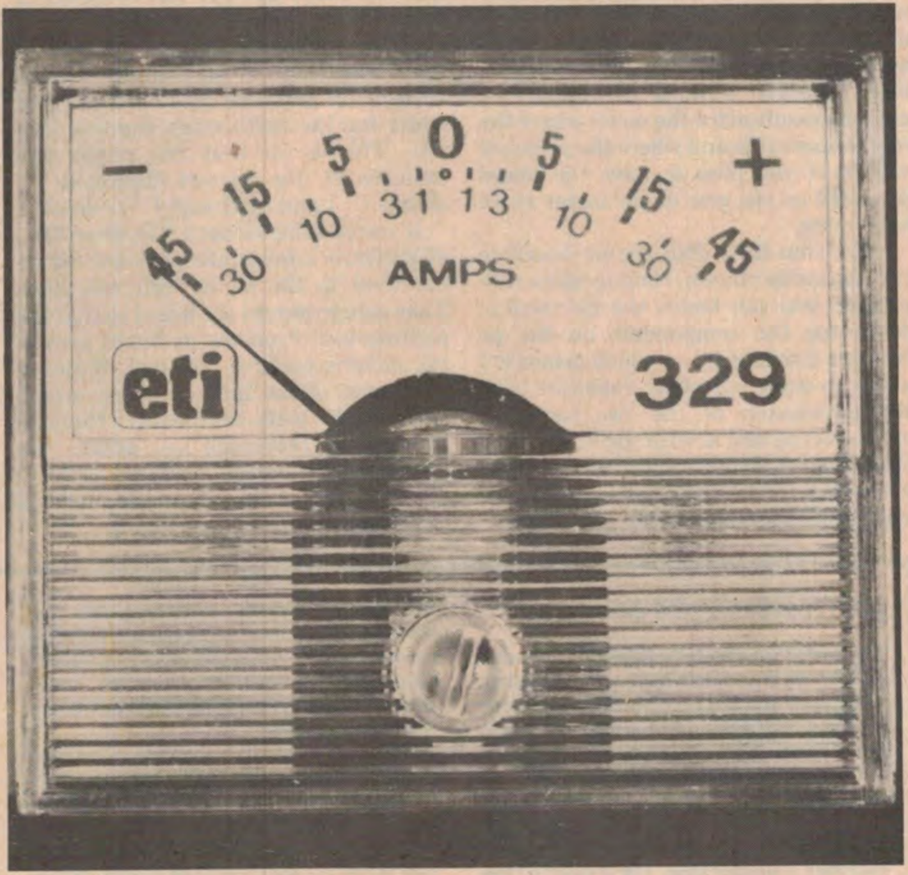
Project 329

Expanded scale vehicle ammeter

This 'electronic ammeter' can be installed without disturbing the vehicle's existing wiring, will operate on 12 V or 24 V systems and features an easy to read scale indicating charge and discharge currents up to 45 amps.

Jonathan Scott



THE CONVENTIONAL current meter, usually a moving iron type, has long been one of those instruments included in the better-equipped 'up market' vehicles. It indicates charging system or other electrical faults more quickly than any other device and warns the perceptive driver of any abnormal currents — even momentary variations.

However, the conventional vehicle ammeter has two main disadvantages: (1) In order to provide a full-scale deflection (FSD) of, say, 30 or 40 amps, it sacrifices the sensitivity necessary to show small currents that might completely discharge the battery in one or two days if the vehicle is left standing for any short or long period. (2) If you wish to install one in a vehicle that does not already include the instrument, it is necessary to interrupt the heavy, main current carrying cables and either install a 'current shunt' and cables to the ammeter, or divert the cables to the ammeter in the dashboard. This may require adding heavy cables (as they will be called upon to carry current up to 40 amps or so). One hardly need point out the inconvenience, not to mention the electrical drawbacks. In addition, off-the-shelf instruments are usually rather expensive for the function they provide because of their rather specific nature and the general cost of automotive bits.

In addition, moving iron types have a cramped scale at the low current end.

This project overcomes these problems. Our instrument offers a non-linear ('expanded') scale so that currents as low as one amp or as high as 45 A can be easily seen. It employs the earth strap of the battery as a current shunt, thus avoiding use of any cable thicker than hookup wire and not requiring the car's current path to be disturbed at all. In addition, it uses readily available components and features a centre-zero scale employing either a centre-zero meter or conventional meter movement. It may be installed in 12 V or 24 V systems and incorporates reverse-polarity protection in case you connect it the wrong way round or try to destroy it by some devious automotive electrical fault. (I recently had the unpleasant experience of momentarily disconnecting a wire on my car which resulted in the *instant obliteration* of every semiconductor in the vehicle.)

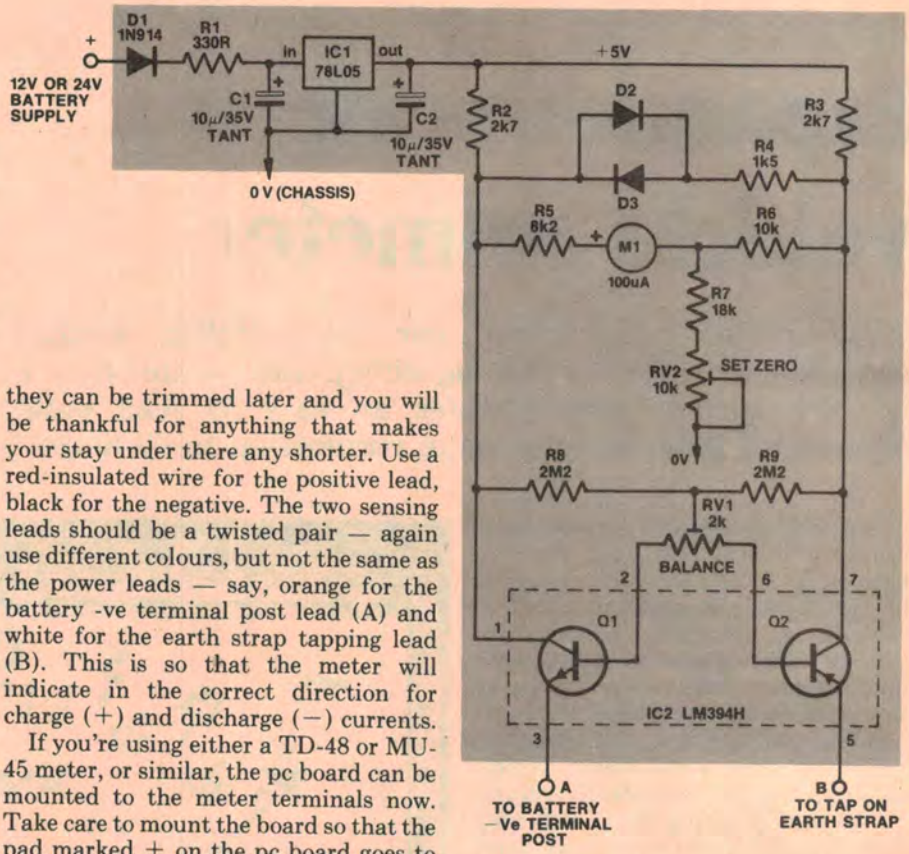
Meters and scales

We have provided artwork of scales to suit several commonly available meters: the University types TD-48 (45 mm face width) and TD-66 (62 mm face width) plus the Minipa MU-45 (51 mm face width).

As mentioned earlier, either a conventional meter movement (100 uA), with zero on the left of the scale, or a centre-zero movement (50-0-50 uA) may be used. The pc board has been laid out to suit the TD-48 meter and it mounts ▶

directly on the meter's terminals. However, the board can be fitted to the MU-45 by drilling the mounting holes through the pads on the board to suit the differently spaced terminals. If you use a larger meter, the pc board will have to be mounted separately.

Obviously, a 50 uA movement can be used provided a shunt equal to the movement's coil resistance is connected in parallel with the meter terminals.



Construction

Before commencing the construction of the electronics, the wisest move is to prepare the dash mounting place for the meter movement. As this is rather a matter for the individual vehicle owner, we will have to leave the details to you. First, though, a word of caution — choose a position for the meter where the rear is accessible and where the pc board will fit if you plan to have the board mounted on the rear of the meter as we have done.

Next step is to drill the pc board to suit the meter chosen. Having taken care of that, you can tackle the electronics. Mounting the components on the pc board is a simple job — which means it's easier to make mistakes! Take care with the orientation of the two tantalum capacitors as well as with the ICs and the three diodes. Attach power supply leads more than long enough to reach suitable termination points under the dash — they can be trimmed later and you will be thankful for anything that makes your stay under there any shorter. Use a red-insulated wire for the positive lead, black for the negative. The two sensing leads should be a twisted pair — again use different colours, but not the same as the power leads — say, orange for the battery -ve terminal post lead (A) and white for the earth strap tapping lead (B). This is so that the meter will indicate in the correct direction for charge (+) and discharge (−) currents.

If you're using either a TD-48 or MU-45 meter, or similar, the pc board can be mounted to the meter terminals now. Take care to mount the board so that the pad marked + on the pc board goes to the meter's positive terminal. If you're using one of the larger meters, attach leads to the pads and connect them to the meter terminals — again, use differently coloured insulated wire to identify each lead so that the meter is connected the right way round.

Setting up

If you have a bench supply that can deliver 12 V or 24 V, it can be used to set up the instrument initially. If you don't have one, then you'll have to do this with

HOW IT WORKS - ETI 329

The circuit senses the voltage drop across a section of the vehicle battery's earth strap, amplifies it and displays the result on a meter having a centre-zero scale so that both charge (+) and discharge (−) currents are indicated.

Heart of the circuit is a transistor differential pair contained on a single slice of silicon, IC2 (Q1-Q2). This ensures that the two transistors, though electrically separate, have closely-matched characteristics. The differential pair is operated as a common-base amplifier, the two emitters being connected across the vehicle battery's earth strap.

The differential pair requires a well-regulated supply and this is provided by IC1, a low power three-terminal regulator. Output is 5 V. Diode D1 protects the unit against the ravages of reverse polarity connection, while R1 and C1 remove supply line transients. Capacitor C2 prevents oscillation of IC1.

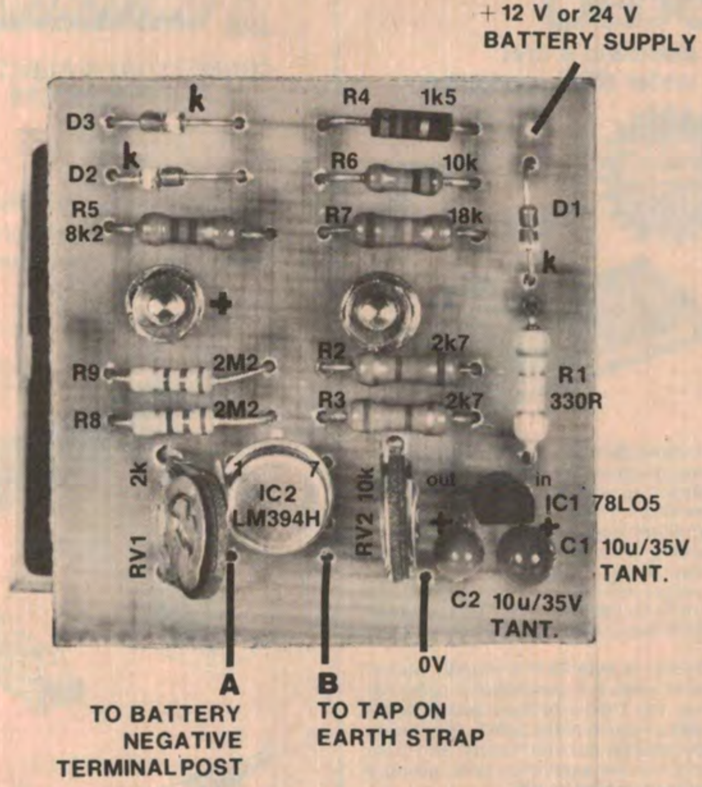
The meter is connected between the collectors of Q1 and Q2 from IC2. The centre-zero function (regardless of which type meter you use) is obtained by shunting some current to the common (0 V) rail via R7 and RV2. The latter provides a zero-point adjustment. Scale-linearity is achieved by the addition of R4 and D2-D3, which effectively shunt the meter circuit. Let's look first at the circuit as if these weren't connected.

When no current is being drawn from or passed into the vehicle battery, the emitters of Q1 and Q2 will be at the same voltage. As the base-emitter voltages of these two transistors will be very nearly identical, each will draw very nearly the same collector current. Only a small amount of base current is applied to each, via R8 and R9, with RV1 serving to balance the base currents, and therefore the emitter-collector currents, of the two transistors to compensate for the differences which inevitably occur. This trimpot is capable of compensating for more than twice the expected maximum error.

With the values chosen, Q1 and Q2, when balanced, will each have around 3 V on their collectors (with respect to 0 V). Now, when the battery is being charged, the current through the earth strap will raise the emitter of Q1 to a slightly higher voltage than the emitter of Q2. Thus Q1 will draw less current, Q2 will draw more, and the collector voltage of Q1 will rise to a higher value than the collector voltage of Q2 (with respect to 0 V). The current will therefore flow through the meter from the positive terminal to the negative terminal and the meter will indicate the current on the + side of the scale (i.e: charge). The reverse happens when current is drawn from the battery.

Now let's have a look at what happens when R4, D2 and D3 are in circuit. When the voltage between the collectors of Q1 and Q2 rises to a value greater than about 0.6 V, either D2 or D3 will conduct, depending on which collector is at the higher voltage. When one of these diodes conducts, some of the meter current will be diverted through R4, reducing the effective reading on the meter for further current increases. The result is a meter scale which is 'compressed' at the higher currents.

Resistor R7 and RV2 are arranged so that equal quiescent currents will flow through R6, R5 and the meter (M1), allowing centre-zeroing of the meter without upsetting the balance of the differential pair. These two components can be deleted if a centre-zero meter is used.



Component overlay for the pc board. Trimpot RV1 is for BALANCE while RV2 is for ZERO SET. The latter, along with R7 are left out if you use a centre-zero meter.

PARTS LIST - ETI 329

Resistors	all ½W, 5%
R1	330R
R2,R3	2k7
R4	1k5
R5	8k2
R6	10k
R7	18k
R8,R9	2M2
RV1	2k min. vertical mount trimpot
RV2	10k min. vertical mount trimpot
Capacitors	
C1,C2	10u/35 V tantalum
Semiconductors	
IC1	78LO5, or similar 5 V reg.
IC2	LM394H supermatch pair
D1,D2,D3	1N914, EM401 etc silicon diode

Miscellaneous

ETI-329 pc board; M1 - 100 uA conventional meter or 50-0-50 uA centre-zero meter (see text); meter scale; hookup wire etc.

Price estimate

We estimate that the cost of purchasing all the components for this project will be in the range:

$15 - $17

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the actual price of a project, whether bought as separate components or made up as a kit.

the unit connected in the vehicle, but not mounted.

Connect up the power supply leads, join leads A and B (the sensor leads) and connect them to zero volts. Adjust both trimpots and see if they both have some affect on the meter reading. This will confirm correct operation, and you can proceed with the setting up. If the meter goes hard over in either direction you have a wiring fault. Disconnect the unit *immediately* and trace the fault before proceeding.

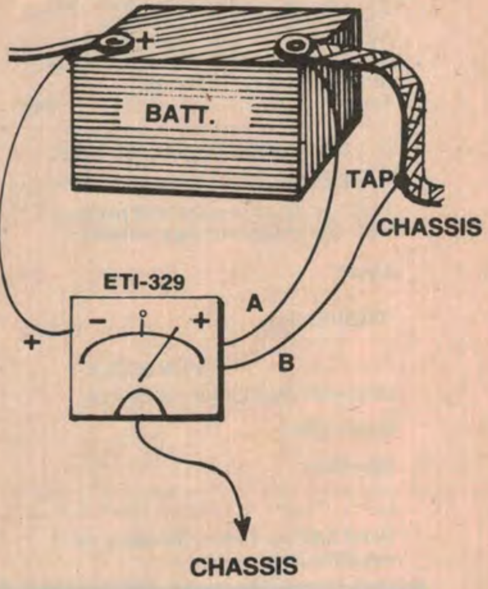
With a multimeter, measure the voltage on the collector of each transistor in the differential pair IC (pins 1 and 7). Adjust RV1 so that these voltages are equal. If you do not have a multimeter, remove R7 and short out R5 and R6. Then adjust RV1 for zero meter reading (i.e: centre scale). This last method is not recommended as accuracy is affected to some extent, but it will suffice in the absence of a multimeter. Restore the circuit when you've finished.

When doing this initial setup, whichever method you use, allow a couple of minutes (with the unit still connected) and check the circuit balance again as it may drift briefly after initial switch on.

When you are confident that the balance is correct, adjust RV2 for exactly half-scale deflection on the meter — zero on the scale. This trimpot functions as a 'set zero' adjustment. If you wished, you could have a scale zero at some position other than centre scale — there is no reason why you couldn't have the zero at quarter-scale, to the left or the right. However, if you're using our meter scale and component values, you can only have zero at centre-scale, and that settles it.

If you cannot achieve balance within the range of RV1 (equal voltages on pins 1 and 7 of IC1), proceed as follows: if you're only a short way off balance then you possibly have an IC and resistors that are all on the edge of their specifications. In this case, reduce the value of R8 and R9 to 1M5 or so and try balancing the circuit again. If there is a gross imbalance you are almost certainly using a meter of the wrong coil impedance. It may be possible to rectify the situation by halving the value of R8 and R9 and substituting a 5k trimpot for RV1, sacrificing some sensitivity.

When you have the unit correctly set up, install it in your vehicle. Be careful to ensure that the sensor leads (from A and B) are of equal length. If all is well, next step is to calibrate the unit. You can leave it connected permanently to the battery (i.e: not via the ignition switch) as it draws very little current. Lead A should be securely connected to the battery negative terminal connector. It is best to solder it to the copper strap just as it terminates at the clamp which attaches to the battery post. Temporarily connect the other sensor lead (B) about 200 mm down the earth strap, toward the chassis termination. ▶



Calibration

To calibrate the ammeter you will either need to have a 'load' of known resistance and a multimeter or temporarily connect an ammeter (say, 10 A or 15 A FSD) between the battery's positive terminal post and the positive terminal clamp.

In the former case, connect the known load between the positive supply rail and *vehicle chassis*. Measure the voltage across the load and calculate the current through it. Note the reading on the meter (it should read in the negative portion of the scale) and adjust the position of sensor lead B on the battery earth strap so that the meter reads the correct current. Move it *towards* the battery terminal to *decrease* the reading, *away* from it to *increase* the reading.

If you don't have a known load, then the series ammeter method will be necessary. With the ammeter connected in series with the battery positive lead, turn on a few accessories until you are drawing a current of say 5 A or 10 A. As before, move sensor lead B along the earth strap until the project indicates the correct current.

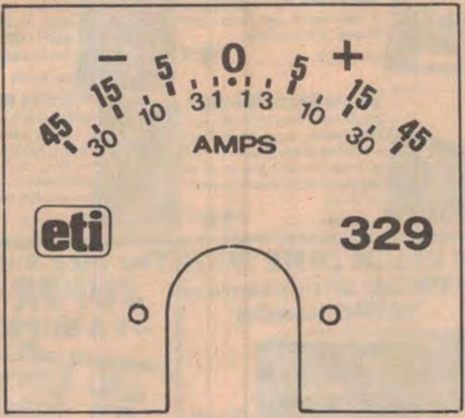
Once the unit is calibrated, permanently connect sensor lead B to the position determined. The length of strap between this point and the battery negative terminal has a resistance of around 1½ milliohms!

Some vehicles have insulation on the earth strap. Small sections may be removed with a sharp penknife or lino cutter.

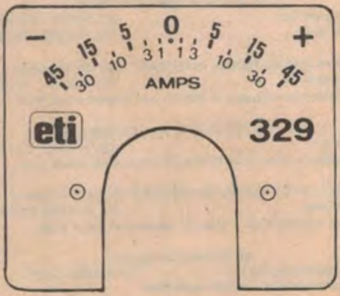
Finished? — that's it!

Once operational, you will notice that your vehicle has characteristic charge and discharge patterns under the usual driving conditions. Get used to them — you can then quickly tell at a glance if and when something may be going wrong.

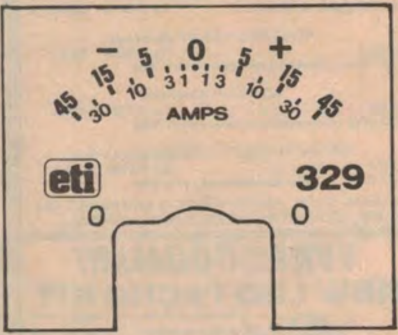
Illumination of the meter scale is useful, although we haven't included details. This will depend on the individual situation and the particular meter used. A hole may be drilled in the rear of the meter case and through the scale panel so that a small 'pea' or bayonet type globe can be fitted. (Be careful!) These lamps can be obtained in 12 V (or 24 V) ratings; lower voltage types will require a series resistor. If the light is too bright, reduce the current through the globe with a series resistor. ●



Scale for the University TD-66



Scale for the University TD-48



Scale for the Minipa MU-45

METERS, SCALES AND SHUNTS

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As mentioned in the text, either a conventional meter movement (100 uA) with zero on the left of the scale, or a centre-zero movement (50-0-50 uA) may be used. The pc board has been laid out to suit the TD-48 meter and it mounts directly on the meter's terminals. However, the board can be fitted to the MU-45 by drilling the mounting holes through the pads on the board to suit the differently spaced terminals. If you use a larger meter, the pc board will have to be mounted separately.

Obviously, a 50 uA movement can be used provided a shunt equal to the movement's coil resistance is connected in parallel with the meter terminals. For some types, meter impedance is 1400 ohms, while for others (particularly the University models) it is 2000 ohms. Resistors having a 1% or 2% tolerance can be used (E48 or E96 series), and values of 1k4 and 2k are available. Alternatively, a parallel combination of standard value, 5% tolerance resistors can be used and will result in sufficient accuracy in this application. For a 1k4 shunt, parallel a 1k5 and a 22k. For a 2k shunt, parallel a 2k2 and a 22k.

LM394

general description

The LM194 and LM394 are junction isolated ultra well-matched monolithic NPN transistor pairs with an order of magnitude improvement in matching over conventional transistor pairs. This was accomplished by advanced linear processing and a unique new device structure.

Electrical characteristics of these devices such as drift versus initial offset voltage, noise, and the exponential relationship of base-emitter voltage to collector current closely approach those of a theoretical transistor. Extrinsic emitter and base resistances are much lower than presently available pairs, either monolithic or discrete, giving extremely low noise and theoretical operation over a wide current range. Most parameters are guaranteed over a current range of 1μA to 1 mA and 0 to 40V collector-base voltage, ensuring superior performance in nearly all applications.

To guarantee long term stability of matching parameters, internal clamp diodes have been added across the emitter-base junction of each transistor. These prevent degradation due to reverse biased emitter current—the most common cause of field failures in matched devices. The parasitic isolation junction formed by the diodes also clamps the substrate region to the most negative emitter to ensure complete isolation between devices.

The LM194 and LM394 will provide a considerable improvement in performance in most applications requiring a closely matched transistor pair. In many cases, trimming can be eliminated entirely, improving reliability and decreasing costs. Additionally, the low noise and high gain make this device attractive even where matching is not critical.

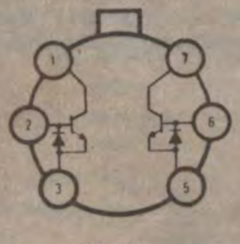
The LM194 and LM394/LM394B are available in an isolated header 6-lead TO-5 metal can package. The LM194 is identical to the LM394 except for tighter electrical specifications and wider temperature range.

features

- Emitter-base voltage matched to 50μV
- Offset voltage drift less than 0.1μV/°C
- Current gain (h_{FE}) matched to 2%
- Common-mode rejection ratio greater than 120 dB
- Parameters guaranteed over 1μA to 1 mA collector current
- Extremely low noise
- Superior logging characteristics compared to conventional pairs

connection diagram

Metal Can Package



TOP VIEW