation between its tab and case. Solder the Triac leads on the top of the PCB and trim the leads close to the PCB.

Now remove the screws to gain access to the underside of the PCB and solder the triac leads from the underside of the PCB. The four rubber feet can be attached to the base of the case now.

Two holes are required in the lid – one for the speed control pot (9.5mm) and the other for the earth screw (4mm).

If you use a countersunk-head earth screw and counter-

Parts list – Full Wave Universal Motor Speed Controller

- 1 PCB coded 10102181, measuring 103 x 81mm
- 1 diecast box 119 x 94 x 34mm [Jaycar HB-5067]
- 1 Talema AX-1000 10A current transformer (T1) [RS Components 775-4928]
- 1 M205 10A safety panel mount fuse holder (F1) [Altronics S5992]
- 1 M205 10A fuse
- 1 4-way PCB mount terminal barrier (CON1) [Jaycar HM-3162]
- 1 3-way PCB mount screw terminals with 5.08mm spacings (CON2)
- 2 cable glands for 5-10mm cable
- 1 DIL-8 IC socket
- 1 2m 250V 10A mains extension lead (cut in half to form mains input and output leads)
- 4 4mm eyelet lugs
- 4 8mm or 6.3mm M3 tapped Nylon standoffs
- 1 M3 x 10mm screw (for triac mounting)
- 1 M3 nut and washer
- 2 M4 x 10mm screws (CSK head preferred)
- 2 4mm ID star washers
- 2 M4 nuts
- 8 M3 x 5mm screws
- 4 stick-on rubber feet
- 1 20mm length of 12mm diameter heatshrink tubing
- 1 80mm length of 3mm diameter heatshrink tubing
- 1 25mm length of 6mm diameter green heatshrink tubing if required for chassis lugs
- 3 150mm lengths of 7.5A mains-rated wire for VR1
- 3 100mm long cable ties

Semiconductors

- 1 PIC12F675 programmed with 1010218A.hex (IC1)
- 1 BTA41-600B insulated tab 40A 600V Triac (Triac1) [element14 1057288 or RS 687-1007]
- 1 BC337 NPN transistor (Q1)
- 1 12V 1W (1N4742) zener diode (ZD1)
- 1 5.1V 1W (1N4733) zener diode (ZD2)
- 2 1N4004 1A diodes (D1,D2)
- 4 BAT46 schottky diodes (D3-D6)

Capacitors

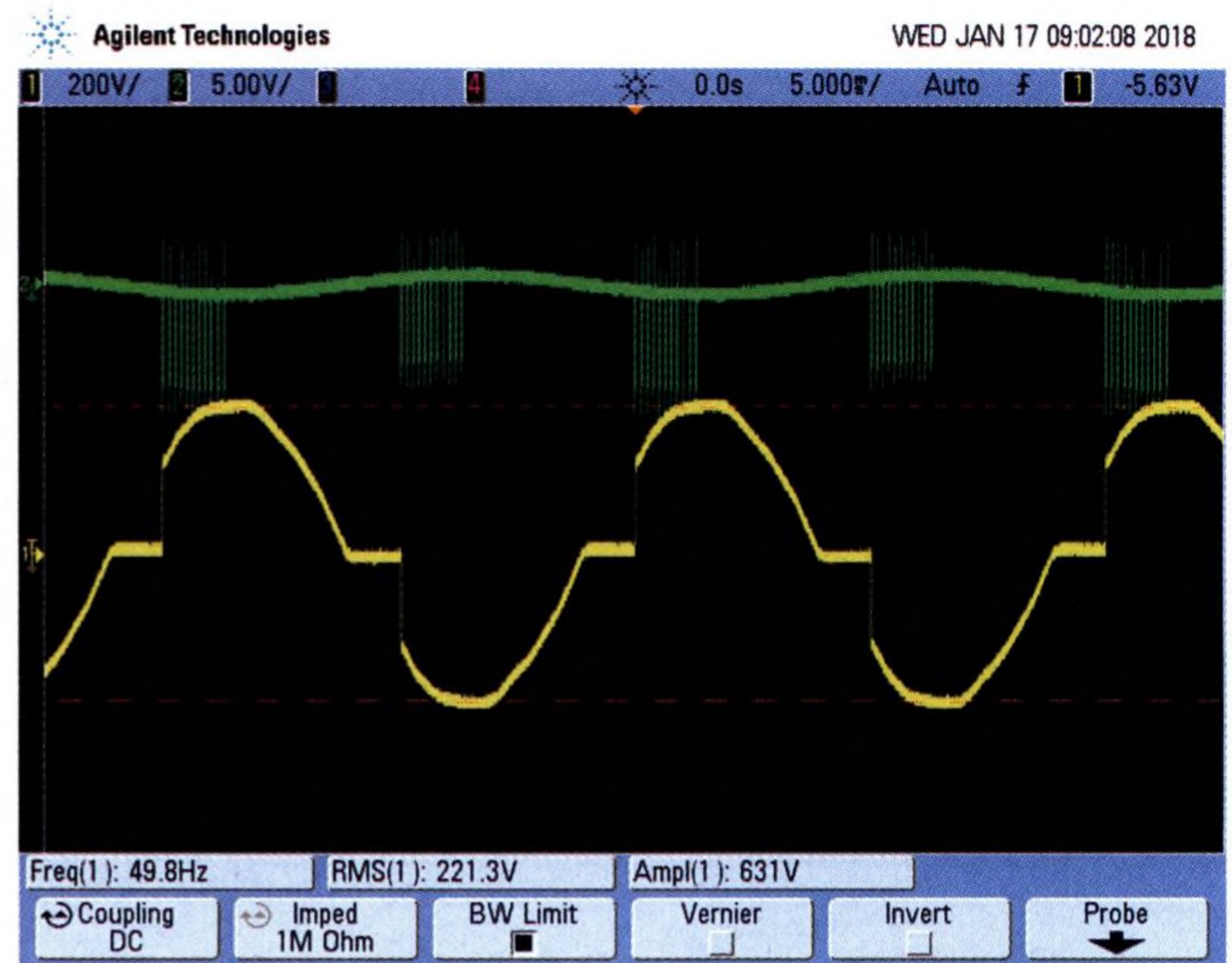
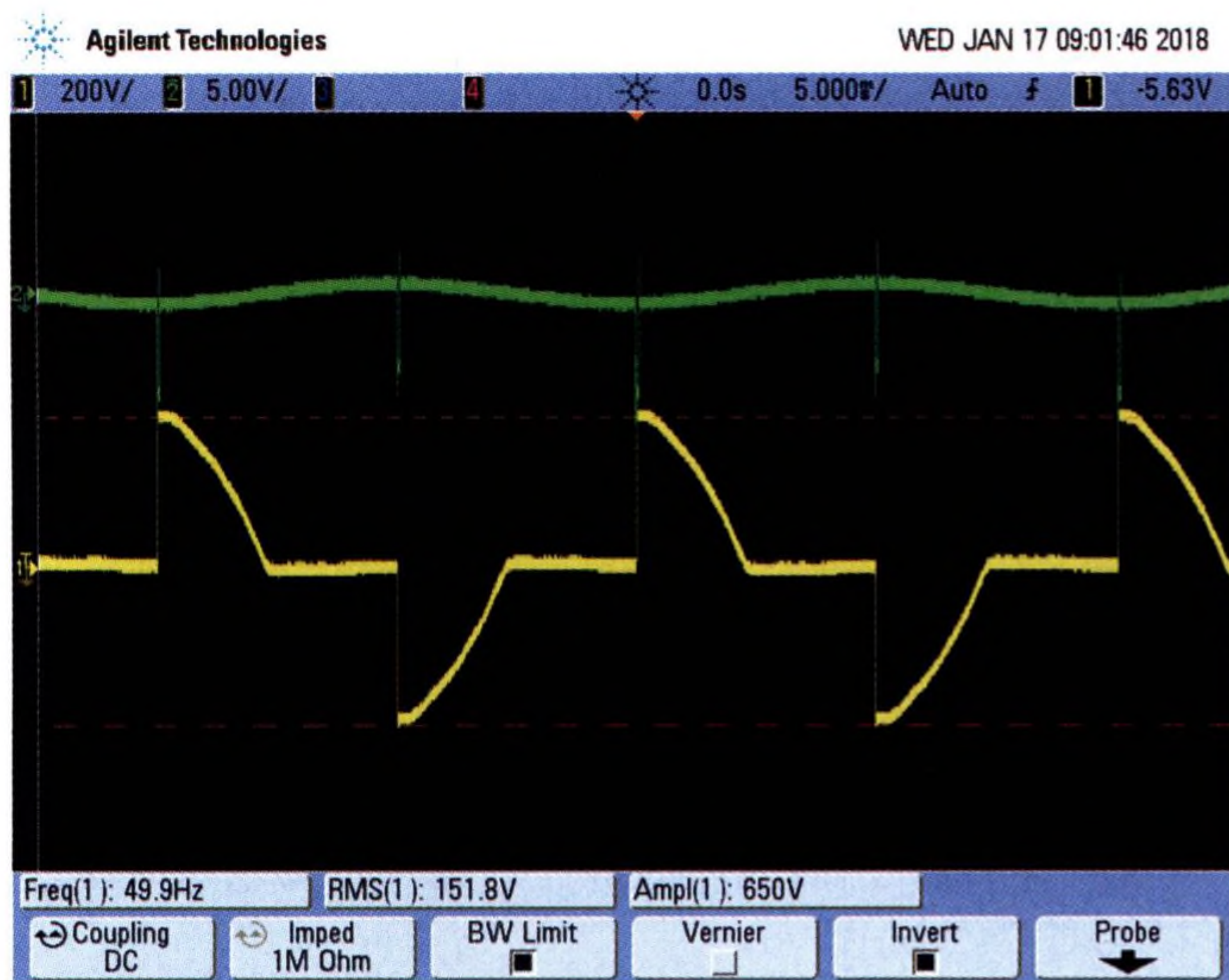
- 2 470µF 16V PC electrolytic
- 1 10µF 16V PC electrolytic
- 1 470nF 275VAC X2 class
- 1 220nF 275VAC X2 class
- 4 100nF 63V or 100V MKT polyester
- 1 4.7nF 63V or 100V MKT polyester

Resistors (0.25W, 1% unless specified)

- 1 330kΩ 1W carbon film
- 1 100kΩ
- 3 10kΩ
- 1 1kΩ
- 1 1kΩ 1W carbon film
- 1 510Ω
- 1 470Ω
- 2 220Ω 1W carbon film
- 2 47Ω
- 1 linear 10kΩ 24mm potentiometer (VR1)
- 1 10kΩ mini, top adjust trimpot (3386F style) (VR2)

Miscellaneous

- 1 knob to suit VR1
- Super glue, heatsink compound, solder



Scope11&12: these show how the Triac triggering varies, depending on the speed setting. At low speed settings, there is only one trigger pulse during each mains half-cycle. At higher power levels, there are multiple trigger pulses during each half-cycle to ensure that the Triac stays turned on, in spite of the lagging load current (due to the inductive motor load).

sink the earth screw hole appropriately, it can be mounted **under** the panel label (looks neater!). Otherwise, you'll need to cut holes in the panel label (with a sharp hobby knife) when the label is stuck on.

The panel label file can be downloaded (free for subscribers) from our website (www.siliconchip.com.au).

To produce a front panel label, you have several options. For a more robust label, print as a mirror image onto clear

overhead projector film (using film suitable for your type of printer). Attach the label printed side down to the lid with a light coloured or clear silicone sealant.

Alternatively, you can print onto a synthetic "Dataflex" sticky label that is suitable for inkjet printers or a "Datapol" sticky label for laser printers. Then affix the label using the sticky back adhesive.

(There's more information on Dataflex at siliconchip.com.au/aabw and Datapol at siliconchip.com.au/aabx. And there's a few more hints on making labels for projects – see siliconchip.com.au/Help/FrontPanels).

Wiring

Cut the 10A extension lead into two to provide one lead with a plug on the end and another with a socket. Where the lead is cut depends on how long you prefer each lead.

You may prefer a long plug cord and short socket lead so the motor appliance is located near to the controller, or the lead can be cut into two equal lengths.

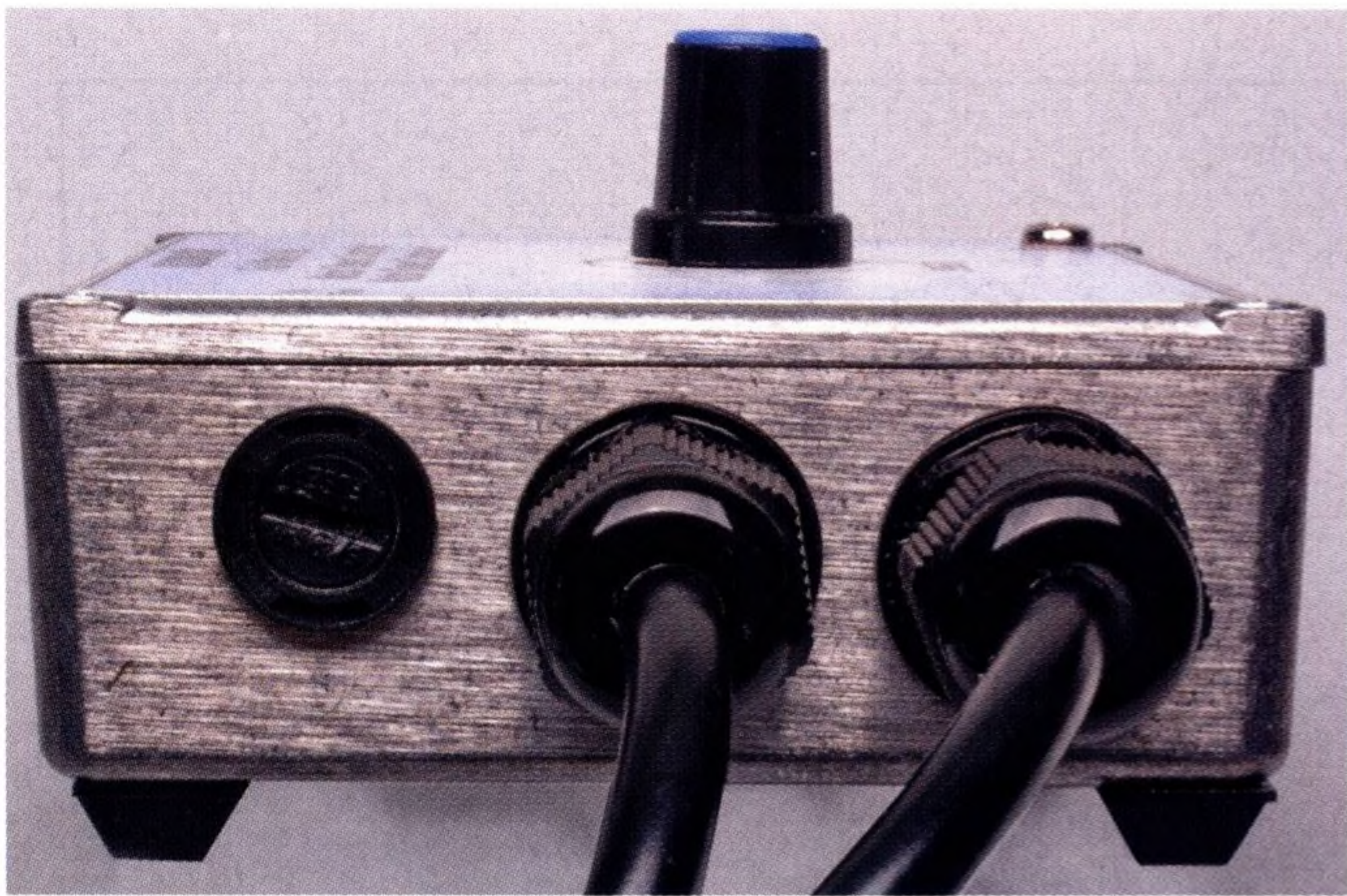
Before cutting make sure you have sufficient length to strip back the insulation as detailed in the next two paragraphs.

Make sure the plug lead and socket lead are placed in the correct gland and wired as shown.

First the socket (output) lead: you need a 100mm length of earth wire (green/yellow stripe) for the connection between the chassis and lid, so strip back the outside sheath insulation by about 200mm. Then cut the blue



The lid, with front panel affixed, "opens out" from the box as shown in this photo, reproduced about three-quarter size. Make sure the wires to the speed pot are all 250VAC mains-rated (don't use rainbow cable!) and use cable ties and heatshrink where shown above and in Fig.2.



Three holes are required in the end of the case – the two on the right are 15mm to suit the cable glands, while the hole on the left is nominally 12.5mm but is “D” shaped to hold the fuseholder in place. On the lid, a 9.5mm hole to house the speed control pot sits slightly off-centre with a 4mm hole (on the left in this photo) for the lid earthing screw. As mentioned in the text, if this hole is shaped to accept a countersunk-head screw, it can go underneath the label and so not be visible.

neutral wire and brown active wires to 50mm and connect them to their respective terminals on the terminal block. You should be left with 100mm of earth wire (green/yellow stripe) which is routed around the edge of the PCB and twists with the earth wire from the plug (input) lead to be crimped into one of the earth lugs.

The spare 150mm brown wire can be used later to connect from the fuse to the CON1 terminal via the transformer, T1. This has two turns of the active wire looped through the transformer hole.

The plug lead outside sheath insulation should be stripped back to expose 100mm of wire. This leaves sufficient lead length. All three wires are passed through the cable glands and connect as shown in Fig.2. Cut the neutral wire to 50mm and strip back the insulation before connecting the neutral (blue) wire to the terminal block

The active (brown) wire solders direct to the fuseholder. 10mm diameter heatshrink tubing should first be placed over active (brown) wire which slides up and over the fuseholder after soldering to cover the side fuseholder terminal.

Similarly, 3mm diameter heatshrink tubing 3mm in diameter is used to cover the fuseholder end terminal. Once both connections are soldered, pass the heatshrink over the join and shrink.

Now twist the ends of the input earth (green/yellow

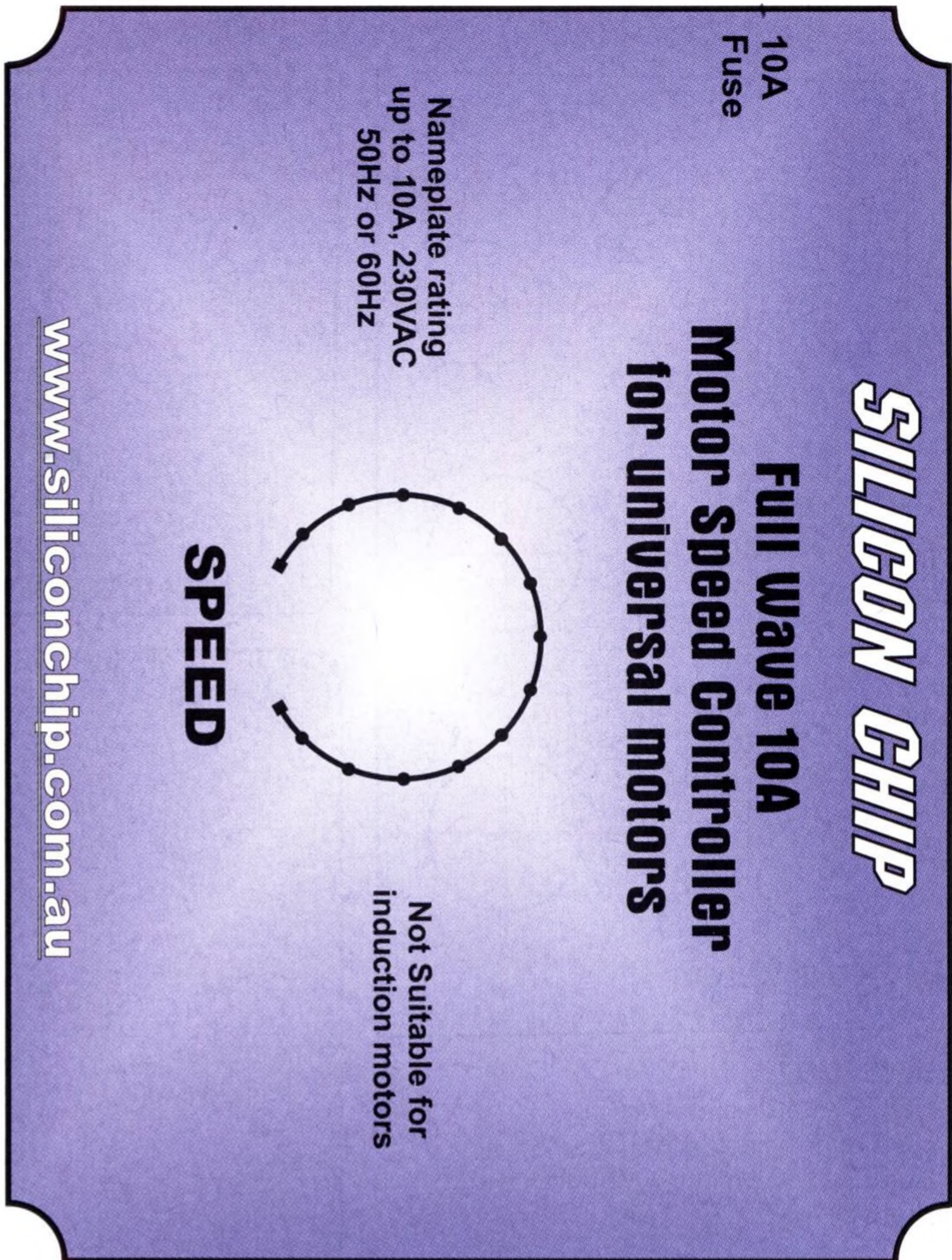


Fig.3: the same-size front panel artwork which is designed to be glued to the case lid. It can be copied, or downloaded (free for subscribers) from siliconchip.com.au

stripe) wire and the output earth wire together and crimp into one of the eyelet earth lugs.

Cut VR1’s shaft to 12mm long and file the edges smooth. Then attach the three 100mm lengths of 7.5A mains rated wire to the three VR1 terminals and cover with the 3mm heatshrink tubing. The other ends connect to CON2.

These wires are secured using a cable tie that feeds through holes in the PCB. Attach VR1 to the lid of the case – note that the potentiometer must be located as shown (ie, leads emerging from the right) so it fits between the two mains rated capacitors on the PCB.

Fit the knob – you may need to lift out the knob cap with a hobby knife and re-orient the cap so its pointer position matches the rotation marks on the panel.

That 100mm length of earth wire you cut off from the output lead can now be crimped into two eyelet lugs, which are screwed to the underside of the box lid and the earth screw on the side of the case using

Resistor Colour Codes			
Qty	Value	4-Band Code (1%)	5-Band Code (1%)
□ 1 [^]	330kΩ	orange orange yellow brown	orange orange black orange brown
□ 1	100kΩ	brown black yellow brown	brown black black orange brown
□ 3	10kΩ	brown black orange brown	brown black black red brown
□ 1+1 [^]	1kΩ	brown black red brown	brown black black brown brown
□ 1	510Ω	green brown brown brown	green brown black black brown
□ 1	470Ω	yellow purple brown brown	yellow purple black black brown
□ 2 [^]	220Ω	red red brown brown	red red black black brown
□ 2	47Ω	yellow purple black brown	yellow purple black gold brown

[^] = 1W, carbon film type

Small Capacitor Codes			
Qty	Value/Type	EIA	IEC
□ 1	470nF X2	474	470n
□ 1	220nF X2	224	220n
□ 4	100nF MKT	104	100n
□ 1	4.7nF MKT	472	4n7

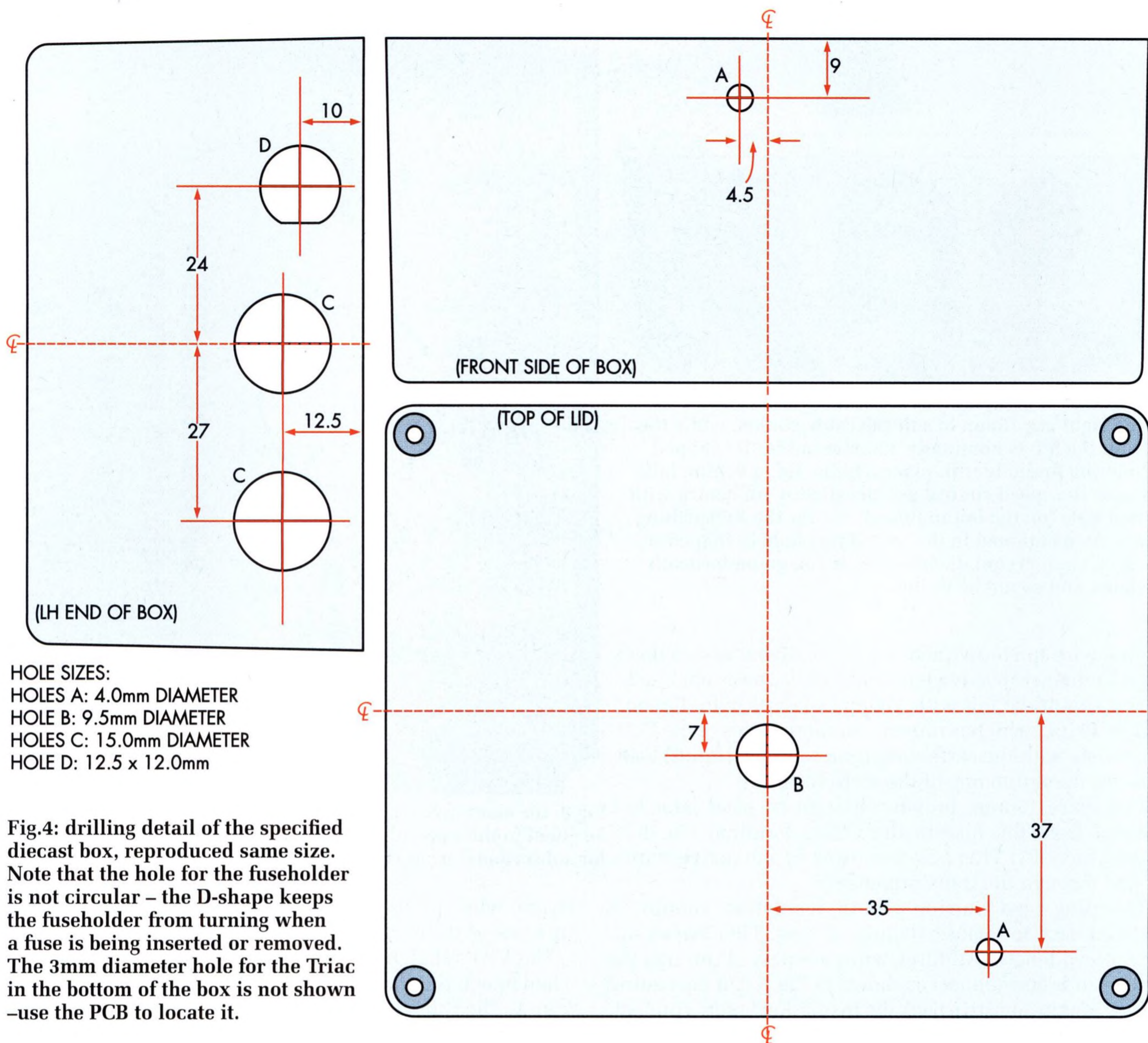


Fig.4: drilling detail of the specified diecast box, reproduced same size. Note that the hole for the fuseholder is not circular – the D-shape keeps the fuseholder from turning when a fuse is being inserted or removed. The 3mm diameter hole for the Triac in the bottom of the box is not shown –use the PCB to locate it.

M4 screws, star washers and nuts. Ensure that the nuts are fully tightened.

Final assembly

Apply a smear of heatsink compound to the underside of the Triac before installing the PCB inside the case. Again, the tab of the Triac is insulated, so it can contact the case with safety.

The last components to inserted are IC1 (taking care it is oriented correctly), the 10A fuse into its holder and the cover for the barrier terminals (CON1) – it is simply pressed on to cover the screw terminals. Finally, rotate VR2 fully anticlockwise to initially disable feedback.

Check your construction carefully and especially check that the earth wires (green/yellow striped) actually connect together the case, the lid and the earth pins on both the mains plug and socket. Check this with a multimeter set to read low ohms.

The cable glands need to be tightened to hold the mains cords in place. Because these are easily undone, the thread of the glands should have a drop of super glue applied to

the threads before tightening. This way the glands cannot be undone. Attach the lid to the case using the four screws supplied with the case (don't be tempted to run the speed controller without the lid in place!).

Testing

Connect up a universal motor appliance (eg, an electric drill) to the controller, apply power and check the motor can be controlled when adjusting the speed potentiometer.

Once you have verified that it works, **switch off power and unplug the mains plug** from the mains outlet. Then remove the lid and adjust VR2 half way. Re-attach the lid and apply power again and check the speed regulation of the motor under load.

Trimpot VR2 may need further adjustment; anticlockwise if the motor speeds up under load and clockwise if the speed drops off too markedly under load.

Note that any adjustment of VR2 must **only** be done with the power off and mains plug disconnected. This means that adjustment is a trial and error process. Power should only re-applied after the lid is re-attached.