Making Low Level AC Voltage Measurements below 1-5 mV with the Agilent™ 34401A and 34410A Digital Multimeters

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Note that we view both the 34401A and 34410A DMMs very favorably. This testing is outside of the rated operating envelope of the 34401A.

The 34401A is a high quality 6 1/2 digit digital multimeter. It has become an industry standard from engineering school labs to the largest corporate R&D labs. An instrument such as the 34401A should not necessarily be able to perform over all dynamic ranges without limitation, and so it is not completely unexpected that at the low end of the 100 mV AC V scale, there is a dead zone for low level ACV measurements as revealed indirectly by footnote 4 of the performance specifications: "[4] For sinewave input > 5% of range. For inputs from 1% and < 50kHz, add 0.1% of range additional error". Footnote 4 applies to the "100.0000 mV" AC voltage scale. It appears to our best current understanding, that footnote 4 indicates that the 100 mV AC scale is only "specified" from 5 mV (5% of range) to 100 mV.

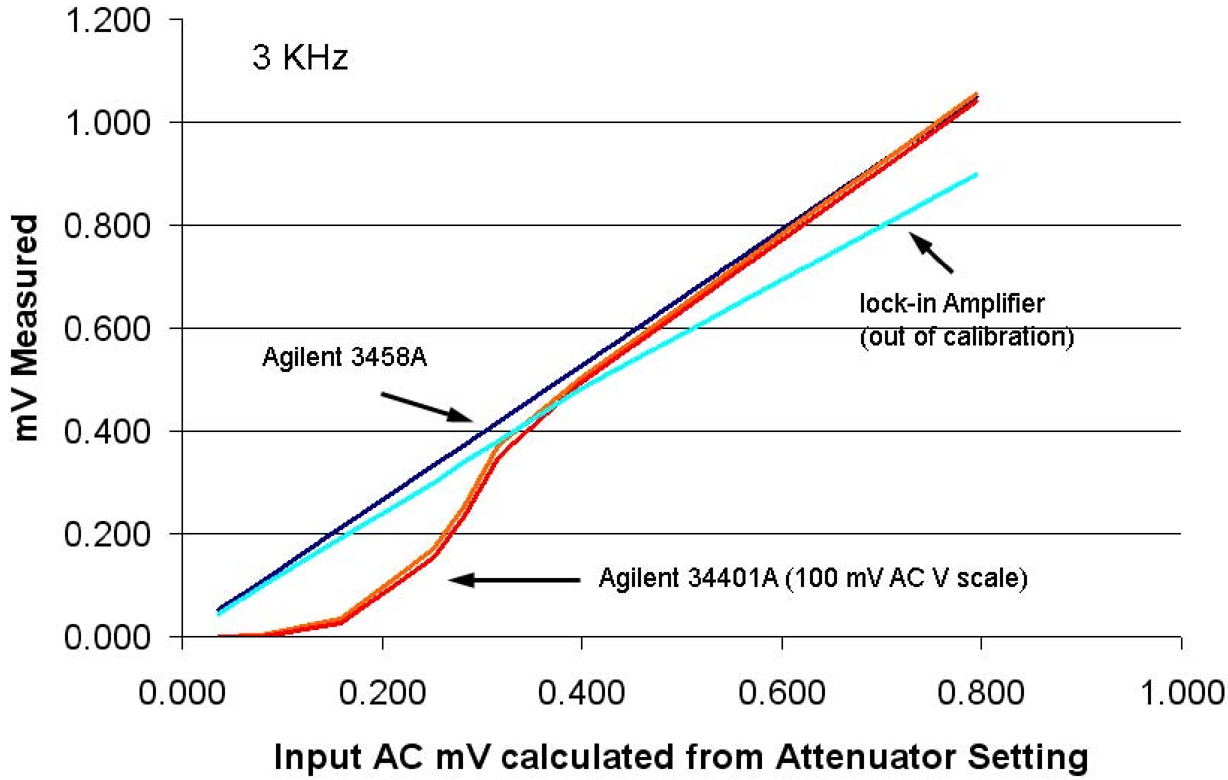
According to our observations of the 34401A, it appears that somewhere below 5 mV, and at least below 1 mV (possibly depending on frequency, individual components, and calibration) there is a region of non-linear response, followed by a dead-zone that displays all zeros.

Some time ago, as a first pass to measure the broad band noise of some of our voltage references, I tried several measurements with two of our 34401A DMMs set to "slow" averaging and 6 digits display. I was pleasantly surprised that the display read 00.000 mV on the AC V 100 millivolt scale. In hindsight, that result was nonsense, since of course the noise floor had be higher. Yet a quick check with a signal generator and a variable attenuator showed seemingly valid measurements down to 10 µV (00.010 mV) or below.

As the months progressed, we made noise measurements with an Agilent 3458A in the ACV "set random" mode which lets us measure to a 3458A AC V noise floor of about 22 µV. Low level non-correlated signals (noise can be random with respect to an applied µV signal such as an attenuated sine wave) appeared correctly as Sqrt (Vin^2 + Vnoise^2). The noise floor measurement is repeatable and reliable. We are easily able to see changes in measured noise levels for various shielding and guarding arrangements.

I had mostly forgotten about those early 34401A 100 mV AC V measurements until recently when I was checking a lock-in amplifier at 3 KHz from about 100 mV down to 1 µV for use in a magnetic measurement experiment. I was using a 34401A to compare the results to the meter readings on the lock-in amplifier and nothing quite made sense from near 1 mV and below. I switched to the 3458A and all of a sudden the data came together okay showing a minor gain calibration problem with the lock-in amplifier, but otherwise normal operation. It was understood that below about 100 µV, the readings would be influenced by our 3458A 22 µV noise floor.

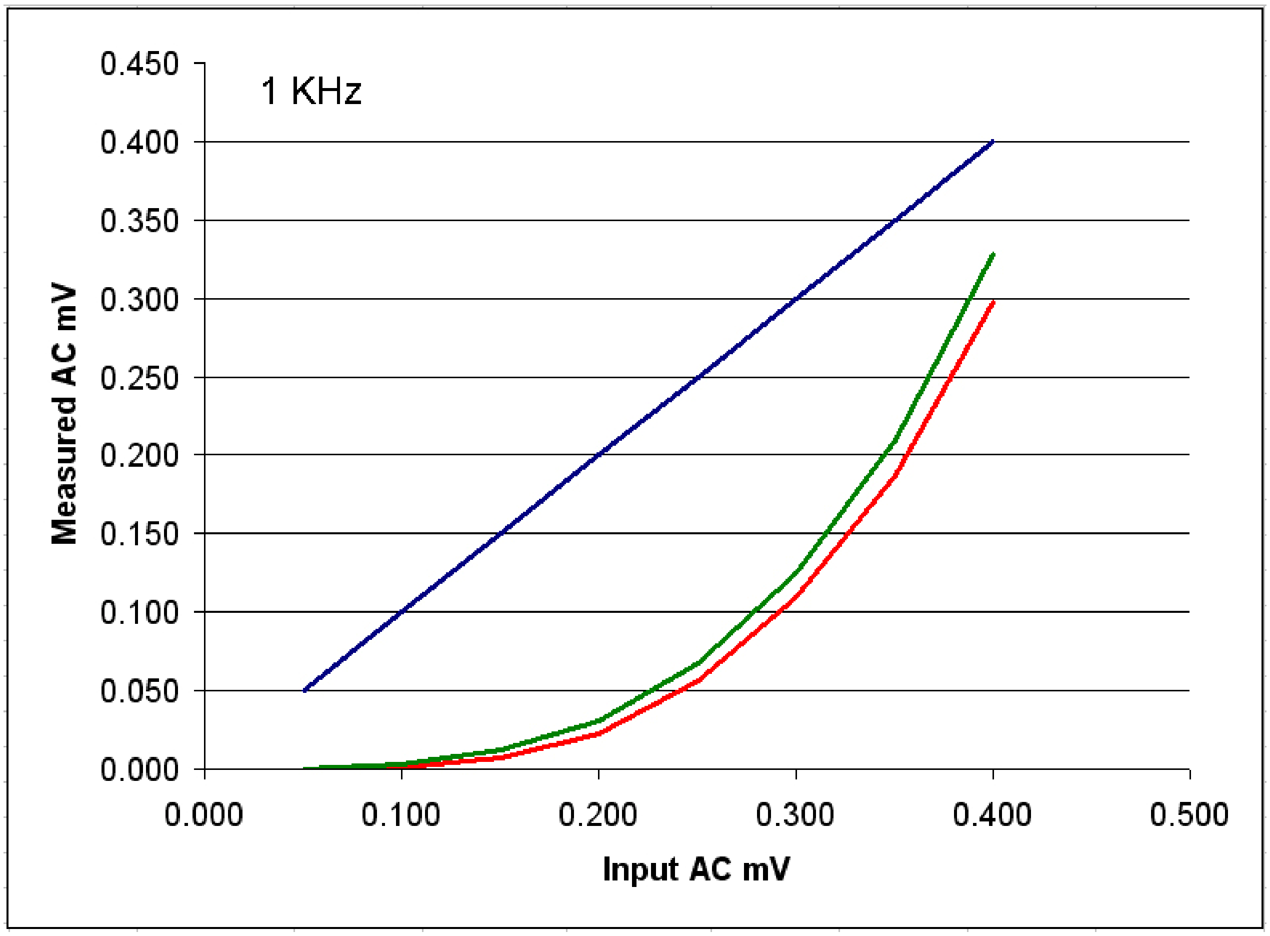
To try to understand what went wrong with the 34401A measurements, I started to plot the response on the 100 mV AC V scale using a hp3325B signal generator, a Kay 839 switch step attenuator, and the 3458A DMM. It turns out that the 34401A becomes very non-linear below about 1 mV, then its gain falls off to zero somewhere below 100 µV. Both of our 34401As display 00.000 mV AC in this region.



In the graph above, dark blue is the 3458A, light blue is the out of calibration lock-in amplifier, and red and orange is the response of our two 34401A DMMs. Note there is also a gain error from the attenuator calibration.

I searched the Agilent website for an answer. I found an informative application note urging caution on making AC voltage measurements on the 100 mV AC scale. It talks about grounding and shielding and stray noise pickup and how uncorrelated noise adds as the square root of the squares. The application note says it is based on the 34401A DMM, "The Agilent 34401A, a 6-1/2- digit, high-performance DMM with both bench top and system features, will be used as an example throughout this article". Yet, there is no reference to footnote 4, or that somewhere below 5 mV, or at least below 1 mV, the 34401A appears to artificially suppress actual converted input data (at least at our test frequencies of 1 KHz and 3 KHz). The result is that for any actual AC V measurement made near the noise floor on the 100 mV scale, a user apparently sees an artificial indication of a relatively quiet zero.

A GoogleTM search found a USENET post that claims that hp / Agilent wrote a software routine into the firmware to display Zero output rather than show the actual noise floor. This might be myth, but is consistent with our observations. Or, the 34401A AC V low end non-linear response followed by a dead zone might simply be a limit of the dynamic range of the AD637 true rms converter chip used in the 34401A (according to the schematic and parts list in the service manual), or some combination of the two.



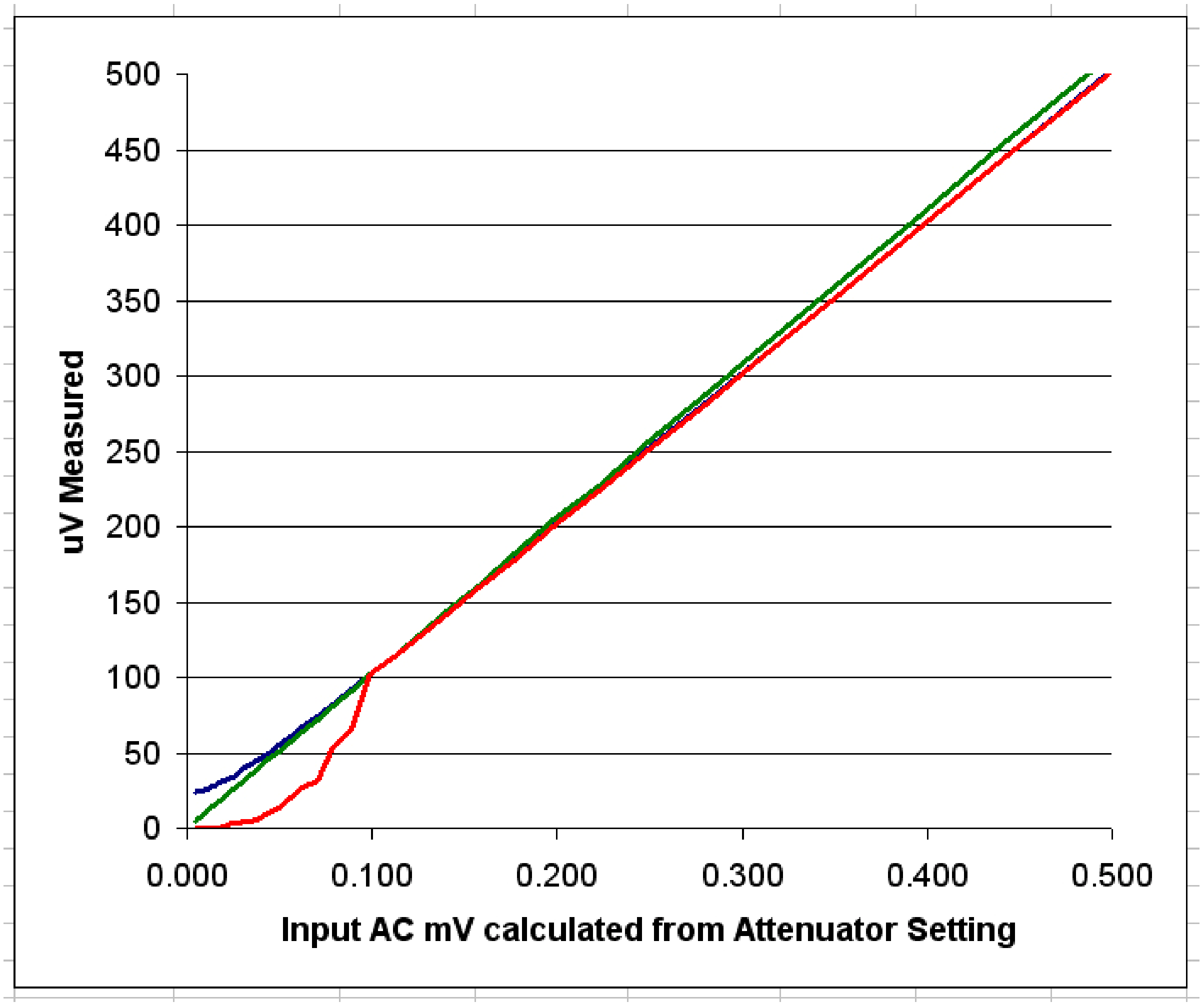
In the graph above, it can be seen that compared to the normalized 3458A data (blue), one of the two 34401As (before and after AC re-calibration) goes very non-linear below about 1 mV and somewhere below 100 µV, the 34401A displays a solid noise free 0.000 mV on the 100 mV AC V scale. The red curve is one of the 34401A tests before calibration and the green curve is a test after performing the 1/100th scale calibration on page 84 (page 86 on the pdf file) of the 34401A service manual with the same 34401A. (This graph shows the low end 100 mV AC V performance for the same DMM before and after calibration.)

Probably few 34401A users actually need to work in this very low range of the 100 mV AC V scale, however, anyone using a 34401A at the very low end of the 100 mV AC V scale seemingly (in our opinion) gets a misleading indication of zero. Below 1 mV, the readings fall first gently and then more rapidly, albeit still smoothly, to zero. On the other hand, we note that the 34401A is one of our most used bench instruments and a favorite tool for circuit development (we had two of them before upgrading to new Agilent 34410A).

Also, it is not particularly surprising or even necessarily a bad thing that an instrument in this mid level performance class apparently has such limitations. Designing low cost autoranging AC RMS voltage measurement circuits that can perform near zero is an extremely difficult problem. It would seem that in today's test equipment market, the only viable options for near noise floor measurements are very high end spectrum and network analyzers having large dynamic ranges that go down to -100 to -140 dB. Even the 3458A 8.5 digit DMM only appears to be viable down to about 25 μV.

This work led to our JCan experiment for measuring resistor Johnson noise. See more information on our JCan pages.

Update: We purchased an Agilent 34410A and repeated the tests of the low level ACV scale using the same hp 3325b, a Kay 837 attenuator, and for comparison, the Agilent 3458A (blue), and a Stanford Research Systems SR510 lock-in amplifier (green) (Line and Line x 2 filters enabled). Below 100 μV, the lack of smoothness of the 34410A curve was probably due to the erratic readings. *Note that this testing is outside of the rated operating envelope of the 34410A.* As can be seen in the graph below, the 34410A (red) is considerably improved over the 34401A and can make AC voltage measurements down to about 100 μV.



As an aside, the dual display of the 34410A offers a statistics mode including a running average on the second line. We have found this feature very useful during development work for a new project.

Feel free to contact us with your low end AC Voltmeter scale observations.