A portable electronic core-balance relay

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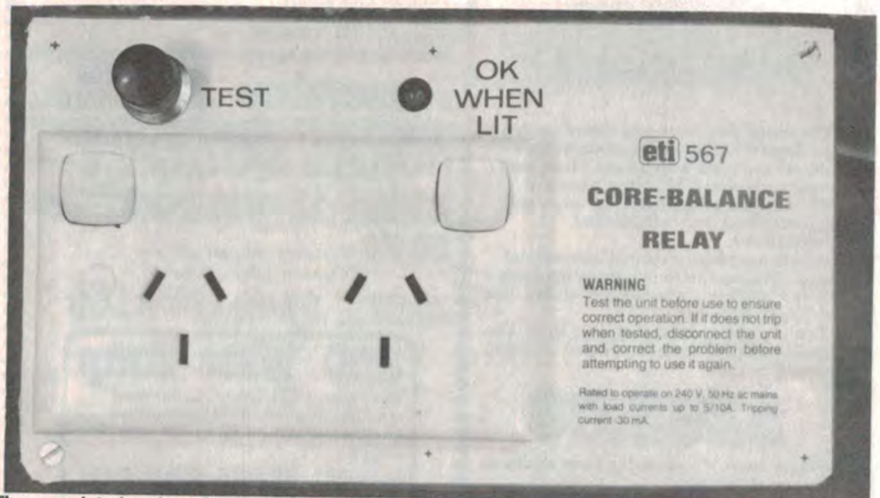
Mains-operated equipment that goes faulty is potentially lethal. Electro-mechanical 'core-balance relays' which sense earth-fault currents and trip a circuit breaker have been available for house-mains installation for some years. Portable core-balance relay units have obvious advantages. Protect yourself — and your equipment — with this simple, inexpensive project.

A FAULT in mains-operated equipment can place any external metal parts at mains potential — if you then happen to complete a path between the equipment and earth, you'll get a nasty surprise at the least or become another victim in the electrocution statistics. In some circumstances a fault may create a leakage path that permits a current to flow through flammable material — with obviously dangerous consequences. A suitable protection device that can sense such fault conditions can prevent possible disaster.



The completed project. Our Scotchcal panel is essential — see page 67 for suppliers.

Also, when servicing mains-operated equipment — particularly such things as light sequencers, dimmers, etc — it is often necessary to work around lethal mains voltages. A device that trips a circuit breaker or relay should you accidentally touch live mains wiring is clearly good for your health!

Every hobbyist or serviceman should have such a device.

When a fault current finds a path to earth in mains-operated equipment the currents flowing in the active and neutral lines are found to be different. This fact can be put to use to sense 'earth faults', as they are called, and trip an isolating relay or circuit breaker. Such a sensing device is referred to as a 'current operated' or 'core-balance' earth-leakage device.

We have designed a portable electronic core-balance relay that can be set to sense earth-leakage currents as low as a milliamp or so, or a maximum of about 25 mA. It is designed to operate on 240 V, 50 Hz ac mains and with rated load currents up to 5 A or 10 A, depending on the relay used. Once tripped, the unit can only be reset by turning off the mains and removing the faulty load.

Australian Standard

The Australian Standard relating to core-balance relays is AS3190-1980, titled "Approval and Test Specification for Current-Operated (Core-Balance) Earth-Leakage Devices". It is published by the Standards Association of Australia, Standards House, 80 Arthur St, North Sydney NSW.

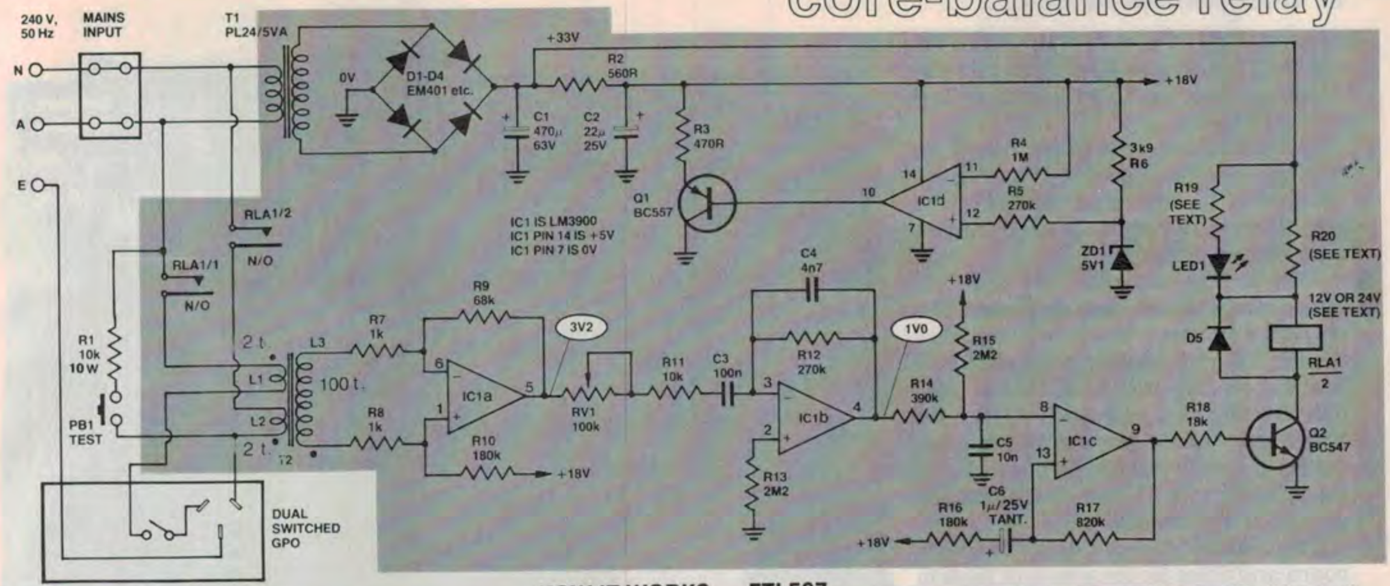
The Standard requires the unit's ratings to be marked on the front panel along with a warning notice. These have been included on our front panel artwork. In addition, the Standard requires any portable device to be double insulated (as per AS C100) between the external surface of the enclosing case and any wiring and component which does not form part of the protected circuit, and the enclosing case to be double insulated from any earth conductor incorporated in the device. Therefore we chose to construct our unit in a plastic case, using nylon bolts to secure the internal components. The Standard also requires that the flexible cord should be of a type not inferior to a heavy duty sheathed type (see AS 3191), correctly wired (as per AS C100) and have a free length of not less than 1.8 metres.

So far as we are aware, our prototype conforms to the construction requirements of AS 3190-1980.

Construction

It would be best to commence construction by marking out and drilling the plastic case. We used a BIM Box, No. 2006-16-ABS, measuring 190 mm long by 111 mm wide by 60 mm high. These are imported and distributed by Crusader Electronics of Sydney. We bought ours at Radio Despatch Service. However, several similar all-plastic 'jiffy'-style boxes are available and you should have little difficulty getting one to suit.

The mains input cable should be secured with a clamp grommet, the leads



HOW IT WORKS — ETI 567

The circuit can be divided into three parts: the unbalance current sensor (T2), the trip circuit, and the power supply. We'll examine each in turn.

TRANSFORMER T2

This senses the unbalance current that occurs with an earth-leakage fault between the active line and earth. The two primary windings, L1 and L2, are bifilar wound (parallel wires, wound in the same direction). Primary L1 is connected in the active line, between the mains input and the output to the load. Primary L2 is connected in series with the neutral line, between the mains input and the output to the load. The two primaries are connected such that the load current through L1 flows in the opposite direction to the load current through L2. Thus the currents are in phase opposition, and if no earth fault is present, will be equal and there will be no output from the secondary of T2 (L3). The spots adjacent to the end of each winding on the circuit diagram indicate the phasing of each winding, showing that L1 and L2 are oppositely phased.

If an earth fault occurs, more current will flow in the active line than the neutral line. Thus, the currents through L1 and L2 will be different, or unbalanced, and an output will appear from the secondary. This output serves as an input for the trip circuitry.

THE TRIP CIRCUIT

We shall have to describe the operation of this circuit 'back to front' in order to make its operation clear. The trip circuit involves three op-amps from IC1 — IC1a, b and c — plus Q2, RLA1 and associated components. IC1 is a quad op-amp, type LM3900.

When power is first applied, capacitors C5 and C6 will first appear as a low impedance (virtually a short circuit) as they are not charged. Thus, C5 will hold the inverting input of IC1c (pin 8) at 0 V and C6 allows a current to flow into the non-inverting input (pin 13) via R16. These two initial conditions will cause the output of IC1c (pin 9) to rise rapidly towards the positive supply rail. Positive feedback via R17 ensures that this op-amp will latch in that condition. When pin 9 of IC1c goes high, base current will flow in Q2 via R18, and Q2 will turn on. When Q2 turns on, collector current will be supplied via the relay and LED indicator circuits, the relay will operate and the LED will light.

When the relay operates (on switch-on) the two relay contacts, RLA1/1 and RLA1/2, close and apply power to the output socket.

A short period after switch-on, C6 will be charged and dc feedback via R17 will hold the output (pin 9) of IC1c high.

When an earth fault occurs, an output voltage will appear across the secondary (L3) of T2. This will be amplified by op-amp IC1a, the output of which (pin 5) drives the input of an active filter involving IC1b, via RV1, R11 and C3. RV1 acts as a sensitivity control, as it is in series with the input of IC1b, the gain of which (at 50 Hz) is determined by the ratio of R12 to RV1+R11.

Op-amp IC1b is arranged as a simple active low-pass filter, having a cutoff of around 130 Hz. This gets rid of high frequency noise spikes passed on from the mains via T2. Any noise transmitted down the mains will not be in phase on the active and neutral lines.

The first positive-going pulse, resulting from the mains earth fault, appearing at the output of IC1b (pin 4) will be applied to the inverting input of IC1c via R14. Now, IC1c will be latched with its output high. When the 'fault' signal appears the output of IC1c will be driven low, removing base current from Q2, which will turn off, causing the relay to drop out and the LED to extinguish. When the relay drops out, its contacts remove power from the output socket.

IC1c will latch into the 'output low' condition as dc feedback via R17 will hold the non-inverting input low.

The CR network R14-C5 helps prevent noise on the mains causing false triggering and only delays the operation of the trip circuit less than 10 milliseconds. The trip circuit will operate no more than about half a cycle after the fault signal occurs, at maximum, and the relay takes about 15 ms to open. Thus, maximum delay is about 35 ms, well under the 50 ms required in AS3190-1980.

POWER SUPPLY

Power supply for the electronics is derived via a small pc-mount transformer, T1. This is a 240 V to 24 V type, rated at 5VA or 7VA. A bridge rectifier is employed, using diodes D1 to D4, feeding a capacitor-input filter consisting of C1, R2 and C2. The nominal output voltage across C1 is about 33 volts. This is used to supply the relay driver (Q2), relay and LED indicator circuits.

A simple shunt regulator is used to derive an 18 volt supply for the trip circuit. IC1d forms a voltage-controlled current source, its output driving the shunt regulator transistor Q1. The emitter-collector current of Q1 flows from the positive supply rail to the 0 V rail via R3. The shunting current via Q1 produces a voltage across C2 of 18 volts, the shunting current being determined by the 5V1 zener diode at the input of IC1d. If the rectifier output voltage attempts to rise, the shunting current via Q1 will rise and the voltage drop across R2 will increase. The opposite occurs if the rectifier output decreases.

This type of supply was chosen for its good noise pulse rejection characteristics.

TEST CIRCUIT

A 10k, 10 W resistor is connected via a momentary-action pushbutton from the neutral line of the output socket to the relay (input) side of the active line. When the pushbutton is operated, a current of about 24-25 mA will flow in L2, but not in L1. This simulates a fault condition and the electronics will trip the relay, removing power from the output. IC1c will latch in the 'output low' condition and the unit can only be reset by removing the mains input for a short period.

being terminated to a six-way plastic terminal strip. We used a Scotchcal front panel (plastic variety, *not* the aluminium type). These should be available from a number of suppliers; see Shoparound in this issue. After drilling the case front panel, the Scotchcal panel should be attached, taking care to smooth out any air bubbles, before mounting the power output socket, pushbutton and LED indicator.

The blank pc board can be used as a template to mark the positions of the mounting holes for drilling in the bottom of the case. Watch the orientation of the board.

The mains cable may be attached and terminated to the terminal strip, and the wires between the terminal strip and output socket may also be installed ▶

at this stage. Note that the 10k, 5W resistor is mounted off the six-way terminal strip, and this can be installed at this time too.

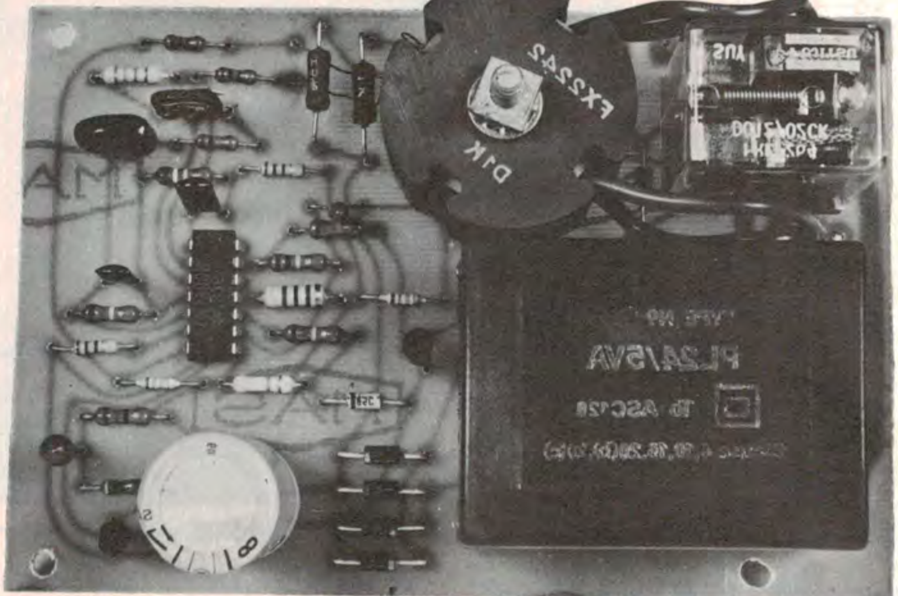
The printed circuit board should be drilled next, if you haven't got one that's pre-drilled. Locate the positions of the mounting holes for the potcore and the power transformer first.

The potcore requires just a single hole, around 4.5 - 5 mm diameter. The power transformer requires three holes. There are two locating pegs that protrude beneath the transformer and holes for these should be drilled about 3.5 - 4 mm diameter. A hole for a securing screw is located between the ac input terminals. This should be drilled about 3 mm diameter.

The relay is soldered direct to the pc board and holes for the pins will have to be drilled, their size depending on the particular relay you're using. We have made the pc board pads large enough to accommodate a variety of relays available. Some, such as the Fujitsu type FRL264, can be obtained with pc mount pins and only a 1.5 mm hole is required for each pin. Others, such as the DEC type MC2U, have flat pins requiring a row of small holes to be drilled in each pad and a slot cut.

The pc board may be assembled next. Mount all the minor components first, taking care with the orientation of the LM3900, the diodes, the two transistors, the electrolytic and two tantalum capacitors. You can leave R7 and R8, which mount adjacent to the potcore, until the potcore is mounted and wired in, as we have done, or pass the secondary leads from the potcore over R7 and R8. Don't forget D5, which mounts between the potcore and the relay — it's difficult to see in the photograph of the pc board, but the overlay should make its location clear.

The potcore should be wound next — see the accompanying box for the winding details. Once you've wound the bobbin, assemble the two potcore halves over the bobbin as indicated in the drawing accompanying the winding details and set the assembly aside for a few moments. You will need a suitable bolt to secure the potcore to the pc board; we used a 4 mm by 35 mm pan head with nut, plus a flat washer and a star washer. Pass the bolt through the appropriate hole in the pc board, from the copper side. Place the potcore assembly over the bolt and secure it with the nut. Use the flat washer against the potcore and the star washer between it and the nut. Terminate the primary and secondary windings to the pc board as indicated on the overlay.



The completed pc board. Assembly is fairly straightforward.

The relay and power transformer may be mounted next. The transformer is secured with a screw which goes between the ac input terminals, as mentioned previously.

Once you have the pc board assembled, check everything carefully — in fact, *double* check. Once you're satisfied all is well, it can be mounted in the box and wired in place. Before mounting the board in the box, attach leads about 150 mm long for the indicator LED (colour code them so you know which is the anode and which is the cathode). Also attach leads for the mains input and output wiring. Use colour-coded 32 x 0.2 mm 240 Vac rated plastic insulated wire for this — red for active, black for neutral. These leads will need to be about 100-120 mm long.

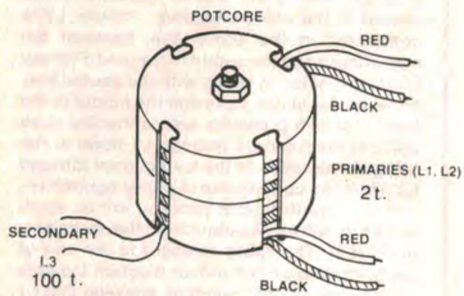
Mount the board in the bottom of the box using nylon nuts and bolts. Raise the board about 5-6 mm off the bottom of the box using fibre spacers.

Wire the ac input and output leads to the six-way terminal block according to the wiring diagram. Once this is done check all your wiring thoroughly, and you're ready for testing.

Test and setup

First thing to do is a series of safety checks before the unit is plugged into the mains. For this you will need a multimeter and a neon test screwdriver. Also, if you can possibly obtain it (beg, borrow or steal ... er, scrounge), a "megger" insulation tester with a rated output of 500 V.

With your ohmmeter on the highest resistance range, measure between the earth and active and neutral pins in turn on the mains input plug. It should read open circuit. Then do the same on the rear of the output socket.

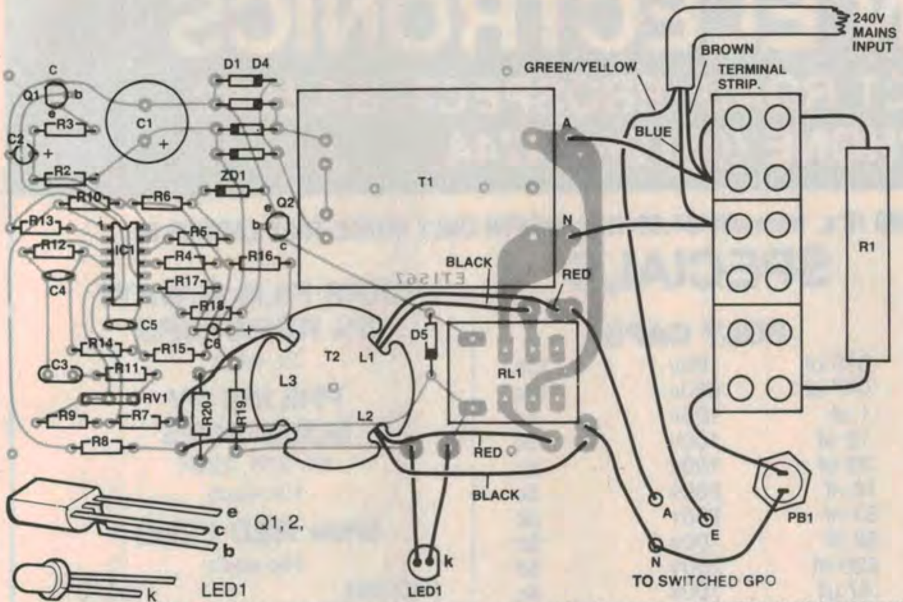


TRANSFORMER T1, WINDING DETAILS

Core: FX2242 36 mm dia. potcore; two halves with bobbin.

Wire: 0.2 mm dia., enamelled copper wire — eight or nine metres will be required; two 300 mm lengths of 32 x 0.2 mm plastic-coated (240 Vac insulation) hookup wire — one red, one black.

Wind the secondary, L3, first, using the 0.2 mm enamelled wire. This may be jumble wound on the bobbin. Put two layers of electrical insulation tape over the finished winding. To wind the two primaries, L1 and L2, lay the red and black insulated wires side by side, place them on the bobbin and wind one turn, followed by almost another turn — such that the start and finish ends come out of adjacent potcore slots. The photograph of the pc board makes this clear, as should the accompanying drawing. Leave about 50-60 mm of lead on each winding for terminating to the pc board.



Component overlay and wiring diagram. Use a clamp grommet for the mains cable. The earth lead input must be the longest of the input leads. Take care with the mains wiring.

Now switch your ohmmeter to a low resistance range (to measure less than 1000 ohms on the scale). Measure between the active and neutral pins on the mains input plug. Your meter should read somewhere between 750 and 800 ohms. This is the resistance of the primary of T1. Do the same on the rear of the output socket. It should read open circuit. Then, manually operate the relay (or connect an external battery or power supply across the relay's coil) and measure across the active and neutral connections on the rear of the output socket. You should measure the resistance of T1's primary again (750-800 ohms).

With the relay operated, check for continuity between the active pin on the mains input plug and the active connection on the output socket. Do the same for neutral line. While you have the relay operated, switch your ohmmeter to the highest range and check for open circuit between the neutral line and earth and the active line and earth.

If you have a megger, you can repeat all the active and neutral to earth checks. Resistance indicated should not be less than 1M. If you then bond all three pins of the input plug together and connect to one terminal of the megger and apply the other terminal of the megger via a flying lead to some part of the case, you should obtain a reading no lower than 10M.

If there are any problems during these tests, sort them out before continuing. If all is well following these tests, you can proceed to test the unit with mains input and set up the trip current.

Set the wiper of the trimpot RV1 to maximum resistance. For the setup test, nothing should be plugged into the output sockets. Plug the unit in and turn it on. The relay should operate immediately and the LED should light. If this does not happen, switch off straightaway, unplug the mains cord and check for wiring or assembly errors. If the LED doesn't light but the relay operates, you've either got the LED connected the wrong way round or R19 is incorrect.

If all is well at this stage, depress the TEST button (the relay should not drop out) and adjust RV1 until the relay just drops out. The LED should go out. Use an insulated handle screwdriver to do this, for safety's sake. Release the TEST button when the relay drops out and turn off the mains input. Wait a few seconds and turn the mains input on again. The relay should operate and the LED should light again. Press the test button again and the relay should drop out, the LED going out also.

Next, reset the unit, plug it in and switch on. Using your neon test screwdriver, check that the active pins on the output sockets are correct. With the earth pin facing you, the active pin should be the upper left hand one. If you find it to be different, switch off and unplug the unit, then test your wall socket to see if it's correct. It is important that the core-balance relay is correctly wired, so that the unit will preserve the active/neutral orientation of the power point with which it is used.

That's it, unless you want to test the unit at ±10% of mains input voltage, etc — the ETI-146 Mainsmaster (Nov. 1979) would come in handy here.

ETI-567 CORE BALANCE RELAY PROTECTOR

Resistors .... all ½W, 5% unless noted

R1	10k, 10 W
R2	560R
R3	470R
R4	1M
R5, R12	270k
R6	3k9
R7, R8	1k
R9	68k
R10, R16	180k
R11	10k
R13	2M2
R14	390k
R15	2M2
R17	820k
R18	18k
R19	1k (12 V relay) or 330R/1 W (24 V relay)
R20	330R/1 W (12 V relay) or 150R/1 W (24 V relay)
RV1	100k

Capacitors

C1	470u/63 V electro.
C2	22u/25 V tantalum
C3	100n greencap
C4	4n7 greencap
C5	10n greencap
C6	1u/25 V tantalum

Semiconductors

D1 to D5	1N4004, EM401 etc.
ZD1	5V1, 400 mW zener
IC1	LM3900
Q1	BC557, BC177
Q2	BC547, BC107
LED1	TIL220R or similar

Transformers

T1	PL24/5VA Ferguson transformer or sim.
T2	FX2242 pot core

Miscellaneous

ETI-567 pc board; PB1 — 230 Vac rated momentary push button (push-on); plastic case to suit; relay (RL1) Fujitsu D024/02CK (24 V) or D012/02CK (12 V); wire, nuts, bolts etc; terminal block; 2m of 10 A rated mains lead.

Price estimate **$42 - $48**

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel (if used) supplied etc — whether bought as separate components or made up as a kit.

Trip current variation

If you would prefer the trip current to be lower, change the value of R1 and set up the unit as previously explained. For a 10 mA maximum trip current, a 27k, 3W or 5W resistor should be used for R1.

The maximum trip current, according to AS3190-1980, is 30 mA, so it would be wise to keep it below that value by at least 10%, and that's what we have done with the design presented here. ●