

# Excellent Quality of METAS' Scattering Parameters in the Type-N Line System

Together with 18 other National Metrology Institutes (NMI), METAS participated in a key comparison of scattering parameters in the coaxial line system covering a frequency range from 2 GHz to 18 GHz. The results confirm the outstanding quality of METAS metrological services in this particular field.

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S-parameters (box 1) are among the most fundamental quantities in RF & MW metrology. The knowledge about their characteristics is often required for a proper determination of other basic quantities as e.g. RF power or pulse parameters. The accurate determination of S-parameters is a demanding task, which requires good operator skills, metrology grade equipment and a deep understanding of the measurement process to take all influences into account that might affect the measurements. The RF & MW laboratory at METAS has various research and development activities [1] in this metrological field to meet the increasingly demanding requirements of the industry.

## Key Comparison of Complex-valued S-Parameters

This key comparison, designated as CCEM.RF-K5b.CL within the notation scheme of the *International Bureau of Weights and Measures (BIPM)*, aimed at the measurement of S-parameters by broad-band methods at frequencies between 2 GHz

and 18 GHz. Nineteen National Measurement Institutes (NMI) participated in the exercise, which took place between June 2003 and October 2006. Seven devices with Type N precision connectors were used as the travelling standards, three attenuators (3 dB, 20 dB, 50 dB), two matched terminations (male and female) and two mismatched terminations (male and female with reflection coefficients of approximately 0.33).

The participants were asked to provide complex-valued S-parameters for a defined list of frequencies together with combined standard uncertainties and an uncertainty budget as well as information about the measurement setup.

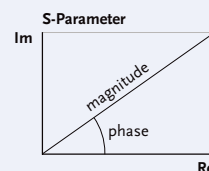
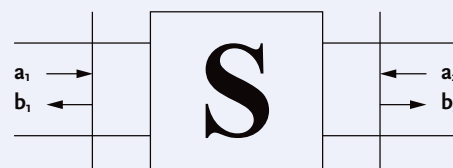
The National Physical Laboratory (NPL), United Kingdom, which acted as pilot laboratory, performed regular stability checks of the devices, which remained stable, except the 3 dB attenuator, which experienced a step change during the measurement loop. Since the stability measurements covered both states of the device, it was still possible to use most of the data for further evaluation.

S-parameters are used to characterise reflective and transmissive behaviour of a device upon impact of a high frequency electromagnetic signal. The illustration schematically represents the situation for a two-port device (e.g. an attenuator) with input signals applied to both ports. If the device is linear, the output signals can be defined in terms of the input signals. Thus,

$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

with the signal amplitudes  $a_1$ ,  $a_2$ ,  $b_1$  and  $b_2$  and the scattering parameters  $S_{ij}$ . The scheme can be generalised to  $n$  ports and the equations can be written more economically in matrix form  $\mathbf{b} = \mathbf{S} \cdot \mathbf{a}$  with the S-parameters contained in the scattering matrix  $\mathbf{S}$  and the column vectors  $\mathbf{a}$  and  $\mathbf{b}$  containing input and output signal amplitudes, respectively.



S-parameters are two-dimensional quantities either described in polar coordinates with magnitude and phase or as complex numbers with real (Re) and imaginary (Im) parts. They can be measured with vector network analysers.

1 Scattering Parameters (S-Parameters).

### Advanced Analysis of the Comparison Data

Measurement comparisons in RF & MW typically create comparably large amounts of data because data is collected over a wide frequency range. This is done for good reason, because the frequency response often provides valuable information about the behavior of a measurement system. For further analysis however, only a subset of the available data was chosen to keep the analysis effort and the data output at a tolerable level. Nevertheless, the final report [2] has a size of more than 250 pages, despite these restrictions.

The guidelines of the BIPM require the pilot laboratory to calculate a key comparison reference value (KCRV) as the best estimate of the actual value of the measurand and degrees of equivalence (DoE), unilateral and bilateral, being a measure of the agreement of submitted data with respect to the KCRV and with respect to the other participants, respectively.

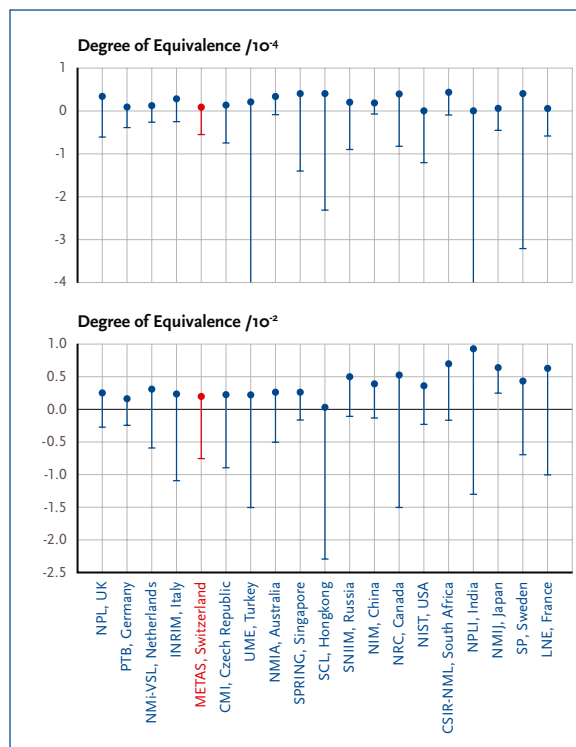
This task is complicated by the fact, that S-parameters are complex-valued quantities. While many publications are available, which address methods of the analysis of measurement comparisons, they almost exclusively deal with scalar measurands.

METAS proposed a method of analysis of complex-valued quantities, or more general vector quantities, when it acted as pilot laboratory in an earlier supplementary S-parameter comparison [3, 4]. Later, METAS refined the method further in a conference paper [5]. NPL basically followed the recipes described in [5] when analysing the data of this intercomparison. A characteristic outcome of this method is the dimensionally reduced DoE shown in diagrams 2 and 3. The one-sided uncertainty bars just underline the fact that the dimensionally reduced DoE is always positive. Besides that, it can be interpreted similarly as the normal DoE: Uncertainty bars crossing the zero line indicate an agreement at the 95 % level or better.

### Metrology Software Developed by METAS

Diagrams 2 and 3 are just two examples of several other results at other frequencies and for other travelling standards. The agreement with the KCRVs and among the participants was generally quite good. METAS results in particular show agreement with the KCRVs in all cases.

The intercomparison also showed, that the uncertainties provided by the participants are generally too large. This conservative approach reflects the fact, that the uncertainty evaluation for S-parameter measurements is elaborate and needs improvement. METAS is actively working on a software [6], which will help to remedy the situation.



2 (above) Dimensionally reduced degrees of equivalence for S<sub>21</sub> measurements of the 50 dB attenuator at 18 GHz.

3 (below) Dimensionally reduced degrees of equivalence for S<sub>11</sub> measurements of the male matched load at 18 GHz.

### References

- [1] [www.metas.ch/hf](http://www.metas.ch/hf).
- [2] Currently in draft B state, will become publicly available on the BIPM key comparison database <http://kcdb.bipm.org> as CCEM.RF-K5b.CL.
- [3] Jürg Rüfenacht, Markus Zeier: Scattering Parameter Measurements in the Coaxial 2.4 mm Line System, METinfo, Vol. 12, Nr. 2, pp. 14–16, 2005.
- [4] Jürg Rüfenacht, Markus Zeier: EUROMET.EM.RF-S16 Final Report: Comparison of scattering parameter measurements in the coaxial 2.4 mm line system, Metrologia, 42, Tech. Suppl., 01001, 2005.
- [5] Markus Zeier: On the analysis of multidimensional quantities in measurement comparison, CPEM 2006 Conference Digest, Torino, pp 458–459, July 2006.
- [6] VNA Tools II project, see [www.metas.ch/hf](http://www.metas.ch/hf).