Operation Parameter Guide

Tensormeter Model RTM1

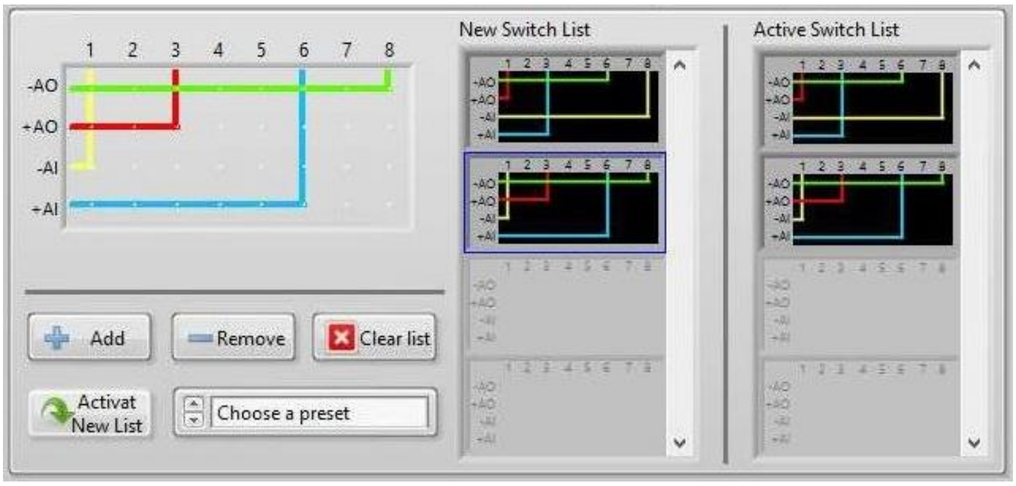
The setting of the measuring parameters of the Tensormeter is usually done by the user in an application program and has to be done specifically for each measurement in order to achieve optimal measuring results. The application software can be e.g. the TMCS software, a sample client software of the manufacturer or a software created by the user in any programming environment. It is also possible to change the parameters directly in the RTM server program for test purposes.

Switching matrix

An essential feature of the Tensormeter is the integrated analog switching matrix. Due to the integration of the switching matrix, the tensormeter is not only extremely versatile, but it can also perform measurement tasks that are impossible with permanently connected devices (multimeters, lockin amplifiers).

The matrix configuration is done via the lower left panel of the TMCS software. The matrix allows each of the eight BNC ports to be assigned any function of a four-wire resistance measurement. These functions are negative and positive supply (AO-, AO+) as well as negative and positive voltage tap (AI-, AI+).

The graphical representation indicates which ports are connected to which function groups. In the example, the supply voltage is output between ports 3 and 8 and the voltage is tapped between ports 6 and 1.



With the Add and Remove buttons, a New Switch List can be built up step by step, which is then transferred to the device using the Activate New List.

If the measurement is to be carried out with a fixed connection, the Switch List only contains a single entry. Operation in this way is comparable to conventional devices such as tabletop multimeters or Lockin amplifiers.

However, a Switch List can also comprise several entries which together form a measurement task. By changing the circuitry, the measuring instrument gains a different perspective on the measured object, which provides additional information compared to a fixed circuitry: In the example, the active switch list includes, in addition to the configuration mentioned above, a second entry with voltage supply through ports 1 and 6 and with voltage tap between ports 3 and 8. Together, both entries result in a typical measurement sequence of a zero-offset Hall measurement, which allows the longitudinal and transverse resistance of the sample to be measured separately.

Other cases for such measurement tasks with dynamic interconnection are the van der Pauw measurement of sheet resistance or the ratiometric/differential measurement between several samples. In the preset dropdown menu further examples are stored and it is possible to save own switch lists as preset.

Setting the supply

The differential output of the tensometer can be up to ±19.8 V and up to ± 0.1 A as DC voltage, as continuous sine wave up to 20 kHz, or as arbitrary signal with 10 µs time resolution. The differential voltage is always balanced between both outputs ($V_{\mathrm{AO}-} + V_{\mathrm{AO}+} = 0\ \mathrm{V}$). Sine and DC voltage can be output simultaneously and can also be demodulated simultaneously. There are some conflicting requirements to consider when selecting the driver strength:

A) The more current flows through a sample, the higher the measurable voltage signal and the better the signal-to-noise ratio. Accordingly, one always wants to use the maximum possible current.

B) The current flow through a resistive sample with resistance R generates Joule loss, according to $E_{\mathrm{Heat}} = R \cdot \left(I_{\mathrm{DC}}^2 + \frac{1}{2} I_{\mathrm{AC}}^2\right)$. This results in a heating of the sample. In low temperature cryostats the thermal budget can sometimes be only a few mW, which limits the possible currents. With filigree structures, the local heat development can also lead to abrupt destruction of the structure. These limitations mean that a certain current value should not be exceeded, which depends on the DUT.

C) The signal-to-noise ratio of the voltage source is optimal when the largest possible signal can be output, i.e. as close as possible to ±19.8 V. However, since this would result in an unwanted high current flow depending on the sample resistance, the tensormeter offers integrated series resistances between 0.2 kΩ and 200 kΩ.

To take account of the above points, the maximum current should first be determined. Then the highest possible series resistance should be selected at which this maximum current is still achievable.

❗	Caution: When reducing the series resistance, an unwanted large amount of current may suddenly flow.

If the sine frequency is not predetermined by the measuring task, it should be selected in such a way that the most precise measurement is possible. As a rule, this means that it should be as far away as possible from harmonics of the mains frequency, e.g. at a mains frequency of 50 Hz, values of X25 Hz, or X75 Hz are ideal, e.g. 775 Hz. If higher harmonics are to be demodulated in addition to the fundamental frequency, it is important that the harmonic to be demodulated is also far away from the mains frequency. Example: Mains frequency is 50 Hz, 1st and 2nd harmonics are to be demodulated. A sine frequency of 275 Hz is not suitable here, as the 2nd harmonic (550 Hz) collides with the 11th harmonic of the mains frequency.

A general formula for good frequencies is $f_{\mathrm{opt}} = f_{\mathrm{mains}} \cdot \left(n \pm \frac{1}{h_{\mathrm{max}}+1}\right)$. Here, the highest harmonic to be demodulated h_max and the mains frequency f_mains is decisive. Furthermore, the sinusoidal frequency should not be too low, since this promotes noise and causes limitations in the integration time - values above 300 Hz are well suited. On the other hand, the sine frequency should also not be unnecessarily high, since the influence of stray capacitances and inductances increases with rising frequency. For most measuring tasks, an optimum result can be achieved with sine frequencies between 300 Hz and 3000 Hz.

Integration time, noise and drift

Longer integration times t_{avg} cause a lower noise σ_V in the measured data, according to $\sigma_V \propto \frac{1}{\sqrt{t_{\mathrm{avg}}}}$.

However, this relationship is not valid indefinitely, but only if both the measured system and the measuring instrument do not change during t_{avg}. This limit of the useful integration time $t_{\max}$ is given by the corner frequency $f_{\mathrm{C}} = \frac{1}{t_{\mathrm{avg}}}$. This frequency marks the transition between flat noise spectrum, where a longer integration time is still useful, and 1/f low frequency noise, where a longer integration time is no longer advantageous. The maximum meaningful integration time can vary greatly depending on the measurement task and the sample, from a few milliseconds for poorly conductive thin films in poorly tempered environments to several tens of minutes for good conductive metals and especially for temperature insensitive measurements such as bridge measurements and transverse resistance measurements.

Nevertheless, integration times beyond about 1 s are rarely useful in practice, since subsequent averaging is more flexible for data evaluation.

Differential and Ratiometric Measurement Modes

The biggest problem for an extremely high measurement accuracy is drift phenomena, as they limit the effective integration time. One of the most efficient ways to combat drift already during the measurement is to use differential and ratiometric measurements.

Differential measurements make sense especially for DC measurements, as they make the offset error of the signal chain irrelevant. However, a better way to achieve this is an AC measurement. This is also insensitive to the offset voltage of the signal chain and offers a higher precision per measurement time. In order to eliminate not only the offset drift but also the gain drift of the signal chain, ratiometric measurements are suitable. Here, in addition to the measurement object, a reference structure is also measured under identical conditions and the relative signal magnitude between the two objects is recorded. Contact the manufacturer for further information and suitable reference objects.

Data channels

The tensormeter illuminates many facets of the physical quantity resistance through the switching matrix and the combination of DC+AC with multiharmonic demodulation. It can be distinguished between real and imaginary part. The non-linearity of the resistance can be evaluated (by harmonics of the fundamental sine frequency). A distinction can be made between the longitudinal and transverse parts of the resistance tensor. All these measurements are not mutually exclusive and should actually all be performed simultaneously for a complete characterization. The tensormeter thus offers a total of 14 data channels, which are divided into two channels (A and B) with 7 resistance values each: Per channel are available:

- DC resistance
- Real and imaginary part of the impedance at the excitation frequency
- Real and imaginary part of the impedance with two higher harmonics

The two data channels A and B contain different information depending on the measuring mode, which are summarized in the following table.

Measurement Mode	Channel A	Channel B
Kelvin	4-wire res.	n/a
Zero-Offset-Hall	Longitudinal res.	Transverse res.
Van-der-Pauw	Sheet res.	Average 4-wire res.
Differential	4-wire res.	Difference to Reference
Ratiometric	4-wire res.	Ratio to Reference

Pulse mode and arbitrary signals

It is possible to use the differential voltage outputs to generate pulse trains or arbitrary signals with a time resolution of 10 µs. The outputs remain balanced. The figure shows the output voltages during a pulse train with 10 µs pulses and 20 µs pauses through a load of 1.1 kΩ.

Pulse and arbitrary signals are defined via a pulse array. This is described in detail in the Tensormeter Command Reference under the command "puar".