100mV Continuity Tester

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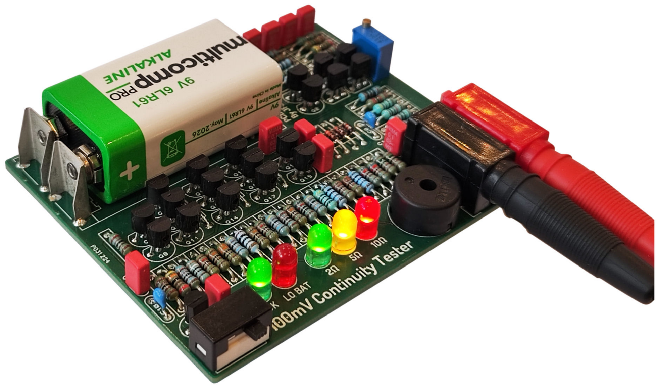
- Test continuity in or out of circuit instantly.
- Only 100mV test voltage across an open circuit.
- 3 low resistance thresholds: 2Ω, 5Ω and 10Ω.
- 3 tones of audible alert.
- Low battery warning.
- Not affected by semiconductor junctions.
- Highly immune to even very large capacitances.
- Fast response (faster than many multimeters).
- Nearly all transistor based (except the regulator).
- Standard 4mm sockets.



Introduction

This design started as a “self challenge”. I wanted to design a good quality continuity tester that would not be fooled by semiconductors and large capacitances. I also wanted to make it with no ICs. Crazy? Yes, of course. The design would be much simpler with a couple of cheap quad Op-Amps, or even a little micro, but where’s the fun in that? Apart from the voltage regulator (which is a low dropout 5V regulator in a TO92 package), there are no ICs at all in this design.

The design is based around long-tailed-pairs (LTPs). LTPs are most frequently seen at the core of Op-Amps.

One LTP is used as a linear amplifier, to amplify the small voltage across the test probes.

Further LTPs are used as comparators to detect the various thresholds associated with 2Ω, 5Ω and 10Ω being across the test probes.

A final LTP is used for low battery monitoring.

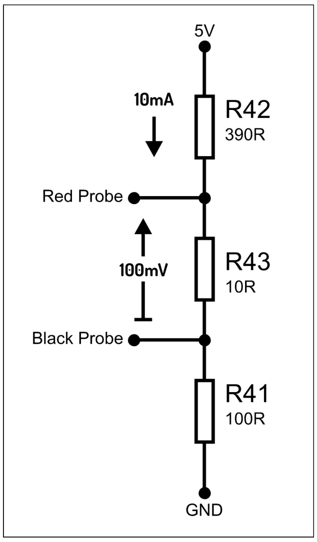
Design Overview

The design comprises of the following stages:

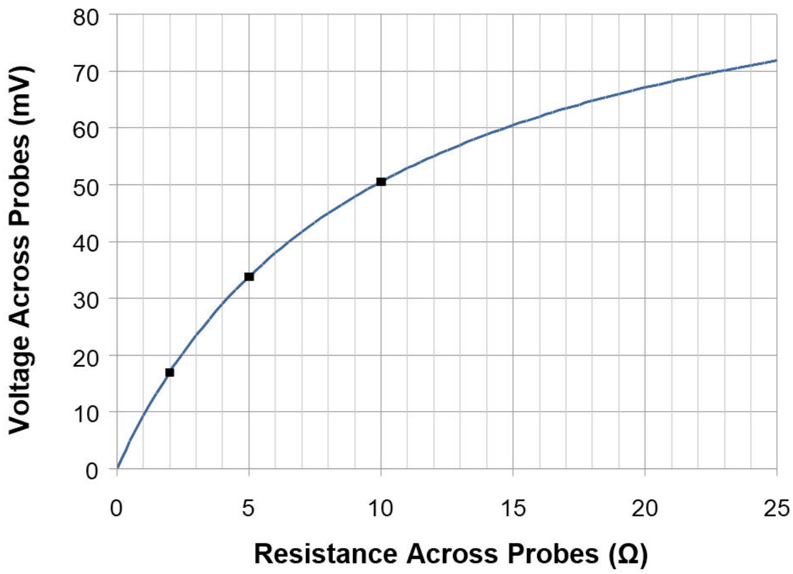
Input Front End - To create 100mV across the probes.
Linear Amplifier - To amplify the voltage across the probes.
Comparators - To switch on LEDs when the amplified voltage reaches certain thresholds.
Oscillator - To produce an audible tone which varies according to the number of LEDs lit.
Comparator - For low battery detection.

Input Front End

The input stage is a simple resistor chain (R42, R43 and R41) connected between the supply rails. The current flowing through that whole resistor chain is 10mA. The voltage across the middle resistor (R43) is therefore 100mV. Both ends of R43 are brought out to test probes. So that means that the voltage across the test probes when nothing is attached to the probes would be 100mV, much lower than you would see in conventional testers such as your multimeter on continuity or resistance settings. If there was a short circuit across the probes, then the voltage would be 0mV of course. For other resistances, the voltage across the probes would be as follows:



Resistance across probes	Voltage across probes
0Ω	0mV
2Ω	17mV
5Ω	34mV
10Ω	51mV
Open circuit	100mV

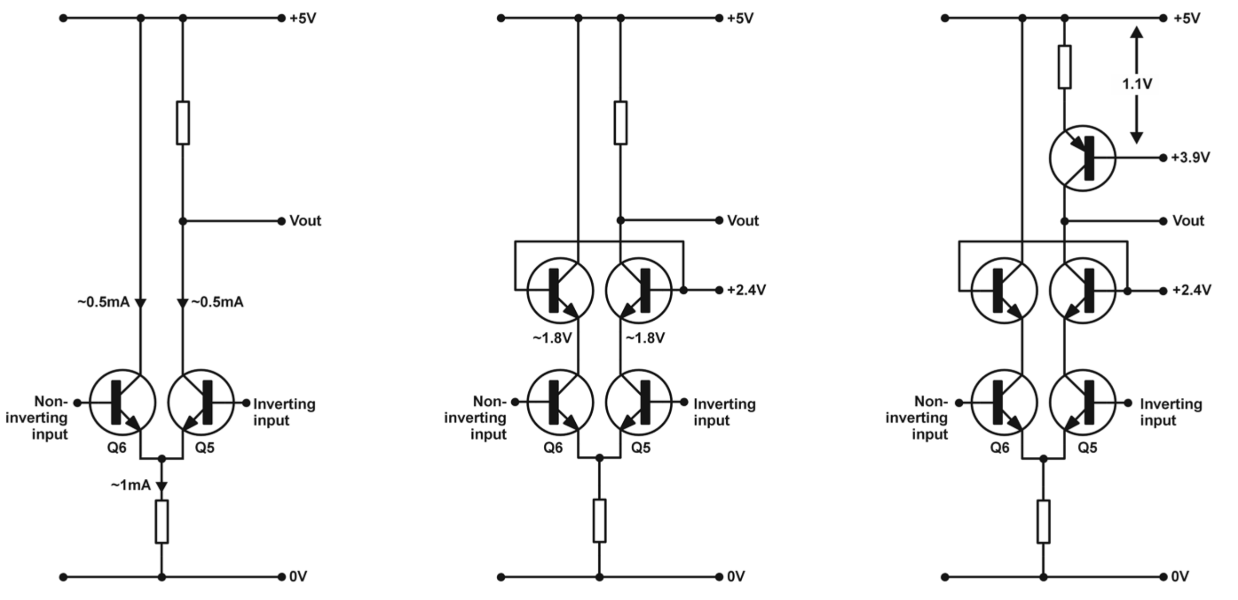


Linear Amplifier

The first active stage of this design is a linear amplifier which is based on a long tailed pair with some simple enhancements.

The performance of the amplifier is enhanced here in two ways. Firstly, the collectors of the two main long-tailed-pair transistors, Q5 and Q6, are "fixed" in potential by means of 2 extra transistors. This is called a "Cascode" arrangement and reduces the voltage changes that occur across the long-tailed-pair transistors which in turn reduces the voltage difference between the 2 bases, thus reducing offset voltages when the pair are in balance. The addition of "cascode" transistors has very little influence on the collector currents of Q5 and Q6.

The amplifier is further enhanced by introducing a constant current source as the main load. The constant current source effectively behaves like a very high impedance load and therefore exhibits a large voltage swing with just tiny changes in current through it, this increases the gain of the amplifier hugely.



Single-ended output Long Tailed Pair

Fixing collector potentials with "cascode" transistors

Increase open-loop gain with constant current load

It is common to implement a constant current sink in the "tail" of the amplifier, in place of the resistor, although that generally only improves the capability to use the inputs over a wider common mode voltage range. As we are operating the inputs over a small, closely defined voltage range, then adding a constant current sink in the "tail" provides little benefit.

As the constant current load of the amplifier is a very high impedance then the output is buffered by a simple emitter follower, Q2.

To yield a fixed, definable gain, resistors R39 and R40 configure the amplifier as a non-inverting amplifier with a gain of around 46.5. For a simple amplifier like this, the open loop gain is not as big as a standard op-amp. The resulting gain of the amplifier here is slightly lower than the calculated value of 46.5, measurements on the prototype suggest the gain is about 44.1. The resistors R39 and R40 however do help to ensure that the gain does remain very stable even if the individual transistor gain (hFE) varies by quite a bit.

The resulting non-inverting amplifier is effectively sitting on a virtual earth voltage of about 1.0V (the negative test probe potential), so any amplified voltage is added to that 1.0V.

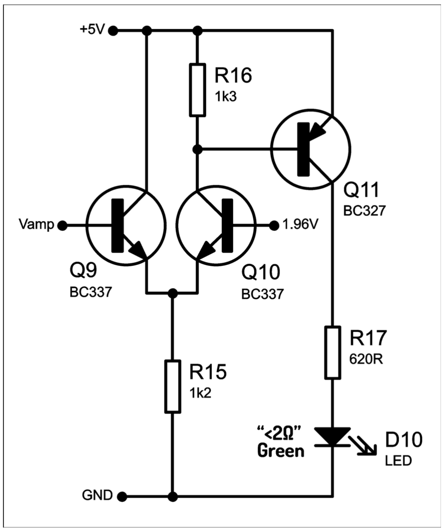
In theory, the output from the amplifier for the various test resistances would be as follows:

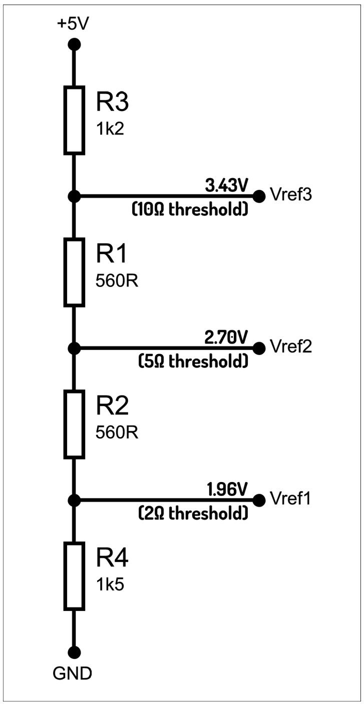
Test Resistance	Amplifier Output
2Ω	2.37V
5Ω	3.11V
10Ω	3.84V

Simulations of the amplifier show that its output has got a useful linear output swing from 1.7V up to 3.7V. To ensure that the output swing for test resistances of 2Ω up to 10Ω are nicely within that range, RV1 can be adjusted to shift the offset that is imposed on the inverting input of the LTP.

Comparators

There are 3 measurement comparators, one for each resistance threshold of 2Ω, 5Ω and 10Ω. Each comparator is a very simple Long Tailed Pair, fed with the output from the linear amplifier (Vamp) into one of the bases and a “reference” voltage from the resistor chain fed into the other base. The output of each comparator is further squared up with an extra transistor.
For example, the “2Ω” threshold comparator consists of Q9, Q10 and Q11.
The Long Tailed Pair is formed by Q9 and Q10 with a current in the tail of about 1mA.
When the LTP is in balance there is about 0.5mA going through both the transistors. That means that the voltage across R16 is starting to reach enough voltage for Q11 to start switching on.
If ***Vamp*** falls below 1.96V, the current balance quickly swings over from Q9 to Q10 and the voltage across R16 allows Q11 to switch on hard.
If ***Vamp*** rises above 1.96V, the current balance quickly swings over from Q10 to Q9 and the voltage across R16 rapidly falls and Q11 is switched completely off. This gives quite a good sharp on/off response for relatively small changes in ***Vamp***.





To obtain useful thresholds, a simple potential divider resistor chain comprises of R3, R1, R2 and R4. The resistors have been chosen to give suitable steps in voltages that match the desired threshold intervals and also sit well within the linear amplifier’s output swing.

By adjustment of RV1, the amplifier output voltages can be set to closely match these “references” when the appropriate resistance is being tested. In fact, adjusting for just one of these conditions (such as the 10Ω threshold) will ensure that the other two are also set.

Consider the comparator formed by Q15 and Q16. When the voltage from the linear amplifier is less than the reference voltage of 3.43V, the currents in the pair of transistors become imbalanced and Q17 turns on. The “10Ω” LED switches on along with the audio frequency oscillator, so you hear a beeping sound.

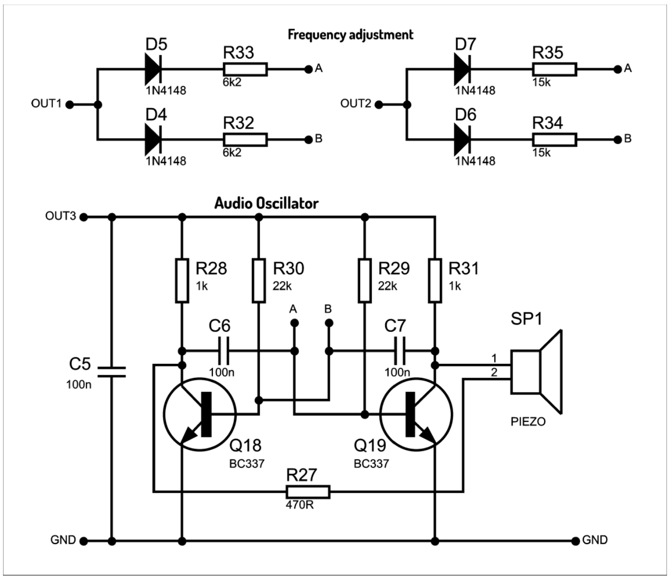
If the voltage from the amplifier falls below 2.70V (due to a resistance on the probes falling below 5Ω), then the “5Ω” LED is lit and the frequency of the audio oscillator is increased by means of D6, D7, R34 and R35.

If the voltage from the amplifier falls below 1.96V (due to a resistance on the probes falling below 2Ω), then the “2Ω” LED is lit and the frequency of the audio oscillator is increased further by means of D4, D5, R32 and R33.

Although the comparators have quite a sharp on/off transition, it’s still possible for them to be in their linear region if the voltages at each base are very close to each other. To ensure a sharp on/off transition of the comparators, a small amount of positive feedback is employed by means of D1, D2 and D3. The positive feedback, determined by the resistor values of R18, R22 and R26, introduces a small amount of current back into one of the inputs of the linear amplifier resulting in a few mV of hysteresis.

Audio Oscillator

The oscillator is required to generate audio tones. The oscillator is switched on when the resistance on the probes is less than 10Ω (“OUT3” goes high).



This oscillator is a simple 2-transistor multivibrator formed by Q18 and Q19. The frequency is determined by resistors R29, R30 and capacitors C6, C7.

The frequency of this type of oscillator is not precise, but for a “beep” sound then the exact frequency is not important. Approximately, the frequency can be calculated with the following formula:

F ≈ 1 / (1.4 x RC)

Where ***R*** is R29 & R30 (equal values), and ***C*** is C6 & C7 (equal values).

The standard (bottom) frequency for the 10Ω threshold is about 320Hz (determined by the 22kΩ resistors and the 100nF capacitors).

In this project, the timing resistors are “shunted” by extra resistors when we want the frequency to be increased for the 5Ω and 2Ω thresholds. This is achieved by means of diodes D6, D7 with resistors R34, R35 and also diodes D4, D5 with resistors R32, R33.

Construction

Assembly is straightforward. Fit the 7 x 1N4148 diodes first. Take care with the diode orientations, they are not all pointing in the same direction. Then move on to the 43 resistors. There are many different values, so be careful to select the correct ones.

Matched Pair

Before fitting the transistors, it's worth selecting 2 out of the 15 NPN transistors that have good characteristics matching for use in positions Q5 and Q6. It's not essential, but having a pair of matched transistors reduces the influence of temperature changes on the thresholds. If possible, use a transistor analyser or suitable multimeter to select 2 transistors that have matching Vbe (within ±5mV) and matching hFE (within ±5%). From my own batch of 15 BC337 devices for this project, it was easy to find several pairs with good matching. Don't worry too much about the matching though, adjustment of RV1 allows for sufficient calibration later on.

Take care with the selection of the NPN (BC337), PNP (BC327) devices and the regulator, they're all in TO92 packages.

Fit the LEDs (remember the long leads are +ve), switch SW1, trimmer potentiometer RV1, the test sockets and the battery connectors. For the battery connectors, it's best to do one at a time. Solder just one pin to start with, check alignment, adjust if necessary and then secure by soldering the other pins with plenty of solder. The pins of the battery connectors need plenty of solder to fill the plated-through-holes of the PCB, that way the connectors will be rock solid and easily withstand the forces of battery installation and removal.

Setting Up and Testing

Make sure the probes are open circuit. Don't fit the battery yet. If you have a variable bench PSU with a current limit, set it to 9V with a 60mA current limit. Apply power to the battery connectors, taking care of polarity. Make sure the switch SW1 is in the On position (slider rightmost). All the threshold LEDs should be extinguished and the sounder should be silent. The "OK" LED should illuminate and the current consumption should be 25-35mA. If the current is outside of that range then switch off and check all joints and components.

If you don't have a PSU with a variable current limit, then use a 9V battery and consider using a multimeter on the current setting, in series with the battery, to check the current consumption before fully fitting battery to the PCB battery connectors.

Now connect a 10Ω resistor across the test terminals. Adjust RV1 until the "10Ω" LED is on the cusp of lighting. Illumination of the "10Ω" LED should coincide with a beep from the sounder. If the adjustment range of RV1 is not sufficient to achieve this then it's worth checking various voltages on the board while the board is powered up and the probes open circuit. Typical voltages are shown on the circuit diagram, most of which are relative to the 0V rail (battery negative). Note that the negative test terminal is NOT the 0V rail. Checking the various voltages will help to identify where any problem is located, or thereabouts.

Assuming that you've been able to adjust RV1 to achieve the "10Ω" LED to be on the cusp of lighting when a 10Ω resistor is connected to the test terminals then you can proceed to check the other thresholds with a selection of resistors that sit nicely between the 3 resistance thresholds.

If your board is being powered from a variable power supply, reduce the voltage slowly and verify that the "Low Battery" LED begins to illuminate when the PSU voltage is around 6.5V ±0.5V.

Finally, you can fit a 9V battery to the battery connectors. Most types are suitable for this application except for Zinc-Carbon or Zinc-Chloride batteries as they have poor current delivering capability and low capacity.

Typical Specifications

Open circuit test voltage	100 ±6.0	mV
Threshold 1 resistance	10.0 ±2.0	Ω
Threshold 2 resistance	5.0 ±1.0	Ω
Threshold 3 resistance	2.0 ±0.5	Ω
Threshold 1 beep frequency	320 ±100	Hz
Threshold 2 beep frequency	750 ±200	Hz
Threshold 3 beep frequency	1900 ±400	Hz
Low battery threshold	6.5 ±0.5	V
Current consumption (open probes)	29.2 ±5.0	mA
Current consumption (shorted probes)	51.6 ±5.0	mA