Logic Probes

someonesdad1@gmail.com 18 Jun 2017

Revision date: 12 Feb 2019

Introduction

A logic probe is a hand-held electrical testing device used to used to determine the electrical 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 also 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 stuff.

The logic probe was invented in the late 1960's and was useful because digital logic voltage levels 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]*.

I use SI units and nomenclature unless otherwise stated. Voltages and currents are RMS unless otherwise stated. DMM means digital multimeter.

Disclaimer: I'm an electrical hobbyist, not an electrical engineer. Some of the comments here may be wrong, incomplete, or unsafe. Thus, this document is intended for informational use only and you're responsible for determining what's safe and what's not.

What are some tasks for a logic probe?

In the following, I'll use the term "blink" to mean the logic probe has detected a pulse or state transition. Some logic probes blink their indicator light for this; others flash an LED labeled "pulse".

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

Setting up a logic probe

Most often 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 outside of it's specified range, as this can lead to quick destruction of the probe. Most probes seem to be protected up to 20 to 25 V.

If possible, 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 there's no reason you have to do this. You can power a logic probe from a separate bench power supply or a battery. Since the logic probe is a high impedance voltmeter, the only further step needed is to ensure the digital circuit you're testing and the logic probe have a reference potential. This is usually done by connecting the grounds. If you forget to do this, you'll get confusing or meaningless results. Therefore, the first thing you should do when using an independent power supply for your probe is to 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 use my probe with a power supply that has a digital setting to limit

the maximum output voltage. In my opinion, this is worth paying extra for, especially after you accidentally fry a circuit being worked on by accidentally bumping a knob or making a typing mistake while setting the voltage.

Once you've got the probe powered correctly, select the logic type you'll test with. Most probes let you choose between TTL and 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.

If you choose CMOS mode and use a separate power supply, you do have a bit of freedom to choose e.g. where the high threshold will be. The typical CMOS thresholds are 30% of Vcc for low and 70% of Vcc for high. But I've never messed with thresholds like this -- and I'd probably just grab a DMM instead if I needed such a thing.

Be aware that 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.

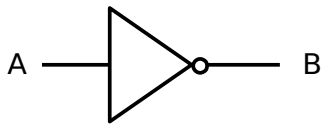
If you need to monitor high speed pulses with the HP 545A or 10525T probes, you'll want to use the associated grounding clip that attaches near the needle probe and keep the leads short (but I've tested them at over 40 MHz with no ground lead).

A useful troubleshooting technique is to compare 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.

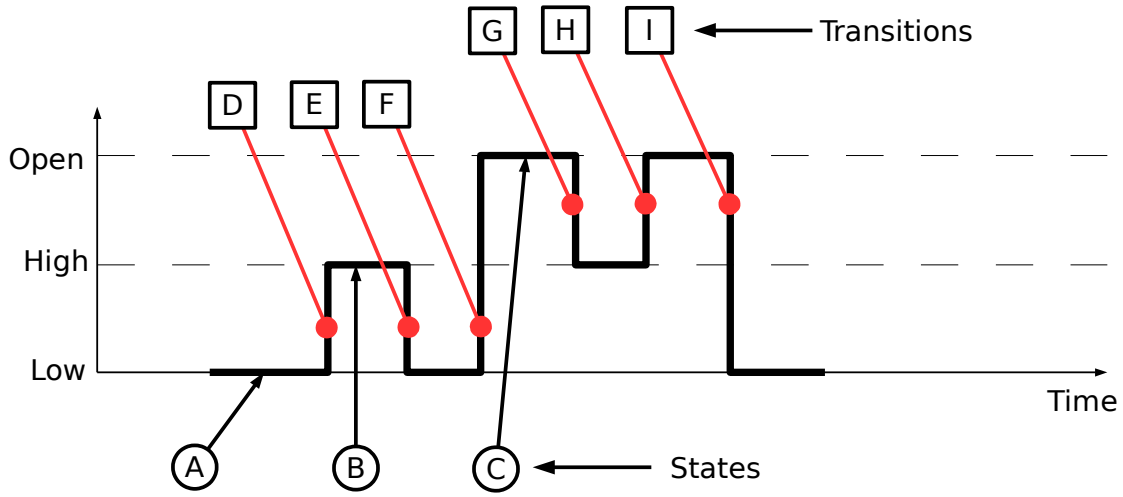
A feature of the logic probe is that you don't have to move your eyes from the point being probed (such as you would to read a DMM's display or look at a scope screen). This helps you test things more rapidly. The high impedance input of the probe's point means you won't damage a circuit element by accidental 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 below 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 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.

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). 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.

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

Signal	Conductor	HP 545 A	RSR 611	GS LP-1
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 low-frequency sine wave (or 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.

A better method for this test is to use 5 V DC 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 a 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 power negative 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 quickly recognizing 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. RSR 611 probe: the probe's tip put 1.4 µA through the LED. HP 545A probe (#1): the probe's tip put 12.0 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**.

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).

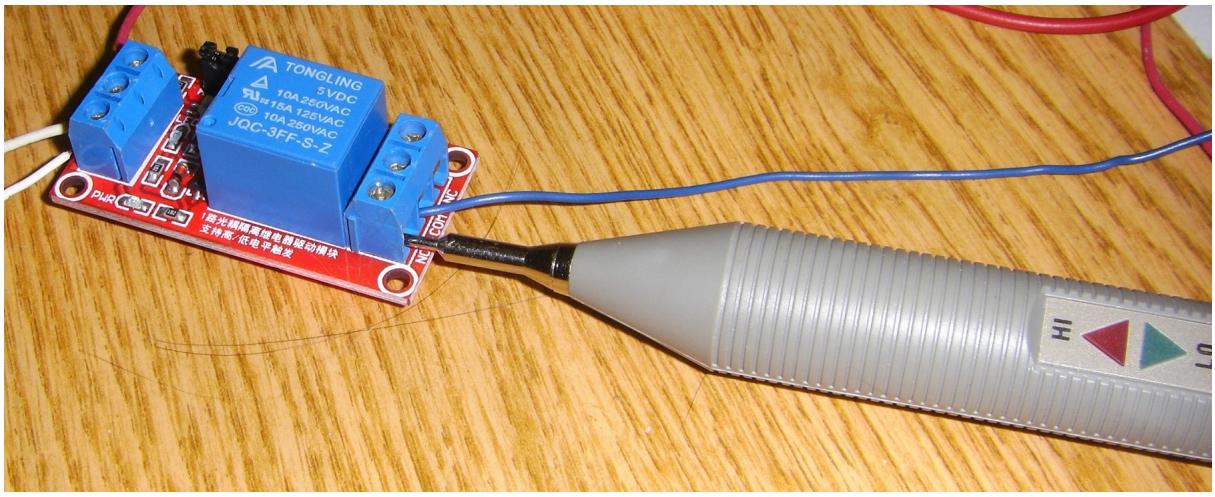


Figure 1

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 wavemeter). Instead, 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. I feel these multimeters are the best troubleshooting tools available for the money ($20 to $25 or so).

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 also 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 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 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 things

just 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.

> One day I may build myself such a tool. I'd want ground to be at 100 Hz and 10 volts to be 1000 Hz. I'd build it using two 9 V batteries so it could run at an 18 V supply and test automotive circuits too. Then I'd spend time training myself to estimate frequencies between 0.1 and 1.8 kHz to be able to estimate the first significant figure of a measured voltage.

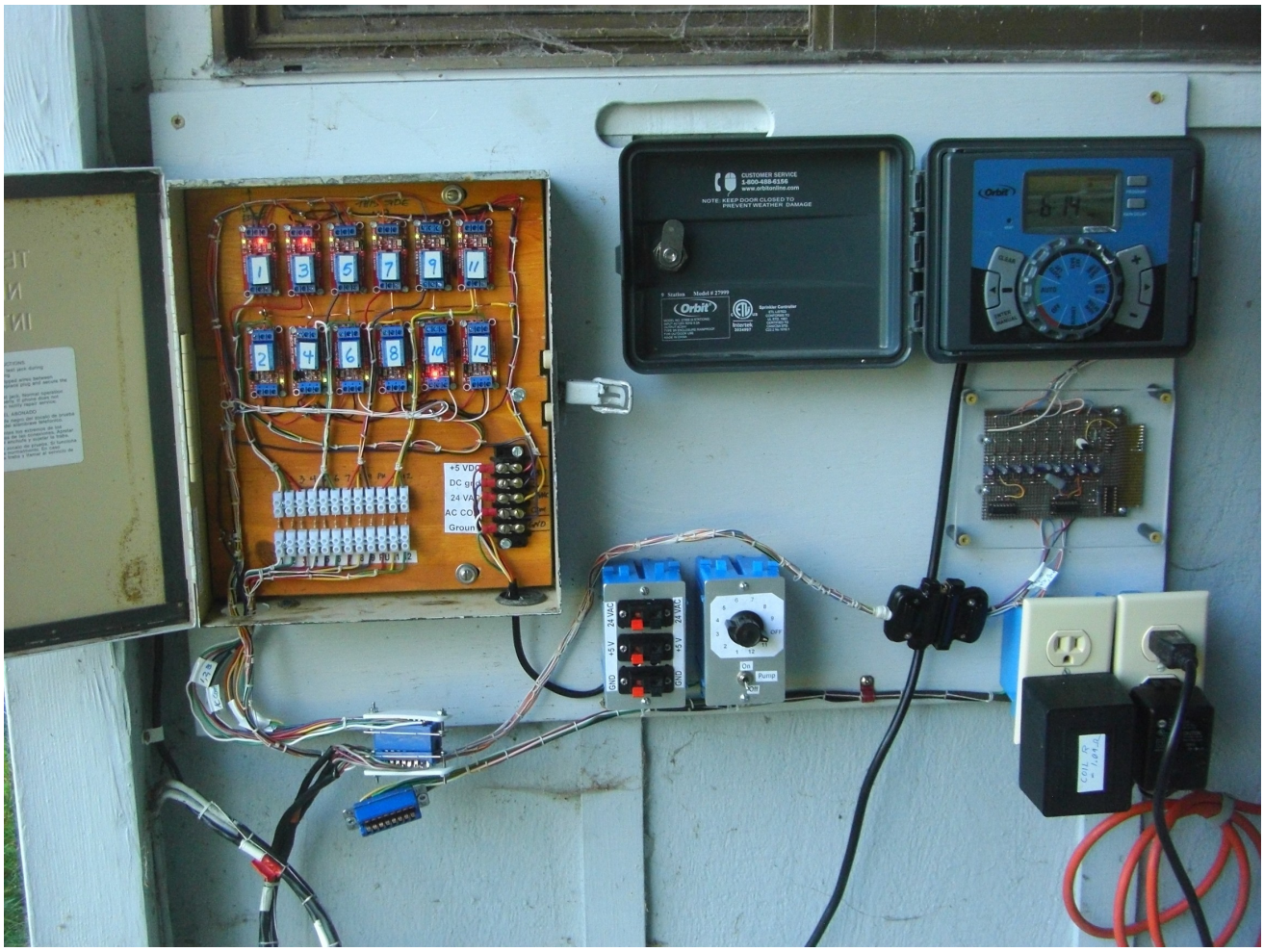
Check a sprinkler system's 24 V AC wiring

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 and 3 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 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).

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 charged car battery 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.

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 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).

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.

Check a phone line

A typical old-style phone line in the US has a 48 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). Neither line is referenced to earth ground. When the phone rings, the ringing signal is about 90 V AC at about 20 Hz.

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 both of these voltage levels are capable of giving you a significant shock (especially the ring signal).

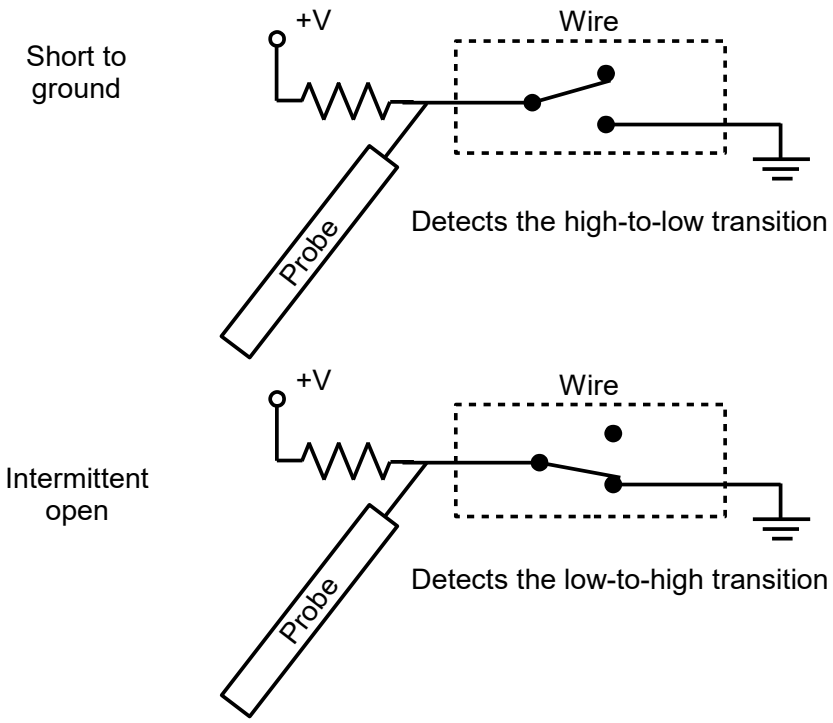
Ringing current can be measured with an AC ammeter and is on the order of 10 mA for a phone with the old metal bells and clappers run by a solenoid.

> If you wonder where the weird 90 V AC 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, the method of choice 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 stay 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 would 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, at least not without visible damage to the cord (but it can happen if a wire pulls loose at the connector on the end). The best tool for this task is 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 or ground, however, you'll have to figure out how to safely apply AC line voltage to these conductors, a task for experienced folks only. If you're a newbie at this stuff, use a 12 to 24 V AC source instead, as modern non-contact voltage sensors can work at these levels.

Some Christmas tree light strings that run from line power are wired in series and the non-contact voltage sensor may help you quickly find the bulb that has burned out. If you can't find the bad bulb, try reversing the polarity of the line voltage connection with a 3-wire to 2-wire adapter. This is for experienced folks only who understand the risks. You might need to file the excess metal off the neutral conductor to be able to plug it in, but this turns it into a non-polarized adapter.

If you can apply probes to the conductor, it's a trivial task to use an ohmmeter or continuity tester to locate the open, but as mentioned in the *Piercing probes* section, if you have to penetrate insulation, you may not be sure you're actually touching the conductor. A wire tracer might help if the wire is fairly isolated.

I once found a high-resistance section in some trailer wiring (it was inside some steel tubing and not visible) by using a constant current source and measuring the voltage drops along the wire (the Kelvin technique in *Find a short*).

> The cause turned out to be a corroded Scotchlok connector. I've seen numerous dry-type Scotchlok connector failures in car and trailer wiring and I won't allow their use in the vehicles I own. The exception would be Scotchlok connectors that contain a dielectric sealant, similar to the butt connectors the phone companies uses. However, I've never seen any trailer or hitch people use such connectors.
>
> If you must use a dry Scotchlok connector (they're convenient and fast), fill the joint area with Vaseline to cut down on later corrosion problems. I also squirt Vaseline into wire nuts when I make sprinkler circuit connections, as I've seen these connections become problematic because of corrosion after a few decades.

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.

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.

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.

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. With a pulser, you can check digital functionality at gate levels.

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.

I recommend buying the RSR 611 or 610B logic probes, as they can be gotten new for under $20. I feel they are the best value for your money. Note 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.

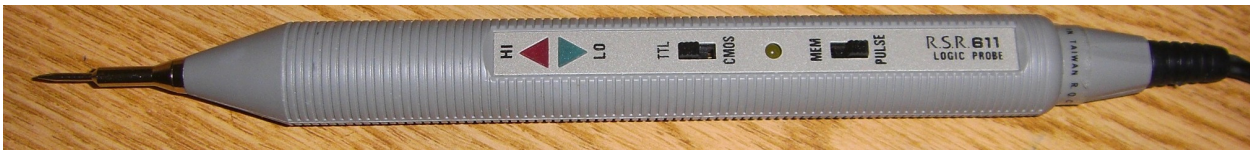
There aren't many new logic probes being made today. It appears a manufacturer in Taiwan makes the parts for logic probes that are branded by a number of different companies, such as RSR Electronics, Elenco, and B&K Precision. The models differ in tips, color, and power cords, but probably all have the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

In 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 more than 10 GΩ. Logic probe tip currents were measured with an Aneng AN8008 digital multimeter.

RSR 611

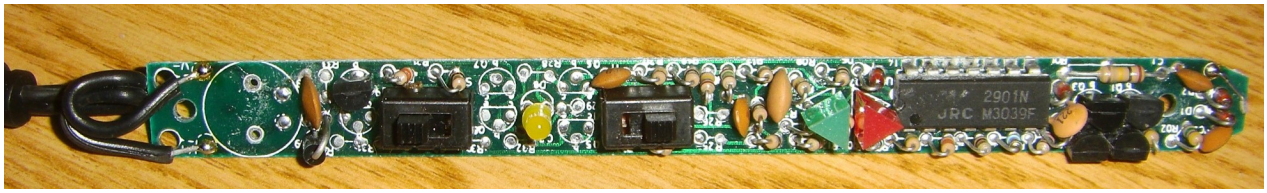
The RSR Electronics model 20 MHz 611 logic probe will cost you around $20 delivered:



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.

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.

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 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. 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" of 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).

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.

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).

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.

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 should be 1 to 1.5 m long. I have an old cord from a wall wart that has a 2.1/5 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.
- The only flaw in the probe in my opinion is that 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.

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

B&K Precision sells logic probes that look to be electrically identical to the RSR probes at about twice the price.

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 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 $450 in 2017 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.

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

The probe is a nice 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 -- the kit was the 5022A and was $700 in HP's 1977 catalog (about $2350 in 2017 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 things 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.
- 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.
- 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 to spot 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 like the HP probe because 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 are 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.
- **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 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 AA batteries if needed, but three batteries work better.
- ♦ You could use the RSR 611 logic probe to troubleshoot 3.3 V digital logic -- you'd just need to 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.

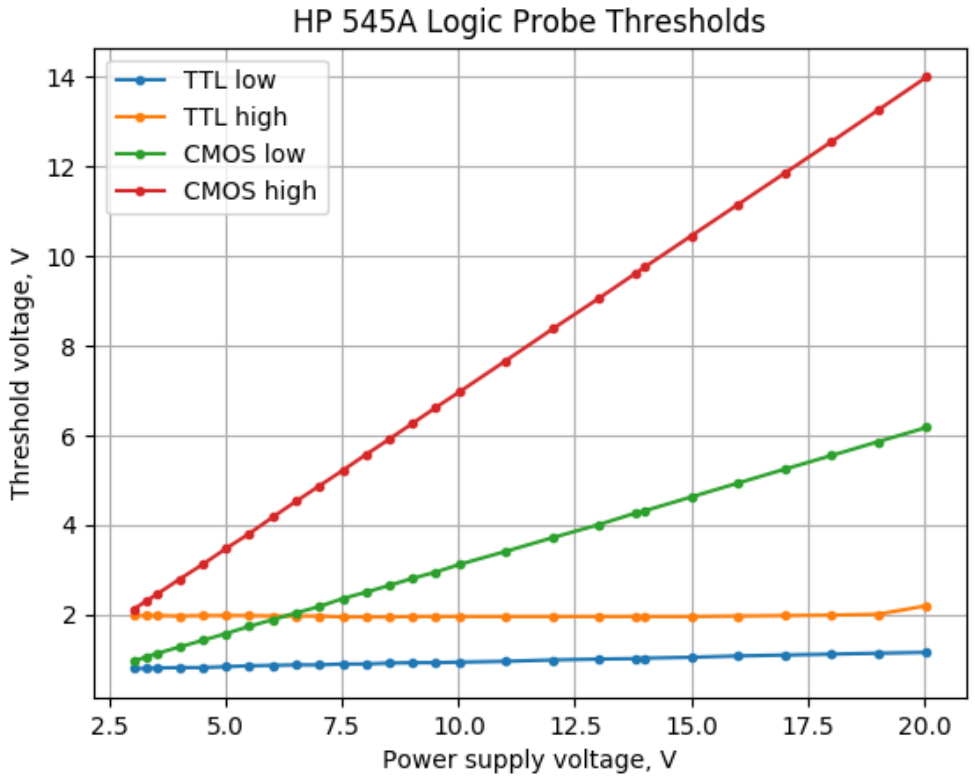
♦ Current draw of probe #2 as a function of supply voltage and tip state (* the inflection point in the last column is real):

	mA			
V	**Low, mem 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.

- 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 even 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.
- 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. As usual, HP's specs are conservative.
- The probe's input will withstand 120 V indefinitely and 250 V for up to 15 seconds.
- **Powering the probe**
  - The end of the power supply lines connected to HP grabber hooks. 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 that contains three AA batteries in series.
  - I'm thinking of converting the other 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 predecessor the 10525T), 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 to ground from the probe's tip in TTL mode was 12.3 µA. This implies the resistance should be or 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).
  - Thus, if you use the probe for checking continuity to ground in TTL mode, all you can say is that the resistance is 100 kΩ or less if it indicates continuity.

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



The graph shows that the TTL thresholds stay pretty constant as a function of power supply voltage (as mentioned in the probe's manual, 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 troubleshoot 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, I'll use the RSR probe.

I have a plastic box with two banana jacks and a power switch. Inside the box are three AA batteries in series. This box works well for remotely powering either the HP or RSR logic probes when no other power is available. There's also a coiled conductor about 1.5 m long to provide for ground connections.

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.

Probe lamp indications with positive logic	Logic ONE: "Bright". Logic ZERO: "Off". Between ZERO and ONE: "Dim".
Input impedance	Greater than 25,000 ohms (input characteristics are similar to low power TTL integrated circuits).
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 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 just as good except for lacking the memory feature and only working on TTL logic with a 5 V supply.

HP 10526T logic pulser

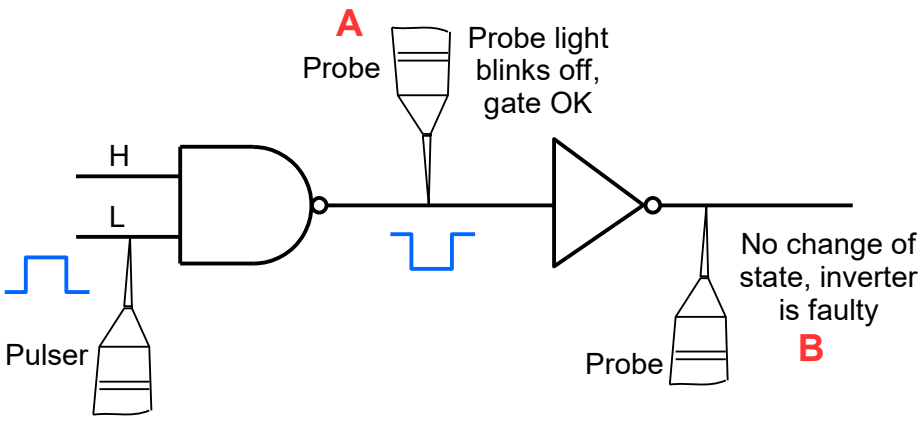
This pulser was sold as an adjunct to the 10525T logic probe. When this probe is connected to a 10X 150 MHz scope probe, the pulses are about 400 ns wide when the pulser's button is pressed. Pulse amplitude is 5 V. On a 200 MHz scope with the pulser's tip directly on the center conductor of the BNC input 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.

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)

Pulse voltage, HIGH output	2 volts at 0.65 Ampere (1 A typical at Vps = 5 V, 25 °C)
	BNC-to-Dual Banana Plug Probe Tip (Straight)

The basic use of a pulser is to make it force a digital line to the opposite state for a short period of time, which avoids significant heating due to extra current. The instruction manual gives the following illustration:



At **A**, suppose the 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 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 probe at B shows no change when the pulser's switch is depressed, then the inverter is bad.

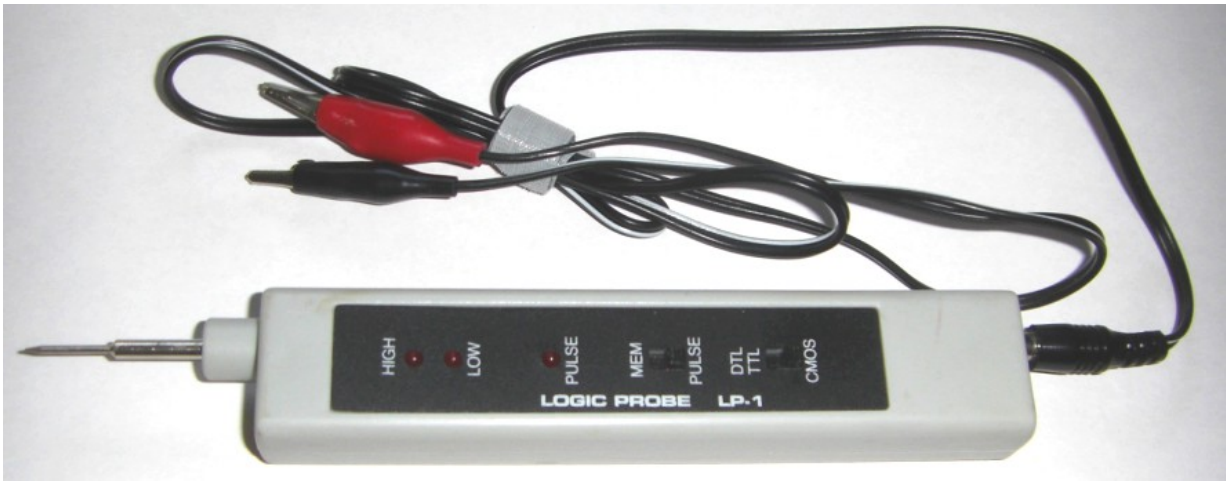
If both the inverter and pulser are connected to the same node and the pulser switch is depressed, if no blink on the probe is seen, then the node is either shorted to the supply voltage or ground.

This older pulser works just 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.

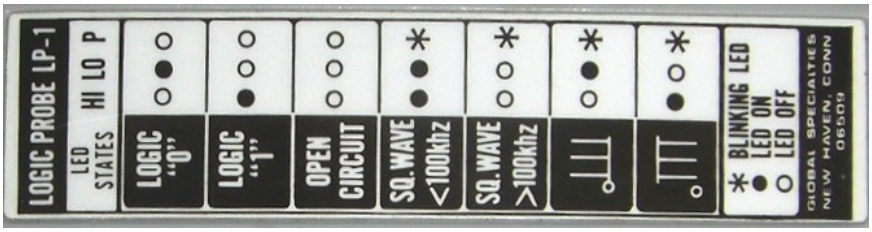
Global Specialties LP-1

This is a plastic body logic probe made by Global Specialties (used to be named Continental Specialties) in the 1980's. 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:



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:

State	Current, mA 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.

Overall, this is an adequate logic probe for a hobbyist. A 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 fix hack

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; 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

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

Elenco LP560

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

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 much better value

Eistar

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

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.

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. I've been disappointed with most of the ones I've built on a prototype board. There are only two I'd consider building for myself:

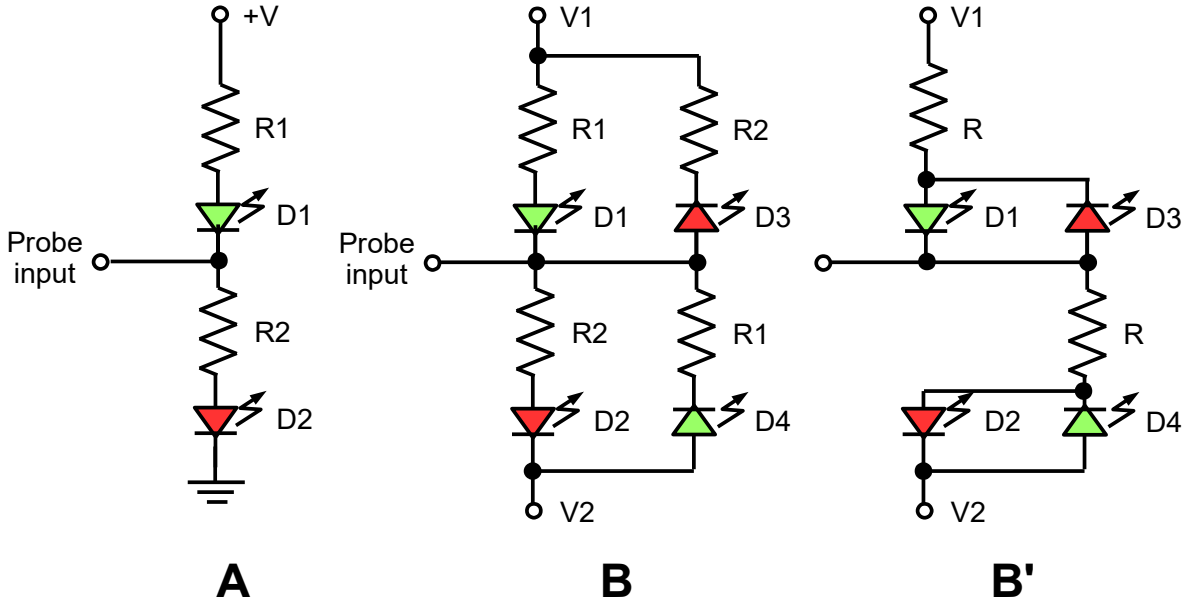
- A simple probe made from two LEDs and two resistors.
- An adjustable threshold tester made from a dual op amp or comparator chip.

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:



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 10 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 2.7 V at this current, so its resistor needs to be (12.6 - 2.7)/0.01 or 990 Ω. The red LED will drop 2 V, so its resistor will be 1.06 kΩ. I'd use a 1 kΩ resistor for both LEDs. The power dissipated in the resistor will be $1000(10^{-2})^2$ or 0.1 W, so a 1/4 W resistor is fine. The currents as a function of voltage with a 1 kΩ (987 Ω measured) resistor were

V	Green, mA	Red, mA
3	0.71	1.2
5	2.6	3.2
12.6	10	10.8
24	21.7	22.5

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.
- ♦ 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).

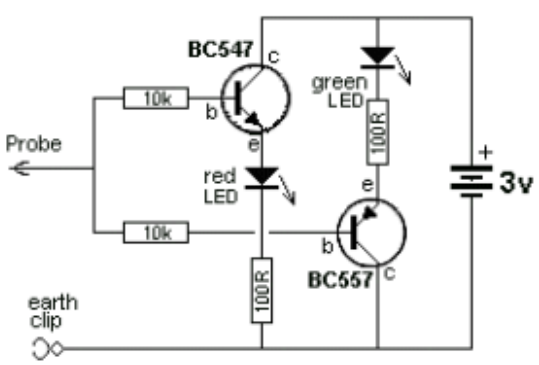
How it works: The two LEDs are illuminated when the input is an open circuit. If you connect the input to a low signal, the green LED will light fully and the red LED will be off because there will be no voltage across the red LED. If you connect the input to a high signal, the red LED will light fully 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.

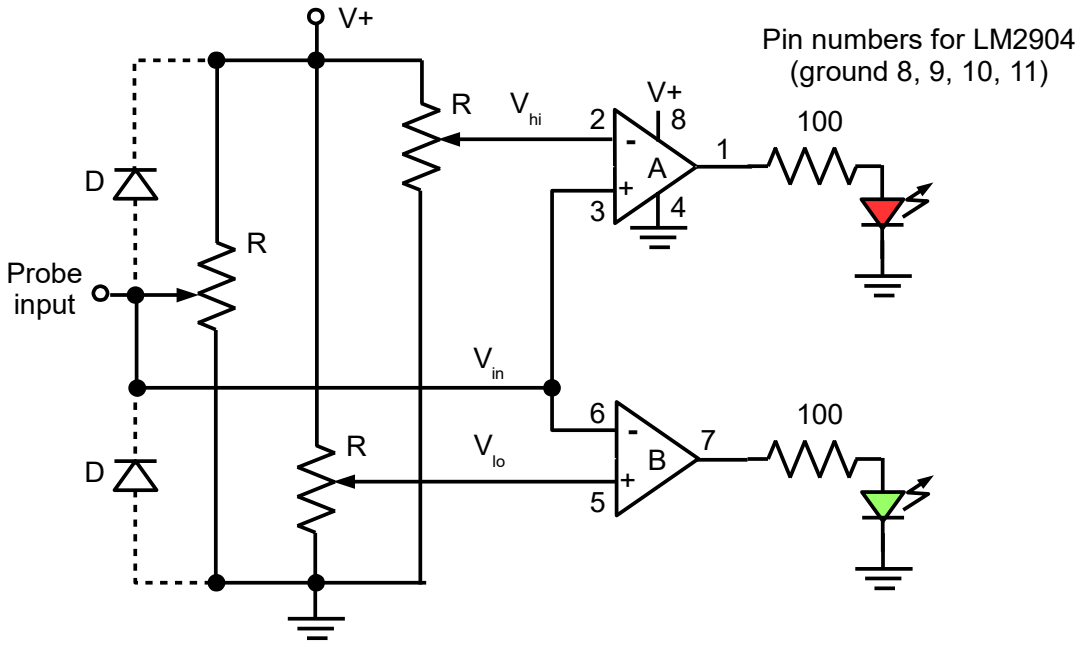
Advantages

- ♦ 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

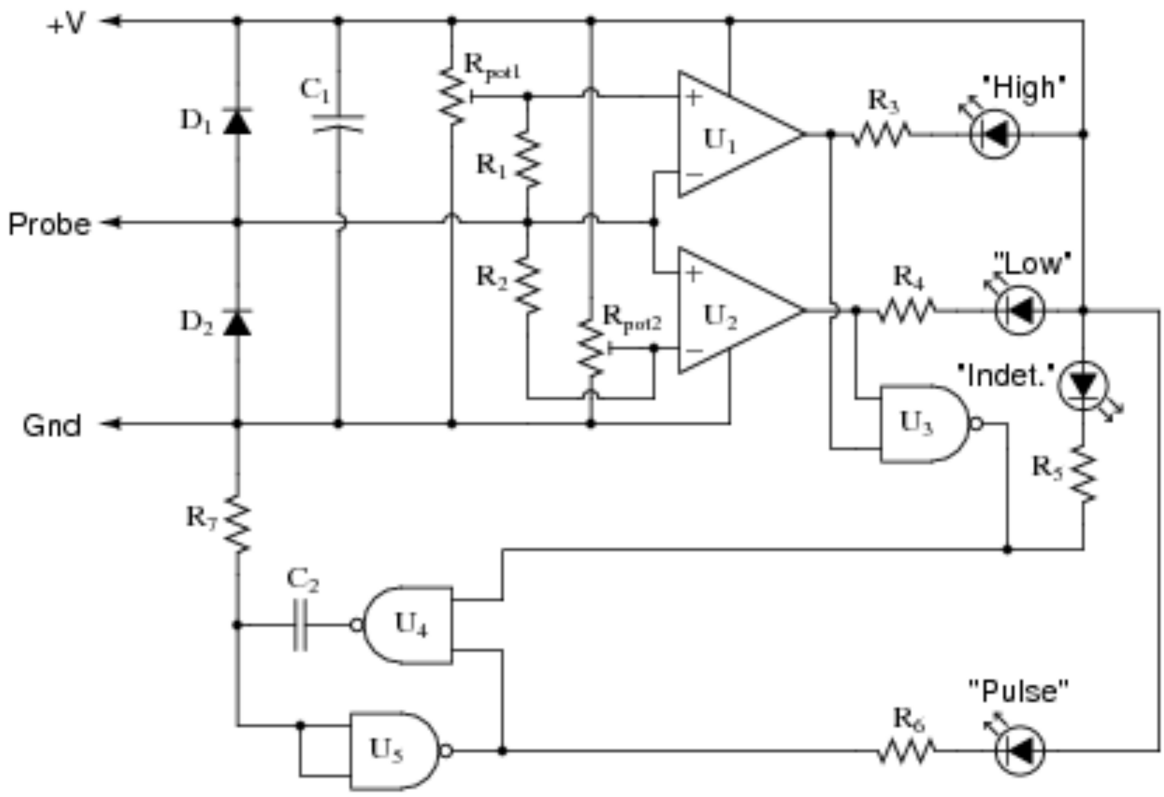
- ♦ Low speed: not effective on pulsating voltages above audio range (but see the peak detection input technique for the HP 545A in *[hpj1976]*).
- ♦ No pulse detection

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.



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] gives a similar logic probe design with a pulse stretcher:



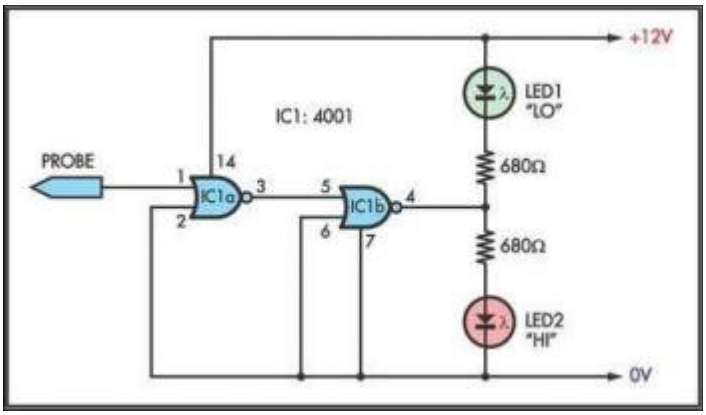
Read the web page for hints about the design.

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.

Comment: If the two potientiometers were panel-mounted with graduated and calibrated dials, this could be used as a go-no go voltage detecting device. The "Indet." LED could be labeled "Accept" and the "High" and "Low" LEDs would be the reason the measurement was rejected. Or, with a constant voltage supply, it could be a logic probe with precisely-defined adjustable thresholds, as good comparators or op amps will give sharp transitions.

Single gate probe

This design came from https://circuitswiring.com/simple-logic-probe, but I haven't tested it. It's attractive because it just needs a CMOS 4001 IC, two resistors, two LEDs, a battery (a 9 V would be fine), and a probe. Run the LEDs around 100 µA and the battery will last a long time. However, it could be damaged on a significant voltage input, so put the IC in a socket with a spare in the box or include some input protection.



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).

> 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.

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.

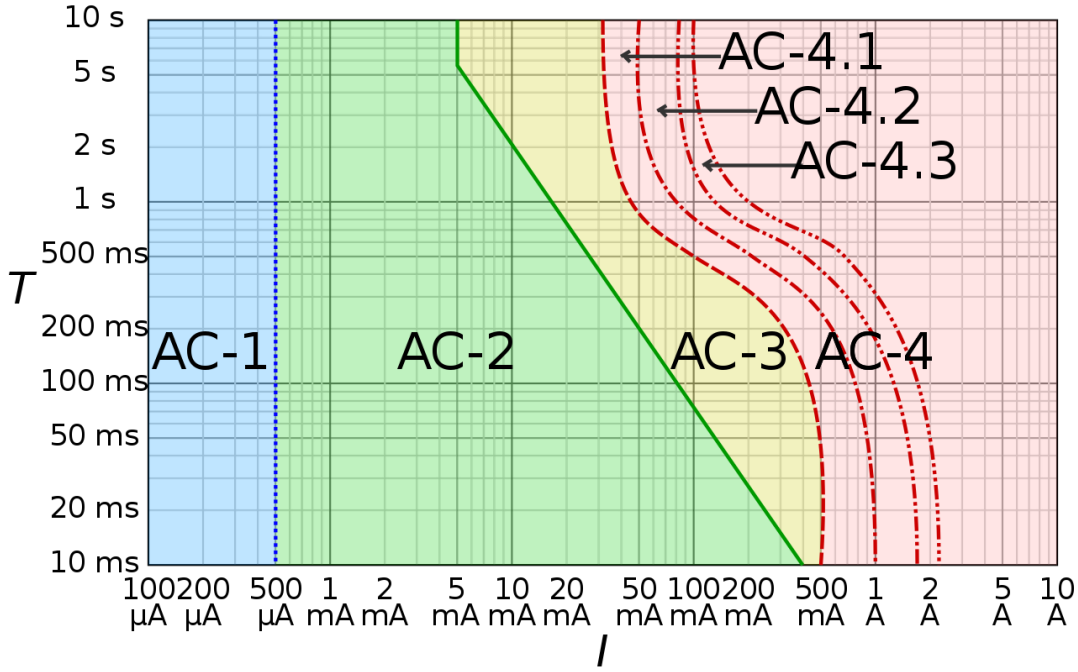
My personal definitions are a bit lower, based on decades of not getting any fatal shocks. I use 24 V RMS at line frequency as my definition of when things transition from low to high voltage. Many wall warts that provide 24 V AC power actually provide an output a few RMS volts higher under no load and 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 is what's important; the voltage level at which this occurs is irrelevant.

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 because of an insulation fault. 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 numerous 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're using a circuit like that shown in the *Simple probe* section.

A second type of probe adds a switch that lets you connect battery voltage or ground to the tip; this allows you to power 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.

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.

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 level 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. the charging plug that came with first generation Amazon Kindles). 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'm thinking of putting an old wall wart cord with one of these jacks on one of my logic probes. This allows for connection to a compact matching jack on a plastic box with battery power. I can also construct two of these jacks back-to-back to let me connect the probe to the male plug from a wall-wart or use a jack that fits on the end of a cable. There are adapters from the 2.1/5.5 mm jacks to USB connectors, letting me plug the probe into a computer for power or a USB hub. I'd also construct an adapter from the 2.1/5.5 mm jack to two banana plugs to let me plug things into a bench power supply. This setup

would let me power the probe from a variety of sources.

> 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 can't be pulled out easily.

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 4 to 8 hours or so).

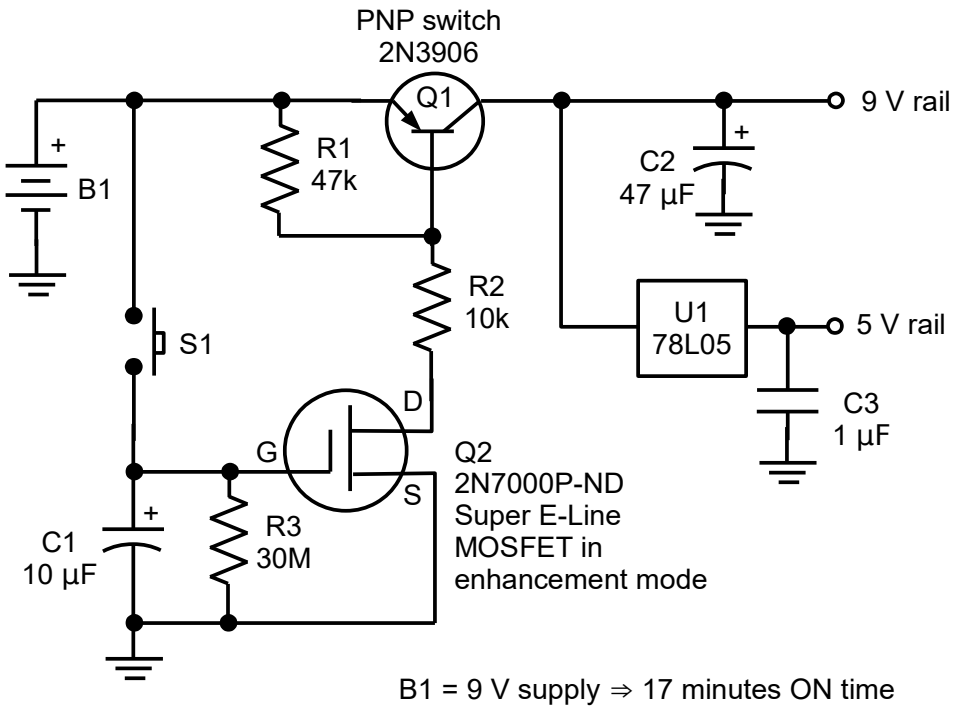
Also as mentioned in the *RSR 611* section, the RSR probe's ability to show an open-to-low pulse seemed to work best in CMOS mode with an 18 V power supply, which could be gotten with two 9 V batteries.

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 10 kΩ resistor for a current-limited (0.9 mA 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 better 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 that is used by a friend in his production products[1]:



You could include a modern high-brightness LED running under 1 mA to indicate the power was on (I have green LEDs that are usefully bright at 100 µA). This circuit works nicely and I plan on building such a power supply box for my RSR logic probes one of these days.

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. This is a cheap way to have a backup battery, but you'll likely drain the backup battery accidentally one day too.

I currently power my logic probes from a 25x50x100 mm plastic box that contains three AA batteries in series. 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.

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

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.

I plan to put a right-angle 2.1/5.5 mm plug on my logic probe. This will then plug into a jack on a plastic box like the above photo. I'll also put on the box a 2.1/5.5 mm jack that has a disconnect for the batteries in the box, letting me power things with a wall wart that has a 2.1/5.5 mm plug (these are very common). Then there will be two banana jacks to allow connecting ground and +Vcc to circuits of interest (the +Vcc connection will include a 10 kΩ resistor to limit the current). Finally, the box will include a pushbutton switch to turn on the power via the above circuit and a green LED running at 100 µA to indicate that the box power is on. A toggle switch will select between the external power jack and the batteries, ensuring that the batteries won't be drained if the box is set down on the power switch.

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. Here are two examples:

The upper one was from Cal Test Electronics (it appears they don't sell these anymore) and the lower one was sold by Fluke a few decades ago; it was a rebranded one from Pomona (Fluke now owns Pomona). Look up Pomona's 6405, 6413, and 5913 for similar items.

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 string 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.

Comment: I will use these piercing probes when necessary, but I'm not overly fond of 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**.

Non-contact voltage detector

These are devices that fit into a shirt pocket and give visible/audible indications when they are close to a line-voltage AC source. 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 it both with my trusted Fluke 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 such 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	☹	☺

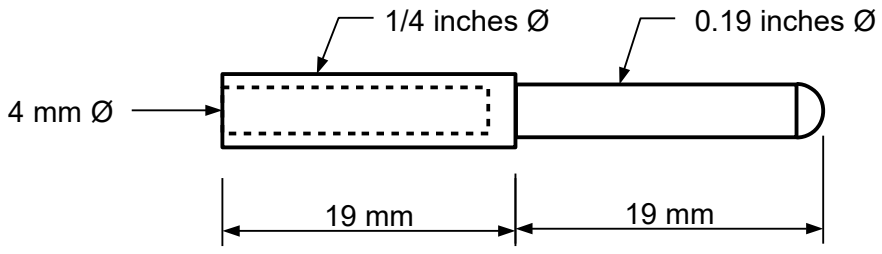
The pink areas are called a **false positive** and a **false negative**. They are decision mistakes and we don't want them.

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 some effort on some 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. 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**. 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**.

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.

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

aac https://www.allaboutcircuits.com/worksheets/design-project-logic-probe/

bb1997 http://www.hparchive.com/Bench_Briefs/HP-Bench-Briefs-1977-09-10.pdf

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 approximate 2017 prices.

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.