Construction project:

Digital current tracer probe

Current tracing probes are very useful for troubleshooting in digital circuitry, but commercial probes are very expensive and beyond the reach of most enthusiasts and small labs. Here's how to make your own, for around $20.

by BARRY KAULER

Technicians and enthusiasts working with digital equipment are always conscious of the need for "something better" with which to troubleshoot. However all servicing instruments that look like they may be particularly useful generally also turn out to be particularly expensive.

A digital current tracer probe is an example of a handy little trouble-shooting tool, but the only (well-known) manufacturer of such a device, not to be named, is asking almost $600.

The build-it-yourself equivalent unit described here has a very much lower component cost, of about $20, but its performance compares favourably with the competition.

A digital current tracer detects the presence or otherwise of current in a wire and needs to be sensitive enough to detect the very small currents flowing in digital circuits, even those using CMOS.

Whenever the output of a gate switches state, current travels down the line to charge the line and input capacitance of the receiving gate, and this current is large enough to be detected. Thus printed circuit board conductors can be traced along and hairline cracks and solder bridges easily located, while the circuit under test is still operating.

With care, it is even possible to detect the presence or otherwise of current flowing in the pins of integrated circuits.

The tracer described here also functions much like a logic probe (and makes use of them partially redundant), in that a single narrow pulse on a line is registered by a loud beep from the piezo-electric buzzer on board the tracer. A logic pulser could be a handy companion instrument, to provide this single-pulse or multiple-pulse stimulus.

A particularly nice feature of this current tracer is that no external power or ground connections need be made, so the user isn't hampered by wires dangling out of the tracer. The internal NiCad battery is a special low self-discharge PCB mounting type, and on-board current regulator circuitry enables external charging from any DC supply from 5V to 15V.

Specifications

Commercial current tracers are very compact and easy to handle. I have not achieved this degree of compactness of body and sensing-head, so for very dense printed circuit boards the more compact unit may be preferred. On the other hand, my unit is perhaps more sensitive than necessary, and the reader might like to try constructing a smaller sensing head. Some hints for doing so are given later in this article.

An excellent possibility is a magnetic head from a video player. Video recorders/players have an internal assembly with two heads, and when one fails, the servicing technician removes both, as they are mounted on the same assembly. These are disposed of, but since one head may still be functional, you could ask for it for free, and use it in this project. The active part of a video head is tiny, and is very delicately cemented to the main assembly, so care is required. The only disadvantage is that the ferrite head has relatively few turns, and sensitivity will be less than my prototype.

The commercial competition probe has sensitivity from 1mA to 1 amp adjustable, will latch single current pulses with a duration greater than 50 nanoseconds, and detects pulse trains up to 10MHz. At the maximum sensitivity setting, the risetime to reach 1mA must be less than or equal to 200ns. External power of 4.5V to 18V is required, at up to 75mA.

My unit will sense single pulses, but due to a limitation of my test equipment, I was not able to experiment on logic with voltage pulse risetimes of less than 10ns. I managed to produce a single pulse of 15ns width, 10ns rise and 5ns falltimes approximately, with an amplitude 3 volts. When this was fed into a line of 1 or 2pF to ground, my tracer detected it with sensitivity to spare. A more precise analysis is given later.

So I know my tracer will detect pulse trains up to at least 66MHz. Into a line of 4pF, pulse risetimes of 150ns or less will be detected, which is quite sufficient. Theoretically I have estimated that for a 1pF load, the pulse rise time must be less than 75ns.

A far less sensitive unit would still give satisfactory service.

How to use it

The simplest application is as a partial replacement for a logic probe. A single pulse or glitch will cause a single clear beep. I have never had any need to latch the beeper or LED on continuously after occurrence of a single pulse; one beep is sufficient notification.

Continuous pulse trains will cause continuous beeping. Of course logic probes require external power, or at least a ground link, which can be a hindrance, and the probe tip must make electrical contact with the conductor. But my tracer needs no ground link, and will detect through plastic insulated wires and coated PCBs.

A typical fault is shown in Fig.1(a), in which a short to ground has occurred. If the driver isn't providing pulses, then stimulation can be provided by a logic pulser. Set the tracer to the minimum sensitivity that still gives beeps, and follow along the track. Current will divide at nodes, but if all or most current is taking one path only, then the tracer will become silent on the other path. Thus it can be determined that nearly all current is going one way only.

If the tracer reaches a node and then follows a number of paths from the node, the current in the individual paths will be lower, so to follow it along one particular path readjust the sensitivity so that beeper is just on, and continue tracing toward the next node.

The same current "hogging" occurs with bridged tracks, as shown in Fig.1(b). This creates an unexpected node, so the sudden drop in current on passing this "node" will cause the beeper to become silent.

You may be surprised to find that open-circuits on tracks can also be located. Fig.1(c) illustrates this kind of fault. Cracks may have occurred during PCB manufacture, or through flexing. Plated-through holes are sometimes at fault.

Generally you'll find there is sufficient current flowing in such a track, right up to the point where the crack is. Actually, if we take a closer look at the line, it is in fact a delay line with a certain characteristic impedance and an unmatched termination that reflects the pulse. But in the macro-time view the reflections are not seen and the line is simply viewed as being capacitive or inductive.

Last, but certainly not least, the tracer will detect 50Hz sinusoidal current. But due to the slow risetime, at least 2.5 amps RMS must be flowing — which I guess would be okay in high power applications. The highest 50Hz current I have tried the tracer on is 30A and I don't know what the current threshold will be at minimum sensitivity setting, though it could be calculated theoretically.

Circuit description

The full circuit of the tracer is shown in Fig.2. Let's now look at the way it works.

When current flows in a conductor, a magnetic field is produced around it. The sensing head on the tracer channels this field through a coil, which induces an EMF. This in turn triggers the beeper timing circuit. The requirement here is a difficult one, as the sensitivity must be 1mV and the frequency response must be up around 100MHz.

A high gain of about 2000 is required to convert the 1mV signal into a useful level that can control a beeper.

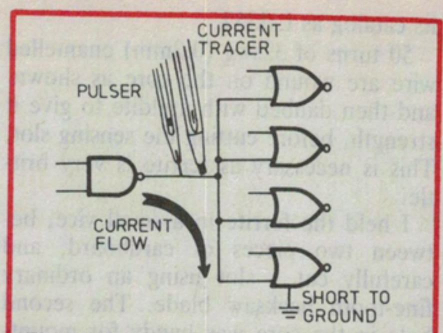

Fig.1(a): Using the current probe with a pulser probe, to track down a shorted gate input.

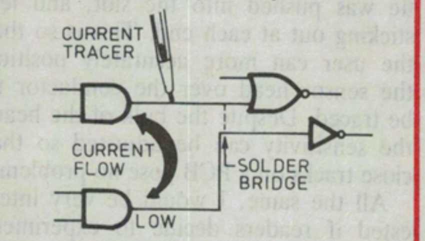

Fig.1(b): Tracking down a solder bridge between PCB tracks.

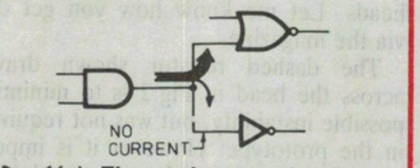

Fig.1(c): The probe can also find hairline breaks in PCB tracks.

Some lateral thinking was called for, and this led to the design of Fig.2, which has the required sensitivity and is very stable.

A 74HC-series high speed CMOS device is used, as this has good gain in the active region. Also, to a certain extent the transition region of the transfer characteristic is proportional to the supply voltage, minimising drift.

TTL exhibits a small hysteresis in the transfer characteristic, which I expect to be less or non-existent in the CMOS. However I designed the circuit to tolerate hysteresis.

Basically the circuit is based on a very sensitive one-shot multivibrator using two of the gates in a 74HC02. At power "on", the potentiometer wiper is at the bottom of the pot element, which gives minimum sensitivity. It is turned up until beeping starts and then backed off fractionally; this provides maximum sensitivity. Thus the voltage on pin 2 of the 74HC02 is just below the threshold, and any signal from the sensor will exceed the threshold, bringing pin 1 low and thus pin 4 high. This brings pin 3 high, which holds pin 1 low.

This also starts the beeper going, but after 0.1 seconds C1 times out, bringing pin 4 low again. Pin 1 must now be reset high, and to achieve this, in case the gate has hysteresis, C2 kicks pin 2 down below the threshold. If the sensor is no longer producing a signal then pin 2 will gradually come back up to just below the threshold, otherwise the process will repeat.

The information that I have on the 74HC series does not completely indicate the threshold spread and gain, but for the chips I have investigated it was close to 1.5V. If you find that the chip you buy has a different threshold, then you may have to modify R1 and R2.

I have been toying with an enhancement to the circuit that compensates for threshold spread and temperature drift, (and also gives a variable beeping rate in proportion to detected current level) but decided to get the article written at this stage, otherwise it will get put off for another twelve months!

The unit is powered by a PCB-mounting NiCad battery of nominal rating 3.6V and 100mAH.

External terminals enable connection of a DC supply of 5V to 15V, to charge the battery. The external charging sup-

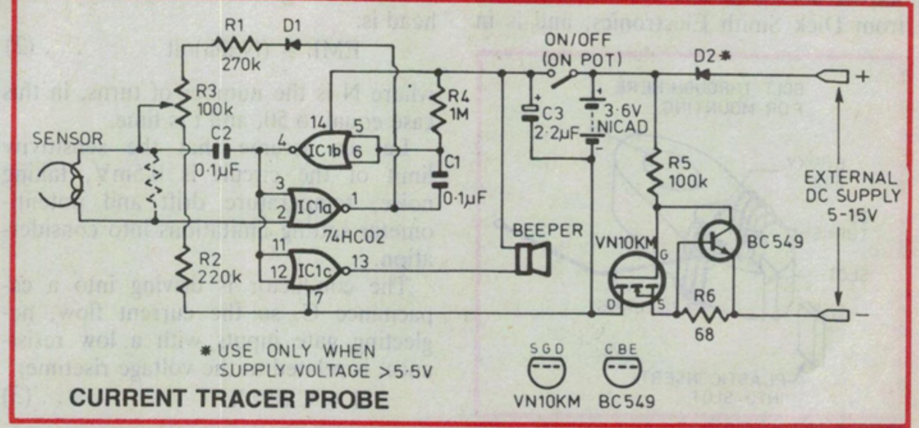

Fig.2: Complete circuit of the current tracer probe. Pot R3 is used to adjust its sensitivity.

Tracer Probe

ply passes to the battery through a 10mA current regulator circuit, which uses a VN10KM power FET. Series diode D2 is also used for reverse voltage protection, but as this introduces a further voltage drop it should only be used if the external charging voltage is greater than 5.5 volts.

The BC549 transistor senses when current approaches 10mA by the voltage drop produced across the 68 ohm resistor. Normally the VMOS transistor is turned on by the 100k resistor pulling up the gate, but when the BC549 starts to turn on, the VMOS transistor starts to turn off, so achieving regulation.

On charge, the battery voltage can rise as high as 4.5V, and if the external supply is only 5V, certain constraints are placed on the design of the regulator circuit, notably omission of the reverse-polarity protection diode.

This particular combination of bipolar junction transistor and VMOS transistor minimises voltage drop and does not allow discharge of the battery through the 100k resistor.

The VN10KM device is available from Radiospares, who list it under catalog number 295-107. The NiCad battery I used is also from Radiospares, catalog number 591-477. The beeper is of the piezo-electric type; I used a Tandy type, catalog number 273-065. The 100k switch pot can be either a Tandy Electronics type 271-216 or a DSE type R-6884.

Note that if the tracer is built without the on-board battery and charger, D2 should be left in and the circuit operated from a 5V supply.

Sensor head

A small high frequency ferrite core of the type having two holes is used, as shown in Fig.3. The core I used was from Dick Smith Electronics, and is in

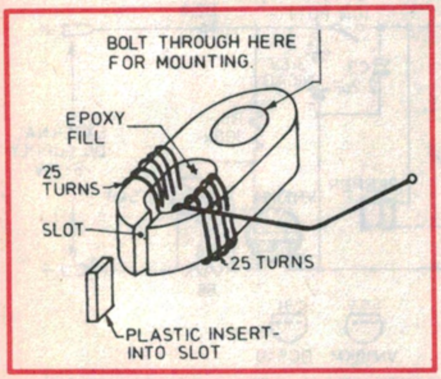

Fig.3: Details of the actual sensor, made from a 2-hole ferrite core.

its catalog as L-1352.

50 turns of 32swg (0.2mm) enamelled wire are wound on the core as shown, and then daubed with araldite to give it strength, before cutting the sensing slot. This is necessary as ferrite is very brittle.

I held the ferrite in a small vice, between two pieces of cardboard, and carefully cut a slot using an ordinary fine-tooth hacksaw blade. The second hole in the core was handy for mounting purposes.

Finally a small length of plastic cable-tie was pushed into the slot, and left sticking out at each end. This is so that the user can more accurately position the sensor head over the conductor to be traced. Despite the bulk of the head, the sensitivity can be adjusted so that close tracks on a PCB pose no problem.

All the same, I would be very interested if readers decide to experiment with smaller ferrite beads, such as the Dick Smith Cat No. L-1430 or video heads. Let me know how you get on, via the magazine.

The dashed resistor shown drawn across the head in Fig.2 is to minimise possible instability, but was not required in the prototype. However it is important during construction to avoid long leads, to keep the head close to the electronics, and the decoupling capacitor close to the IC pins.

Some calculations

I used these calculations while designing the tracer, but note that they are intended to give ball-park results only.

A very rough estimate of the total magnetic flux ϕ available around a conductor, per length W, is:

$$\phi = 10^{-6}.I.W \quad \ldots (1)$$

where I is the electron current in the conductor.

The emf generated by the sensor head is:

$$EMF = (N.d\phi)/dt \quad \ldots (2)$$

where N is the number of turns, in this case equal to 50, and t is time.

Let us assume that the sensitivity limit of the circuit is 0.5mV, taking noise, temperature drift and potentiometer setting limitations into consideration.

The conductor is driving into a capacitance C, so the current flow, neglecting gate inputs with a low resistance, is related to the voltage risetime:

$$I = C.dV/dt \quad \ldots (3)$$

It would be reasonable to take dV, the voltage change, as being at least 3V.

Combining equations 1, 2 and 3 we obtain

$$C = \frac{EMF\,.\,dt^2}{10^{-6}.W.N.dv} \quad \ldots (4)$$

This is the *minimum* value of line capacitance required.

Tabulating, for EMF = 0.5mV and with an effective W of 20mm, and with N = 50, dv = 3:

Pulse Risetime dt (nsec)	Minimum line capacitance (pF)
300	15
150	3.75
75	0.94

Final note

The prototype was built on a small piece of Veroboard and not housed, however you might prefer some type of case. A probe case would be nice and some arrangement could be worked out for mounting the sensor on the probe tip; use Araldite, maybe. Probe cases are available from Jaycar and Radiospares.

This is a project for fiddlers. It's fun to build and even more fun to operate. The final product is however a serious and extremely useful troubleshooting tool.

If you are happy to have leads trailing out of your tracer while in use, then you won't need the NiCad battery or charging circuit. If you try an original design for the sensing head, let me know how it works.

PARTS LIST

Semiconductors

1 74HC02 IC (Motorola)
1 BC549 NPN transistor
1 VN10KM VMOS power FET (Siliconix)
1 1N4002 or similar silicon diode

Resistors All 1/4W:

1 x 68Ω, 1 x 100k, 1 x 220k, 1 x 270k, 1 x 1M
1 100k carbon pot with switch

Capacitors

2 0.1uF metallised polyester
1 2.2uF tantalum

Miscellaneous

1 Piezo beeper (see text)
1 3.6V 100mA.H NiCad battery (see text) 1 ferrite core (see text)
Piece of utility board, case etc.