WHITEPAPER

VXInstruments
the test solutions provider

THE SUM OF MEASUREMENT UNCERTAINTY AND MEASUREMENT ERROR

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In our whitepaper "This is how to select oscilloscope, digitizer, and DMM" we explained the differences between a digital multimeter (DMM), a digitizer, an oscilloscope, and the properties of a multi-measurement device (MMD) of VX Instruments. We provided an overview of important technical data and discussed the advantages of isolated measurement technology.

This whitepaper addresses the reasons for measurement inaccuracy at static measurements (DC) for not isolated and isolated measuring instruments. In addition, we show the effects of a different number of measuring ranges of a measuring instrument.

1. MEASUREMENT ACCURACY, UNCERTAINTY AND ERROR

Measurement accuracy describes a value which characterizes the expected deviation of the measured from the physically true value. The exact definition varies in different publications. In addition, terms such as standard error, measurement inaccuracy, measurement accuracy, or measurement errors are used. The tolerance with which a value can be captured is referred to below as measurement accuracy. On one hand it consists of the measurement uncertainty of the measuring instrument itself. It is typically specified in the datasheets or device specifications by accuracy, which in turn consists of the sum of the accuracy of the measurement itself (gain error, unit% of value) and the accuracy of the measurement range (offset error, unit% of range). Examples of such a specification are shown in the table.

On the other hand, the measuring instrument itself affects the signal to be measured. This is done primarily by the input impedance, which consists of a resistance and a parallel capacitance. A typical value for this is 1 MOhm || 20 pF for oscilloscopes and 10 MOhm || 150 pF for a digital multimeter (DMM). In the case of slow DC measurements, the ohmic resistance is decisive for the measurement error. The parallel capacity is left out in the first instance of consideration. This effects are described in the whitepaper "Measuring accuracy and measuring ranges in dynamic AC measuring applications".

The falsification of the measured value caused by the input impedance of the measuring instrument thus generates the so-called measurement error. Measurement accuracy is defined as the sum of measurement uncertainty and measurement error. The focus of this paper is the measurement accuracy in the static measurement case. So the input capacitance and the parasitic capacitances of the measuring device are not relevant. For longer measurements, they usually are beneficial, as they minimize interference and noise.

2. HOW MEASUREMENT ERRORS OCCUR IN THE STATIC MEASUREMENT CASE

First, we consider the effects of measurement with a non-isolated measuring instrument (Figure 1) in a low-side measurement, i. e. the measurement of a voltage with respect to the ground (protective connector) as reference point. Here, the components to be measured, as well as the measuring instrument are connected directly to the measuring mass or ground via a connector.

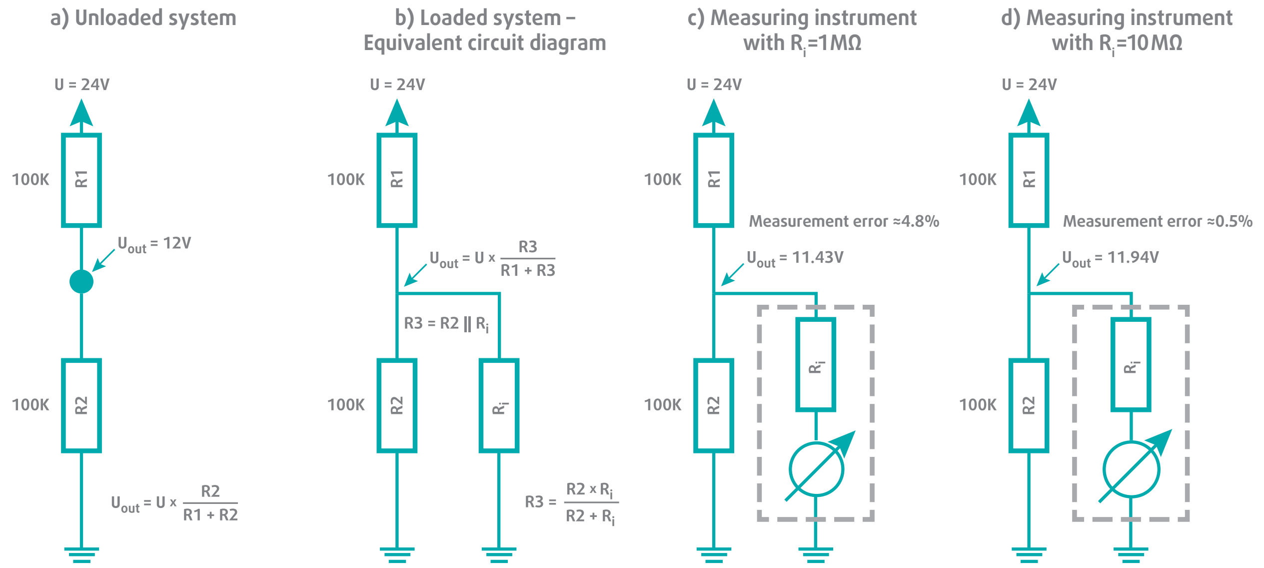

Figure 1: The effects on a measurement with a non-isolated measuring instrument.

Figure 1 in detail:

Figure (a) shows the unloaded system with the ideal output voltage of 12 V. If a measuring instrument is connected to measure the voltage via R2, this works like a parallel-connected resistance in static measuring.

Figure (b) shows an equivalent circuit diagram. For the two instruments that are taken as examples, the internal resistance is assumed to be 1 MOhm and 10 MOhm.

Figures (c) and (d) shows how the measuring instrument generates a visible measurement error. The measurement error depends significantly on the internal resistance of the measuring instrument.

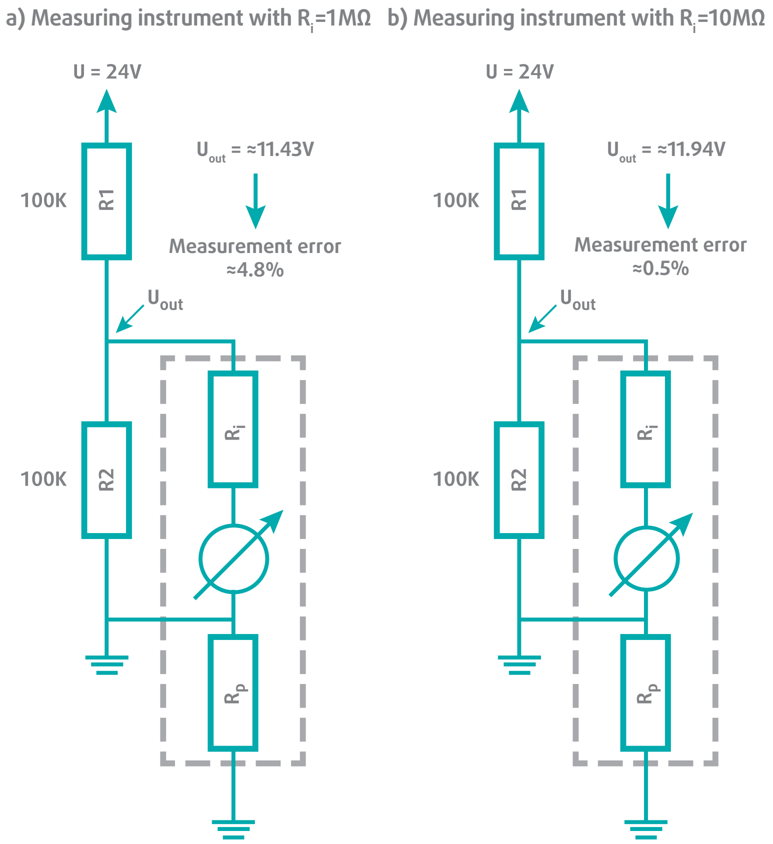
a) Measuring instrument with R_i=1MΩ b) Measuring instrument with R_i=10MΩ

Figure 2: The figure shows an isolated measurement with an isolated measuring instrument.

When measuring with an isolated measuring instrument, it can be seen in Figure 2 that the internal resistance has the same effects. Usually the very high insulation resistance RP that exists in reality can be ignored.

By realizing a connecting to the resistance to be measured, one input of the measuring instrument is connected directly to the measuring mass, thus short-circuiting the insulation resistance Rp. In the specific case of the low-side measurement, resistance Rp has no effect regardless of its size. Isolated and non-isolated measuring instruments are equally suitable for this measuring case.

3. MEASURING UNCERTAINTIES AND MEASUREMENT RANGES

The size of the measurement error depends on the ratio of the internal resistance of the device to the resistance of the object to be measured. A device with high input resistance falsifies a measurement less, regardless of the impedance of the signal to be measured, and is therefore always suitable for precise measurements. In the follow-up of this whitepaper series, among other things, the measurement accuracy in high-side measurements and the accuracy of measurement in dynamic measurement processes of AC signals will be discussed.

The measurement uncertainty is, as already mentioned, the sum of gain error and offset error. In this case, the gain error depends on the measured value and the offset error is constant within a measuring range. This means that the measurement uncertainty increases linearly within a measuring range. The two errors are not the same size in all measuring ranges. Typically the errors increase slightly towards the smallest or the largest measuring ranges. Since this has hardly any influence on the representations of the effect of a different number of measuring ranges, the same errors are assumed in all measuring ranges for an easier comparison (see Table 1).

Device	Measuring Range [V]	Gain Error [%]	Offset Error [%]
Measuring instrument 1	1, 10 and 100	0.08	0.01
Measuring instrument 2	1, 2, 4, 8, 16, 32, 64 and 128	0.08	0.01

Table 1: Comparison of both measurement instruments.

Here you can clearly see the respective constant offset errors of the measuring ranges and the variable gain errors which are dependent on the measured value (Figures 3 and 4).

It is also apparent that the selection of a suitable measuring range is essential. It is possible to measure a voltage of 8 V with the measuring range of 100 V, but in our example this would be done with an approximately double measurement uncertainty as in the measuring range of 10 V. Measuring instrument 2 has a larger number of measuring ranges (Figure 4). The diagrams in Figures 3 and 4 show that the differences between the two devices grow with increasing voltage. The reason for this is that the offset error always applies to one measuring range. The larger the available measuring range, the greater the effect on the gain error in the lower part of the measuring range.

Due to a larger number of measuring ranges, the absolute measurement uncertainty is reduced in large parts of the entire measuring range. This is due to the different and necessary utilization of the measuring ranges.

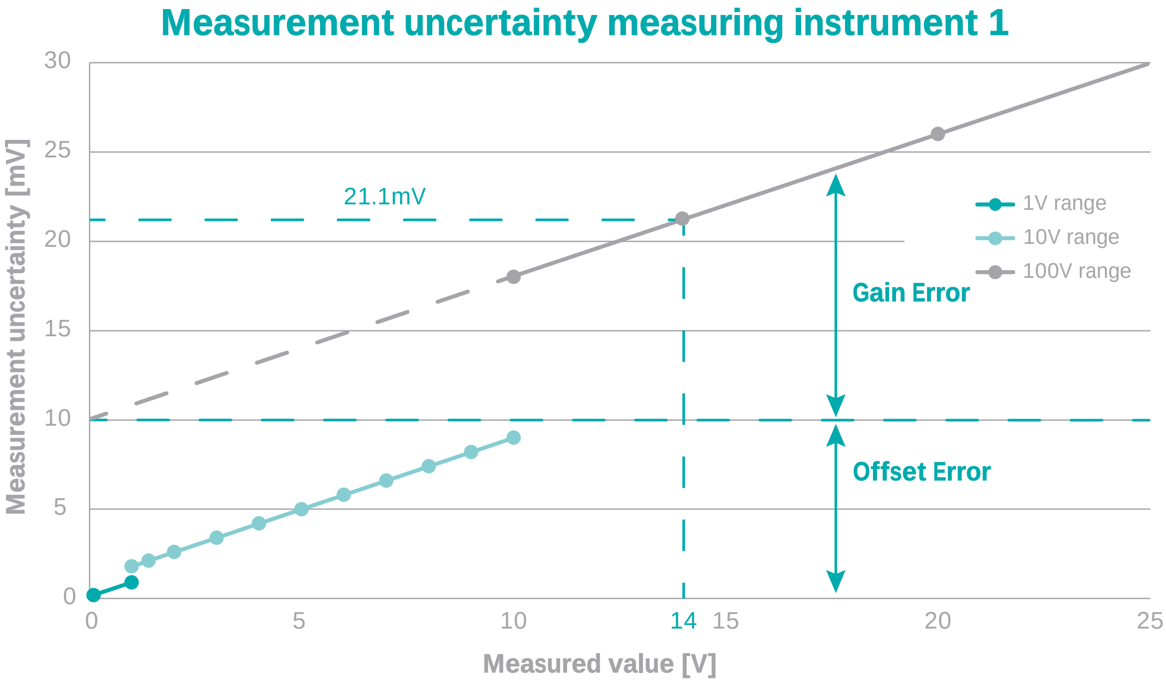

Figure 3: The absolute error measured on measuring instrument 1.

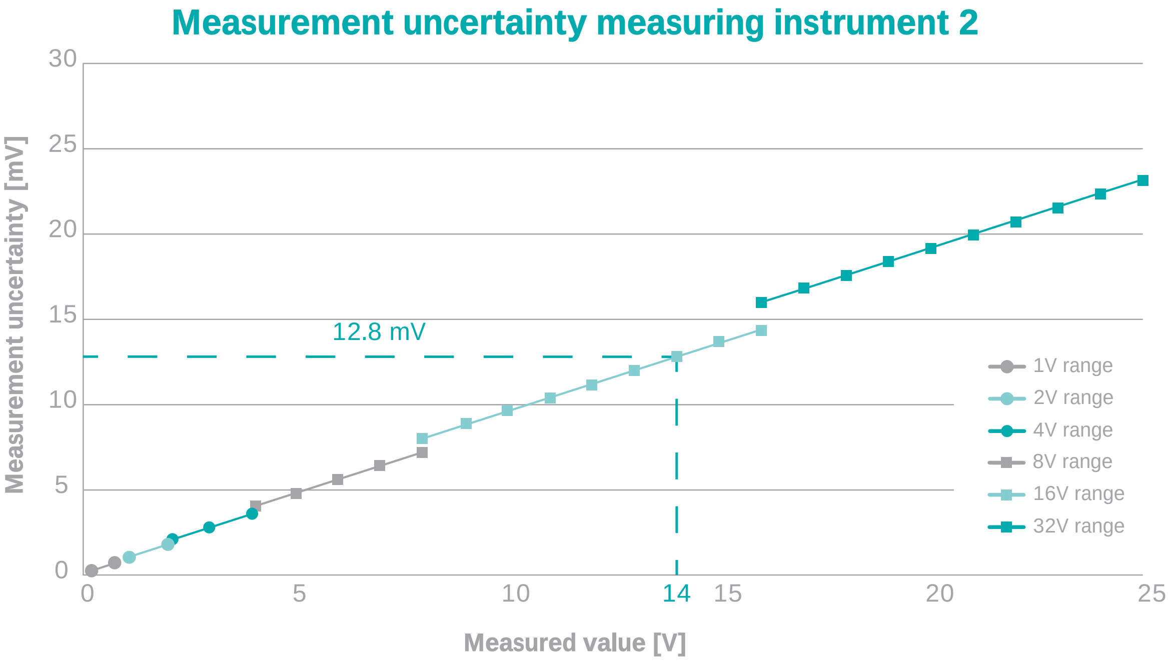

Figure 4: Measuring instrument 2 has a larger number of measuring ranges.

4. THE EFFECTS OF THE DIFFERENT MEASURING RANGES

With a 10-part division of the measuring ranges, the 100 V measuring range extends from 10 to 100 V. This means that 90 percent of the measuring range must always be used. With a 2-part division, the 128 V measuring range extends from 64 to 128 V, which represents only 50 percent of the measuring range. For users, it is crucial how precisely a value can be measured. To verify that the output voltage of a test sample of 14 V ± 0.1 percent is correct, the accuracy of the measuring instrument must be standardized to the measured value of 14 V. To do this, the absolute error is calculated at 14 V and divided by 14 V. Figures 5 and 6 show the standardized representation of the measurement uncertainty for both measuring instruments.
The advantage of the 2-part division becomes particularly clear.

The standardized error can thus be kept low over the entire available measuring range. In our examples, we chose devices with an offset error of 0.01 percent and a gain error of 0.08 percent. It can be assumed that in this way, it can always be measured with an uncertainty of 0.09 percent.

In the standardized representation, it can be seen that this assumption only applies to the maximum measured value within a range. The lower the measured value within a range, the greater the measurement uncertainty related to the measured value itself. A voltage of 14 V is measured with measuring instrument 1 with an uncertainty of 21.2 mV. This corresponds to a standardized error of approximately 0.15 percent. Measuring instrument 2 measures the voltage with an uncertainty of 12.8 mV, which corresponds to a standardized error of 0.091 percent. This means that the measurement uncertainty of the measuring instrument 1 is about 65 percent worse for this measured value than for the measuring instrument 2.

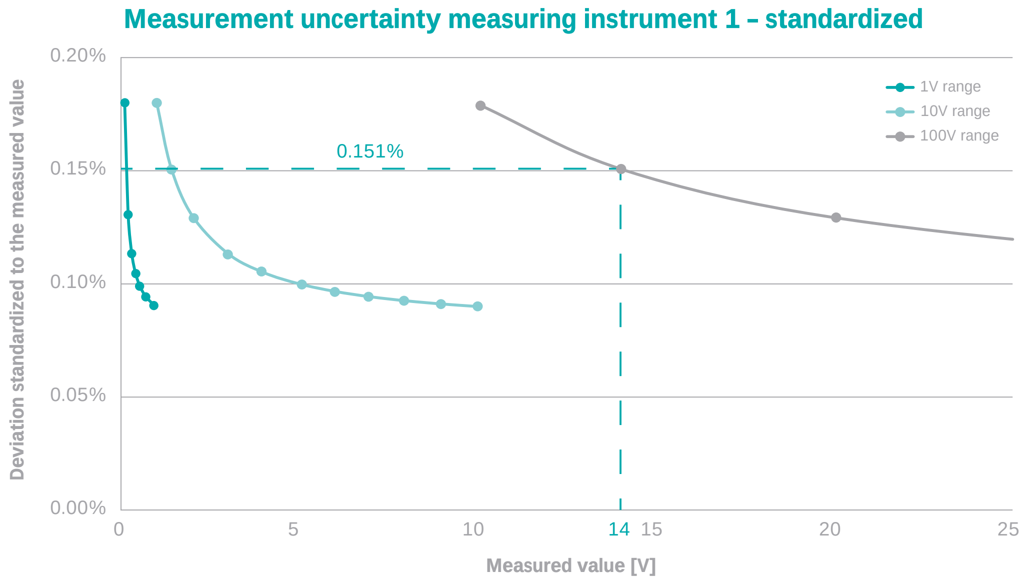

Figure 5: Standardized representation of the measurement uncertainty for measuring instrument 1.

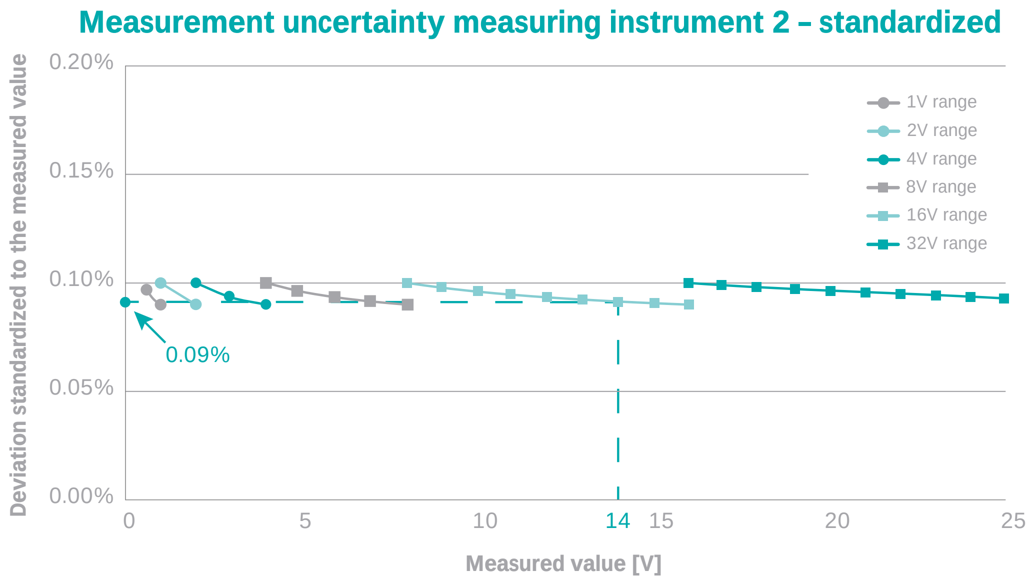

Figure 6: Standardized representation of the measurement uncertainty for measuring instrument 2.

The user should always be aware that a measurement always generates a measurement error. This can be minimized by the use of devices with high input impedances. In applications with high demands on the measurement accuracy, it is also advisable to use a device with a larger number of measurement ranges in order to keep the measurement uncertainty correspondingly low.

The next part of this whitepaper series explains the accuracy of high-side measurements, the differential measurement with a common mode component, and the effects on the measurement accuracy in dynamic measurements of AC signals.

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