Logic Probes

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Introduction

A logic probe is a hand-held electrical measuring device used to used to determine the electrical logic state of a node in a circuit. It's a high-impedance voltmeter that will indicate whether the node's state is low (less than 0.8 V), high (greater than 2 V), or open circuit (these levels are for TTL, CMOS levels will be different). Some models will show you if the node is oscillating, stretch short pulses into time intervals you can see, or latch on transitions to another state. They can be useful tools for troubleshooting electrical circuitry.

The logic probe was invented in the late 1960's. The voltage levels of digital logic became standardized and, thus, only three states (low, high, and open) needed to be understood for understanding much of a digital circuit's behavior *[gg]*.

In this document, I wanted to discuss some of the things I've done with a logic probe, then look at the characteristics of the logic probes I own. The behaviors given are what I've seen with the probes I have; don't assume that all probes of that particular model behave the way I've described.

Disclaimer: I'm an electrical hobbyist, not an electrical engineer. Some of this document's statements may be wrong, incomplete, or unsafe. This document is intended for informational use only. Unless you are experienced with electrical work, I recommend you do not work with voltages over about ±35 V peak -- and you still need to be careful, as even these voltages can be lethal.

For alternating electrical signals, RMS values are meant unless otherwise given. DMM is an acronym for digital multimeter. When I discuss things like AC line voltage, I specifically mean the typical 120 V RMS line voltage seen in US houses.

"Blink" means a logic probe has detected a pulse (a state transition). To indicate a pulse, some logic probes blink their indicator light and others flash an LED labeled "pulse".

Product prices at time of introduction have been converted to today's approximate equivalent cost using inflation. See [*cpi*] for details.

Examples of logic probe use

See *[hpj1976]* for other examples of things a logic probe can do.

Logic probe setup

Usually the logic probe's power leads are connected to the DC supply of the digital circuit being tested. Since it's easy to accidentally connect things backwards, a decent logic probe is protected against reverse power supply connections. You'll want to pay attention to the specifications of the logic probe and not connect it to a voltage beyond its specified range, as this can lead to quick destruction of the probe. The probes I've used are protected up to 20 V to 25 V.

Turn the equipment off that you'll be connecting the logic probe's power leads to. This can save you the embarrassment of accidentally shorting something with the alligator clips and causing fix-it work before you can get back to what you were going to work on before you had the accident.

Using the digital circuit's DC supply is a convenience, but this is not required. You may power a logic probe from a separate bench power supply or a battery. Since the logic probe is a high impedance voltmeter used to measure voltages in the digital circuit, they must share a reference potential by connecting their grounds. If this is not done, you'll get confusing or meaningless results.

When using an independent power supply for the logic probe, check the digital circuit's Vcc and ground connections to verify they are logic high and low, respectively.

If you do use an independent power supply for your logic probe, be careful not to accidentally exceed the maximum allowed power supply voltage for the probe. While you might not think this can happen to you, it's not hard to accidentally grab the wrong knob or turn a knob in the the wrong direction. Because of this, I like to use my probe with a power supply that has a digital setting to limit the maximum output voltage. Older analog supplies use a crowbar circuit.

Once the probe is powered correctly, select the logic type you'll test with, typically DTL/TTL or CMOS. Most of the time I leave the probe in TTL mode and power it with 5 V. Then I know I'll see lows below 0.8 V and highs above 2 V.

Some logic probes require you to connect the tip first to a node before resetting the pulse memory. This is because these probes' memory latch only works for sure on a high-to-low or low-to-high transition.

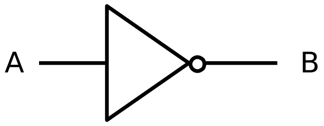
If you need to monitor high speed pulses with the HP 545A or HP 10525T probes, you'll want to use the associated grounding clip that attaches near the needle probe and keep the leads short (but I've tested them at over 40 MHz with no ground lead).

A useful troubleshooting technique is to compare the behavior of a known-good circuit with a suspect one. This can help you locate discrepancies more quickly.

Determine a digital state

This is the canonical application of a logic probe. You can probe the nodes in a TTL or CMOS digital logic circuit and see whether they are high, low, or open (open can also mean an invalid voltage level) circuit. The probe is also useful to check that a digital IC has power and ground connections. The logic probe is useful in analog circuits too, as you can trace ground and V_{cc} lines.

An example is an inverter:



Suppose the logic probe shows that point A is high. Checking point B with the logic probe must show that it is low. If not and assuming the probe is set up and working correctly, then the inverter is bad, it isn't powered correctly,there's a short to V_{cc} on the B side, or some other fault exists.

Testing of these logic elements can be done in conjunction with a logic pulser. The pulser will change the state of the line it is connected to, but this is done only for a short period. Pulsers can supply 0.1 to 1 A of current over this short period of time and this overwhelms the current sourcing/sinking ability of the IC's node. If you were to manually connect line A in the above inverter to ground or V_{cc}, you might damage the circuitry that was connected to it. The pulser's pulse is short enough (typically 0.3 to 10 µs) that no damage will occur. The pulser detects the line's state and momentarily drives it to the other state. With the logic probe connected to side B of the inverter, you should see it blink or the logic probe's pulse LED should flash when the inverter is pulsed on line A with the pulser. If you see no blink or flash, then something is wrong and you troubleshoot further. See *HP 10526T logic pulser* for more details.

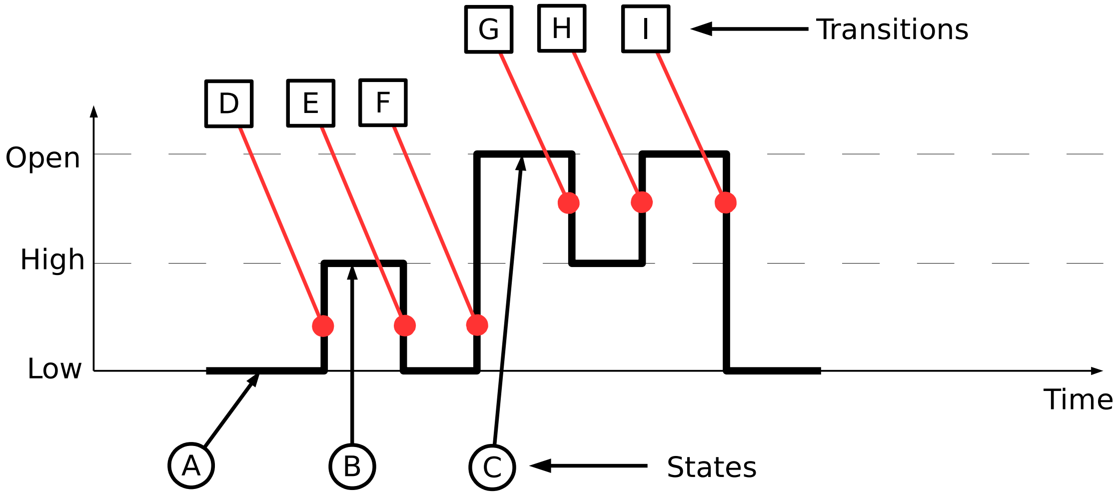
A feature of the logic probe is that you don't have to move your eyes from the point being probed (such as you would to read a DMM's display or look at a scope screen). This helps you test things more rapidly. The high impedance input of the probe's point means you won't damage a circuit element by accidental contact. However, a danger on modern high-density packaging is that you can short two leads with the probe.

A logic probe identifies only the following electrical states:

- ♦ High state
- ♦ Low state
- ♦ Open circuit state (can also mean a voltage in between the low and high thresholds or an invalid voltage)
- ♦ Pulsing state (a transition from one logic state to another or a sequence of such transitions)

Once you start using a logic probe, you'll find through experience that you can discover quite a bit about a system's behavior by using the logic probe.

Here are state transitions that may affect a logic probe:



The transitions are

Letter	Transition/state	Pulse indication
A	Low	--
B	High	--
C	Open	--
D	Low to high	Yes
E	High to low	Yes
F	Low to open	Maybe
G	Open to high	Maybe
H	High to open	Maybe
I	Open to low	Maybe

All probes will show low-to-high and high-to-low transitions. Some probes consider open-high, high-open, open-low, or low-open transitions to be pulses and some don't.

From a measurement standpoint, the logic probe is a high-impedance voltmeter. Read the probe's specifications for details, but here are the conclusions I draw from a logic probe when the switch is in the TTL position and the probe is connected to 5 V power:

- ♦ If I see an indication of the high state, I know the voltage at the tip is greater than about 2 volts.
- ♦ If I see an indication of the low state, I know the voltage at the tip is less than about 0.8 volts. The probes I use also indicate the low state for voltages more negative than power supply ground.
- ♦ If I see an indication of an open circuit, I know that the tip is either floating or connected to a voltage between 0.8 and 2 volts.
- ♦ If I see the probe blink once, I know it saw a state transition.
- ♦ If the probe is blinking continuously, it's seeing an AC waveform or a pulse train.

In practical work, if I see the probe blinking, I have to figure out what I'm likely seeing from context. If I'm checking an outlet with line power, I'll conclude I'm either seeing a phantom voltage (e.g. on the neutral conductor) or a 120 V AC signal on the hot conductor. If it's on a 24 V AC sprinkler circuit with one side of the transformer grounded, then I'm seeing the "hot" 24 V AC signal. If it's on a TTL node, then I'm seeing a TTL pulse train.

I don't work on clocked logic systems, but one technique with a logic probe and pulser is to set the system up in a known state without the clock running. Then the pulser is used to inject one clock pulse at a time and the logic probe can be used to verify the relevant nodes are in the desired state after each clock pulse. Today, such systems can be more efficiently tested with a multiple-channel logic analyzer.

Identify an AC signal

If an alternating or pulsing voltage is on a conductor, you'll be able to identify it if it's within the logic probe's ratings (i.e., crosses the logic threshold voltages) because the logic probe will blink. For a sine wave, this means approximately a 1 to 2 V RMS sine wave with no DC offset to work with a TTL logic probe (the voltage depends on the logic probe). The lowest voltage must be less than around 0.8 V.

The input protection of the logic probe is important, as you don't want to exceed it and possibly damage the probe. Commercial probes can typically withstand short connections (less than about 15 seconds) to the 120 or 240 V AC line (before using your probe on an AC line, check the probe's specifications to ensure the probe is able to withstand such voltages).

If I'm testing an unknown circuit and I see my logic probe indicate an AC signal, all I know about that waveform is that it exceeds about 2 V and has a minimum less than about 0.8 V. It could be a 2 V RMS sine wave, a 240 V line voltage, or a phantom voltage on a 120 V AC neutral line. In such conditions, I don't recommend a logic probe, as you'll want a DMM to characterize both the DC and AC voltage levels present (even better, use an oscilloscope). Once the maximum voltage levels are known, the logic probe can be used as needed.

One strength of a logic probe is that it can detect rapidly changing signals, typically 20 MHz or higher. This speed means it is unlikely you'll miss short pulses, transients, or intemittents, as long as they cross the probe's threshold voltages.

Though a logic probe only shows you the three states (high, low, and open) and a pulsing state, you can see differences between different waveforms. For example, setting a function generator to a 1 Hz signal with a 0 V low and 5 V high amplitude, switching between a sine, square, triangle, and pulse waveforms shows distinctly different behaviors on the RSR 611 logic probe. With the sine wave, the pulse LED doesn't light and the green and red LED on-times are a bit asymmetric. For a square wave, the LEDs are on the same amount of time, the transition is sharp (one LED is always on), and the pulse light blinks. The triangle wave looks about the same as the sine wave. A 0.1% duty cycle pulse has the green (low) LED lit continuously and the pulse LED blinks once per second. A pulse with 99.9% duty cycle shows a solid red (high) LED; the green and pulse LED blinks quickly when the pulse goes low.

A common use of the logic probe's ability to detect a pulse stream is to quickly check that a digital system has an operating clock signal.

Car troubleshooting

A digital multimeter is handy around a car, especially to know actual resistances or voltage drops. However, for most elementary troubleshooting (particularly on a vintage car), a logic probe is a more useful tool, as often you only want to know whether a wire has ground or battery voltage on it.

A good example of this is to test whether a wire has a turn signal's voltage on it. A DMM without a bar graph display will show a set of changing numbers and you may be unsure if it's a leakage voltage or the real signal. A logic probe is a good tool for this. In fact, a better tool can be an incandescent light bulb. If you use a bulb with the same rating as the turn signal bulb (often a #1157 on older cars), you'll also see if the wire is conducting enough current to light the bulb.

However, there are some problems when using a commercial logic probe for such testing.

Sunlight: In bright sunlight, it can be nearly impossible to see the indicator of a logic probe because they are designed for indoor use. Using some high-brightness LEDs, you can build the *Simple probe* and have an effective tool for finding power and ground connections on a car. See below for a probe I made myself that works well in sunlight and only cost a few dollars.

Hard to contact wire conductor: Trying to contact the center conductor of a wire with a logic probe, even one with a great tip like the HP 545A or HP 10525T probes, can be difficult. With the cheaper logic probes, it's even tougher. Eventually you're going to miss the wire and stab the finger you were holding behind the wire. I find the best solution here is to use a piercing probe with your logic probe.

Voltage ≠ working: Just because you find a wire has the needed power or ground on it doesn't mean that it's working. The logic probe doesn't tell you whether the wire can conduct enough current to do its job. The auto testers can help with such questions. If you're handy at building things, you can construct a current sink/source that can answer such questions.

A logic probe for the car

In this section, I'll show a logic probe I made for troubleshooting car problems using the basic schematic in Figure 3. I chose to use the LM2904 dual op amp, as I had a few of those on-hand. You can use nearly any dual op amp or comparator for this task.

I had some specific design goals for this probe:

- Probe
  - It must be small and lightweight to maneuver into cramped spaces.
  - It only needs to indicate battery voltage and ground. Pulse detection is not important.
  - A green LED indicates ground.
  - A red LED indicates battery voltage.
  - These two LEDs must be in the translucent probe and visible from any angle.
  - These LEDs must be visible in direct sunlight.
  - The probe tip must be needle sharp and able to penetrate wire insulation.
    - There must be a cover for the sharp tip so the user doesn't get accidentally stabbed.
    - The cover must store on the probe.
- Operation
  - Low threshold of about 1% of Vcc
  - High threshold of 90% Vcc
  - High input impedance
- Probe power
  - The probe should use the car's battery for power (nominally 12.6 V).
  - The probe should draw on the order of 1 mA when neither LED is on.
  - The LEDs should be run at 30 mA to 50 mA to ensure they are bright.
  - The power connection should be both a 2.1/5.5 mm jack and plug, allowing either to be used. Center pin is positive.
  - An adapter to allow connection to a cigarette lighter plug should be included.
  - An adapter from a 2.1/5.5 mm connector to dual banana plugs should be available. This allow use of large alligator clips to e.g. connect to battery terminals. This also allows use of the Mueller Electric BU-60 alligator clips.
  - The probe's lead length should be about 2 meters for normal operation. An extension cord should be available that allows use at about 5 meters away (here's a 5 m extension cord for $3).

Here's my rationale for the choice of the 0.1 V ground threshold voltage. A wire that is connected to ground may have a current through it. Assume that we're within 1 m of the connection point to ground. Also assume that the wire is 18 gauge copper with a linear resistance of 0.02 Ω/m. Further assume the wire is carrying 5 A. Then the voltage drop will be 0.1 V. I want the logic probe to indicate a ground in this situation. Most of the wires I test on a car will be larger than this, meaning they will have smaller voltages if carrying a current.

Probe body

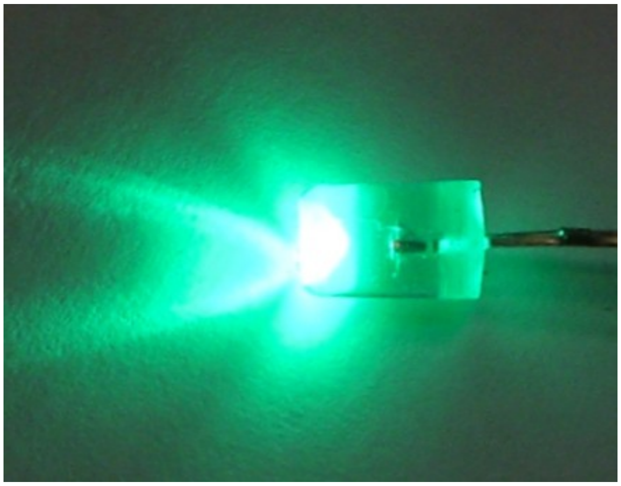
I first needed to design the probe body because I had to verify the probe's LEDs were visible in sunlight. I used the plastic translucent body of a BIC Grip pen for the probe body. This pen has a rubberized grip and the ball point insert can be pulled out, leaving a sleeve that a brass piece with a needle tip can be pressed in. If I bring the wires into the probe through a hole in the side, the pen's cap can be stored on either end. The body's plastic tubing is 8 mm outside diameter and 6.6 mm inside diameter.

The problem was how I was going to get a decent view of the LED from the side. The standard LED package sends the light forward in a narrow cone. This works OK for indoor use, but it will be hard to see in direct sunlight. What's needed is a 90° cone just in front of the LED that reflects the light in the azimuthal direction. Rather than make a part to do this, I decided to drill a hole in the LED.

A 5 mm LED can be held in a 3/16 inch or 5 mm collet. The bottom flange can be turned off, giving the LED roughly the shape of a cylinder. Then the LED can be turned around in the collet and a 90° drill point can drill a shallow hole in the dome end. This hole's internal surface will scatter light out in the azimuthal direction, exactly what we want. (There's nothing magical about a 90° angle, but I happened to have a suitable small drill for this.)

I did my testing with the green LED. At 10 mA of current, it's plenty bright for indoor use. I tested the design with LED currents around 40 mA and it worked well in direct sunlight.

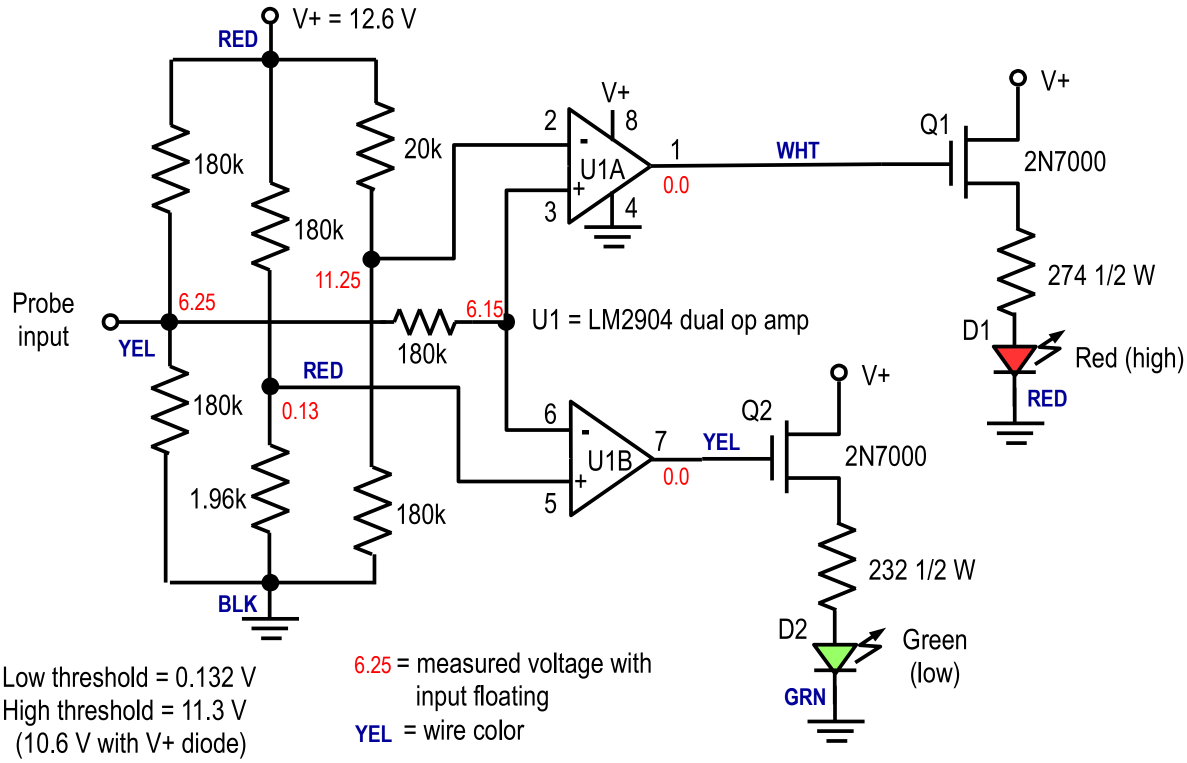
Here's a picture of it running at 5 mA showing the light being scattered in the azimuthal direction (i.e., towards the camera lens, whose axis was perpendicular to the rotational axis of the LED):



I plan to make another of these probes using a red-green-blue LED, as this will make things more compact. Instead of modifying the LED, I'd make a cone from a material like white nylon. A notch in the cone's edge well let the small wire from the probe tip pass to the rear of the probe.

Circuit

Here's the circuit I used:



Low threshold = 0.132 V
High threshold = 11.3 V
(10.6 V with V+ diode)

6.25 = measured voltage with input floating
YEL = wire color

The LM2904 dual op amp will source about 10 mA through the LEDs. Since this is not enough drive current for the LEDs to make them bright enough in sunlight, I used a 2N7000 transistor and suitable resistors to get about 40 mA at a power supply voltage of 12.6 V.

If you only want to use this probe indoors, 10 mA through modern LEDs will be very visible and would work well for an indoor logic probe, so the transistors Q1 and Q2 and the current-limiting resistors can be eliminated.

When the probe is connected to a node, 35 μA flows through the node, so there is minimal loading of the test point (but note the probe will be at 6.3 V, which may not be suitable for some things in a modern car).

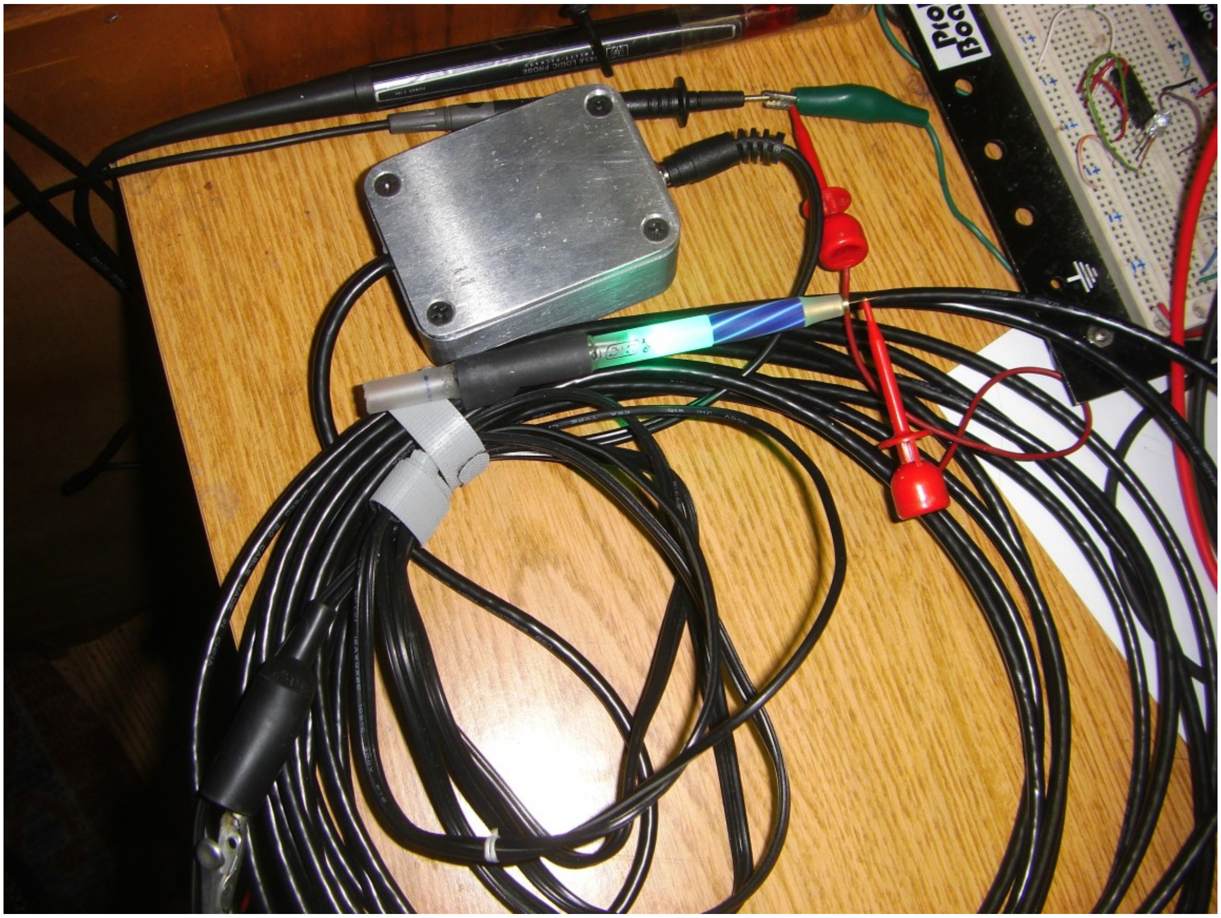
This circuit works fine for 12.6 V, but the red LED stops working at a power supply voltage of 10.1 V, so there's something wrong in my circuit (I haven't figured it out yet). As such, this is a usable design for working on a car, but not as a general-purpose logic probe.

After building the circuit, I modified it by putting a silicon small signal diode in series with the connection to the battery. This diode protects the circuit from a reversed connection to the power supply and it lowers the high threshold voltage by about 0.65 V.

My prototype probe was a spare digital multimeter probe. I tied the red and green LEDs to the body, along with the USB cable I used (I needed the four conductors in the cable: signal, ground, red LED voltage, and green LED voltage). I wrapped it in transparent packing tape. Though it looks hokey, it worked wonderfully when my son and I worked on his 1972 Nova project car, as the LEDs were nicely visible in the sunlight. The first important task this probe did was identify a brown wire that had been cut off near the firewall -- the wire's copper strands were exposed and the probe showed it had 12 V power on it.

Comment on the design: I had two choices when designing this probe: let it run from its own battery power or let it run from the battery of the car it's connected to. The advantage of the first design is that a long cord isn't required; all that's needed is a ground cable to connect to the car chassis. But the box containing the circuit and batteries is heavier. The advantage of the second design is that the tester will always work if the car's battery has a charge, but you do have to drag around a long cord.

Here's a picture of the probe with the long cord (an 8 m USB cable). The red lead with IC clips is connecting the needle tip to ground to light up the green LED:



A friend of my son's used a 3D printer to make the plastic box (I made an aluminum lid for it).

Check a car's trailer wiring

You can power your logic probe from either the car's battery (a cigarette lighter adapter is handy for this) or from a separate battery. The nice thing about using the cigarette lighter or car's battery is that you'll know you have a good ground connection, something that can sometimes be a bit hard to find on modern cars with all the plastic and painted metal.

Once you've verified the probe is working correctly by checking on a known ground and battery voltage line, you're ready to find the turn signal conductors and the tail light conductor. If you have an RV connector, then auxiliary power, the electric brake power, and backup lights can also be found.

A properly-charged car battery's voltage will be around 12.6 V. If you power the logic probe from it and use CMOS mode, then the probe will indicate a logic low for a voltage less than 3.8 V and a logic high for a voltage over 8.8 V. Note you might be fooled by something being labeled a ground connection, but it's not a real ground connection. You could also be fooled thinking something the probe labels as a high logic state is a good battery connection, but isn't. Thus, keep in mind that a logic probe can lie to you. But most of the time you just want to know if something is connected to the battery or ground and the logic probe will tell you quickly and usually be accurate. For better discrimination, use a DMM.

Another problem with a high-impedance device like a logic probe is that it won't tell you if the wire or terminal you've found will conduct enough current. For this, I use an 1157 auto incandescent taillight bulb with two alligator clips to connect to the line. The turn signal filament takes about 2 A if the bulb lights up, telling you that circuit is able to supply adequate current for the turn/brake signal. On an RV connector, testing the auxiliary power and electric brake power will take a load that can withstand higher currents (typically around 10 A from what I've seen on our trailer) -- a DC load is an excellent tool for this if you have one (but they're expensive).

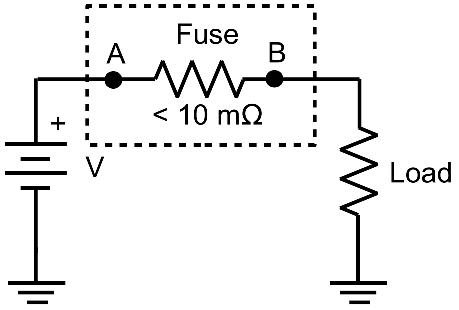
There are logic probes aimed at the automotive market; see the *Automotive logic probes* section.

Find a blown car fuse

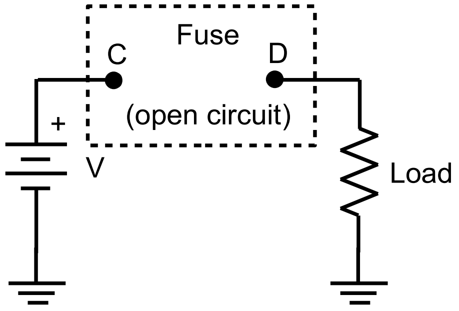
Using a logic probe powered from the car's battery, apply the probe's tip to both sides of a fuse. If the probe indicates a high logic state on both sides of the fuse, then the fuse is not blown. If one side of the fuse is high and the other is open or low, then the fuse is blown. This a fast test on groups of ATO-style fuses because they have small openings to provide access to their conductors.

This is a simple concept that I've seen some folks get confused over, so let's illustrate it:

Non-blown fuse



Blown fuse



In the non-blown fuse case, the resistance of the fuse is a low value (a 10 ampere ATO fuse has a measured resistance of 7 mΩ and higher-current fuses have smaller resistances) and if you measure the voltage at either of points A or B, you'll measure the same voltage, as there will be very little voltage drop even if the circuit is operating. However, if the fuse is blown, then the voltage at point C will be the battery voltage and the voltage at D will be indeterminate (or near ground if there's no switch for the load).

Again, with a logic probe, for a blown fuse you'll measure the high logic state at A, B, and C, but an indeterminate or low logic state at D.

Identify a conductor in a cable

Suppose you have one end of a conductor in a cable and you want to find this conductor on the other end (suppose there's a connector on the cable and you can't see the end of the cable to e.g. identify the conductor by wire color). About the easiest way to do this is to connect a grounded lead to the conductor of interest and find the conductor's other end when the logic probe indicates low (this **assumes** no connections to the other conductors of the cable nor any cable faults). Logic probes will detect ground through hundreds to thousands of kΩ, so to be sure there's really continuity, you'll want to use a more discriminating tool like a DMM. But this testing with a logic probe goes quickly and you can believe the results unless there are faults in the cable or connector.

You can use high logic levels too. With your logic probe powered from a battery or DC power supply, connect the supply's voltage to the conductor, then probe each available connector pin at the other end to find the conductor. For long battery life, put a 10 kΩ resistor in series with the battery to avoid lots of current if you accidentally short the battery. Where the cable ends are far apart, you'll want to use a voltage reference (earth ground is convenient) for both the supply and the logic probe at the other end. See *RSR 611 preferred* below for why this approach is useful.

You might think it would convenient to put an oscillating signal on a wire to find it because the probe would then be blinking and a blinking LED is easier to see. An experiment shows this has to be done carefully.

Use a multiple conductor cable with at least three conductors. I used an IEC power cable. Attach a function generator's output to two of the leads and set the generator to a 10 V peak-to-peak 1 Hz sine wave. Using the logic probe, you should see the low LED light on the function generator's ground connection and the high LED blink on the function generator's signal connector. Then touch the logic probe to the third conductor in the cable that isn't connected to anything. You should see no signal and no pulse blink.

Change the function generator to output a 10 V peak-to-peak 1 Hz square wave. Now the logic probe may show you pulsing activity on two of the three conductors of the cable. The explanation is simple if you can look at both of the signals with a scope -- you'll see the sharp transitions of the square wave on the third unconnected conductor because of the charging and discharging of the capacitance between the two conductors because of the high frequencies present in the square wave (though the capacitances are small, the capacitive reactance is low because the frequencies of the relevant harmonics are high).

Change the generator's frequency to e.g. 5 MHz and see if you can predict what you'll see with your logic probe for both the sine wave and square wave.

Here are the responses I saw with three different logic probes. The function generator's output was 5 V peak-to-peak and applied to the power cord's hot lead and the generator's ground (same as power line ground) was applied to the neutral lead. The cord's ground lead was floating. All three logic probes were powered from 5 V independent supplies with their negative lead connected to power line ground.

OC = open circuit, B = blinking, AB = asymmetric blink, P = pulse indication, IP = irregular pulse, HF = high (flickering), HLA = high & low alternating evenly, HLF = hi & low flickering (faint)

Signal	Conductor	HP 545 A	RSR 611	GS LP-1
1 Hz sine wave	Hot Neutral Ground	AB Low HF	AB Low OC	AB & P Low OC
1 Hz square wave	Hot Neutral Ground	AB Low HF	HLA & P HLF OC	HLA & P Low P
10 Hz sine wave	Hot Neutral Ground	B Low HF	HLA Low OC	HLA & P Low OC
10 Hz square wave	Hot Neutral Ground	B Low B	HLA & P Low HLA (faint)	HLA & P Low P
100 Hz sine wave	Hot Neutral Ground	B Low HF	HLA Low Low	HLA Low OC
100 Hz square wave	Hot Neutral Ground	B Low B	HLA & P Low HLA (fainter) & IP	HLA Low P
1 MHz sine wave	Hot Neutral Ground	B Low B	HLA & P Low Low	Low & P Low P
1 MHz square wave	Hot Neutral Ground	B B B	HLA & P Low Low	Low & P Low P

It was interesting to see the contrast in the responses of the different probes. Of course, most of us would have only one logic probe, so we wouldn't be able to do such a comparison -- but it's still worthwhile learning how your probe responds to these different conditions.

A **key observation** is how the square wave transitions and higher frequency sine waves caused various signals on the unconnected ground conductor of the cable due to capacitive coupling. The experiment demonstrates that you'll probably want to use a low-frequency sine wave for identifying conductors to minimize the effects of crosstalk. I like a sine wave frequency of about 8 to 10 Hz, as this is very noticeable with a logic probe and there's no high-frequency content.

Contrast this use of a logic probe to identify a conductor to the commercial wire tracers which put a multi-tens-of-kHz square wave signal on a wire at tens of volts, which can cause significant crosstalk on a multi-conductor cable. You can fiddle with the sensor's sensitivity and narrow things down, but often the test is ambiguous. A logic probe with a DC voltage works every time with virtually no chance of making a mistake. If you do see a spurious signal, you suspect a cable fault.

Validation: You'll want to validate this sine wave technique on the cable type you're testing to make sure it works correctly before making decisions with it. For example, with a 10 V peak-to-peak sine wave on the blue and white/blue pair of a CAT5 cable, the HP 545A probe blinked on every conductor except the blue conductor, which was earth ground, which indicated low (the HP probe is too sensitive for this test with this cable at this voltage and frequency). The RSR 611 probe worked fine in this situation and identified the conductors unambiguously and saw no crosstalk. The Global Specialties LP-1 probe found the conductors with the ground and sine wave on them, but the pulse LED lit up on all the other conductors, demonstrating crosstalk.

This simple experiment demonstrates logic probes behave differently -- and for this test with a sine wave, the RSR probe was unquestionably the best. Also remember that capacitance goes up as wires get closer together, so what worked on an IEC power cable may not work on a USB cable.

A better method for this test is to use a DC voltage and ground because there will be no capacitive coupling causing spurious signals. The three logic probes were all able to identify the wires unambiguously with a DC or ground signal. The HP probe proved its worth by the short blink on the open conductors, identifying them as unconnected to anything. But I liked using the RSR 611 probe the best, as the blue wire turned the probe's red LED on and the white/blue conductor turned the green LED on.

RSR 611 preferred

Here's a situation where the RSR 611 logic probe works better than the HP 545A logic probe.

As mentioned above, for quick identification of an isolated conductor, connect power line ground to the conductor of interest and use the probe to find the other end of the conductor. This works, but you have to methodically touch each conductor and look for the RSR probe's green LED to light up or the HP probe's bulb to go out.

A faster technique is to use the RSR 611 probe and put a logic high voltage (or e.g. a 9 V battery with a 10 kΩ series resistor) on the conductor. Ground the negative battery terminal and the probe's negative power supply connection. Now when you contact the other end of the conductor, the RSR probe's red LED and the yellow pulse LED will light up. If the RSR probe's slide switch is in the MEM position, the pulse LED will stay on. **This is a powerful technique**. For example, you can wipe the probe tip quickly down an IC's leads and if the pulse LED is on afterwards, you know you encountered at least one high logic state on that side of the IC. **You can't do this with the HP 545A probe** because the HP probe's memory light will come on for any transition, even the momentary blink seen on an open conductor. Those HP probe's momentary blinks confound a quick recognition of a connection to either a logic high or low.

The RSR 611's pulse LED's operation is **quirky**. For example, powered by 5 V in either CMOS or TTL modes, the pulse LED won't flash when an open-to-low transition is encountered. Things work better in TTL mode if you use a power supply 15 V or more, but there can still be an occasional miss. I found switching to CMOS mode and using a power supply of 7 V or larger to be more reliable, with an 18 V supply appearing to give the best behavior (this is the maximum supply voltage for the RSR probe).

More practical: Therefore, a practical strategy for identifying a conductor with the RSR 611 probe is to power the probe from a 9 V battery in CMOS mode, connect the conductor and battery negative terminal to ground, and look for a pulse while wiping the connector/wire candidates. Turn on pulse memory to be more sure of catching the transition. It will occasionally miss the detection, so it doesn't hurt to wipe more than once and this takes very little time.

A benefit of the RSR probe and a 9 V battery is that you can connect the battery to two conductors in a cable at one end of the house and identify these conductors' ends at the other end of the house. One conductor will have logic low on it and the other will have logic high. The catch is that one of the conductors will e.g. have to be at ground potential (make sure it's the negative terminal of the battery) so you can reference your logic probe power supply to ground at the other end. If you can't do this, then you'll want to use a digital multimeter and search for the two wires that have 9 volts on them, a pair of wires at a time (the voltage polarity will identify the wires). The logic probe is preferable for this task because you don't need to keep looking at a meter's display -- instead, you keep your eyes on the probe tip while moving it from conductor to conductor and can see the LEDs light up with your peripheral vision. You'll want to use a ground reference at both ends for the convenience of using a logic probe. Run an extension cord if you need to and use its earth ground connection (see *Earth ground adapter*).

If the cable is long and there is leakage to ground along the cable, you may want to remove the current-limiting resistor from the battery to ensure detecting an adequate voltage at the other end.

Remember, these logic probe indications of connection can be through a large resistance, so they don't necessarily indicate good conductor continuity. A cable or connector fault could indicate a connection on multiple conductors.

Test a diode

Attach the power supply ground lead to the cathode of a silicon diode. You should be able to touch the logic probe tip to the anode and see the probe indicate low. This lets you check the polarity of silicon diodes and transistors.

This test on the probes I use won't work on some LEDs if the power supply is 5 V and the logic probe is set to TTL. Set the probe to CMOS and increase the power supply voltage to check LEDs. With the two probes I use regularly (HP 545A and RSR 611), I found 6 to 9 volts would let me check green, blue, and white LEDs; 12 V would be a good general purpose test voltage for this task. You won't hurt the diode because of the large impedance of the probe means microamps of current through the diode. A 9 V battery makes a good power source for the RSR 611 probe because it only draws 1 mA if none of the LEDs are on.

To characterize your logic probe, power it with a variable DC power supply and measure the open-circuit voltage on the logic probe's tip with a high input impedance voltmeter. Here are some data for the two probes I use:

	Probe tip voltage, V			
	HP 545A (#1)		**RSR 611**	
Supply, V	**TTL**	**CMOS**	**TTL**	**CMOS**
4	1.43	2.04	0.79	1.51
5	1.47	2.43	0.95	1.84
6	1.49	2.73	1.11	2.17
7	1.51	3.03	1.28	2.50
8	1.52	3.33	1.44	2.83
9	1.54	3.63	1.60	3.17
10	1.56	3.93	1.76	3.51
11	1.57	4.23	1.92	3.84
12	1.59	4.52	2.09	4.18
13	1.60	4.82	2.25	4.52
14	1.62	5.12	2.41	4.85
15	1.63	5.42	2.57	5.19
16	1.65	5.72	2.74	5.53
17	1.67	6.02	2.90	5.87
18	1.68	6.32	3.06	6.20

These tip voltages are linear with the supply voltage.

For silicon transistors, it's a good idea to stay below a tip voltage of 5 V, as you may exceed the maximum base-emitter voltage specification (check the transistor's data sheet). The red cells in the table are where the probe tip voltage is greater than 5 V. The green cells show why I picked a power supply of 9 to 12 V and CMOS mode for general testing of diodes and LEDs.

Test: a 5 mm green LED was put in series with a DMM measuring current on the 200 μA scale. The probes were powered with 18 V and put in CMOS mode. The RSR 611 probe put 1.4 μA through the LED. The HP 545A probe (#1) put 12 μA through the LED.

Continuity tester

The easiest continuity test with a logic probe is to apply a ground (logic low) signal to one side of a wire and check to see if there's a low logic state on the other end of the wire. Since logic probes are high-impedance voltmeters, **this isn't a very sensitive measurement**, as continuity can be indicated for hundreds of kΩ or more. **But it's quick and easy**. I keep my two power supply grounds connected together and a test lead with a probe is connected to ground. Since a logic probe is always available, it's easy to trace a connection with the probe and ground lead.

Here's an example of this use of the logic probe as a continuity tester. The RSR 611 logic probe's tip was connected to the normally-open contact of a relay and let me see when the relay was actuated because the other side of the switch (the blue wire) was connected to ground. When the relay actuated, the probe's green LED came on. This let me characterize the board's input current as a function of applied voltage (I used these relays in my sprinkler controller circuitry).

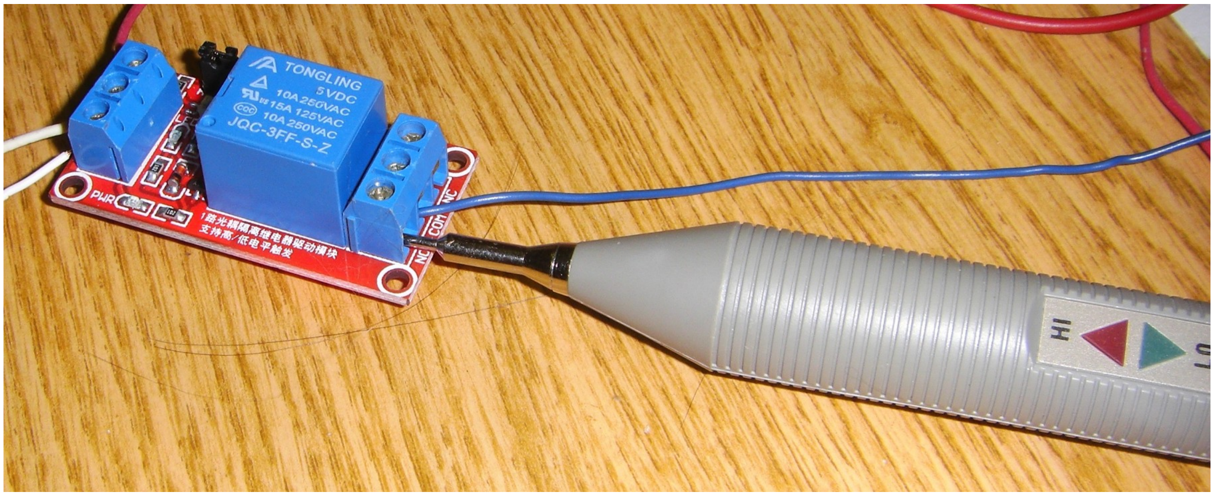


Figure 1

If you have a digital storage scope, you can perform this same test using a battery. To test the normally open contact, connect the battery's positive terminal to the common terminal on the switch, the battery's negative terminal to power line ground, and the scope's probe to the normally open terminal on the switch. Set the scope's trigger to 1/2 the battery's voltage, the trigger slope to positive, and the triggering mode to normal. Actuate the switch and you should see the contact closure on the screen. You'll see contact bounce too. Testing the normally closed contact is the same except you set the trigger slope to negative. Set the trigger to auto if you only want to see if the line is high or low.

Comment: I do a lot of continuity testing when working on things or trying to troubleshoot something. I like the convenience of a logic probe, but its sensitivity to continuity often isn't good enough. Years ago I made a wonderful continuity tester similar to the design in *Threshold logic probe* and it has selectable continuity levels of 0.1, 1, 10, 100, 1k, and 10k ohms. Unfortunately, it's another test box to drag around (it's in a heavy die cast aluminum box I salvaged from an old HP instrument). Most of the time I use my Aneng AN8008 or AN8009 digital multimeters because they are small, lightweight, powerful, and have a nice audible continuity test feature (continuity is indicated for resistances less than 50 Ω). I feel these multimeters are the best troubleshooting tools available for the money ($20 to $25 or so).

Checking with 9 V battery: A 9 volt battery is a convenient voltage source for continuity testing if you put a resistance in series with the leads to limit the short-circuit current. Assuming an end-of-life voltage of 7 V, the HP 545A probe #2 was able to detect 7 V as a logic high (5 V power with switch in TTL position) through a resistance of 0.5 MΩ. The RSR 611 probe was able to detect this 7 V through a 10 MΩ resistor (also in TTL mode with a 5 V power supply). I chose to use the 0.5 MΩ resistor in series with a 9 V battery as my standard testing device. I included a power switch, but a short only draws 18 μA from the battery, so the battery should last for years. An advantage of using a battery is that you can also use it to identify two wires in a long cable as long as you reference the battery's negative terminal and the logic probe's supply to a common reference potential (e.g., earth ground).

Bench tester

When I'm working at my bench, I'll often leave a logic probe connected to a power supply ready for testing and keep a test lead with an alligator clip or probe connected to ground handy. The HP 545A logic probe is handy for this because its red light is always on when the tip isn't connected to ground, letting me find the probe quickly in the mess on the bench. It's easier to see when testing compared to the RSR 611 probe because I don't have to turn the body until the LEDs become visible. Another reason I prefer the HP probe is because the power lead is longer -- the stock RSR probe often can't reach where I need to test.

Typical tasks with this logic probe are:

- Find a grounded conductor
- Check for continuity between two points
- See a DC or AC voltage that's greater than 2 V. For example, when working on an analog circuit, this is used to check that ground and Vcc are where they are expected.
- Check that a function generator's output is working.
- Find a diode's or transistor's polarity.

A key feature of a logic probe is that these tasks can be done with your eyes on the thing being probed, rather than looking up at a scope screen, meter face, or DMM display. This makes testing go a bit faster.

A tonal voltmeter that translates voltage levels to an audible frequency is another testing strategy. If such a thing interests you, look for the 1998 Poptronics article by Mark Bender that elegantly uses a CMOS 4046 phased-lock loop IC to do this.

Check a sprinkler system's 24 V AC wiring

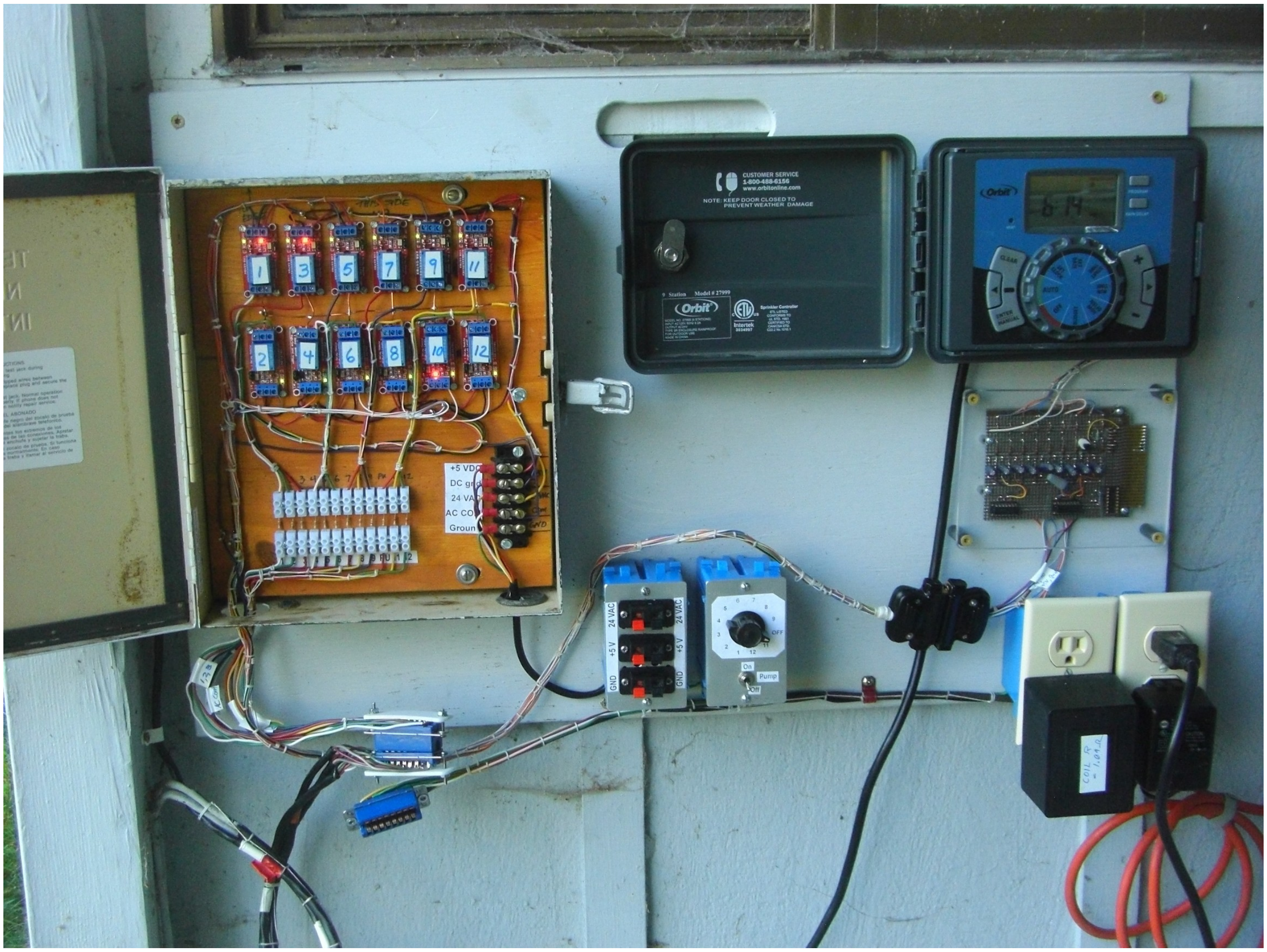
To first order, my sprinkler system is a digital system: power line ground is the low state and 24 V AC is the high state. Using my battery-powered logic probe with the battery's negative terminal connected to the 24 V common terminal, I can troubleshoot sprinkler problems as if it was a digital system. If I use the HP 545A logic probe, it blinks when put on a 24 V AC conductor. When I use the RSR 611 logic probe, the green (LO) and red (HI) LEDs are lit at the same time.

To check for the existence of 24 V AC on a particular wire in a remote sprinkler box, it's more convenient to use a non-contact voltage sensor unless I can easily reference the probe's DC supply to the AC common line. In the wiring box next to the sprinkler controller, it's more convenient to use a logic probe, as there are numerous wires with 24 V AC on them and the 24 V common line is easy to find.

In the spring of 2017, I changed my sprinkler system to use TTL signals to turn the sprinklers on and off. This let me overcome the limitations of the commercial sprinkler controller I use. The basic method is to rectify the 24 V AC signal coming from the commercial controller and filter it to turn it into a 5 V DC signal. This signal then drives an optically-isolated 5 V relay (shown in *Figure 1*), which is used to switch 24 V AC to the sprinkler circuit's solenoid valve. This sounds like a needless step. However, I have the special condition that one of my sprinkler circuits must not have our ditch pump turned on when it is run, as this special case will ruin the ditch pump because this sprinkler circuit gets its water from a different supply (our house well) and running the ditch pump with no water flow can ruin the pump's seal. This logic condition was handled by a TTL NAND gate. It also let me have simple manual control of the sprinklers, which is needed when troubleshooting and in the fall when I have to blow the water out of the sprinkler lines (these tasks are clumsy with the commercial controller). Another need I have is to run multiple sprinkler circuits at one time and the commercial controller won't allow this, as its output can (barely) turn on one sprinkler solenoid at a time.

The logic probe is the tool of choice for working on this sprinkler controller box, as it lets me identify

DC and AC ground (low), DC high (5 V), and 24 V AC. Here's a picture of the sprinkler controller and relay box:



The PC board above the duplex AC power outlets changes the commercial sprinkler controller's 24 V AC output voltages to 5 V DC. These signals then operate the numbered relays in the old metal telephone box on the left. You can see the green LEDs on the relays indicating they have 5 V DC power. The red LEDs show which relays are on. Relays 1, 3, and 10 are on; the relays switch 24 V AC to the sprinkler solenoids. Relay 10 controls the 24 V AC contactor for our ditch pump which is about 70 m from this location. The terminal strip positions at the lower left each have a 1 Ω resistor to let me monitor each solenoid's AC current. Except for measuring the solenoid current, I can troubleshoot the system quickly using only a logic probe.

A major reason for converting things to TTL control was to let me eventually replace the commercial controller with a custom one built from an Arduino or Raspberry Pi. Part of the reason for this is that the rules for when one can run sprinklers get more complex as years go by, especially in years where the water supplies behind our dams are low. The commercial controllers can't deal with some of the legal constraints we have to deal with.

Switching glitches

When designing my sprinkler system's TTL logic and controller box, I wondered whether it would be a good idea to tie both the 24 V AC common line and the 5 V DC negative line to power line ground. This would be convenient because I could use a single logic probe for troubleshooting both the DC and AC circuits, but there might be switching transients getting into the DC power. The only way to know was to measure it. I hooked up a logic probe to the 5 V supply and used the 5 V line to actuate the optically-coupled 5 V relay used to switch the 24 V AC to the solenoid. I armed the pulse memory, then actuated the relay, trusting the logic probe to see any glitches on the 5 V line. I followed this up by viewing things with the scope, but the logic probe was convenient to see if any transients developed on the 5 V supply (there were none).

Determine if an outlet has AC line voltage

This is really a job for a non-contact voltage tester, an outlet tester, or a DMM, but you may be able to use your logic probe if it is rated to handle line voltages -- even intermittently, since you only make a connection for a second or so. I power my logic probe with three AA batteries in series and connect the batteries' negative terminal to the power line's ground (see warning below and *Earth ground adapter*). Then I probe the hot and neutral sockets. The probe will blink on the hot side and may or may not blink on the neutral side. I check both hot and neutral unless I know the outlet is correctly wired.

Warning: This is not a test that beginners should do, as they won't understand the risks and possible problems. You should be an experienced electrical person and knowledgeable about working on line voltage circuits. First use an outlet tester or DMM on an arbitrary outlet, as there's no measurement danger if the outlet is miswired. To illustrate this, suppose someone miswired the outlet by putting the hot line on the ground conductor. Now your logic probe's ground lead could have line voltage on it and **you wouldn't know it**. This could be a deadly shock waiting to happen. Once you know an outlet is wired correctly, there's no problem with using a logic probe to see if it is energized -- unless you get a false negative.

You can get a false negative if the logic probe's tip never touched the conductor inside the outlet. This is why I prefer an outlet tester for this task, as it is designed to plug into the outlet and make proper contact. But even an outlet tester can fail on an old outlet whose metal contacts have relaxed over time. Our house was built in 1971 and I've replaced nearly every outlet in it over the last 30+ years because these older outlets' contacts would often feel weak and make poor contact, sometime causing arcs. Good spec-grade replacement outlets are worth their cost.

When I'm going to work on a line voltage outlet, I use two independent tools to verify no line voltage is present. Both of these tools are tested first on a known-working outlet to verify the tools are working properly. My two tools of choice are an outlet tester and a non-contact voltage sensor, but I often have my DMM with me and will use that instead. DMM leads and logic probes can give a false negative if the probes don't make contact with the outlet's conductors. To be extra safe when using a DMM, check for dangerous DC and AC voltages (or use a DMM with an AC+DC function).

> There are special test leads for outlets with shrouded banana plugs that can be plugged into a DMM. However, a simple LED-based or neon bulb outlet tester is much cheaper and, in my opinion, is the preferred test tool to check outlets.

If you don't have a test tool handy, plug in a radio or lamp and use it to tell you when line power has been switched off. **Caution**: check *both* outlets of the typical duplex outlet, as they may be wired on independent circuits. Also check first on a known-working outlet to verify the test device is working.

Check a phone line

A typical old-style phone line in the US has about a 50 volt DC potential on the two phone line conductors (called tip and ring) when the line is in the on-hook state (i.e., open circuit). Supposedly the positive line (tip) is referenced to earth ground. When the phone rings, the ringing signal is about 86 V RMS at about 20 Hz. For more information, consult page 935 of [*aoe*].

The on-hook voltage is typically 48 to 52 V on the red ("ring") and green ("tip") wires, with the green wire having the most positive voltage.

> "Tip" and "ring" refer to conductor locations on the old 1/4 inch 3-conductor telephone plugs and have nothing to do with the ringing of the telephone. A black/yellow pair of conductors can also be tip/ring pairs.

Both of these signals can be detected with a logic probe that is capable of being used on AC line voltages. I recommend powering the logic probe from a battery and connecting the negative side of the battery to the most negative phone wire (the red wire). You'll see a logic high indication if there's a DC voltage on the green wire and a blinking indication if there's a ring signal.

If you connect the negative side of the battery to the most positive phone wire, the logic probe will measure a logic low level on the other conductor and this is an ambiguous test, as the line will either be about 50 V below ground or have no voltage on it. Thus, to be sure, test with both polarities. A DMM is a better tool for this because only one measurement is needed and there's no ambiguity.

Be careful when testing, as these voltage levels are capable of giving you a significant shock (especially the ring signal). The phone company can supply higher voltages when testing the lines. More importantly, the phone line can have deadly voltage spikes on it caused by lightning strikes. You do this testing at your own risk.

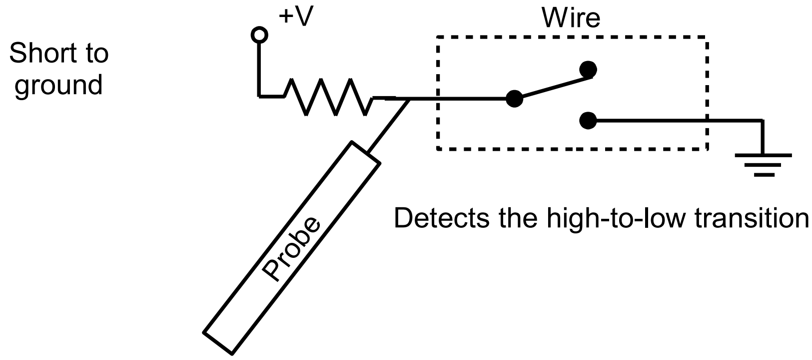
Ringing current can be measured with an AC ammeter and is on the order of 10 mA for a phone with the old metal bells and clappers run by a solenoid.

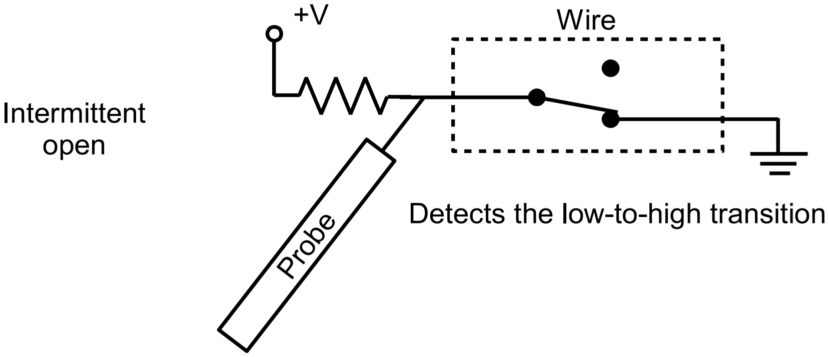
> If you wonder where the weird 86 V RMS at 20 Hz came from, these designs date from before AC electrical power became common and 20 Hz was something that a human could crank on the old-style phones you'll only see in cartoons these days. Consult the tech pages at http://www.sandman.com/ for more phone information.

Find an intermittent

Connect the logic probe to the suspect wire and bias it with the voltage from a battery or ground the other end. Clear the pulse memory and wiggle the wire. If you have an intermittent open or short, you may see the pulse memory LED light up.

Note: some logic probes may not detect transitions from a low or high state to the open circuit state. In such cases, you can use the following connections:





The resistor acts as a pull-up in the short-to-ground case and a pull-down in the intermittent-open case. You may have to experiment to find an appropriate value of the resistor; I'd start with around 1 to 10 kΩ (use a higher value for higher voltages).

The HP 545A logic probe is particularly convenient for these tests, as no pull-up/pull-down resistor is needed because the pulse memory works for any transition between low, high, and open.

Find a short

I don't know of an easy way to find the location of a short with just a logic probe. If you have a logic pulser, then you may be able to verify that something is shorted by putting the probe and the pulser both on the conductor and not see the probe blink when you pulse the line, indicating a short to ground or supply voltage. Use caution for the short to supply voltage, as the supply's output impedance might be high enough so that you do see the probe blink (this can also be caused by a current-limited power supply).

Folks working on digital circuitry use an HP 547A current tracer with an HP 546A pulser (see *[hpj1976]*) for tracing shorts, but few people will have these powerful tools. You can see videos of such things in use on the web.

Without a specialized tool, one method is to use a 4-wire (Kelvin) measurement of conductor resistance. Power the short with a DC power supply at a constant current (keep the current low to avoid burning something up, but make the current as large as is practical). Use a DC voltmeter to measure the voltage drop along the wire or PC board trace to find where the short is. As you approach the short, the voltage with respect to ground should continue dropping, assuming it's a short to ground. If the voltage stays constant as you move the test probe, you're on a connected conductor that doesn't contain the short (there's no voltage change because there's no current flow in the conductor)..

This is a method that will always work, but if you can't apply enough current, you may need a bench voltmeter with better voltage resolution than a hand-held DMM, which usually only resolve to roughly 1 mV levels (the DMM may resolve to 0.1 mV, but you'll find it may not be stable enough or your current supply may not be constant enough to usefully use that fraction of a millivolt). The inexpensive Aneng AN8008 or AN8009 DMMs can measure sub-millivolt voltages and are recommended.

A voltmeter that can resolve to 1 μV or better can let you trace 1 mΩ shorts pretty easily with 100 mA currents. Various expensive commercial tools have been developed to do such things quickly e.g. for PC board manufacturers, but a sensitive voltmeter and constant current source are all you need to do this task occasionally. A constant current source might be an AA, C, or D battery in series with a 15 ohm 1/2 W resistor to give around 100 mA of current, so you're looking at a simple measurement setup as long as you have a suitable voltmeter.

A related tool is the *stuck node tracer*, discussed on page 953 of *Art of Electronics*. This project uses a micropower op amp as a logarithmic amplifier to measure voltage drops from microvolt levels up to around 1 V and having these measurements displayed on a center-zero analog meter.

Here are some other techniques to think about:

- ♦ **Audio tracing**: Use a function generator to put a 500 Hz sine wave across the conductor. Using an audio amplifier (like an old Radio Shack "Archer" Mini Amplifier-Speaker), you can trace along the conductor. You're moving toward the short as the signal gets quieter; if it's constant, you're not on the conductor that has the short. The function generator may not be able to output enough current into a short.
- ♦ **Thermal tracing**
  - ♦ I've used my little $10 CenTech IR thermometer (Harbor Freight #93983) to find PC board traces that are carrying enough current to warm up over background temperatures.
  - ♦ You may be able to make an adequate tracing tool from an IR photodiode or phototransistor. This could be worth some experimentation. You may be able to just plug it into a DMM; if that's not sensitive enough, check out some photodiode biasing techniques in op amp application notes.
  - ♦ I don't have one, but a thermal imaging camera that can show temperature differences of, say, a degree C or so could be a wonderful tool to show you where the current is flowing. Such tools are expensive.

♦ I've read some folks have sprayed PC boards with a refrigerant or put them into the freezer to get ice condensation on the board. Putting current through the short and seeing where things melt could tell you where the current flow is.

  ♦ One of those thin liquid crystal sheets that could be laid over a PC board might be able to do something similar if you could get good thermal contact.

♦ Use a thermistor mounted in a small aluminum case with heat sink compound to measure temperatures across PC board traces, similar to the IR measurement method. A tiny thermocouple junction might even work better because of the lower thermal mass.

A short in the car

Suppose a car has current being drawn from the battery when everything should be off (e.g., doors closed, headlights off, etc.). Then there's a short somewhere or an energized circuit you haven't found yet. An incandescent troubleshooting light can be handy in this situation because you can remove the positive battery cable and insert the test light between the + battery terminal and the positive battery cable (caution: some cars with electronic controls don't like to have their battery disconnected). If the light is on, then it's demonstrating that a short exists. Low currents won't light the bulb, so I use a clamp-on DC ammeter that reads to 1 mA to work on such things.

> For low currents, try a 24 V grain-of-wheat bulb; at 12 V, these can draw around 40 mA. For smaller currents, you can use an LED and a resistor in series.

You start pulling fuses to isolate the subcircuit has the short -- when the light goes out, the circuit whose fuse you just pulled has the short, so now you've localized where the short is. This is inherently a current measurement, so a logic probe won't work.

Find an open

Suppose you have an open in an extension cord, but you don't know where it is. I don't know of an easy way to use a logic probe to find such a thing unless you can penetrate the correct wire with a sharp tip. And I've never seen such an open on an extension cord[1], at least not without visible damage to the cord (but it can happen if a wire pulls loose at the connector on the end).

One too tool for this task might be a non-contact voltage sensor, as it can be moved along the cord with line power on it until it stops indicating a voltage, which locates the break. If the break is on the neutral, you can use a 3-to-2 wire adapter to connect the hot line to the neutral conductor in the cord (carefully!). My non-contact voltage sensor is too sensitive for this test.

A better test is to apply e.g. 5 V DC to one conductor and ground to another conductor. These are easy to find at the other end with a logic probe. If you don't find one or both at the other end, there's a break in the cable. A probe with a sharp tip like the HP 545A is ideal for this testing because it can penetrate the insulation to reach the center conductor. This works well on stranded zipcord of 16 gauge and larger and 14 gauge solid conductors and larger. Smaller conductors may be harder to contact inside the insulation -- if you miss the conductor, you may falsely conclude the conductor is broken.

> If you don't have an HP 545A logic probe, you can clamp a small needle in some Vise Grip pliers and penetrate the insulation in a similar fashion (of course, only do this test with a low voltage like 5 V).
>
> If you need to do this frequently, it's simple lathe work to make a needle tip for your logic probe. Use some 1/4" inch brass stock and drill a hole for a small needle and solder it in place. Drill a hole at the opposite end to fit your logic probe's tip and fit the adapter with a small set screw to clamp it to the logic probe's tip.

Similar testing is straightforward to do with an ohmmeter, but I find the logic probe more convenient.

The HP 545A logic probe will give a short blink when connected to a conductor that isn't connected

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[1] In the spring of 2019 I did see this for the first time in an older Panasonic massager my wife uses on her neck and back. There was an intermittent open in the zip cord for line power a few mm from the strain relief and there was no visible damage in the cord.

to anything. This is different from when it is connected to a node at an illegal TTL voltage such as 1.5 V, where the probe does not change its indication from the "dim" bulb state. For example, I can touch the 545A logic probe to the outside of a BNC connector on a test instrument and see immediately if that instrument is connected to power line ground. As mentioned elsewhere, this useful behavior of the HP logic probe alerted me to an unconnected wire in my sprinkler controller box.

Digital scope as logic probe

If you have a digital scope, you effectively already have a logic probe with memory. If you have to do a lot of troubleshooting with it, however, you'll find it's not as convenient as a real logic probe because you'll have to place the probe and look up to the scope to see the state. More subtle problems are

- An open circuit looks like a low measurement if you're using auto trigger.
- An open circuit to a low state won't trigger the scope. You can use a pull-up resistor if necessary to see the transition to low.
- An open circuit to a high state will cause the scope to trigger if the trigger level is set properly. Choosing the trigger slope lets you see the leading or falling edge.
- Noise and high bandwidth can make for spurious triggers.

You can simulate a pulse memory using the scope's single trace mode, but you'll have to reset it each time you get a trace and want to see a new one (this gets tiresome if you have to test lots of nodes).

Where logic probes don't work well

It's hard to use a logic probe in direct sunlight because the LEDs or bulb can be hard to see. Using some shade is the only easy fix. A probe with audio output like the RSR 610B could be an advantage in this situation. See *A logic probe for the car* for a probe that works well in sunlight.

You may want to use a DMM instead in bright sunlight. For pulse streams, use the frequency measurement feature if your DMM has it. My Aneng AN8008 works well for 5 V TTL square waves above 1 Hz and measures frequencies to at least 5 MHz. Pulses can be identified by measuring the duty cycle, although low or high duty cycles won't be measurable for higher frequencies.

Do you need a logic probe?

I find a logic probe convenient for troubleshooting things because it is compact, fast, and gives me basic information that is often enough to solve problems.

The logic probe tells me things like:

- This conductor is connected to ground.
- This conductor has a voltage on it.
- This conductor has an alternating voltage on it (the logic probes I use will work on AC line voltages up to 250 V AC).
- This conductor is not connected to anything (or it may have a negative voltage).

For simple systems, such knowledge is often sufficient to figure out what's wrong.

When dealing with electrical problems, most of the the time I'll use a digital multimeter because it gives the most information for routine problems. I find a logic probe useful when dealing with simple systems, such as my sprinkler system or an automotive circuit.

Should you make or buy a logic probe?

First ask yourself if you really need a logic probe. If you have a DMM or scope, you can use those tools instead of a logic probe and they'll give you more information than the logic probe can. But troubleshooting some electrical things can go faster with a logic probe.

If you're planning on working on digital systems and don't have the money for a logic analyzer, a logic probe can certainly help with troubleshooting, but it likely won't help much with complicated problems. Techs who troubleshoot computer systems often use logic probes and continuity testers for high-level checks of basic system functionality. Certainly a logic probe is easy to hook up and use to test for power supply voltages and grounds where you expect them and to look for alternating behavior. In conjunction with a pulser, you can check digital functionality at gate levels and locate likely shorts.

Though I'm in favor of building things to save money, learn new techniques, and have fun, I feel the best approach to getting a logic probe is to buy one. This will give you the features and speed you need and provide the probe in a convenient package with clips to connect it to a power supply. You can certainly build something functional, but it probably won't have the usefulness, convenience, and speed of a commercial logic probe.

I recommend buying the RSR 611 or 610B logic probes, as they can be purchased new for about $20. I feel they are the best value for your money. The 610B has audio output that you can't turn off, so if you need to work in a quiet environment, get the 611. If you think you'll want a pulser to help with testing, look at the RSR 620 pulser, also available for less than $20. RSR sells a 50 MHz logic probe that includes a pulser as the RSR 625 for $24.

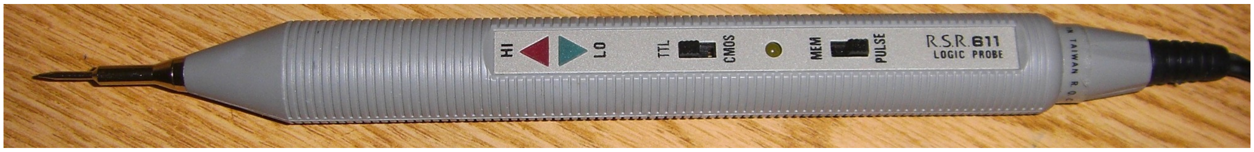
There aren't many new logic probes being made today. It appears a manufacturer in Taiwan makes the parts for logic probes that are branded by a number of different companies, such as RSR Electronics, Elenco, and B&K Precision. The models differ in tips, color, and power cords, but may have the same internal parts.

For the measured data in this section, the 16 ns pulses are the narrowest that my function generator can supply at a 5 MHz pulse rate. Probe tip voltages were measured with an HP 3456A voltmeter, which has an input impedance of greater than 10 GΩ. Logic probe tip currents were measured with an Aneng AN8008 digital multimeter with the negative lead connected to power supply ground.

I have five logic probes: the HP 545A, HP 10525T, RSR 611, RSR 620, and the Global Specialties LP-1. The sections below on these probes have measured data and more detail. I have no experience with the probes in the *Other logic probes* section.

RSR 611

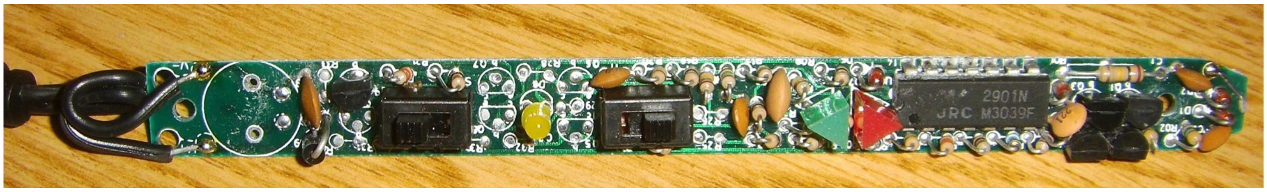
The RSR Electronics model 20 MHz 611 logic probe will cost you around $20 delivered:



The metal tip at the left is used to contact the nodes in a circuit. On the right end, out of the picture, is a 2-conductor power cord used to connect to the DC supply of the circuit you're testing (the end of the cable has two alligator clips). The probe body is about 18 mm in diameter and about 185 mm long excluding the power cord, which is about 0.5 m long (it's unfortunately too short for many situations).

The RSR 610B probe is similar except it has a speaker that provides sounds to indicate the logic states in addition to the LEDs (you can't turn the sound off). Logic low and high use low and high frequencies, respectively and pulse trains have other sounds. My hearing stops at 2.9 kHz and I can't hear this logic probe. Refer to the picture in the section *Elenco LP560* because it may also apply to the 610B probe's operation.

Here's a picture of the circuit board of the RSR 611 probe:



I believe the empty circle on the left is the location for the audio element used in the RSR 610B, showing that they use the same circuit board. The 2901 number on the 14-pin IC may mean it's a quad differential comparator chip. Note the four plastic TO-92 objects (probably transistors) near the tip. The picture demonstrates that 1960's transistor radio printed circuit boards are still alive and well.

Specifications:

Maximum input signal frequency	20 MHz
Input impedance	1 MΩ
Operating supply range	4 V DC minimum to 18 V DC maximum
TTL: logic 1 (HI LED) logic 0 (LO LED)	> 2.3 ± 0.2 V DC < 0.8 ± 0.2 V DC
CMOS: logic 1 (HI LED) logic 0 (LO LED)	> 70% Vcc ± 10% < 30% Vcc ± 10%
Minimum detectable pulse width	30 nanoseconds
Maximum signal input protection	±220 V AC/DC (15 sec)
Power supply protection	±20 V DC
Pulse indicator flash time	500 ms

There are five controls/indicators of interest on the probe:

- ♦ **HI** (red LED): Turns on when the tip is connected to a logic high level.
- ♦ **LO** (green LED): Turns on when the tip is connected to a logic low level.
- ♦ Neither LED is illuminated when the tip is an open circuit or connected to a "bad" (disallowed) logic level.
- ♦ The **TTL/CMOS** switch lets you select which voltage thresholds the probe will respond to.
- ♦ The **MEM/PULSE** switch lets you see pulses on the yellow LED between the two switches. The **MEM** position is used to remember if one or more pulses is seen; it's called the pulse memory and is useful for capturing transient events too fast to normally see. In **PULSE** position, it will blink to indicate a pulsing signal and works on signals too fast to see any flicker.

You can't tell when the RSR 611 probe is powered on by looking at it, as the default state is no LEDs on with nothing connected to the tip. Touch your finger to the tip to make the red and green LEDs light up because of phantom AC voltages. (This typically only works if your probe is powered from a grounded bench power supply. If you've powered it with a battery, just touch the +V or ground connector to light the LED.)

You might think this phantom voltage behavior could be useful for casual continuity checking by touching a wire in a cable with your finger and finding the wire at the other end with the logic probe, but there's too much cross talk at 50 or 60 Hz. It works a little better on e.g. the twisted pairs in a CAT5 cable, but it's still not good enough for careful tracing. The simplest technique is to connect the power supply ground to the wire of interest and find its other end by the green LED; it's fast and unambiguous (but can indicate "continuity" through hundreds of kΩ). If it's ambiguous, suspect a cable fault or an incorrect connection.

Here are some measured power supply currents for a 5 V supply (probe in TTL mode):

State	RSR 611 current, mA
No LEDs on	0.86
Red LED on	11.3
Green LED on	9.8
Pulse LED on	9.9
Pulse and red LED on	19.4
Pulse and green LED on	18.0

I consider the 1 mA quiescent current draw a nice feature of this logic probe (contrast it to the HP 545A probe's quiescent current of about 40 mA). You can thus operate the RSR probe from a battery and get good battery life (see logic probe power).

For reference, here are the same measurements for an RSR 610B logic probe with a 5 Volt supply (probe in TTL mode):

State	RSR 610B current, mA
No LEDs on	1.3
Red LED on	22.7
Green LED on	19.8
Pulse LED on	11.5
Pulse and red LED on	32.3
Pulse and green LED on	29.4

5 V TTL mode pulse tests:

- ♦ I tested the RSR 611 probe on a TTL 5 MHz square wave and it was difficult to see the red and green LEDs in the on state in office lighting, but they were easy to see in a dark room. The blinking yellow pulse LED was easy to see. The pulse LED blinked for square waves up to 43 MHz, so it does have adequate speed to detect at its specified 20 MHz frequency. Since I virtually never use a logic probe on fast circuits, this isn't an issue for me. For a 1 MHz square wave, the probe's red and green LEDs were easy to see.
- ♦ At a 5 MHz pulse repetition frequency, I started with a 16 ns wide pulse of 0 to 5 V, but the RSR probe couldn't see it (the probe's specification is 30 ns minimum). The probe started detecting the pulses at 25 ns widths, so it still exceeded its specification. The complemented waveform with a 16 ns drop-out pulse was detected.

When connected to an ungrounded conductor, the RSR 611 probe's green LED will occasionally blink faintly or the pulse LED will blink. This is similar to how the HP probe blinks on an ungrounded conductor, but the HP probe's response is more noticeable and reliable.

I mostly prefer using the HP logic probes, but the RSR 611 probe can be a better tool when tracing conductors. See the *RSR 611 preferred* section.

My RSR 611 logic probe won't indicate a pulse on the open-to-low transition (i.e., flash the yellow pulse LED) when it is powered from 5 V and in TTL mode. I found this behavior to be power supply voltage dependent. The most reliable behavior for TTL mode was gotten by powering the probe with 15 to 18 V. At 5 V in CMOS mode, the pulse LED won't light on either an open-to-low or open-to-high transition, but both started to work at a supply voltage of 7 V and greater. With a 9 V power supply, a 100 kΩ resistor between the low signal and the probe tip stopped the probe from detecting the pulse, but it detected the pulse with a 10 kΩ resistor.

Input impedance: When the tip is connected to 5 V through an ammeter with 1 kΩ resistance, the current is 3.7 µA. Therefore, the input impedance of the probe is around 1.3 MΩ.

Resistance to ground: The RSR 611 probe supplies 0.28 µA of current when connected to an ammeter connected to power supply ground. This is for a power supply of 5 V in TTL mode. Since the probe's open circuit voltage is 1.40 V, this implies it will indicate ground through a resistance of 5 MΩ. It did through a 4.1 MΩ resistor, but not through a 6 MΩ resistor (these were the resistances I had on-hand to bracket the calculated value). Thus, a "continuity test" with this tool is not very discriminating, so follow up with a more discriminating tool like a DMM.

Power from 9 V battery: An inexpensive power supply for the RSR 611 logic probe is a 9 volt battery. When the LEDs are lit, the current draw is around 25 mA (50 mA if the yellow pulse LED is on also). A 9 volt battery's capacity is around 600 mA·hr at this current draw, meaning you should get around 24 hours of use with an LED on. Since you typically only leave an LED on for a second or two, the battery should last hundreds of hours, as the current draw when the LEDs are off is 1 mA. With a 9 V supply, you can test all the common semiconductor junctions you'll come across. See *Logic probe power* for more information. The disadvantage of the RSR logic probes is that the TLL thresholds are proportional to the battery voltage and aren't constant like the HP 545A probe.

Power from AAA batteries: The table below shows that three AAA batteries in series would work nicely as a power supply for the RSR probe. A quickie hack can be made by using vinyl tape to connect three batteries together in a triangular "lump", then you'd solder wires to the battery ends for the needed connections (don't overheat the batteries while soldering). Make the negative lead e.g. a meter long and put an insulated alligator clip on it to connect to the voltage reference (e.g., ground) of the circuit you're testing. Note AAA batteries have about twice the mA·hr rating of a 9 V battery and cost less.

Thresholds: Measured thresholds as a function of power supply voltage (the 4 to 5 V CMOS high thresholds had 10 to 50 mV of hysteresis):

	TTL		**CMOS**			
Supply, V	**Low**	**High**	**Low**	**High**	**Low, %**	**High, %**
4	0.57	1.87	1.18	2.42	30	61
4.5	0.65	2.10	1.34	2.91	30	65
5	0.71	2.33	1.47	3.42	29	68
6	0.85	2.80	1.76	4.20	29	70
9	1.27	4.21	2.65	6.30	29	70
12	1.69	5.62	3.53	8.40	29	70
13.8	1.95	6.46	4.06	9.66	29	70
15	2.12	7.03	4.41	10.50	29	70
18	2.54	8.44	5.29	12.60	29	70

The TTL behavior at a supply voltage of 4.5 V means this probe would work nicely with three AA or AAA batteries in series for power.

I only have a few complaints about the RSR 611 probe:

- The power supply cord is too short (it was likely designed by a bean counter who doesn't use such tools); it should have been 1 to 1.5 m long. I have an old cord from a wall wart that has a 2.1/5.5 mm plug on it that I'm going to solder to the probe.
- The power supply cord uses alligator clips with plastic insulators that may not cover them completely. There may be risk of shorting something to the power supply voltage or ground when you're using the probe because the cord is short.
- An open-to-low transition doesn't cause the pulse LED to light when run at 5 V in TTL mode (an open-to-high transition does light the pulse LED). At 5 V in CMOS mode, neither open-to-low nor open-to-high transitions cause the pulse LED to light. However, both high-low and low-high transitions cause the pulse LED to light in either CMOS or TTL mode at 5 V, as you'd expect.
- The probe tip has too large of a diameter to fit into the pin sockets of an Arduino board, which could be a common use for a hobbyist. The HP 545A probe will fit into such sockets without

modification. However, the RSR probe tip unscrews and you can make a new tip from a 5 to 6 mm diameter chunk of brass or steel: cut a 3mm thread with a 0.5 mm pitch on the end, and solder in a sewing needle into a hole. This produces an excellent tip for probing, though you'll be more likely to stab yourself on the sharp tip.

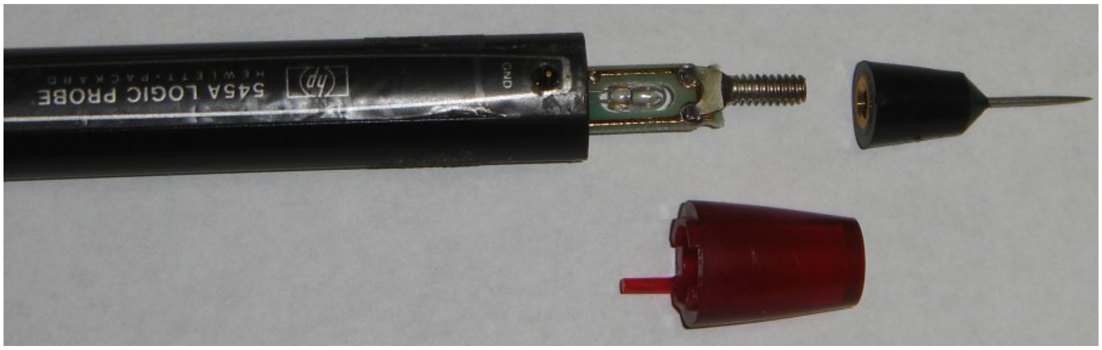
Overall, I consider the RSR 611 probe a good value for a hobbyist and it should meet most folks' needs.

HP 545A

A popular used logic probe is the HP 545A probe:

This probe was manufactured from 1977 (it was introduced on page 103 of the 1977 HP catalog to replace the older 10525T logic probe) to around the middle 1990's (they were in the 1993 catalog, but not the 1997 catalog). It used an incandescent bulb (ANSI 7210, 5 V 30 mA) for the light near the tip, probably because the LEDs of the time weren't bright enough and the lighting was more omnidirectional. It cost $125 in 1976 and was $320 in the 1993 HP catalog (both are equivalent to about $550 in 2019 dollars). If the bulb near the tip is not lit, the tip is connected to logic low. If the bulb is dim, the tip is connected to an open circuit or connected to an indeterminate or invalid logic voltage. If the tip is bright, it is connected to a logic high voltage.

Here's the tip unscrewed from the probe, showing the red plastic lens. You can see the incandescent bulb on the PC board to the left of the 6-32 (0.138 inches in diameter with 32 threads per inch) threaded stud.



A decade or two ago, these logic probes were easily found on places like ebay and sold for $25-$50. Today, they are pretty scarce and sell for substantially higher prices.

The probe is an elegant industrial-strength design, uses aluminum extrusions for the body, and has the best tip of any logic probe I've used. Consult *[hpj1976]* to learn more about this probe's design and the HP 546A pulser and 547A current tracer (also see *[bb1997]* describing their use). These three tools were sold with a logic clip in a leatherette case like HP calculators came in and were common tools for digital EEs in the late 1970's and 1980's -- the kit was the 5022A and was $700 in HP's 1977 catalog (about $2900 in 2019 dollars). These tools were designed and manufactured to HP's usual stunning engineering and quality standards.

I have two HP 545A probes; #1 was manufactured in Oct 1978 and #2 was manufactured in Dec 1987.

The specifications are (from a November 1976 HP manual 00545-90004):

Input current	≤ 15 µA (source or sink)
Input capacitance	≤ 15 pF

Logic thresholds	TTL: Logic ONE 2.0 +0.4, -0.2 Vdc TTL: Logic ZERO 0.8 + 0.2, -0.3 Vdc CMOS: Logic ONE 0.7 × V_{supply} ± 0.5 Vdc CMOS: Logic ZERO 0.3 × V_{supply} ± 0.5 Vdc
Input minimum pulse width	10 ns with ground lead (typically 20 ns without ground lead)
Input maximum pulse repetition frequency	TTL: 80 MHz; CMOS: 40 MHz
Input overload protection	±120 V continuous (DC to 1 kHz); ±250 V for 15 seconds (DC to 1 kHz)
Pulse memory	Indicates first entry into new valid logic level; also indicates return to initial valid level from bad level for pulse ≥ 1 μs wide.
Power requirements	TTL: 4.5 to 15 Vdc CMOS: 3 to 18 Vdc Maximum current: 70 mA Overload protection: ±25 Vdc for 1 minute
Temperature	0 to 55 °C
Weight	113.4 g (4 oz) net; Shipping weight 170 g (6 oz)
Size	Probe body, 15.24 cm (6 in); Cable 119.38 cm (47 in)

Some observations about this probe:

- ♦ Since manufacturing of the HP probes stopped a couple of decades ago, the number of working probes will decrease over time, meaning the probes will get more expensive over time.
- ♦ Most of the functionality is in an IC custom-manufactured by HP; there are a handful of other discrete components.
- ♦ It's likely that spare parts aren't available, so if the probe's IC fails, the probe can't be fixed (unless someone engineers a replacement). Instead, you could use the body to build a new probe.
- ♦ The power cord is a bit over 1 m long.
- ♦ In CMOS mode, the probe's logic thresholds track the power supply's ripple up to 1 kHz, allowing better immunity from noisy power supplies.
- ♦ **Probe voltage**: With a 5 V supply in TTL mode, the tip voltage is 1.5 V.
- ♦ **Input impedance**: When the tip is connected to 5 V through an ammeter with 1 kΩ resistance, the current is 9.1 μA. Therefore, the DC input impedance of the probe is around 550 kΩ.
- ♦ **Sharp tip**: The HP probes came with a clear plastic piece of tubing that is slipped over the probe tip. The closed hemispherical dome of the tubing protected you from getting stabbed by the sharp tip. You'll want some kind of substitute if your probe is missing this protector because it's easy to get an accidental stick. Some tubing with a nominal inside diameter of 14.2 mm and around 60 to 70 mm should work. In a pinch, wrap a 3x5 card around tightly the probe and secure it with vinyl electrical tape.
    - ♦ This sharp probe tip unscrews from a 6-32 stud, allowing you to disassemble the probe. In a pinch, a hobbyist could make a new tip by soldering a sewing needle into a chunk of brass that was tapped, then potting the thing in epoxy. HP made two styles of tips: the stock straight one and one with a near-90° bend.
- ♦ **Visible bulb**: An advantage of HP's design is that you always can tell when the probe is powered on because the incandescent bulb is at its dim level when the probe isn't connected to anything. This helps me find the probe on a messy work surface. A concomitant disadvantage is that the probe won't operate as long from a battery as a probe like the RSR 611.

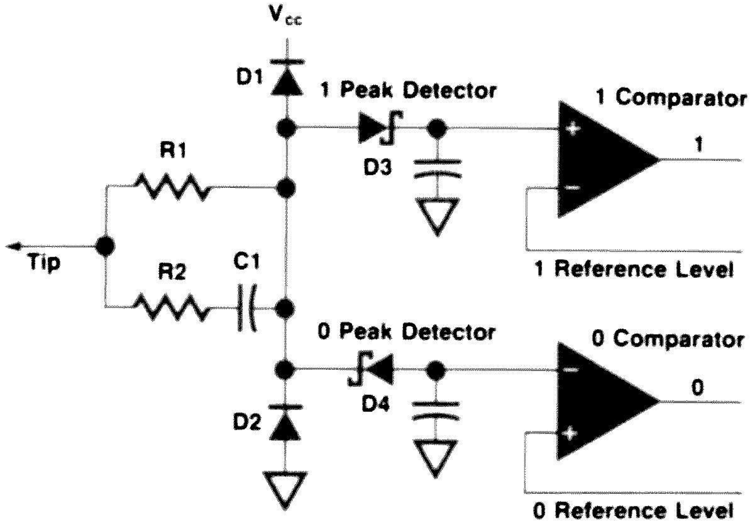
  - ♦ I can see the incandescent bulb from any orientation of the probe about its longitudinal axis. With other brands of probes, you have to rotate the probe until the LEDs become visible.
- ♦ **Transfer function**: In TTL mode, the transfer function is simple. The probe indicates logic low for tip voltages with respect to power supply ground of less than 0.8 volts (including negative voltages), logic high for voltages greater than 2 volts, and open circuit (indeterminate state) for any other voltages. See the figure below for the CMOS transfer function.
- ♦ **5 volt supply behavior for the #2 (Dec 1987) probe**
  - ♦ TTL mode:
    - ♦ The probe draws 38 mA for an open circuit (44 mA if the memory LED is on). Connected to a low signal so the indicator bulb is off, 29 mA is drawn. On a high signal with the indicator bulb brightly lit, the current is 52 mA. The latter two measurements are with the memory LED off.
    - ♦ The probe's light flickers between the low level state and the open state light at 0.88 V. It flickers between the open state light and the high level at 1.9 V and switches to a solid high indication at 2 V.
  - ♦ CMOS mode:
    - ♦ The probe draws 34 mA for an open circuit (41 mA if the memory LED is on). Connected to a low signal so the indicator bulb is off, 17 mA is drawn. On a high signal with the indicator bulb brightly lit, the current is 42 mA. The latter two measurements are with the memory LED off.
    - ♦ The probe's light flickers between the low level state and the open state light at 1.61 V. It flickers between the open state light and the high level at 3.4 V and switches to a solid high indication at 3.45 V.
- ♦ **Other power supply voltages**
  - ♦ This is the only commercial logic probe I know of that can be powered from a 3.3 V power supply to use on 3.3 V digital logic.
    - ♦ My #2 probe works at power supply voltages in TTL mode down to 2.2 V, although the incandescent bulb is quite dim. At 3.3 V it correctly indicates TTL states (thresholds are 0.83 V and 1.97 V) and blinks on a 3.3 V amplitude 5 MHz pulse waveform of 16 ns wide pulses. I could power it with two 1.5 V batteries if needed, but three 1.5 V batteries work better.
    - ♦ You can use other probes like the RSR 611 logic probe to troubleshoot 3.3 V digital logic. Power the probe from a 5 V power supply and tie the grounds together.
  - ♦ The TTL position of the TTL/CMOS switch honors TTL voltage levels pretty well for all allowed power supply voltages (see the plot below) . This is because the custom IC had a voltage reference in it. Most logic probes use a voltage divider on the power supply to get these threshold voltages, so the TTL thresholds change with the power supply voltage. If I'm using the HP 545A probe and the mode switch is in the TTL position, I know a low logic state is less than 0.8 V and a high logic state is greater than 2 V.
  - ♦ You can power the logic probe from a different DC power supply than the circuit you're testing; the two power supply grounds must be connected together.
  - ♦ Current draw of probe #2 as a function of supply voltage and tip state (* the inflection point in the last column is real):

	mA			
V	Low, mΩ off	Low, mem on	Open, mem off	High, mem off
2.5	18.1	25.3	27.6	30.6
3	18.7	28.1	30.6	34.4
3.3	19.0	28.4	32.0	36.3
3.5	19.1	28.5	32.9	37.5
4	19.5	28.8	35.2	40.2
4.5	19.7	29.1	37.2	42.8
5	20.0	29.3	38.1	45.3 *
9	22.0	31.1	40.2	45.2 *
12	23.4	32.4	41.7	46.7
13.8	24.3	33.1	42.7	47.7
15	24.8	33.4	43.3	48.4

    - The memory LED draws about 6 to 9 mA depending on supply voltage and tip state.
    - Three AA batteries in series can be used to power this logic probe. If we assume the probe draws about 30 mA most of the time, three Duracell alkaline AA battery should last for approximately 30 to 40 hours of use. You can get three AA batteries for about $1.
- Pulses are stretched to 50 ms and pulse trains of higher frequency than 10 Hz are displayed at about 10 Hz.
- The pulse memory records transitions between any of the three states low, high, and open. **You don't need pull-up/pull-down resistors to latch on intermittents**. I consider this one of the probe's most valuable features. However, for conductor tracing, it can be a detriment -- see *RSR 611 preferred*).
- The probe pulsates to some AC voltages that are fully below ground. This doesn't usually cause a problem, but it's something to be aware of. The RSR 611 probe doesn't respond to such signals.
- **Blinking on an unconnected conductor**
    - When putting the probe's tip on a conductor that's not connected to anything, the probe will virtually always blink. I assume this is due to charging or discharging a stray capacitance. It's not trivial to predict how the probe will blink. The probe's tip is always around 1.5 V. Sometimes touching the same conductor sequentially will result in open to low transitions, sometimes open to high, occasionally no transition. Interestingly, it won't transition when touched to my skin when I'm connected to the 5 V or ground (I assume this is due to my large skin resistance). On a 25 m roll of 24 gauge 4 conductor telephone cable, I'll get a blink on every conductor, every time. I get a blink when touching the ungrounded engine of our van.
    - I rely on this behavior to indicate a conductor that is not connected to anything. **I find this an enormously useful feature** because the blink is very noticeable.
    - In the summer of 2017 when building my sprinkler controller, this feature alerted me that a wire was accidentally unconnected.
    - When I power this HP probe from either a bench DC power supply or some batteries, it always blinks when I turn my fluorescent desk lamp on or off. This demonstrates it's pretty sensitive through its high input impedance.
- **Pulses**: The probe will detect TTL pulse trains at up to 80 MHz and CMOS pulse trains to 40 MHz. It will also detect 10 ns wide pulses when used with the auxiliary ground lead (20 ns without the lead).
    - HP 545A logic probe #1 responded up to a 44 MHz and #2 to 47 MHz TTL pulse trains. An HP 10525T logic probe responded to 49.8 MHz. These tests were done without the auxiliary

ground lead and with a B&K 4076 50 MHz function generator producing suitable square waves. As usual, HP's specs are conservative.

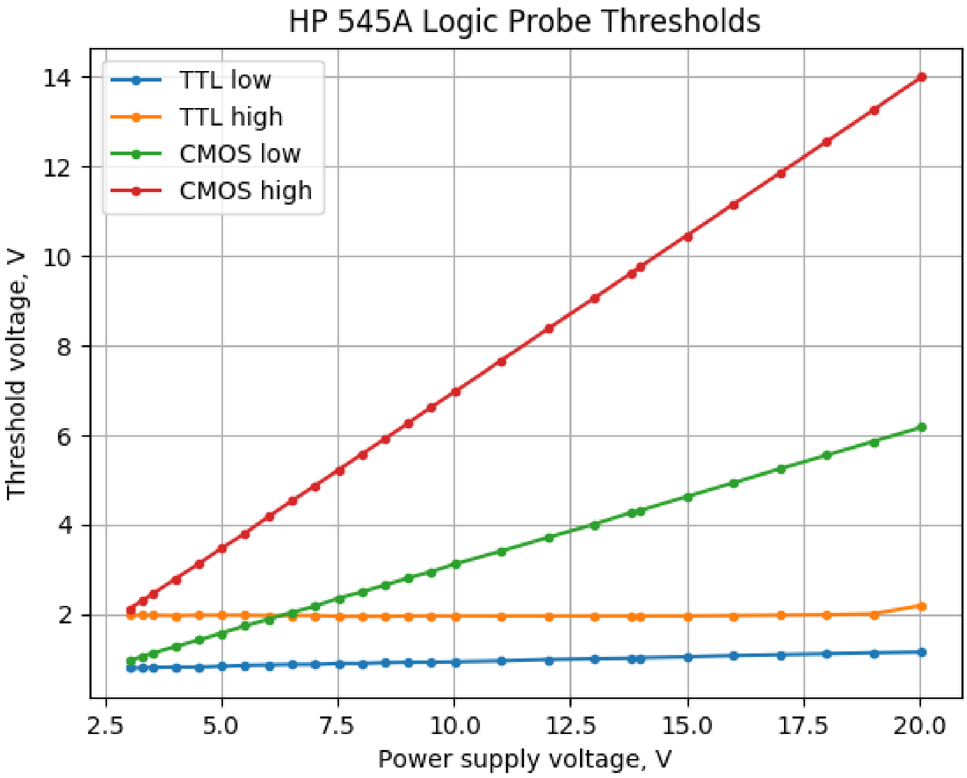
- **Input protection**: The probe's input will withstand 120 V indefinitely and 250 V for up to 15 seconds. I find this probe useful for finding AC line voltages on conductors around the house. Here's a diagram from [*hpj1976*] showing the input protection for this probe:



The schematic gives R1 as 20 kΩ or 24 kΩ (depending on manufacturing version), R2 as 130 Ω, and C1 as 47 pF.

- **Powering the probe**
  - In the production probes, the end of the power supply lines connected to HP grabber hooks. These are easy to lose (they connect to IC leads nicely, but are problematic on larger conductors). I installed some Cal Test solderless CT3276 banana plugs over the brass ends on the cords. This lets me plug the probe into a plastic box (see *Logic probe power*) that contains three AA batteries in series or plug the probe into a DC power supply.
  - I converted the other HP probe to use a 2.1/5.5 mm plug for power. There are adapters to e.g. USB connections and others that would then let the probe be conveniently powered.
- **Indicating ground through a resistance**
  - Logic probe #2 had a tip voltage of 1.5 V in TTL mode (2.5 V in CMOS mode) with a 5 V supply. Since the input current (either source or sink) to the probe is about 10 μA (10 times less than its model 10525T predecessor), this means a resistance on the order of about 150 kΩ is the threshold of where ground can be detected for TTL mode.
  - The measured current through an ammeter connected to ground from the probe's tip in TTL mode was 12.3 μA (the ammeter's resistance was 1 kΩ). This implies the resistance should be 121 kΩ. An experiment showed that a ground could be detected through a 99 kΩ resistor, but not a 116 kΩ resistor (the two closest values I had on-hand).
  - If you use the probe for checking continuity to ground in TTL mode, all you can say is that the resistance is about 100 kΩ or less if it indicates continuity.

Here's a graph of measured voltage threshold values for the HP logic probe:



The graph shows that the TTL thresholds stay pretty constant as a function of power supply voltage (the probe's manual mentions the low threshold rises slightly with increasing power supply voltage).

Though I like using the HP logic probes, I also use my RSR 611 logic probe. The RSR probe's red/green LEDs are slightly more expressive and responsive than the HP probe's incandescent lamp. I'm happy troubleshooting things with either logic probe model. For high speeds or needing to latch on any transition, I'll use the HP probes. For tracing wires or battery operation, I'll use the RSR probe. The HP probes don't leave my bench because they would be expensive to replace if lost or broken. The RSR probes are lightweight and handy to take places for battery operation.

HP 10525T

Before the HP 545A logic probe was introduced, HP sold the 10525T logic probe (introduced in the 1973 HP catalog on page 106). The 10525T is a 5 V DC only logic probe that uses a BNC connector for power. There are no controls on the probe and it is only usable on TTL circuitry. Like the 545A, it used an incandescent lamp for display, but it's white instead of red (the 545A used a red plastic filter). If you're only going to work at TTL levels, it's an excellent probe. The input is protected to ±70 V continuous and 120 V AC for 30 s. It's a 50 MHz probe.

Specifications from 10525T manual dated Feb 1975:

Probe lamp indications with positive logic	Logic ONE: "Bright". Logic ZERO: "Off". Between ZERO and ONE: "Dim".
Positive logic threshold voltages	Logic ONE: 2.0 ± 0.2 volts, logic ZERO 0.8 +0.2 -0.4 volts.
Input impedance	Greater than 25,000 ohms (input characteristics are similar to low power TTL integrated circuits).

Probe lamp indications with positive logic	Logic ONE: "Bright". Logic ZERO: "Off". Between ZERO and ONE: "Dim".
Pulse width sensitivity	(minimum input pulse duration for probe tip lamp indication): 10 nanoseconds (a 5 nanosecond input pulse will typically give a lamp indication). A ground clip is required for best pulse width sensitivity. Without a ground clip the positive pulse width sensitivity is typically 10 nanoseconds and the negative pulse width sensitivity is 15 nanoseconds. NOTE: the indication is an approximately 50 millisecond lamp flash. ON for positive pulses and OFF for negative pulses.
Maximum input pulse repetition frequency	Greater than 50 MHz.
Input overload protection	(allowable input overloads): ±70 volts dc maximum continuous; ±200 volts dc transients; 120 volts ac for 30 seconds.
Power requirements	+5 Volts dc ±5% at 60 milliamperes (the probe is protected against supply voltages between +7 and -15 at the power input connector). VOLTAGE CAUTION: Probe DAMAGE will occur with power supply potentials more positive than +7 volts or more negative than -15 Volts.
Operating environment	0 °C to 55 °C.
Weight	2½ ounces.
Size	Probe body, 6 inches; cable 3.5 feet.
Accessories provided	Ground clip and BNC-to-alligator adapter.
Options available	*Option 005: Tip Kit (10525-60012)* -- Straight Tip, Hooked Tip, Spring Tip, Banana Tip, Back Plane Adapter, Dual Banana-to-BNC Adapter. *Option 006: Pulse Memory (10525-60015)* -- A small box connected between the Probe and the +5 Volt power source. The Pulse Memory stores the occurrence of a transient pulse.

This particular logic probe came in the HP 5015T logic troubleshooting kit with manuals, the model 10526T logic pulser, the model 10528A logic clip, and a few accessories. The ground clip for the probe is similar to oscilloscope probe grounding leads manufactured around the same time.

This probe is the predecessor to the 545A probe and works on 5 V TTL logic only. It's a capable design and should do the same things you can do with the 545A probe in TTL mode except latch on logic transitions. Like the 545A probe, it has the **useful feature** of blinking its light when it is connected to a conductor that is not connected to anything.

Here are measured data for power supply current draw (4 V is the minimum voltage my probe would operate at):

		mA	
V	**Low**	**Open**	**High**
4	28.8	44.0	57.1
4.5	34.9	50.2	64.4
5	40.8	56.0	72.3
5.5	46.5	62.0	80.2

The probe blinks on 16 ns wide pulses at 5 MHz when the peak amplitude is 2.0 V, but not at 1.9 V.

It also blinks on the logical complement of this pulse train -- and continues to do so when the low level of the train is raised to 0.78 V.

The voltage at the probe's tip is 1.60 V when measured with a voltmeter with an input resistance of more than 10 GΩ. When the probe tip was connected through an ammeter to ground, the current was 101.0 µA. This implies the probe will indicate ground through a resistance less than 15.8 kΩ (the measured threshold was 16.2 kΩ).

If you want an HP545A logic probe and can't get one, the 10525T is nearly as good except for lacking the memory feature and only working on TTL logic with a 5 V supply.

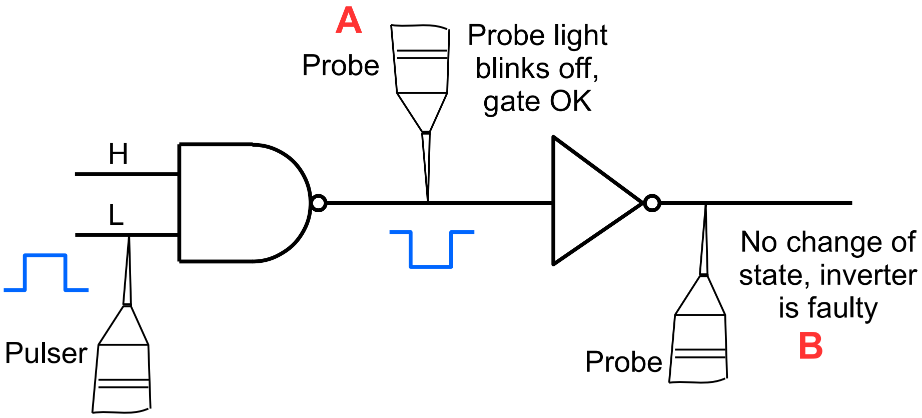
HP 10526T logic pulser

This pulser is an adjunct to the 10525T logic probe. A pulser forces a digital line to the opposite state for a short period of time (on the order of a microsecond), which avoids significant heating due to extra current. The logic probe can indicate this state transition.

Specifications from the 10526T manual dated March 1974:

Pulse voltage, HIGH output	2 volts at 0.65 Ampere (1 A typical at Vps = 5 V, 25 °C)
Pulse voltage, LOW output	0.8 volts at 0.65 Ampere (1 A typical at Vps = 5 V, 25 °C)
Output impedance, active state	2 ohms
Output impedance, off state	> 1 Megohm
Pulse width	0.3 microsecond nominal
Input overload protection	±50 volts continuous
Power supply input protection	±7 volts (includes power lead reversal protection)
Power required	5 Volts ± 10% at 25 milliamperes
Temperature	0° to 55° Celsius
Accessories supplied	Power supply connector adapter: BNC-to-dual alligator clips Common return clip: Clip lead for probe-to-alligator clip
Options available	Opt. 004 -- Multi-pin Stimulus Kit (Pulser tip to four clip leads), 10526-60002 Opt. 005 -- HP Tip-Kit, part number 10525-60012, includes one of each of the following parts: Probe Tip (Wire Wrap Terminal 0.1") Probe Tip (Banana) Probe Tip (Bent 90° Std.) Probe Tip (Flexible Lead-Pin (.025") Terminal Receptacle) BNC-to-Dual Banana Plug Probe Tip (Straight)

The instruction manual gives the following illustration:



At **A**, suppose the logic probe is on the output of the NAND gate and the pulser is used to change the state of the gate's bottom input. If the logic probe light blinks, then that demonstrates the gate's output line changed state momentarily.

At **B**, if the inverter's input has been demonstrated to change per the test at A, if the logic probe at B shows no change when the pulser's switch is depressed, then the inverter is bad.

If both the inverter and pulser are connected to the same node and the pulser switch is depressed, if no blink on the logic probe is seen, then the node is either shorted to the supply voltage or ground.

This older pulser works fine with the HP 545A logic probes.

At a 5 V supply, the pulser drew 13.9 mA from the supply. Pressing the pulse button would increase the DMM's current reading by 0.1 mA momentarily.

When this probe is connected to a 10X 150 MHz scope probe on a 200 MHz scope, the pulses are about 400 ns wide when the pulser's button is pressed. Pulse amplitude is 5 V. With the pulser's tip directly on the center conductor of the scope's BNC input connector, the pulse was about 400 ns long, then took 100-200 μs to decay back to zero volts. With a 50 Ω feed-through termination, the pulse was more rounded, reached 4 V, and decayed back to zero in 700 ns. With a 2.2 Ω resistor for termination, the pulse height was 4.5 V and the pulse lasted for 500 ns, decaying to 1.2 V, then decaying back to 0 V in about 250 μs.

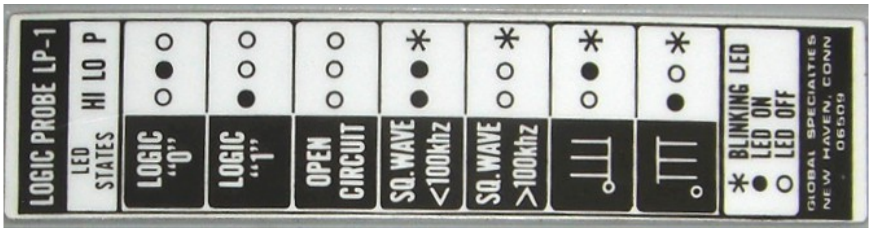
Shorts to the power supply or ground can be found by putting the logic probe and pulser both on a node and pulsing. If it stays high, it's likely a short to Vcc; if it stays low, it's likely a short to ground. The short can be inside an IC or in the circuit you're troubleshooting.

Global Specialties LP-1

This is a plastic body logic probe made by Global Specialties in the 1980's (they used to be named Continental Specialties and are now owned by B&K Precision). They can be found used on places like ebay for $10 to $20.

There are three LEDs to indicate state, labeled LOW, HIGH, and PULSE (later models used red, green, and yellow LEDs). A switch labeled MEM or PULSE is used to latch on transitions and clear them. Another switch chooses DTL/TTL or CMOS thresholds. Here's the internal construction of this probe:

Here's the label on the back showing how to interpret the readings:



LOGIC PROBE LP-1

LED STATES	LOGIC "0"	LOGIC "1"	OPEN CIRCUIT	SQ. WAVE <100khz	SQ. WAVE >100khz		
HI	○	●	○	●	○	○	●
LO	●	○	○	●	○	●	○
P	○	○	○	*	*	*	*

* BLINKING LED
● LED ON
○ LED OFF

GLOBAL SPECIALTIES
NEW HAVEN, CONN
06509

Specifications from the 1981 instruction manual:

Input impedance	100,000 Ω
Thresholds	Switch selectable DTL/TTL HTL/CMOS Logic 1 (HI) 2.25 ± 0.15 70% Vcc Logic 0 (LO) 0.80 ± 0.10 30% Vcc
Min. detectable pulse width	50 nanoseconds
Max. input signal frequency	10 MHz
Pulse detector	High speed pulse train or single events (+ or - transitions) activate 1/3 second pulse stretcher, light PULSE LED
Pulse memory	Switch selectable. Pulse or level transition detected and stored until reset, keeping PULSE LED lighted.
Input overload protection	±40 V continuous, 117 VAC for less than 15 seconds.
Power requirements	5 Volt Vcc @ 30 mA 15 Volt Vcc @ 40 mA 30 volts max, with power lead reversal protection

Operating temperature	0 to 50 °C
Physical size L x W x D	6.05 x 1.0 x 0.7 inches 147 x 25.4 x 17.8 mm
Weight	3 oz 0.085 kg
Power leads	24" (610 mm) with color coded insulated clips.

It has capable speed, as it detected 17 ns 5 V pulses at 5 MHz in TTL mode and the complement waveform of 25 ns dropout pulses at the same speed.

The power cord has insulated alligator clips with a 2.1/5.5 mm plug to the power jack on body. It is 1 m long, although the manual says power leads were only 0.6 m long.

The instructions explicitly tell you to avoid applying more than 30 V to the probe as it will cause destruction of the probe.

Power supply current consumption in TTL mode:

	Current, mA	
State	**5 V**	**15 V**
No LEDs on	12.4	26.3
Low LED on	20.7	57.9
High LED on	20.7	57.8
Pulse LED on	20.3	32.0
Pulse and Low LED on	28.2	76
Pulse and High LED on	28.2	76

Measured thresholds as a function of supply voltage in TTL mode:

	TTL, V		**CMOS, %**	
Supply, V	**Low**	**High**	**Low**	**High**
4	0.67	1.78	31	69
5	0.81	2.23	31	69
6	0.95	2.69	31	69
9	1.40	4.03	31	69
12	1.85	5.38	31	68
13.8	2.13	6.19	31	68
15	2.31	6.72	31	68
18	2.78	8.03	31	68

At 15 V supply in TTL mode, the memory works for open-to-low transitions, but not open-to-high ones. At 5 V, it's just the opposite behavior. The manual is careful to point out that to use the memory feature properly, first put the probe on the node of interest, then arm the memory capture. This is because the probe only reliably latches on low-to-high and high-to-low transitions.

For either TTL or CMOS modes, the probe's tip supplied 14.5 μA through an ammeter connected to ground. The tip voltage was 2.03 V, implying the probe will indicate ground through about a 140 kΩ resistance.

Overall, this is an adequate logic probe for a hobbyist. An annoying weakness is the tip which wobbles when you probe something (it still wobbles even after it's tightened); this will eventually break and will require a hack to fix.

Other logic probes

HP 10525A

The 10525A was the first logic probe HP offered in the 1969 catalog, pg 549 (see *[gg]*).

Specifications were (HP 1970 catalog, page 92):

Input impedance	10 kΩ
Trigger threshold	+1.4 V, nominal
Minimum pulse width	25 ns
Overload protection	-50 V to +200 V continuous, -200 V to +200 V transient, 120 V ac for 10 s.
Power	5 V ± 10% at 75 mA. BNC power connector. Internal overload protection to ±7 V supply.
Temperature	0 to 55 °C.
Accessories included	BNC to Alligator Clips, BNC to banana plug adapter, BNC bulkhead connector, ground cable assembly.
Price	1 to 4 units, $95 ($615 in 2019 dollars); 5 to 9, $90; 10 to 20, $85; for larger quantities, please consult Hewlett-Packard.

The pulses were stretched to 0.1 s. The light flashed on or blinked off, depending on the pulse polarity.

HP 10525E

The 10525E was made for ECL logic systems. Specifications from page 104 in the 1977 HP catalog:

Input impedance	12 kΩ in both high and low state
Logic one threshold	-1.1 V ± 0.1 V
Logic zero threshold	-1.5 V ± 0.1 V
Input minimum pulse width	5 ns
Input maximum pulse repetition frequency	50 MHz (typically 100 MHz at 50% duty cycle)
Input overload protection	±70 V continuous, 200 V intermittent, 120 V ac for 30 seconds
Power requirements	-5.2 V ± 10% at 80 mA; supply overload protection for voltages from -7 to +400 volts.
Accessories included	BNC to alligator clips, ground clip.
Price	$150 ($620 in 2019 dollars)

HP 10525H

The 10525H High Level Logic Probe was for logic systems with 12 to 25 V power supply ranges. It was aimed at HTL, HiNIL, MOS, relay, and discrete logic. Specifications were (HP 1973 catalog, page 107)

Input impedance	> 20 kΩ
Logic one threshold	9.5 V ± 1 V
Logic zero threshold	2.5 V ± 1 V
Input minimum pulse width	100 ns
Input maximum pulse repetition frequency	> 5 MHz

Input overload protection	±70 V continuous, ±200 V intermittent, 120 V ac for 30 seconds
Power requirements	+12 to +25 V at 100 mA. Includes power lead reversal protection.
Temperature	0 to 55 °C
Accessories included	BNC to alligator clips, ground clip.
Option	005: Tip Kit, $15
Price	$95 ($540 in 2019 dollars)

B&K Precision

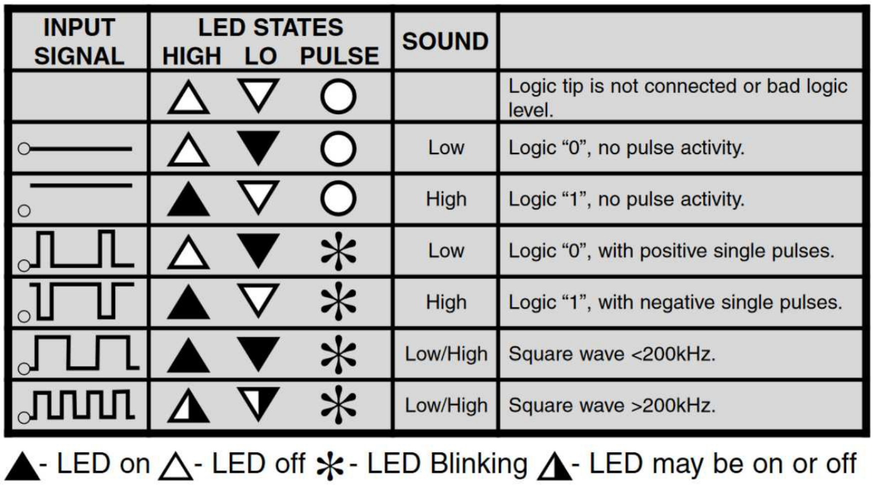
Their DP 21 logic probe looks the same as the RSR 611 probe. Their model DP 31A logic pulser looks the same as the RSR 620 pulser.

Their 50 MHz DP 52 appears to be similarly-manufactured to the RSR and Elenco probes, but I haven't seen a similar model elsewhere (unless it's a stripped-down RSR 625).

Elenco LP560

This is a $25 logic probe that appears to be a similar model to the RSR 610B. See https://www.elenco.com/product/logic-probe/ for more details. A manual and specifications are at https://www.elenco.com/wp-content/uploads/2017/10/LP560-3.pdf.

Here's a diagram comes from the manual explaining the probe's output:



INPUT SIGNAL	LED STATES HIGH	LO	PULSE	SOUND	
	△	▽	○		Logic tip is not connected or bad logic level.
	△	▼	○	Low	Logic "0", no pulse activity.
	▲	▽	○	High	Logic "1", no pulse activity.
	△	▼	✻	Low	Logic "0", with positive single pulses.
	▲	▽	✻	High	Logic "1", with negative single pulses.
	▲	▼	✻	Low/High	Square wave <200kHz.
	◭	⧨	✻	Low/High	Square wave >200kHz.

▲- LED on △- LED off ✻- LED Blinking ◭- LED may be on or off

This diagram also applies to the RSR 611 probe's behavior.

Radio Shack 22-304

A manual is here.

Kit

I've seen $18 logic probe kits on ebay that are a PC board, two LEDs, an 8 pin DIP IC, and a few other components. Don't waste your money on such a thing -- get an RSR 611 logic probe instead, which is a better value.

RSR sells the LP525K kit for about $13 which looks similar to the Global Specialties LP-1.

Eistar

There's also a $10 model with the brand name Eistar the model number LP-1.

It looks identical to the $12 01LPPRO1 probe sold by RSR.

Make a probe

Since I have commercial logic probes, I haven't made the logic probes in this section for real-world use (I've made them on prototyping boards). I think it's best to buy a commercial probe because it will give you a tool better than you can make, at least without consuming a lot of your time designing, building, and debugging. The exception is a logic probe for working on cars in the sunlight, where commercial logic probes are nearly useless.

One of the problems of making your own logic probe is that ***you want it to indicate three states, not two***. These states are high, low, and open circuit. A naive design approach is to use a buffer from the logic family of interest -- but the flaw is the typical gate will return either a low or high output, regardless of the input. What you actually want is a low indication for voltages less than the low threshold, a high indication for voltages above the high threshold, and both LEDs off otherwise. To do this properly requires analog circuitry. A complication is that you need different thresholds for TTL and CMOS circuitry.

You can search the web and find many designs for a DIY logic probe. Use search phrase like ***build your own logic probe*** or ***make a logic probe*** and you'll get lots of hits.

I've been disappointed with most of the ones I've built on a prototype board. I've included in this section some I might build for myself.

Another comment on designs found on the web: many of these don't have the pulse detection or latching feature that the commercial probes have. I use this feature a lot, which is why I recommend the commercial probes. You can get an RSR 611 probe for $20 or less and it will do the things needed, probably better than anything you can design and build in a reasonable amount of time.

If you're going to build your own logic probe, you'll want to read the logic probe article in *[hpj1976]* and particularly look at figure 2 on page 10. Also read the **Inside the Probe** section on page 11.

Simple probe

This simple probe is made from LEDs and resistors:

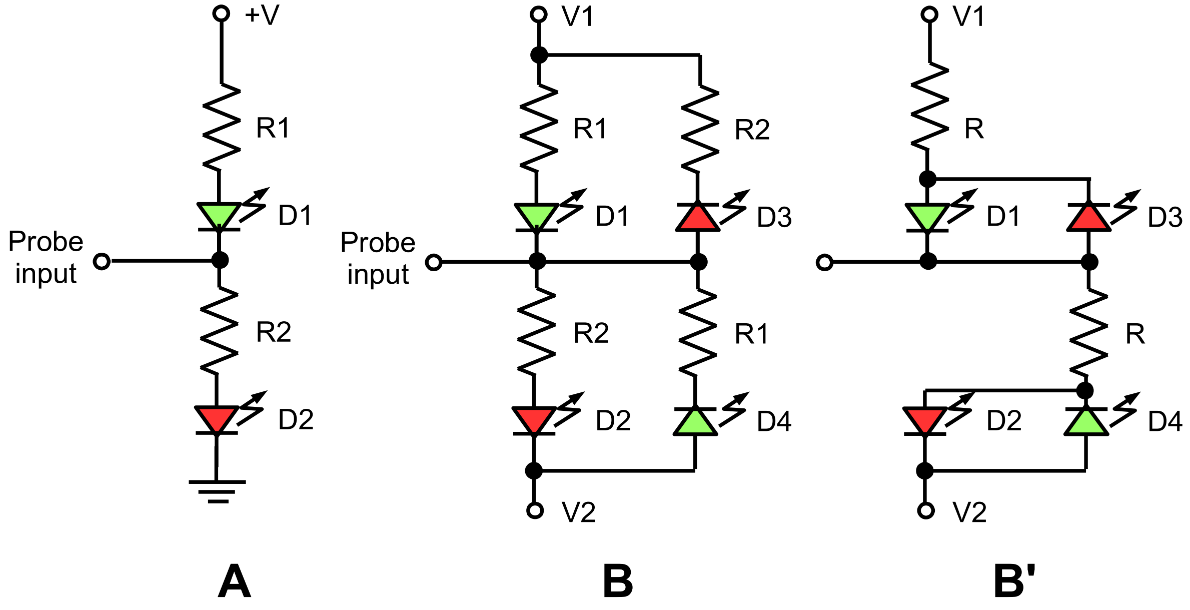


Figure 2

Version A requires the connection polarity indicated (it won't be damaged if you connect things backwards, but the LEDs won't come on). Version B lets you connect the probe to the DC power supply without paying attention to the lead polarity. In both cases, the green LED indicates low and the red LED indicates high. In version B, if you can use the same resistor with both LEDs, then you only need one resistor in each leg as shown in B'.

I've purchased inexpensive (2 cents each) 5 mm diameter LEDs from China; here are their representative voltage drops as a function of current:

Color	1 mA	10 mA	20 mA
White	2.65	3.00	3.24
Blue	2.67	3.09	3.32
Green	2.32	2.71	2.93
Yellow	1.89	2.07	2.16
Red	1.81	1.99	2.07

These LEDs are adequately bright for most tasks at 1 mA and quite bright at 10 mA. Running them at 20 mA makes them almost too bright for most tasks. The green LED is nicely visible at 100 µA. Surprisingly, I've run each of these up to 100 mA without them burning out (my engineering judgment says the yellow and green LEDs should probably be limited to 80 mA).

Example design: For my own use, I'd design these to work at about 20 mA on the 12.6 V battery voltage of a car (this is the typical voltage of a fully-charged lead-acid battery at 20 °C). The green LED will drop 2.93 V at this current, so its resistor needs to be (12.6 - 2.93)/0.02 or 482 Ω. The red LED will drop 2.07 V, so its resistor will be 526 Ω. I have 546 Ω 1/4 W resistors on-hand. The power will be $0.02^2(546) = 0.22$ W, so a 1/4 W resistor will work fine.

This design makes a useful tool for voltages from 3 to 24 V, which covers virtually all of the type of work I do excluding AC line voltages. If I was only testing 3 and 5 Volt stuff, I might halve the value of the resistors to get larger currents for brighter output. Note the resistor was dissipating 1/2 W at 24 V. However, in a logic probe as shown above, there would be two resistors in series along with the two LEDs if they were connected to 24 V and the current would be more than halved, meaning the dissipation would be less than 1/4 W. When the probe is connected to ground or 24 V, it's only for a short period of time, so the resistor should survive. To be safe, though, use a 1/2 W resistor.

This design around the 12.6 V point is nice to use on autos or the 12 V system of an RV.

For AC line voltages, change the resistor to 10 kΩ. Interestingly, the red and green LEDs are still usable with a 10 kΩ resistor at 3 V, although you have to look directly at them to see them. The green LED operates at 75 μA and the red at 120 μA.

Advantages

- ♦ Cheap
- ♦ Low parts count
- ♦ Easy construction
- ♦ Can be used to check for DC or AC power without needing to connect to a power source. For example, in circuit A, connect +V to a 12 Volt connection and the probe to ground and the green LED will light up. Connect +V and ground to a low-voltage AC source and both LEDs will light up.
- ♦ You can use modern high-brightness LEDs and run them at currents under 1 mA, meaning less of a load for the probed circuit and longer battery life.

Disadvantages

- ♦ The LED that is on has its current go through the node you're probing. This can be objectionable for low power or low current circuits.
- ♦ Both LEDs are on for an open circuit. This tells you both LEDs are working, but it will be confounded with alternating voltage inputs unless you can see some flicker.
- ♦ Not very discriminating. For example, the green LED will light up for voltages above ground. However, you can somewhat tell what's going on by how much one LED's brightness increases and the other's decreases.
- ♦ Can't detect pulses or pulse trains faster than about 30 Hz (i.e., the lowest frequency you can visually detect flicker).

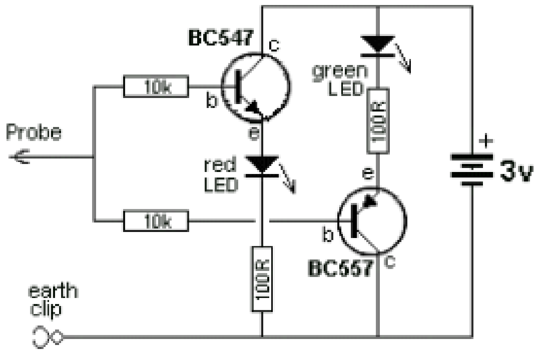
How it works: The two LEDs are illuminated when the input is an open circuit. If you connect the input to a low signal, the green LED will light fully and the red LED will be off because there will be no voltage across the red LED. If you connect the input to a high signal, the red LED will light fully and the green LED will be off because it has no voltage across it. Since this is an analog circuit, connection to other voltage levels will produce intermediate results. Connection to an AC voltage higher than the supply voltage V will cause both LEDs to light up more brightly than the open-circuit case. If the voltage is too high, you'll burn out the LED or resistor.

You can design this to work well for a specific power supply voltage and the LEDs you're using. You need to know the voltage drop across the LEDs at the current level you wish to run them. You find the resistance values as follows. Suppose we want R1. The green diode will be on fully when the probe input is grounded, so the voltage across the diode V_d plus the voltage drop across R1 is equal to the supply voltage V. Thus, $R1 = (V - V_d)/i$.

You can make a low cost emergency logic probe of this design for your car or RV: use a nails for probes (insulate all but the tip with shrink wrap tubing), wrap the resistors and LEDs in insulating vinyl tape, and use e.g. an old USB cable or some zip cord with alligator clips to reach the power supply. It's lightweight and can be stashed away until you need it. It's useful for checking ATC fuses in your RV or car (if only the red LED lights on one side of the fuse and only the green LED lights on the other side of the fuse, the fuse is blown). For checking fuses, an even simpler tester is a single LED and a resistor in series -- if the LED lights when the leads are placed across the fuse, the fuse is blown.

Two transistor probe

I don't know where I found this on the web, but it does work.



SIMPLE LOGIC PROBE

This circuit consumes no current when the probe is not touching any circuitry. The reason is the voltage across the green LED, the base-emitter junction of the BC557, plus the voltage across the red LED and base-emitter junction of the BC547 is approx: 2.1v + 0.6v + 1.7v + 0.6v = 5v and this is greater than the supply voltage.
When the circuit detects a LOW, the BC557 is turned on and the green LED illuminates. When a HIGH (above 2.3v) is detected, the red LED is illuminated.

I substituted a 2N2222 transistor for the BC547 and a 2N2907 for the BC557, as these were what I had on hand. The red and green LEDs were inexpensive 5 mm LEDs that work well in the 1 to 5 mA range. I ran it at 4.5 V and got 8 mA through the green LED when the probe was grounded and 13 mA when the probe was connected to the 4.5 V supply. The high threshold was 2.1 V and the low threshold was 1.9 V, so it could use a lower low threshold. At 5 V input, the current was 16 mA. I ran the input voltage up to 6.5 V and it saturated the current at 23.3 mA; then I ran the input voltage up to 31 V and it stayed at or below this maximum current. Thus, I'd feel confident using the probe on a 12 automotive system.

Threshold logic probe

A threshold logic probe uses an op amp or comparator to decide whether an input voltage is above or below a threshold. Two LEDs indicate high or low state; with both LEDs off, it's the open circuit state.

If you think you might want to build a probe using this type of design, I recommend you read the article on the HP 545A logic probe in *[hpj1976]*, as you may want to copy some of the input design details.

Advantages

- ♦ Simple construction: one IC, three pots, two resistors, two LEDs.
- ♦ Good discrimination -- makes an effective GO/NO-GO voltage tester
- ♦ High impedance: draws little current from probed node
- ♦ Low power consumption when LEDs are off (i.e., input is floating)
- ♦ You can set logic thresholds precisely with a voltmeter

Disadvantages

- ♦ Low speed: not effective on pulsating voltages above audio range (but see the peak detection input technique for the HP 545A in *[hpj1976]*).
- ♦ No pulse detection

Here's the circuit I used; the pin numbers are for the LM2904 dual op amp, as that's what I had on-hand. The three pots were 1 MΩ 10-turn trimmers. This should operate from 3 V to 26 V for V+. The input protection diodes D are optional.

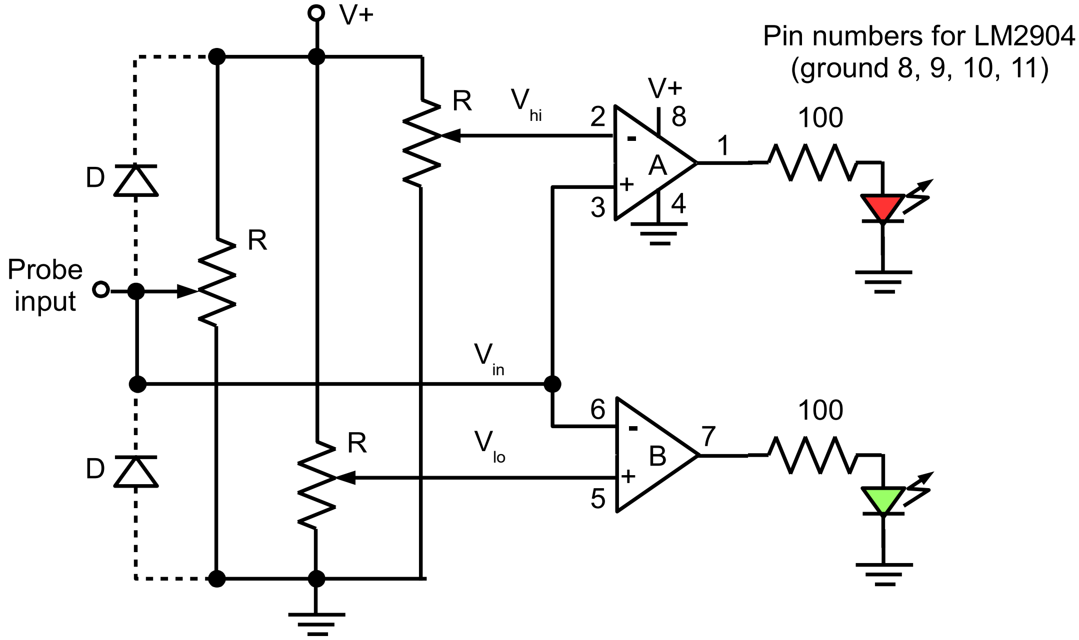
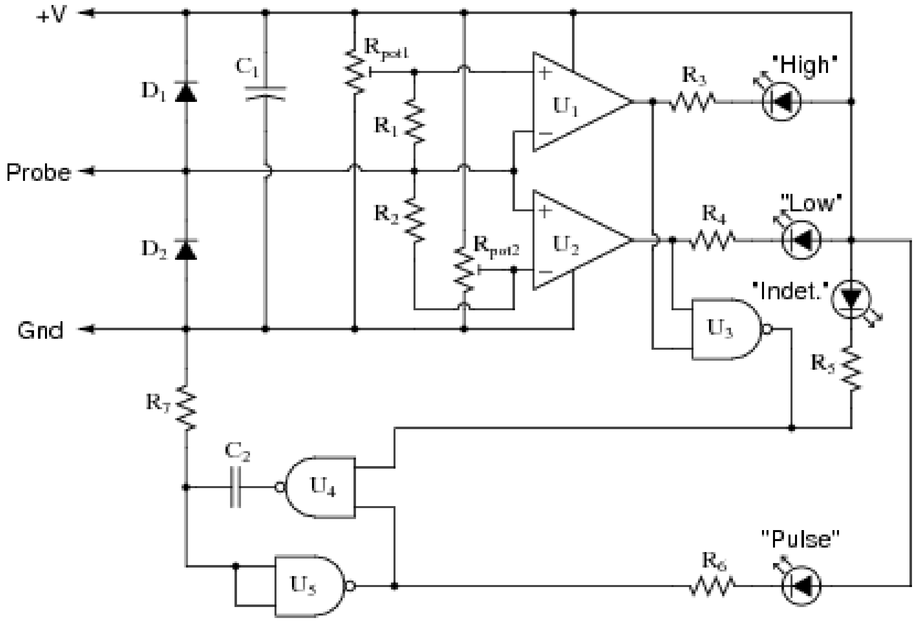


Figure 3

Performance: At a 5 V supply with the LEDs off, the quiescent current is less than 1 mA (2 mA at 26 V) and with one LED on, 8 mA. Eliminating the 100 Ω resistors in series with the LEDs resulted in 37 mA (43 mA at 26 V) through the LEDs. The transitions in the LED on to off or off to on are sharp and happen over a few mV. Minimum operating voltage is about 3.3 V. The LEDs indicate an alternating voltage for square waves up to around 35-40 kHz (you don't see flicker, but rather both LEDs are on simultaneously).

[aac] (https://www.allaboutcircuits.com/worksheets/design-project-logic-probe/) gives a similar logic probe design with a pulse stretcher:



Read the web page for hints about the design. R1 and R2 are 1 MΩ to force an indeterminate state so that the probe doesn't turn on an LED when it's not touching anything.

I would put fixed resistors in series with the two pots to let them adjust to e.g. 50% to 100% of Vcc for the high and 0% to 50% of Vcc for low. They could be marked for quick setting for TTL and CMOS levels. (16% for low, 40% for high for TTL; make the low mark on the high pot equal to the TTL level when the power supply is 5 V).

Note the LEDs are tied to V_{cc} because op amps or comparators can sink more current than they can source. With modern ultra-bright LEDs that can be run at 1 mA, this isn't a big deal and you can connect the LEDs how you please.

Logic probe safety

There's little that's inherently unsafe about a logic probe. About the only things I can think of are poking yourself with the sharp tip, pinching yourself with an alligator clip, swallowing the probe, or garroting yourself with its power supply leads. Safety problems come about when the probe is used on circuits which might have dangerous voltages.

"Dangerous voltage" is not a well-defined term. The most conservative statement is that all voltages can be dangerous (it depends on the context). It's just like asking "What's a safe speed for traveling in a car?" -- the answer depends on the context.

> You might think 200 mV is a safe voltage. What if it was directly applied to your heart muscle (see *[bikson]*)? Oh, then 10 mV must be safe. What if it was applied to neurons in your brain that controlled your jumping muscles while you were standing on the edge of Yosemite Falls? I would label a voltage as safe only if a brilliant highly-motivated evil Nazi sadistic torturer was told to hurt someone with that voltage and failed after months of diligent experimentation with lots of overtime.

Another way to think about the dangers from voltage concern the energy that can be delivered from a circuit. A good example is a car battery -- most folks think that the nominal 12 V car battery is not a voltage hazard. However, a person working on a car who shorts the positive battery terminal to ground with a ring on his hand can get a painful burn. Or, the reaction to a shock can be what injures you: I once got a tingle from some electrical device and my involuntary jerk away from the shock caused me to get a nasty cut on my arm from an exposed sharp piece of sheet metal.

> Humans unfortunately want to be given "safe" limits with the thinking that safety is digital: any condition less than the "safe" limit is safe and anything over is hazardous. For example, an RV trailer will have a

label giving the gross vehicle weight rating (GVWR), which is the maximum allowed weight of the trailer and everything in it. The trailer doesn't magically become unsafe just after the GVWR is passed -- nor is an underweight trailer safe if the driver towing the trailer does risky maneuvers.

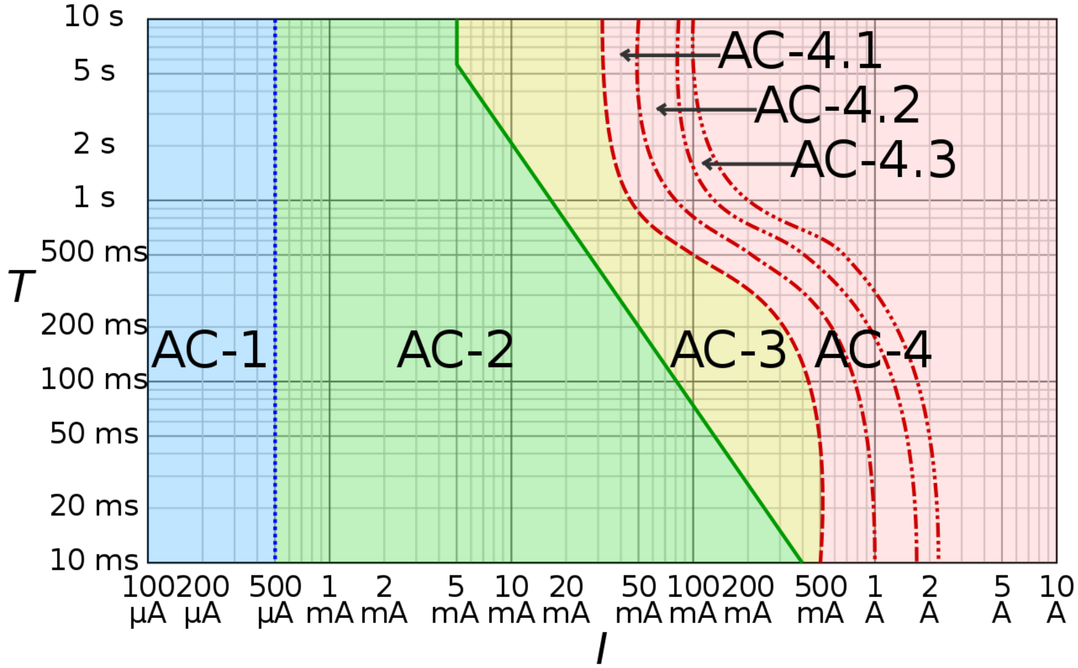
OK, we'll acknowledge the limits are wide, but how about some practical limits? Common industrial thinking is that voltages below 30 V RMS and 42.4 V DC are defined to be "low voltage" circuits. The zero-to-peak value (i.e., the mathematical amplitude) of the RMS value of a sine wave is the RMS value multiplied by $\sqrt{2}$, which is where the 42.4 V comes from (30 times the square root of 2). Consult *[lv]* for other levels.

My personal definitions are a bit lower, based on decades of not getting any fatal shocks. I use 24 V RMS at line frequency as my definition of when things transition from low to high voltage. Many wall warts that provide 24 V AC power actually provide an output a few RMS volts higher under no load and light load conditions, so I relax my definition a little. I also define DC voltages above 31 V as being high voltage (this is the maximum output of two of my bench power supplies).

Note I'm not labeling these "low voltages" as safe, as you can still be electrocuted by them (worst-case resistance across the human chest can be less than 100 Ω *[bikson]*). Recently (July 2017) I got an accidental shock from the 24 V AC of my sprinkler system -- I thought I was getting poked by the sharp end of a cut copper wire, but it was actually a tingle from 24 V AC (I had mislabeled a schematic a few decades before and thought I was touching an unenergized wire).

Though I've indicated that you can use a logic probe to check for presence of line voltage in power outlets, this is a task only for an experienced person who understands the risks and potential problems. If you're a newbie, stick with low-voltage DC systems and still be careful -- remember, you're only allowed one fatal electrical shock in this life.

The following illustration that shows the effects of alternating electrical current *[wpiec]*:



The horizontal axis *I* is RMS current and the vertical axis is the time duration of the alternating current. The nomenclature of the colored regions is

AC-1: imperceptible
AC-2: perceptible but no muscle reaction
AC-3: muscle contraction with reversible effects
AC-4: possible irreversible effects
AC-4.1: up to 5% probability of ventricular fibrillation
AC-4.2: 5-50% probability of fibrillation

AC-4.3: over 50% probability of fibrillation

The AC-4 region is where ventricular fibrillation can occur and the risk of death is significant. Note the current through the body and heart are the important metrics; the voltage level at which this occurs is irrelevant. This is why it's hard to define "safe" voltage levels.

Usually, a key requirement in being able to understand the behavior of a system is you need to have an accurate schematic of the circuit. Alas, in fixing things around the home, this often isn't possible. Before jumping in with a logic probe, your best strategy is to use more capable tools like an oscilloscope, a digital multimeter, or a non-contact voltage sensor and safe probing strategies to satisfy yourself that it's safe to explore this system with a logic probe. **Assume everything has a lethal voltage on it until proven otherwise**. Even if you have a schematic, you need to assume that the system could have a fault, leading to lethal voltages on conductors. Note there are ways of this happening on AC-line-powered devices **even with the power switch off**. Also ask where your measuring equipment could be telling you something that isn't correct, forcing you to make an incorrect decision (see *Binary decisions*).

A second strategy is to assume your measurement equipment isn't working or it failed while you were making the test. When I am about to work on a line-powered circuit in my house (i.e., touch conductors that could have a lethal voltage on them), I use both my digital multimeter and a non-contact voltage sensor. I first check them on a known-working circuit. To be cautious, check them again **after** making the measurement to make sure they didn't fail during the measurement you're using to decide whether to risk your life or not.

Check for both lethal AC and DC voltages. Unless you have a multimeter that measures "AC+DC" voltages (i.e., a "real" RMS measuring tool), this requires two separate measurements or the use of an oscilloscope.

Overly conservative? Maybe -- **it's your call and your life**. I've had some close calls in my life that make me want to use these conservative techniques.

The safety rules for working on electrical stuff are written in blood, meaning people have died when these rules weren't followed.

Automotive logic probes

There are various logic probes sold for servicing automobiles. I haven't used any of these, but from what I can tell, there are two basic types.

The first type is a clear plastic handle with a sharp steel probe. Inside the handle are a red and green LED indicators. The probe connects to a vehicle's battery and displays an indication when the probe's tip is connected to battery voltage or ground, just like a regular logic probe. They sell for about $10 to $30 and are usually labeled "computer safe", but fail to explain exactly what that means. I'd guess they mean the current drawn from the circuit being tested is low so that sensitive computer circuits aren't damaged.

A second type of probe adds a switch that lets you connect battery voltage or ground to the tip; this allows you to have current flow through a component to test it. For example, if you wondered whether a tail light bulb was working, you'd put the probe's tip on the bulb's lead and press the switch to provide power. This latter feature is in probes similar to those marketed under the brand name Power Probe (and there are a number of knockoffs). Various models add features like a white LED for illumination, voltmeter, ohmmeter, and ammeter, along with more specialized automotive tests. The wiring is protected by a circuit breaker.

There are different models of this second type of probe that range from $40 to hundreds of dollars. Here's one for about $70, but lacks a decent description of capabilities on its web page. Here's a homemade knockoff. Here's a $30 unit that might be suitable for occasional use.

Technical documentation on these products is poor or non-existent and the manufacturers I've contacted don't respond to email, so I am unable to indicate how they typically work or give representative specifications. My overall assessment is it's over-priced stuff that an electrical hobbyist can do without, but the stuff may pay for itself fairly quickly for a professional mechanic. As a hobbyist, you can make stuff that works just as well and use it with a DMM or commercial logic probe. If I worked on cars a lot, I might buy one. Though I describe them as over-priced, that doesn't mean they're not powerful tools.

The first thing I do when working on a vehicle with my DMM is to set the range so that I see voltage measurements to the nearest 0.1 V. That's all you need for most problems. It keeps useless information (extra digits) out of your brain. The ability to connect Vcc and ground to the point being tested are powerful tools, letting you see current draw or trace a short.

These probes can do similar things that you'd do with an electronic tester. For example, to test that you have a good ground connection, apply the probe tip to the wire and press the switch to apply battery voltage to the wire. The circuit breaker may trip on a good ground. The thing you're looking for is to see that the logic high indicator (near battery voltage) doesn't come on. This is the identical test for a short using a logic probe and pulser, although the duration of the high current will be much longer.

Logic probe power

If you'll use your logic probe mostly for testing 5 V logic, consider replacing the power cord with a USB cord with a standard USB connector on it. This lets you plug the logic probe into any handy USB connector to get power. Make an adapter that converts from USB to two alligator clips for when you e.g. need to connect to a power supply. There are also compact line power to USB power devices that would let you power such a probe from the AC line (e.g. a charging plug for a smart phone). Be careful with exposed wires, as you could damage the USB device if you short the leads. You could also use the ubiquitous wall warts used for charging cell phones, although you may have to hack a suitable connector.

A useful connector is the coaxial 2.1/5.5 mm plug often used on wall-warts. I find these useful for powering a logic probe (see *2.1/5.5 mm plugs and jacks* below.

> A disadvantage of these types of plugs is they can be pulled out accidentally while you're working. If this happens, a retainer can be made from e.g. a piece of string or rubber band. Or, find an old wall wart with a 2.1/5.5 mm right-angle plug made for panel mounting -- these are harder to pull out with an axial pull.

You can buy cords such as the following:

With a suitable 2.1/5.5 mm jack on your logic probe, this would let you power the probe from USB ports on computers, a USB hub, or 120 VAC to USB charging devices. Or, power your probe directly from a 5 V to 18 V wall wart that has a 2.1/5.5 mm connector.

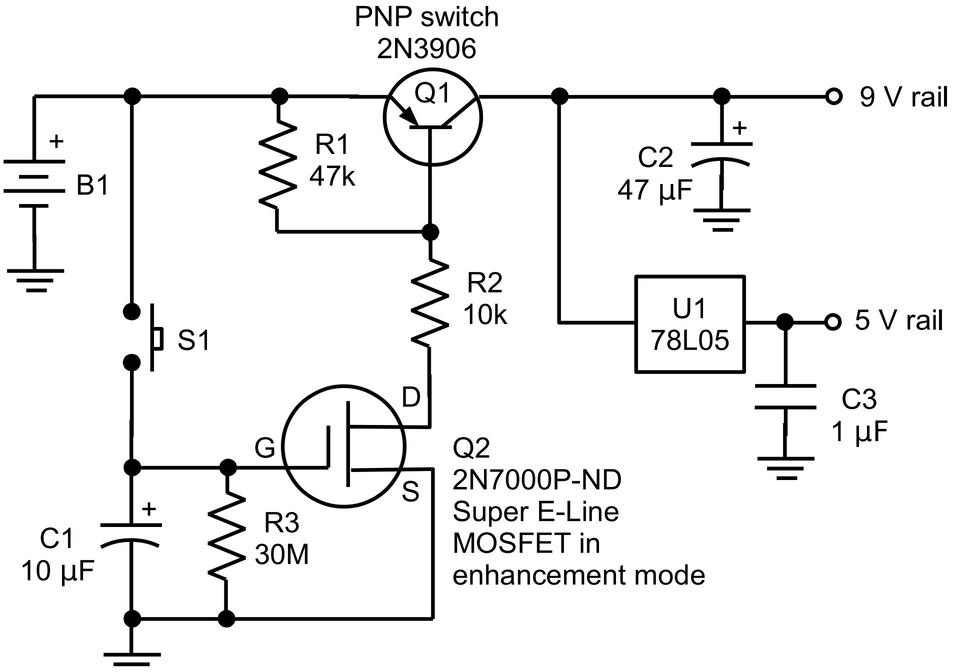
As mentioned in the RSR 611 section, a 9 V battery could be a good source of power for the RSR probes because they only draw about 1 mA when the LEDs aren't on (the RSR 610B draws 2 mA with no LEDs on, but 70 mA with speaker on with yellow and red LEDs on). The HP 545A probe isn't a good choice here, as it draws 40-50 mA for the open state (you can still use a 9 V battery to power the HP probe, but it will probably only last a few hours).

Also as mentioned in the RSR 611 section, the RSR probe's ability to show an open-to-low pulse seemed to work best in CMOS mode with an 18 V power supply, which could be gotten with two 9 V batteries.

A nice design for the RSR probe would be to wire the probe to a plastic box with a 9 V battery (or maybe two of these for 18 V), a power switch, a 2.1/5.5 mm jack, and two banana jacks. The 2.1/5.5 mm jack would allow you to power the probe with an external wall wart; you'd use the switch in the jack to disconnect the battery. The banana jacks allow you to connect the negative battery terminal to a ground reference when desired and the other banana jack would supply +9 V through a 100 kΩ resistor for a current-limited (9 µA maximum) logic high signal. These jacks also let you quickly test that the probe's LEDs are working. I'd keep this in a zippered case with some leads and alligator clips for convenience. This would be handy for quick testing of automotive/trailer stuff and general-purpose tracing.

Instead of banana jacks, all that's really needed would be some small round head screws you could connect to on the box with alligator plugs. This cuts down on needed space, as 4 mm banana jacks take up a fair bit of room, especially the dual style I like to use with 3/4" spacing.

A disadvantage of this 9 V battery power for a logic probe is that you're going to forget to turn it off sometime, meaning the battery will be dead the next time you try to use it. Around our house, 9 V batteries are used seldom enough that they can be hard to find, as they don't get on shopping lists very often. A useful design would be a push-button switch that turned the power on and kept it on for a timed period. Here's a circuit that does this (it's used by a friend in his production products[2]):



B1 = 9 V supply ⇒ 17 minutes ON time
B1 = 6 V supply ⇒ 12.5 minutes ON time

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[2] It was designed by Carl Miller, an EE who passed away in the late 1990's.

You could include a modern high-brightness LED running under 1 mA to indicate the power was on.

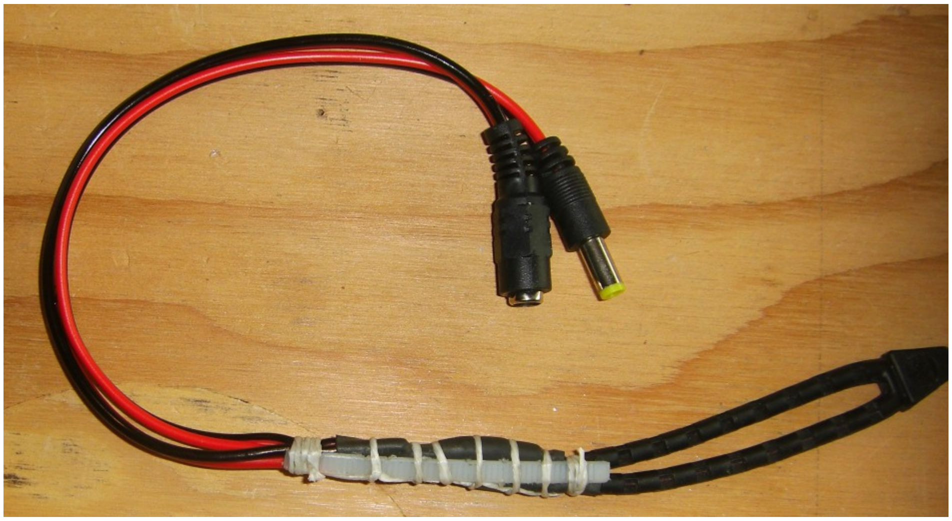
If you didn't want to build the above circuitry, another approach is to use a box large enough for two 9 V batteries and provide a flush-mounted slide switch to select between the batteries (see the Altoids box below that does this). This is a cheap way to have a backup battery, but you'll likely drain the backup battery accidentally one day too.

Here's a 25x50x100 mm plastic box that contains three AA batteries in series that will power my logic probes. It has a power switch and 4 mm banana jacks separated by 19 mm that supply the power to the probe. A separate connector provides a ground connection for the reference potential of the circuit being tested.

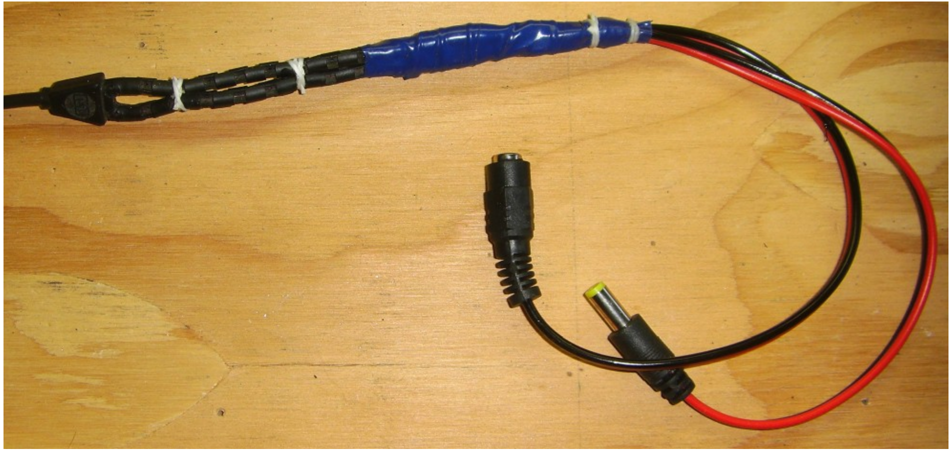
I had to use a BNC connector for the ground connection because there was no room for a standard banana jack. The ground wire is from an old 3M static grounding wrist strap.

2.1/5.5 mm plugs and jacks

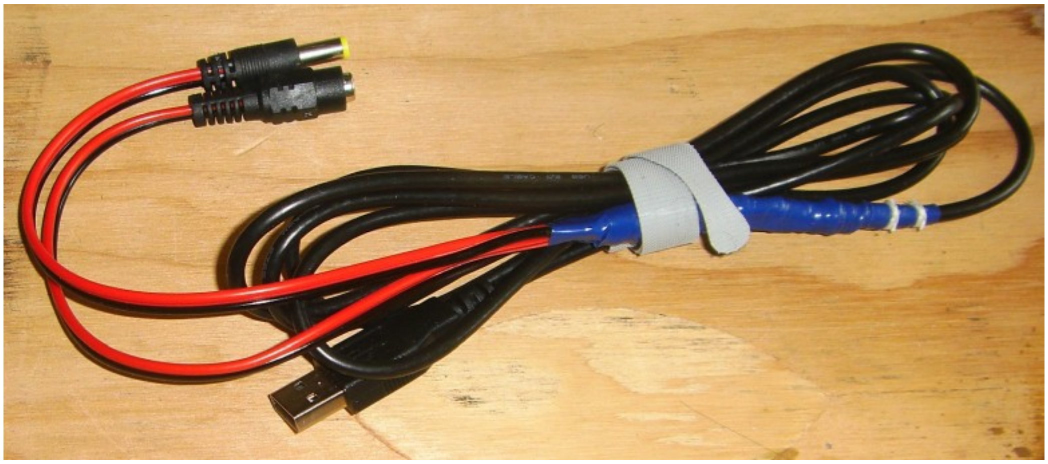
For powering my logic probes, I decided to standardize on the 2.1/5.5 mm coaxial plugs and jacks that are commonly seen on wall warts. I modified one of my HP 545A logic probes to utilize both a jack and plug on the end as shown in the following pictures (the other HP probe uses banana jacks, which is more convenient at the bench). I soldered the plug/jack wires directly to the plugs of the HP probe. This lets me remove/replace the soldered wires later if desired or use the original HP connectors. I put heat shrink tubing over the joints, then used a piece of nylon from a tie wrap with some waxed lacing cord to lash the nylon to the joint. This gives the solder joints strength to withstand a pull:



If this wasn't done, the thin wires in the 2.1/5.5. mm plug or jack would be broken fairly quickly. I followed up with a layer of blue vinyl tape, using constrictor hitches in the nylon lacing cord to secure the tape end and bring the HP cable leads together:



Here's a cord made from a scrap USB cable that provides 5 V power from a USB computer connection or cell phone charger:



There are a variety of adapters for these 2.1/5.5 mm connectors. Here's one that lets you connect to a USB type A connector on your computer or a cell phone charger:

This logic probe can be used with a 9 V battery in an Altoids box (see Figure 4 below). An ON-OFF-ON toggle switch lets me power the probe from the 2.1/5.5 mm plug. The banana jacks supply 9 V for wire tracing through a 100 kΩ resistor with the switch in the down position. With the switch in the up position, the banana jacks can be used to power my other HP 545A probe.

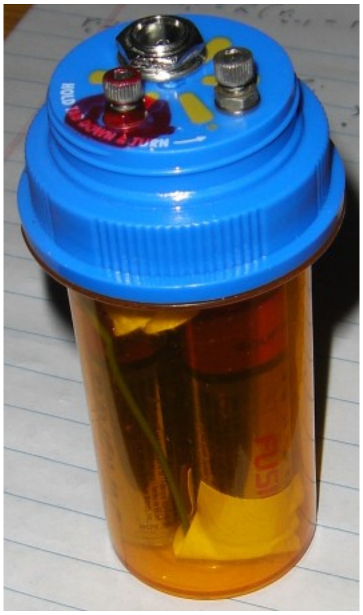
Figure 4

The 2.1/5.5 mm plug's wires came through a hole that was previously drilled in the lid (this box has been used for a few previous projects); a rubber grommet protects the wires from getting cut. The wires pass through the slot of a Velcro strap which is used to hold the box shut. Conveniently, the Velcro strap holds the box in place on the carpet-like dash covering of my wife's van when I'm troubleshooting.

The Altoids box had room for a spare 9 V battery. At the upper left of Figure 4, you can see the head of a stainless steel cap screw that is attached to the box; this lets me attach an alligator clip to the negative battery terminal for wire tracing when I'm using the banana jacks for probe power (the box is connected to the negative battery terminal).

If you just want to use a 9 V battery and you have a 2.1/5.5 mm jack on your probe, this $1 part is probably the simplest.

The most convenient power supply for my logic probes is the following, which contains three AA batteries in series in a Wal-Mart pill container:



Two 4-40 socket head cap screws provide positive and negative connections with a 10 kΩ resistor in series with the positive (it's marked in red with a felt pen) screw. 4.5 volt power for the probe is provided by a 2.1/5.5 mm jack.

The pill bottle is 32 mm in diameter and the overall length with the cap is 80 mm. It is nearly a perfect container, as the three batteries fit snugly and there's just enough room at the top for the connections, jack, and screws. A cotton cosmetics removal pad insulates the jacks and screws from the tops of the batteries.

I estimate this small supply will power my HP 545A logic probe for 30-40 hours and the RSR 611 logic probe for hundreds of hours.

The AA batteries were connected in series by judicious soldering of some 22 gauge wire to the battery ends. The goal is to get a good solder joint without overheating the battery ends, which can lead to seal failure and leakage of contents.

Dewalt batteries

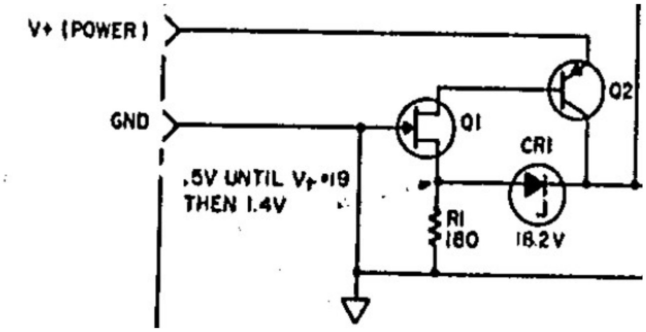
Since I use Dewalt cordless power tools with the 20 volt lithium batteries, they can be useful sources of DC power for a logic probe with a suitable step-down board. This site gives details on the tear-down of a 3 A·hr version of this battery, giving you enough information to adapt one to power your logic probe (he also tore down a 6 A·hr battery). One of these step-down boards can reduce the voltage to the desired level for the logic probe. You may want to filter the output with a suitable capacitor to reduce the switching noise.

These Dewalt batteries can be used directly by connecting to the B+ (positive) and B- (negative) terminals. You can push a male 1/4 inch spade terminal into the battery to make the connection or design a mounting setup for more permanent attachment. A conservative estimate for the 3 A·hr battery indicates it will power the HP logic probe for more than 100 hours continuously.

Interestingly, one could use this $13 DC-DC step-down board with this $6 LED voltage/current display to make a nice DC power supply that could be operated by these power tool lithium batteries. You could have a 13 V 10 A supply for $20.

Power input protection

The HP 545A probe shows in its manual the following circuit for the input power:



The parts are given as (all made by HP, R1 is 1/4 W):

Part	HP part number	Description
Q1	1855-0228	Silicon JFET transistor, N-channel depletion mode TO-92
Q2	1853-0389	Silicon PNP transistor TO-92 PD = 350 mW, FT = 4 MHz
CR1	1902-0594	Zener diode 18.2 V 5% DO-15 PD = 1 W, TC = + 0.068%

This circuit apparently allowed the probe to have the ±25 V for 1 minute specification.

Other tools

Piercing probes

Various vendors offer piercing probes. These have spring-loaded vees that can force a wire into a hard sharpened pin that penetrates the wire's insulation, making contact with the wire's conductor (the vee centers the piercing pin, meaning it's more likely it will contact the center conductor). Here are two examples:

The upper one was sold by Cal Test Electronics (it appears they don't sell these anymore) and the lower one was sold by Fluke a few decades ago; look up the Pomona model 5913. Pomona models 6405 and 6413 do similar tasks.

When you push on the plunger, the jaw opens; you put it around the wire and stop pushing on the plunger. The sharpened spike is pushed into the wire because of a stiff spring.

You can also look for telecom clips (often called Popper clips) that contain a spike or bed-of-nails tester (see Pomona 6483-48-02 for an example), as these will also pierce wire insulation.

I will use these piercing probes when necessary, but I'm cautious using them because there's no easy way to know whether the probe is actually contacting the central conductor or not. In other words, they can give a **false negative**. **Do not trust these tools to determine whether there is a hazardous voltage on a conductor**. For around 18-20 AWG wires or larger, they seem to work pretty well, but they may be untrustworthy on smaller wires.

One place where I find them useful is working on a car where access to wires can be crowded and no open ends are commonly encountered. See the section *Car troubleshooting* for more information.

Non-contact voltage detector

These are devices that fit into a shirt pocket and give visible/audible indications when they are close to an AC voltage, typically at line voltage and/or line frequency. They only need to be close to a conductor. How close depends on the model and its sensitivity.

Older models typically only respond to AC line voltages above 90 V. Newer models extend this range down to 12 VAC and usually include an LED flashlight to boot. They can be had from $5 to $20 typically (you can pay more for some brand names).

You'll find numerous models on the market because they sell pretty well. I have an older Gardner-Bender unit I got for $10 at Wal-Mart and it is a trusted and important tool of my set of test equipment. Before I touch line voltage wiring, I'll test the wiring with both my DMM and my non-contact voltage detector. I verify both measuring tools work correctly on a known-working outlet before measuring.

A unit that indicates 12 V AC voltages is useful for working with 24 V AC circuits like doorbells and sprinkler systems. It's especially handy in sprinkler boxes to find the solenoid's wire that has been energized. If you don't have one of these non-contact testers, you'll have to cut a wire, take it apart at a connection, or use a piercing probe to determine whether 24 V AC power is on it. However, if you have a clamp-on AC ammeter, you may be able to find the energized wire by measuring the AC current in the wire. The sprinkler solenoids in my yard all use around 1/4 A of current. I have one of these 12 V AC sensitive devices and they work, but they can be overly sensitive. They would have been a better design with a small pot to adjust the sensitivity. They are sensitive enough to do a fairly good job of tracing AC power lines in the wall.

Things to try

Logic probe

- **Basics**: Hook up a CMOS 4001 quad two-input NOR gate IC with various connections and explore its behavior with a logic probe and pulser.
- **Instrument inputs**: Test the inputs of various instruments (powered on and off) with the logic probe. Can you predict the results you see?
- **AC outlets**: If your logic probe can handle AC line voltage levels, test various AC line outlets with the probe. Can you trust the tool to tell you whether line voltages are present or not? Before doing this, verify the outlet is wired correctly with an outlet tester. Note: this is only for people experienced with electrical testing and dealing with line voltages.
- **DIY**: Build some of the DIY logic probe circuits found on the web on a prototype board and critique their behaviors.
- **24 V AC**: Using your logic probe, test a 12 to 24 V AC circuit isolated from power line ground to see how your probe responds. Connect the probe's negative power supply lead to one side of the AC voltage.
  - Knowing how your probe behaves, try to predict what you will see when you connect the probe's positive power supply lead to one side of the AC voltage.
- **Equivalent circuit**: Your logic probe is connected to a 5 V DC power supply with sufficient

current to power it normally. Consider the logic probe and its ground lead as a two-terminal black box. Describe its equivalent circuit. See if you can measure the actual values of this equivalent circuit.

- **GFI on 24 V AC sprinkler system**: Your sprinkler system is powered by a 24 V AC transformer. Assuming the transformer is a wall wart plugged into a properly-wired and operating outlet with a GFI (ground fault interrupter) that is also working correctly, will you be protected by a ground fault on the 24 V AC side? Explain why or why not. Even if everything is installed and operating correctly, explain how you could be electrocuted by your sprinkler system.
- **Detecting transient events**: Use your logic probe to detect transient events. See if your probe can identify the following transitions (you'll probably want to back your measurements up with a scope so you know exactly what happened):
    - Low to high
    - High to low
    - Low to open
    - Open to low
    - High to open
    - Open to high
    - You'll also want to see if your probe's pulse memory stores these transitions, as such knowledge is useful for studying intermittent opens or shorts in conductors.
    - Suggestion: a debounced switch with some CMOS logic at 10 to 12 V could be useful for these tests. Use it to switch a MOSFET for the transitions that contain the open state. MOSFET channel resistances can range from > 500 kΩ to under 10 MΩ.

Pulser

- Use a scope to characterize the pulser's output such as beginning logic state, ending logic state, pulse width and peak current.
- Is a pulser and logic probe combination a good tool to identify conductors in cables? Why?
- You have a pulser like the RSR model 620. Describe how you would use it to deliver one single pulse to a circuit.

Binary decisions

We make a large number of binary decisions in our lives with questions like

- Should I marry this person?
- Is the defendant guilty or innocent?
- Is this wire safe to touch?

We use some scheme (measurement, advice, tea leaves) to help us decide yes/no, guilty/innocent, safe/not safe answers. The possible outcomes of using the scheme are

Scheme decided ↓	**True state of nature is:**	
	True	**False**
True	☺	☹
False	☹	☺

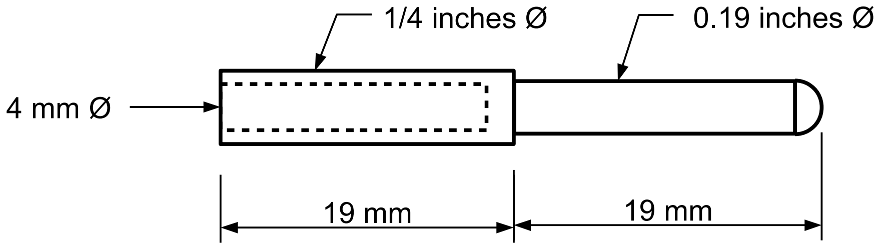
The pink areas are called a **false positive** and a **false negative**. They are **decision mistakes** and we don't want them. Statisticians use the terms type 1 and type 2 errors.

Their impacts are usually not equal. For example, if you decide a wire was not safe to touch and it was, then you've probably wasted effort on extra tasks. But if you decided it was safe to touch and it wasn't, it could kill you. Most people would probably decide it's better to let a guilty person go free than to convict an innocent person.

If you manufacture a product, you might use 100% inspection to determine whether the product was good or not and this is an example of a binary decision. If you decide it's good, you'll ship it to your consumers. If you shipped it and it was bad, you've caused your consumers a problem (cost them monetary and/or quality problems); this is called a **consumer's risk** (you decided it was good, but the true state of nature was bad). Conversely, if you decide it's bad, you rework it or throw it away. If you threw out a good part, you've lost the money you put into that part and affected the quantity that your consumers will be able to receive. This is called a **producer's risk** (you decided it was bad, but the true state of nature was good).

Earth ground adapter

In the US, to plug into the earth ground conductor in a NEMA 5-15R receptacle (a 125 V 15 A 2-conductor outlet), use a conductor of 0.190 inches (4.83 mm) in diameter to plug into the outlet. If you use 4 mm banana plugs and have a lathe, you can machine the following adapter:



I made mine from brass and insulated the 1/4 inch diameter area with green vinyl electrical tape (heat shrink tubing is also a good choice).

There's no way this can be inserted into the neutral or hot conductor orifices. Still, only use it on an outlet that you know is wired correctly because it's possible the hot conductor could be mistakenly connected to the outlet's earth ground conductor -- then you'd be inadvertently exposing yourself to a potentially lethal shock.

References

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bb1997	http://www.hparchive.com/Bench_Briefs/HP-Bench-Briefs-1977-09-10.pdf A good tutorial in digital troubleshooting.
bikson	http://bme.ccny.cuny.edu/faculty/mbikson/BiksonMSafeVoltageReview.pdf
cpi	http://www.usinflationcalculator.com/inflation/consumer-price-index-and-annual-percent-changes-from-1913-to-2008/ I used this information to transform old prices into an approximate price at the beginning of 2019.
gg	G. Gordon, *IC Logic Checkout Simplified*, Hewlett-Packard Journal, June 1969, page 14-16. http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1969-06.pdf#page=14. This was the invention of the logic probe; you may want to look up the US patent 3543154 to read some of the details (in particular, look at figure

	1).
hp163	HP application note AN 163-2, *New Techniques of Digital Troubleshooting*, part number 5952-7558, dated January 1980.
hpj1972	*HP Journal*, Sep. 1972, http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1972-09.pdf. Introduced the 10525T logic probe and 10526T logic pulser, both which operated from 5 V DC.
hpj1976	*HP Journal*, Dec. 1976, http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1976-12.pdf. This article discussed the design and packaging of the HP 545A, 546A, 547A, and 548A digital troubleshooting tools, HP's second generation of such tools.
lv	https://en.wikipedia.org/wiki/Low_voltage
osp616	https://www.physics.ohio-state.edu/~p616/safety/fatal_current.html
wpiec	https://en.wikipedia.org/wiki/Electric_shock#Factors_in_lethality_of_electric_shock References IEC publication 60479-1.