DIGITAL VOLTMETER For Your Car's Dashboard

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Keep an eye on the condition of your car's electrical system with this 3-digit digital voltmeter. Even if you're just a beginner in electronics, you can easily assemble it.

MOST CARS THESE DAYS DON'T HAVE gauges or meters on their dashboards—they have "idiot lights" instead. They're great for telling you when something has gone wrong, but they do very little to warn you when something is *about to* go wrong. What's more, even if you are one of the lucky ones and your car does have gauges, their accuracy is not the best. A device with a digital readout would be much more satisfactory in many cases and easier to read as well.

The digital voltmeter described here can be installed in your car (or boat, or truck) to give you constant and accurate (to a tenth of a volt) information about the state of your battery. It is equally useful in electrically powered vehicles like golf carts and electric service-trucks (fork-lifts, baggage carts, etc.). While most of the latter do have meters, this voltmeter will prove to be more accurate.

The meter is very simple to build—it has only three IC's, three capacitors, five resistors, three transistors (and, of course, three LED's)—and for that reason makes an excellent project for the electronics novice who wants to "get his feet wet." Because it may be your first project, we'll go into the details of construction a little more deeply than we usually do in **Radio-Electronics**.

How it works

Figure 1 is a schematic of the entire voltmeter. The LM340T-5 regulator, IC1, has an output of five volts, which is ideal for the other two IC's in the circuit and for the LED displays. The input to the regulator is protected by diodes D1 and D2, and by a 47 μF capacitor, C1. Those components minimize positive- or negative-going voltage spikes that may be caused by switching inductive devices like the windshield wipers, air conditioning, electric windows, etc., on or off. A 10 μF capacitor, C2, at IC1's output damps any noise or transients that may appear on the five-volt output line and makes the regulator a very stable voltage source, which is critical for accurate readings.

The heart of the voltmeter circuit is IC2, a CA3162E dual-slope, dual-speed, A/D (*A*nalog-to-*D*igital) converter that reads the battery voltage and converts it into a BCD (*B*inary-*C*oded *D*ecimal) digital number. That number appears at pins 2, 1, 15, and 16 of the IC and is fed to pins 7, 1, 2, and 6, respectively, of IC3, a CA3161E BCD 7-segment decoder/driver that drives the three FND507 seven-segment LED numeric displays (DISP1–DISP3).

The CA3161E deserves a little further attention. It performs several functions that, in the past, would have required the circuit to contain a number of additional components. For one thing, it limits the current that is drawn by the displays. Without current-limiting, the LED's would tend to overheat and burn out and, in the past, current-limiting resistors would have been required to prevent that from happening; the CA3161E eliminates the need for them. That IC also allows the displays to be multiplexed; that means that only one LED is on at a time—although they're switched on and off so rapidly through driver transistors Q1–Q3 that they all seem to be on simultaneously. Multiplexing the displays saves a lot of power, and the total current needed to operate the voltmeter is 160 mA or less.

The maximum voltage differential allowed between the input pins on IC2—pins 10 and 11—is 999 mV. Therefore, resistors R1 and R2, whose values have the ratio 100:1, are used to form an attenuation network with a factor of 100. If 13.8 volts are applied to the attenuator network, the voltage difference between the pin 10 (which is grounded) and that at pin 11 (the input pin) will be, according to Ohm's law, 136.6 mV. What we want it to be, though, is 138.0 mV. That differ-

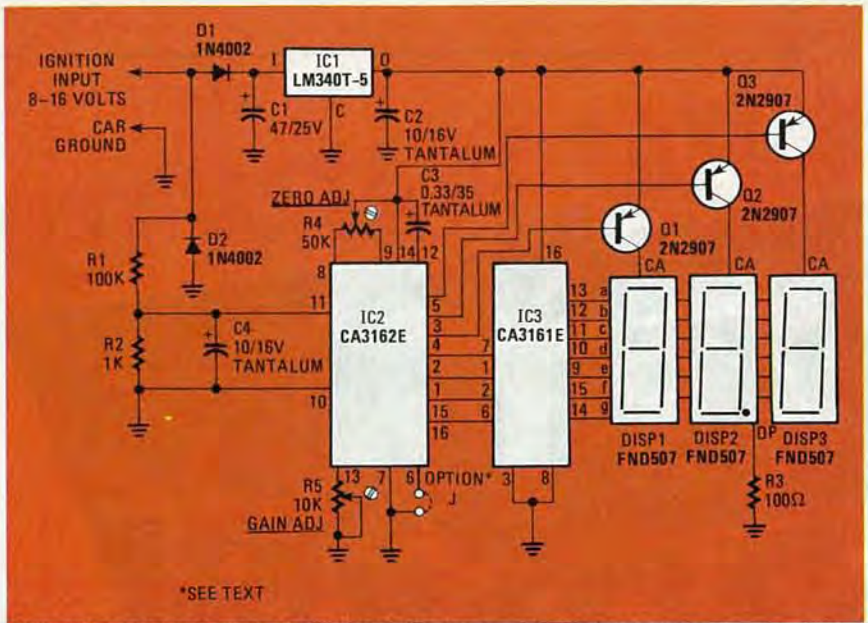

FIG. 1—NOTE THE POINTS MARKED "OPTION" at pins 6 and 7 of IC2; they allow the sampling rate of the converter A/D to be changed. See the text for details.

ence is compensated for by the GAIN ADJUST potentiometer, R5.

The ZERO ADJUST potentiometer, R4, is used—together with a 0.33 μF capacitor, C3—to generate the correct internal ramp-voltage (needed for the dual-slope A/D conversion process) for IC2. We'll discuss the adjustment of both potentiometers later.

Finally, there are two different conversion rates (the rate at which the A/D converter samples the analog input and changes it to digital form) available from IC2. Tying its pin 6 to five volts will produce a conversion rate of 96 (samples) per second. That speed, though, will cause the last digit of the display to become a blur, so we use the other conversion rate—four samples-per-second—by tying pin 6 to ground. The point at which the choice of conversion rates is made is marked "OPTION" in the schematic.

Construction tips

The voltmeter is so easy to build that the process really needs little description. Instead, we'll assume that this is the first circuit you've ever put together, and give you lots of helpful information. Even if you're an experienced constructor, you may find something of interest here, so don't skip this section!

While an etched and drilled circuit board is available from the source indicated in the Parts List, you may decide to go all the way and make your own (the foil pattern is reproduced in Fig. 2). Techniques for making your own PC boards were discussed in detail in the December 1982–February 1983 issues of **Radio-Electronics**. If the board's foil traces are naked copper, there is the possibility that some oxidation may have taken place if the board was not used immediately, and the copper may be difficult to solder to. If that's the case (or even as a preventative measure) use a clean *dry* scouring pad to wipe the copper side of the board gently and bring it to a relatively high polish. *Do not* try to clean it up using a buffing wheel! Then wipe it off with a soft cloth. It should then be as solderable as a board that's just been produced.

The choice of a soldering iron is very important. It should be low power—about 27 watts—and should be used sparingly. Keep it in contact with the points to be soldered only long enough to do the job; if you apply too much heat to a PC board the foil is apt to separate from the board. Use as fine a tip as you can get—that not only keeps heat-buildup down, but lessens the possibility of your creating solder blobs and bridges between adjacent foil points that were meant to be isolated. A fine (thin) rosin-core solder will also help keep your work neat. Use only as much solder as is needed to "wet" the connection; don't make big blobs.

A final word about soldering: keep the tip of the iron clean. A clean tip is a requirement for precision soldering. As your work progresses, solder will usually accumulate on the tip of the iron and it is important that you start soldering with a clean tip, and that you stop the buildup of solder on the tip before it gets started. A damp (not sopping wet) sponge makes a good tip cleaner. Place it out of the way on a plate where you can lightly wipe the tip against it frequently. Wipe the tip whenever you are about to put the iron down after using the it, or at intervals if you are soldering something like a series of IC pins. And, of course, wipe the tip well at the end of your work session.

Many components—like IC's, LED's, diodes, transistors, and tantalum or aluminum electrolytic capacitors—are polarized. That means that they will work properly only if they are installed in the circuit so that the correct pins or leads go to the appropriate points.

The polarities of diodes and capacitors are clearly indicated in schematics and parts-placement diagrams. On diodes, the cathode end is indicated a band; on capacitors, the positive lead may be marked with a dot on the body of the capacitor, or in another fashion. The September 1982 and November 1982 issues of **Radio-Electronics** contained a lot of valuable information on the various types of electronic components; you might want to take a look at them.

Integrated circuits like the ones used in the voltmeter come in DIP (*D*ual *I*n-line *P*in) packages. The pin-1 end of the IC may be marked with a notch, a dot (usually placed next to pin 1), or both. Many IC sockets—which you should use, by the way, in case you have to remove an IC for some reason—also have their pin-1 ends marked, even though the sockets themselves are not polarized. Those markings help you to remember which way the IC is to be installed.

Finally, a word of caution about IC's. Many of them—including the CA3161E

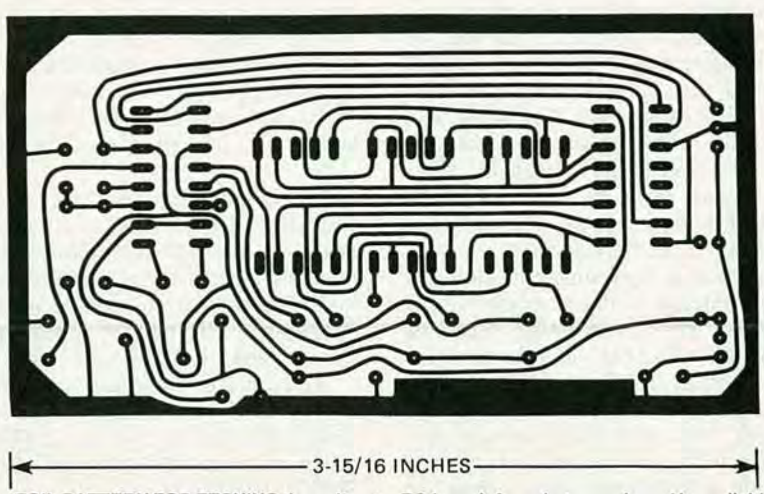

FIG. 2—FOIL PATTERN FOR ETCHING the voltmeter PC-board. A ready-to-use board is available from the supplier indicated in the Parts List.

and CA3162E—can be damaged by static electricity. Do not wear clothing made of synthetic fibers when working with such devices (although, once they've been installed on the PC board, they're relatively safe from harm and you can pretty much wear what you like). If static electricity is a problem for you, handle the IC's under humid conditions. A good solution to the problem is to steam up your bathroom by running the hot water in the shower for a few minutes and then installing the IC's in their sockets in that room while the air is still damp. That trick is especially useful in winter.

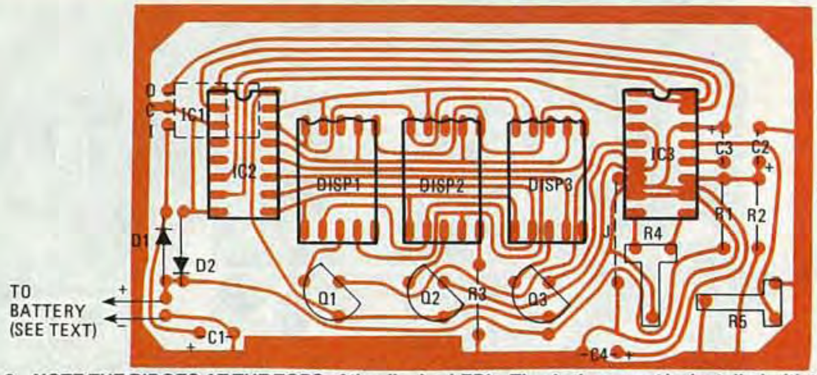

FIG. 3—NOTE THE RIDGES AT THE TOPS of the display LED's. The devices must be installed with the ridges in that position.

Construction

A red plastic filter will make the displays of the voltmeter easier to read under difficult lighting conditions. Use a piece of plastic ⅛-inch thick and a little larger than the PC board. Drill a hole in each corner of the PC board, and drill matching holes in the plastic. To avoid cracking the fragile material, drill small pilot-holes first, and then carefully enlarge them. Be careful not to scratch the plastic. Then set the plastic aside temporarily and, with the advice just given in mind, proceed to "stuff" the PC board.

Use Fig. 3, the parts-placement diagram, to guide you. Install the IC sockets first, and then the resistors, diodes, and capacitors. Don't forget the "OPTION" jumper, which can be a piece of leftover resistor lead. Save the larger parts, like the potentiometers, for last. The 47 μF capacitor, C1, can be mounted on the foil side of the board if you wish to conserve height between the plastic filter and the voltmeter board.

When you install the LED's, which can be soldered directly to the board, be certain that you mount them with the side with the ridges at the top (if you look closely, you'll be able to see the decimal point of the display at the lower right). Solder only two pins, at opposite corners of each device, first. That will allow you to reposition the displays easily if you find that they're in at an angle.

The five-volt regulator, IC1, should be mounted on the foil side of the board as shown in Fig. 4. Bend the leads carefully as shown so they arch backwards. The reason for installing the regulator on the back of the board is, again, to conserve height.

Connect about three feet each of red and black 22-gauge wire to the "IGNITION" and "GROUND" pads of the board, respectively. That will prevent confusion later on in connecting the voltmeter to the vehicle.

Finally, *do not* install IC1 and IC2 in their sockets until you have carefully inspected the board for poor solder-connections, solder bridges, proper component-orientation, and anything else that you might conceivably have done wrong (*anyone*—even you—can make a mistake). Then verify that the supply voltages to the IC sockets are correct. If you temporarily connect the red and black wires to a 12-volt-DC source, you should measure five volts at pin 14 of the socket for IC2 and at pin 16 of the socket for IC3. Pins 7 and 8, respectively,

FIG. 4—THE FIVE-VOLT regulator is mounted on the bottom of the PC board, exactly as shown.

PARTS LIST

All resistors 5%, ¼ watt unless otherwise indicated

R1—100,000 ohms
R2—1000 ohms
R3—100 ohms
R4—50,000 ohms, trimmer potentiometer
R5—10,000 ohms, trimmer potentiometer

Capacitors

C1—47 μF, 25 volts, electrolytic (axial leads)
C2, C4—10 μF, 16 volts, tantalum or electrolytic (axial leads)
C3—0.33 μF, 35 volts, tantalum

Semiconductors

IC1—LM340T-5 (7805) five-volt regulator, tab type
IC2—CA3162E dual-speed, dual-slope A/D converter
IC3—CA3161E BCD 7-segment LED decoder/driver
Q1–Q3—2N2907 or similar PNP transistor
DISP1–DISP3—FND507 or FND510 7-segment LED
D1, D2—1N4002

Miscellaneous: PC board, IC sockets, wire, red plastic filter, mounting hardware, etc.

The following are available from Digital World, PO Box 5508, Augusta, GA 30906: PC board only, $7.50; PC board with schematic, $8.50; CA3161E and CA3162E, $12.00; PC board with all three IC's and with IC sockets, $20.00; kit of all parts (no filter, chassis or solder) $30.00. The prices of the *first two items only* include postage and handling costs within the continental U.S. and Canada. For all other items add $2.00 within the continental U.S.; $3.00 all other U.S., APO, and FPO. Canadians please use $U.S. postal money order. Other countries write for prices and shipping costs. Please allow 4–6 weeks for delivery.

FIG. 5—THIS IS WHAT the completed voltmeter should look like prior to installation.

of those sockets should be at ground potential; you should measure no voltage there.

If your voltage readings are correct, you can disconnect the board from its temporary power supply and install the two remaining IC's. If your measurements differed from those indicated, recheck the board carefully for errors. The completed board should look similar to the one shown in Fig. 5, assuming, of course, that you used the same types of capacitors and other parts.

Calibration

Connect a known, accurate, voltage source to the red and black input wires of the voltmeter. If you already have an accurate meter, connect it in parallel with the one you're calibrating to act as a double check. The calibration voltage should be between 10 and 16 volts; 13.8 volts is recommended. Do not attempt to use a source of less than 10 volts, for it may result in inaccuracies.

To set the ZERO ADJUST trimmer potentiometer, R4, temporarily ground pins 10 and 11 of IC2 to the ground foil of the PC board. Then, very carefully adjust the pot until the display reads "00.0." (You'll need a very fine screwdriver—and some patience—for this.) You can then unground the two IC pins.

Adjust the GAIN ADJUST trimmer potentiometer, R5, until the display indicates the exact value of the calibration voltage being applied. That's all there is to it.

Troubleshooting

If the voltmeter did not light up for the calibration procedure, first make sure that potentiometer R4 is centered. If there is still no response, double check your work once again for solder bridges, unsoldered connections, components installed incorrectly, etc. *Carefully* remove the IC's from their sockets and make sure that none of their pins were bent under.

If the displays are dim, check the emitter and collector leads of transistors Q1–Q3; you might have mistakenly inserted the transistors backwards.

If a digit seems to be trying to display two numbers at the same time, its driver transistor may be defective.

If, after you've installed the meter, it doesn't work, make certain that the red and black wires are properly connected to the "tie in" point and to ground, respectively.

Installation

The first step in installing the meter is to mount the plastic filter in front of it. That can be done using ¾-inch spacers, or by making spacers using 1½-inch bolts and nuts. If you use the latter method, insert a bolt through the plastic and put a nut on the reverse side. Then put a second nut on the bolt, allowing ¾-inch of space between it and the first nut. Do that at all four corners of the plastic. Next, insert the bolts through the holes drilled in the PC board, and secure them with four more nuts. Securing the plastic at all four corners gives the assembly greater strength and minimizes the potential for the plastic's cracking from vibration.

The voltmeter does not require a special cabinet or chassis. It can be mounted in a recess in the dashboard of the vehicle and the edges of the mounting hole covered with a frame, or bezel. For a touch of class, the displays can be mounted on a separate board (a duplicate of the voltmeter board will do quite nicely) and "remoted" from the meter itself. In that case you'll need a 14-conductor ribbon cable to connect the two boards.

The black wire should be securely connected to the vehicle's chassis ground. The red wire should go to a point in the vehicle's electrical system that is active only when the ignition switch is turned on; a good place for that connection is at the same fuse terminal to which the radio is connected.

Now that your voltmeter is installed and working, what voltages should you expect to read? You're probably thinking that the answer is 12 volts. Wrong! Actually, it should be about 12.6 volts. When you're driving, and the battery is being charged, expect to read about 13.8 volts. Any readings above 17 volts or below 11 volts (such as when cranking the starter) indicate trouble!

A possible problem

It is possible that the display-multiplexing circuit will interfere with the operation of an AM radio (especially if the meter and the radio are connected to the same point) by generating some radio-frequency interference that will cause the radio to "whine."

Some radios are more sensitive to that problem than others. There are several solutions to that problem, should it occur.

First, try using a "tie in" point other than the one used by the radio. Just remember that it should be active only when the ignition switch is on.

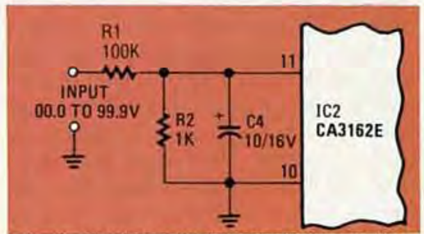

FIG. 6—USING RESISTOR R1 as the input allows you to measure up to 99.9 volts. See the text for precautions.

You can also try moving the meter away from the radio (or vice versa).

Finally, you can try shielding the voltmeter circuit in a metal box. That is usually very effective.

If you decided to "remote" the display from the rest of the meter circuit, wrap the connecting ribbon cable in aluminum foil, and connect the foil to ground. That is almost a "must" in applications where the two units will be separate.

Use with higher voltages

The voltmeter can be used to measure voltages up to 99.9 volts *provided that two conditions are met.*

First, the supply voltage to the board must be between 8 and 16 volts. Any lower, and the regulator will not function properly; any higher and it will quickly self-destruct.

Second, the end of the 100K resistor (R1) connected to D2 should be disconnected from that diode, and the voltage being measured applied to the circuit through that resistor. This is shown in Fig. 6.

A last word of advice: Even though your new meter will almost certainly be more accurate than the old indicator you were using, don't get rid of the old one! Keep it in place to monitor the functioning of the meter you built, and to act as a backup just in case something should go wrong.

If you follow the instructions given here, you will not only have learned something about electronics construction-techniques, but you will also have built yourself a very useful measurement instrument. **R-E**