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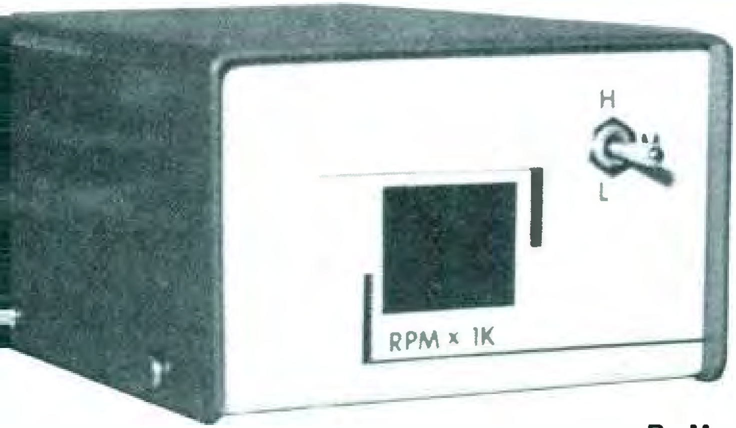


DIGI-TACH

A solid-state readout device that lets you check your car's engine performance during tune-ups and on the road!

By Mark C. Worley

MOST AFTER-MARKET TACHOMETERS ARE EITHER EXPENSIVE, inaccurate, or both. With the all-CMOS, digital tachometer (we call it Digi-Tach) described in this article, you can have reliability, accuracy, an easily read display, and freedom from mechanical damage due to shock and vibration. Digi-Tach will work with any car with a conventional ignition system.

A 2-digit tachometer may seem to lack resolution, but the primary application for this circuit is for use while driving. When fine-tuning an engine, you can't beat a quality, expanded-range analog tachometer, but for use in the car, a digital tachometer should be your choice.

How it works

A digital tachometer is actually a low-frequency counter with a readout calibrated in *rpm*'s instead of Hertz. Much like a frequency counter, the Digi-Tach (Fig. 1) contains a master-clock circuit (U6), latch and reset pulse generators (U2-b–U2-d), input signal conditioner (U1, U2-a), pulse counter (U3), display and display drivers (DIS1, DIS2, U4, and U5), and a voltage regulator (U7). As an added feature, Digi-Tach contains a dimmer circuit (U2-e) as an added feature.

Since we're counting *rpm*'s, we have to scale the counting period via the master-clock generator, U6, to display a pulse rate as something other than pulses-per-second. A 4-cylinder car idling at 1000 *rpm* has its engine *turning over* one-thousand times a minute. So how does that equate to a pulse frequency? If we assume that each cylinder will fire once per revolution, there would be 4 × 1000, or 4000 pulses per minute from the ignition coil, so, 4000 divided by 60 equals 66.66 pulses per second. However, only half the spark plugs fire each revolution, so there's really only 33.33 pulses per second in this case. An 8-cylinder engine has twice as many spark plugs, so 1000 *rpm* equals 66.66 pulses per second, and a 6-cylinder engine generates 50.00 pulses per second. All that refers to 4-cycle (Otto) engines; 2-cycle (diesel) engines operate differently.

Now that we know the pulse rate we're going to measure, we need to figure out how to display that rate in *rpm*. Since, again, a 4-cylinder engine generates 33.33 Hz at 1000 *rpm*, we can count the pulses for 300 milliseconds, which will be ten pulses. If we now display that count of 10 with a decimal point between the two digits, we can read it as 1.0 x 1000 *rpm*. For 6-cylinder engines, we need to count the pulses for 200 milliseconds, and for 8-cylinder engines we only need to count the pulses for 150 milliseconds, to convert from Hz to *rpm*.

For those that still insist on more than two digits, consider that for a 4-cylinder engine we'd have to count pulses for 3 seconds to be able to display three digits. For 8-cylinder engines we could cut that time in half, to 1.5 seconds, but that would still give us a pretty unresponsive display. An alternative would be to use a frequency-multiplier circuit, but the added expense and trouble isn't worth it. With that behind us, let's look at each part of the circuit in detail.

Master Clock

The master-clock generator, which sets the time-period during which the ignition pulses are counted, is a 4060 CMOS oscillator/divider set to run at 424 Hz when used for 4 or 8-cylinders. That frequency is divided down to the clock frequency of 3.3 Hz at pin 6, and 6.6 Hz at pin 4. For 6-cylinder engines, the oscillator frequency is set to 320 Hz and is divided down to a clock frequency of 5.0 Hz at pin 4; the resistor and capacitor values that are used allow the oscillator to be tuned through both frequencies.

The oscillator frequencies are somewhat arbitrary, being determined in part by the values of the components that were

PARTS LIST FOR DIGI-TACH DIGITAL TACHOMETER

SEMICONDUCTORS

D1—1N4004 silicon diode
D2, D3—1N914, 1N4148, or equivalent silicon diode
U1—MCT2 optoisolator
U2—4584 or 74C14 hex Schmitt trigger integrated circuit
U3—4518 dual BCD counter integrated circuit
U4, U5—4511 BCD-to-7-segment decoder/driver integrated circuit
U6—4060 binary counter integrated circuit
U7—7805 5-volt regulator

CAPACITORS

C1,C2—0.1-µF, ceramic disc
C3—.047-µF, Mylar
C4, C5—.001-µF, ceramic disc
C6—.01-µF, ceramic disc
C7—1000-µF, 16-WVDC, electrolytic
C8—100-µF, 16-WVDC, electrolytic
C9—10-µF, 16-WVDC, electrolytic

RESISTORS

(All fixed resistors are 1/4-watt, 5%, units unless otherwise specified)
R1—10-ohm
R2—2200-ohm
R3—27,000-ohm
R4—10,000-ohm
R5—20,000-ohm, miniature trimmer potentiometer
R6, R25—4700-ohm
R7, R8, R24—47,000-ohm
R9-R22—150-ohm
R23—620-ohm

ADDITIONAL PARTS AND MATERIALS

DIS1, DIS2—5082-7740 LED displays (Hewlett-Packard), or equivalent
S1—SPDT, center-off, toggle switch
Metal box, perfboard, wire, solder, Bishop Graphics *E-Z Circuit* part number EZ1206, display sockets (see below), etc.
The display sockets used in the project are Aries Electronics part number 14-810-90T, 14-pin, 90-degree, tin-plated, vertical-mount sockets. Check with your local wholesale electronics distributors or contact Aries Electronics, Inc., PO Box 130, Frenchtown, NJ 08825, (201) 996-6841, for their nearest distributor.

on hand. In addition, we wanted to keep the frequency low and use moderate component values for R4–R6 and C3 to maximize the frequency stability. Large-valued resistors and capacitors tend to be less temperature-stable than smaller valued components. In any case, the master clock must be available from some one of the divider outputs regardless of the oscillator frequency used.

Latch and Reset

The latch and reset pulses are generated by three of U2's inverters. The rising edge of the pulse from U6 is coupled into U2-b through an R-C network made up of C4 and R7. That spike causes the normally-high (5-volts) output of U2-b to go low (0-volts) for about 50 microseconds, which is used to latch the updated count into the display. The rising edge of that latch pulse also causes the output of U2-c to pulse low for about 50 microseconds in an identical manner. Since the reset pulse has to be positive, U2-d inverts it to the proper polarity.

You can see the relationship between the master-clock pulses and the latch & reset pulses if you refer to the timing diagram shown in Fig. 2. As with most frequency counters, the gating or counting period is not synchronized to the incoming frequency and sometimes causes the last digit to vary by ±1 count.

Counting Pulses

The input circuit uses an optoisolator and a Schmitt trigger to make the noisy, high-voltage ignition pulses suitable for the pulse counter. The optoisolator was chosen as the input device because it is a current operated device that ignores voltage transients. Only when a few milliamps of current flow through the internal light-emitting diode (LED), will the signal be coupled to its phototransistor and be recognized by the circuit as an ignition pulse. Resistor R1 is used as a fuse and is mounted at the coil-end of the pickup wire. Diodes D1 and D2 protect the LED from high reverse voltages caused by ringing in the ignition coil. Capacitors C1 and C2 further help to immunize the circuit from extraneous noise pulses. Before the ignition points close, the LED in U1 is drawing about 6 mA through the primary winding of the ignition coil. That keeps pin 5 of U1 low. When the points close, current is cut off from the LED and pin 5 goes high because of pull-up resistor R3. The inverter, U2-a, squares-up the pulses before they're fed to U3.

Schmitt triggers have the unique ability to take a noisy signal, or one with a slow rise time and shape it into a straight-sided, clean signal suitable for digital use. Their outputs switch from high-to-low or low-to-high as the input signal passes through a point equal to about 50 percent of the supply voltage. In the pulse generator, the pulse-shaping of inverters U2-b–U2-d is used create clean pulses from narrow, rounded spikes. In the signal conditioner, inverter U2-a shapes the output pulses from U1, while the dimmer circuit finds another use for Schmitt triggers.

Getting a Display

The ignition pulses from U2-a clock the dual divide-by-ten, BCD counter, U3, whose two counters are ripple-cascaded. The reset pins, pins 7 and 15, are tied together and are normally low, allowing the counters to advance on each clock pulse. When a reset pulse is received, the internal counters are reset to zero to clear the counters before they count the new *rpm* rate. The output data from U3 is in BCD (*B*inary *C*oded *D*ecimal), which is required by the display drivers.

The data from pins 3 through 6 are the least significant digit (LSD) bits and should drive the right-most digit, while the data from pins 11 through 14 should drive the most significant digit (MSD), the left one. If you wire those backwards, it takes a lot of rewiring to turn things around, so be careful.

The display drivers, U4 and U5, convert the BCD data into 7-segment display code for the two displays. The latch signal, which is normally high, keeps the previous *rpm* value latched

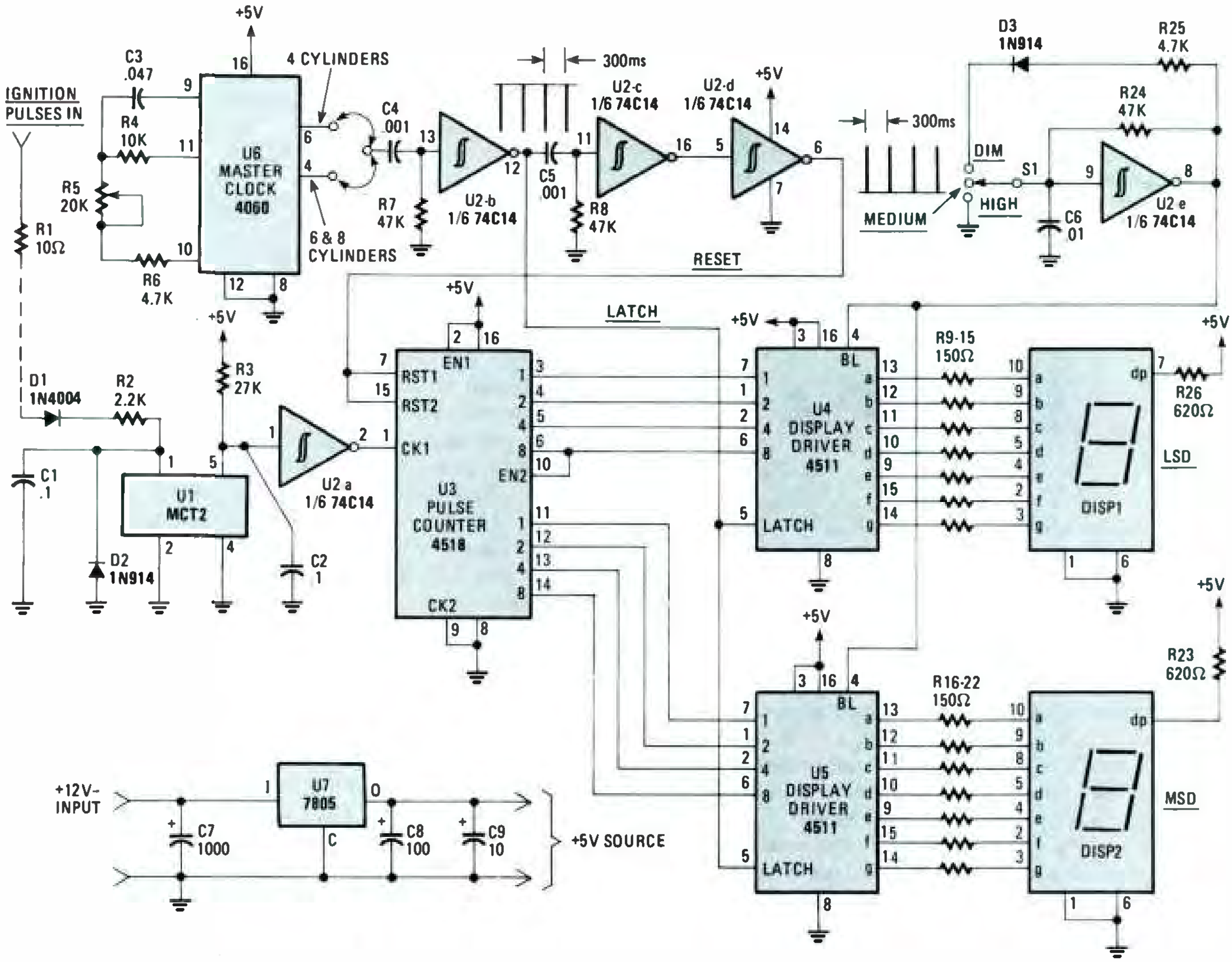
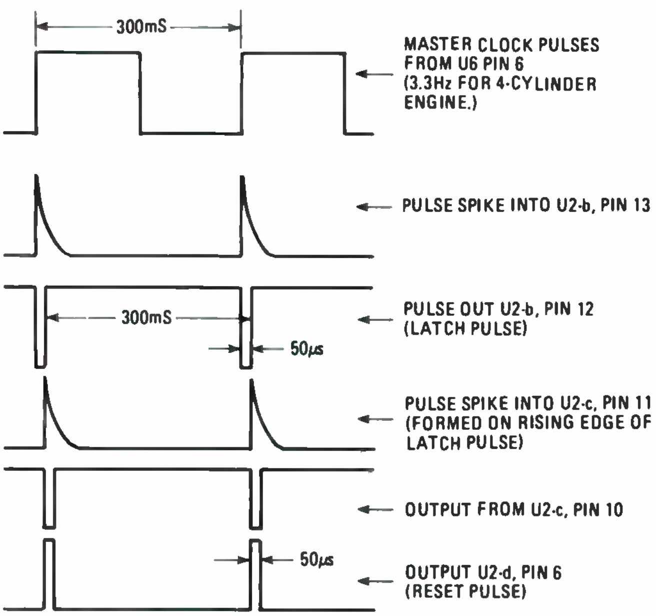


FIG. 1—THE SCHEMATIC DIAGRAM of Digi-Tach circuit. Since this device is to be mainly used while driving, two-digit resolution was used to keep response time short. An optoisolator is used to render the noisy, high-voltage ignition pulses suitable for input to the circuit.

into the displays until the master-clock generates another timing pulse. At that time, the latch pulse locks in a new display count, then the reset pulse clears the counters to zero.



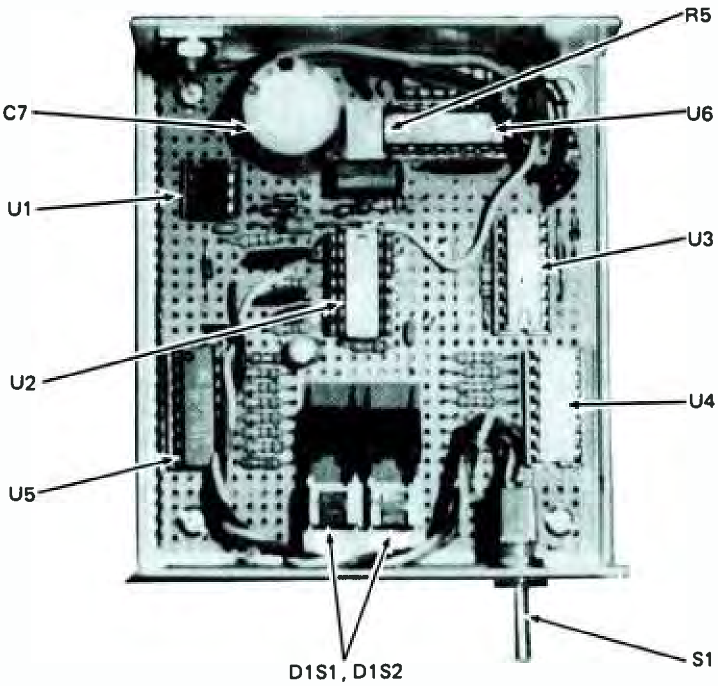
The 100 µs that latch and reset operation takes is a very small portion of the 150–300 ms used to count the ignition pulses, so it can be ignored.

Since a car's interior has widely varying lighting levels from bright sunlight to midnight blackness, the display should be capable of being adjusted to those conditions. A display with sufficient brightness to be viewed in sunlight is usually too bright and blurry in darkness, while one suitable for viewing in darkness is too dim to be seen in sunlight. Using an SPDT, center-off, toggle switch (S1), we can have a brightness control with HIGH, MEDIUM, and LOW positions.

The blanking input of the display drivers, pin 4, will turn the displays on or off if it is taken high or low respectively. If we modulate the blanking input with a variable duty-cycle signal, we can control the brightness of the display by varying the ratio of the on and off times.

The versatile Schmitt trigger can become a simple oscillator with a duty-cycle of about 50 percent by adding only a

FIG. 2—THE RELATIONSHIP between the master-clock pulses from U6 pin 6 and the latch and reset pulses are shown here. The example illustrated is for a 4-cylinder engine, hence the master-clock frequency is 3.3 Hz. As with most frequency counters, the gating or counting period is not synchronized to the incoming signal, which sometimes causes the last digit to vary by one count. Note: waveforms are not drawn to scale.



PEEKING INSIDE THE CASE you find the author's neatly assembled perfboard circuit. Author used point-to-point wiring; however, you could use the wire-wrap technique. Approximate location of parts on your layout to take advantage of author's successful planning.

capacitor and a resistor. That is done with the U2-e circuit. If the output of that circuit is fed to the blanking input of the display drivers, it dims the display somewhat to give us a medium display brightness. By adding a diode and resistor, the duty-cycle of the oscillator can be made controllable, and, depending upon which direction the diode faces, the duty-cycle can be mostly high or mostly low. For a dim display (LOW), we want the pulses to be mostly low, which keeps the display turned off more than it is turned on. Note that we're not particularly interested in the oscillator's frequency, as long as it is sufficiently high to avoid flickering the display; we need to vary the duty-cycle to control the brightness.

The value of resistor R25 can be changed to whatever gives you the desired low illumination level. Reducing the value dims the display even more. It would even be possible to replace R24 with a photosensitive resistor mounted on the front panel to make a display that automatically adjusts to ambient lighting. Just eliminate the switch and permanently connect the cathode of D3 to ground. If the dark resistance of the photo resistor is too high, the oscillator frequency may drop top low and cause a flickering display, so you'll have to experiment a bit. If you replace R25 with the photoresistor (instead of R24), the dimming action will be in reverse because its resistance decreases with an increase in light.

When the input to the oscillator is grounded by the switch, the output goes high, which turns the displays on to their brightest for the HIGH setting. Since the 4511 display drivers have a maximum safe-current capacity of 25-mA-per-segment, 150-ohm limiting resistors are used to limit the current in each segment to about 23 mA with a 5-volt DC supply. The decimal point is driven directly from the supply, instead of from the decoder/drivers, so a 620-ohm resistor is used to limit the brightness to a suitable compromise between the LOW and HIGH settings. Figure 3 compares the outputs from U2-e for the three brightness settings.

Power-Supply Details

The 7805 voltage regulator is used primarily for circuit protection and to stabilize the master oscillator frequency. The typical +12-volt system in most cars generates about 13.8-volts, which is safe for the CMOS IC's in this circuit, but a voltage spike of only a couple volts would exceed their safe ratings. Additionally, changes in the power-supply voltage affect the oscillator frequency, which must be kept stable for accurate *rpm* readings.

The circuit draws about 200 mA with the displays at full brightness, so the 7805 voltage regulator will get moderately warm. The voltage regulator, U7, will remain well within its safe limits as long as it's properly heat-sinked.

Construction

Digi-Tach is built on a 2⅝ × 2⅜-inch perfboard, which fits into an aluminum box that measures about 3⅛ × 3½ × 2 inches. Power, ground, and the ignition pickup wire come in through a 3-wire cable in the back. The voltage regulator, U7, is mounted in the left, rear corner of the box, which acts as a heatsink for it. The LCD's and dimmer switch, S1, are mounted up front.

Use sockets for all the IC's except U7. Mount the decoder/drivers near the two displays. The other IC's can be installed where convenient since the layout isn't critical.

The prototype was hand-wired with the help of Bishop Graphics *E-Z Circuit*, which is a stick-on type of instant printed-circuit pattern. The author prefers to use just the dual-in-line pattern to hold the IC sockets in place, then use wire-wrapping wire to interconnect the pads and parts. We don't wirewrap with the wire—we solder it. (The part number for the DIP pattern is EZ1206.) Route your wires directly between the two points they solder to instead of cabling them all together. That *rat's nest* method doesn't look as pretty, but it is easier to troubleshoot and usually results in less noise being coupled between wires.

No doubt you've noticed the vertical sockets used to hold the displays in place (see photo). They're amazingly convenient since they eliminate the need for a second board to mount the displays on. That way, the whole circuit is built as one modular piece. Check the parts list for the part number and source for those. We also used the *EZ Circuit* pattern to hold the sockets in place. Be careful when wiring the sockets—it is especially easy to get "turned around" and misidentify the pins since they make a 90 degree bend. The displays have ten pins, so each socket will have four unused pins, one at each corner, which can be conveniently used for tie-points.

Small-gauge wire will handle the power, ground, and interconnections for the complete circuit except for the power and ground leads for U4 and U5. Run a separate 20-gauge wire from the 5-volt output of U7 to the supply pins of the display drivers, and a separate ground lead, too. If any of the other IC's tie into those leads, the current surges that occur as the displays update can cause erratic circuit behavior. Feel free to add extra 10-μF electrolytic or 0.1-μF disc capacitors between power and ground at various spots on the board to eliminate noise. Capacitor C9 in the schematic is one such added capacitor. Also be sure to tie the circuit common to the metal box. A terminal-lug under a screw in the right, rear corner of the box was used for that.

After wiring the board and checking for incorrect wiring, shorts, etc., use a power supply capable of at least 200 mA with an output between 9- and 15-volts DC, and apply power without any of the CMOS IC's or displays installed. Check for 5 volts on the proper pins of each IC and correct any problems you may find. Now plug in the IC's and the displays and fire it up again; you should have two random numbers (or zeros) and a decimal point displayed. Try the 3-position dimmer switch but don't try changing R26 until you've had a chance to view the display at night in your car.

Calibration

Determine whether Digi-Tach will be used with a 4-, 6-, or 8-cylinder car and jumper C4 to either pin 4 or pin 6 of U6 accordingly. (Pin 6 is used only for 4-cylinder cars, while pin 4 is used for both 6- and 8-cylinder cars.) Apply power, then set a stable audio-frequency generator to about 60 Hz (sinewave or squarewave) at maximum output and connect it to the pickup wire. If you get any kind of a steady display that varies only when the frequency is changed, then set the generator to a frequency that should equal 5000 *rpm*, and adjust R5 until the display shows "5.0." Note, 166.66 Hz = 5000 *rpm* on a 4-cylinder engine, 250.0 Hz = 5000 *rpm* on a 6-cylinder engine, and 333.33 Hz = 5000 *rpm* on an 8-cylinder engine. Use a frequency counter, if available, to get the most accurate calibration by setting the main oscillator to either 424 Hz or 320 Hz on pin 11 of U6, or by accurately measuring the audio frequency used to calibrate the tach.

If the signal generator doesn't have the power to drive U1, check to make sure that there aren't any circuit problems causing that, then remove U1 from its socket. Next insert a 10,000-ohm resistor into pin 5 of U1's socket, turn the generator's output to minimum and connect it to the free end of the resistor. Slowly increase the generator's output to somewhat above where the display has a steady reading, and adjust R5 until the display shows the proper *rpm*. Remove the 10,000-ohm resistor and replace U1.

Installation

Installation of Digi-Tach is a matter of personal preference and convenience, but mount it where it's easily viewed and doesn't interfere with your driving. The power lead should go to a terminal on the fuse block that is powered only when the ignition is on. Better yet, include a ½-amp fuse in series with the Digi-Tach's power lead. Route the ground lead via the shortest path to a good chassis ground and make a proper connection.

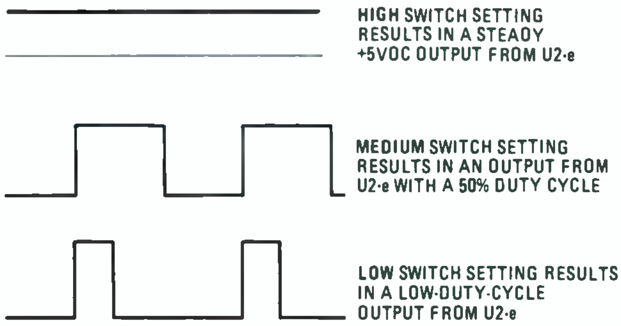


FIG. 3—A FRONT-PANEL SWITCH allows the brightness of the display to vary. These waveforms, which are output by U2-e and fed to the blanking input of the display drivers, are used to set that brightness. The waveform in *a* is the output when the brightness switch is in its HIGH position. The waveform in *b* is the output when the switch is in its MEDIUM position. The waveform in *c* is the output when the switch is in its LOW position.

The pickup wire should have a heavy, insulating jacket to protect it against abrasion and possible shorts to the car chassis. Avoid routing the ignition pickup wire near the radio since it may radiate some noise into the radio. The pickup wire should go to the ignition-coil terminal marked with a "–." That is the terminal that the car's points (part of the ignition system) connect to. Connect the pickup wire to the terminal through a 10-ohm resistor (R1 in Fig. 1) to isolate the terminal in case the pickup wire shorts to the chassis. Solder the resistor to the end of the wire, put sleeving over the resistor, and solder a spade lug to the other end of the resistor for connection to the coil. In the event that the wire shorts to the chassis, the resistor will safely burn open like a fuse. If you prefer, a 1/10-amperefuse could be used in place of R1.

Do not connect the pick-up lead to the heavy, high-voltage lead coming out of the top of the coil, or to the spark plugs. You shouldn't have any problems making Digi-Tach work if you have a conventional ignition system or a capacitive-discharge ignition system. Digi-Tach isn't intended for use on the newer "breakerless" and "high-energy" systems and may not work on them, however, with an inductive pickup coil and a few additional parts you could probably convert Digi-Tach to work on those types of ignition systems.

With proper usage, Digi-Tach should help improve the performance and gas mileage of your vehicle. ■

THE AUTHOR'S completed Digi-Tach was designed to match the interior style and color of his car. Dashboard mounting was used; however, the unit was so position that a sudden stop would not make it a hazzard to the driver. The front panel switch presets the light intensity of the display taking into account daylight and night-time driving.