SKIP CAMPISI

BUILD A PORTABLE PULSE GENERATOR

Add this economical, easy-to-build instrument to your test bench, or carry it in your tool kit.

If you enjoy doing digital- or analog-circuit-design work, or if digital troubleshooting is one of your priorities, you will probably agree that a good, wide-range pulse generator would come in very handy. Commercial units are available, of course, but being in the range of several hundred dollars, the cost of a decent unit is prohibitive for many.

Most function generators have a pulse mode of operation that is created from their squarewave output by adjusting the duty cycle and DC offset. That function is limited to how fine of a duty-cycle adjustment you can make. For example, generating a one-microsecond pulse at a one-second repetition rate is practically impossible when using that method. Another problem is that the repetition rate is set by frequency rather than time period, making a mental calculation necessary for the correct time-period display. Further, most commercial pulse and function generators are line operated, making portability a problem.

The Portable Pulse Generator presented in this article has been designed to avoid those problems by using standard components that are readily available and quite affordable. The unit is powered by a single 9-volt battery, and for true portability has a time-period display. The device makes an excellent companion to the "D.I.Y. Function Generator," which appeared in the August, 1997 issue of **Electronics Now,** for generating any type of waveform.

The instrument is divided into two parts: the actual pulse generator itself and an analog time-period display. You have the option of constructing either section by itself—each can be a standalone project—or combining both parts into one unit. If you would like to include a duty-cycle display, you can add in the "Duty-Cycle Monitor" circuit described in the May 1997 issue of our sister publication, **Popular Electronics**.

How it Works. The pulse-generator section supplies 5-volt pulses that can range from 1 microsecond to 100 milliseconds. The time period (repetition rate) is independently adjustable bewteen 10 microseconds and 1 second. The pulse-width section and the time-period section each have their own five-position range switch and fine-adjust controls. The 5-volt amplitude of the pulses is only under no-load conditions.

A specially-designed output stage safely sources or sinks up to 100 milliamperes to or from the load. The output was designed without any form of short-circuit protection in order to achieve very high speeds. Output protection can be easily implemented; we'll show you how later. Typical rise and fall times for the output are about 25 nanoseconds, and either a positive- or negative-going pulse can be used. Direct interfacing to standard TTL or CMOS logic using 5-volt supplies is quite easy.

The time-period display section uses some unusual techniques to provide an analog display of either the period or pulse width. A 0–100 microampere analog panel meter provides the display, and simply indicates 0%–100% of the full-scale range selected. This section has its own individual range controls to cover 1.0 microsecond through 1.0 second with a typical accuracy of a couple of percent of full scale.

About the Circuit. The generator's circuit, shown in Fig. 1, is a simple, basic design. The circuit uses two ICs, four transistors, and a handful of passive components, all of which are commonly available.

The heart of the circuit is IC1, a TLC556 CMOS dual timer. That version of the timer is used because it is *much* faster than a standard bipolar 556 timer. The two independent timers in the one package are both needed for the Portable Pulse Generator. One timer section is set up as an astable multivibrator that supplies a basic squarewave. That squarewave sets the "period" function of the generator.

The overall period of the waveform is selected by S2 in five steps: 0.1, 1, 10, 100, and 1000 milliseconds. Fine adjustment is done with R4. That lets the period be continu-

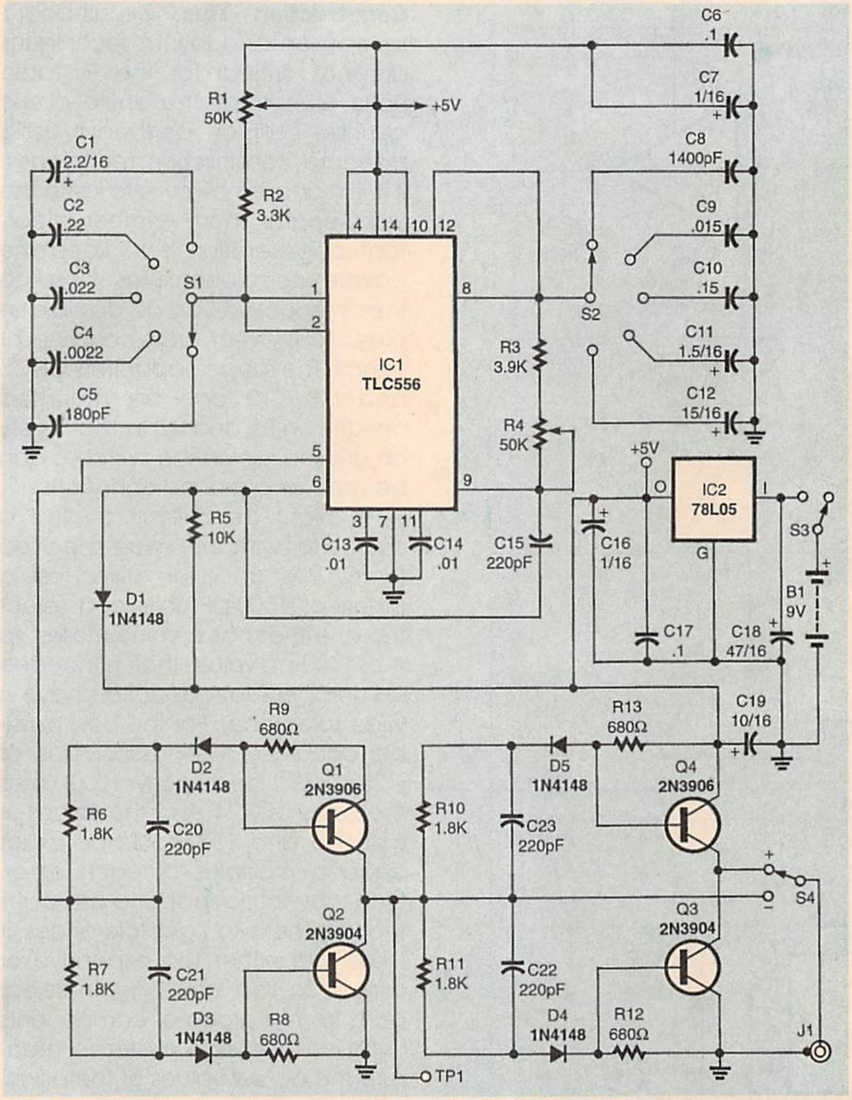

Fig. 1. The Portable Pulse Generator is built around a TLC556 dual CMOS timer chip. Very accurate results can be obtained with careful selection of the various timing components.

ously adjusted from 10% to 100% of the period selection. The output of that section (IC1, pin 9) is applied through C15 to the trigger input of the other section of IC1.

The second timer section of IC1 is configured as a monostable multivibrator. The signal from pin 9 through C15 to pin 6 triggers the pulse output at pin 5. The pulse at that output has a repetition rate set by the astable oscillator and a pulse width set by S1 and R1. The use of S1 is similar to S2 in that it sets the overall pulse width of the waveform in five steps: 0.01, 0.1, 1, 10, and 100 milliseconds. Similar to R4, R1 allows continuous adjustment of the pulse width from 10%–100% of the selected range. The final waveform is then applied to the output-driver section.

An inverter circuit made from Q1 and Q2 has a very fast rise time (less than 10 nanoseconds). A second identical inverter circuit is made from Q3 and Q4. Those two inverters let the final output be either a positive-going or a negative-going pulse. The polarity of the output pulse is selected with S4.

A standard coaxial cable that is less than 3 feet long and terminated with short-clip leads will make a good output cable when connected to J1. For more stringent applications, the output is quite capable of driving a 50-ohm terminated cable. That will be explored later.

A 78L05 5-volt regulator, IC2, is powered by B1, a standard 9-volt battery. That supply is quite suitable for normal operation. However, if you plan on driving heavy loads or 50-ohm lines, you should consider replacing B1 with a set of six series-connected AA cells. That arrangement will give you higher efficiency and less internal resistance. The on-off switch, S3, can be ganged with R1 in order to save space on the front panel.

About the Display. The input for the time-period display circuit, shown in Fig. 2, comes from TP1, the generator's inverting output from the collectors of Q1 and Q2. If you are building the display as a stand-alone instrument, the input needs a negative-going pulse of the proper width to be measured. The maximum positive voltage should be 5 volts with the minimum no higher than 100 millivolts.

The semiconductors were specially selected for this unusual, analog/digital hybrid-circuit design. CMOS ICs are used throughout to keep current drain to a minimum. Those type of integrated circuits are sensitive to electrostatic discharge (ESD) as is IC1. Analog-panel-meter display M1 can be any type of 0- to 100-microamp meter that you would like to use.

The input pulse coming from TP1 goes directly to IC3, a CD4013 CMOS dual flip-flop. The flip-flop is configured in its "toggle" mode. Either the output of IC3 or the original pulse width can be selected by S5. The selected pulse is applied to Q5, a 2N5117 dual matched-pair PNP transistor, which is configured as a high-speed, gated current mirror. That current-source "integrator" turns on when the pulse signal is low, charging C24 or C25. Whichever capacitor is charged is selected by S7-a, which determes whether the display will be in microseconds or milliseconds.

When the pulse goes high, the current source turns off and the voltage present on C24 or C25 represents the pulse width's integration period. At that point, one of IC4's one-shots is triggered. Its three-microsecond output turns on one of the analog switches in IC5. A "sample" of the voltage on C24 or C25 is sent to C27, a "hold" capacitor, through buffer amplifier IC6-a. The voltage held by C27 drives M1 through IC6-b. As soon as the sam-

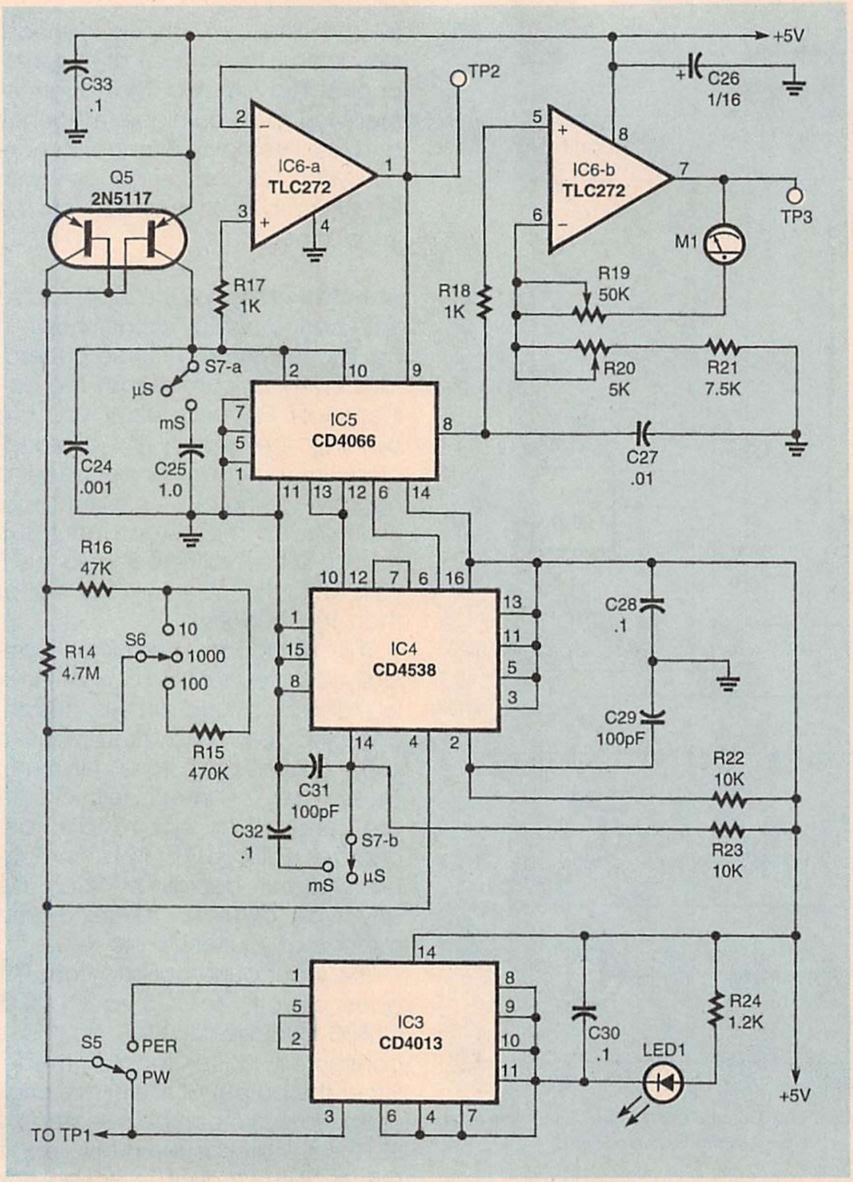

Fig. 2. The display portion of the Portable Pulse Generator is simple and accurate. It can be built as a part of the generator, or can be built as a stand-alone project.

ple is taken, the other half of IC4 is triggered, producing a reset pulse to two of the analog switches in IC5. Those switches, wired in parallel, discharge C24 or C25 rapidly, making the circuit ready for the next pulse. The reset pulse is three microseconds long when S7-b is in the microsecond position; it is one millisecond long when S7-b is in the millisecond position. That gives enough time for C24 or C25 to fully discharge.

Meter M1 is a part of the feedback loop for IC6-b, which converts the hold voltage from C27 to a current that drives the meter. With a 100-microamp display, the meter is read directly as a 0%–100% display of the full-scale range selected by S6 and S7. The meter is protected from over-range currents by R19, and R20 lets the meter be calibrated for precise displays.

The timing diagram in Fig. 3 shows how the display circuit works with the controls set to generate and measure a pulse train with a 15-microsecond period and a 5-microsecond pulse width. Those settings readily demonstrate the integration, sampling, and reset functions of the display circuit. With a dual-trace oscilloscope, the two waveforms can be seen by connecting the scope's probes to TP1 (the inverting-pulse waveform) and TP2 (the sampling waveform).

Construction Tips. Circuit-board fabrication and layout techniques are not critical for the Portable Pulse Generator. The entire circuit can be built on perfboard using standard construction techniques. It is important, however, to keep the lead lengths short. Another important consideration is to keep the passive components as close to their respective ICs as possible in order to prevent cross-coupling of signals. The range capacitors C1–C5 and C8–C12 can be mounted directly on S1 and S2. In that case, an unused lug on the switches can be used as a ground connection.

It might be difficult to find a capacitor with the value specified for C8. As an alternative, test a group of 1500-pF units and select the one that has a value closest to the 1400-pf value that is needed (remember that capacitors have a wide tolerance). For the best possible accuracy, the actual value of C25 should be exactly 1000 times the value of C24. Also, the values of R14, R15, and R16 should be exact decade multiples of each other. One way to do that is to use parts that are held to tight tolerances. If those are either too expensive or difficult to find, once again select parts from a group of components using an accurate meter to measure the actual values of the parts.

As there are many controls involved, designing the front panel might be difficult. If you wish, you may follow the layout of the author's unit as shown in Fig. 4 for a suggested front-panel layout. Many connections will need to be made between the PC board and the front-panel components, so good initial positioning will let the leads remain as short as possible.

A 2¼-inch by 4¼-inch by 7³/₈-inch plastic enclosure will hold everything with room-to-spare. A simple "tilt stand" can be made from a length of heavy-gauge coat-hanger wire and held in place with ¹/₈-inch plastic cable clamps on the bottom of the case.

Once the case has the controls mounted in it, and the board has been double-checked for wiring accuracy and proper component polarities, install the board on spacers in the case and connect all of

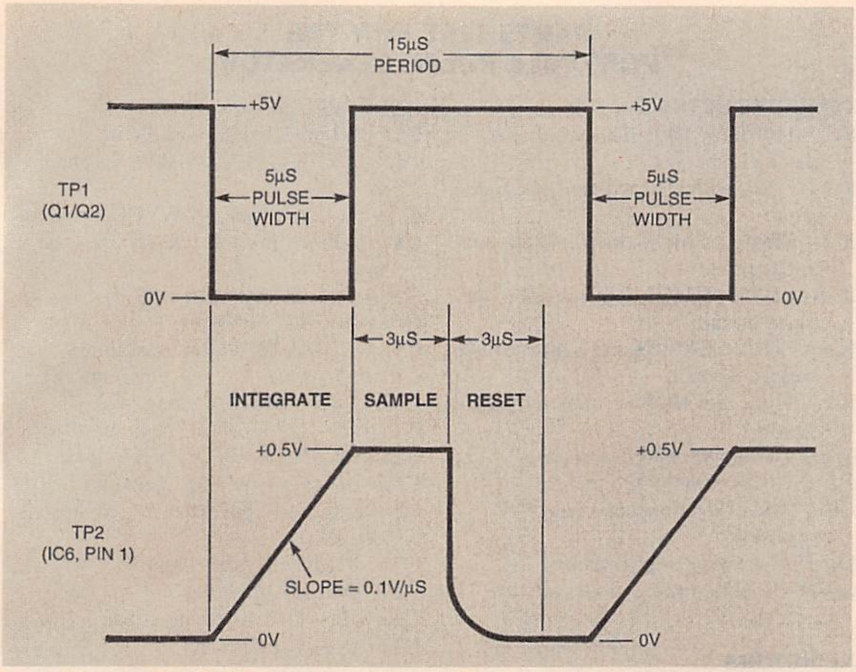

Fig. 3. When the Portable Pulse Generator is set to deliver a 5-microsecond pulse that repeats every 15 microseconds, the overall operation of the circuit can be seen on an oscilloscope.

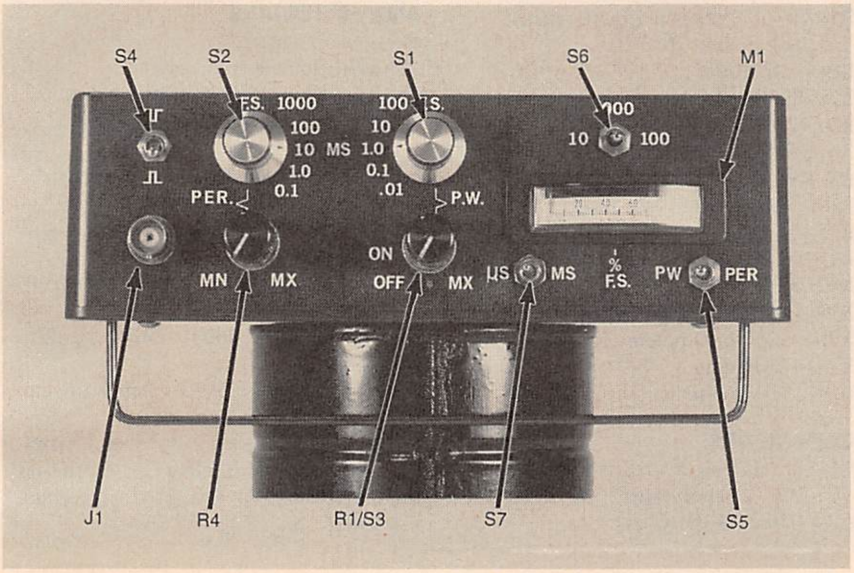

Fig. 4. As with any piece of test equipment, a simple and logical layout of the front-panel controls is a must. Here is the author's layout showing where the various controls were mounted.

the panel components to the board. Install a fresh battery in its holder, and the Portable Pulse Generator is ready for testing and calibration.

Setup and Calibration. Before turning on the power, set the front-panel controls as follows: S1 to 1 millisecond, R1 to its "off' position, S2 to 1 millisecond, and R4 to full clockwise. For the display portion of the circuit, S5 should be set to "PERIOD," S6 to "1000," and S7 to "microseconds." Set R19 and R20 on the board to their midpositions.

Connect an oscilloscope probe to TP1 and set the scope controls to display a 5-volt squarewave with a 1.0 millisecond period. Turn on power to the unit and advance Rl to its mid-rotation position. The oscilloscope should be showing a rectangular waveform with a one-millisecond time period. The squarewave's amplitude should be 5 volts. If no waveform is present, check pin 9 of IC1. If the squarewave is present at that location, double the value of C15 and check TP1 again. If necessary, C15 may be increased to about 600 pF before the overall performance of the circuit starts to fall off. If, on the other hand, there is no waveform present at pin 9, check for any wiring errors or replace IC1.

With the oscilloscope probe on TP1, adjust R4 for an exact one-millisecond time period. Now set S6 to 100 microseconds. That will put M1 in an overload condition. Rotate R19 back and forth until Ml reads somewhere on scale. Advance R19 so that Ml's pointer needle "pegs" gently against its full-scale stop. That setting will prevent M1 from seeing any high-current overloads by forcing IC6-b's output to operate near its maximum positive value. Set S6 back to 1000, and adjust R20 so that M1 displays exactly 100% (100 microamperes). As R19 and R20 might interact, recheck both of those last adjustments and readjust as necessary for best results.

Leaving S6 set at 1000, set S1 to 0.1 millisecond. Adjust R4 for a waveform time-period display on the oscilloscope of exactly 100 microseconds. The reading on M1 should now be 10% (10 microamperes). If not, there is an offset-voltage error in the meter. It is easily corrected by changing the *mechanical* setting of M1 for a 10% reading. If you make that adjustment, it will then be necessary to start the display calibration over again.

Now we will set the Portable Pulse Generator to create the waveforms shown in Fig. 3 to see how well the unit is working. Set the front-panel controls as follows: Sl to "0.01 milliseconds," R1 to midrotation, S2 to "0.1 milliseconds," R4 to midrotation, S5 to "pulse width", S6 to "10," and S7 to "microseconds". Adjust R1 for a display of 50% on M1, which indicates a pulse width of 5 microseconds. Set S5 to "PERIOD" and S6 to "100." Adjust R4 to display 15% on M1 for a time period of 15 microseconds. In order to obtain correct measurements, always set the generator controls for a longer time period than the desired pulse width *before* attempting any measurements!

With the oscilloscope attached to TP1, the waveform should be the same as Fig. 3. You should see a nice negative-going pulse 5 microseconds wide that repeats every 15 microseconds. Set S5 to "PULSE WIDTH" and attach the oscilloscope probe to TP2 (pin 1 of IC6). You will now be able to see the entire integrate/sample/reset waveform sequence.

Examine the waveform at TP3, located at pin 7 of IC6. You should see a perfectly straight, horizontal line that represents the DC-output voltage. There might be some small "glitches" occurring at the points where the circuit switches on or off. If the line has a ramp-like appearance, IC5 might be too "leaky." Most accuracy problems can be solved by replacing IC5 with a good unit.

Using a standard, good-quality coaxial cable such as RG-58 or RC-174 with a BNC connector at each end, connect J1 directly to the oscilloscope. The cable should be less than 3 feet in length for best results. The 15-microsecond waveform should be seen. Switching S4 back and forth will change the polarity of the pulse. With a high-quality, high-speed scope, you can also see the very fast (about 25 nanoseconds) rise and fall times of the pulse. Rotate R1 and R4 back and forth to see that there is a linear change in time period and pulse width.

Going Further. As we said before, short-circuit protection is easy to add to the output-driver stage of the Portable Pulse Generator. One possible method is to install resistors of about 22 ohms each in series with the emitters of Q1–Q5. A simpler method is to install a second output jack that is connected to J1 with a 100-ohm resistor between the center terminals of both jacks. The second jack can be used as a protected output, with J1 remaining as a direct output. Of course, peak output-pulse voltage will drop accordingly by using those methods.

A standard coaxial cable will provide an excellent output signal from the Portable Pulse Generator—even without impedance matching. From a practical point of view, most applications only need a pair of standard clip leads that have been connected to either a BNC connector or a dual-binding-post adapter. However, if you require the ultimate in impedance matching to your load, the additional output jack mentioned before can be used once again.

Keeping in mind the power supply requirements and the load that will be driven by the Portable Pulse Generator's battery, select the cable impedance that will be needed to drive the output load. Select an appropriate jack for the additional output jack—a BNC female jack for 50-ohm lines; a female "F" jack for 75-ohm lines; etc. Then connect the proper source resistor (50 ohms, 75 ohms, etc.) between the center conductors of J1 and the new output jack. Connect the proper cable between the new output jack and the load, and terminate the cable at the load with the proper (50 ohm, 75 ohm, etc.) terminating resistor.

You can also use a 300-ohm line with a standard 300-ohm "twin-lead" cable and 300-ohm source and terminating resistors. The jack on the generator can be a standard RCA phono jack, with clips on the other end of the twin-lead wire. The generator's 9-volt battery is enough to drive that type of load. But keep in mind that, when using terminated lines, the peak voltage to the load will be only 50% of the output voltage at J1!

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PARTS LIST FOR THE PORTABLE PULSE GENERATOR

SEMICONDUCTORS

IC1—TLC556 CMOS dual timer, integrated circuit
IC2—78L05 voltage regulator, integrated circuit
IC3—CD4013 CMOS dual flip-flop, integrated circuit
IC4—CD4538 CMOS dual one-shot, integrated circuit
IC5—CD4066 CMOS quad analog switch, integrated circuit
IC6—TLC272 CMOS op-amp, integrated circuit
Q1, Q4—2N3906 PNP transistor
Q2, Q3—2N3904 NPN transistor
Q5—2N5117 dual matched-pair PNP transistor
D1–D5—1N4148 silicon diode
LED1—Light-emitting diode, red, low-current

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1, R4—50,000-ohm potentiometer, panel- mount
R2—3300-ohm
R3—3900-ohm
R5, R22, R23—10,000-ohm
R6, R7, R10, R11—1800-ohm
R8, R9, R12, R13—680-ohm
R14—4.7-megohm (see text)
R15—470,000-ohm (see text)
R16—47,000-ohm (see text)
R17, R18—1000-ohm
R19—50,000-ohm potentiometer
R20—5000-ohm potentiometer
R21—7500-ohm
R24—1200-ohm

CAPACITORS

C1—2.2-µF, 16-WVDC, tantalum
C2—0.22-µF, polyester
C3—0.022-µF, polyester
C4—0.0022-µF, polyester
C5—180-pF, mica or polystyrene
C6, C17, C28, C30, C33—0.1-µF, ceramic-disk
C7, C16, C26—1-µF, 16-WVDC, tantalum
C8—1400-pF, mica or polystyrene (see text)
C9—0.015-µF, polyester
C10—0.15-µF, polyester
C11—1.5-µF, 16-WVDC, tantalum
C12—15-µF, 16-WVDC, tantalum
C13, C14—0.01-µF, ceramic-disk
C15, C20–C23—220-pF, ceramic-disk
C18—47-µF, 16-WVDC, electrolytic
C19—10-µF, 16-WVDC, tantalum
C24—0.001-µF, polyester or polystyrene (see text)
C25—1-µF, polyester (see text)
C27—0.01-µF polyester
C29, C31—100-pF, ceramic-disk
C32—0.1-µF, polyester

ADDITIONAL PARTS AND MATERIALS

B1—9-volt battery
J1—BNC female connector
M1—0–100-µA panel meter, analog
S1, S2—Rotary switch, single-pole, 5-position
S3— Single-pole, single-throw switch, integral to R1 (see text)
S4, S5—Single-pole, double-throw, toggle switch
S6—Single-pole, double-throw, center-off, toggle switch
S7—Double-pole, double-throw, toggle switch
Case, spacers, wire, solder, hardware, etc.

Note: One suggested source of hard-to-find components, including Q5, is: Johnson Shop Products, P.O. Box 2843, Cupertino, CA 95015; Tel: (408) 257-8614.

PULSE GENERATOR

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Another point to consider when driving heavy loads is the accuracy of the measurement system. The input signal for the display comes from the inverting driver output (TP1); certain conditions might introduce errors. All measurements in the "PERIOD" mode or any measurements made with the load driven with the non-inverting (positive-going) driver output will, however, be accurate. When driving a heavy load with the inverting (negative-going) output, a "PULSE WIDTH" measurement might be inaccurate or non-existent. That is due to the fact that the voltage swing from TP1 might not be enough to turn Q5 completely on or off with a heavy load pulling TP1 further away from the supply rails. The answer in that case, of course, is to make the measurement *before* applying the load!

Since the Portable Pulse Generator runs on a 5-volt supply, it can drive standard 5-volt TTL or CMOS logic directly. It is possible to also drive the newer 3-volt logic systems. In that case, simply use one of the balanced-impedance, terminated cable methods mentioned earlier. That will supply a 2½-volt (maximum) pulse to the load.

As mentioned previously, the author's "Duty Cycle monitor" can be used with this project. In fact, the duty-cycle monitor circuit can be installed and wired to the Portable Pulse Generator, sharing the same display meter and power supply. If that is done, the duty-cycle monitor's input protection circuit will not be needed.

As you can see, the Portable Pulse Generator is a versatile and accurate instrument. It is simple to use and easy to construct, making it a great addition to your bench. Ω