DRAWING BOARD

Let's build a simple, inexpensive logic probe for the home workbench.

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Even though the main reason for spending time at the bench is to wind up with a working circuit, there are other good reasons for spending hours and hours hunched over a breadboard. Nothing ever works out the way you want it to, and that's especially true at the test bench. Dealing with unexpected (or perhaps expected) design glitches is what makes bench time a great way to stretch your brain.

Working your way through a project is a good learning experience, but only if you have the right equipment. For instance, a logic analyzer can instantly give you a window into the nitty gritty of a complex design. But there aren't many of us that can justify parting with the kind of cash that's necessary to get your hands on a logic analyzer—or any other kind of exotic test equipment for that matter. That's especially true when the project has nothing to do with generating income.

While there's no argument that high-tech designs can really be debugged only with high-tech equipment, you can do a lot of work with much simpler and less expensive test gear if you're willing to do a bit more work with your brain. High-speed circuitry can be slowed down, gated latches can be added to catch pulses, and other similar tricks can be pulled to snoop around a circuit.

An extremely useful, but relatively inexpensive addition to any test bench is a logic probe. Now there are all sorts of different logic probes, and just how useful it can be depends on how many bells and whistles it has. A simple two-LED probe is about the bottom line, and the sort of information it can give you is just basic, bottom-line information.

When designing a logic probe, you have to provide a way for the probe to operate with different logic families. That can complicate things slightly because each family—TTL, CMOS, etc.—has its own idea of what voltages constitute a high or low. Not only that, but some of them, such as TTL, also have about a one-volt dead band in which the whole idea of logic levels gets a bit murky.

When you get right down to it, a logic probe is simply a circuit with the ability to detect and react to particular voltage levels. Anytime you're designing something like this and you plan on building it out of parts that are cheap and easily available (as we are), your mind should immediately turn to voltage comparators.

A voltage comparator is really nothing more than an op-amp with a built-in hysteresis that makes it react sharply to voltages that cross a particular threshold. You can build one out of any standard op-amp, but its a lot easier to use a part like an LM339.

The pinouts for the chip are shown in Fig. 1, and you should be struck by how much they look like op-amps. Just about the only pins that are missing are the ones for frequency compensation and offset adjustments. Those aren't needed in a comparator since the chip is designed to operate more like a switch than an op-amp. The gain is extremely high, the chip can be driven by a single-ended supply, and the output can typically sink as much as 16 mA.

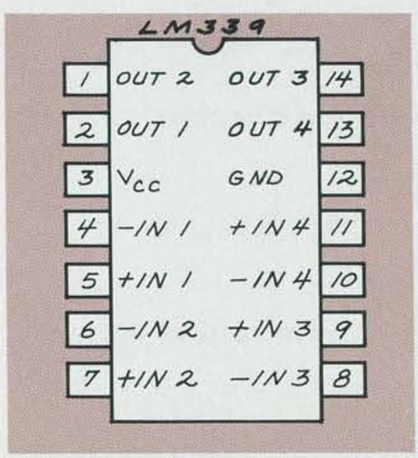

FIG. 1—THE LM339 VOLTAGE-comparator IC contains four comparators on the same substrate. We need only two comparators for a logic probe, so we'll have an extra pair.

The simplest circuit for a logic probe is shown in Fig. 2. As you can see, we've tied together two of the pins; one on each of the comparators. Those are the pins that are going to receive the input voltage from the probe. Since we want the output of both the high and low detectors to go high when they're turned on, we have to make the low detector inverting and set the high detector to be non-inverting. That's why we've connected the non-inverting input of IC1-a, the high detector, to the inverting input of IC1-b, the low detector.

Now that we've decided where we want to put the input signal, the next step in the design is to work out the reference voltages that are going to be applied to the other input pins of the comparators. The easiest way to do that is by building a resistor voltage divider—and that brings us to our first real problem.

If we were going to use the logic probe only with CMOS, the design of the divider would be relatively simple. Since CMOS changes state halfway up the power rail, we could use two equal-value resistors for the divider. But that would seriously affect the versatility of the design so I'm only mentioning it as an aside. We have to do more than that because we also want it to be able to work with the standard TTL levels of below 0.8 volts for a low and above 2 volts for a high.

The way to do that is to use three resistors in the divider chain, as shown in Fig. 2. By separating the high and low reference inputs of the comparators with a resistor, we can have our design account for the TTL deadband voltage range between 0.8 and 2 volts. In Fig. 2, the output of IC1-a will go high if the applied voltage at pin 6 is more than the reference voltage at pin 7, and the output of IC1-b will go high if the applied voltage at pin 5 is lower than the reference voltage at pin 4.

Now that we've got the basic configuration worked out, the next step is to calculate the values for the resistors. As we go through this, we'll be aiming for the 0.8- and 2-volt thresholds but, since we're going to be using standard-value resistors (things have to be cheap and available, remember?), we'll probably miss the exact numbers by a little bit.

Since we want the reference voltage for IC1-a to be 2 volts (assuming a system voltage of 5 volts), we're aiming for a 3-volt drop across R1—a final ratio of 3/5. That means the value for R1 has to be 60% of the total value of R1 + R2 + R3. Things are a more complex when we calculate the individual values for R2 and R3 since those two resistors don't see the 5-volt system voltage. The voltage division has to be based on the voltage appearing at pin 7 of IC1-a.

Let's be a bit more rigorous about working this out. The voltage drop across the entire resistive chain is about equal to the system voltage. I'm saying "about" because there is a slight drop due to presence of the comparator, but the impedance of the inputs is so high that we can forget about it for all practical purposes. Since the three resistors are in series, the sum of the voltage drops is equal to the system voltage.

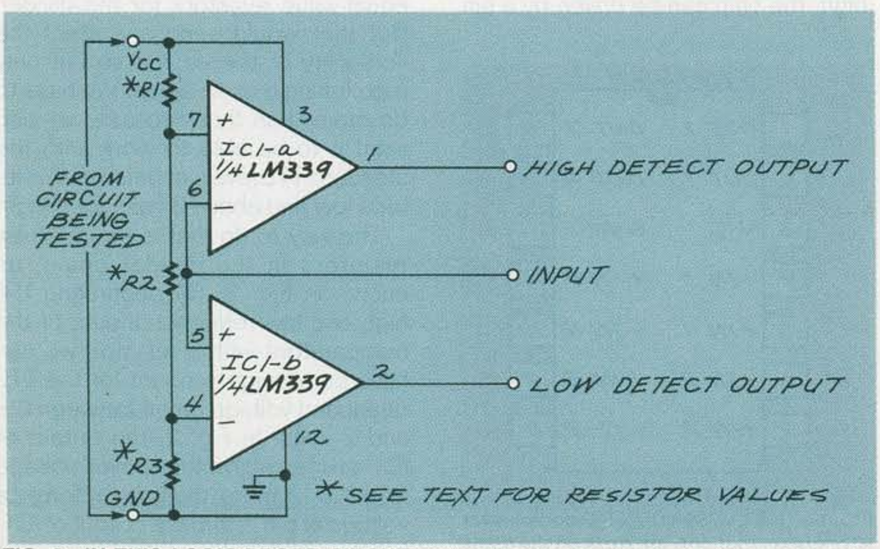

FIG. 2—IN THIS LOGIC-PROBE CIRCUIT we've tied together one pin from each comparator. Those pins will receive the input voltage from the probe. The low detector is inverting and the high detector is non-inverting.

Since we know that the voltage drop across R1 has to be 3V, the combined voltage drop across the other two resistors will be 2V. We also know that we want the drop across R3 to be 0.8V since that's the value of the reference voltage we're aiming toward. Some simple arithmetic tells us that the R2 drop has to be 1.2V.

Once we've taken the analysis this far, we've also calculated the relative values of the resistors. Since the resistors are in series, the same current is flowing through all of them and that means the resistor values are going to be directly proportional to the voltage drops. R1 is going to be ⅗ of the total, R2 is going to be 1.2/5 of the total, and R3 is going to be 0.8/5 of the total. Putting things in simpler terms, if R_T is the total value of the three resistors, R1 has to be $0.60R_T$, R2 has to be $0.24R_T$, and R3 has to be $0.16R_T$.

Knowing the resistor ratios is only part of the answer since it's still short of knowing the actual values. In theory, any combination of resistors in the correct ratio will work for us but there are some other things we have to take into consideration to come up with the final resistor values.

When we get together next time, we'll take care of that, add a few surprises to the circuit, and get to talking about some other test gear you can build yourself. **R-E**