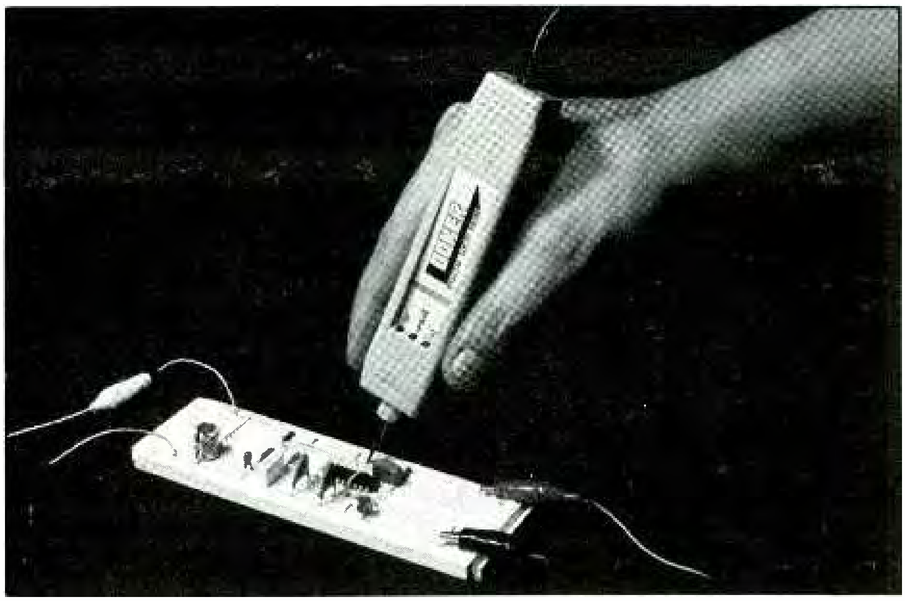
The Looker

A low-cost digital logic probe you build

By J. Daniel Gifford



Though everyone regularly acknowledges that a digital logic probe is a very useful tool to have around any electronics bench, many people still don't own one. This is surprising since a logic probe offers a fast, powerful way to check out digital circuits and devices with easy-to-use go/no-go indicators.

If you don't yet have a logic probe, here is a low-cost project that will give you a good taste of what it can do for you in tracing digital circuits and isolating defects. I call this probe the "Looker" because it lets you "look into" a circuit.

When completed, this probe offers good, professional performance. It uses the universal 30%/70% thresholds, has a high 2-megohm input impedance, 3.5-to-16-volt supply range, and low standby current of about 1.5 mA at 15 V. It easily handles multi-family logic, such as CMOS and TTL devices. If the probe has any shortcomings it is in its limited input-frequency response, which is up to 800 Hz. Also, the shortest pulse handled is 300 ns. However, a simple design option extends these specifications, though trading away other advantages.

The finished probe shouldn't cost you more than $20 and could cost much less. At the higher price there's a probe case kit available.

Circuit Description

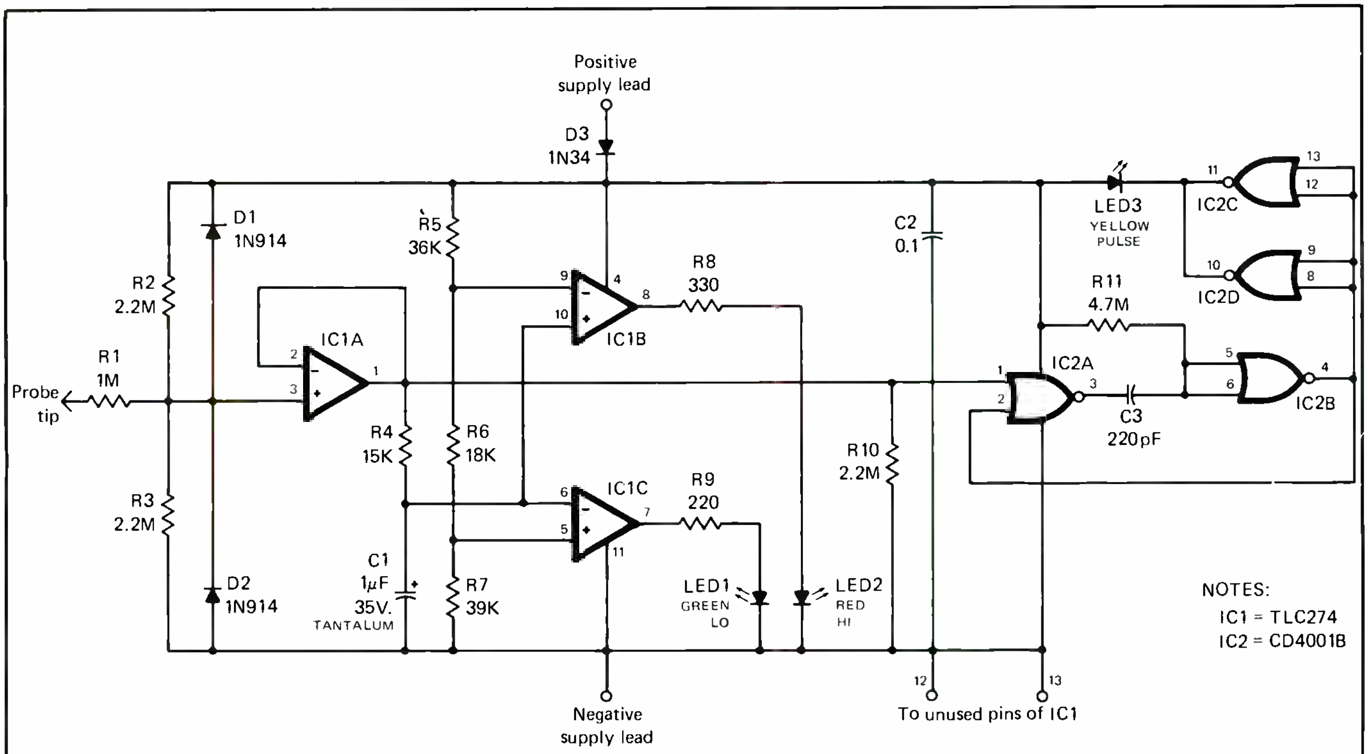
At the heart of the Looker (Fig. 1) are two ICs, a TLC274 quad CMOS operational amplifier (*IC1*) and a CD4001B quad CMOS NOR gate (*IC2*). Though the TLC274 is a pin-for-pin replacement for the common LM234 quad op amp, it offers vastly improved performance, most notably very low supply current and very high input impedance (10^{12} ohms).

Only three of the four op amps in the TLC274 are used. The fourth must be disabled by tying its inputs to ground. The first op amp, *IC1A*, is used as a voltage follower to decouple the input from the rest of the probe circuit. The output of *IC1A* is always equal, within a few millivolts, to the input voltage. Resistors *R2* and *R3* bias the input at about 50% of the supply voltage when no signal is applied to the probe tip. Diodes *D1* and *D2* protect the input against over- and under-voltages, and resistor *R1* limits input current to a safe level.

The other two op amps in *IC1* are used as an offset comparator string, with the inverting (−) inputs of *IC1B* connected to the junctions between *R5* and *R6* and of *IC1C* to the junction between *R6* and *R7*. The values of *R5, R6* and *R7* were chosen so that comparator *IC1B* switches on when input voltage rises past 70% of supply voltage, and comparator *IC1C* switches on when input voltage drops below 30% of the supply. HI/LO visual indication is provided by *LED2* (red), driven by *IC1B,* and *LED1* (green), driven by *IC1C.*

A low-pass filter, composed of *R4* and *C1,* deliver the switching signal from the output of *IC1A* to the inverting inputs of *IC1B* and *IC1C.* The filter keeps the HI and LO LEDs from flashing or lighting up at input frequencies beyond about 15 Hz.

To detect fast pulses that might not



PARTS LIST

Semiconductors

D1,D2—1N914 or 1N4148 signal diode
D3—1N34A germanium signal diode
IC1—TLC274 quad CMOS op amp (Radio Shack No. 276-1750) or TL084 quad JFET op amp (Radio Shack No. 276-1714) or LM324 quad op amp (Radio Shack No. 276-1711) (see text)
IC2—CD4001B quad CMOS NOR gate
LED1 thru LED3—T-1 light-emitting diode (one each red, green, yellow/amber)

Capacitors

C1—1-µF, 35-volt dipped tantalum
C2—0.1-µF, 50-volt Mylar
C3—2200-pF, 50-volt Mylar

Resistors (¼-watt, 5% carbon-film)

R1—1 megohm (or 100,000 ohms; see text)
R2,R3,R10—2.2 megohms
R4—15,000 ohms
R5—36,000 ohms
R6—18,000 ohms (or 47,000 ohms; see text)
R7—39,000 ohms
R8—220 ohms
R9—330 ohms
R11—4.7 megohms

Miscellaneous

Global Specialties No. CTP-1 probe case kit with perforated board and test leads/clips (available from Global dealers locally or from some mail-order houses); printed-circuit or perforated board and solder posts; gold-contact, low-profile 14-pin DIP IC sockets (2); one red, one black alligator test clips with attached leads; rubber cement; ¾"-wide clear tape or clear spray acrylic; hookup wire; solder; etc.

Fig. 1. Note in this overall schematic diagram of the Looker digital logic probe that only three of the four operational amplifiers in IC1 *are used. The fourth op amp is disabled by having its inputs grounded. Also,* IC2C *and* IC2D *are tied together in parallel to form a high-current buffer/driver for* LED3.

otherwise be captured by the Looker, the circuit also contains a pulse stretcher consisting of *IC2* and PULSE indicator *LED3* (yellow). Two of the NOR gates (*IC2A* and *IC2B*) are used as a positive edge-triggered monostable multivibrator with an output period of about 0.01 second. The other two gates are wired together as a high current buffer/driver, with their inputs connected to the monostable's output and their outputs driving *LED3*. The input of the monostable is connected directly to the output of *IC1A*. A brief positive or negative pulse at the probe tip will cause *LED3* to flash, while a pulse train at the input will continually retrigger the monostable and hold *LED3* on at a steady brightness.

Like all logic probes, the Looker is powered by the circuit it is testing via a cable terminated in a pair of alligator clips. Diode *D3* is inserted into the

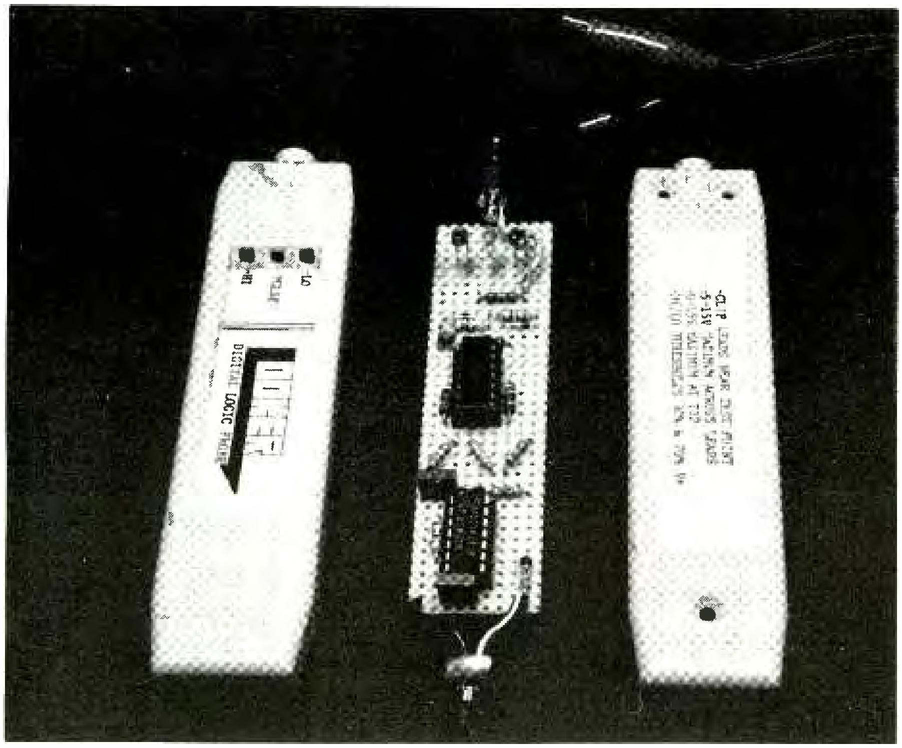


Fig. 2. Shown here is the probe case kit described in the text. Note the threaded removable tip; replacement and specialty tips are available.

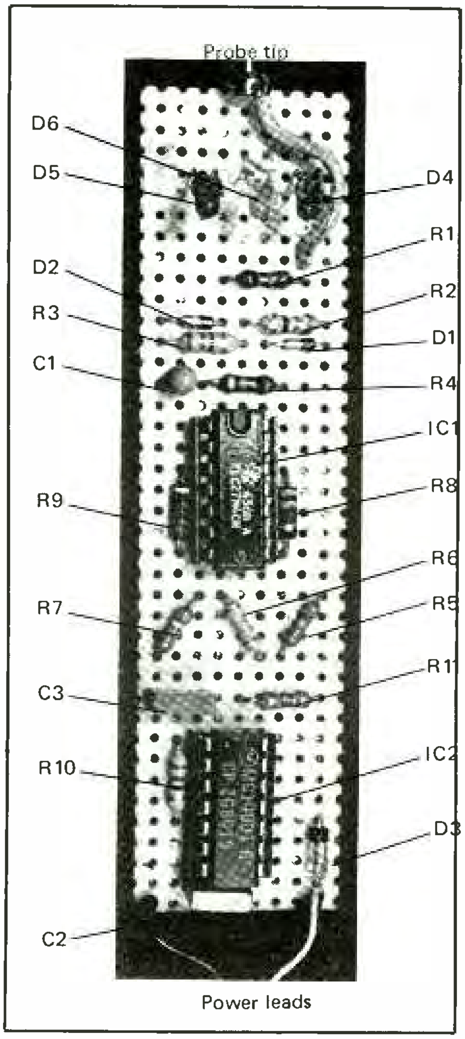


Fig. 3. This is the recommended layout for the parts on the perforated board supplied with the probe case kit. Note the unusual mounting of the LEDs. Use sockets for the ICs.

positive supply lead to protect the probe against damage from reversed connections. A germanium diode is used here, rather than a silicon diode, because of its lower voltage drop—0.3 vs. 0.7 volt for silicon. The lower voltage drop means less interference with the probe's thresholds at lower supply voltages. (The *R5/R6/R7* resistor divider string is also offset upwards slightly to compensate for the unavoidable drop across *D3* and to give true 30%/70% thresholds.) Capacitor *C2* filters out transients and stray frequencies that may interfere with the Looker's operation.

Construction

For a professional appearance, as well as comfortable handling, the Looker is best built into a molded-plastic housing designed specifically for probes. In this case, the No. CTP-1, logic probe kit from Global Specialties is ideal (Fig. 2). The kit is composed of the two shell halves, perfboard, tip holder and tip (replacement tips are available), LED support and lead set with preattached clips and molded strain relief. If you make your own case, follow the general layout shown in the photos.

As mentioned earlier, with only one design change you can extend the Looker's frequency range to about 3.5 MHz, pulse sensing to about 100 ns, and voltage range to 18 volts. You do this by replacing the CMOS TLC274 with a pin-for-pin-compatible JFET-input TL084. However, there's a penalty to be paid. The TL084 will cause the Looker to draw more standby current (about 10 mA at 15 volts). More importantly, it will not permit full operation when connected to a power source that delivers less than 6 volts.

The TL084 version will indicate HI logic levels as well as frequencies and pulses at the 5-volt level, but because the JFET voltage follower cannot swing its output below the LO threshold at 5 volts, it cannot indicate LO logic levels correctly. If you're willing to accept these shortcomings to obtain a greatly extended frequency range, the TL084 version may be the better choice.

A second design option, suitable only for very-low-performance use, is to use the original LM324 quad op amp in place of the TLC274. The

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LM324 will operate from 5 to 18 volts, but has a very-low input impedance and a maximum frequency response under 50 kHz.

If either the TL084 or LM324 are used, the values of *R1* and *R6* must be changed to 100,000 and 47,000 ohms, respectively. No other changes are necessary, and all three devices have identical pinouts.

Since space on the kit's perfboard is limited, it's necessary that you carefully follow the layout shown in Fig. 3. Use low-profile gold-contact sockets for the two ICs. Sockets will allow you to exchange ICs easily in the event you change your mind about the op amp you wish to use.

All resistors are ¼-watt, 5% tolerance carbon-film types—avoid carbon-composition devices here. Tantalum and Mylar are specified for the capacitors, as much for their small size as for their performance characteristics. Other types can be substituted for *C1* and *C2*, space permitting, but only a Mylar or polystyrene capacitor should be used for timing capacitor *C3*.

Connections from the probe tip holder to *R1*, *R1* to the voltage follower input, and the voltage follower output to the input of *IC2A* at pin 1 should be at least 22-gauge wire to ensure a low-impedance path for high frequencies. The supply bus wires should also be at least 22 gauge, but the rest of the connections are not critical and may even be made with wire wrap.

One tricky part of building the Looker is properly positioning the three LEDs. They must be raised above the perfboard and angled to fit into the three holes in the top half of the case. The kit includes a support that was useful for aligning the LEDs but was discarded from the prototype as it tended to interfere with assembly of the two case halves.

The only other tricky part of building the Looker is properly applying the two case labels shown in Fig. 4.

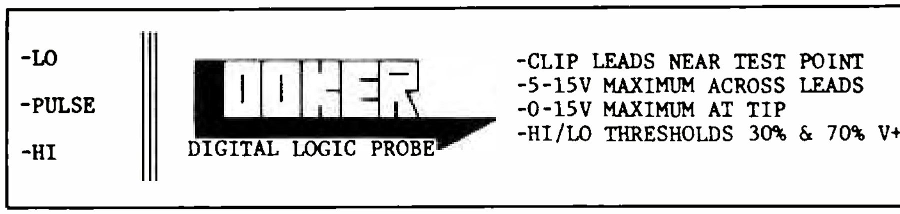

Fig. 4. These are actual-size labels for the Looker's case. The left label goes on the top of the case, with the LO, PULSE *and* HI *legends aligned with the LEDs. The right label goes on the bottom of the case. Photocopy both labels and protect them with clear tape or several coats of acrylic.*

These can be cut from the page or photocopied on a good-quality plain-paper copier and cut from the copier sheet. (The copier method is recommended, since there will be no bleed-through from backside images, lets you use color bond paper, and allows room for mistakes).

Use either rubber cement or a artist's stick adhesive (Glue Stic, UHU, etc.) to fix the labels in place. Also, to protect the labels from smearing and/or wearing away, it's a very good idea to cover them with a strip of ¾″ *clear* tape or spray several thin coats of clear acrylic over them.

Using the Probe

The Looker can be used to test any circuit or device with a minimum supply of 3.5 volts (6 volts for the TL084; 5 volts with the LM324) and a maximum supply of 16 volts (18 volts with the other two ICs.) Since the Looker is partly or wholly CMOS, performance varies with the supply voltage (one of CMOS's quirks). For this reason, the Looker will respond to a maximum frequency of 800 kHz at 15 volts, 500 kHz at 10 volts, and 150 kHz at 5 volts. Pulse sensing is correspondingly voltage related, but the HI and LO indicators operate the same regardless of supply voltage.

The Looker can be used to test almost any logic family, including regular and LS TTL, CMOS, NMOS and even PMOS and ECL, if the supply voltage is within range of the probe. With regard to the last, it is important that you first use a voltmeter to measure the supply voltage of the circuit to be tested to make certain that it is within the supply range of the probe. Be especially alert for negative voltages; application of a voltage that is lower than the probe's supply ground can damage the instrument.

Once the supply voltage is determined to be safe, connect the probe's power leads to the most positive and most negative supply rails in the circuit being tested. Unless unavoidable, the power leads should not be more than about 6″ from the test area. If necessary, a pair of mini-hooks, such as Radio Shack's No. 270-334, can be added to the alligator clips to facilitate hookup on crowded circuit boards.

Before touching the probe tip to any test point, touch it briefly to the two supply clips to confirm proper operation. You should obtain a HI indication from the positive clip, a LO from the negative clip. If you obtain neither indication, you have a bad or reversed connection. This test should always be repeated each time the clips are moved; it takes only a moment and it may save you from damaging the probe, the circuit or both.

Once the probe is connected and tested, all you need do is touch the tip to any point in the circuit to see what's happening there. Be careful to avoid shorting together IC pins and other closely spaced component leads. Most probes, like the Looker, have very high input impedance and will disturb the circuit under test only minimally, if at all.

Although you can't determine frequency with a logic probe, you can trace a waveform through a circuit to see where it goes, disappears or goes awry. A common indication is to have the probe indicate all HI or all LO conditions for every point in a circuit or pins on an IC. This means that the circuit or IC is lacking a ground or positive supply voltage.

There are seven basic responses a probe can give. With a schematic diagram or other documentation and a little practice, you'll soon learn to interpret them:

(1) *No indication at all*—the point being tested is dead or is at a voltage level between the two thresholds (see 7 below).

(2) *Steady* HI *indication*—the point under test is at a voltage level greater than 70% of the supply (logic-1 for most circuits).

(3) *Steady* LO *indication*—the point under test is at a voltage level less than 30% of the supply (logic-0 for most circuits).

(4) *Steady* HI *with flashing* PULSE *indication*—the presence of a negative pulse or pulses at that point.

(5) *Steady* LO *with flashing* PULSE *indication*—the presence of a positive pulse or pulses at that point. [Note: The probe point must be held firmly against the test point to eliminate the chance of false pulse indications. Many probes—including the Looker—may flash the PULSE indicator when the tip is touched to or removed from the test point.]

(6) *Steady* PULSE *indication*—the presence of a frequency between 0 Hz and maximum range of the probe at that point. The presence of a steady HI or LO simultaneously may mean a frequency that's slightly out of range for the probe, a frequency with a strong dc component, a very high or very low duty cycle, or a waveform with its amplitude biased toward one end of the supply.

(7) *Flickering* PULSE *indication*—may indicate a frequency that's out of range of a voltage that's between the thesholds. This shouldn't be interpreted as a valid state. Use a voltmeter or frequency counter to check.

Conclusions

If you've never used a logic probe before, you will be surprised how quickly and easily it can give a comprehensive look at the operation of a digital circuit. With a schematic diagram or a timing chart of a circuit and a logic pulser for signal injection, you will find that a logic probe is particularly useful in design/experiment work as well as for troubleshooting.