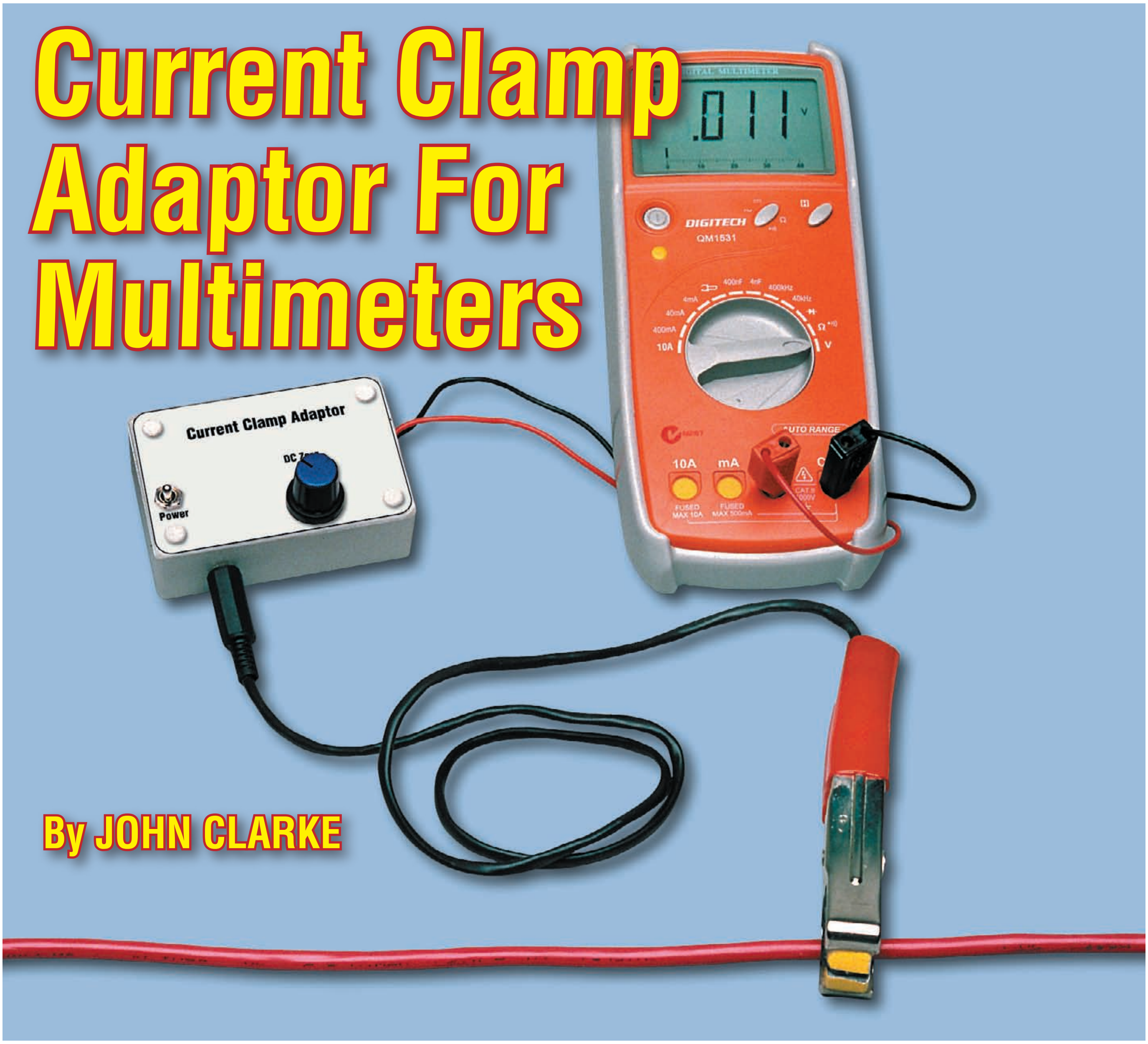
Current Clamp Adaptor For Multimeters

By JOHN CLARKE



Looking for a current clamp meter that won't break the bank? Here's a simple clamp meter adaptor that you can build for about £15. It plugs into a standard DMM and can measure both AC and DC currents.

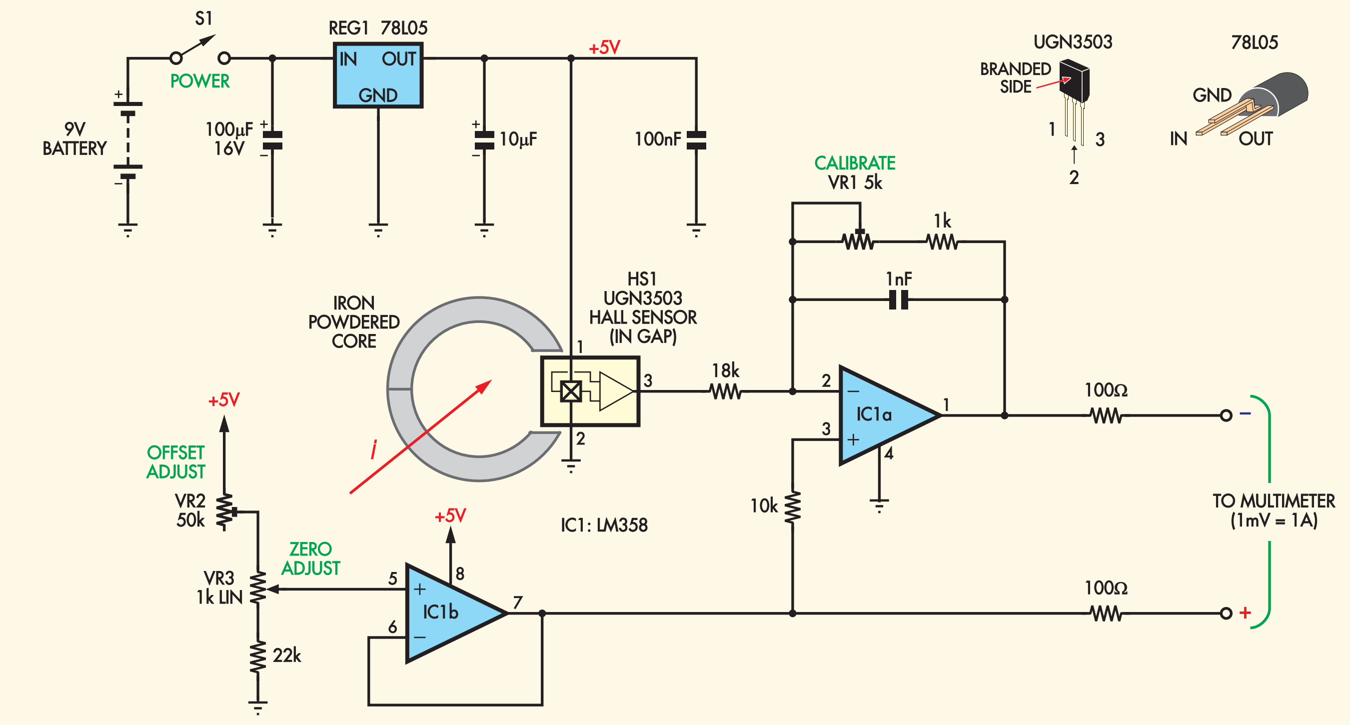
CLAMP METERS are very convenient when it comes to measuring current, since they do not require breaking the current path. Instead, they simply clip over the wire or lead that's carrying the current and the reading is then displayed on the meter.

This is not only much easier than "in-circuit" current measurements but is often a lot safer as well; eg, where high voltages and currents are involved. However, clamp meters are not particularly useful for making low-current measurements (ie, below 1A) due to their inaccuracy and lack of resolution.

Unlike this unit, many commercial current clamp meters can only measure AC. That's because they are basically current transformers, comprising turns of wire around a magnetic core. This magnetic core is clipped around the wire to be measured, which effectively behaves as a half-turn primary winding. The winding on the core itself acts as the secondary and connects to the multimeter's current terminals.

The measured current is a divided down value of the true current flowing in the wire. Usually, the division ratio is 1000:1 so that 1mA shown on the meter equates to 1A through the wire that's being measured.

Clamp meters capable of measuring DC as well as AC do not use a current transformer but a Hall effect sensor instead. This sensor is placed inside



CURRENT CLAMP ADAPTOR

Fig.1: the circuit uses Hall effect sensor HS1 which produces a voltage at its pin 3 output that depends on the magnetic field induced into an iron-powdered toroid core. This voltage is fed to op amp IC1a which then drives the negative terminal of the multimeter. IC1b drives the meter's positive terminal and provides null adjustment.

a gap in an iron-powdered toroid core. It measures the magnetic flux produced as a result of the current flowing through the wire and produces a proportional output voltage.

How it works

To make it as versatile as possible, the Clamp Meter Adaptor also uses a Hall effect sensor so that it can measure both DC and AC currents. The output of this sensor is then processed using a couple of low-cost op amps which then provide a signal for a standard DMM or analog multimeter.

When measuring DC current, the multimeter is set to its DC mV range and 1A through the wire in the core equates to a reading of 1mV on the meter. A potentiometer allows the output to be nulled (ie, adjusted to 0mV) when there is no current flow.

Similarly, for AC current measurements using the clamp meter, the multimeter is simply set to its AC mV range. In this case, the DC offset potentiometer is not needed, since the multimeter automatically ignores any DC levels.

The high-frequency response of the adaptor for AC measurements is 3dB down at 20kHz (ie, 0.7071 of the real value). However, the actual measurement displayed will also depend on the high-frequency response of the multimeter itself. Some multimeters give useful readings up to 20kHz, while others begin to roll off the signal above 1kHz (ie, frequencies above this will not be accurately measured).

If necessary, the output from the Clamp Meter Adaptor can be monitored using an oscilloscope if AC measurements have to be made at high frequencies. However, AC current measurements at 50Hz (ie, the mains frequency) will be accurate using virtually any multimeter.

Note that most multimeters are calibrated to display the RMS values of AC current measurements, although they are only accurate for sinusoidal waveforms. This unit will not affect meter calibration, since it does not change the shape of the waveform for signals below 20kHz and only converts the current waveform to a voltage waveform. However, for non-sinusoidal waveforms, the multimeter will display an erroneous result unless it is a true RMS type.

Specifications

Output: 1A = 1mV for AC and DC ranges

Resolution: multimeter dependent (100mA with 0.1mV resolution on multimeter)

Maximum DC current: 150A recommended (up to 900A if core is demagnetised afterwards)

Maximum AC current: 630A recommended

Linearity: typically better than 4% over range at 25°C

AC frequency response: -3dB at 20kHz (meter reading depends on multimeter AC response)

Current consumption: 15mA

Demagnetising the core

One problem with clamp meters is that the core can remain magnetised after making high DC current measurements; ie, even when the current flow has been reduced to zero. In fact, this effect becomes apparent when measuring DC currents above about 150A. It is easily detected because the output from the sensor remains at several millivolts after the current ceases flowing.

Fortunately, there's an easy solution to this. If the core does become magnetised, it can be demagnetised again by momentarily reversing the current flow in the core.

In practice, this is done by unclipping the core from the wire, replacing it over the wire upside down and applying the current again for a brief period of time.

Modified battery clamp

To keep costs down, the Clamp Meter Adaptor uses a modified car battery clip as the current clamp. This is fitted with an iron-powdered toroid core which is cut in half so that the clip can be opened and slipped over the current-carrying wire. The Hall effect sensor sits in a gap in the toroid, near the front of the clip – see Fig.2.

The output from this sensor is fed to a processing circuit which is built on a small PC board and housed in a plastic case, along with the battery. This circuit in turn connects to the meter via two leads.

By the way, commercial clamp meters using Hall effect sensors usually place the sensor at the hinge end of the core. This can be done when the clamp material is non-magnetic. However, when the clamp is magnetic, as in this design, the magnetic flux is conducted through it instead and bypasses the air gap where the sensor sits – see Fig.2 (top drawing).

This problem is solved by simply placing the sensor in an air gap at the front of the clamp, so that it cannot be bypassed.

Circuit details

Refer now to Fig.1 for the circuit details. It's relatively simple and comprises a dual op amp (IC1a & IC1b), a 3-terminal regulator (REG1), the Hall effect sensor (HS1) and a few resistors and capacitors.

Power for the circuit is derived from a 9V battery and is fed to REG1 which provides a regulated +5V rail. This then powers the Hall effect sensor and op amps IC1a & IC1b. Note that a regulated supply is necessary, since the Hall sensor output will vary with supply rail variations.

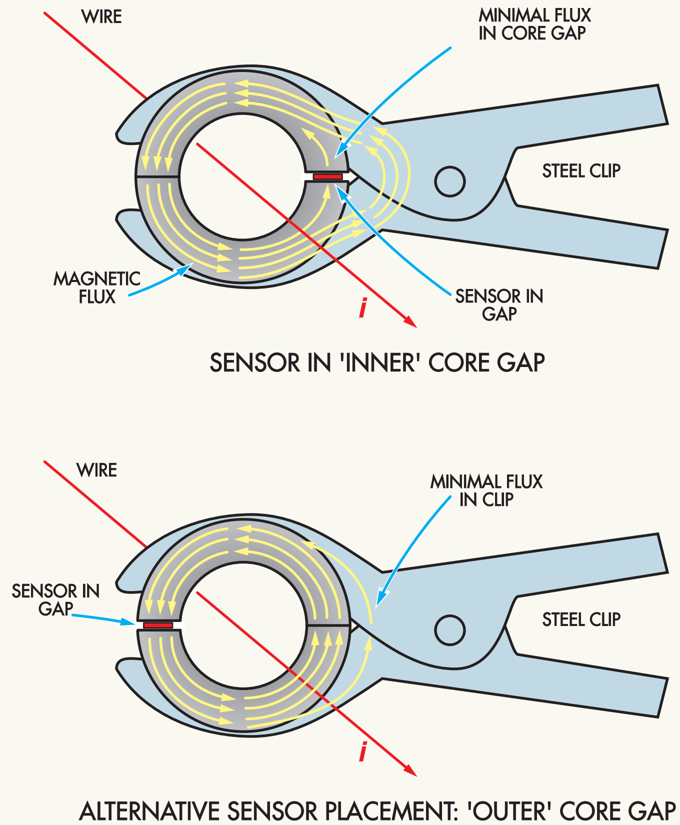


Fig.2: if a steel (ie, magnetic) clamp is used, the Hall sensor must be placed in an air gap in the toroidal core as shown in the bottom diagram. This is necessary to ensure that it is not bypassed by magnetic flux flowing through the clamp instead.

In operation, the Hall effect sensor produces a voltage at its pin 3 output that depends on the magnetic field in the core. If the marked face of the sensor faces a south magnetic field, its output voltage will rise. Conversely, if it faces a north field, the output voltage will fall.

The sensor's output with no magnetic field applied to it will sit between 2.25V and 2.75V, depending on the sensor. This voltage remains stable, providing the supply voltage remains stable.

The output of the Hall effect sensor is fed to op amp IC1a. This stage is wired as an inverting amplifier and it attenuates the signal by an amount that depends on the setting of trimpot VR1 (calibrate). Note that the gain of IC1a is set by the resistance between pins 1 & 2 divided by the 18kΩ input resistor.

This means that if VR1 is set to half-way, IC1a has a gain of (2.5kΩ + 1kΩ)/18kΩ = 0.19.

In practice, VR1 is adjusted so that it produces an output of 1mV per amp flowing through the current-carrying wire.

Op amp IC1b and its associated circuitry compensate for the initial DC voltage at the output of the Hall effect sensor (ie, with no magnetic field applied). As shown, IC1b is connected as a unity gain buffer with its output connected to its pin 6 inverting input. The non-inverting input at pin 5 connects to a resistive divider network consisting of VR2, VR3 and a 22kΩ resistor.

The output from IC1b (pin 7) goes to the positive meter terminal and is also used to bias pin 3 of IC1a via a 10kΩ resistor. This bias voltage is nominally about 2.5V (ie, 0.5Vcc) and allows the output of IC1a to swing up or down about this voltage, depending on the sensor input. It also effectively allows the quiescent voltage from the Hall sensor to be nulled so that we get a 0V reading on the meter when no current is being measured.

VR2 is initially adjusted with VR3

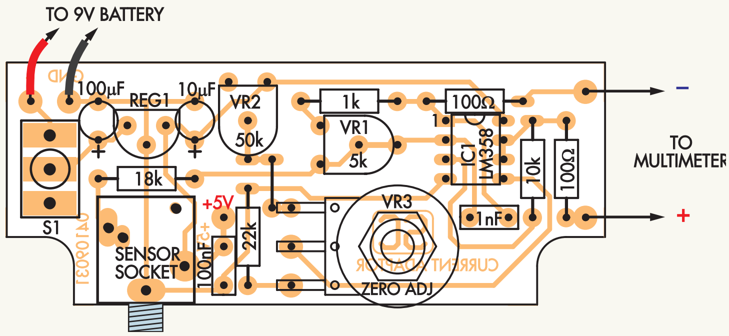


Fig.3: install the parts on the PC board as shown here. The Zero Adjust pot (VR3) is installed by soldering its terminals to three PC stakes.

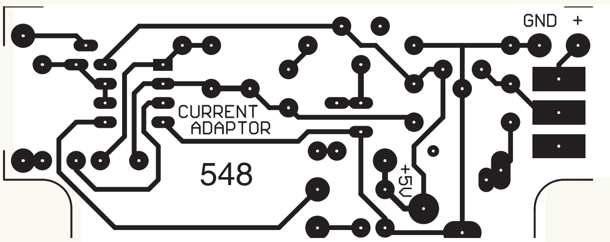


Fig.4: the full-size etching pattern for the PC board.

set to mid-range, so that the multimeter reads 0V with no magnetic field applied to the Hall sensor. VR3 is then adjusted during subsequent use of the clamp meter – it can vary IC1b's output by about 25mV to null out any small voltage readings.

In effect, trimpot VR2 acts as a coarse offset adjustment, while VR3 allows fine adjustment to precisely zero the reading.

Looked at another way, VR2 & VR3 are simply adjusted so that the voltage on pin 7 of IC1b is the same as the voltage on pin 1 of IC1a when there is no magnetic field applied to the Hall effect sensor – ie, the voltage between pins 1 & 7 is 0V.

The outputs from both op amps are fed to the multimeter via 100Ω resistors. These provide short-circuit protection for the op amp outputs and also decouple the outputs from the cable capacitance.

Construction

Building the circuit is easy since all the parts are mounted on a small PC board coded 548 and measuring 75 × 30mm. Begin construction by checking the PC board for any shorts between tracks and for any breaks in the copper pattern. Also check that the hole sizes are all correct for the various components, particularly those for the PC-mount stereo socket and the on/off switch (S1).

Note that two of the corners on the PC board need to removed, so that the board later clears the corner pillars inside the case. If your board is supplied with these corners intact, they can be cut away using a small hacksaw and carefully finished off using a rat-tail file.

Fig.3 shows the assembly details. Install the resistors and wire link first, using Table 1 to guide you on the resistor colour codes. It's also a good idea to check the resistor values with a DMM, just to make sure.

IC1 can go in next, taking care to ensure that it is oriented correctly. That done, install the trimpots and the capacitors, noting that the electrolytics must be oriented with the polarity shown. The trimpots are usually labelled with a code value, with 502 equivalent to 5kΩ (VR1) and 503 equivalent to 50kΩ (VR2).

Next, install PC stakes at the two power supply inputs, the +5V terminal, the three VR3 terminal positions and the two multimeter outputs. These can be followed with the switch and the PC-mount stereo socket.

Finally, complete the board assembly by installing potentiometer VR3 – it is mounted with its terminals soldered to the top of its PC stakes. Position it so that the top of its mounting thread is at the same height as the top of the switch thread.

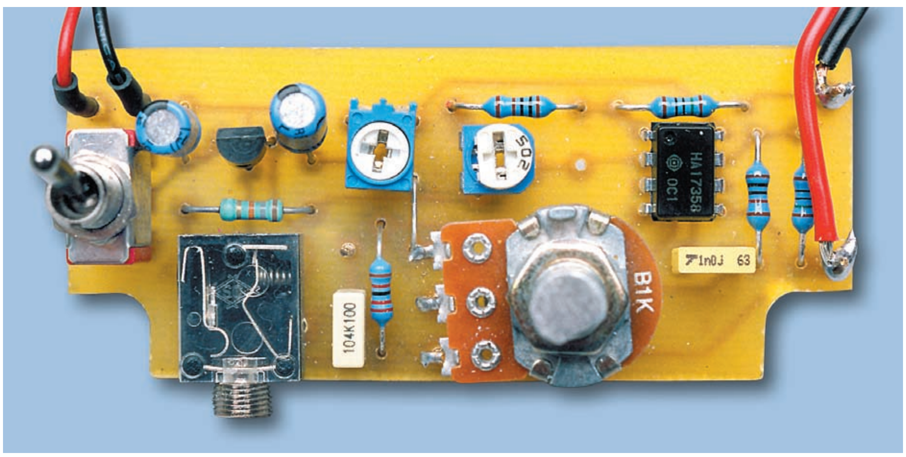
Drilling the case

The front panel artwork (Fig.8) can now be used as a template to mark out and drill the lid of the small plastic utility case that's used to house the board. You will need to drill two holes – one for the switch and the other for the potentiometer.

In addition, you will have to drill a 4mm hole in one end of the case for the multimeter leads, plus a 7mm hole in one side to accept the stereo socket. The latter should be positioned 14mm down from the top of the case and 21mm in from the outside edge.

Note that it's always best to drill small pilot holes first and then carefully enlarge them to size using a tapered reamer.

Next, the integral side clips inside the box need to be removed using a



Check your completed PC board assembly carefully to ensure that all polarised components have been correctly installed. These parts include IC1, REG1 and the two electrolytic capacitors.

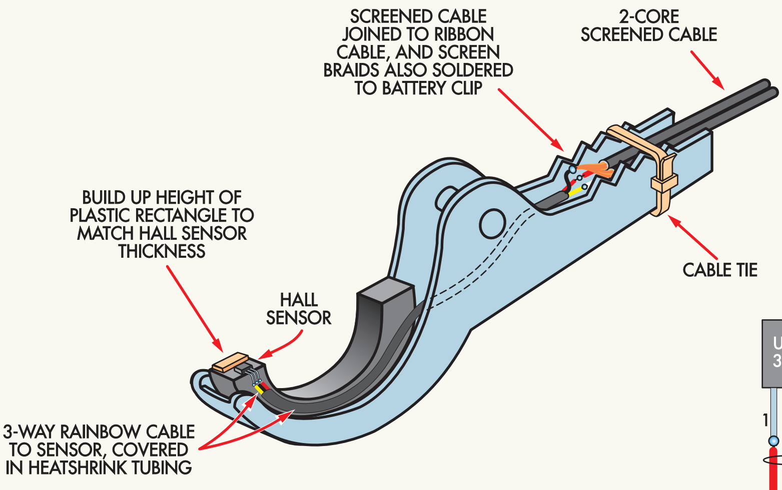
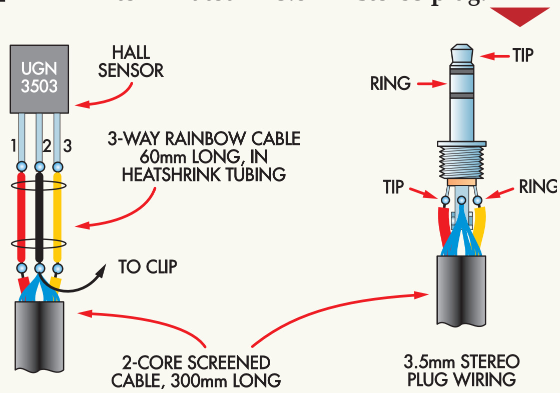


Fig.5 (above): this exploded diagram shows how the toroid core and Hall sensor are fitted to the clamp. Each core half is secured in position using builders' adhesive, as are the Hall sensor and the adjacent plastic rectangle. Note the earth connection to the metalwork of the clamp.

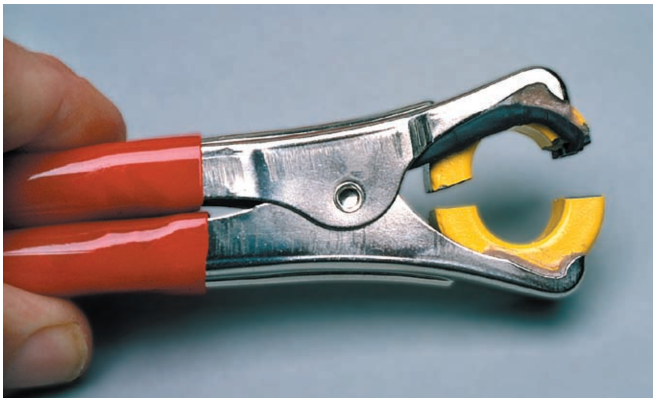
Fig.6 (below): a 60mm-length of 3-way rainbow cable is used to make the connections to the Hall sensor. This cable is then joined to a 300mm length of 2-core shielded cable which is then terminated in 3.5mm stereo plug.



chisel. Be sure to protect your eyes when doing this, as the plastic tends to splinter and fly out. You can then attach the front panel label and cut the holes out with a sharp knife.

The next step is to solder the battery clip leads to the supply terminals (red to positive, black to negative). That done, connect the multimeter leads to the output terminals, then feed these wires through the hole in the box and attach banana plugs to each free end.

Don't fit the board to the case lid at this stage. That step comes later, after calibration has been completed.



This view of the completed current clamp clearly shows the general arrangement. If the toroid core becomes magnetised during use, it can be demagnetised by momentarily reversing the current flow in the core.

Clamp assembly

The clamp assembly comprises a car battery clip, the toroidal core and the Hall effect sensor. Figs.5 & 6 show the assembly details for this unit.

The first step is to cut the core in half using a fine-toothed hacksaw blade. That done, the Hall sensor should be wired using a 60mm length of 3-way rainbow cable which should be sheathed in heatshrink tubing (see Fig.5). The other end of this cable is then connected to a 300mm length of 2-core shielded cable which in turn is terminated with a 3.5mm stereo plug.

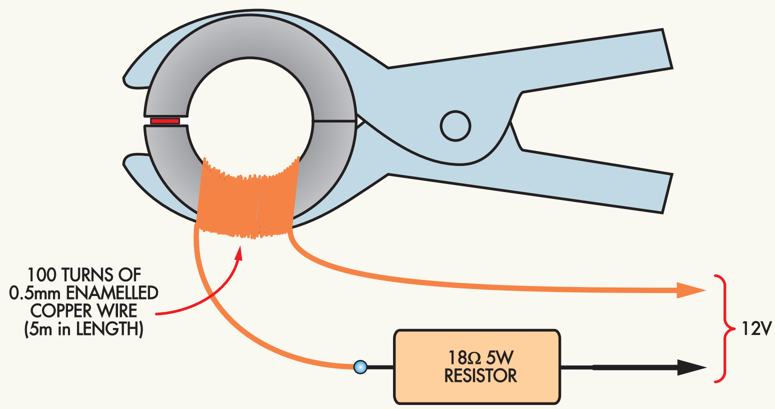
As shown in Fig.6, the cable shields are joined together and connected to the earth lead of the rainbow cable. They are also connected to the metalwork of the clip using a short length of hookup wire. Small pieces of insulating tape should be used to prevent shorts between the wires where the cables join, after which the join should be covered using heatshrink tubing.

Table 2: Capacitor Codes

Value	µF Code	EIA Code	IEC Code
100nF	0.1µF	104	100n
1nF	0.001µF	102	1n0

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	1	22kΩ	red red orange brown	red red black red brown
❏	1	18kΩ	brown grey orange brown	brown grey black red brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	1	1kΩ	brown black red brown	brown black black brown brown
❏	2	100Ω	brown black brown brown	brown black black black brown



CALIBRATE FOR 66.7A (66.7mV)

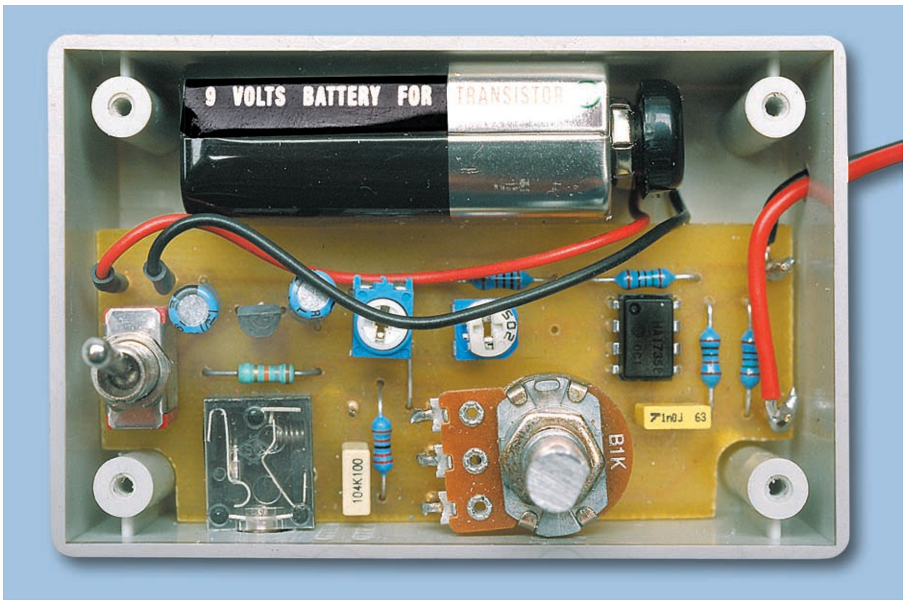
Fig.7: this simple setup can be used to calibrate the Clamp Meter Adapter. Null the reading first using potentiometer VR3, then switch on the 12V supply and adjust trimpot VR1 for a reading of 66.7mV.

The next step is to glue the Hall sensor to one of the core pieces using some builders' adhesive (it can go in either way up). That done, glue a small piece of plastic to the remaining part of the core gap to protect the Hall sensor from damage when the clamp closes. Naturally, this piece of plastic needs to be slightly thicker than the Hall sensor to provide this protection.

The two core pieces can now be glued in position on the jaws of the battery clip, again using builders' adhesive. Make sure that the two halves are correctly aligned before the glue sets.

Once the core pieces are secure, the wiring for the Hall sensor can be glued in position and secured at the end of the clip with a cable tie. In addition, the metal tabs on the clip should be bent over to hold the wire in place. This must also be done on the other handle, so that the jaws of the clamp can be opened as wide as possible.

The 3.5mm stereo plug is wired as shown, with the tip and ring terminals connecting to the red and black wires respectively. If your twin shielded wire has different colours, take care to ensure that pin 1 on the Hall sensor goes to the tip connection. Pin 3 must go to the ring terminal and pin 2 is the ground and shield.



There's plenty of room inside the case for the PC board and a 9V battery. The board is held in position by slipping the case lid over the switch and pot shafts and doing up the nuts.

As it stands, the clamp can be slipped over leads up to 7mm in diameter. A larger clamp with jaws that open wider than the specified unit will be necessary if you intend measuring currents flowing in leads that are thicker than 7mm.

Note that the clamp adapter is not suitable for use with 240VAC mains when the wiring is uninsulated.

Testing

The unit is now ready for testing. First, connect the battery and check that there is +5V at the test point on the PC board (ie, 5V between this test point and ground). There should also be +5V on pin 8 of IC1.

If these measurements check OK, plug the clamp assembly into the socket on the PC board and check the voltages again. If they are no longer correct, check component placement and the wiring to the Hall sensor.

Next, connect the output leads from the unit to the voltage inputs on your multimeter and set the range to mV DC. That done, set VR3 to its mid-position and adjust VR2 for a reading of 0mV.

Calibration

The Current Clamp Adaptor is calibrated using a 12V power supply, a 5m length of 0.5mm enamelled copper wire and an 18Ω 5W resistor.

First, wind 100 turns of the ECW around the core and connect it to the 12V supply via the 18Ω resistor as shown in Fig.7. The current through the wire will be 12/18 = 0.667A and, as far as the clamp meter is concerned, this is effectively multiplied by 100 due to the number of turns on the core.

All you have to do now is adjust VR1 for a reading of 66.7mV. And that's it – the calibration is complete!

Note that if the power supply is not exactly 12V, you can compensate for this by calibrating to a different reading. Just measure the supply voltage, divide the value by 18 (to get the current) and multiply by 100 to obtain the calibration number.

For example, if you are using a 13.8V supply, you will have to set VR1 for a reading of 76.7mV on the meter (ie, 13.8/18 × 100 = 76.7).

Once the calibration has been completed, the PC board can be attached to the case lid. It's held in place simply by slipping the lid over the switch and pot shafts and doing up the nuts.

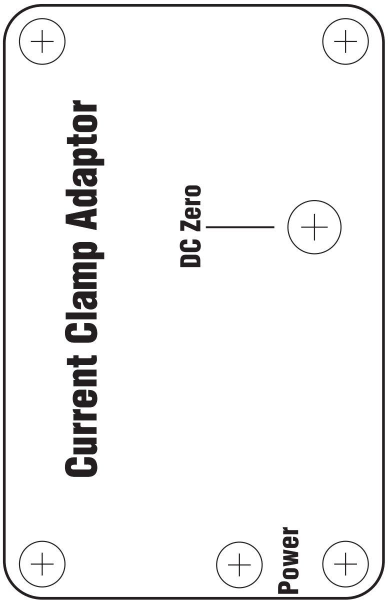


Fig.8: this full-size artwork for the front panel.

Using the clamp meter

Note that before making a measurement, the DC Zero potentiometer must first be adjusted so the multimeter reads 0mV when there is no current flow. Note also that the core may need to be demagnetised after measuring high DC currents, as described previously. This will be necessary when the DC Zero control no longer has sufficient range to null the reading.

When measuring relatively low currents (eg, between 100mA and 10A), increasing the number of turns of the current-carrying wire through the core will improve the resolution. However, this will only be possible if the wire diameter allows the extra turns to be fed through the core.

Note that the readout on the multimeter must be divided by the number of turns through the core to obtain the correct current reading. Note also that the accuracy of the unit will vary according to the temperature of the Hall sensor, particularly when making high current measurements.

By the way, it's a good idea to mark the top of the clamp with an arrow to indicate the direction of positive current flow once you have the unit working correctly. This can easily be determined by trial and error.

Finally, do not forget to switch the unit off when it is not in use. There's no power indicator LED to warn you that the unit is on, so take care here! *EPE*

Reproduced by arrangement with
SILICON CHIP magazine 2006.
www.siliconchip.com.au

Parts List

1 PC board, code 548, 75 x 30mm, available from the *EPE PCB Service*
1 plastic box, 82 x 54 x 30mm
1 iron powdered toroidal core, 28 x 14 x 11mm
1 50A car battery clip
1 3.5mm stereo PC board mount socket
1 3.5mm stereo jack plug
1 SPDT toggle switch (S1)
1 5kΩ (code 502) horizontal trimpot (VR1)
1 50kΩ (code 503) horizontal trimpot (VR2)
1 1kΩ 16mm linear potentiometer (VR3)
1 red banana line plug
1 black banana line plug
1 9V battery clip
1 9V battery
1 potentiometer knob
1 4 x 4 x 2mm piece of soft plastic
1 300mm length of twin core shielded cable
1 60mm length of 3-way rainbow cable
1 200mm length of red heavy duty hookup wire
1 200mm length of black heavy duty hookup wire
1 50mm length of green heavy duty hookup wire
1 50mm length of 4.8mm diameter heatshrink tubing
1 100mm cable tie
8 PC stakes

Semiconductors
1 LM358 dual op amp (IC1)
1 UGN3503 Hall effect sensor
1 78L05 5V regulator (REG1)

Capacitors
1 100µF 16V PC electrolytic
1 10µF 16V PC electrolytic
1 100nF MKT polyester
1 1nF MKT polyester

Resistors (1% 0.25W)

1 22kΩ	1 1kΩ
1 18kΩ	2 100Ω
1 10kΩ	

Calibration parts
1 5m length of 0.5mm enamelled copper wire
1 18Ω 5W resistor

There's no power LED on the front panel to warn you when the power is on, so be sure to switch the unit off when it is not in use to save battery life. Also, be sure to null the reading on the multimeter (ie, when there is no current flow through the core) before taking a measurement.