BUILD A

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Digital Phototachometer

Low-cost unit measures rotational speeds by optical coupling.

MOST ANALOG and digital tachometers require a mechanical or electrical interface with a rotating shaft. By contrast, this project, a digital phototachometer, measures rpm by optical means. It features a two-digit LED readout to display rotational speeds from 100 to 9900 rpm and a time base derived from the 60-Hz ac line, obviating the need for calibration adjustments.

Stability of the time base is good enough so thet tach readings are accurate to the usual ±1-count uncertainty in the least significant digit. Modifications of the counting circuitry or sensing system can extend the measuring range one decade above 9900 or below 100 rpm, respectively. Total project cost is about $30.

Optical Sensing. As its name implies, the photo tach measures rpm by

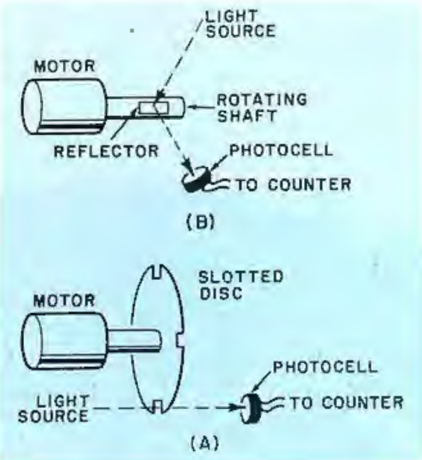


Fig. 1. Transmissive (A) or reflective (B) mode can be used to chop light for photosensor.

optical interaction with a rotating device. Measurements can be made by either of two basic means, which we'll call the transmissive and reflective modes. In the transmissive mode, the rotating device momentarily interrupts the optical path between a light source and a photosensor (Fig. 1A). This mode has limited usefulness. Although it's ideal for measuring the rotational speed of a fan or similar device, there are many situations in which it cannot be used. The transmissive mode requires a light chopper such as fan blades or a notched disc mounted on the motor shaft. If there isn't room enough to accommodate the chopper, this mode is impracticable.

The reflective mode is illustrated in Fig. 1B. A small strip of reflective tape is mounted on the motor shaft. If necessary, contrast can be increased by darkening the shaft background with black paint or tape. The light source and photo sensor are arranged so that light is reflected from the foil and toward the sensor as the shaft rotates.

About the Circuit. The schematic diagram of the phototach is shown in Fig. 2. Phototransistor *Q1*, the optical sensor, is connected to the rest of the project by a short length of shielded cable terminated with *P1*, an RCA phono plug. When *Q1* is illuminated by a chopped light beam, it alternately turns on and off. The resulting waveform at the collector of *Q1*, which approximates a square wave when the light beam is sharply chopped, is coupled by *C1* to *IC1*, a comparator used as a Schmitt trigger. Feedback provided by *R6* establishes the hysteresis that is characteristic of Schmitt trigger behavior.

Resistors *R2* through *R5* are close-tolerance components that maintain nearly equal biasing on the inverting and noninverting inputs of *IC1*. The output of the Schmitt trigger is a square wave compatible with the TTL integrated circuits forming a two-decade frequency counter.

Output pulses from *IC1* are gated by flip-flop *IC2*. The control signal for *IC2* is the time-base waveform, which is generated from the 60-Hz line in the following manner. Transformer *T1* and diodes *D2* and *D3* form a full-wave rectifier which develops a 120-Hz output. Diode *D4* isolates the cathodes of *D2* and *D3* from filter capacitor *C5*. The full-wave rectified sinusoid at the cathodes of the rectifier diodes is coupled to the base of *Q2* by *R11*.

This transistor saturates so easily that it converts the input waveform into a square wave appearing at its collector. The 120-Hz square wave is applied to *IC6*, a TTL ÷12 counter. Output signals from *IC6* are applied to *IC7*, another ÷12 counter. The net result is a square wave with a 50% duty cycle and a 1.2-second period. This is the time base that controls the gating and counter IC's.

Flip-flop *IC2* performs the gating function in a synchronous manner so that no spurious pulses reach the counters as a result of the gating process itself. The K input of the flip-flop is permanently grounded. Its J input is driven by the time-base signal, and output pulses from Schmitt trigger *IC1* are applied to the clock input. During the 0.6-second interval when the time base is at logic 1, pulses from *IC1* are gated to counter *IC3*. When the time base returns to logic 0, no more pulses are passed to the counter circuit.

The two-decade counter and readout comprises *IC3*, *IC4*, and *LED* displays *DIS1* and *DIS2*. TTL 74143 counter chips are employed in this project. They contain BCD decade counters, latches, and decoder/drivers. Current limiting is built in, so that the chips can be directly connected to the DL-747 common-anode displays.

Counter *IC4* counts the overflow pulses of *IC3*. The negative transition of the time-base waveform, which appears at the end of the 0.6-second counting interval, triggers one half of *IC8*, a 74123 dual monostable multivibrator. A negative-going, 100-microsecond wide pulse appears at pin 12 of *IC8*. This strobe pulse causes the transfer of data from the counter outputs into the latches. When pin 12 of *IC8* returns to logic 1, the second one-shot in *IC8* is triggered. A second negative-going pulse is generated, this time at pin 4 of *IC8*, which clears counters *IC3* and *IC4*. When the time base returns to logic 1, pulses are gated to the counter to repeat the process.

If more than 99 pulses are applied to *IC3* and *IC4* during the counting interval, the BCD outputs of both counters return to 0000 and *IC5* catches the overflow pulse from *IC4* in the following manner. Assume that the clear pulse has just appeared. This pulse not only clears the counters, but resets one half of *IC5*, a 7474 dual D flip-flop, so that the Q output (pin 5) is at logic 0. When the time base returns to logic 1, *IC3* and *IC4* begin to count. If more than 99 pulses are received, a positive transition occurs at pin 22 of *IC4*. This pulse is applied to the clock input of the first D flip-flop, causing the Q output to go to logic one.

The strobe pulse at pin 12 of *IC8* clocks the second flip-flop in *IC5* after the counting interval is over. This flip-flop's D input is connected to the Q output of the other flip-flop in the *IC5* package. If the Q output (pin 5) is at logic one when the strobe pulse appears at the second flip-flop's clock input, a logic 0 appears at pin 8, the second flip-flop's $\overline{Q}$ output. This causes the decimal points on both displays to glow, indicating the overflow condition. The clear pulse then resets the first flip-flop, but the overflow information remains safely stored in the second flip-flop.

The power supply furnishes both a regulated dc voltage and, as mentioned earlier, a full-wave rectified sinusoid which is converted into the time-base waveform. Transformer *T1* and diodes *D2* and *D3* form a full-wave rectifier whose output is applied to switching transistor *Q2* and to filter capacitor *C5*. Diode *D4* isolates the signal driving the base of *Q2* from the filtering effect of *C5*. The stable +5 volts dc required by the TTL integrated circuits is provided by regulator *IC9*. Capacitors *C6* through *C9* shunt any noise on the +5-volt line to ground, and improve the IC regulator's transient response.

Construction of the photo tach is straightforward because circuit layout is not critical. Suitable pc etching and drilling and parts placement guides are shown in Fig. 3. Molex Soldercons or sockets can be used with the IC packages. Be sure to observe pin basing and polarity of all semiconductors and electrolytic capacitors. Mount regulator *IC9* on the project's metallic enclosure for

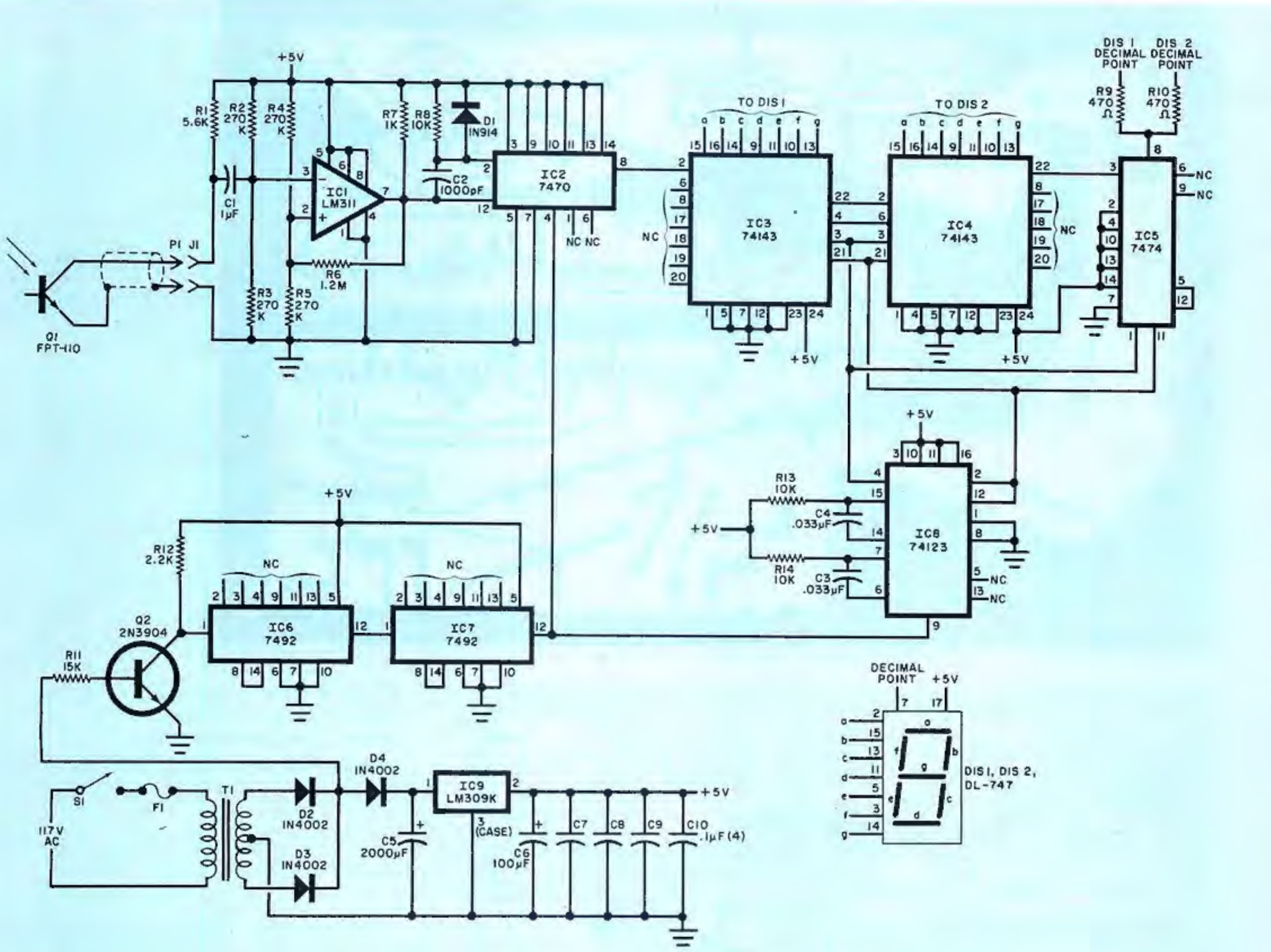


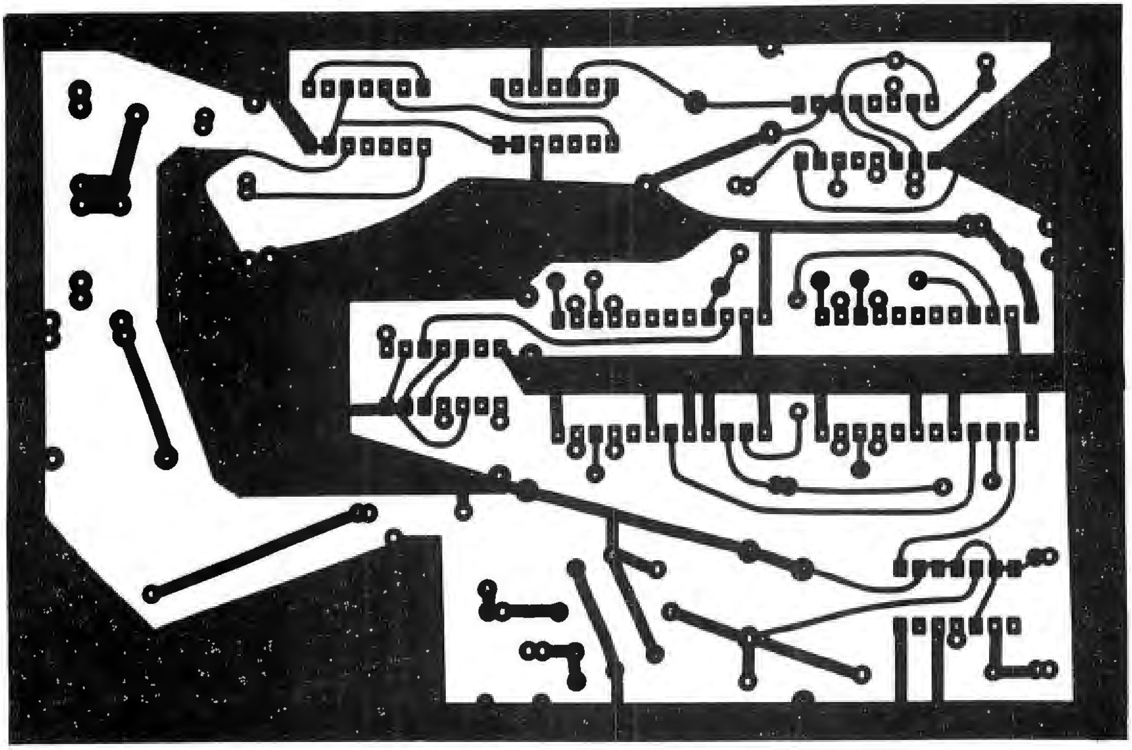
Fig. 2. Schematic diagram shows how pulses from sensor Q1 are squared up by IC1, gated by IC2, and counted by IC3 and IC4.

heat sinking. Spread a thin layer of silicone heat-sink compound on the bottom of the TO-3 can before mounting it. This will ensure a good thermal bond between the IC and the enclosure.

The seven-segment displays should be mounted on a small piece of perforated board installed upright inside the enclosure. Interconnect the displays and integrated circuits with short lengths of hookup wire. Insulated hookup wire should also be used for the eight jumpers on the pc board. The power transformer, switch, and phono jack fuseholder for *F1* are mounted off the board. A probe assembly must be fabricated to house transistor *Q1*. The plastic barrel of a spent ballpoint pen provides a good basis for the probe. Discard the point and exhausted ink tube. Then prepare the phototransistor by clipping its base lead (see Fig. 4). Remove 1" (2.54 cm) of the vinyl jacket from one end of a suitable length of RG-174-U or RG-58-U coaxial cable. Comb out the braid and

PARTS LIST

C1—1-μF Mylar capacitor
C2—1000-pF polystyrene
C3, C4—0.033-μF Mylar
C5—2000-μF, 35-volt electrolytic
C6—100-μF, 16-volt electrolytic
C7, C8, C9, C10—0.1-μF disc ceramic
D1—1N914 signal diode
D2, D3, D4—1N4002 rectifier diode
DIS1, DIS2—DL-747 common-anode, seven-segment LED display
F1—¼-ampere fuse
IC1—LM311 comparator
IC2—7470 J-K flip-flop
IC3, IC4—74143 decade counter/decoder/display driver
IC5—7474 dual-D flip-flop
IC6, IC7—7492 ÷12 counter
IC8—74123 dual monostable multivibrator
IC9—LM309K 5-volt regulator
J1—RCA phono jack
P1—RCA phono plug
Q1—FPT-110 phototransistor (Fairchild)
Q2—2N3904 npn silicon transistor
The following are ½-watt, carbon composition resistors with 10% tolerance unless specified otherwise:
R1—5600 ohms
R2 through R5—270,000 ohms, 5%
R6—1.2 megohms
R7—1000 ohms
R9, R10—470 ohms
R8, R13, R14—10,000 ohms
R11—15,000 ohms
R12—2200 ohms
S1—Spst switch
T1—16-volt center-tapped, 1-ampere transformer (Signal No. 241-5-16)
Misc.—Suitable enclosure, printed circuit board, hookup wire, RG-174-U or RG-58-U coaxial cable, solder, machine hardware, display bezel, etc.
Note—Phototransistor *Q1* is available (No. 22A21011-6) for $3.50 from Burstein-Applebee, 3199 Mercier, Kansas City, MO 64111. Decade counter/decoder/display drivers *IC3* and *IC4* are available for $3.25 (each IC), from James Electronics, 1021 Howard Avenue, San Carlos, CA 94070. Transformer T1 is available from Signal Transformer Co., 500 Bayview Avenue, Inwood, NY 11696 for $5.50. Postage and sales tax (if applicable) extra.



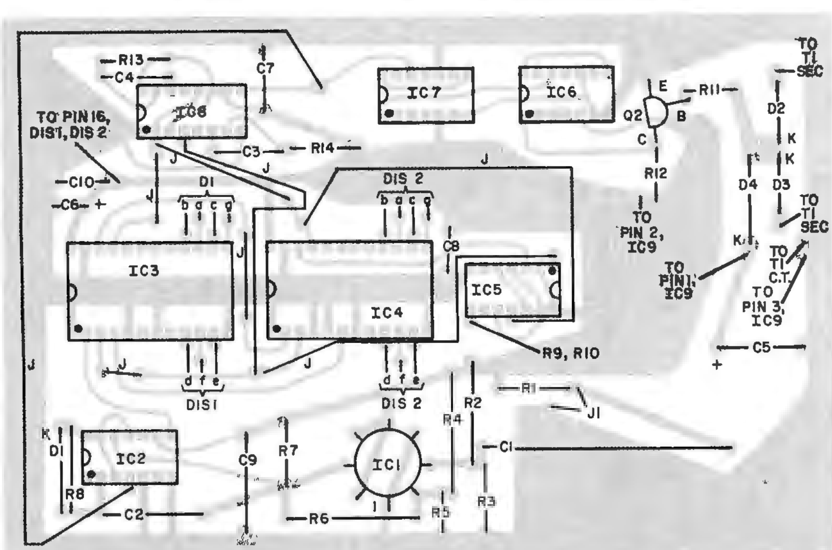


Fig. 3. Full-size etching and drilling guide for pc board is shown above with parts placement guide at left.

twist the strands together. Expose ¼" (6.3 mm) of the inner conductor. Tin the inner conductor and braid with a small amount of solder.

Feed the coax through the pen barrel until the prepared leads extend through the other end. Then attach the inner conductor to the collector of the phototransistor and the braid to the emitter. Pull the coax so that the phototransistor retracts into the barrel, stopping when the light-sensitive surface of *Q1* is recessed about 1" (2.54 cm). Cement or otherwise secure the phototransistor in place, and apply silicone glue where the coax leaves the barrel. Finally, terminate the free end of the cable with an RCA phono plug.

Checkout. No calibration of the photo tach is necessary. With *P1* (the phono plug at the end of the probe cable) removed from *J1*, apply power to the photo tach. Two digits may flash on, but will disappear in about a second. No input pulses are being received, and the outputs of the counters are 0000. Automatic ripple-blanking is built in to the IC counters, so the readouts are darkened and do not display "00."

Apply a 60-Hz, 2-volt p-p sine wave to *J1*. Use either a signal generator or the circuit shown in Fig. 5 as a test source. If the project is functioning properly, "36" will be displayed by the LED readouts. This corresponds to an input of 60 Hz or 3600 rpm.

The operation of the overflow indicator can be verified by either applying a 2-volt p-p sine wave at a frequency of 167 Hz or more, or by optically coupling the probe to an object rotating at 10,000 or more rpm. Both display decimal points will glow, indicating an overflow.

Extending the Range. The photo tach can be modified to measure rotational speeds greater than 9900 rpm by inserting another decade of counting and display between *IC3* and *IC4*. Sever the following connections: pin 22 of *IC3* to pin 2 of *IC4* and pin 4 of *IC3* to pin 6 of *IC4*. Pins 2 and 6 of the additional decade counter should be connected to pins 22 and 4 of *IC3*, respectively. Also, pins 22 and 4 of the additional decade counter should be connected to pins 2 and 6

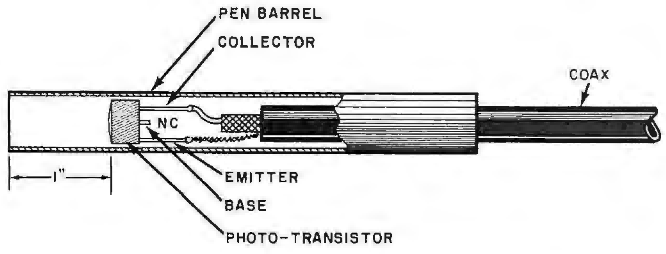


Fig. 4. To make probe, phototransistor is mounted in an old pen barrel and connected to a coaxial cable.

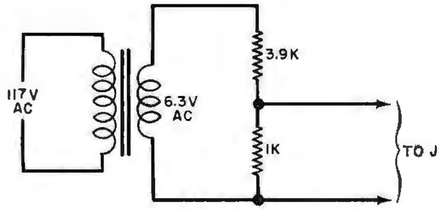


Fig. 5. Schematic diagram of a suitable test source to verify proper circuit operation.

of *IC4*, respectively. Of course, the new counter must be a 74143 IC, and it should be connected to an additional DL-747 display and to the positive supply and ground in the same manner as *IC3* and *IC4*. When this modification has been made, *IC3*'s count will represent hundreds of rpm, the newly installed counter thousands of rpm, and *IC4* tens of thousands. The project's power supply has enough reserve to handle the extra components' demand without any strain.

It is also possible to obtain resolution smaller than hundreds of rpm. If ten light pulses occur during each shaft resolution, the bit significance of each decade of the display is reduced by a factor of ten. Let's consider a specific example. To measure the speed of a slowly turning power drill, a circular disc of metal or plastic should be formed. Ten slots should be punched out at equal intervals along the perimeter and a hole drilled through the center of the disc. Then pass a bolt through the center hole, secure with a nut, and install the entire assembly in the drill's chuck. The rotational speed will then be measured using the transmissive mode and displayed in hundreds and tens of rpm. The addition of another decade of counting and display, as described earlier, can be combined with this multiple triggering technique to display thousands, hundreds, and tens of rpm.

Using the Tach. The optical mode used in a given situation will depend largely on practical considerations. In any event, avoid using fluorescent bulbs as light sources because they are strong electrical noise generators. Ordinary 75- or 100-watt frosted incandescent lamps are well suited for use with the photo tach, as is sunlight. Just remember, however, that if you're checking the speed of a four-blade fan, the actual rate of rotation is one-fourth of what is displayed by the readouts. ◇

Photo of author's prototype shows layout of components in chassis.