

# Multicore Cable Tracer

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Imagine being faced with a dozen or more cable ends, all the same colour and bearing no identification. The other ends emerge in another part of the building, and you have no way of knowing which is which.

You could use a continuity tester and a long length of wire to extend one of the probe leads. But if you had fifty wires, and a five minute walk from one end to the other, it would take you a good working day just to trace them all through!

The Multi-core Cable Tracing System presented here is designed to make this sort job less of a nightmare! The Sender unit is connected to up to 64 wires at one end, and then the Readout unit is used to indicate which is which from the other end. The Readout is simply connected to any two wires at the other end, and the display indicates which wire number the positive lead is connected to. Unlike some commercial systems, this system does not require a separate known common connection between the two units.

The two units are both battery powered, allowing them to be used in situations where mains power is not readily available. A red LED on each unit indicated that the battery is OK. If the LED does not light or is very faint, the battery should be replaced.

PP3 batteries were used in the prototype, but for more regular use larger capacity 9V batteries would be a better choice, for example six AA cells in a suitable holder. Low cost 9V plug-in mains adaptors could also be used. The 2 digit seven segment LED display on the readout unit is blanked whenever it is not connected to a cable, to conserve battery life.

This system must never be used on live cables. Ensure both ends of the cables to be traced are disconnected before using this system. If in any doubt, check with a test meter. Connection to live cables will cause damage to this system, and could endanger the operator.

## Circuit Design Decisions

With any cable tracing system, a different signal must be sent down each wire. The signal is then identified at the other end. Several systems were considered before deciding on the simple solution used here.

An analogue system using differing voltage levels were ruled out, primarily because it would not work with my plan of having no specific ground wire between the two halves of the system. Noise pickup and voltage drops in long cables could also affect the results.

I then considered a digital coding system, where a different serial code is sent down each wire. Although this would work well, it would result in a rather complex design. A system using differing frequencies was also considered, but again ruled out for reasons of complexity.

## Design Considerations

I finally settled on a system that sends different length pulses along each wire. The receiver simply has to measure the pulse duration to determine which wire it is connected to. This has the advantage of being relatively straightforward and cheap.

The only potential problem is that the capacitance of long cables might affect the pulse shape. By using logic devices with symmetrical outputs to drive the cable (74HC series logic), any pulse shaping distortion should occur equally on the rising and falling edges. This works well in practice, providing the receiving device has a Schmitt trigger input. The clock frequency is fairly low, so any distortion in the pulse shape would have to be fairly severe before the reading accuracy would be affected.

If use with long cable lengths is likely, I would suggest using 74AC logic devices for the output drive. 74AC devices have an output drive of  $\pm 16\text{mA}$  compared to  $\pm 4\text{mA}$  for 74HC, so they should be less affected by capacitive loads. However they are not so readily available, and are typically two or three times the price of 74HC devices.

74LS devices are not really suitable due to having non-symmetrical outputs (they can sink 8mA but only source 400uA).

Only one wire is driven at a time. This is necessary to fulfill the requirement of not having a common ground wire. All output lines are normally high, and a low pulse appears on each wire in turn. The total time taken to cycle round all outputs is approximately half a second.

The readout unit has two probes, which for clarity I will refer to as the "Reading" probe and the "Non-Reading" probe. The display on the readout indicates the number of the wire that the "Reading" probe is connected to. The "Non-Reading" probe may be connected to any other wire. Please remember that the power rails in the Sender and Readout units are not linked together, so some sort of reference is needed.

The "Non-Reading" probe is internally connected to the readout positive rail. The level on the "Reading" probe therefore goes low for a period, depending on which wire it is connected to. Then the wire that the "Non-Reading" probe is connected to goes low, this effectively results in the "Reading" probe going 5V higher than a logic high level. This does not reach the logic devices due to a resistor-diode circuit, and is ignored.

Hopefully this is clear - it is not the easiest arrangement to describe!

## Circuit Operation - Sender Unit

We will start with the Sender unit. The complete circuit is shown in figure #.

IC1a and IC1b (4093) form an oscillator running at about 5KHz. This drives a 4024 counter (IC2). The outputs of IC2 and another counter (IC3) are compared by a logic comparator (IC4), the output of which goes low when the two inputs are equal. This resets IC2 and increments IC3.

Assume the decimal value of the outputs of IC3 is at ten. Also assume IC2 has just been reset, so the value of its outputs is zero. These two output values are not equal, so the output on pin 19 of IC4 is high. Once IC2 has received ten clock pulses from the oscillator, its output will be equal to that of

IC3, and the output of IC4 will go low. This will increment IC3 so its output value is eleven, and also reset IC2 so its output value is again zero. As soon as this occurs the counter outputs are no longer equal so the output of IC4 will go high again. The sequence now repeats, but this time eleven clock pulses are needed before the two counter outputs are equal.

The outputs of IC3 are decoded into 64 individual outputs by IC5 through IC13. The 74HC138 is a three to eight line decoder, with active-low outputs. IC5 decodes into banks of eight, which are then individually decoded by IC6 to IC13.

Therefore each of these decoded lines will go low in turn, for a period determined by the number of clock cycles needed for the two counter outputs to become equal. Referring to the previous examples, the "10" output (SK11) will be low for ten clock cycles, and the "11" (SK12) output will be low for eleven clock cycles. The output number is the SK terminal number less one.

Output "0" from SK1 will be low for a very short duration, set by the values of C7 and R6. This may not work properly in practice, so it may be better to just use outputs "1" to "63". The delay components were found to be necessary to ensure IC2 resets correctly and IC3 increments correctly.

If less than the full 64 outputs are required, you can omit some of the higher numbered 74HC138 devices. In this case, connect a wire from the pin 4 position of the first omitted device to SK66. This will cause the counter system to be reset when the missing device is reached, speeding up the process by not generating unwanted outputs.

I originally planned to run the circuit from a 6V battery with a diode to drop 0.7V. However the frequency of the oscillator was found to vary with supply voltage, so the output pulse durations would vary as the battery ran down.

Instead I have used a 78L05 regulator, run from a 9V battery. The LED (D1) across the regulator lights when the voltage across it exceeds about 2.5V, indicating that the battery is OK. The LED series resistor (R4) has a high value to ensure insufficient current flows through it to disturb the action of the regulator. If you are using a higher voltage battery or a mains power supply unit, you may need to increase R4 further, or omit D1 and R4 completely.

## **Circuit Operation - Readout Unit**

Note that the component reference numbers start at 1 on both the Sender and Readout. Try not to get confused!

IC1b and IC1c form an oscillator, the same as the one in the sender unit. One resistor value is variable over a range of  $\pm 10\%$ , so that the unit may be calibrated. The output is connected to the Clock input of IC2.

The frequency of this type of oscillator varies with different makes of 4093 IC. To avoid any problems use the same make of 4093 IC in the Sender and Readout units. This can usually be assured by purchasing them from the same place at the same time.

IC2 and IC3 are decimal counters with decoded 7 segment outputs. These outputs are connected to the displays via emitter follower circuits. The carry output (CO) of IC2 is connected to the clock input of IC3, so IC3 is incremented when IC2 steps from nine to zero. IC3 thus drives the tens

display while IC2 counts the units.

The test probes are connected to SK1 ("Non-Reading") and SK2 ("Reading"). The "Reading" input is protected by R1, D1 and D2, as described earlier. R2 holds the input low when it is not connected, blanking the display to conserve battery power. IC1a inverts the signal. When the unit is connected to the Sender, the output of IC1a is normally low, and goes high on the Sender output pulse.

When the input is high (IC1a output low), the clock inhibit inputs (pin 2) of IC2 and IC3 are held high (via IC1d), so that the counters do not respond to the clock input. The display enable inputs (pin 3) are also held high, so the displays are illuminated.

When the input goes low, the reset inputs (pin 15) of IC2 and IC3 are pulsed high momentarily high, resetting the counters. This brief reset pulse is also coupled to the oscillator via D7, to bring the oscillator into line with the Sender unit. The clock inhibit input goes low, allowing the counters to count the clock pulses and the display enable inputs also go low, blanking the displays. This blanking period is brief, and hardly visible in practice.

When the input goes high again, the displays show the number the counters reached. This number depends on the length of time the input was low, and is therefore the wire number.

The power supply arrangement is identical to that in the Sender unit.

## PCB Construction

Because both PCB's use the same component references, the parts list has been divided into two distinct sections. To save confusion, it may be easier to completely build one PCB at a time.

The PCB construction is very straightforward, and requires little comment from me. Note that some wire links pass under components, so these should be fitted first. Use terminal pins or single-in-line header strip for the off-board components - particularly on the Sender PCB - these will make wiring up much easier. Drill a hole in the Readout PCB below VR1 to allow it to be adjusted once it is fitted into the case.

Do not fit the LED's yet. In the Sender unit the LED is mounted on the case, so terminal pins should be fitted in the PCB. In the Readout the LED has to fit through a hole in the case so it would be better to solder it once everything has been lined up.

On the prototype, the IC's and LED displays were soldered directly into the PCB. You may find it useful to use sockets for the displays to space them away from the PCB.

You may also wish to fit the IC's in sockets, particularly IC6 through IC13 on the Sender unit, since these are most likely to be damaged if the unit is inadvertently connected to low voltage live wires. The same applies to IC1 on the Readout unit. If the units are accidentally connected to live mains voltage wiring, they will almost certainly be damaged beyond repair.

## Sender Unit Case

The sender unit fits neatly in a low cost plastic box, type MB6, which is readily available. Everything is constructed on the lid, simplifying construction.

The lid overlay is shown in figure #. This diagram could be photocopied and used as a drilling template. An additional copy can be fixed to the lid before finally mounting the components.

Low cost 5A terminal block was used for the cable connections on the prototype. Wires from one side pass through small (1.5mm) holes in the box, to reach the PCB. Push these wires through from the outside, to avoid lifting the overlay.

You could use barrier strip connectors (the type with one screw terminal and a rear solder tag) but this is more expensive.

It is obviously not necessary to use every fixing hole in the terminal block connectors, four screws per 12 way length are sufficient. M3 screws and nuts are ideal. The PCB mounts on the two end fixing screws of the middle row of terminal block. If you fit 12mm spacers in place of the nuts on these two screws, the PCB can be fixed to them with two short M3 screws.

The LED is fitted in a normal LED clip, which requires a 6.5mm hole. A rectangular cutout is needed for the power switch (a small slide switch). However if you are using figure # as an overlay you could just drill a large round hole and let the overlay hide it! The slide switches are not normally supplied with M2 fixing screws, so you will need to order these separately.

The interwiring is very straightforward. Firstly each terminal on the outside of the case is connected to the appropriately marked point on the PCB. Take care to get these correct, although any errors will show up during testing.

The LED should then be connected to the appropriate points on the PCB. If you are in any doubt about the LED pinouts, hold it up to the light so you can see it's innards. The anode lead connects to the smaller internal piece to one side, and the cathode to the larger piece with a cupped shape in the top middle. This is easy to remember if you think of Cup for Cathode and Arm for Anode (same initial letters). This simple method of lead identification holds true for all conventional single colour visible LED's and most IR LED's. However it should not be relied on for some of the more fancy LED's such as the multi-colour, flashing and low current types.

The LED anode connects to the pin closest to the edge of the PCB. Finally connect the battery lead and the switch to the PCB. The battery negative (black) lead goes to SK66, and the battery positive (red) lead goes to the centre pin of the switch. Connect a piece of wire between SK67 on the PCB and the uppermost switch terminal.

On the prototype the PP3 battery was retained with a self-adhesive 'C' shaped cable clip. A double sided sticky pad may be a more readily available solution. If you are using a larger capacity battery such as 6 AA cells in a suitable holder, you will need to devise some method of securing this. Check that your proposed battery holder will fit the case before ordering it - you may need to use two or more smaller battery holders wired in series.

## Readout Unit Case

The prototype readout unit was constructed in a type MB2 case. However this was rather too tight for comfort, and the corners of the PCB had to be filed down. An MB3 type is slightly bigger and would be a better choice. If you want to use a higher capacity battery you may need something larger still.

The front panel overlay of the prototype is shown in figure #. This may be of limited use if you are not using an MB2 case, but it does give some idea of the layout.

You will need to make a rectangular hole for the LED displays to show through. As mentioned previously, by using an overlay you can hide any irregularities in your cutting. A piece of red filter material fitted behind the cutout will dramatically improve the contrast of the display.

The PCB is spaced away from the box lid with 12mm long spacers. On the prototype a piece of plastic sheet (available from model shops) was fitted behind the PCB, to prevent the battery causing short circuits. This adequately retained the battery in the MB2 case, but if you are using an MB3 case you may need to add some foam to stop it rattling.

Before finally fixing the PCB, the wiring should be completed. The LED solders directly into the PCB, however you will need to form the leads to allow it to show through the hole in the case. You may need to sleeve the leads to prevent them shorting. The LED anode connection on the PCB is closest to R20.

Battery negative connects to SK4 and battery positive connects to SK3 via the switch. The positive (+) test-lead (the "Reading" lead) connects to SK2, and the negative (-) to SK1. These leads pass through the small holes shown in the case and the free ends may be fitted with crocodile clips or similar. Knot the cables inside the case to save straining the PCB if they are pulled.

## Testing

If you constructed the units carefully and luck is on your side, they should work first time. All you would then have to do is calibrate the Readout unit.

Initially it is best to test the units by connecting them directly together. Once this is working OK, you can try them with a length of multi-core cable.

Switch the Readout unit on. The 'Battery OK' LED should light, and the display should be blank. Touch the two test leads together and the display should light up, and show a number between 00 and 99. It is most likely to show 00 due to contact bounce as you touch the probes together. If you can get it to show a number other than 00 (by touching the probes together abruptly), you can be confident that it is working OK.

Now switch the Sender unit on. It should not do anything exciting but the LED should light.

Connect the positive readout probe to terminal 63 on the Sender, and connect the negative to any other terminal. The display should show a steady number, although it may alternate between two adjacent numbers. You should just be able to see the display flicker about twice a second.

Adjust VR1 in the Sender until the display indicates 63. Find the points where the reading alternates

between 62 and 63, and between 63 and 64. Set the preset mid-way between these two points.

If the preset does not have enough range, you may need to adjust the value of R4 or R21. If the two 1n0 timing capacitors and the two 4093 IC's are from the same batches (bought from the same place at the same time), you should have no problems.

Now try connecting the positive probe to each of the other terminals in turn. You should get the appropriate number displayed. You may get one number as the probe is connected, followed by another which remains constant. In this case just ignore the first number.

As mentioned previously, the zero output may not work correctly due to the pulse being so short. If this is the case you would be best just to ignore it.

If you are building more than one pair of units, please note that they are calibrated in pairs. Clearly mark the units so that the right units are always used together.

## Longer Cables

If you have a long piece of multi-core cable to hand, try the units on it. It is not possible to give a maximum permissible cable length since this depends mainly on the capacitance, which in turn depends on the cable construction. In the case of individual wires, it depends on how they are installed, for example whether they are in metal conduit and how closely they are packed.

If you have problems with long lengths of cable affecting the readings, there are a couple of things you can try. Firstly you could try using 74AC138 devices for the output drive, as described earlier. Secondly you can try decreasing the clock speed. Simply increase the values of both C1 capacitors. Remember to re-adjust VR1 after changing any values.

The problem is caused by the edges not rising and falling quickly. If the total rise and fall time exceeds about half a clock period, there is a possibility of inaccuracy. By slowing the clock, we effectively widen the acceptance range.

The drawback with this is that the time taken to get a valid reading will increase, although even if it takes several seconds it is still much quicker than messing around with a multimeter. If the capacitors are increased to 10n, the time to get a valid reading will be no more than five seconds, which seems reasonable and should allow vast lengths of cable to be identified with no problems. This is probably the largest practical capacitor value.

If you will only be testing a limited number of wires, you can reduce this time delay by removing one or more of the output IC's and connecting the pin 2 position of the first empty IC space to SK65 (see circuit description earlier). The time saving obtained can be quite significant since the higher numbers take more time than the lower numbers.

## Parts List - Sender Unit

### Resistors (all 5% 0.25W or better)

R1	22K
R2	100K
R3,R5	4K7
R4,R6	1K0

### Capacitors

C1	1n0
C2	10u 25V Radial Elect
C3,C4,C5	100n
C6	2u2 35V Radial Elect
C7	470p

### Semiconductors

IC1	4093 Quad NAND Gate
IC2,IC3	4024 7 Stage Binary Counter
IC4	74HC688 8 Bit Logic Comparitor
IC5,IC6,IC7,IC8,IC9, IC10,IC11,IC12,IC13	74HC138 3 to 8 Line Decoder
IC14	78L05 5V 100mA Voltage Regulator
D1	RED LED

### Miscellaneous

Case type MB6, PCB code ???, Terminal block (6 off), SPDT slide switch, LED clip, PP3 battery, PP3 battery clip, wire.



# Parts List - Readout Unit

## Resistors (all 5% 0.25W or better)

R1,R19	4K7
R2	100K
R3	22K
R4	68K
R5,R6,R7,R8,R9,R10,R11,R12, R13,R14,R15,R16,R17,R18	680R
R20	1K0
R21	27K
VR1	10K Horizontal preset

## Capacitors

C1	1n0
C2	47u 16V Radial Elect
C3,C4,C5,C7	100n
C6	220p

## Semiconductors

IC1	4093 Quad NAND Gate
IC2,IC3	4026 Decimal counter (7 seg output)
IC4	78L05 5V 100mA Voltage regulator
TR1,TR2,TR3,TR4,TR5, TR6,TR7,TR8,TR9,TR10, TR11,TR12,TR13,TR14	BC548 NPN Transistor
D1,D2,D6,D7	1N4148 Diode
D3,D4	0.3" Com Cathode Red 7 Seg LED Display
D5	RED LED

## Miscellaneous

Case type MB2, PCB, Red and black croc-clips, SPDT slide switch, Red LED filter material, LED clip, PP3 battery, PP3 battery clip, wire