



EURAMET Project 1796:

Pilot Study ILC: METAS and NIST - Coaxial Noise Source up to 50 GHz

Final Report, 17.09.2026



Travelling Standards: Two Keysight 346CK01 Noise Sources

Participants:

- National Institute of Standards and Technology NIST, USA
- Federal Institute of Metrology METAS, Switzerland

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1 Objective and general information

The subject of this project was an interlaboratory comparison (ILC) of the noise temperature of 2.4 mm coaxial noise sources up to 50 GHz. To the best of our knowledge, no previous comparison for this quantity has been conducted in coaxial transmission lines up to 50 GHz.

METAS intends to extend its Calibration and Measurement Capabilities (CMCs) for noise temperature measurements of coaxial noise sources from the current upper frequency limit of 33 GHz to 50 GHz. Acceptance of the extended CMCs requires supporting evidence from an international measurement comparison.

NIST is, to the best of our knowledge, the only other National Metrology Institute (NMI) with measurement capabilities for 2.4 mm coaxial noise sources up to 50 GHz. NIST agreed to participate in this comparison with METAS.

METAS acted as the pilot laboratory for the comparison.

The ILC was conducted for noise temperature measurements in coaxial line over the frequency range from 1 GHz to 50 GHz. The travelling standards consisted of two 2.4 mm noise sources with male connectors. Due to the long measurement time, one noise source was measured by NIST over the frequency range from 1 GHz to 12 GHz only, whereas the second noise source was measured over the full frequency range from 1 GHz to 50 GHz.

METAS provided the travelling standards and was responsible for the evaluation and reporting of the comparison results.

The travelling standards were measured by METAS twice: once before shipment to NIST and again after their return. These measurements enabled an assessment of the stability of the travelling standards throughout the comparison.

The results of the comparison were also presented jointly by NIST and METAS at CPEM 2026.

2 Travelling Standards

The travelling standards were two noise sources with 2.4 mm male connectors. They were provided by METAS.

1. Noise Source, Keysight, 346CK01, SN: MY62300342
2. Noise Source, Keysight, 346CK01, SN: MY62300343

2.1 Keysight 346CK01 Specifications

Frequency Range: 1 GHz to 50 GHz

Connectors: BNC (f) input bias / 2.4 mm (m)

Typical ENR: 20 dB at 1 GHz, decreasing to 7 dB at 50 GHz

3 Summary of the ILC Results

The ILC was successful, with normalized errors below 1 throughout the comparison.

The traveling standard 1 (SN: MY62300342) was stable during the comparison.

The travelling standard 2 (SN: MY62300343) showed a change during the comparison. Above 40 GHz, the noise temperature changed significantly. However, both METAS measurements agreed with the NIST results within the stated uncertainties (normalized errors below 1).

4 Participants

4.1 NIST

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5 Scope of the Comparison

For the sake of clarity, the parameter list has been limited to the most relevant quantities compared to Annex 1. The effective noise temperature can be converted into available noise temperature, available excess noise ratio, and effective excess noise ratio. As these quantities are directly derived from the effective noise temperature, reporting them would not provide any additional information for this comparison.

The Off Reflection Coefficient has been omitted, as it is not relevant to the effective noise temperature.

Furthermore, NIST and METAS provided reports rather than calibration certificates to document the results, since calibration certificates were not required for this comparison.

5.1 Noise Source, Keysight, 346CK01, SN: MY62300342

Parameter	Frequency
Effective Noise Temperature T_{ne} , On Reflection Coefficient Magnitude $ \Gamma_{on} $	1 GHz to 12 GHz in 1 GHz steps

5.2 Noise Source, Keysight, 346CK01, SN: MY62300343

Parameter	Frequency
Effective Noise Temperature T_{ne} , On Reflection Coefficient Magnitude $ \Gamma_{on} $	1 GHz to 50 GHz in 1 GHz steps

A GUM-compliant measurement uncertainty budget is provided for three frequency points: 1 GHz, 33 GHz and 50 GHz.

6 Measurement Conditions

Ambient temperature: 23 °C
The noise source is operated continuously, unmodulated at 28.00 VDC.
The noise source is warmed up for at least 30 min.

7 Time Schedule

Task	Date	Document
Measurement at METAS	2025-08-19	Report 346CK01_MY62300342_2025-08-19.pdf Report 346CK01_MY62300343_2025-08-19.pdf
Measurement at NIST	2026-03-12	METAS_D16BZ342_March2026.pdf METAS_D16BZ343_March2026.pdf
Measurement at METAS	2026-05-29	Report 346CK01_MY62300342_2026-05-29.pdf Report 346CK01_MY62300343_2026-05-29.pdf
Final Report by METAS	2026-09-17	This document

8 Metrological Traceability

8.1 NIST

The reported measurements are traceable to NIST primary thermal noise standards, which produce thermal noise radiation linked to thermodynamic temperature via Planck's radiation law.

8.2 METAS

The reported measurement values are traceable to national standards at METAS and thus to internationally supported realisations of the SI units.

9 Measurement Uncertainty

9.1 NIST

The measurement uncertainty includes components arising from the standards and instruments used in the measurement process; however, it excludes the device's long-term temporal variation. Certain uncertainty components—such as those related to scattering parameters—were estimated using worst-case scenarios, as more rigorous analyses based on Monte Carlo simulations were unavailable at the time of this work.

9.2 METAS

The reported uncertainty of measurement is stated as the combined standard uncertainty multiplied by a coverage factor $k = 2$. The measured value (y) and the associated expanded uncertainty (U) represent the interval ($y \pm U$) which contains the value of the measured quantity with a probability of approximately 95 %. The uncertainty was estimated following the guidelines of the JCGM 100:2008 (GUM).

The measurement uncertainty contains contributions originating from the measurement standard, from the calibration method, from the environmental conditions and from the object being calibrated. The longterm characteristic of the object being calibrated is not included.

10 Measurement Procedure

10.1 NIST

The noise-temperature measurements were conducted using NIST total-power radiometers. For this inter-laboratory comparison, five radiometers were utilized: one coaxial and four waveguide. Because these radiometers feature different connector types, adapters were employed to interface the 2.4 mm object connector with the radiometers; the effects of these adapters were accounted for during data post-processing.

Throughout the measurement process, the radiometers were repeatedly calibrated, and the object's noise temperature was measured during each cycle. Averaging these repeated measurements effectively mitigated the drift of the measurement systems.

Alongside the radiometric noise-power measurements, the reflection coefficients of the test objects and radiometer ports were measured separately. Mismatch errors resulting from non-ideal reflection coefficients were corrected for in the noise-power delivery analysis.

10.2 METAS

The noise temperature was measured using a noise receiver. The noise parameters of the noise receiver were calibrated using traceable power and ambient temperature standards. The equivalent noise bandwidth of the noise receiver was calibrated using a traceable power standard.

The reflection coefficient was measured using a vector network analyzer (VNA). The VNA was error corrected with a one port calibration technique.

11 Normalized Error Calculation

The normalized error is computed according the following formula:

$$E_n = \frac{|X_{lab} - X_{ref}|}{\sqrt{U_{lab}^2 + U_{ref}^2}}$$

X_{lab} : Measured value of the industrial laboratory

X_{ref} : Measured value of the NMI

U_{lab} , U_{ref} : Uncertainties of each value ($k=2$)

Interpretation:

If E_n is less than 1, the result is considered acceptable

If E_n is greater than 1, the result is considered as not acceptable

12 Results

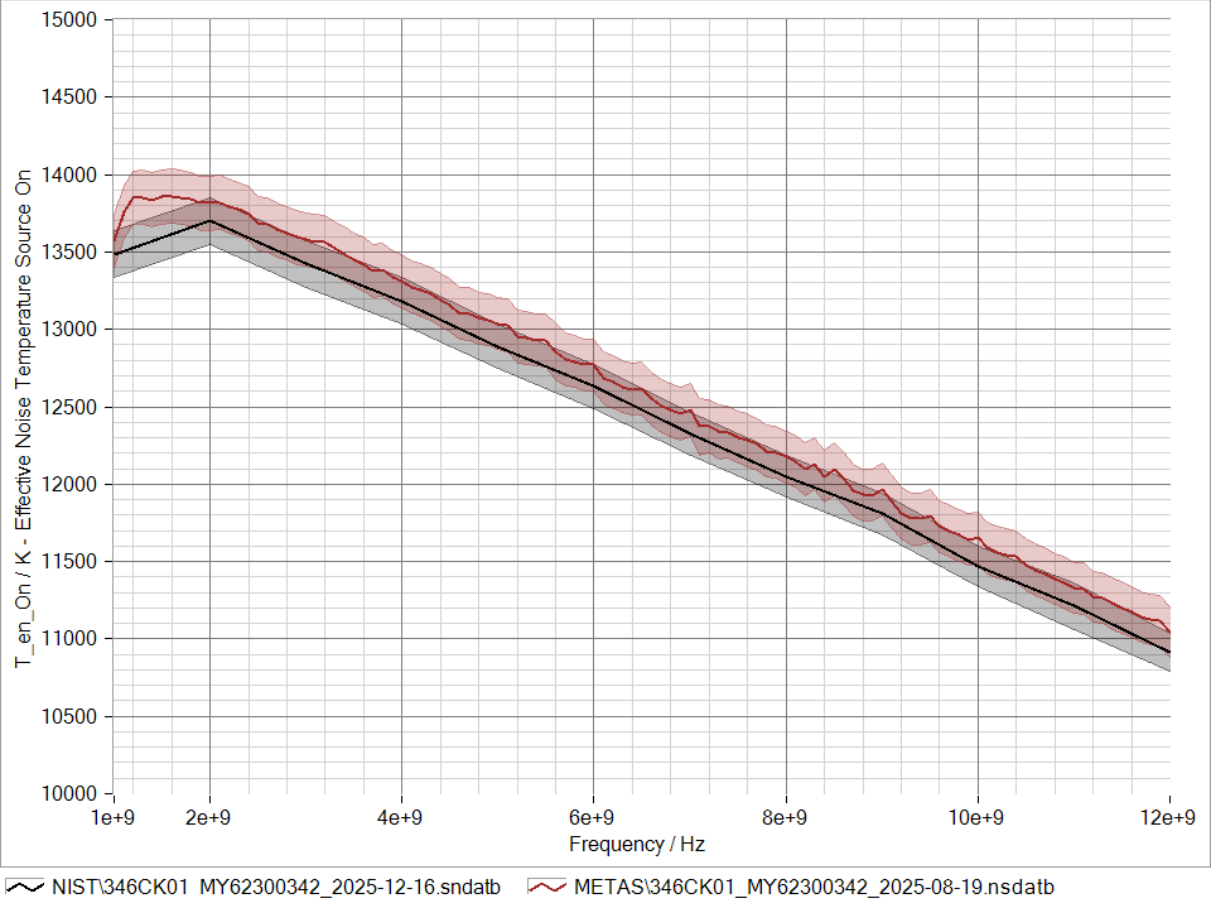
The measurement data submitted by the participants can be found in the documents listed in 7. The following measurement data graphs show the measurement data with uncertainty regions with a coverage factor of 2.

The curves on the following pages are assigned as follows:

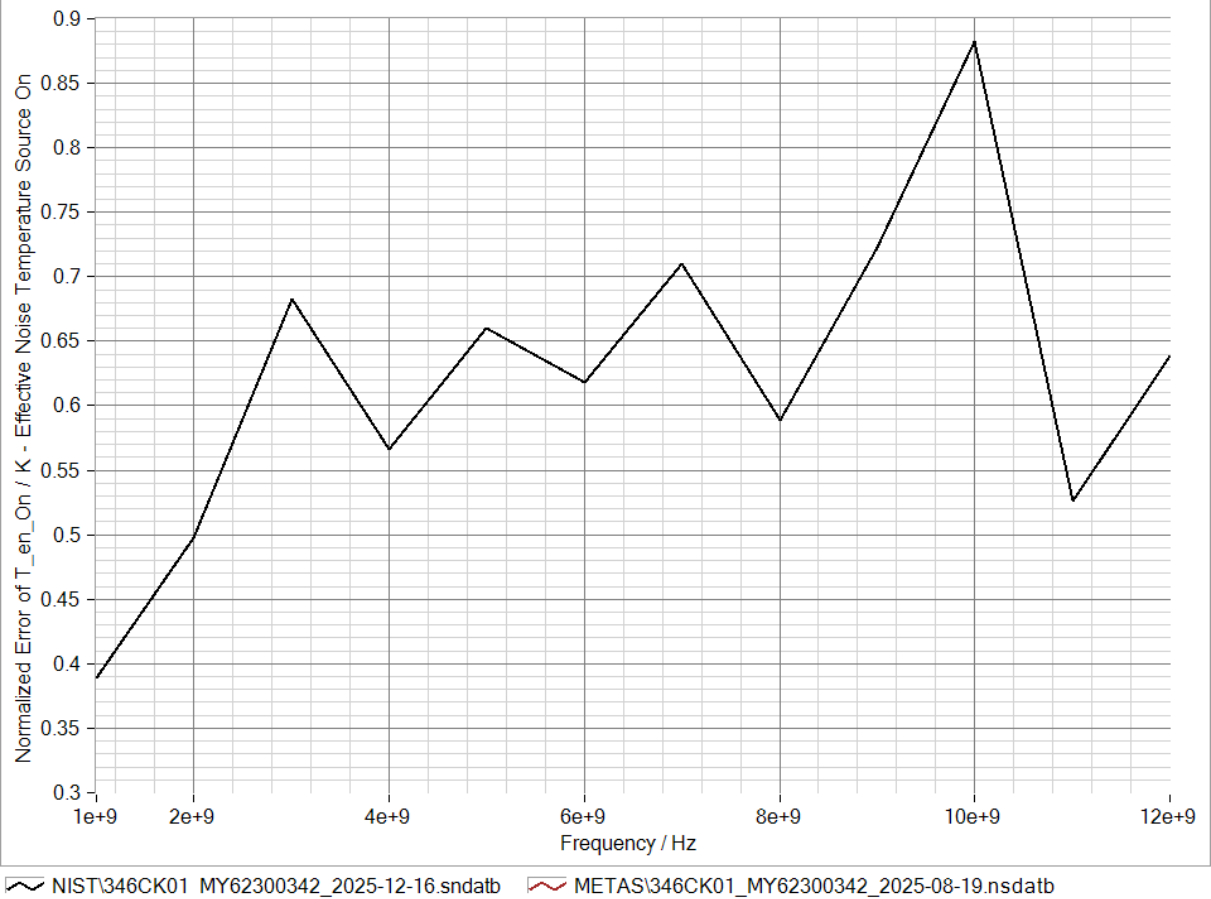
Black Curve: NIST (in 1 GHz steps)

Brown Curve: METAS (in 100 MHz steps)

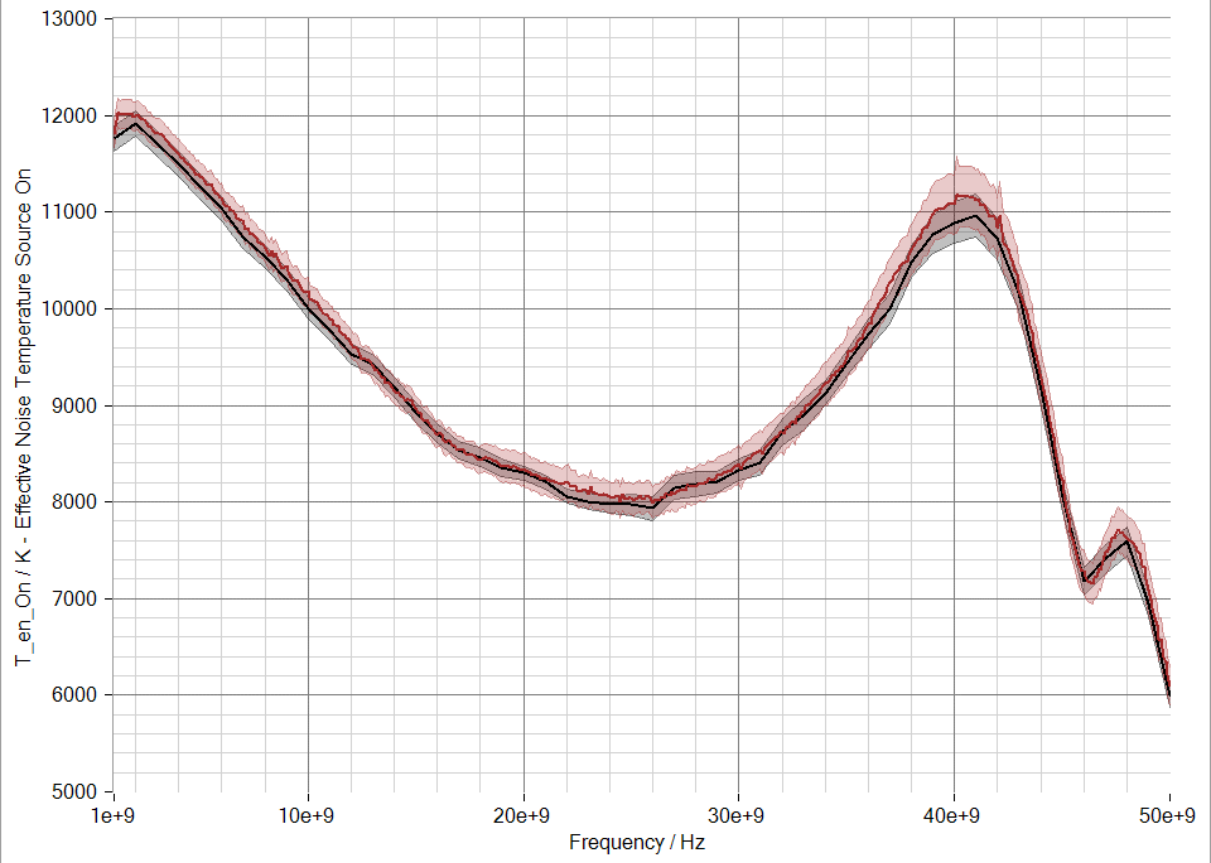
12.1 Effective Noise Temperature T_{ne}
12.1.1 Measurement Data, SN: MY62300342



12.1.2 Normalized Error, SN: MY62300342

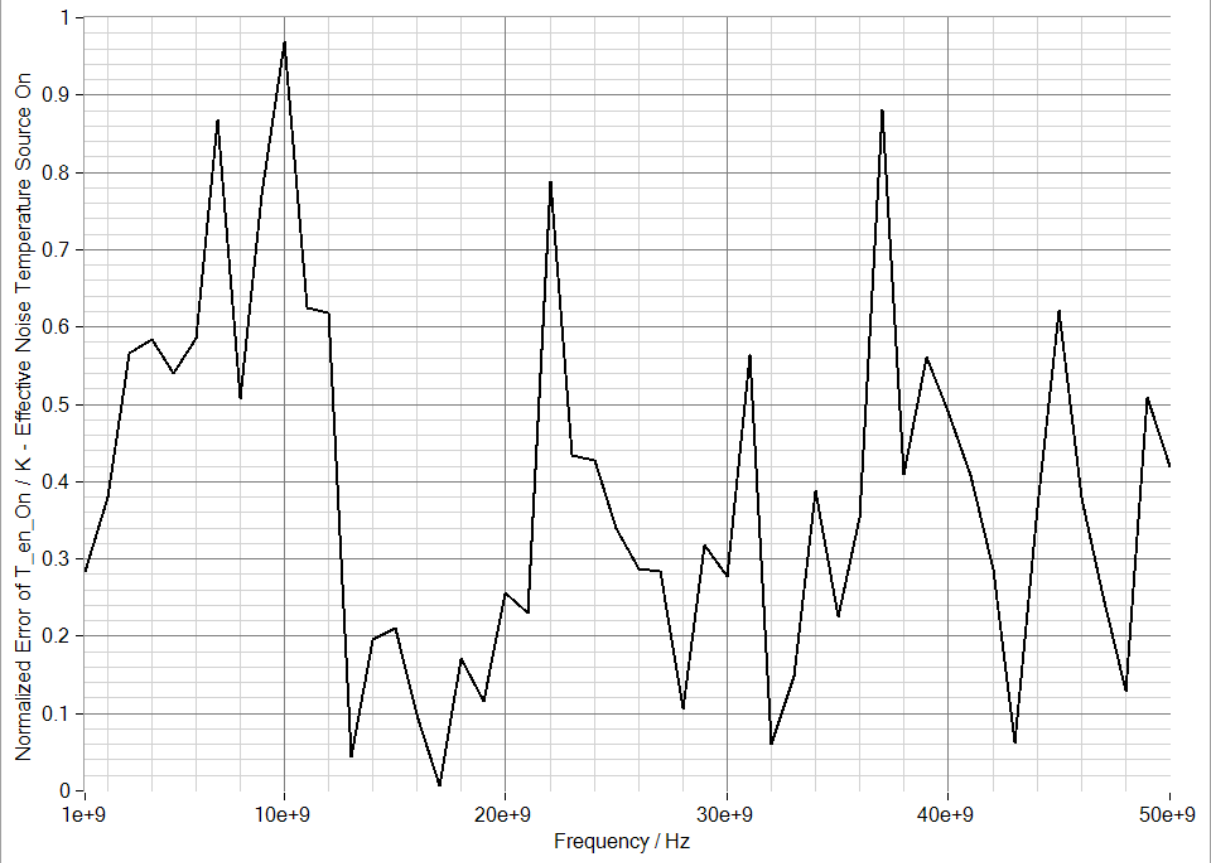


12.1.3 Measurement Data, SN: MY62300343



NIST\346CK01_MY62300343_2026-03-10.sndatb METAS\346CK01_MY62300343_2025-08-19.nsdatab

12.1.4 Normalized Error, SN: MY62300343, NIST – 1st METAS measurement



NIST\346CK01_MY62300343_2026-03-10.sndatb METAS\346CK01_MY62300343_2025-08-19.nsdatab

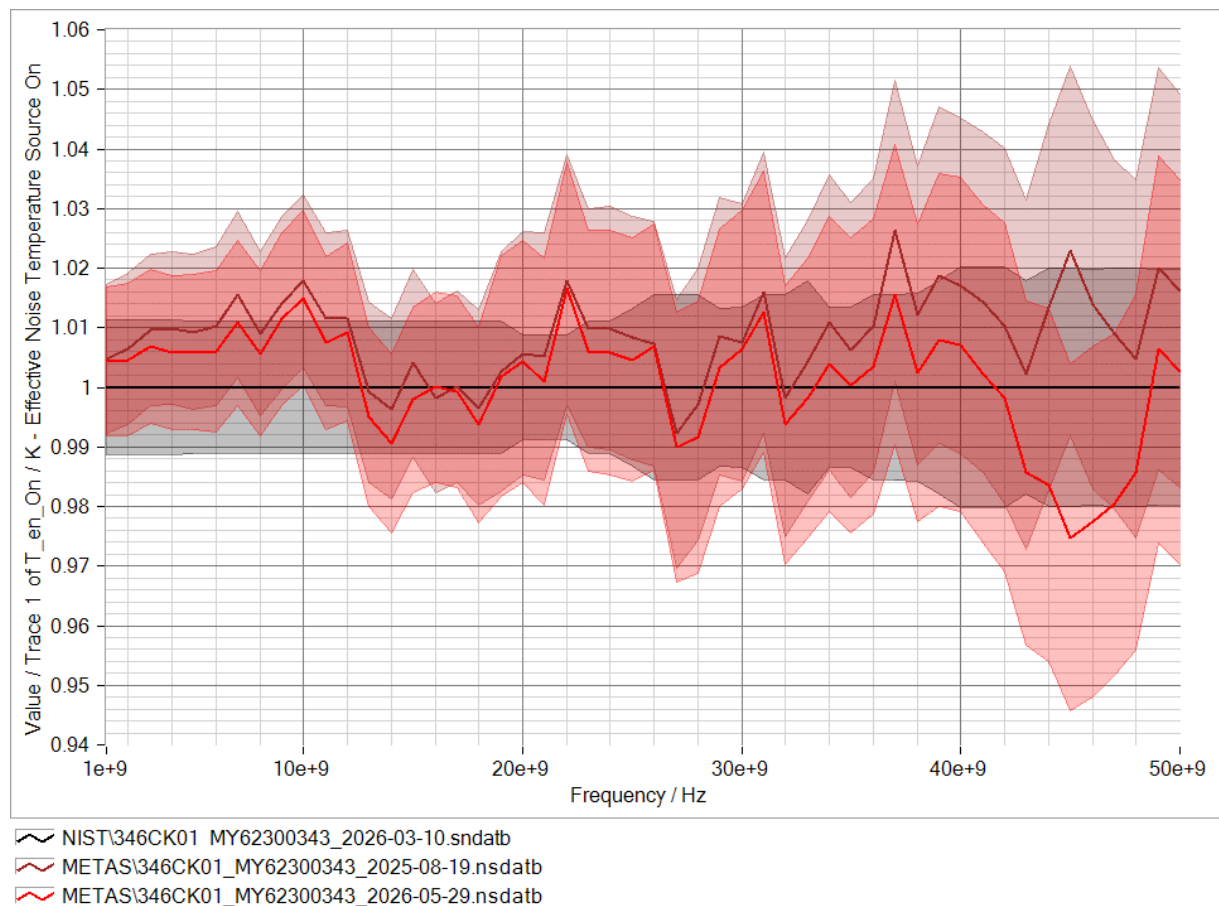
12.1.5 Measurement Data normalized to NIST for 1st and 2nd METAS measurement

The travelling standard 2 (SN: MY62300343) showed a change during the comparison. Above 40 GHz, the noise temperature changed significantly. However, both METAS measurements agreed with the NIST results within the stated uncertainties (normalized errors below 1).

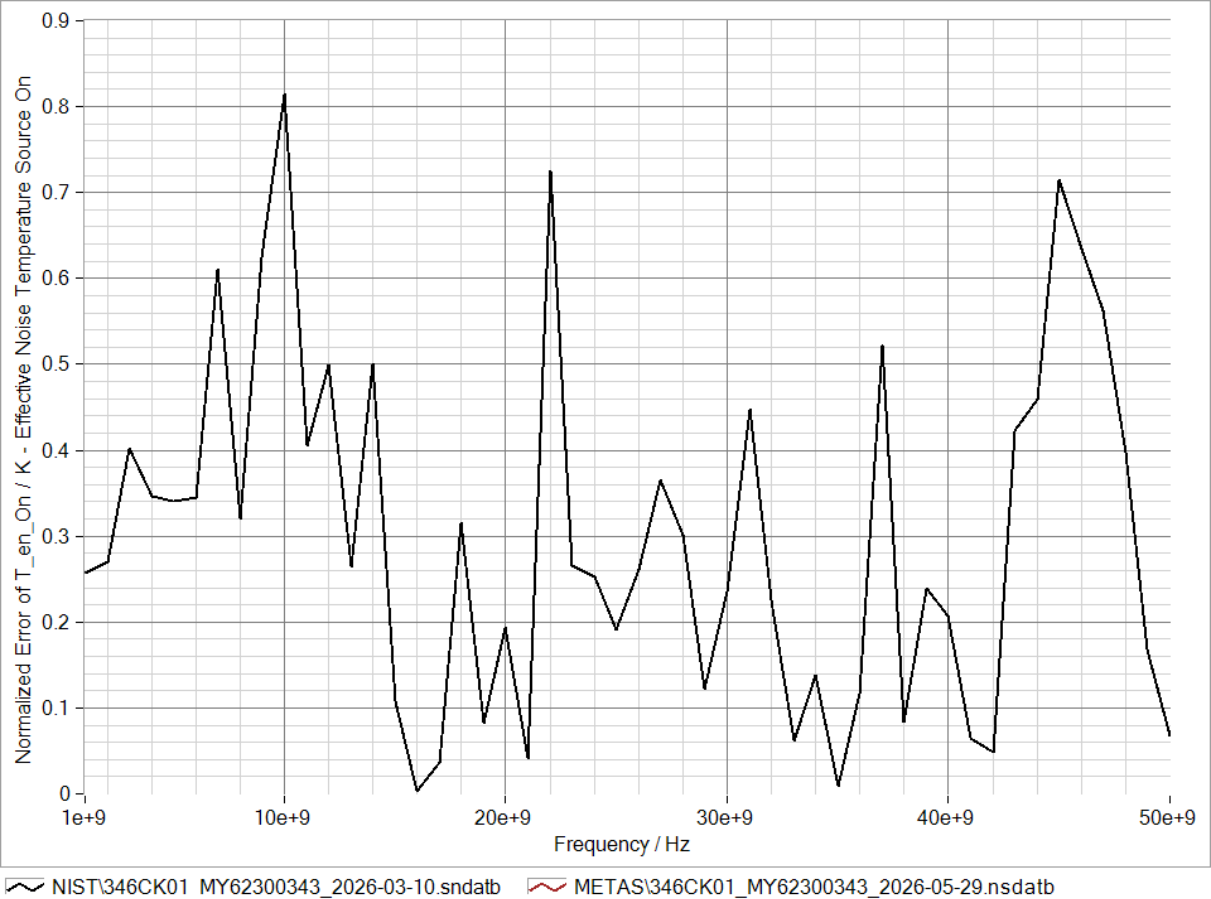
Black Curve: NIST

Brown Curve: METAS before NIST

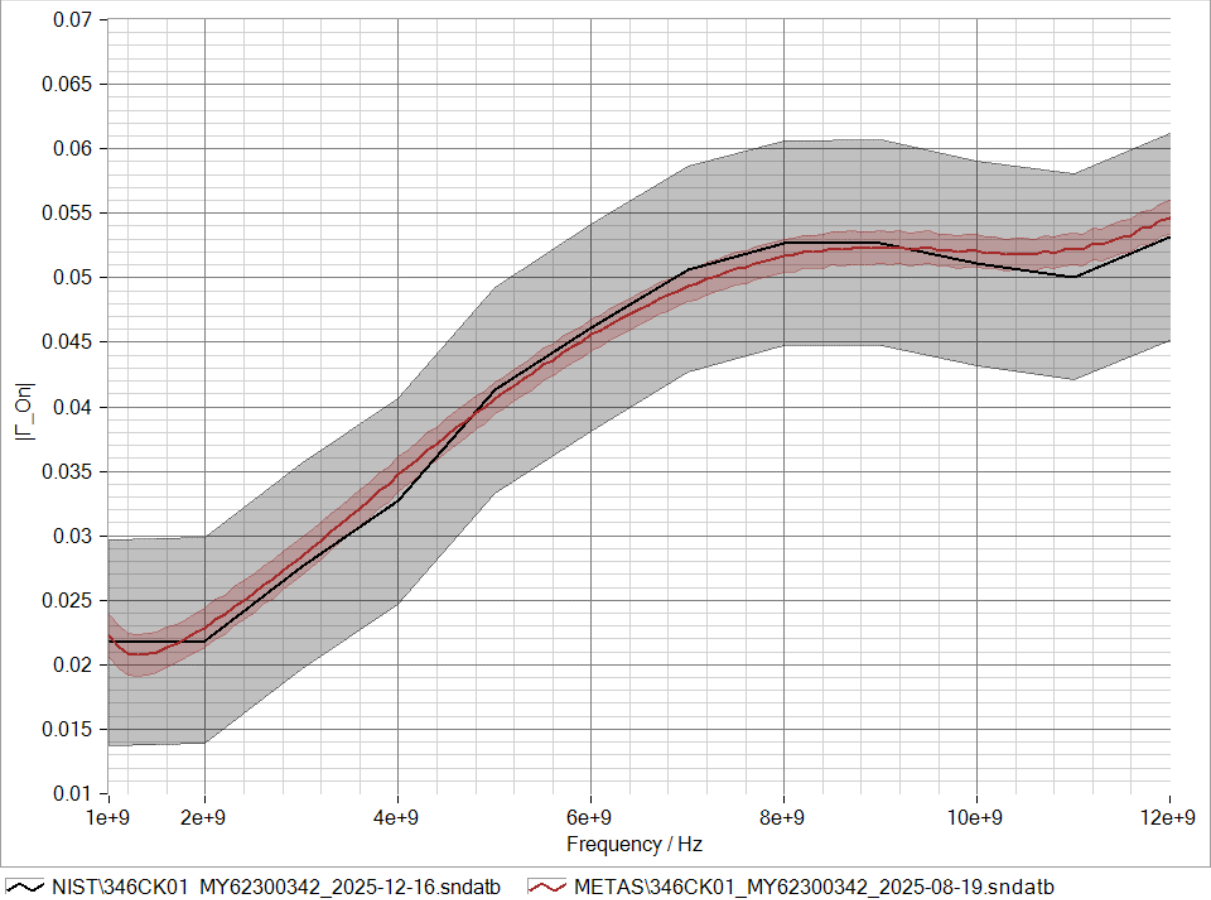
Red Curve: METAS after NIST



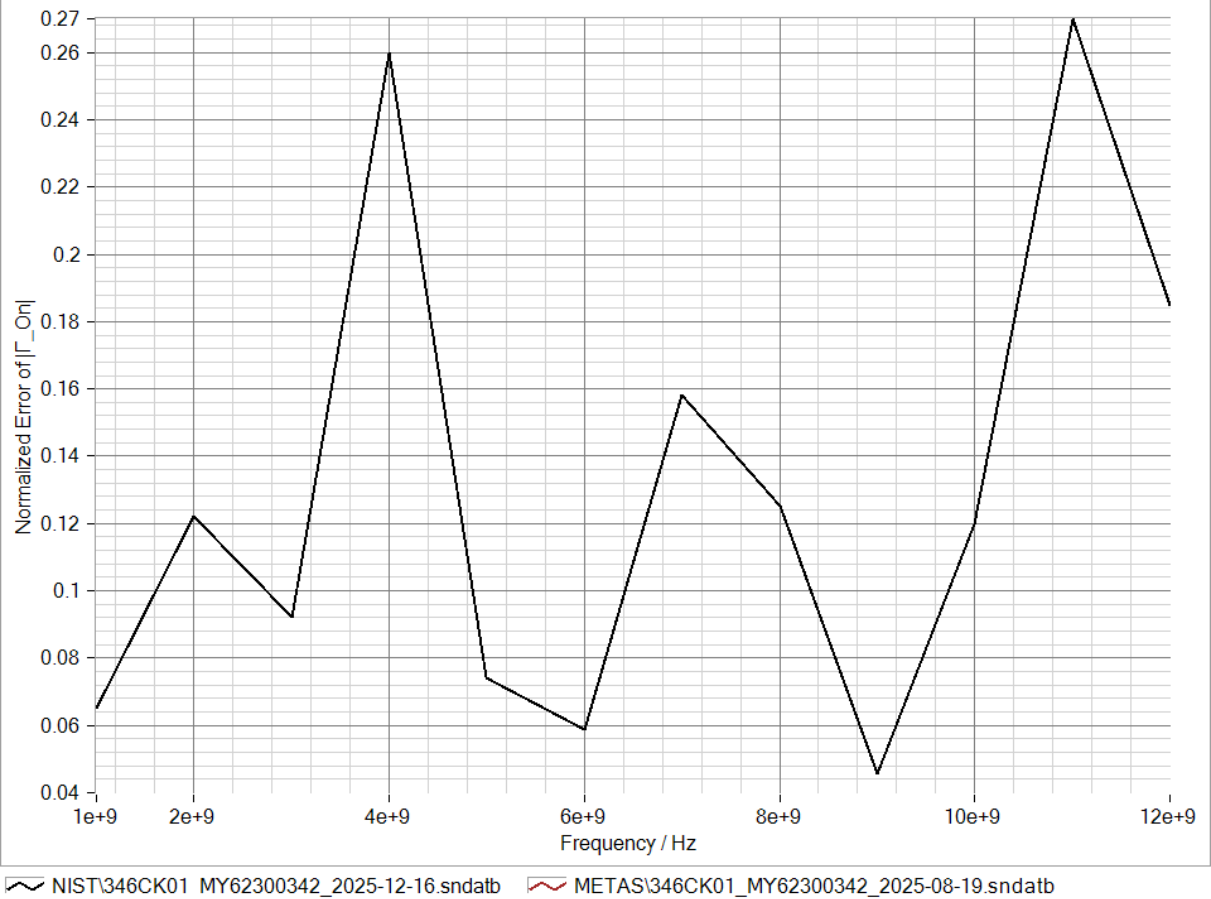
12.1.6 Normalized Error, SN: MY62300343, NIST – 2nd METAS measurement



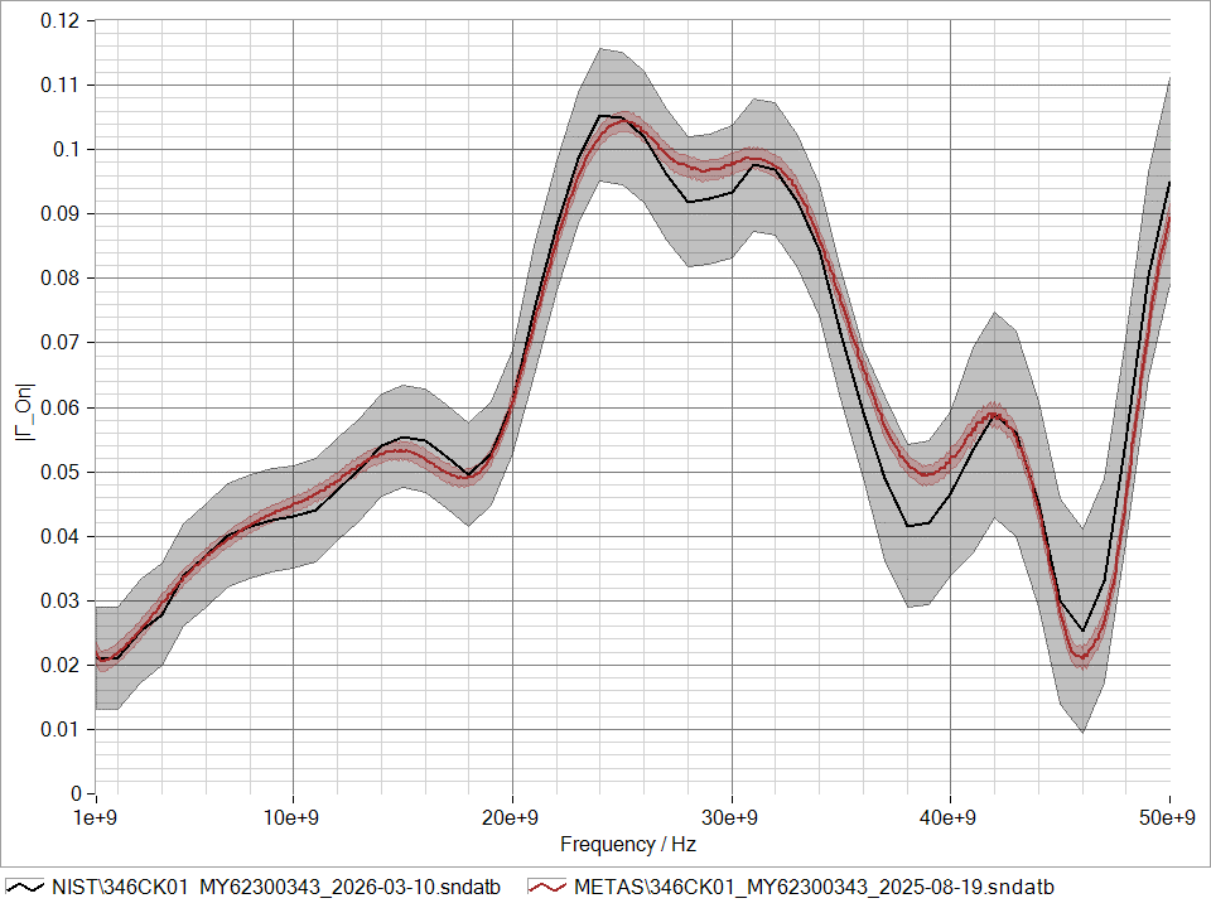
12.2 Reflection Coefficient $|\Gamma|$
12.2.1 Measurement Data, SN: MY62300342



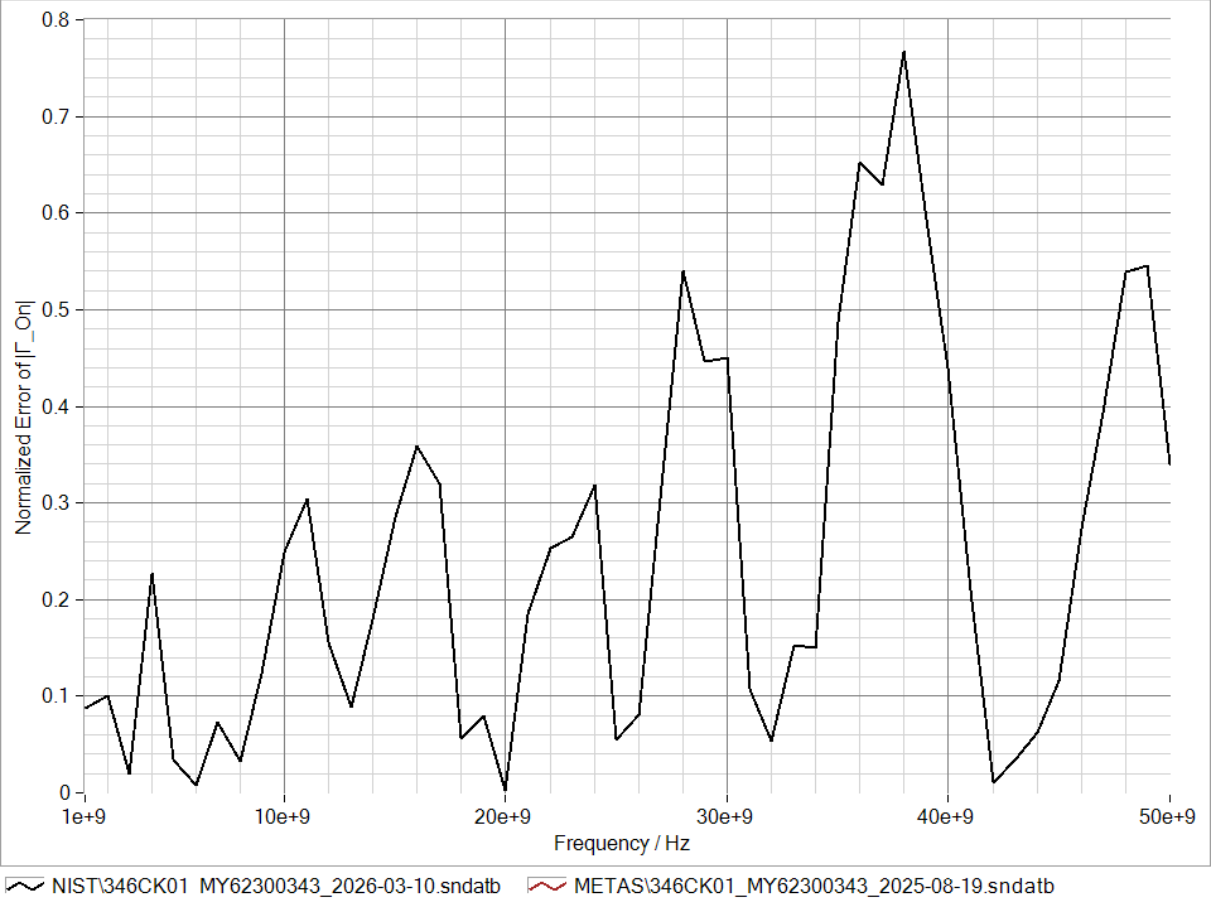
12.2.2 Normalized Error, SN: MY62300342



12.2.3 Measurement Data, SN: MY62300343



12.2.4 Normalized Error, SN: MY62300343



13 Stability Check during the Comparison

METAS measured the travelling standards twice: once before sending them to NIST, and again after receiving them back. This allowed the evaluation of the stability during the comparison.

The traveling standard 1 (SN: MY62300342) was stable during the comparison.

The travelling standard 2 (SN: MY62300343) showed a change during the comparison. Above 40 GHz, the noise temperature changed significantly. However, both METAS measurements agreed with the NIST results within the stated uncertainties (normalized errors below 1).

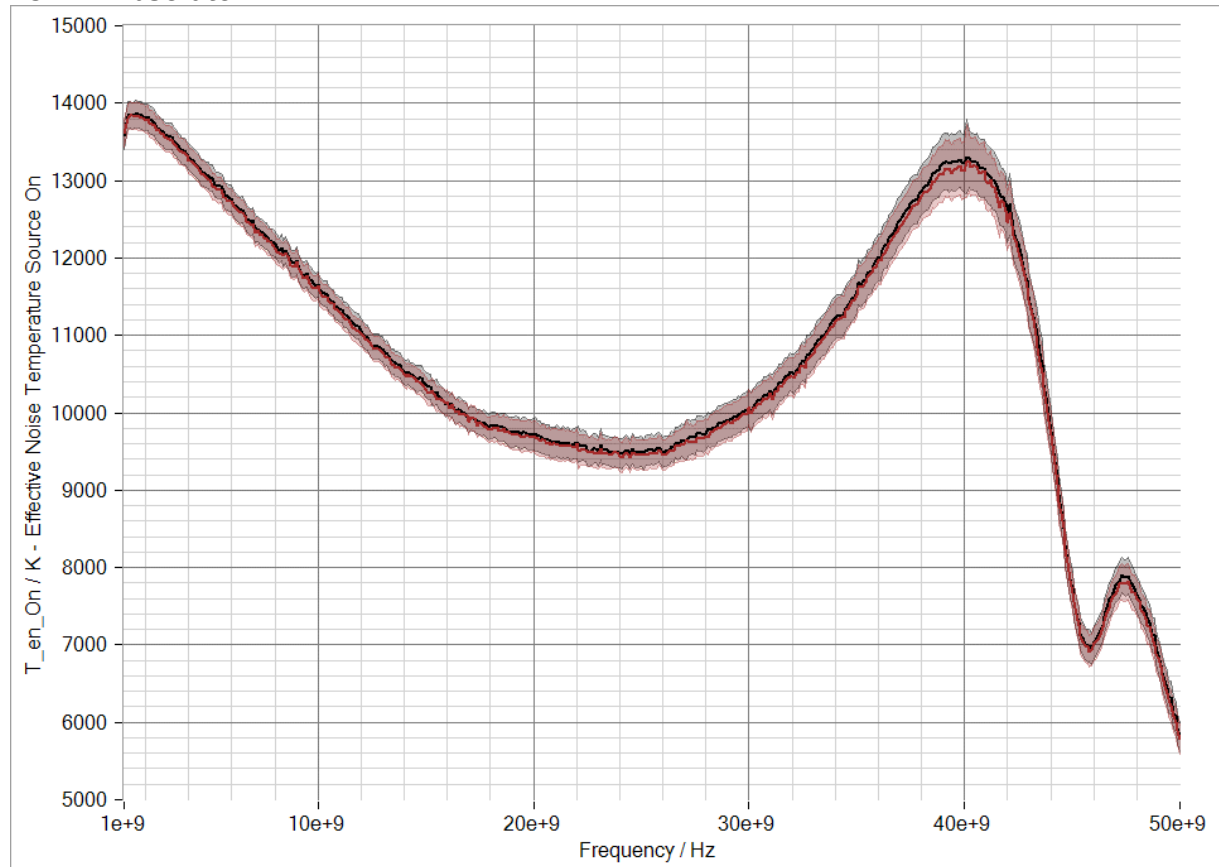
The curves on the following pages are assigned as follows:

Black Curve: METAS 2025-08-19

Brown Curve: METAS 2026-05-29

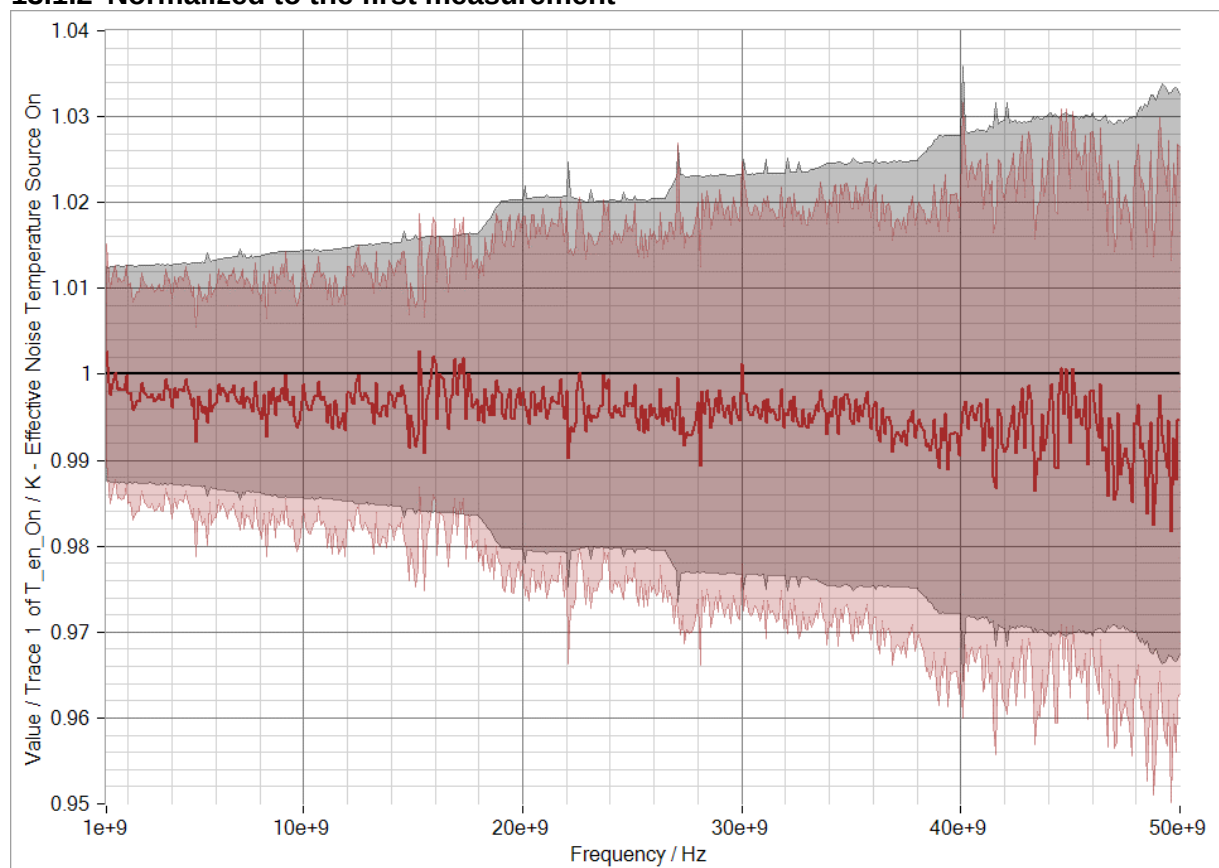
13.1 Effective Noise Temperature T_{ne} , SN: MY62300342

13.1.1 Absolute



METAS\346CK01_MY62300342_2025-08-19.nsdab METAS\346CK01_MY62300342_2026-05-29.nsdab

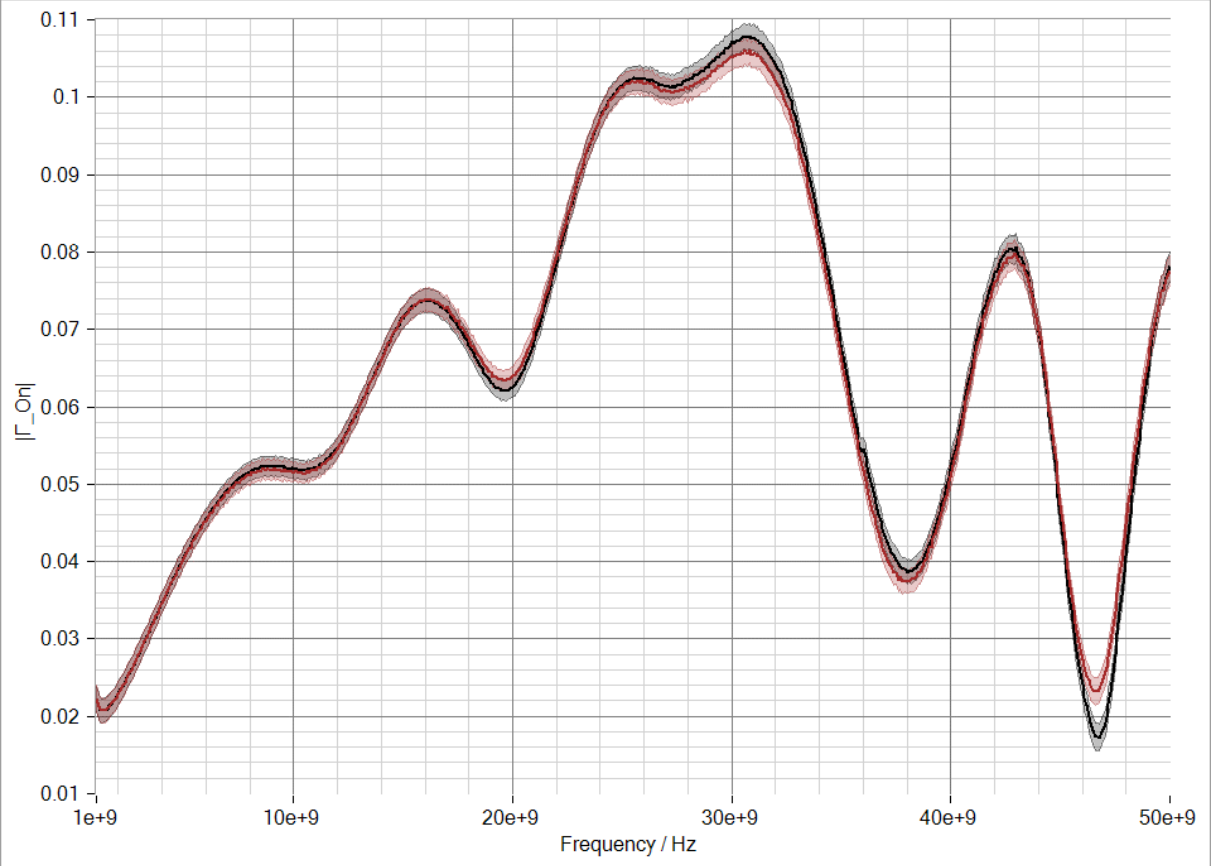
13.1.2 Normalized to the first measurement



METAS\346CK01_MY62300342_2025-08-19.nsdab METAS\346CK01_MY62300342_2026-05-29.nsdab

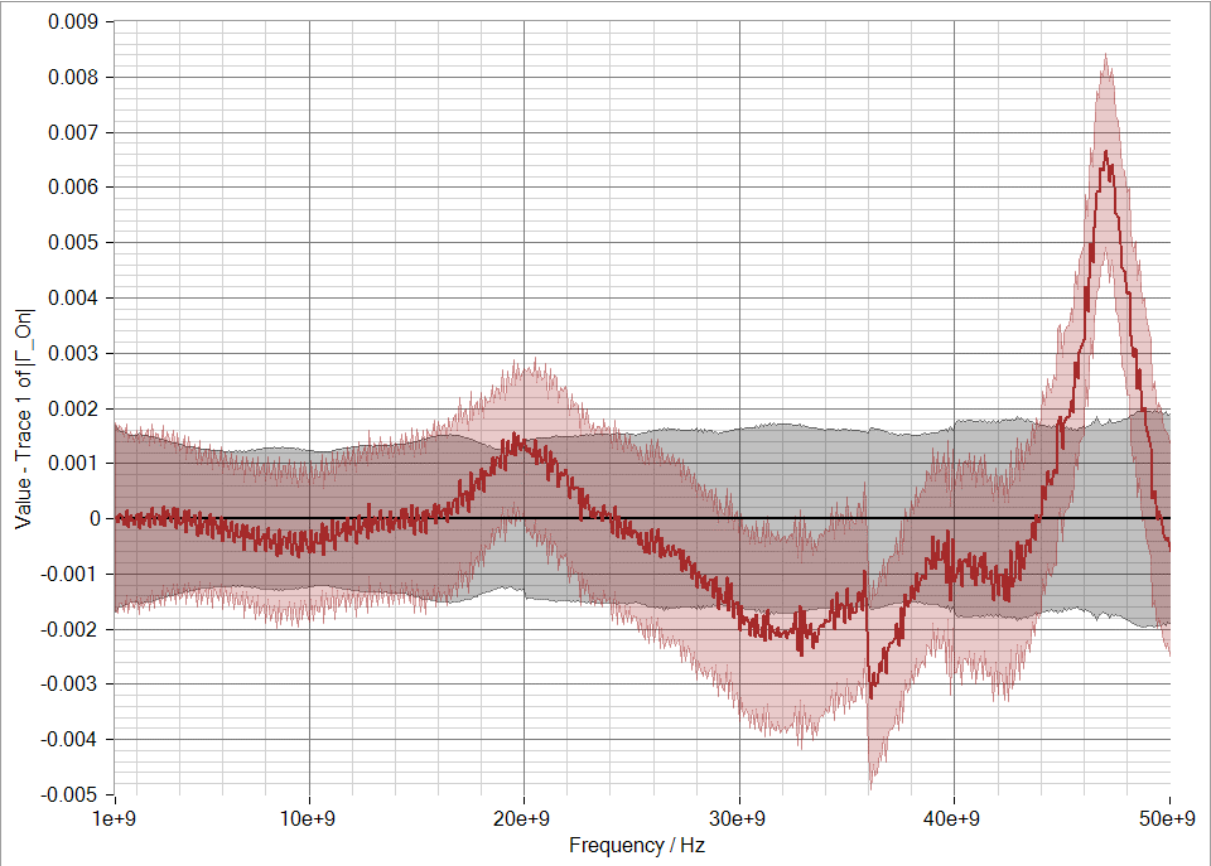
13.2 Reflection Coefficient $|\Gamma|$, SN: MY62300342

13.2.1 Absolute



METAS\346CK01_MY62300342_2025-08-19.nsdab METAS\346CK01_MY62300342_2026-05-29.nsdab

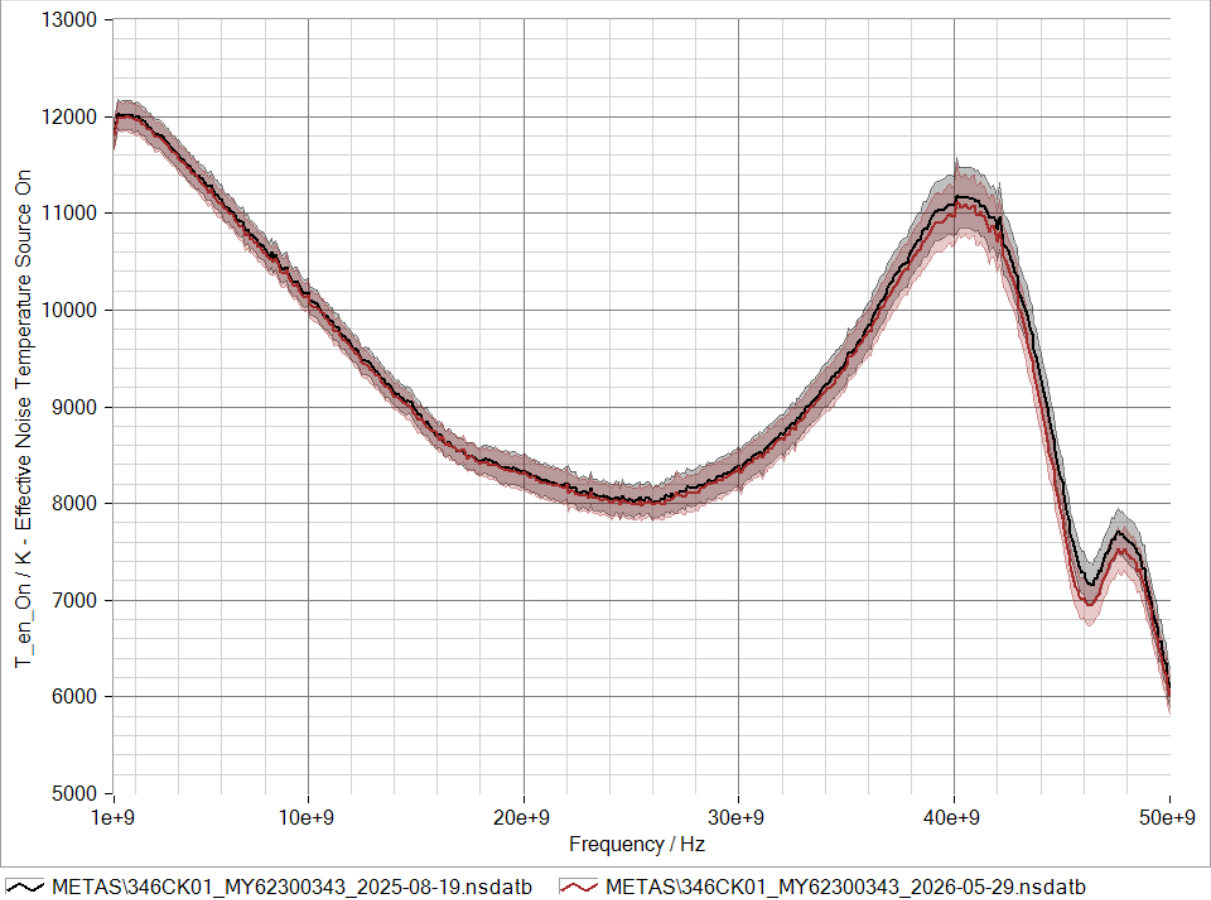
13.2.2 Normalized to the first measurement



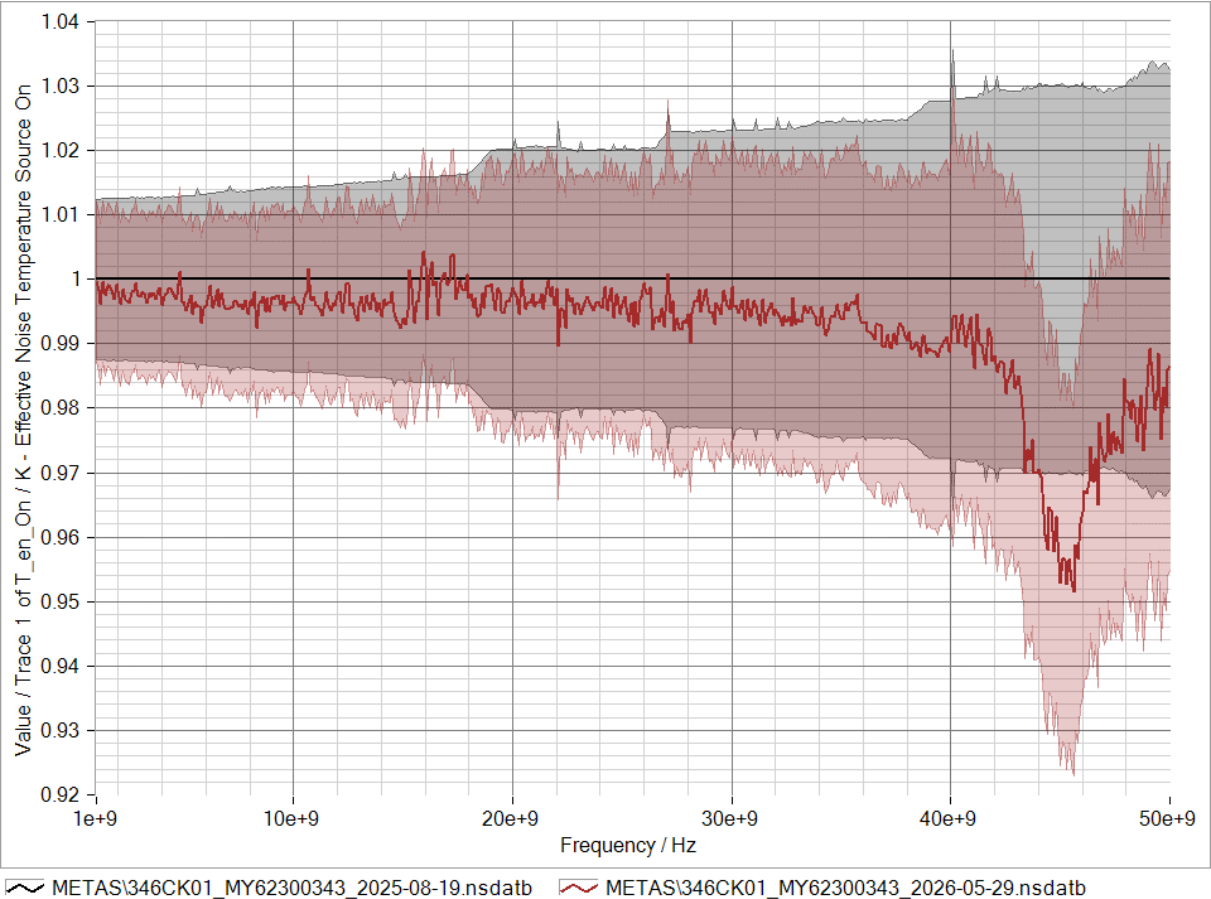
METAS\346CK01_MY62300342_2025-08-19.nsdab METAS\346CK01_MY62300342_2026-05-29.nsdab

13.3 Effective Noise Temperature T_{ne} , SN: MY62300343

13.3.1 Absolute

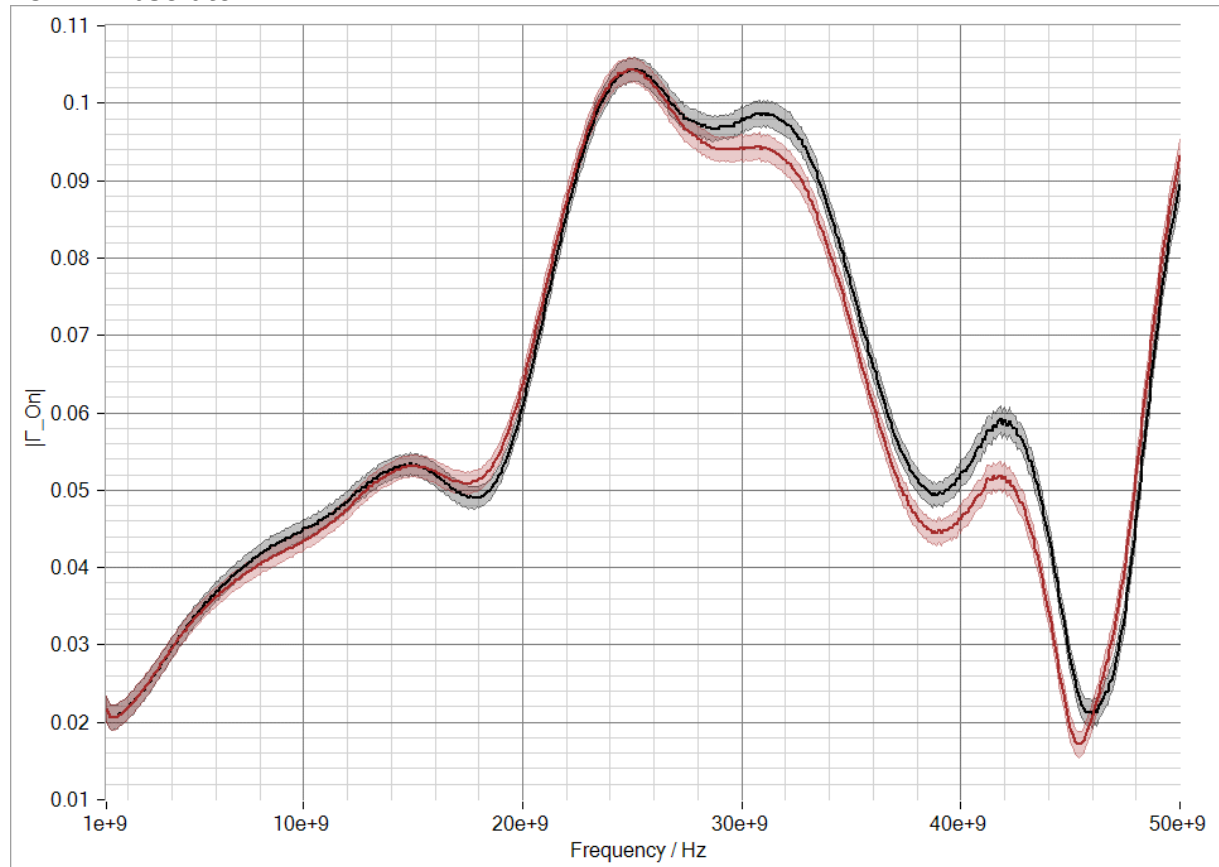


13.3.2 Normalized to the first measurement



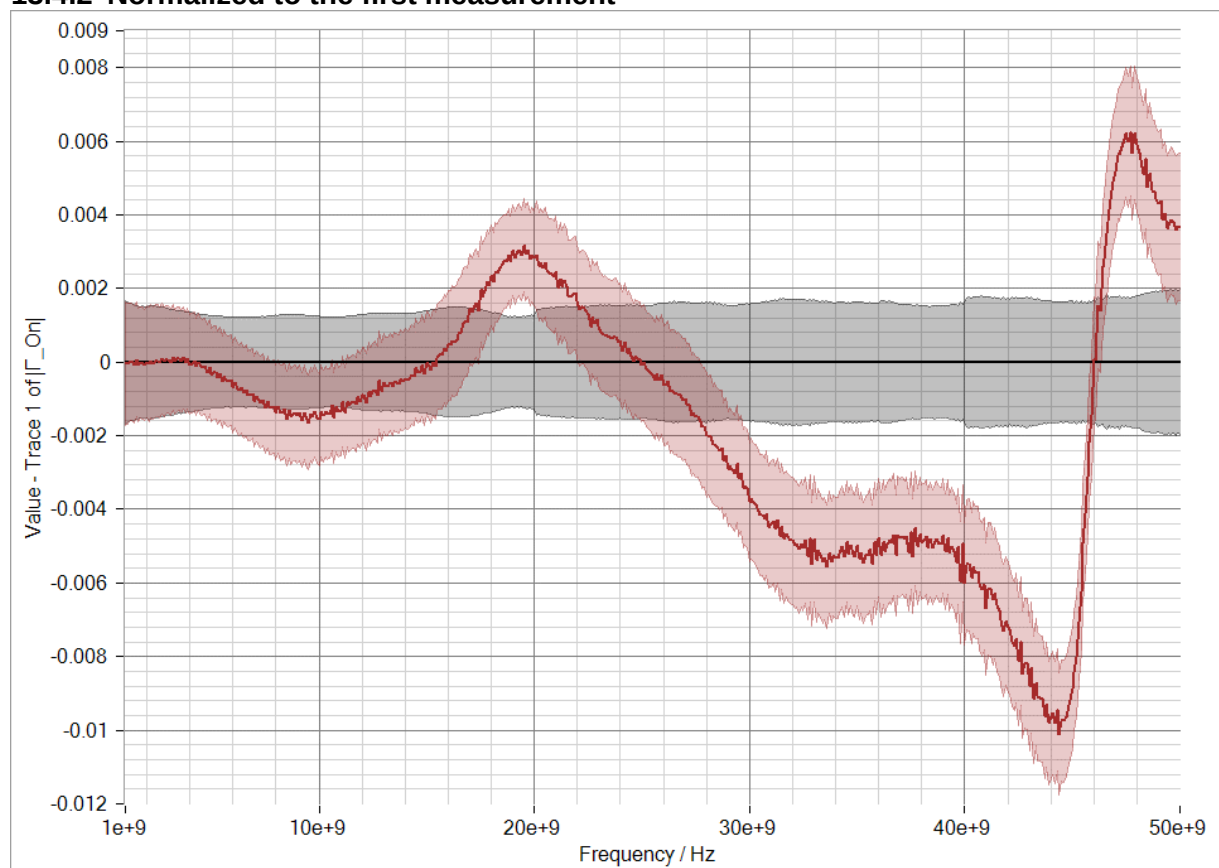
13.4 Reflection Coefficient $|\Gamma|$, SN: MY62300343

13.4.1 Absolute



METAS\346CK01_MY62300343_2025-08-19.nsdab METAS\346CK01_MY62300343_2026-05-29.nsdab

13.4.2 Normalized to the first measurement



METAS\346CK01_MY62300343_2025-08-19.nsdab METAS\346CK01_MY62300343_2026-05-29.nsdab

14 Measurement Uncertainty Budgets

The measurement uncertainty budgets are provided for the noise source with SN: MY62300343.

14.1 NIST

14.1.1 1 GHz

	Uncertainty Value (K)	Uncertainty Percentage (%)
Type-A	5.7	0.2
Cryogenic Standard	66.9	26.4
Ambient Standard	10.9	0.7
Y-factor	0.0	0.0
Mismatch	23.4	3.2
Asymmetry	78.2	36.1
Isolation	2.4	0.0
Frequency offset	0.2	0.0
Nonlinearity	23.6	3.3
Adapter	71.5	30.2

14.1.2 33 GHz

	Uncertainty Value (K)	Uncertainty Percentage (%)
Type-A	0.6	0.0
Cryogenic Standard	9.9	0.5
Ambient Standard	7.8	0.3
Y-factor	6.8	0.2
Mismatch	81.1	30.1
Asymmetry	94.1	40.6
Isolation	4.7	0.1
Frequency offset	10.4	0.5
Nonlinearity	17.4	1.4
Connector repeatability	66.6	20.3
Adapter	40.5	7.5

14.1.3 50 GHz

	Uncertainty Value (K)	Uncertainty Percentage (%)
Type-A	0.5	0.0
Cryogenic Standard	15.2	1.8
Ambient Standard	5.2	0.2
Y-factor	4.4	0.2
Mismatch	7.1	0.4
Asymmetry	62.0	29.7
Isolation	2.9	0.1
Frequency offset	1.3	0.0
Nonlinearity	7.0	0.4
Connector repeatability	54.0	22.5
Adapter	76.3	44.9

14.2 METAS

METAS has used VNA Tools for both the measurements and the uncertainty calculations. Additional details on the noise parameter uncertainty analysis are available in the paper "VNA Tools: Noise Parameter Uncertainty Calculation", published in the 2026 107th ARFTG Microwave Measurement Conference (ARFTG).

See: <https://doi.org/10.1109/ARFTG68740.2026.11614613>

14.2.1 1 GHz

Frequency: 1 000.000 MHz, Parameter: N1,1 / K						
Id Detail Dof Flat Expand All Collapse All Numeric Format: f6 Copy						
Value		Std Unc	U95 (k = 2)			
11811.512015		73.403785	146.807570			
Description	Distribution	Value	Standard Unc	Sensitivity	Unc Component	Unc Percentage
[-] Cable Stability					37.859857	26.602
[-] Reflection					19.074787	6.753
[-] Transmission					32.703536	19.850
[-] Connector Repeatability					3.204564	0.191
[-] Noise Parameters					27.171394	13.702
[-] Bandwidth	Normal	2119200.000000	5000.000000	-0.005431	27.153004	13.684
[-] Physical Temperature	Normal	303.150000	1.000000	0.999528	0.999528	0.019
[-] Power Calibration Standard					44.563521	36.857
[-] 2.4 mm Rohde & Schwarz NRP-Z56 Pow...					40.128938	29.887
[-] Aging					8.137824	1.229
[-] Calibration Factor					36.999251	25.407
[-] Frequency: 1.000 GHz / (W/W)	Normal	0.979800	0.003150	-11745.794081	36.999251	25.407
[-] Linearity					13.234911	3.251
[-] Rohde & Schwarz FSW 67					19.379777	6.970
[-] Linearity					19.379777	6.970
[-] Power Measurement					16.840032	5.263
[-] Drift					12.313451	2.814
[-] Repeatability					8.137824	1.229
[-] Type A					8.105739	1.219
[-] Zero Drift					0.059757	0.000
[-] Zero Offset					0.186678	0.001
[-] Primary Calibration Standard					17.015601	5.374
[-] Switchable Unit Repeatability					0.293591	0.002
[-] VNA Drift (Ideal VNA correlated)					9.866042	1.807
[-] VNA Linearity					23.180194	9.972
[-] Reference Receiver					18.738018	6.516
[-] S-Parameter					13.643547	3.455
[-] Switch Term					0.248346	0.001
[-] VNA Noise					0.843633	0.013
[-] VNA Type A					3.422012	0.217

14.2.2 33 GHz

Frequency: 33 000.000 MHz, Parameter: N1,1 / K						
Id Detail Dof Flat Expand All Collapse All Numeric Format: f6 Copy						
Value	Std Unc	U95 (k = 2)				
8946.764384	105.064436	210.128871				
Description	Distribution	Value	Standard Unc	Sensitivity	Unc Component	Unc Percentage
[-] Cable Stability					27.394352	6.798
[-] Reflection					9.172911	0.762
[-] Transmission					25.812947	6.036
[-] Connector Repeatability					7.010644	0.445
[-] Noise Parameters					20.425745	3.780
[-] Bandwidth	Normal	2119200.000000	5000.000000	-0.004080	20.401678	3.771
[-] Physical Temperature	Normal	303.150000	1.000000	0.991262	0.991262	0.009
[-] Power Calibration Standard					82.321238	61.392
[-] 2.4 mm Rohde & Schwarz NRP-Z56 Pow...					80.911916	59.308
[-] Aging					6.115129	0.339
[-] Calibration Factor					80.065250	58.073
[-] Frequency: 33.000 GHz / (W/W)	Normal	0.864000	0.008000	-10008.156288	80.065250	58.073
[-] Linearity					9.944804	0.896
[-] Rohde & Schwarz FSW 67					15.167332	2.084
[-] Linearity					15.167332	2.084
[-] Power Measurement					13.043509	1.541
[-] Drift					9.347258	0.792
[-] Repeatability					6.114757	0.339
[-] Type A					6.727049	0.410
[-] Zero Drift					0.104893	0.000
[-] Zero Offset					0.327797	0.001
[-] Primary Calibration Standard					48.049121	20.915
[-] Switchable Unit Repeatability					0.058053	0.000
[-] VNA Drift (Ideal VNA correlated)					14.765464	1.975
[-] VNA Experiment					0.249107	0.001
[-] VNA Linearity					17.904823	2.904
[-] Reference Receiver					14.079293	1.796
[-] S-Parameter					11.060878	1.108
[-] Switch Tem					0.114780	0.000
[-] VNA Noise					0.610033	0.003
[-] VNA Type A					5.200807	0.245

14.2.3 50 GHz

Frequency: 50 000.000 MHz, Parameter: N1,1 / K						
Id Detail Dof Flat Expand All Collapse All Numeric Format: f6 Copy						
Value	Std Unc	U95 (k = 2)				
6093.723090	99.164840	198.329679				
Description	Distribution	Value	Standard Unc	Sensitivity	Unc Component	Unc Percentage
[-] Cable Stability					18.706587	3.559
[-] Reflection					7.425719	0.561
[-] Transmission					17.169598	2.998
[-] Connector Repeatability					7.851829	0.627
[-] Noise Parameters					13.706656	1.911
[-] Bandwidth	Normal	2119200.000000	5000.000000	-0.002734	13.670714	1.900
[-] Physical Temperature	Normal	303.150000	1.000000	0.991966	0.991966	0.010
[-] Power Calibration Standard					84.743080	73.029
[-] 2.4 mm Rohde & Schwarz NRP-Z56 Pow...					84.035533	71.814
[-] Aging					4.097115	0.171
[-] Calibration Factor					83.670693	71.192
[-] Frequency: 50.000GHz / (W/W)	Normal	0.831000	0.012000	-6972.557761	83.670693	71.192
[-] Linearity					6.663302	0.452
[-] Rohde & Schwarz FSW 67					10.927890	1.214
[-] Power Measurement					9.825646	0.982
[-] Drift					6.495540	0.429
[-] Repeatability					4.097115	0.171
[-] Type A					6.117738	0.381
[-] Zero Drift					0.113011	0.000
[-] Zero Offset					0.354175	0.001
[-] Primary Calibration Standard					35.656347	12.929
[-] Switchable Unit Repeatability					0.223058	0.001
[-] VNA Drift (Ideal VNA correlated)					8.382185	0.714
[-] VNA Experiment					0.255507	0.001
[-] VNA Linearity					12.369902	1.556
[-] Reference Receiver					9.433944	0.905
[-] S-Parameter					7.999216	0.651
[-] Switch Term					0.166463	0.000
[-] VNA Noise					1.200149	0.015
[-] VNA Type A					21.449161	4.678