DENT #003 | Positional Current Probe Calibrator

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Small calibrator PCB helps to take full advantage of AIM's I-520 Positional Current Probe

Often circuit designers need to perform In-Circuit-Current-Measurements (herein ICCM). This especially applies to analog circuits - amplifiers, power supplies and such. Information and clues obtained from not only observing the shape of current waveform but knowing its value often helps to understand why the circuit behaves the way it does and simplifies troubleshooting, but ICCM presents known challenges. Most obvious one is necessity to break the circuit. In the old days this was not as much of a problem - with through hole components it was at least possible albeit cumbersome. Now days with SMT technology practically displacing through hole and use of multilayer PCBs, ICCM becomes nearly impossible unless some measures are taken at the design stage.

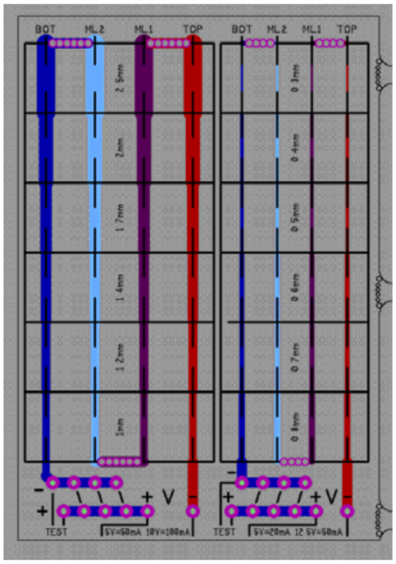
When I design a circuit requiring current measurement or trimming, I usually include zero Ohm resistors (jumpers) placing them in strategic places along PCB tracks that will require current monitoring once the circuit is assembled. This later on allows to temporary replace jumpers with calibrated shunt resistors and perform current measurements. I also bring inner layers' tracks to the PCB surface just for that purpose. Finished product's PCB layout doesn't have to be redone - it can still contain zero Ohm jumpers which are very cheap compared to the cost of changing layout just to remove them. Now, using the positional current probe it is possible to observe current waveform and measure current flowing through SMT components and PCB tracks without using jumpers which introduce insertion losses and may adversely affect your circuit operation. Principle of operation of this tool was covered in detail in [Dent_002](http://www.metricmind.com/data/dent_002.pdf): (http://www.metricmind.com/data/dent_002.pdf). However, there is one problem with using this very helpful tool - difficulty of initial calibration, so the measurements can be trusted. The

AIM Positional Current Probe

problem lies in the principle of operation of the probe - it measures current indirectly by measuring magnetic field created by it. Unfortunately, magnetic flux crossing probe's sensor is not generated only by the current of interest - any near-by current carrying conductors have impact on the measurements. Even position of the probe in respect to Earth's magnetic field may impact the readings in most sensitive measurement range.

The probe's amplifier includes compensation circuit consisting of manual gain and offset adjustments. You can set output scaling to any convenient ratio, for instance 1V = 10mA, this calibration is simple and done by inserting the probe tip into the calibration hole where the tip touch the PCB track with known current flowing through it. That is all good until you try to move the to real circuit - you can immediately see DC offset as you move the probe through the space around your project circuit.

Another issue is that the probe actually registers flux density which is function of current density. This means that if your PCB track changes width from, say, 4 mm to 2 mm, the same current flowing through such track will result in twice as much current density in its narrow section as it wide one. Accordingly the instrument's output will be higher if you touch narrower track, even though the current value is the same. AIM includes the calibration chart with the probe you're suppose to use for different PCB track widths but this is inconvenient for multiple tracks, especially where the relationship between output as a function of track width becomes non-linear for tracks narrower than the probe tip (2.6mm).



Calibrator PCB layout

Lastly, the probe output is highly sensitive to the distance from the current carrying conductor - its output drops exponentially with increase of the distance. This means that the same current flowing through the tracks with identical widths but located in different PCB layers will produce very different output.

All this makes practical accurate measurements very difficult. After using the probe for some time and understanding its limitations I decided to simplify calibration task so no charts will be needed to convert output instruments readout to the current value for different track widths and layers. So I just came up with a very simple calibration PCB consisting of two serpentine shaped PCB tracks with sections of different known most commonly used widths narrowing toward

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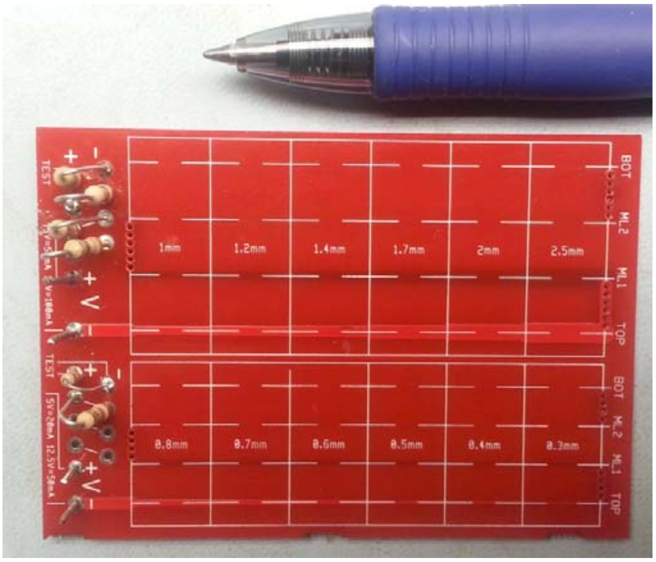
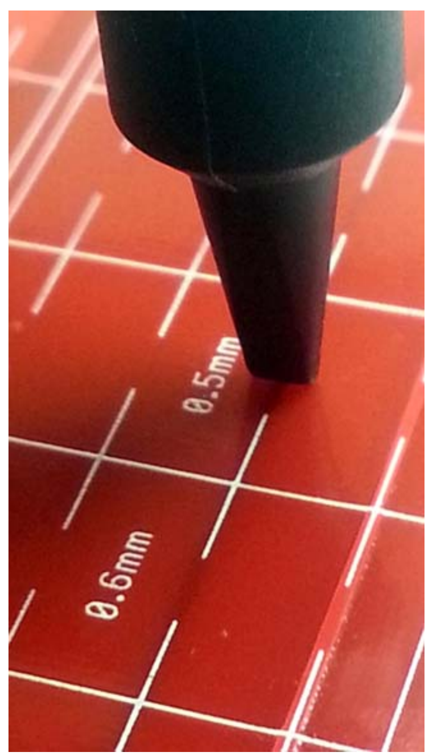


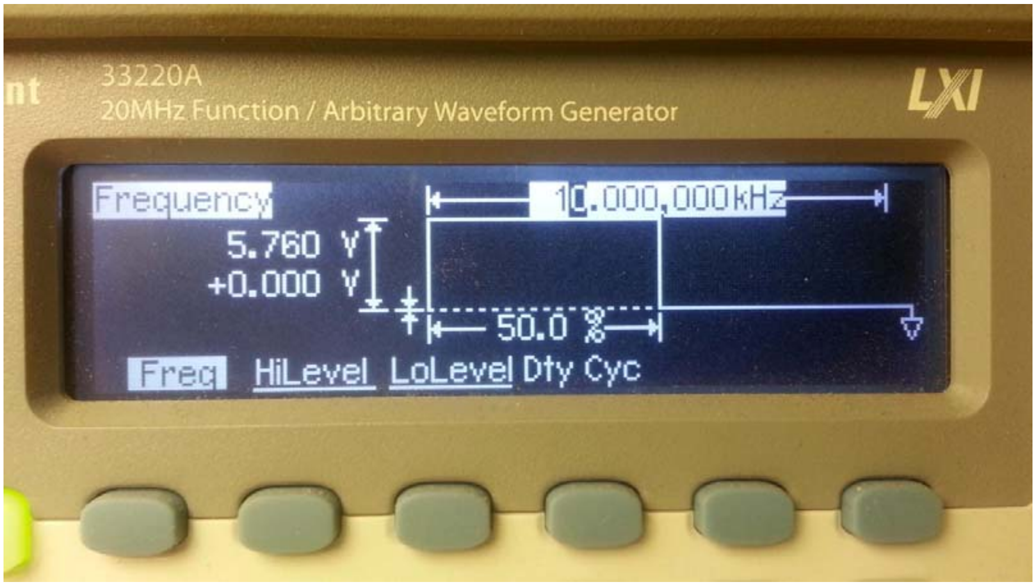
Complete calibrator PCB

one edge. The track pattern repeats in all 4 layers which is typical layer stack I use almost exclusively in all my designs. The end of the track is connected to the test pads through the precisely calibrated resistor converting applied known voltage to known current. There are two separate circuits - one for lower calibrated current (20mA @ 5V applied, 250 Ohm resistor installed) and another one for higher current - 50mA @ 5V applied, 100 Ohm resistor installed). So now knowing exact current value and positioning the probe tip above the section of track with the same width and on the same layer as in my real application PCB I can adjust instrument's gain to have known output for given track. For instance, if I need to measure current through the 0.5mm wide track located on the second layer in my PCB design, I just tough that section width on the calibrator PCB, apply 5.000V from a function generator and adjust the gain so the output of the instrument is, for instance, 1.000V as shows on the scope. Since I know the current is exactly 20mA, with scope gain set to 1V/div the instrument scale becomes 20mA/div. So now I can touch any 0.5mm wide track on the second layer on my PCB and take direct accurate measurements without inserting any jumpers.



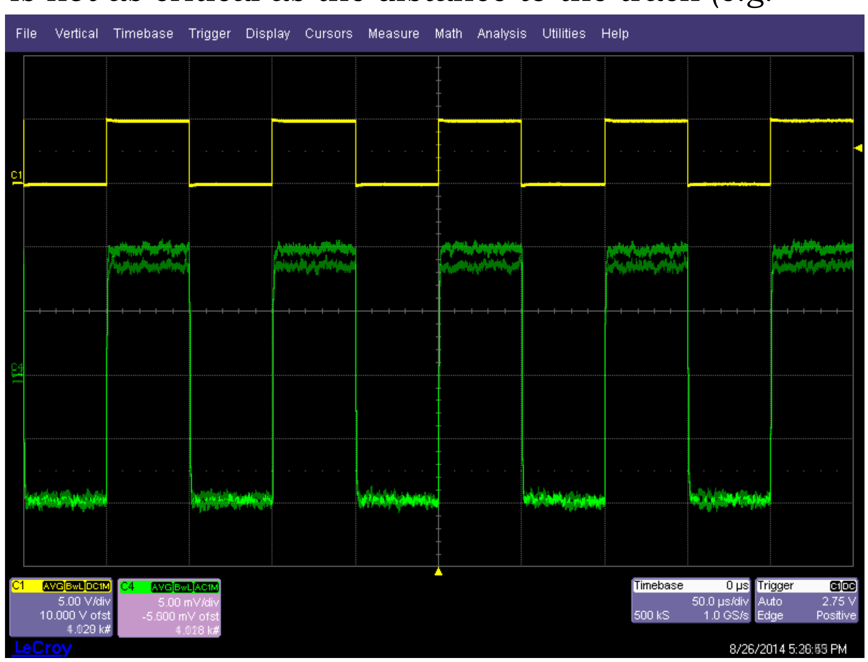
Probing the track

To make my future work more efficient I wanted to verify the impact of the track width and distance and compare to info supplied by AIM. So I set up an experiment - supplied 100 kHz rectangular waveform with 5V amplitude from the function generator to the test pads of the calibrator PCB. This resulted in the rectangular shape current with exact 20mA value. Granted, the output of the generator had to be above 5V to compensate voltage drop on the test leads. Because the scope was Kelvin connected to the test pads, I could dial required output to set actual voltage on the PCB to 5.000V. In my case it took 0.76V more to do that. Here is what the generated output looked like:



The settings of the function generator that produced plots below.

So once the current was fixed to 20mA, I captured several waveforms while moving the probe tip along the track over sections with different widths as well as different layers. Combined plots of the experiments are presented below. It turned out that for given track widths range sensitivity to the width is not as critical as the distance to the track (e.g. layer) Here is the plot of 20mA current measured over 0.3mm and 0.8mm sections of the same track. The scale here is adjusted to 5mA/div.You can see that the current difference is minimal - top green trace is measurement taked over 0.3mm adjusted to 20mA, and moving to the 0.8mm width results in dropping reading to 18mA. In other words more than doubling track width results in 10% charge of the prober's output. This is good news, and it happens because these widths are far smaller



20mA flowing through 0.3mm and 0.8mm wide tracks

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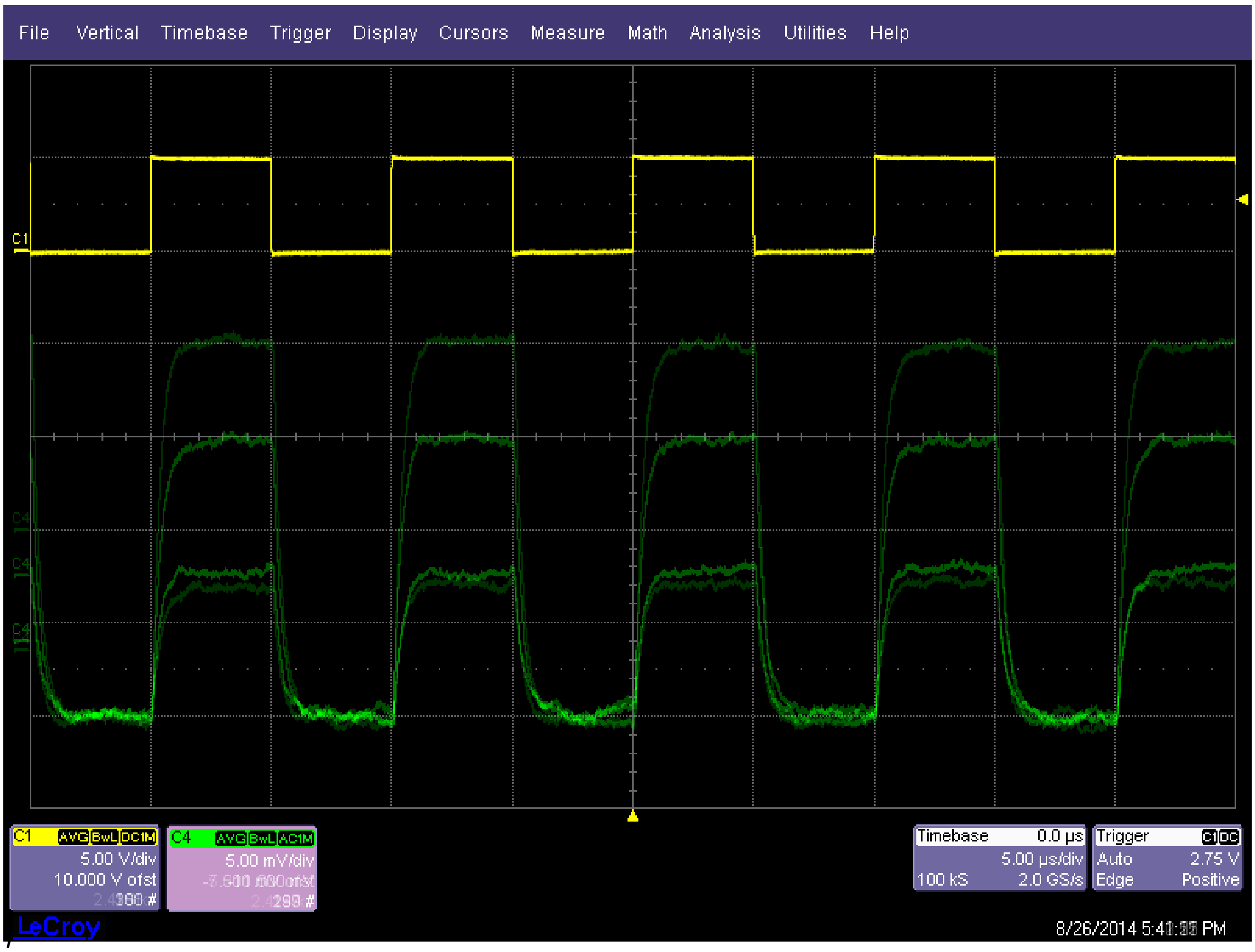
than the width of the probe tip, e.g while flux density of the magnetic lines around the track is different, *all* the flux lines in both cases still cross the sensor, resulting in nearly identical output. No flux lines close around the track outside the sensor head. For the tracks wider than 2.4mm this will not be the case, some flux line will miss the head so the probe output dependency on the track width will be more pronounced.

The test results for different layers were more interesting:



20mA flowing through 0.5mm wide tracks located on different layers.

Here four green traces represent signal captured by the current probe from all four layers - top trace - from top layer, two mid layers and bottom trace from the bottom layer. From theory we know that the magnetic field strength drops

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exponentially with the distance from the conductor. From the snapshot above we can see this is obviously the case with one oddity - the signal strength from the third layer down seem to be too low - about the same as from the bottom layer. Unless the probe tip was not positioned exactly above the trace and oriented perpendicular to it, the only explanation to this is that the physical distance between all layers on this PCB was not even - the third layer is closer to the fourth (bottom) one than to the second layer. To confirm this some destructive PCB analysis is in order. Because of quite a few PCBs were made, this will be done shortly and will be informative investigation. The result could also mean that the manufacturing tolerance of positioning copper clad while manufacturing a PCB, while will not impact your circuit operation, will impact accuracy of measurements with positional probe - something to keep in mind if you plan to use this instrument. For critical designs it could be advisable to attach a small calibration break-away PCB that is manufactured along with your main PCB as one board, so the layer structure is preserved identical top both. If you use your break-away PCB for calibration, because it will match the actual product board layering, all the measurements will be accurate.

One last interesting test was to get reading directly off the surface of passive components such as SMT or through hole resistors. Below Here is the photo of positioning the probe to the surface of a resistor. Obtained current measurement can be calibrated the same way as the track and any resistor of the same type can become the sensing point. However, the tests revealed that positioning the probe tip at the angle increases the flux and resulted in higher output. Since the maximum output is obtained when the probe tip is perpendicular to the current flow, this actually reminded how resistors are manufactured. The common carbon film deposition resistors have spiral groove around the body, and effective angle of the carbon "track" around resistor's body depends on the amount of groves, which in turn depends on the value. Only very low resistor values have continuous carbon coating. So positioning the probe at the angle to the resistor body will actually result in positioning perpendicular to the carbon track thus

Positioning probe tip for measurement.

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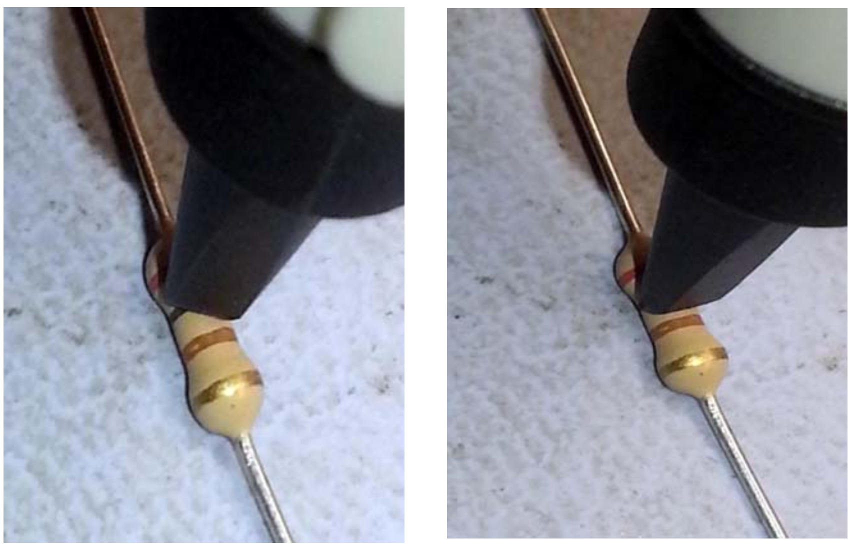
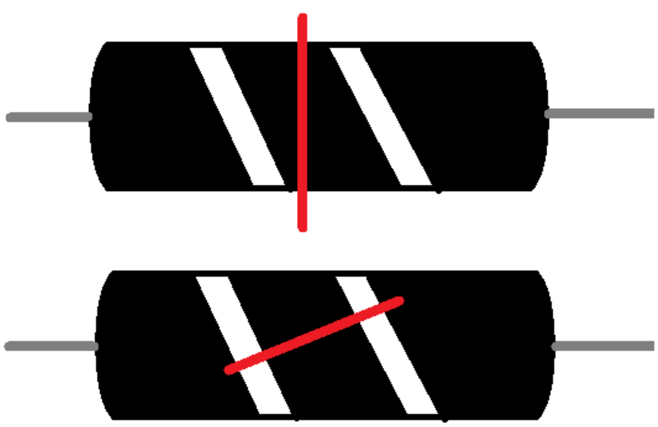
maximizing amount of flux lines crossing the sensor head. You have to keep this in mind if you plan to use resistors as test structures for your measurements. This applies to some power SMT resistors as well !



Positioning probe tip at the angle affects prober output.
The probe on the left photo is oriented properly .
The probe on the left photo is oriented properly

Here is the sketch illustrating this last point. Red line on the sketch below represents the probe tip orientation. You can see that on the bottom sketch the line is perpendicular to the carbon track, resulting higher prober output.

So, as a conclusion, Because design of resistors from different manufacturers is likely to be different as well, these tests confirm that taking measurements off such components is not a good idea You can observe the shape of the current waveform alright, but taking accurate quantitative measurements this way is not really possible.



This is what is happening. On the bottom sketch the tip is at proper 90° to the resistor's carbon track.

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