Project 326

Expanded-scale LED voltmeter has wide application

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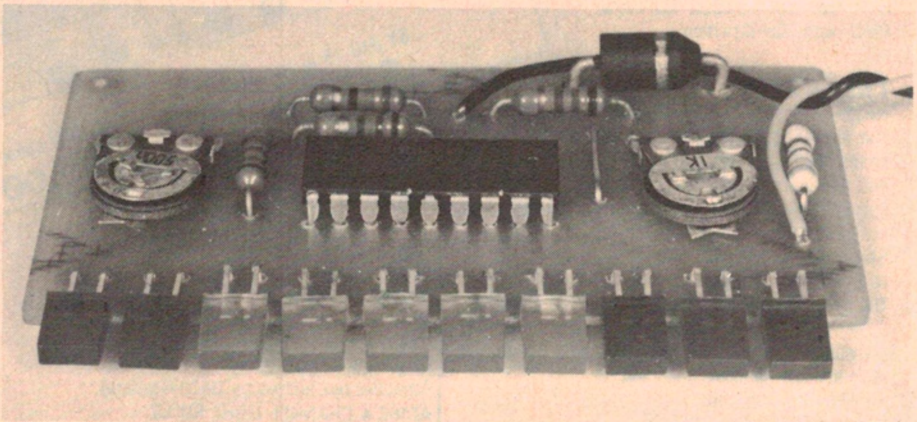
One of the most useful monitors of battery 'condition' is an expanded scale voltmeter. This novel, but nonetheless useful, project should find applications in vehicles, battery chargers etc.

THE 12 V BATTERY, in its many forms, is a pretty well universal source of mobile or portable electric power. There are lead-acid wet cell types, lead-acid gel electrolyte (sealed) types, sealed and vented nickel cadmium types, and so on. They are to be found in cars, trucks, tractors, portable lighting plants, receivers, transceivers, aircraft, electric fences and microwave relay stations — to name but a few areas.

No matter what the application, the occasion arises when you need to reliably determine the battery's condition — its state of charge, or discharge. With wet cell lead-acid types, the specific gravity of the electrolyte is one reliable indicator. However, it gets a bit confusing as the recommended electrolyte can have a different S.G. depending on the intended use. For example, a low duty lead-acid battery intended for lighting applications may have a recommended electrolyte S.G. of 1.210, while a heavy-duty truck or tractor battery may have a recommended electrolyte S.G. of 1.275. Car batteries generally have a recommended S.G. of 1.260. That's all very well for common wet cell batteries, but measuring the electrolyte S.G. of sealed lead-acid or nickel-cadmium batteries is out of the question.

Fortunately, the terminal voltage is also a good indicator of the state of charge or discharge. In general, the terminal voltage of a battery will be at a defined minimum when discharged and rise to a defined maximum when fully charged. Under load, the terminal voltage will vary between these limits, depending on the battery's condition.



The completed voltmeter. LED1 (10.5 V) is on the right and LED10 (15.0 V) is at far left.

Hence, a voltmeter having a scale 'spread' to read between these two extremes is a very good and useful indicator of battery condition. It's a lot less messy and more convenient than wielding a hydrometer to measure specific gravity of the electrolyte!

Let's look at battery characteristics, before we get into the project's circuitry, to get an understanding of what the project can do.

Lead-acid batteries

The fully-charged, no-load terminal voltage of a lead-acid cell is between 2.3-2.4 volts. This drops under load to about 2.0-2.2 volts. When discharged, the cell voltage is typically 1.85 volts. The amp-hour capacity is determined from a 10 hour discharge rate. The current required to discharge the battery to its end-point voltage of 1.85 V/cell is multiplied by this time; e.g: a 40 AH battery will provide four amps for 10 hours before requiring recharge. Note however that the amp-hour capacity varies with the discharge current. The same battery discharged at a rate of 10 amps will not last four hours, on the other hand if it is discharged at 1 amp it will last somewhat longer than 40 hours. The typical discharge characteristics of a (nominal) 12 V battery are shown in Figure 1.

The initial charging current for the fully discharged battery (cell voltage under 2.0 V), should be about 20 amps per 100 amp-hours of capacity (i.e: 8 amps for a 40 AH battery). Once the electrolyte begins to gas rapidly, the terminal voltage will be around 13.8 volts and rising rapidly. At this point, the charging current should be reduced to somewhere between 4-8 amps per 100 AH until charging is complete.

At the end of charging, terminal voltage may rise to about 15.6 volts or more but this decreases slowly after the charger is removed, the terminal voltage then usually reading around 14.4 volts per cell (see Figure 2.).

NiCad batteries

The no-load terminal voltage of a nickel-cadmium cell is typically 1.3-1.4 volts. This drops to about 1.2 volts under load, and to about 1.1 volts when discharged. As the electrolyte does not change during discharge (as it does in lead-acid batteries), the number of amp-hours obtained from a Nicad battery is much less affected by the discharge rate than are lead-acid batteries (see Figure 3.). Ten individual cells are generally used to obtain 12 V.

A number of charging systems can be used to replenish the charge in NiCad batteries. Constant current chargers are well known and quite common (such as the ETI-578 in the June 1980 issue). Fast charging at a high rate, as illustrated in the ETI-563 Fast Charger, is another method while some commercial manufacturers (Christie Electric Asia, for example) employ the "reflex" technique — the battery is alternately charged and discharged at a high rate over a short period. Increased battery life and extremely rapid charging are the claimed features of this method.

The typical charging characteristics of a single cell are illustrated in Figure 4.

For more details on lead-acid and nickel-cadmium batteries, see "Batteries" in ETI, November 1977.

The voltmeter

This voltmeter uses ten LEDs to provide an 'expanded' voltage scale over the range 10.5 V to 15 V to suit applications with 12 V (nominal) batteries. Heart of the device is an LM3914 LED bargraph driver chip. In this application, we are using it in the 'dot' mode to provide an unambiguous display. The IC has been connected in this circuit such that the first LED (LED1) lights at 10.5 V, the second at 11.0 V and so on at 0.5 V intervals up to 15 V at LED10. Red LEDs have been employed at the extremes of the range to indicate 'problem' conditions. The first three LEDs, covering 10.5 - 11.0 - 11.5 volts, are red to show the discharge condition, while the last two LEDs, covering 14.5 and 15.0 volts, are also red to indicate the overcharge condition. The LEDs covering the 12.0 to 14.0 volts range are all green showing that the battery's within its normal operating voltage range.

An 'idiot' diode (ZD1) and a line fuse protect the instrument in the event of reverse connection or an over-voltage condition. Should the unit be inadvertently wired in reverse polarity, ZD1 will conduct in the forward direction and the line fuse will blow. If a voltage greater than 18 V is applied, which may happen if the unit is installed in a car and a battery terminal comes loose allowing the alternator voltage to rise, then the zener action of ZD1 will cause the line fuse to blow, preventing too high a supply voltage from destroying the unit. ▶

VEHICLE BATTERY FAULTS

Symptom	Probable cause
☆ Voltage falls rapidly to low end of green after engine is switched off.	Battery in poor condition or possibly faulty. Check terminals for good connection.
☆ Battery voltage falls considerably overnight	ditto
☆ Voltage falls rapidly from high end of green to low end if lights switched on with engine off.	ditto
☆ Voltage falls more than about one volt when lights are switched on with engine running at moderate speed	Charging system may be supplying low current. Check alternator slip rings, diodes and regulator adjustment. Check battery terminals.
☆ Voltage rises over 14.5 V (LED9) when engine running	Charging system may be overcharging. Check regulator voltage adjustment.
☆ Voltage never rises to top end of green (LED8).	Charging voltage too low. Adjust regulator voltage.

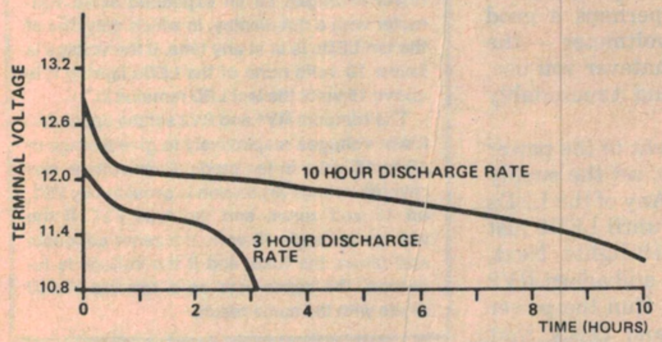


Figure 1. **Typical discharge characteristics of a 12 V (nominal) lead-acid battery.**

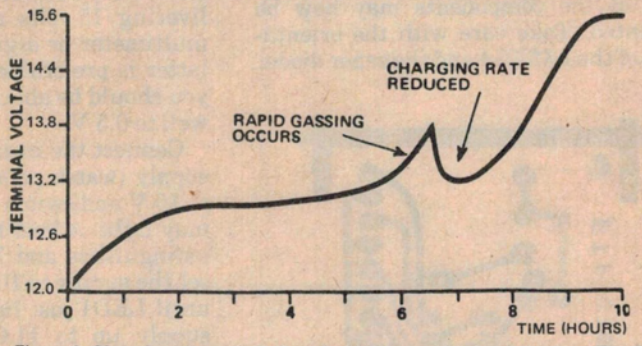


Figure 2. **Charging characteristics of a 12 V (nom.) lead-acid battery. The 'kink' in the curve near 6 hrs is explained in the text.**

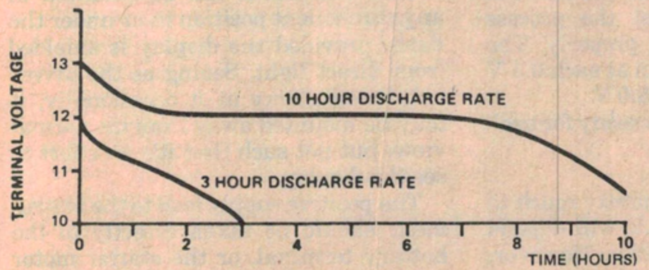


Figure 3. **Typical discharge characteristics of a 12 V (nom.) nickel-cadmium battery (usually consisting of 10 cells in series).**

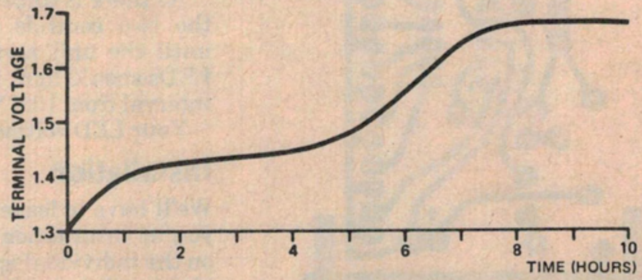


Figure 4. **Typical charging characteristics of a single nickel-cadmium cell charged at 1.4 times the discharge rate.**

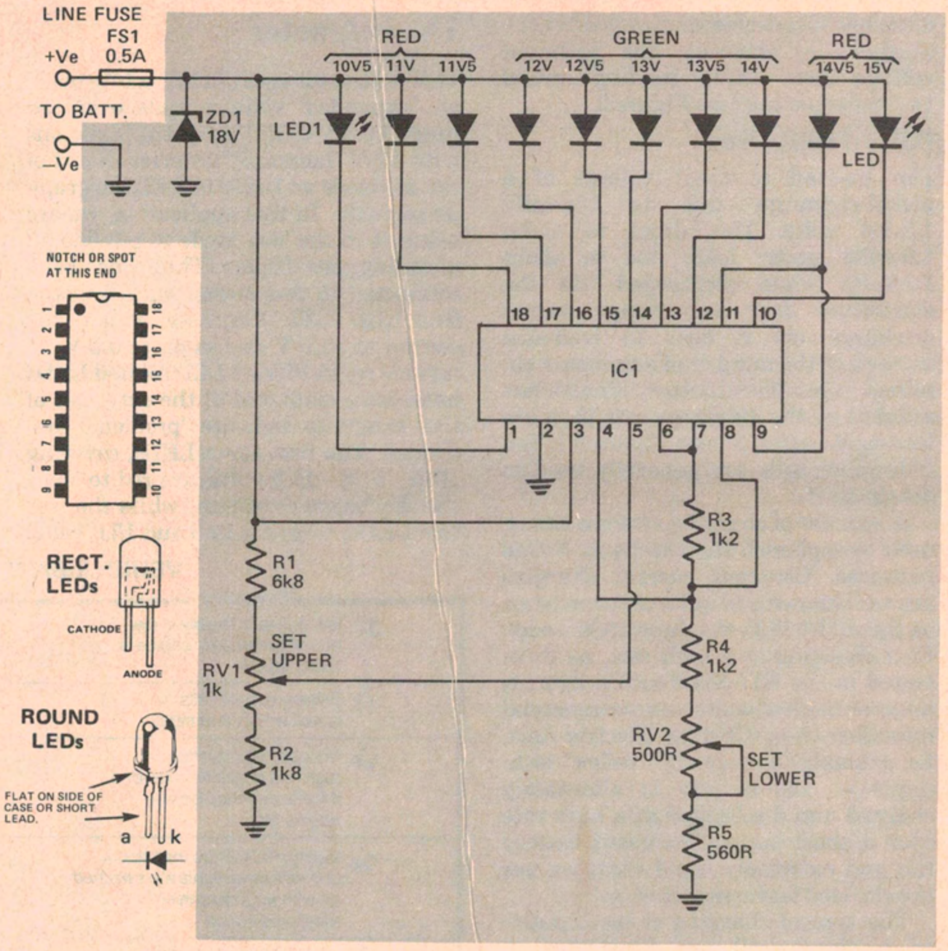
Construction

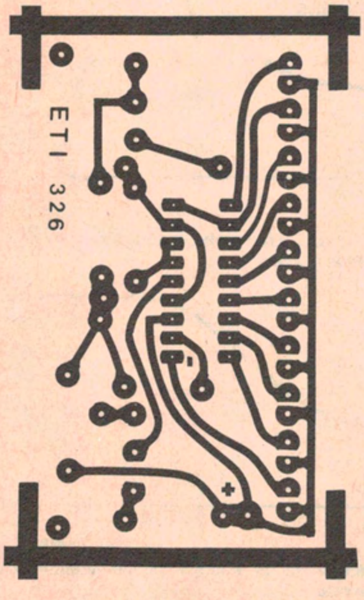
Assembling the project is extraordinarily simple! We recommend you use the printed circuit board — it does make things easier and helps avoid mistakes, although it is not essential.

As with our LED Tacho (ETI-324) we have used rectangular LEDs and mounted them in a row down the front of the pc board. The components may be mounted in any order, but you might find it easier with this project to mount the LEDs first. It is *most important* that they be placed in the board the right way round. About the best way to ensure this is to place them on the table or workbench in front of you with all their leads correctly oriented, just as they would be when mounted in the board. Refer to the overlay and you can't go far wrong. The hard part is getting them all level! Starting at LED1 or LED10 — it doesn't matter which, insert its leads in the board and then bend it over such that it lies flat on the board with the base of the LED flush with the edge of the board. This is clear from the overlay picture. Solder the leads and bend the LED back upright. Insert the next LED carefully positioning it so that it is flush with the first LED and solder its leads. Proceed like this until all the LEDs are in place and then bend the whole row over, parallel to the board.

Note that, although we have used rectangular LEDs, conventional types may also be employed.

If you haven't already done so, the rest of the components may now be mounted. Take care with the orientation of the LM3914 and the zener diode.





Setting the scale limits

To set the scale limits, you will need a variable power supply capable of delivering 15 volts and perhaps a good multimeter or digital voltmeter — the latter is preferable. Whatever you use, you should be able to read it reasonably well to 0.5 V.

Connect the instrument to the power supply (watch polarity), set the supply to 15 V and switch on. Any of the LEDs may light. Adjust RV1 until LED9 just extinguishes and LED10 lights. Next, set the supply to 10.5 V and adjust RV2 until LED1 just lights. Run the power supply up to 11.0 V and check that LED2 lights and LED1 goes out.

As there is some interaction between the two controls, repeat the process until the unit performs properly. The LEDs should light in turn at each 0.5 V interval from 10.5 V to 15.0 V.

Your LED voltmeter is ready for use!

Installation

We'll have to leave this pretty much to you as installation details will depend on the individual application. However, if you plan to mount the unit in a vehicle, here are some general hints.

HOW IT WORKS — ETI 326

The circuit uses an LM3914 LED bargraph driver arranged as an expanded scale voltmeter with a dot display, in which only one of the ten LEDs is lit at any time. If the voltage is below 10 volts none of the LEDs light, if it is above 15 volts the last LED remains lit.

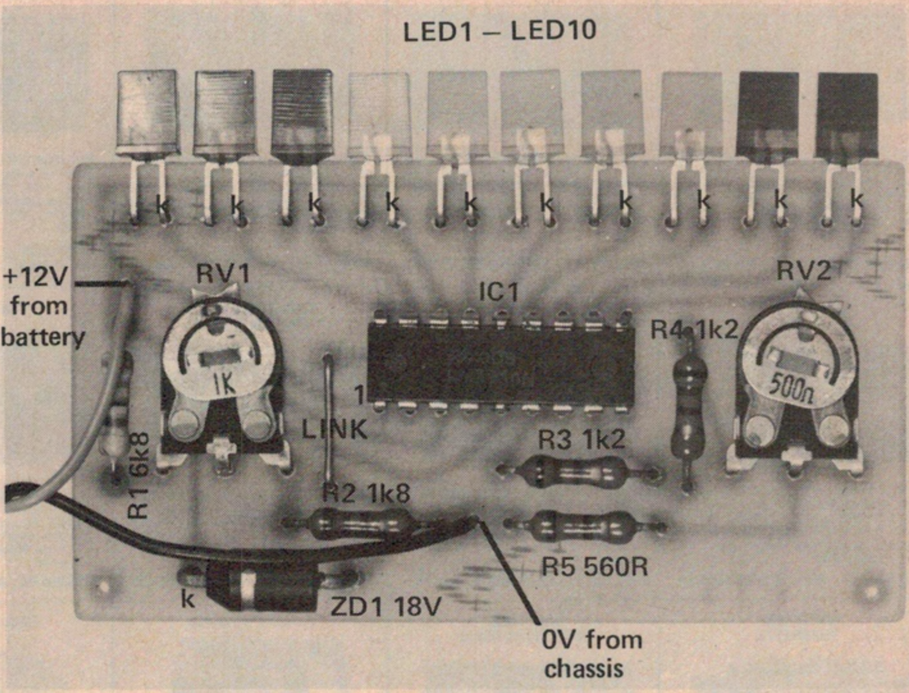
The trimpots RV1 and RV2 set the upper and lower voltages respectively to give a range of 10 to 15 volts in ten steps. Over-voltage and reverse voltage protection is provided by ZD1, an 18 volt zener, and the fuse FS1. If the voltage exceeds 18 volts the zener conducts and blows the fuse, and if the voltage is reversed, the zener acts as a forward-biased diode with the same result.

The instrument can be mounted in any convenient position in or under the dash, provided the display is shielded from direct light. Seeing as the driver only need glance at it occasionally, it may be mounted away from his normal view, but not such that it's an effort to see the display.

The positive supply lead to the instrument should be taken directly to the battery terminal, or the starter motor connection. This is to avoid any voltage drop in the vehicle's wiring from affect-

PARTS LIST — ETI 326

Resistors	all ¼W, 5%
R1	6k8
R2	1k8
R3,R4	1k2
R5	560R
Trimpots	
RV1	1k min. vert. mounting trimpot.
RV2	500 R min. vert. mounting trimpot.
Semiconductors	
ZD1	18V, 1W zener diode
LED1-LED3	red LEDs round or rect.
LED4-LED8	green LEDs round or rect.
LED9-LED10	red LEDs round or sq.
IC1	LM3914N
Miscellaneous	
ETI-326 pc board; in-line fuse holder with 0.5 A fuse.	



ing the reading (such as in the headlight wiring). The chassis connection can be made to the car body under the dash, wherever convenient, or taken to a chassis connection point in the engine bay.

Use in a vehicle

Say you get into your car in the morning. Before you start the engine, the unit will probably register in the upper range of the green portion of the scale. If you left the lights on overnight the battery voltage will most likely be low. If below 11 volts, you'll probably have to push start the car.

Let's assume you've got the car going. As you drive off, the voltage should rise until it reaches the maximum charging voltage — about 14.0 to 14.5 volts. When you reach your destination and switch off the engine the voltage should fall slightly — maybe 0.5 V - 1.0 V, to about 13.0 or 13.5 volts (LED6 or LED7 should light). The accompanying table may be used as a general guide to battery faults. ●

THE LM3914 — HOW IT WORKS

The LM3914 is a highly versatile device designed to sense an analogue input voltage and drive a row of ten outputs, usually LEDs or other indicators, in either a 'dot' or 'bar' graph mode.

The IC contains a ten resistor potential divider. Ten voltage comparators in the chip each have their non-inverting (+) input connected to successive taps on the ten-resistor divider. All the inverting inputs of the comparators are tied together and are driven by the output of a buffer from the input. The buffer has unity overall gain, so that for all intents and purposes the voltage on the inverting inputs of the ten comparators is the same as that on the input pin (pin 5). The outputs of the comparators each go to an individual pin on the IC and are capable of driving an LED or other circuitry.

An internal reference voltage source provides a highly stable 1.2 volts between pins 7 and 8. Since this reference is 'floating', the voltage between pins 7 and 8 always remains at 1.2 volts, irrespective of whether pin 8 is tied to ground or held at some voltage above ground.

Finally, the IC also contains an internal logic network that can be externally programmed to provide either a 'dot' or 'bar' display from the outputs of the ten voltage comparators. When the dot mode is selected, only one of the ten outputs will be 'active' as the input voltage varies. When the bar mode is selected, each output becomes 'active' in succession as the input voltage increases, and vice versa.

If the reference voltage (1.2 V) is connected across the internal resistive divider, by connecting pin 7 to pin 6 and pin 8 to pin 4, 0.12 volts is applied to the non-inverting input of the lowest voltage comparator, 0.24 V to the next 'up' the divider line, 0.36 V to the next, and so on.

When the input voltage on pin 5 is zero, all the comparator outputs are high. As the input voltage is increased, the buffer output will increase. When it passes 0.12 V, the first comparator in the string (output on pin 1) will switch and its output will go low and remain low. If the input continues to rise, the next comparator will switch over and pin 18 will go low and remain low when the input passes 0.24 V. Pin 17 will go low and remain low when the input passes 0.36 V etc; pin 10 (output of the tenth comparator) will go low and remain low when the input reaches or exceeds 1.2 V. This is what happens when the bar mode is selected. For the dot mode, pin 1 will go low when the input reaches 0.12 V. When the input reaches 0.24 V, pin 1 will go high and remain high and pin 18 will go low. When the input reaches 0.36 V, pin 18 will go high and remain high while pin 17 will go low . . . and so on.

The output currents from the comparators may be programmed by a connecting resistor across the reference supply, between pins 7 and 8. Each comparator output current is approximately ten times the output current of the voltage reference source. This can supply about 3 mA maximum, so the maximum output current from each comparator is 30 mA.

A detailed explanation of the operation and applications of the LM3914 appeared in the March 1980 issue of ETI, page 61.