A generic DMM test and calibration strategy

Application Note

The Digital Multimeter or DMM is one of the most widely used electrical measurement instruments and provides electrical traceability to many industrial users. However, it is the nature of measurement products that they require regular checks to ensure that they operate not only in a functional sense, but also within their specifications. Such regular checks are known as calibrations and require a certain amount of knowledge of DMM technology in order to calibrate them effectively. This application note seeks to identify the important functional and calibration parameters and to offer a generic guidance strategy for their routine verification.

DMM specifications

A DMM manufacturer has two important goals when specifying a DMM. They must ensure that the performance and functionality are clearly presented to the prospective purchaser such that the purchasing decision can be made, and he will also ensure that the instrument's metrological performance is expressed to the best possible advantage in a competitive situation. The specification is actually describing the performance of the instrument's internal circuits that are necessary to achieve the desired functionality. Each function will have an accuracy expressed in terms of a percentage of the reading ± %R with additional modifiers or adders such as ± digits or ±μV. This is known as a compound specification and is an indication that there are several components to the specification for any particular parameter. Sometimes this is seen as a way of hiding the true performance, when in reality, it is the only practical way to express performance over a wide parametric range with a single accuracy statement. Over the 40 years or so that DMMs have developed, the terminology has evolved to describe the performance parameters. A summary of these terms is given in appendix 1.

Performance parameters

It is convenient to think of the performance in terms of functional and characteristic parameters, where the former describes the basic capability or functionality e.g. the DMM can measure voltage, and the latter is a descriptor or qualifier of its characteristics e.g. with an accuracy of ± 5 ppm. One can easily see that it is essential to understand the significance of the characteristics if the instrument is to be verified correctly.

Examples of functional parameters

- Functions: V, A, Ω
- Scale length/Resolution
- Read rate
- Amplitude range
- Frequency range

Examples of characteristics

- Stability with time and temperature
- Linearity
- Noise
- Frequency response or flatness
- Input impedance
- Compliance/Burden
- Common/Series mode rejection
- Crest factor
- Power coefficient

DC voltage

Nearly all DMMs can measure dc voltage. This is because of the nature of the analogue to digital converter (ADC) used to convert from a voltage to (usually) timing information in the form of clock counts. The most common way of doing this is to use technique known as dual-slope integration. This method involves applying the input signal to an integrator for a fixed period and then discharging the integrator capacitor and measuring the time taken to do so. This basic dual slope method is used in low resolution DMMs, but longer scale length instruments require more complex arrangements to ensure good performance. DMMs are available with up to 8½ digits Resolution and these usually employ multi-slope, multi-cycle integrators to achieve good performance over the operating range. An ADC is usually a single range circuit, that is to say it can handle only a narrow voltage range of say zero to ± 10 V, however, the DMM may be specified from zero to ± 1000 V. This necessitates additional circuits in the form of amplifiers and attenuators to scale the input voltage to levels that can be measured by the ADC. In addition, a high input impedance is desirable such that the loading effect of the DMM is negligible. Each amplifier and attenuator or gain-defining component introduces additional errors that must be specified. The contributions that affect the specifications for dc voltage are given below together with their typical expression in parenthesis.

Contributions to dc V specifications

- Reference Stability (% of reading)
- ADC linearity (% of scale)
- Attenuator stability (% of reading)
- Voltage offsets (Absolute)
- Input bias current (Absolute)
- Noise (Absolute)
- Resolution (Absolute)

These contributions will be combined to give a compound specification expressed as ± % Reading ± % Full Scale or Range ± µV. In order that the performance of the instrument can be verified by calibration, the above effects must be isolated. That is to say, it is not possible to measure Linearity for example until the effects of Offset and Gain errors have been removed. Figure 1 shows these basic parameters.

The ADC is common to all ranges of all functions, therefore its characteristic errors will affect all functions. Fortunately, this means that the basic dc linearity need only be verified on the basic (usually 10 V) range. The manufacturer's literature should indicate which is the prime dc range. If this is not stated directly, it can be deduced from the dc voltage specification i.e. the range with the best specification in terms of ± % R, ± FS and ±µV will invariably be the prime range. Other ranges e.g. 100 mV, 1 V, 100 V and 1 kV will have a slightly worse performance because additional circuits are involved. At low levels on the 100 mV and 1 V ranges, the dominant factor will be noise and voltage offsets. For the higher voltage ranges, the effects of power dissipation in the attenuators will give a power law characteristic, the severity of which will depend on the resistor design and individual temperature coefficients. Knowledge of the design and inter-dependence of the DMM's functional blocks can greatly assist the development of effective test strategies.

DMM functionality tree

A DMM's functionality and range dependence is quite logical and is generally designed to get the maximum use out of a minimum of components through the use of common circuits wherever possible. As an example the ADC will be used for all functions, the current sensing resistors will be used for both ac I and dc I, the ac rms converter will be used for both ac V and ac I. A typical functionality "tree" is given in figure 2.

DC voltage calibration strategy

For a new DMM, the manufacturer will test every aspect of the instrument's performance. However, for routine repeat calibrations, the number of tests can be dramatically reduced if one accepts that instruments can be

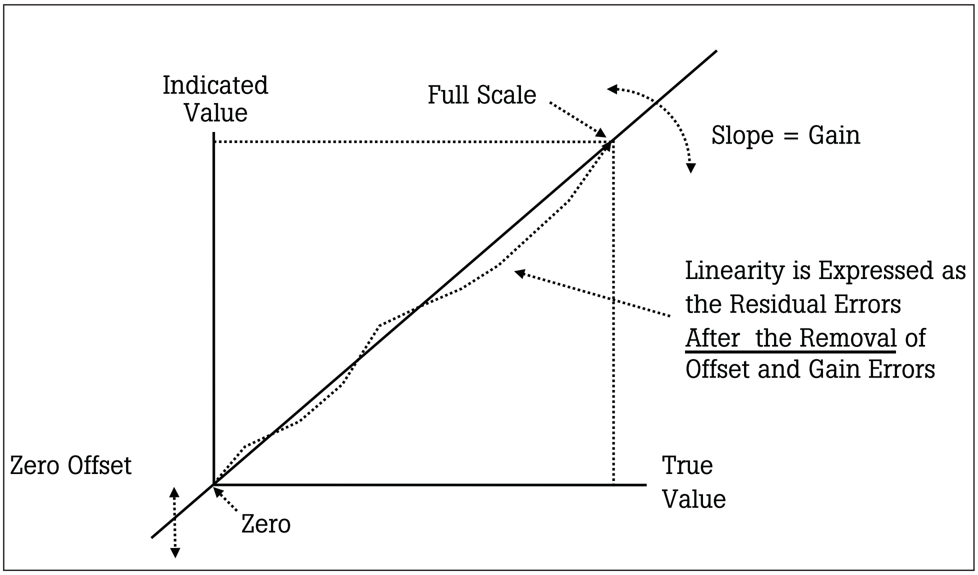

Figure 1. DMM offset, gain and linearity

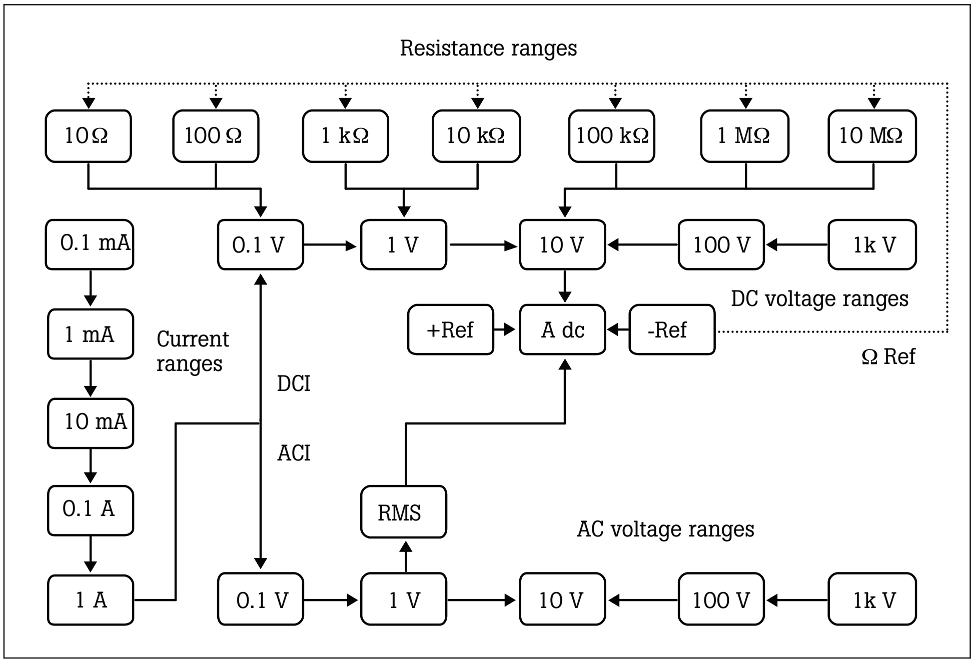

Figure 2 DMM Functional Blocks

characterized according to their technology, operating principles and accumulated historical data. It will usually be necessary to calibrate each dc voltage range in both polarities. The "prime range", where there is neither gain nor attenuation of the input voltage will typically be 10 V. This will be the first range to be measured, as its errors will also be passed on to the other ranges. Calibration would then progress to the lower ranges of 1 V and 100 mV, then on to the 100 V and 1 kV ranges. These are left until last because of the effects of increasing power dissipation on both the DMM and the calibration source at the higher voltages. The order of the tests might be as follows:

DC voltage calibration sequence

10 V Zero, +10 V Gain, -10 V Gain

10 V Linearity: ±1 V, ±5 V,±15 V, ±19.9 V

1 V Zero, +1 V Gain, -1 V Gain*

100 mV Zero, +100 mV Gain, -100 mV Gain*

100 V Zero, +100 V Gain, -100 V Gain*

1 kV Zero, +1 kV Gain, -1 kV Gain*

* Some DMMs may not have negative polarity range adjustments

Careful analysis of the results can reveal much about the instrument's performance. Changes in the error of the 10 V range will also be passed on to other dependent ranges. Therefore if the 10 V range was found to have increased by +5 ppm and the 100 V range showed no change, it means that the 100 V range had actually changed by -5 ppm but was compensated by the 10 V range error.

This kind of evaluation can be very useful if failures against specification are observed. If the 100 V range indicated a change of +10 ppm and the specification allowance was ±5 ppm, at first glance the 100 V range gain-defining components might be thought to be defective, when in fact, the failure was caused by the instrument's internal reference. Either way, the 100 V range has failed against the specification, but the cause of the problem has nothing to do with the 100 V range components. Without this knowledge, the wrong components might be replaced resulting in loss of history and additional expense.

Functional tests

It is a good idea to carry out essential functional testing before committing valuable time and effort to a potentially lengthy calibration process. Some microprocessor-controlled DMMs have a diagnostic self-test function that can be used to perform sophisticated internal checks. If such a facility is not available, each function and range should be selected and a Copper short, or known voltage, resistance or current applied to the DMM's input. This will ensure that a stable reading can be obtained and that the controls and displays are operating correctly. Functional checks may be extended to cover input switching circuits, auxiliary outputs and remote-control digital interface if applicable. If an IEEE-488 interface is fitted and the DMM is one of a type that will be regularly calibrated,it may be worth writing a simple program to perform the functional testing. If a functional problem is found, a decision must be made as to whether it is safe to proceed with a pre-adjustment calibration check. This is desirable if historical performance data is required, but may also assist with fault diagnosis. However,if there is any risk of personal injury, or damage to the instrument, it is better to repair the instrument before proceeding with the calibration.

Input characteristics

There should be a periodic test to ensure that the DMM's input characteristics are correct. The test requires the use of an LCR Bridge or relatively low accuracy DMM. The object of the test is to ensure that there are not gross errors in the input characteristics. Note that it is essentially a functional test looking for percentage rather than ppm errors. As an example, a common ac V input resistance is 1 MΩ. The test will be to ensure that it is not excessively high or low - say within ±10 %. For most instruments, the ac input resistor will form part of the input attenuator so significant changes in value will obvious when the calibration is verified. The dc V function input resistance measurement can be more difficult. For higher ranges e.g. 100 V to 1 kV, there will be an input attenuator of typically 10 MΩ that determines the input resistance and voltage division ratio. Changes in the value of this component will cause changes in the dc V calibration. However, for lower ranges, the input resistance will probably be determined by feedback and so may be very high indeed. In fact it may be so high that it is not possible to measure reliably. The usual reason for checking the input characteristics is to ensure that they do not significantly disturb the test circuit conditions. This is sometimes described as being non-intrusive. For current measurements, it is the Burden voltage that is important. In a DMM, the burden is determined by the value of the current sensing resistors and can be measured as a resistance between the current sensing terminals. Typically, the resistors will be chosen such that the burden is 0.1 V or lower. For the resistance function, there are two parameters of interest. The first is the input resistance of the voltage sensing terminals (assuming 4 wire capability). This will usually be very high indeed and may be the same as that for the lower dc V ranges.

Any change in input resistance will be directly reflected in the resistance function accuracy and so it is not normally necessary to measure it. The second parameter is the Compliance of the DMM's current source. Ideally, the current flowing through the external resistance being measured should be independent of the voltage developed across the resistor—a true constant current source with infinite output impedance. However, if the current does vary, it will affect the resistance function's linearity. This is discussed further in the resistance section.

Resistance calibration strategy

The resistance function of a DMM consists primarily of a constant current source providing a range of currents typically from 10 nA to 10 mA. Selecting a resistance range selects an appropriate constant current to pass through the unknown or standard resistance. The voltage developed across the resistance is then measured by the DMM's DC voltage function with an appropriate range set. It can be seen from figure 2 that the accuracy of the resistance function is dependent upon both the resistance current source (providing the resistance ranges) and the dc voltage ranges of the DMM. Stability of the currents will typically be controlled from the DMM's dc reference circuit. In this case, changes in the reference are common to both the current sourcing and voltage sensing resulting in no change in resistance measurement accuracy. However, changes in the performance of the either the current defining resistors or voltage gain-defining resistors will affect the resistance calibration. For this reason, the resistance function is usually measured after the dc voltage function. Where adjustments are made, older designs of DMM must have the dc voltage adjustments made first. Consult the manufacturer's handbook to check for functional inter-dependence in the calibration regime.

For sensitive long-scale DMMs it is usually better to start with the high resistance ranges and then work down. This is will allow a longer thermal stabilization time for the connecting leads and the DMM's internal circuits, which may be working at the 10 mA and 100 mV levels for the current source and voltage measurement circuits respectively. In any case,where a 4 wire capability is available, it should be used. Unless the DMM has a true ohms function, the effects of voltage offsets must be considered.

Resistance function linearity tests

For DMMs with a resistance function accuracy of not better than 100 ppm (4½ to 5½ digit resolution), a decade resistor box could be used, but for the more accurate "premium" DMMs, resistance linearity can be more difficult to determine unless a selection of suitably accurate four- terminal resistances is available. One of the problems of trying to measure resistance linearity directly is the uncertainty of the individual resistor values. For example, to measure linearity on the 10 kΩ range of a 7½ digit DMM with a maximum indication of 19.000 000 kΩ would require several different resistance standards. Assuming that measurements were to be made at a minimum of five evenly spaced points throughout the range e.g. at zero, 5 kΩ, 10 kΩ, 15 kΩ and 19.9 kΩ, the difficulties in finding suitable standards soon become obvious. Typically, resistance standards will be available at the normal decade values of 10 Ω (25 Ω may be available), 100 Ω, 1 kΩ, 10 kΩ, etc. and so do not provide even coverage throughout the range.

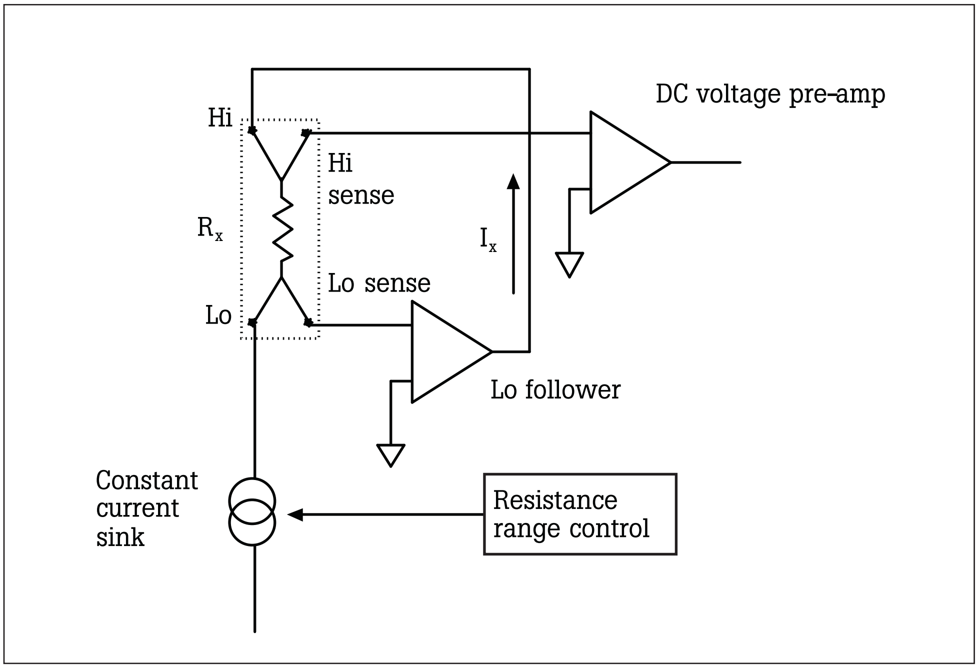

Figure 3. DMM resistance converter

When one considers that some DMMs have resistance linearity specifications of better than 0.5 ppm, and that individual resistance standards may have uncertainties of 1 ppm or more, test methods using separate resistors or decade boxes will be inadequate.

For this reason, resistance linearity is not usually measured for routine calibrations of medium to high accuracy DMMs. For lower accuracy DMMs with up to 5½ digits resolution, resistance calibrators suitable for resistance linearity testing are readily available. If it is necessary to determine the resistance linearity of a long-scale DMM, or confirm that the circuits are operating correctly,the following test might be considered.

Figure 3 shows the circuit configuration for resistance measurement used in a high accuracy DMM. The resistance function is primarily a range of selectable constant currents. A constant current generator forces a current Ix to flow through the test resistor. A true constant current source will generate a current independently of the voltage developed across its terminals,in this case designated Hi and Lo. It therefore follows that if a known resistance is applied to the DMM and the display value noted, the insertion of an additional resistance in series with the Hi lead should not significantly affect the DMM's reading. This will confirm that the current source can deliver the same current through a range of resistance values.

If it can also be confirmed that the dc voltage range used for the resistance measurement (see figure 2) is also linear,there is then a technically sound way of confirming resistance linearity without the need for a resistance linearity standard. Note that the series resistance does not need to be a precision resistor—it could be a low-noise potentiometer.

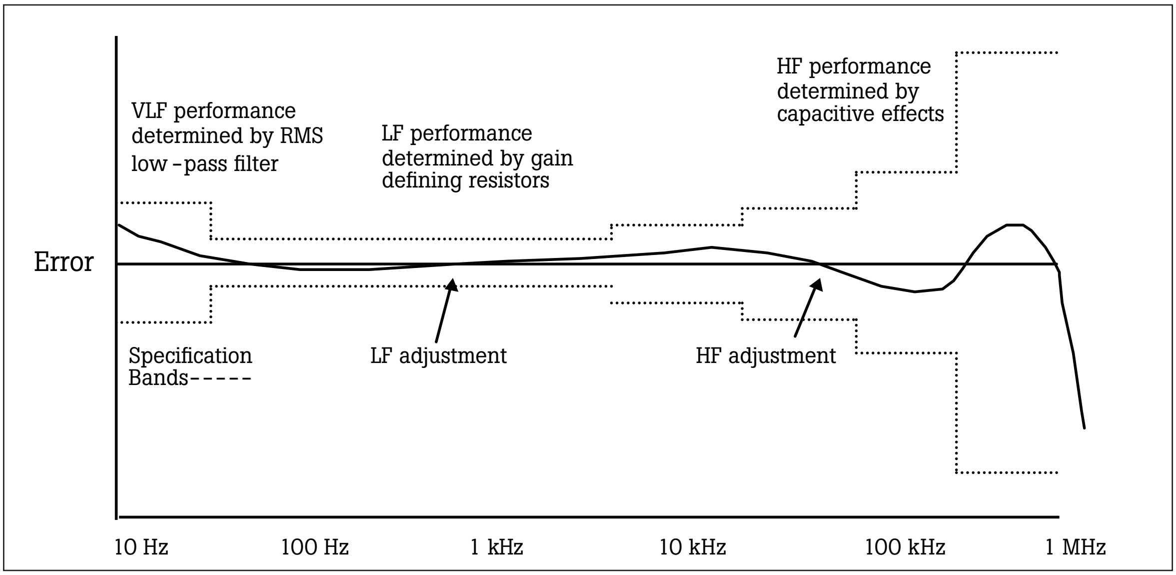

Figure 4. DMM frequency response

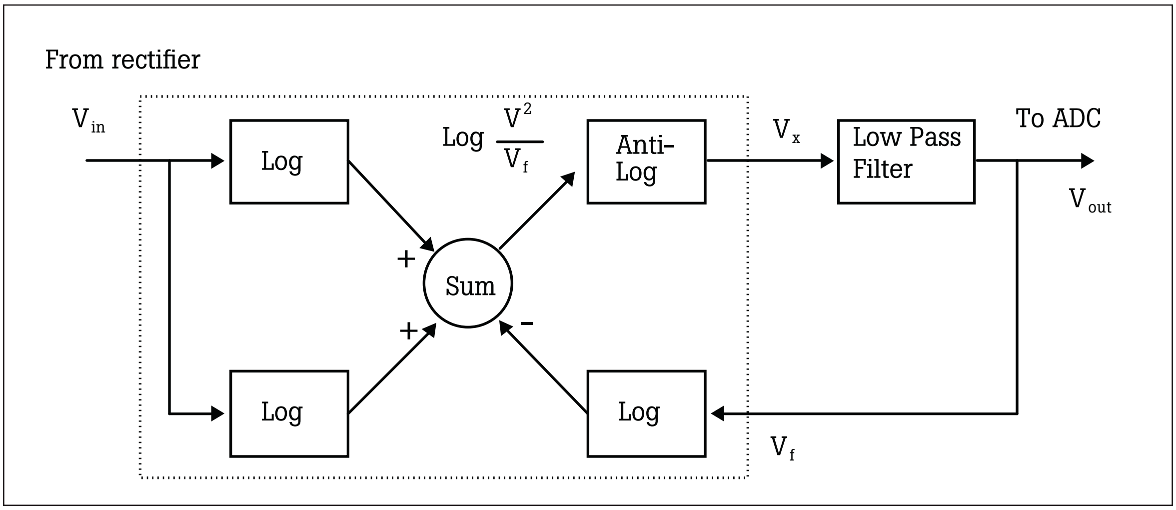

Figure 5. Log-feedback RMS converter

AC voltage calibration strategy

The ac functions have the added dimension of frequency. This complicates calibration by introducing additional test points for each amplitude range. In a typical DMM, the ac measurement is made by an ac converter. This module is must provide gain and attenuation for a wide range of signals from typically a few millivolts to 1 kV. DMMs are available with 6½ digit 100 mV ranges with a resolution of 100 nV. This resolution is only meaningful down to an input voltage level of perhaps 1 mV, below this level, noise and linearity errors are likely to dominate the reading. It is likely that the limiting factor will be the noise of the calibration source, rather than the DMM.

The gain of a DMM's ac function will vary with frequency. This is known as its Frequency Response and requires that measurements are made at key points throughout each amplitude range. At low frequencies, say from 40 Hz to 5 kHz, the DMM's gain is determined by resistor networks, its ac to dc converter and dc reference. At higher frequencies, reactive effects, primarily capacitive, will determine the flatness of the DMM's frequency response. Various means maybe used to trim the response e.g. variable capacitance trimmers or perhaps software-controlled adjustment of the high frequency gain.

The DMM manufacturer will recommend certain adjustment points that will compensate for LF gain and frequency response for each range. These should be strictly observed as they are designed to give the best overall performance over the specified frequency range. Figure 4 shows a typical response and controlling mechanisms.

The prime range of the ac function is usually 1 V, with other ranges being obtained by gain or attenuation of the input signal. From figure 2 it can be seen that all the ac ranges depend on the rms converter.

A true-rms converter consists of a precision rectifier, Logarithmic and Exponential amplifiers that perform the function shown in figure 5.

The circuit performs an analogue computation of the rms value of the signal through the use of logarithmic amplifiers that effectively square and square-root the input signal. The output of the multiplier V_x has a dc ripple content that is averaged (to obtain a Mean value) by applying it to an active low-pass filter. V_{out} is also used to provide the feedback signal V_f which provides the square-root element of the computation and controls the gain of the circuit to give a wide dynamic range. The low-pass filter determines the low frequency response of the instrument. Some log-feedback DMM's are capable of operating down to 0.01 Hz.

There are two calibration adjustments that are peculiar to log-feedback, true-rms detectors. The first is dc Turnover, where the gain of the precision rectifier is adjusted to be identical for both positive and negative excursions of the input signal. The second is Crest Factor, which can be affected by non-symmetry of the rectifier and also by the bias arrangements of the analog multiplier. Analogue multipliers require very careful matching of their semiconductors. In order to achieve this, there may be bias adjustments in the circuit that will affect crest factor performance. These adjustments tend to be very interactive and must be made in a strict order, and usually before the individual range gain adjustments are performed. However, it is not usually necessary to make adjustments to the rms circuits for routine calibrations. If these adjustments are required and there is no requirement for pre-adjustment data, the sequence would be as follows:

AC voltage calibration sequence

1 V ac zero, ±1 V dc turnover*

Crest factor: (at 3:1 or 5:1 as required)*

1 V LF gain, 1 V HF gain, check frequency response*

1 V LF linearity, 1 V HF linearity*

100 mV zero, 100 mV LF, 100 mV HF, check frequency response*

10 V Zero, 10 V LF, 10 V HF, check frequency response*

100 V Zero, 100 V LF, 100 V HF, Check frequency response*

1 kV Zero, 1 kV LF, 1 kV HF, check frequency response*

* These adjustments will usually be iterative. Always follow the manufacturer's recommendations for the adjustment sequence.

Note that there may be significant differences between the methods recommended by different manufacturers. AC zero measurements are often made with a short-circuit applied to the DMM's input, but some instruments will require a small ac bias voltage because the rms converter cannot operate with a zero input. Where the DMM has a very low frequency capability, the zeros and gain measurements make take an appreciable time to settle to their final values—particularly after a large change in signal amplitude.

Current calibration strategy

A DMM measures current by sensing the dc or ac voltage developed across a current-sensing resistor or shunt. The same shunts will be used for both dc and ac current. A separate pair of terminals will be provided to simplify internal signal switching and minimize the impedance of the internal connections to the shunts. It is very desirable to keep the Burden voltage as low as possible, typically this will be in the region of 100 mV. Figure 2 shows that the current ranges are linked together. The shunts are connected in series with suitable tapping points for the voltage sensing. To measure 0.1 mA, the current is passed through all of the shunts in series and their values will be chosen such that the sum of their resistive values for any particular current range will develop 100 mV for the specified current. This greatly simplifies the current switching but also means that for any given current range, all of the shunts included will have an affect on that range's performance. Knowledge of the inter-dependence of the shunts can assist with drift and fault diagnosis. The voltage developed across the shunts will be passed to the dc or ac 100 mV ranges depending upon whether the DCI or ACI function has been selected.

Therefore changes in the dc or ac 100 mV range performance will also affect the current ranges. Current calibration will normally be the last function to be calibrated for the simple reason that knowledge of the dc V and ac V performance is essential before the DCI and ACI range performance can be evaluated. The order of calibration would normally be as shown below and is intended to minimize any heating effects by measuring the lowest current ranges first. Note that it is not normal practice to switch alternately between DCI and ACI functions for each range, although this could be done. Note that some DMMs do not have independent adjustment of the ac current ranges but rely on the dc gain adjustment, the Flatness of the shunt's ac response and the accuracy of the ac voltage converter. In this case the ac voltage and dc current ranges must be adjusted first.

DC current calibration sequence

100 µA zero, +100 µA, -100 µA
1 mA zero, +1 mA, -1 mA

10 mA zero, +10mA,-10mA

100 mA zero, +100 mA*, -100 mA*

1 A Zero*,+1 A*,-1 A*

* These measurements may require a longer settling time due to self-heating and-thermo-electric effects.

AC current calibration sequence

100 µA LF gain, 100 µA HF gain**

1 mA LF gain, 1 mA HF gain**

10 mA LF gain, 1 mA HF gain**

100 mA LF gain, 1 mA HF gain**

1 A LF gain, 1 A LF gain**

** Some DMMs do not have an HF adjustment

Zero considerations

All dc functions will need their zero offsets evaluated and compensated before measurements of the gain values are made. Generally, it is the gain values that transfer traceability. This is recognition of the fact that zero is really only a baseline for the measurements. It is important that all DC measurements are referred to a known offset state, but that state does not have to be exactly zero. In fact, at normal room temperatures, it is very difficult to achieve a true zero in terms of Volts, amps or ohms. Consideration of zero offsets should also include the calibration source, as all sources have residual offsets. From figure 1 it can be seen that an offset will affect all readings by a fixed amount. It is very important that a"system" zero is performed when a DMM is being calibrated. A system zero means zeroing the DMM to the zero offset of the calibration standard. This will remove the effects of the standard's offset from the measurement of the gain or full-range values.

For voltage measurements the DMM should be zeroed to the source "zero" output. For resistance measurements the DMM should be zeroed to the resistor (as described in the user's handbook) such that the effects of voltage offsets in the Hi and Lo circuit are removed. Current measurements require the DMM to be zeroed in the open-circuit state, although some calibration sources have a "zero" current output to which the DMM should be zeroed.

Generating a test plan

After considering the preceding discussions and the intended application of the DMM, a Test Plan can be devised. The plan must ensure that the basic calibration requirements of the instrument and user are met, that the measurements are made using standards of sufficient accuracy, and that the functionality and integrity of the instrument are verified. The plan must also consider actions to be taken if the instrument requires repair. It is likely that there will be two strategies depending on whether or not a fault condition is suspected or has been reported.

Routine calibration (no repair)

- Have any problems been reported?
- Functional checks, controls, etc.
- Measure prime dc and ac linearity
- Measure all gain values
- Adjust as required
- Check volt/hertz limits, etc.*

* Unless restricted use intended

Additional requirements if repaired*

- Adjust ADC if required
- Adjust line locking if required
- Adjust Crest Factor if applicable
- Check Input Characteristics
- Check CMRR

* Knowledge of instrument design and repair details will facilitate test plan generation

Measurement uncertainty

The most significant contribution to the quality of DMM calibration is consideration of the measurement uncertainty. It is beyond the scope of this application note to give a detailed analysis of the uncertainty contributions and their combination, but it is worth identifying what the sources of uncertainty will be.

Uncertainty contributions

- Uncertainty of the standard
- Resolution of the DMM
- Short-term stability of the DMM with time and temperature
- Combined noise of standard and DMM
- The calibration procedure

It is imperative that the calibration standard is of sufficient accuracy to be able to calibrate the DMM with confidence. Some manufacturers separate DMM specifications into two parts: the calibration uncertainty and the instrument's relative accuracy. If the available calibration uncertainty is larger (worse) than the specified calibration accuracy, the DMM's total accuracy specification will no longer apply. Sometimes Test Accuracy Ratios (TAR) are quoted as a requirement i.e. a TAR of 4:1 requires the accuracy of the standard to be four times better than the specification of the DMM. This is to ensure that the residual errors of the standard do not significantly affect the calibration accuracy of the DMM. In an ideal world, TARs could be applied to all measurements—including those made by National Standards Laboratories. However, it is not practical at this level—or even necessary, if all sources of error have been identified and corrected and that a sound uncertainty analysis has been performed. Where such corrections are not applied, or where there is no calibration accuracy requirement specified, TARs are appropriate.

The resolution or scale-length of the DMM determines the smallest change in the reading that may be observed. Clearly, it could become a limiting factor in the measurement regardless of how accurate the calibration standard might be. Assuming the calibration of 1 V dc, a 6½ digit DMM with a scale-length of 1.000 000 V can resolve 1 µV or 1ppm of its nominal range, whilst a 4½ digit DMM can only resolve 100 µV or 0.1 % for the same conditions.

The short-term stability of the DMM (and the calibration standard) with time and temperature will also affect the uncertainty of measurement. Usually the dominant factor here is temperature coefficient of the DMM and stability of the calibration environment. Secular drift is not usually significant unless the calibration takes several hours or the instrument is defective. An allowance for temperature coefficient and short-term stability can usually be obtained from the manufacturer's specification data.

A more dominant uncertainty contribution will usually be the noise or run-around of the DMM reading during the measurement. Whilst it may be interesting to consider the individual noise contributions of the standard and the DMM, in practice it is their combined effect that is important. If individual readings can be easily observed, and if the noise is predominantly random,the sample standard deviation of the readings can be calculated and used as the uncertainty contribution for combined noise. It is important that the configuration of the DMM is representative of normal use for this measurement.

Finally, the calibration procedure itself will have an influence on the measurement uncertainty. A poorly chosen test sequence, insufficient settling time or poor interconnection techniques will all introduce additional errors that may pass unnoticed by the operator. This is the reason why the manufacturer's recommended procedure should be used as the basis for DMM calibration. Note that this also applies to the use of the calibration standards. If further reading is required on the subject of uncertainty analysis it is recommended that a study of one of the Guides to the Estimation of Uncertainty of Measurement be made.

Summary and recommendations

The calibration of long-scale DMMs can be technically challenging but there is a great deal of satisfaction to be obtained from doing it well, understanding the technology and having total control of the process. However, the standards required for the effective support and calibration of such DMMs can be very expensive and hard to justify if the number of units to be calibrated is small. For this reason, the manufacturer's calibration service should be used if there is any doubt about the adequacy of the locally available equipment and expertise.

Appendix 1- DMM terminology

This appendix gives definitions of some of the terms commonly used by DMM manufacturers. Text in Italic typeface indicates related terms.

Function – Functional options of a DMM e.g. dc voltage, ac voltage, resistance, current, frequency, etc. Can also apply to ratio/channel switching or math and statistical functions.

Range – A DMM's measurement capability is split into ranges such that the input signal can be scaled to a level appropriate for its A dc or RMS converter. Typical ranges would be 100 mV, 1 V, 10 V, 100 V, 1 kV ac or dc, 10 Ω, 100 Ω, 1 kΩ, 100 kΩ, 1 MΩ, 10 MΩ, 100 MΩ, 1 GΩ, 100 µA, 1 mA, 10 mA, 100 mA,1 A and sometimes, 10 A ac or dc. Some DMMs have ranges in threes.

Resolution and scale length – A way of describing how many figures a DMM can display. Resolution is the number of digits e.g. 1.000 000 V is a 6½ digit display where the ½ digit is the "1" and there are six places after the decimal point. The Scale Length is the maximum reading available on any particular range i.e. on the 1 V range a maximum reading of 1.999 999 V might be available before an overload is indicated. The maximum resolution on the lowest range is the Sensitivity.

Linearity – Basically linearity is a description of how the response of an instrument's ADC might vary with the amplitude of the measured signal. This should not be confused with power coefficient, which is a measure of the effects of self and mutual heating in resistive attenuators.

Zero or Offset – All dc measurements are affected by residual offsets that may be in volts, amps or ohms. However, it would be very unusual (in the context of DMM calibration) to find offsets of such large amplitude.

Typically, offsets would be in µV, µA or µW. In a voltage measurement, placing a Copper short across the voltage input terminals of the DMM should result in a reading of exactly zero Volts. However, thermally generated offsets, resulting from the use of dissimilar metals in the DMM's internal circuits and electronics, will result in a small net voltage offset that may amount to several tens of µV. Such offsets will normally be relatively stable in a controlled environment and most DMMs will have some form of offset compensation or Input zero function that may be used to remove their effects. It is very important that the effects of offsets are removed from the measurement, otherwise they will introduce a fixed error (in terms of volts, amps or ohms) throughout the measurement range.

Frequency response – Traditionally, frequency response is interpreted as the -3 dB point i.e. the high frequency point at which the reading has reduced to 70.7 % of its nominal low frequency value. The manufacturer may employ various hardware and software adjustments to the response to make the -3 dB point as high as possible. This can result in undesirable peaks and troughs at lower frequencies. A more meaningful measure of response is flatness. Flatness is a measure of the deviation from an assumed flat response over specific frequency bands and may be specified in ppm or % rather than dBs. Depending on the rms conversion technique used, a DMM's ac response can suffer from low frequency problems as well as high frequency roll-off.

Input resistance – Is important because it describes the potential loading effect of the DMM on the test circuit. For dc voltage up to 20 V, the input resistance may be >10^{12} Ω and is the result of using feedback and FET devices. Note that some DMMs have a significant input capacitance on their dc voltage function.

At higher voltages up to 1 kV, an attenuator is switched in to divide the applied voltage down to 10 V or 1 V. The attenuator typically has a resistance of 10 MΩ. For ac voltage, the input resistance will usually be lower—typically 1 MΩ with 150 pF in parallel. Note that at high frequencies the input Impedance will reduce.

Input bias current – Amplifiers are usually designed for high gain, high bandwidth, high input impedance, low output impedance and low input voltage offsets. However, all bi-polar semiconductor devices are essentially current operated. That is to say they require an input current to "bias" them into a desirable (usually linear) portion of their operating curve. Even field-effect devices may exhibit some internal leakage current back to their power supplies. Sensitive DMM design seeks to minimize these leakages by component selection and careful circuit design. However, there will inevitable be some residual input current, which unless preventative action is taken, will flow in the external measurement circuit. A small current of 1 µA flowing in a 1 MΩ resistance will develop a voltage of 1 V, 10 pA in 1 MΩ will develop 10 µV. A modern sensitive DMM would be expected to have an input bias current of <50 pA.

Compliance – Is a measure of the maximum voltage that can be developed by the (usually constant) current source of a DMM's resistance converter before the current changes significantly. It is an indication of how much lead resistance can be tolerated between the DMM and the resistor being measured.

Crest factor – Is the peak-to-rms ratio capability of a DMM's ac converter. A pure sine-wave has a crest factor of 1.414:1, a square wave has a crest factor of 1:1. Ideally, a DMM should indicate the "True" rms value for any waveform applied to its rms detector.

Where amplifiers and protection circuits are employed in the DMM's ac signal path, the peaks of high crest factor signals may be clipped resulting in a distorted signal being applied to the rms converter. It is desirable to have a high crest factor capability. The actual capability may vary with the overall magnitude of the signal in relation to the DMM's nominal range and internal power supply voltages. Where crest factor problems exist, it may be possible to select a less sensitive range such that no additional distortion of the signal occurs.

Common mode rejection – A measure of how the DMM responds to the presence of a particular kind of interference (unwanted) signal. The interference may be ac or dc. If a voltage is simultaneously applied (common) to both inputs of an operational amplifier and varied in relation to the amplifier's power supplies, there should be no change in its output voltage. In practice, due to small variations in gain of the amplifier's internal complementary stages with amplitude, there will be a change in output—even though the inputs are at a common level. High quality DMMs will have special power supplies for the amplifier that "track" or follow the input voltage. As a result, the voltage difference between the amplifier's input and its power supplies remain constant over the operating range such that changes in differential gain with amplitude are eliminated. Another example is where there is a leakage between the Lo input and power line ground. In this case, common mode errors can be reduced by careful Guarding techniques to reduce the effects of unwanted leakages to ground. The guard effectively diverts interference currents such that they do not flow in the Hi or Lo signal path and therefore do not generate unwanted voltages due to the impedances and leakages involved. The Common Mode Rejection Ratio (CMRR) is expressed in dBs and is measured by inserting a 1 kΩ (source imbalance) resistor in series with the Lo input connection to the DMM whilst varying the applied input voltage.

Series mode rejection – A measure of how the DMM responds to an interference signal that is not common to both inputs. Usually this means that an unwanted ac signal is superimposed on a wanted dc voltage. The signal is removed by various type of signal conditioning or filtering. Filtering may be through the use of analogue passive or active circuits comprising RC networks, or may be digital utilizing an integration rejection notch or averaging the results of a number of readings. An integration rejection notch synchronizes the input integration time of the ADC such that the conversion cycle is locked to the line frequency. The input voltage is integrated over one or more complete line frequency periods, effectively integrating any line frequency content to zero. Line-locking is a very effective way of reducing line-related noise. Care must be taken however to ensure that where line frequency is selectable, the line-locking is set to the correct line frequency i.e. 50 Hz or 60 Hz.

Guard – A guard is a circuit that may be used to intercept and divert, or control leakage currents. It may be passive, where it is simply a conductive screen or case around sensitive components and circuits, or active where amplifiers actively sense and control the screen potential. In either case, the guard will be connected to a defined point and potential. Connection to the guard will usually be via a 4 mm binding post terminal. Electrically, the guard potential lies at a defined point between ground and (usually) the Lo input terminal. When line powered instruments are connected together, circulating leakage currents may flow around the "loop" formed by their respective power supplies and input lead connections. The "loop" is completed by the connections to the line supply. Such currents usually manifest themselves as noisy or inflated readings in sensitive measurements and may be eliminated by connecting the guard of the DMM to the "earthy" terminal (not directly to earth) of the "source" instrument. In order for the guard to work, it must be used in "remote" configuration. This is enabled by means of a local/remote guard switch or a short link. In either case, local guard usually connects the DMM's Lo and Guard terminals together.

4 wire resistance – A measurement technique used to minimize the effects of the resistance of the connecting leads. In a four wire resistance measurement, separate conductor pairs are used to connect the current and voltage circuits. Ideally, a sensitive resistance measuring DMM should source its test current from a constant current Source, where the output impedance is sufficiently high such that the current flowing through the resistor is independent of the voltage developed across it. Additionally, the voltage measurement circuit should have a low input bias current and sufficiently high input resistance such that all of the test current flows through the test resistor and there is no current flowing in the voltage sensing leads. Under these conditions, the measurement will not be affected by the connecting lead resistance. Because of power supply limitations, there will be a limit on the maximum lead resistance which may be of the order of 100 Ω in any or all of the connecting leads.

True ohms – In a sensitive resistance measurement, it can be difficult to separate residual resistance from residual voltage offsets. Several methods may be employed to determine and remove voltage offsets. One method, sometimes employed in highly accurate resistance bridges, is to make two measurements, one with the test current flowing through the resistor in the normal direction, then a second measurement with the current polarity reversed. Simple voltage offsets will add to one measurement and subtract from the other. As a result, the effects of the offset will cancel. Current reversal is not normally employed in DMMs, but a technique known as true ohms is used to cycle the test current on and off. The residual voltage present across the test resistor when the current is off, is mathematically subtracted from the voltage developed when the current is on, to provide an offset corrected reading. Careful control of the cycle time means that the effects of dynamic (varying) offsets can also be removed. True ohms may not be effective where the test resistor has a significant time constant. For this reason, its use is normally restricted to values less than 10 kΩ.

True-rms – In high accuracy ac voltage measurement, the most useful description of the amplitude is the root-mean-square value. Traditionally, this has been based on equivalent or effective heating power or work that could be done. The realization of this is through thermal converters and some DMMs employ this technique for ac measurements. However, thermal converters are not appropriate for all applications, resulting in the development of electronic RMS converters. These effectively compute the RMS value of the signal in analogue terms by using log and anti-log (exponential gain) circuits to simultaneously square and square-root the signal followed by an averaging filter that extracts the mean value, so providing the true root-mean-square of the signal. The term true-rms was coined to distinguish between modern RMS sensing instruments and the older or lower cost DMMs that used mean or average sensing, but were adjusted to indicate the RMS value. The method assumes that the signal being measured is a perfect sine wave.

If non-sinusoidal waveforms are measured the DMM's reading will be incorrect.

Calibration uncertainty – The total uncertainty of the calibration standard (of whatever type) traceable to national and international standards. The uncertainty will include the contribution of the DMM during the calibration process.

Relative accuracy – The accuracy of the DMM relative to but not including calibration standards. This term can be misleading but is really a measure of the instrument's performance in terms of stability with time and temperature, linearity, flatness and noise. Generally, these parameters are independent of the calibration uncertainty.

Total accuracy – The combination of calibration uncertainty and Relative Accuracy. In specification terms, the combination may be a simple arithmetic summation of the two terms, or a more complex Root-Sum-of-Squares (RSS) combination at a specified confidence level.

Fluke Calibration.
Precision, performance, confidence.™

- ▶ Electrical
- RF
- Temperature
- Pressure
- Flow
- Software

Fluke Calibration
PO Box 9090, Everett, WA 98206 U.S.A.

Fluke Europe B.V.
PO Box 1186, 5602 BD
Eindhoven, The Netherlands

For more information call:
In the U.S.A. (877) 355-3225 or
Fax (425) 446-5116
In Europe/M-East/Africa +31 (0) 40 2675 200 or
Fax +31 (0) 40 2675 222
In Canada (800)-36-FLUKE or
Fax (905) 890-6866
From other countries +1 (425) 446-5500 or
Fax +1 (425) 446-5116
Web access: http://www.fluke.com

Printed in U.S.A. 3/2011 3988747A A-EN-N PubID 10963-eng