Application Note

MEASUREMENT ACCURACY VERIFICATION TOOL FOR R&S® HMC8012 AND UDS

Products:

- R&S®HMC8012 Digital Multimeter
- R&S®UDS500 Digital Multimeter
- R&S®UDS600 Digital Multimeter

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1 Overview

The R&S®HMC8012 and R&S®UDS600 digital multimeters support a wide range of electrical measurement functions. The permissible measurement error depends on the selected function and measurement range, the value indicated by the instrument, the signal frequency for AC measurements and the ambient temperature. Manually applying the corresponding accuracy tables can therefore be time-consuming and may lead to calculation or range-selection errors.

This application note describes the Measurement Accuracy Verification Tool, a Windows desktop application developed to simplify and standardize this evaluation. The user selects the digital multimeter, measurement function, range and input unit, and then enters the reference value, the value indicated by the multimeter and the ambient temperature. For AC measurements, the applicable signal frequency and optional crest-factor contribution can also be specified.

The application automatically selects the relevant instrument-specific accuracy coefficients and calculates the contributions related to the indicated value, selected range and temperature deviation. It then determines the minimum and maximum permitted values around the multimeter indication and compares the reference value with this interval. The result is displayed as a clear PASS or FAIL decision together with the calculated limits and any relevant notes or warnings.

The tool can be used for manual measurement verification and calibration support. It does not communicate directly with the instruments and does not replace a calibrated reference standard or the procedures specified in the applicable instrument documentation.

2 Measurement Accuracy Fundamentals

The verification result depends on the accuracy specification of the selected instrument and on the conditions under which the measurement is performed. The calculation therefore uses the applicable function, measurement range, ambient temperature and, for AC measurements, signal frequency.

2.1 Accuracy specification and measurement range

For most supported functions, accuracy is specified as $\pm(\%\text{ of reading} + \%\text{ of range})$. The basic absolute error limit is calculated as:

$$E_0 = \frac{a}{100}|x_{\mathrm{ind}}| + \frac{b}{100}R$$

where x_{ind} is the multimeter indication, R is the selected range value, and a and b are the applicable percentage coefficients. The reading contribution changes with the indicated value, while the range contribution remains constant within the selected range. Selecting a higher range can therefore increase the absolute error limit. The range entered in the application must match the range used on the instrument.

For example, the HMC8012 specification of 0.020% of reading + 0.002% of range gives an error limit of 3.57 mV for an indication of 13.85 V on the 40 V range, before additional contributions are applied [1].

The frequency-counter specification uses a percentage-of-reading term only. Its calculation does not include a conventional percentage-of-range contribution [1], [3].

DC Specifications DC Accuracy in ± [% of reading + % of range]:

Function	Range[1]	Test Current Voltage drop	Input Impedance	1 Year 23 °C ±5 K	Temp. Coefficient 0-18 °C, 28-55 °C
DC Voltage	400,000 mV		10 MΩ/>10 GΩ	0,015+0,002	0,0010+0,0005
	4,00000 V		10 MΩ/>10 GΩ	0,015+0,002	0,0008+0,0003
	40,0000 V		10 MΩ	0,020+0,002	0,0010+0,0005
	400,000 V		10 MΩ	0,020+0,002	0,0015+0,0005
	1000,00 V		10 MΩ	0,025+0,002	0,0015+0,0005
Resistance	400,000 Ω	1 mA		0,050+0,005	0,0020+0,0005
(2/4-wire)[2]	4,00000 kΩ	1 mA		0,015+0,002	0,0020+0,0002
	40,0000 kΩ	100 µA		0,015+0,002	0,0020+0,0002
	400,000 kΩ	10 µA		0,030+0,003	0,0020+0,0002
	4,00000 MΩ	1 µA		0,060+0,005	0,0020+0,0002
	40,0000 MΩ	100 nA		0,250+0,003	0,0080+0,0005
	250,000 MΩ	460 nA||10 MΩ (parallel)		2,000+0,010	0,200+0,0005
DC Current[4]	20,0000 mA	<0,30 V		0,05+0,010	0,008+0,0010
	200,000 mA	<0,27 V		0,05+0,010	0,008+0,0010
	2,00000 A	<0,2 V		0,25+0,070	0,012+0,0015
	10,0000 A[3]	<0,60 V		0,25+0,070	0,010+0,0010
Continuity	4000 Ω	1 mA		0,05+0,010	0,005+0,0005
Diode Test	5 V	1 mA		0,05+0,010	0,005+0,0005

Notes:
1] 240.000 / 480.000 counts exept in 1000 V and 10 A range
2] Specifications are for 4-wire measurement; 2-wire measurement using NULL function.
3] Maximum current load at >5 A is 30 seconds, followed by a pause of >30 seconds
4] At 250 V maximum

Fig. 2.1: DC accuracy specifications of the R&S®HMC8012, including reading, range and temperature coefficients.

2.2 Temperature and warm-up conditions

The published accuracy data apply within a defined temperature interval and after the required warm-up period. These conditions differ between the supported instruments [1], [3].

Instrument	Base accuracy temperature interval	Warm-up period
R&S®HMC8012	18 °C to 28 °C (23 °C ± 5 °C)	At least 90 minutes
R&S®UDS600	20 °C to 30 °C (23 °C −3 °C / +7 °C)	30 minutes after ambient acclimatization

For the UDS600, the datasheet specifies three hours of storage at ambient temperature before warm-up operation [3].

Outside the base accuracy interval, the application adds the specified temperature contribution:

$$E_T = \Delta T \left(\frac{k_a}{100} |x_{\mathrm{ind}}| + \frac{k_b}{100} R \right)$$

Here, k_a and k_b are the reading and range temperature coefficients in %/K. The temperature deviation ΔT is measured from the nearest boundary of the interval; it is zero inside the interval. For example, at 32 °C, it is 4 K for the HMC8012 and 2 K for the UDS600. The additional contribution is added to the error limit; it does not correct the displayed reading.

2.3 AC frequency and waveform conditions

For AC voltage and current measurements, the applicable accuracy coefficients depend on signal frequency. The application selects the corresponding frequency band and applies the associated reading, range and temperature terms. A frequency outside the supported bands cannot be evaluated using those tables.

The AC tables must be read together with their notes. For UDS600 AC voltage, indications at or below 20% of the selected range require a larger range contribution in the 20 kHz to 50 kHz and 50 kHz to 100 kHz bands. Range exclusions and input-sensitivity requirements must also be observed [3].

The published AC voltage specifications refer to sinusoidal signals. Where the documented crest-factor condition applies, the application's optional additional contribution is 0.5% of the indication. This option does not extend the supported frequency or waveform limits [1], [3].

AC specifications of the R&S®UDS500/UDS600

Function	Range [7]	Frequency	1 year deviation [2] (+23 °C – 3 °C/+ 7 °C)	Temperature coefficient [2] (0 °C to +20 °C, +30 °C to +55 °C)
AC voltage [8]	200 mV [9]	10 Hz to 20 Hz	3.0 + 0.05	0.01 + 0.01
	2 V	20 Hz to 45 Hz	1.5 + 0.05	0.01 + 0.01
	20 V	45 Hz to 20 kHz	0.3 + 0.05	0.01 + 0.01
	200 V	20 kHz to 50 kHz [10]	1.0 + 0.05	0.02 + 0.01
	750 V [11]	50 kHz to 100 kHz [12]	3.0 + 0.05	0.05 + 0.01
AC current [5]	20 mA	20 Hz to 40 Hz	1.5 + 0.05	0.01 + 0.01
	200 mA	40 Hz to 1 kHz	0.5 + 0.05	0.01 + 0.01
	2 A	1 kHz to 5 kHz	1.5 + 0.05	0.01 + 0.01
	10 A [6]	5 kHz to 10 kHz [13]	2.5 + 0.05	0.01 + 0.01

Fig. 2-2: Frequency-dependent AC specifications of the R&S®UDS series.

2.4 Resolution and measurement settings

Display resolution describes the smallest increment shown by the instrument. It must be distinguished from the accuracy limit calculated from the specification coefficients. The number of displayed digits alone does not define the permitted measurement error.

The HMC8012 provides up to $5^{3/4}$ digits and the UDS600 up to $6^{1/2}$ digits. Resolution and reading rate depend on the selected function and ADC setting. The user manuals recommend the SLOW ADC setting for maximum measurement accuracy [1], [2]. No separate digit term is added when the applicable specification is expressed solely as percentages of reading and range.

For resistance measurements, the specified connection method must also be observed. The accuracy tables specify four-wire measurements or two-wire measurements with NULL compensation [1], [3].

Reading Rates

Function	Setting	Resolution	Display	Reading Rates (per sec.)
AC Voltage	Slow	5 3/4	400,000	5
	Medium	4 3/4	40,000	10
	Fast	4 3/4	40,000	200
DC Voltage	Slow	5 3/4	400,000	5
	Medium	4 3/4	40,000	10
	Fast	4 3/4	40,000	200
AC Current	Slow	5 3/4	200,000	5
	Medium	4 3/4	20,000	10
	Fast	4 3/4	20,000	200
DC Current	Slow	5 3/4	200,000	5
	Medium	4 3/4	20,000	10
	Fast	4 3/4	20,000	200
Resistance (2-wire)	Slow	5 3/4	400,000	5
	Medium	4 3/4	40,000	10
	Fast	4 3/4	40,000	50
Resistance (4-wire)	Slow	5 3/4	400,000	5
	Medium	4 3/4	40,000	10
	Fast	4 3/4	40,000	25
Frequency	Slow	6	999,999	1
	Medium	5	99,999	10
	Fast	4	9,999	100
Diode		4 3/4	40,000	10
Continuity		4 3/4	40,000	200
Temperature		4	999,9	10

(a)

Reading rates [1)]

Function	Setting	Resolution		Reading		Measurement rate in readings/s
		R&S®UDS500	R&S®UDS600	R&S®UDS500	R&S®UDS600	
AC voltage	slow	5½	6½	200,000	2,000,000	5
	medium	4½	5½	20,000	200,000	10
	fast	4½	5½	20,000	200,000	200
DC voltage	slow	5½	6½	200,000	2,000,000	5
	medium	4½	5½	20,000	200,000	10
	fast	4½	5½	20,000	200,000	200
AC current	slow	5½	6½	200,000	2,000,000	5
	medium	4½	5½	20,000	200,000	10
	fast	4½	5½	20,000	200,000	200
DC current	slow	5½	6½	200,000	2,000,000	5
	medium	4½	5½	20,000	200,000	10
	fast	4½	5½	20,000	200,000	200
Resistance (2-wire)	slow	5½	6½	200,000	2,000,000	5
	medium	4½	5½	20,000	200,000	10
	fast	4½	5½	20,000	200,000	50
Resistance (4-wire)	slow	5½	6½	200,000	2,000,000	5
	medium	4½	5½	20,000	200,000	10
	fast	4½	5½	20,000	200,000	25
Frequency	slow	6	7	999,999	9,999,999	1
	medium	5	6	99,999	999,999	10
	fast	4	5	9,999	99,999	100
Diode		4½	5½	20,000	200,000	10
Continuity		4½	5½	20,000	200,000	200
Temperature		4	5	999.9	99,999	10

(b)

Fig. 2-3: Resolution and reading-rate settings: (a) R&S®HMC8012; (b) R&S®UDS series.

2.5 Verification principle

The application adds the applicable error contributions:

$$E_{\text{total}} = E_0 + E_T + E_{\text{additional}}$$

$E_{\text{additional}}$ represents the optional crest-factor contribution. When enabled, it equals 0.5% of the absolute multimeter indication; otherwise, it is zero.

The permitted interval is calculated around the multimeter indication:

$$[x_{\text{ind}} - E_{\text{total}},\ x_{\text{ind}} + E_{\text{total}}]$$

The entered reference value x_{ref} is compared with this interval. The result is PASS when:

$$|x_{\text{ind}} - x_{\text{ref}}| \leq E_{\text{total}}$$

Otherwise, the result is FAIL. The calculation uses the multimeter indication for percentage-of-reading contributions and includes the interval boundaries in the PASS condition.

This is a comparison against the implemented accuracy limits. It does not calculate the combined uncertainty of the verification setup or apply a guard band. Reference uncertainty and any required decision rule must be addressed by the applicable verification procedure.

3 Prerequisites and Startup

3.1 Prerequisites

A Windows PC with the application executable and a suitable calibrated reference source or reference instrument are required. Verification uses manually entered values from the reference and the multimeter.

Before recording measurements, observe the warm-up and measurement conditions described in Section 2. The selected function, range, ambient temperature and, for AC measurements, signal frequency must be known. The connections must be appropriate for the measurement function.

3.2 Startup

Launch the application and select **R&S®HMC8012** or **R&S®UDS600**. The selection loads the corresponding measurement functions, ranges and accuracy coefficients.

Select the function, range and input unit, then enter the reference value, multimeter indication and ambient temperature. For AC voltage or current, also enter the signal frequency. Confirm that the selected range matches the range used on the instrument before starting verification.

The input fields and result display are described in Section 4.

4 User Interface and Operation

The main window contains three panels: **Measurement setup** for entering the verification conditions, **Verification result** for displaying the outcome, and **Accuracy components** for reviewing the individual error contributions.

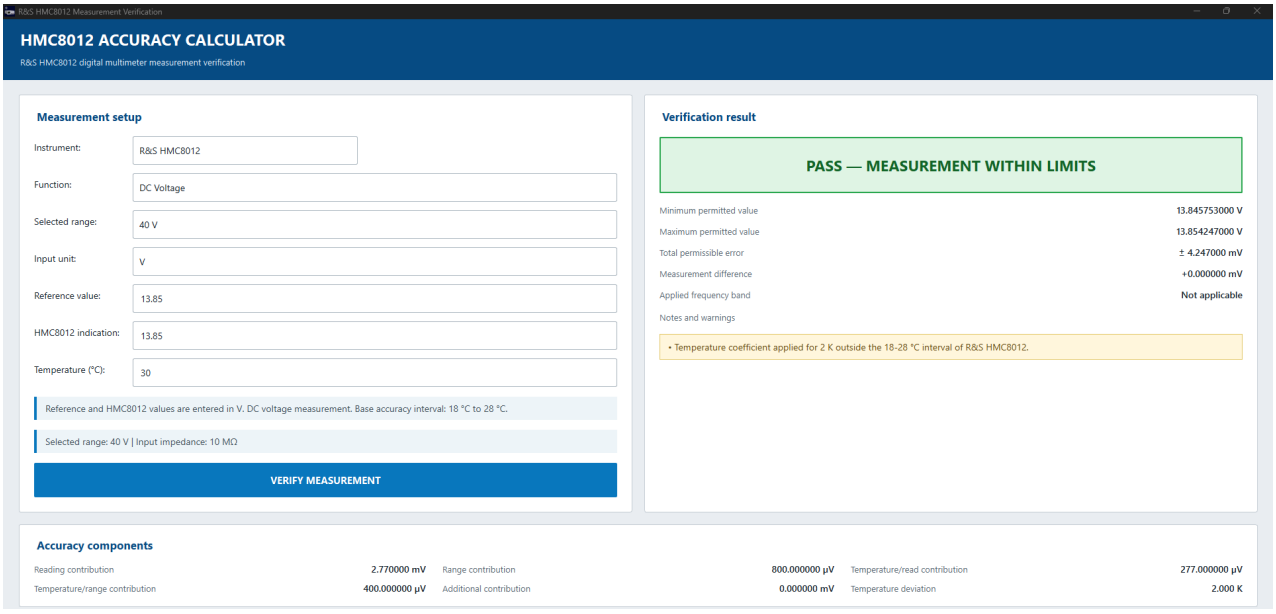


Fig. 4-1: Measurement setup and verification result for an R&S®HMC8012 DC voltage measurement.

4.1 Measurement Setup

Select the instrument, measurement function and range. The selected range must match the range used on the multimeter.

Choose the input unit and enter the reference value and instrument indication in that unit. Enter the ambient temperature in degrees Celsius.

The application can also be used to review the specified accuracy without a physical instrument. Enter the nominal value as both the reference value and the instrument indication, then select the function, range and operating conditions. The displayed error contributions, total permissible error and limits show the specification applied to that case. Since both values are identical, PASS is expected; this is an accuracy lookup, not verification of a physical measurement.

For AC measurements, also enter the signal frequency in hertz. Enable the optional crest-factor contribution when the condition described in Section 2.3 applies.

Press **VERIFY MEASUREMENT** to perform the calculation.

4.2 Verification Result

The result panel displays the minimum and maximum permitted values, total permissible error and signed difference between the instrument indication and reference value. For AC measurements, it also identifies the applied frequency band.

PASS indicates that the reference value lies within the permitted interval, including its boundaries. **FAIL** indicates that it lies outside this interval.

The **Accuracy components** panel displays the reading, range, temperature and optional additional contributions. Review **Notes and warnings** for the conditions applied to the calculation. If an invalid input is reported, correct it and repeat the verification.

5 Calculation Example

Consider an R&S®HMC8012 DC voltage indication of **13.85 V**, measured on the **40 V range** at an ambient temperature of **30 °C**. The measurement conditions described in Section 2 are assumed to be satisfied.

The 40 V specification in Fig. 2.1 gives a base accuracy of $\pm(0.020\%$ of reading $+\ 0.002\%$ of range$)$ [4].

The reading contribution is:

$$\begin{aligned} E_{\text{reading}} &= 13.85\,\text{V} \times \frac{0.020}{100} \\ &= 2.770\,\text{mV} \end{aligned}$$

The range contribution is:

$$\begin{aligned} E_{\text{range}} &= 40\,\text{V} \times \frac{0.002}{100} \\ &= 0.800\,\text{mV} \end{aligned}$$

Therefore, the base error limit is:

$$E_0 = 2.770 + 0.800 = 3.570\,\text{mV}$$

The ambient temperature exceeds the upper reference-temperature limit of 28 °C by:

$$\Delta T = 30 - 28 = 2\,\text{K}$$

The temperature coefficients are 0.0010% of reading and 0.0005% of range per kelvin [4]. Their contributions over 2 K are:

$$\begin{aligned} E_{T,\text{reading}} &= 13.85\,\text{V} \times \frac{0.0010}{100} \times 2 \\ &= 0.277\,\text{mV} \end{aligned}$$

$$\begin{aligned} E_{T,\text{range}} &= 40\,\text{V} \times \frac{0.0005}{100} \times 2 \\ &= 0.400\,\text{mV} \end{aligned}$$

Thus:

$$E_T = 0.277 + 0.400 = 0.677\,\text{mV}$$

For this DC measurement, $E_{\text{additional}} = 0$. The total permissible error is:

$$\begin{aligned} E_{\text{total}} &= 3.570 + 0.677 \\ &= 4.247\,\text{mV} \\ &= 0.004247\,\text{V} \end{aligned}$$

The application calculates the permitted interval around the indication:

$$x_{\min} = 13.85 - 0.004247 = 13.845753\,\text{V}$$

$$x_{\max} = 13.85 + 0.004247 = 13.854247\,\text{V}$$

For example, an entered reference value of **13.852000 V** lies within this interval. Its difference from the indication is **2.000 mV**, below the **4.247 mV** limit, so the application displays **PASS**.

6 Literature

[1] Rohde & Schwarz, *R&S®HMC8012 User Manual*, version 06, Chapter 5 (Instrument Functions), Chapter 10 (Specifications), printed pages 44–46 and 62–63.

[2] Rohde & Schwarz, *R&S®UDS Series User Manual*, document 1179.1670.02, version 02, Sections 3.4.1 and 3.4.3, printed pages 36 and 41–42.

[3] Rohde & Schwarz, *R&S®UDS Digital Multimeters Data Sheet*, document 3673.1318.32, version 03.00, printed pages 7–11.

[4] HAMEG Instruments GmbH, *HMC8012 Digital Multimeter Data Sheet*, document HMC8012E/170613.

7 Ordering Information

Designation	Type	Order No.
HMC8012 R&S 5 ¾-Digit Multimeter	R&S®HMC8012	3593.0980K02
HMC8012-G R&S 5 ¾-Digit Multimeter	R&S®HMC8012-G	3593.0997K02
Digital multimeter, 5 ½ digit	R&S®UDS500	3658.6470.02
Digital multimeter, 5 ½ digit, IEEE-488 (GPIB)	R&S®UDS500-G	3658.6470.04
Digital multimeter, 6 ½ digit	R&S®UDS600	3658.6470.03
Digital multimeter, 6 ½ digit, IEEE-488 (GPIB)	R&S®UDS600-G	3658.6470.05

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