Format of S-parameter entries in CMC database

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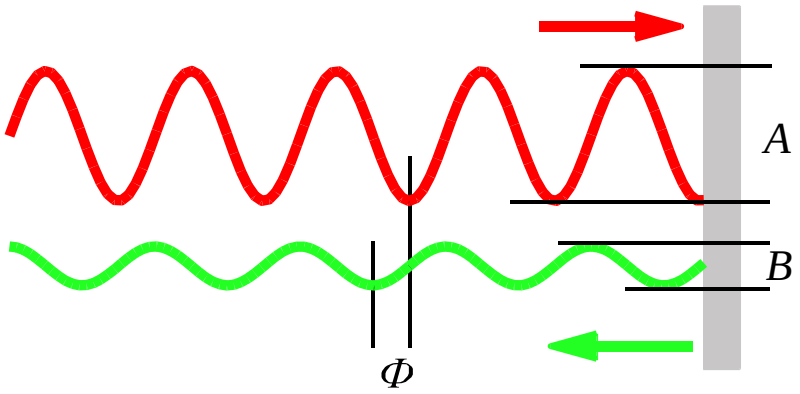
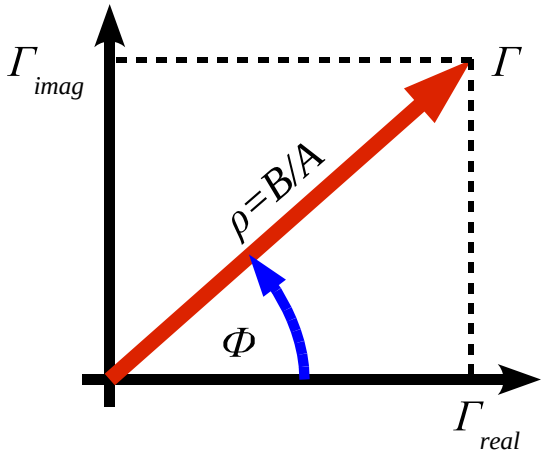
S-parameters

- Scattering parameters are fundamental quantities in RF & MW metrology.
- They are measured with Vector Network Analyzers (VNA)
- They represent reflection and transmission properties of a DUT
- The quantity is complex-valued

Representation

- Polar coordinates (magnitude and phase) or cartesian coordinates (real and imaginary)





Polar coordinates

Magnitude and phase are related to physical phenomena and therefore more intuitive

but

The phase is cyclic and magnitude is >0
This leads to computational problems when doing statistical analysis or uncertainty propagation (non-linearities!)

Cartesian coordinates

Real and imaginary components are better suited for calculations
but
less intuitive

Recommendation:

- Use cartesian coordinates for any type of calculation and as exchange data format
- Convert to polar coordinates for interpretation

S-parameter CMCs

- Mag/Phase: 10 NMIs
- Re/Im: 8 NMIs
- Mixed/Undefined: 4 NMIs

Due to the above mentioned arguments Re/Im entries were promoted over the last years

But METAS changed back from Re/Im to Mag/Phase in last CMC round.

CMCs

- declare best uncertainties
- are reviewed and approved

→Certificate with BIPM/MRA logo should not quote uncertainties that are smaller than CMC entries.

→In case of secondary parameter (independant variable: e.g. frequency):
CMC entries quote the smallest uncertainty for a range of the independant variable.

Example of CMC entry

$|S_{11}|$: magnitude of reflection coefficient

	abs(Sxx)	9 kHz to 3 GHz	3 GHz to 18 GHz	18 GHz to 33 GHz	33 GHz to 40 GHz	40 GHz to 50 GHz	50 GHz to 67 GHz
BNC 50 Ohm	0.0	0.005 to 0.007	-	-	-	-	-
BNC 50 Ohm	0.1	0.005 to 0.008	-	-	-	-	-
BNC 50 Ohm	0.2	0.005 to 0.009	-	-	-	-	-
BNC 50 Ohm	0.3	0.005 to 0.011	-	-	-	-	-
BNC 50 Ohm	0.4	0.005 to 0.013	-	-	-	-	-
BNC 50 Ohm	0.5	0.006 to 0.015	-	-	-	-	-
BNC 50 Ohm	0.6	0.006 to 0.019	-	-	-	-	-
BNC 50 Ohm	0.7	0.007 to 0.022	-	-	-	-	-
BNC 50 Ohm	0.8	0.008 to 0.026	-	-	-	-	-
BNC 50 Ohm	0.9	0.009 to 0.031	-	-	-	-	-
BNC 50 Ohm	1.0	0.010 to 0.036	-	-	-	-	-
Type-N 75 Ohm	0.0	0.005 to 0.006	-	-	-	-	-
Type-N 75 Ohm	0.1	0.005 to 0.006	-	-	-	-	-
Type-N 75 Ohm	0.2	0.005 to 0.008	-	-	-	-	-
Type-N 75 Ohm	0.3	0.005 to 0.010	-	-	-	-	-
Type-N 75 Ohm	0.4	0.005 to 0.012	-	-	-	-	-
Type-N 75 Ohm	0.5	0.005 to 0.015	-	-	-	-	-
Type-N 75 Ohm	0.6	0.006 to 0.018	-	-	-	-	-
Type-N 75 Ohm	0.7	0.006 to 0.022	-	-	-	-	-
Type-N 75 Ohm	0.8	0.007 to 0.026	-	-	-	-	-
Type-N 75 Ohm	0.9	0.008 to 0.030	-	-	-	-	-
Type-N 75 Ohm	1.0	0.009 to 0.035	-	-	-	-	-
Type-N 50 Ohm	0.0	0.004	0.004 to 0.006	-	-	-	-
Type-N 50 Ohm	0.1	0.004	0.004 to 0.007	-	-	-	-
Type-N 50 Ohm	0.2	0.004	0.004 to 0.007	-	-	-	-
Type-N 50 Ohm	0.3	0.004	0.004 to 0.007	-	-	-	-
Type-N 50 Ohm	0.4	0.004	0.004 to 0.008	-	-	-	-
Type-N 50 Ohm	0.5	0.003 to 0.004	0.004 to 0.009	-	-	-	-
Type-N 50 Ohm	0.6	0.003 to 0.004	0.004 to 0.010	-	-	-	-
Type-N 50 Ohm	0.7	0.003	0.003 to 0.012	-	-	-	-
Type-N 50 Ohm	0.8	0.003 to 0.004	0.004 to 0.014	-	-	-	-
Type-N 50 Ohm	0.9	0.002 to 0.004	0.004 to 0.016	-	-	-	-
Type-N 50 Ohm	1.0	0.002 to 0.004	0.004 to 0.018	-	-	-	-
PC-7 mm	0.0	0.003	0.003	-	-	-	-
PC-7 mm	0.1	0.003	0.003	-	-	-	-
PC-7 mm	0.2	0.003	0.003	-	-	-	-
PC-7 mm	0.3	0.003	0.003 to 0.004	-	-	-	-
PC-7 mm	0.4	0.003	0.003 to 0.004	-	-	-	-
PC-7 mm	0.5	0.003	0.003 to 0.004	-	-	-	-
PC-7 mm	0.6	0.002 to 0.003	0.003 to 0.005	-	-	-	-
PC-7 mm	0.7	0.002 to 0.003	0.003 to 0.006	-	-	-	-
PC-7 mm	0.8	0.002 to 0.004	0.004 to 0.007	-	-	-	-
PC-7 mm	0.9	0.002 to 0.004	0.004 to 0.008	-	-	-	-
PC-7 mm	1.0	0.001 to 0.004	0.004 to 0.008	-	-	-	-
PC-3.5 mm	0.0	0.001 to 0.002	0.001 to 0.002	0.002 to 0.005	-	-	-
PC-3.5 mm	0.1	0.001 to 0.002	0.001 to 0.002	0.002 to 0.005	-	-	-
PC-3.5 mm	0.2	0.001 to 0.002	0.001 to 0.002	0.002 to 0.005	-	-	-
PC-3.5 mm	0.3	0.001 to 0.002	0.002	0.002 to 0.005	-	-	-
PC-3.5 mm	0.4	0.001 to 0.002	0.002	0.002 to 0.006	-	-	-
PC-3.5 mm	0.5	0.001 to 0.002	0.002 to 0.003	0.003 to 0.006	-	-	-
PC-3.5 mm	0.6	0.001 to 0.002	0.002 to 0.003	0.003 to 0.007	-	-	-
PC-3.5 mm	0.7	0.002 to 0.003	0.003	0.003 to 0.007	-	-	-
PC-3.5 mm	0.8	0.002 to 0.003	0.003 to 0.004	0.003 to 0.008	-	-	-
PC-3.5 mm	0.9	0.002 to 0.003	0.003 to 0.004	0.004 to 0.009	-	-	-
PC-3.5 mm	1.0	0.001 to 0.003	0.003 to 0.004	0.004 to 0.010	-	-	-
PC-2.92 mm	0.0	0.009	0.009	0.009 to 0.011	0.011 to 0.013	-	-
PC-2.92 mm	0.1	0.009	0.009	0.009 to 0.011	0.011 to 0.014	-	-
PC-2.92 mm	0.2	0.009	0.009 to 0.011	0.011 to 0.013	0.013 to 0.015	-	-
PC-2.92 mm	0.3	0.008 to 0.009	0.009 to 0.012	0.012 to 0.015	0.015 to 0.017	-	-
PC-2.92 mm	0.4	0.008 to 0.010	0.010 to 0.015	0.015 to 0.018	0.018 to 0.020	-	-
PC-2.92 mm	0.5	0.007 to 0.011	0.011 to 0.018	0.018 to 0.022	0.022 to 0.024	-	-
PC-2.92 mm	0.6	0.006 to 0.012	0.012 to 0.021	0.021 to 0.026	0.026 to 0.028	-	-
PC-2.92 mm	0.7	0.006 to 0.013	0.013 to 0.026	0.026 to 0.031	0.031 to 0.033	-	-
PC-2.92 mm	0.8	0.005 to 0.015	0.015 to 0.030	0.030 to 0.036	0.036 to 0.038	-	-
PC-2.92 mm	0.9	0.005 to 0.017	0.017 to 0.036	0.036 to 0.042	0.042 to 0.045	-	-
PC-2.92 mm	1.0	0.005 to 0.020	0.020 to 0.041	0.041 to 0.049	0.049 to 0.052	-	-
PC-2.4 mm	0.0	0.001 to 0.002	0.002 to 0.003	0.002 to 0.003	0.003	0.003 to 0.004	-
PC-2.4 mm	0.1	0.001 to 0.002	0.002 to 0.003	0.002 to 0.003	0.003	0.003 to 0.004	-
PC-2.4 mm	0.2	0.001 to 0.002	0.002 to 0.003	0.002 to 0.003	0.003	0.003 to 0.004	-
PC-2.4 mm	0.3	0.001 to 0.002	0.002 to 0.003	0.002 to 0.003	0.003 to 0.004	0.003 to 0.005	-
PC-2.4 mm	0.4	0.001 to 0.002	0.002 to 0.003	0.002 to 0.004	0.003 to 0.004	0.003 to 0.005	-
PC-2.4 mm	0.5	0.001 to 0.003	0.002 to 0.003	0.003 to 0.004	0.003 to 0.005	0.004 to 0.006	-
PC-2.4 mm	0.6	0.002 to 0.003	0.003	0.003 to 0.004	0.003 to 0.006	0.004 to 0.006	-
PC-2.4 mm	0.7	0.002 to 0.003	0.003 to 0.004	0.003 to 0.005	0.004 to 0.006	0.004 to 0.007	-
PC-2.4 mm	0.8	0.002 to 0.003	0.003 to 0.004	0.003 to 0.005	0.004 to 0.007	0.005 to 0.007	-
PC-2.4 mm	0.9	0.002 to 0.003	0.003 to 0.004	0.004 to 0.006	0.004 to 0.008	0.005 to 0.008	-
PC-2.4 mm	1.0	0.002 to 0.004	0.004 to 0.005	0.004 to 0.006	0.005 to 0.009	0.006 to 0.009	-
PC-1.85 mm	0.0	0.002 to 0.005	0.002	0.002 to 0.004	0.004	0.004 to 0.005	0.005 to 0.007
PC-1.85 mm	0.1	0.001 to 0.004	0.002	0.002 to 0.004	0.003 to 0.004	0.004 to 0.005	0.005 to 0.007
PC-1.85 mm	0.2	0.001 to 0.004	0.002	0.002 to 0.004	0.004	0.004 to 0.005	0.005 to 0.008
PC-1.85 mm	0.3	0.001 to 0.004	0.002	0.002 to 0.004	0.004 to 0.005	0.004 to 0.006	0.005 to 0.008
PC-1.85 mm	0.4	0.001 to 0.004	0.002 to 0.003	0.002 to 0.004	0.004 to 0.005	0.004 to 0.006	0.005 to 0.008
PC-1.85 mm	0.5	0.001 to 0.004	0.002 to 0.003	0.003 to 0.004	0.004 to 0.005	0.004 to 0.006	0.005 to 0.008
PC-1.85 mm	0.6	0.002 to 0.004	0.003	0.003 to 0.005	0.004 to 0.005	0.004 to 0.007	0.006 to 0.009
PC-1.85 mm	0.7	0.002 to 0.004	0.003	0.003 to 0.005	0.004 to 0.005	0.005 to 0.007	0.006 to 0.009
PC-1.85 mm	0.8	0.002 to 0.004	0.003 to 0.004	0.004 to 0.006	0.005 to 0.006	0.005 to 0.008	0.007 to 0.010
PC-1.85 mm	0.9	0.002 to 0.004	0.004	0.004 to 0.006	0.005 to 0.006	0.005 to 0.009	0.007 to 0.011
PC-1.85 mm	1.0	0.002 to 0.004	0.004 to 0.005	0.004 to 0.007	0.006 to 0.007	0.006 to 0.010	0.008 to 0.012

S-parameter uncertainty matrix representation within EURAMET:
3 independent variables:

- Connector family
- Value of $|S_{11}|$
- Frequency

Example of CMC entry (part of)

$|S_{11}|$: magnitude of reflection coefficient

Magnitude of S_{11} Frequency ---------→

	abs(Sxx)	9 kHz to 3 GHz	3 GHz to 18 GHz
BNC 50 Ohm	0.0	0.005 to 0.007	-
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BNC 50 Ohm	0.3	0.005 to 0.011	-
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Type-N 75 Ohm	0.8	0.007 to 0.026	-
Type-N 75 Ohm	0.9	0.008 to 0.030	-
Type-N 75 Ohm	1.0	0.009 to 0.035	-
Type-N 50 Ohm	0.0	0.004	0.004 to 0.006
Type-N 50 Ohm	0.1	0.004	0.004 to 0.007
Type-N 50 Ohm	0.2	0.004	0.004 to 0.007

Connector family 1

Connector family 2

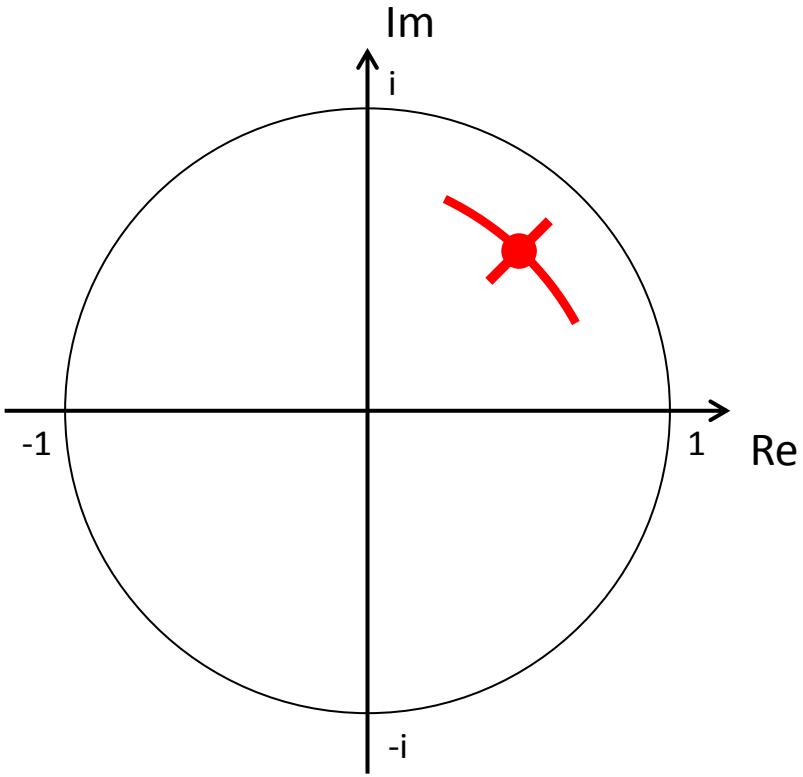
S-parameter uncertainties

depend on the value of the measurand in the complex plane!

Due to

- Uncertainty in characterisation of standards
- Proximity to standards used for VNA calibration
- Other influences (cables, VNA etc)

S-parameter uncertainties



Rigorous propagation of uncertainties through VNA measurement model

→ Re/Im uncertainties vary strongly. Quoting smallest uncertainty is not very informative.
Another dimension in the CMC uncertainty matrix would be needed.

→ Dependence on phase relatively weak. Mag/Phase uncertainties in the current CMC matrix structure more informative.

Conclusion

- The structure of the current CMC uncertainty matrix for S-parameters can’t be extended by another dimension. This would just create confusion.
- Mag/phase representation is more informative than Re/Im for S-parameter CMC entries.