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Digital doubts

We are spoiled for choice when it comes to making electrical measurements; digital multimeters (DMMs) displaying anything between three and nine digits are readily available. However despite the accomplishments of these digital devices we must keep in mind that they are complex instruments with imperfections and often subtle but significant faults.

Our experience is that many of the high-level DMMs submitted to us for calibration have faults (or even just odd patterns of behaviour) of which the owner is unaware.

Calibration of a DMM not only provides for traceable measurements but also gives us assurance that any such faults will have been identified.

Figure 1 shows a simplified model of a DMM in its DC voltage mode. Most imperfections and faults can be classified in terms of the various building blocks (or possibly interactions between the blocks). Such a model is therefore vital for understanding the DMM's limitations and for determining how a DMM should be calibrated.

The essential building blocks are:

- A DC voltage reference. Any shift in this reference will affect all measurements.
- An A/D converter. This is the heart of the DMM and is mainly limited by differential non-linearity (the non-uniformity of successive digital increments). This can be a significant error when the DMM is used to measure small changes in voltage.
- An input buffer/amplifier. This is a very high impedance amplifier that provides gain for lower ranges (resulting in greater noise and offset voltages on these ranges).
- Scaling by a resistive divider is necessary to bring higher voltages into range of the A/D converter at the expense of a lower input impedance.
- Protection circuitry, which, when functioning correctly, does not usually detract from the performance.

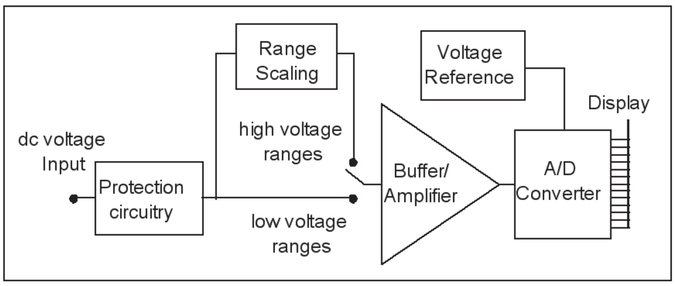

Figure 1: Simple block diagram of a DMM in dc voltage mode

The typical reading of a DMM as a function of applied voltage is shown in Figure 2 (black line). The curve of the line is caused by integral non-linearity while the fuzziness (for clarity shown only in the middle of the curve) is caused by the differential non-linearity. The red line represents the response of a perfect DMM.

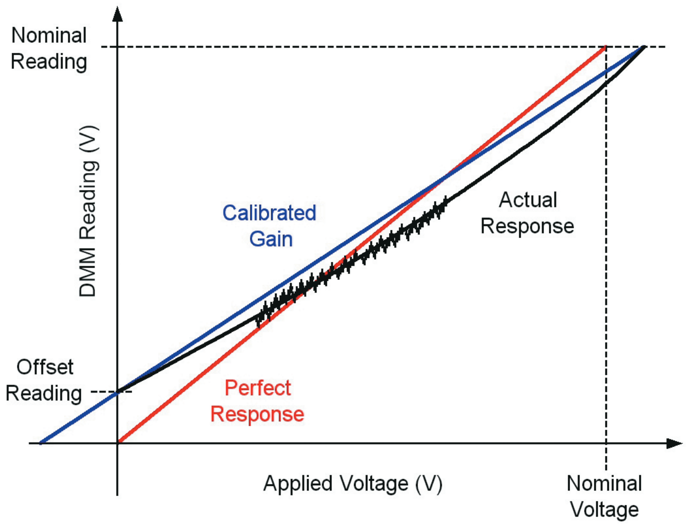

Figure 2: Typical DMM response (the imperfections are highly exaggerated in this figure).

A well designed calibration will make apparent the failure of any of the elements in the block diagram. A calibration process that will achieve this is:

- First characterise the linearity on the most accurate range to quantify the effect of differential non-linearity. It is impractical to correct for this, but it does become an uncertainty component for other measurements.
- Measure the gains and offsets on all ranges. It is best to measure the gain separately by measuring the change in voltage that generates a particular change in reading (the blue line of Figure 2).
- Check additional points on ranges where there are likely to be additional effects, such as integral non-linearity on high voltage ranges owing to heating of the scaling resistors.

While this simplified model gives a handle on identifying the major limitations of DMMs, there are many other imperfections. Thermoelectric voltages, bias currents, common mode offsets, normal mode offsets, interference from external sources and so on may need to be considered. Using the block diagram approach is a good starting place to account for such effects in these very complex instruments.