CCEM KEY COMPARISON CCEM.RF-K5c.CL

Scattering Coefficients by Broad-Band Methods

0.1 GHz - 33 GHz, 3.5 mm connector

Final version

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Contents

Abstract

An international measurement comparison, identified as CCEM.RF-K5c.CL, for scattering parameters and reflection coefficients by broad-band method was conducted between twenty national metrology institutes. The purpose of the comparison is to establish the calibration measurement capability of each participating laboratory. This report presents the key comparison reference values and degree of equivalence of each participant with respect to the key comparison reference values of the comparison. The participants measured seven travelling standards, an adapter, a 20 dB attenuator, a 40 dB attenuator, two matched terminations, and two flush short terminations with 3.5 mm coaxial connectors from 0.1 GHz to 33 GHz. The pilot laboratory is National Metrology Institute of Japan (NMIJ) and the supporting laboratories are Federal Institute of Metrology (METAS) and National Physical Laboratory (NPL), National Institute of Metrology (NIM), and National Institute of Standards and Technology (NIST). Most of the reported measurement results were generally consistent, while there was a small number of outlying values.

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1: Introduction

This document is a report on CCEM.RF-K5c.CL, which is an international key comparison of scattering parameters (S-parameters) by the initiative of the Consultative Committee for Electricity and Magnetism (CCEM) Working Group on Radiofrequency Quantities (GT-RF). CCEM.RF-K5c.CL is the third key comparison about S-parameter measurement; the pervious key comparisons are CCEM.RF-K5a.CL and CCEM.RF-K5b.CL [1][2].

The purpose of CCEM.RF-K5c.CL is to compare S-parameter values measured by the participants and establish the calibration measurement capability (CMC) of each participating laboratory. The key comparison reference values (KCRVs) and degree of equivalences (DoEs) between the reported results and the KCRVs were calculated. These analysis results will be used to establish the mutual recognition arrangement (MRA).

The travelling standards are seven devices with 3.5 mm coaxial connectors. These devices are the following: an adapter, 20 dB attenuator, 40 dB attenuator, matched termination with a female interface, matched termination with a male interface, flush short termination with a female interface, and flush short termination with a male interface. The first three travelling standards are two-port devices. The transmission characteristics are high, medium, and low, respectively. The others are one-port devices with low and high reflection characteristics. The frequency range in this comparison is from 0.1 GHz to 33 GHz. The measurement and analysis were conducted from April 2012 to March 2019.

Twenty national metrology institutes participated in CCEM.RF-K5c.CL. The laboratories measured the travelling standards using their own metrology standards and measurement systems. The pilot laboratory is National Metrology Institute of Japan (NMIJ). The supporting laboratories are Federal Institute of Metrology (METAS) and National Physical Laboratory (NPL), National Institute of Metrology (NIM), and National Institute of Standards and Technology (NIST).

This report involves six sections and five appendixes. Section 2 summarizes the technical protocol of CCEM.RF-K5c.CL published before the measurements were started. Section 3 shows the measurement data reported by the participants and the results of the analysis of KCRVs and DoEs. Discussions about the analysis are shown in Section 4. Problems that occurred during this comparison and recommendations for the next comparison are reported in Section 5. Section 6 is a conclusion of this report. Appendix 1 discusses the calculation method for the KCRVs and DoEs. Measurement uncertainty budgets reported by the participants are listed in Appendix 2. Detailed information about the measurements by each participant are shown in Appendix 3. Appendix 4 shows the pin depth measurement results of the travelling standards by the participants. The stability monitoring measurement results of the travelling standards by the pilot laboratory are described in Appendix 5.

2: Technical Protocol

Before the measurements were performed by the participants, a technical protocol [3] was prepared based on the previous related key comparisons [1][2] and guidelines [4]. This section summarizes the contents of the technical protocol.

2.1: Travelling Standard

The travelling standards in CCEM.RF-K5c.CL were the following seven devices with the 3.5 mm coaxial connectors: an adapter, 20 dB attenuator, 40 dB attenuator, matched termination with a female interface, matched termination with a male interface, flush short termination with a female interface, and flush short termination with a male interface (Fig. 2.1). All of the seven travelling standards were commercially available artefacts (Table 2.1).

The travelling standards used in CCEM.RF-K5c.CL were selected based on the results and recommendations obtained in the previous related comparisons, CCEM.RF-K5a.CL [1] and CCEM.RF-K5b.CL [2]. K5c.CL/1, K5c.CL/2, and K5c.CL/3 were two-port devices whose attenuation characteristics were low, medium, and high, respectively. K5c.CL/4 and K5c.CL/5 were one-port devices with nominally zero reflection. K5c.CL/6 and K5c.CL/7 were also one-port devices, but with high reflection characteristics.

Devices with unsupported inner conductors, such as air-dielectric coaxial lines and mismatch lines, were not included in this comparison, because the mechanical stability was found to be suspicious compared with that of supported devices [1].

Because of the large number of participants, two sets of the travelling standards composed of the same described devices were used for this comparison. Each participant essentially had to measure only one of the two sets. However, the pilot and supporting laboratories measured both sets.

Fig.2.1. Photograph of the travelling standards of CCEM.RF-K5c.CL.

Table 2.1. Travelling standards of CCEM.RF-K5c.CL.

Identifier	**Manufacture** **Device** **Model number**	**Serial number**	**Nominal value**
K5c.CL/1	Agilent Technologies Adapter 85052-60013	Loop 1: 84240 Loop 2: 84282	$\|S_{ii}\| < 0.1$ $\|S_{ij}\| \fallingdotseq 1.0$
K5c.CL/2	Agilent Technologies 20 dB attenuator 85053-60001	Loop 1: 02915 Loop 2: 02793	$\|S_{ii}\| < 0.1$ $\|S_{ij}\| \fallingdotseq 0.1$
K5c.CL/3	Agilent Technologies 40 dB attenuator 85053-60002	Loop 1: 02871 Loop 2: 02870	$\|S_{ii}\| < 0.1$ $\|S_{ij}\| \fallingdotseq 0.01$
K5c.CL/4	Agilent Technologies Matched termination 00902-60004	Loop 1: 11123 Loop 2: 11575	$\|S_{ii}\| < 0.1$
K5c.CL/5	Agilent Technologies Matched termination 00902-60003	Loop 1: 11728 Loop 2: 11655	$\|S_{ii}\| < 0.1$

K5c.CL/6	Agilent Technologies Flush short termination 85052BK25	Loop 1: 7 Loop 2: 9	$\|S_{ii}\| \doteqdot 1.0$
K5c.CL/7	Agilent Technologies Flush short termination 85052BK26	Loop 1: 031 Loop 2: 032	$\|S_{ii}\| \doteqdot 1.0$

2.2: Measurement

In the technical protocol provided in advance, the following points were requested when measuring the travelling standards of CCEM.RF-K5c.CL. These requests contribute to ensure the effectiveness of the results of this comparison.

1) All participants should do "visual inspections" of the connectors of the travelling standards and the test ports of their own measuring instruments before connections.
2) All participants should measure the pin depths of the travelling standards and the test ports of their own measuring instruments before connections.
3) For the two-port travelling standards, the female and male connector sides were defined as ports 1 and 2, respectively.
4) The participants' measurement test ports of the measuring instruments, such as vector network analyzers, must have 3.5 mm coaxial connectors defined in the IEEE P287 [5] or IEC 60169-23 standards [6]. SMA/WSMA connectors must not be used.
5) Use of 3.5 mm test port connectors with the precision grade was recommended. K and 2.92 mm connectors, which are mechanically compatible to 3.5 mm connectors, were not recommended because of possible degradation of participants' measurement capability.
6) All participants should use torque wrenches to connect the travelling standards to the test ports of their own measuring instruments. The value of the torque is 0.90 N m. Rotating the device bodies when connecting to their test port was prohibited.

7) Following the above requirements, the details of the measurement, procedure, instrument, and devices were left to the discretion of each participant.

The frequency range in this comparison is from 0.1 GHz to 33 GHz.

The measurands for each travelling standard are the scattering parameter (S-parameter) and reflection coefficient listed in Table 2.2.

Table 2.2. Measurands of CCEM.RF-K5c.CL.

Travelling standard	**Measurand**
K5c.CL/1	Complex-valued S-parameters (S_{11}, S_{21}, S_{12}, and S_{22})
K5c.CL/2	
K5c.CL/3	
K5c.CL/4	Complex-valued reflection coefficient (S_{11})
K5c.CL/5	
K5c.CL/6	
K5c.CL/7	

The measurands were reported to the pilot laboratory in the following form:

$$S_{ab} = x + jy. \quad (a, b = 1, 2) \tag{2.1}$$

Here, x and y are the real and imaginary components, respectively, of the S-parameter or reflection coefficient. j represents the imaginary unit.

The measurement uncertainties to be reported were the combined standard uncertainties of the real component, $u(x)$, and the imaginary component, $u(y)$. When $u(x)$ was equal to $u(y)$, only a single value should be reported. An evaluation method for the uncertainties was left to the discretion of each participant; however, the European Association of National Metrology Institutes (EURAMET) guideline [7] was referred to in the technical protocol.

The participating laboratories may report the correlation coefficient between x and y, $r(x, y)$. However, the values were not analyzed as part of this comparison. Using $r(x, y)$, $u(x)$, and $u(y)$, the covariance matrix, $\boldsymbol{V}$, is given as following:

$$\boldsymbol{V} = \begin{pmatrix} u(x)^2 & r(x,y)u(x)u(y) \\ r(x,y)u(x)u(y) & u(y)^2 \end{pmatrix} = \begin{pmatrix} u(x)^2 & u(x,y) \\ u(x,y) & u(y)^2 \end{pmatrix}. \tag{2.2}$$

2.3: Analysis Method

The technical protocol says that the following values are calculated using the measurement results reported by the participants [8]:

1) The KCRV and the uncertainty.
2) The DoE of each participant with respect to the KCRV and the uncertainty.

A suitable calculation method for KCRVs and DoEs for complex-valued S-parameters was not trivial. However, the uncertainty-weighted mean was proposed in the technical protocol.

2.4: Time Schedule

Because of the large number of participants, two measurement loops, named Loop 1 and Loop 2, were constructed in CCEM.RF-K5c.CL. The travelling standards for each loop had the same manufacturer and model numbers but different serial numbers (Table 2.1). The characteristics of the two devices were similar.

The time schedules of measurements by the participants are shown in Table 2.3 and Table 2.4.

To monitor the stability of the travelling standards, the pilot laboratory measured the travelling standards seven times for Loops 1 and 2.

NIST, NMIA, and Trescal did not measure the travelling standards and were withdrawn from CCEM.RF-K5c.CL. NIM and KRISS have measured the travelling standards but have not submitted their reports by the deadline. The pilot laboratory considered that the two laboratories have withdrawn from this comparison.

Table 2.3. Time schedule of measurements (Loop 1).

Laboratory	**Date of measurement**
NMIJ	October 2012
METAS	November 2012
NMIJ	July 2013
NMC, A*STAR	October 2013
KRISS	Measurements have been completed, but report has not been submitted.
NMIJ	February 2014
NMIA	Withdraw
UME	May 2014
NMISA	June 2014
NRC	August 2014

NMIJ	September 2014
SNIIM	February 2015
NMIJ	April 2015
NIM	Measurements have been completed, but report has not been submitted.
NMIJ	November 2016
NPL	October 2017
NIST	Withdraw
NMIJ	March 2019

Table 2.4. Time schedule of measurements (Loop 2).

Laboratory	**Date of measurement**
NMIJ	October 2012
METAS	November 2012
NMIJ	July 2013
CMI	October 2013
GUM	January 2014
NMIJ	February, 2014
INRIM	April 2014
PTB	-
SP	June 2014
NMIJ	September 2014
VSL	November 2014
Trescal	Withdraw
LNE	February 2015
NMIJ	April 2015
NIM	Measurements have been completed, but report has not been submitted.
NMIJ	November 2016
NPL	October 2017

NIST	Withdraw
NMIJ	March 2019

3: Analysis

The reported measurement results and analysis of KCRVs and DoEs using the results are shown in this section.

3.1: Data

To reduce the amount of data analyzed in detail, the 20 measurands described below were selected. Only the 20 sets of the data below were compared in this report.

S_{21} of K5c.CL/1 at 0.1 GHz, 12.4 GHz, 26.5 GHz, and 33 GHz.
S_{21} of K5c.CL/2 at 0.1 GHz, 12.4 GHz, 26.5 GHz, and 33 GHz.
S_{21} of K5c.CL/3 at 0.1 GHz, 12.4 GHz, 26.5 GHz, and 33 GHz.
S_{11} of K5c.CL/4 at 0.1 GHz, 12.4 GHz, 26.5 GHz, and 33 GHz.
S_{11} of K5c.CL/7 at 0.1 GHz, 12.4 GHz, 26.5 GHz, and 33 GHz.

Using the measurement results of K5c.CL/1, K5c.CL/2, and K5c.CL/3, the transmission measurement results can be compared. K5c.CL/1, K5c.CL/2, and K5c.CL/3 have low-, middle-, and high-loss transmission characteristics, respectively. Comparisons of reflection measurements can be possible using K5c.CL/4 and K5c.CL/7. K5c.CL/4 and K5c.CL/7 have low- and high-reflection characteristics, respectively.

3.2: Method

KCRVs were calculated using the uncertainty-weighted mean. The detailed calculation method is discussed in Appendix 1.

The correlation of the measurement traceability source was neglected when calculating KCRVs and DoEs, because there was insufficient information about the traceability source and the propagation from the source to the measurement results.

3.3: Results

The following four tables and eight figures are shown for each set of the reported measurement data:

a) Table of the reported results and KCRV (Loop 1).
   Table 3.n.1. (n=1, 2, ⋯, 20).
b) Table of the reported results and KCRV (Loop2).
   Table 3.n.2. (n=1, 2, ⋯, 20).
c) Figure of the reported results and KCRV for real component of S-parameters.
   Fig. 3.n.1. (n=1, 2, ⋯, 20).
   The left and right sides show the reported results in Loop 1 and Loop 2, respectively.
   The red solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 1.
   The blue solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 2.
d) Figure of the reported results and KCRV for real component of S-parameters (Loop1).
   Fig. 3.n.2. (n=1, 2, ⋯, 20).
   The red solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 1.
   This is an enlarged version of Fig. 3.n.1. (n=1, 2, ⋯, 20).
e) Figure of the reported results and KCRV for real component of S-parameters (Loop2).
   Fig. 3.n.3. (n=1, 2, ⋯, 20).
   The blue solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 2.

This is an enlarged version of Fig. 3.n.1. (n=1, 2, ⋯, 20).

f) Figure of the reported results and KCRV for imaginary component of S-parameters.

Fig. 3.n.4. (n=1, 2, ⋯, 20).

The left and right sides show the reported results in Loop 1 and Loop 2, respectively.

The red solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 1.

The blue solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 2.

g) Figure of the reported results and KCRV for imaginary component of S-parameters (Loop1).

Fig. 3.n.5. (n=1, 2, ⋯, 20).

The red solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 1.

This is an enlarged version of Fig. 3.n.4. (n=1, 2, ⋯, 20).

h) Figure of the reported results and KCRV for imaginary component of S-parameters (Loop2).

Fig. 3.n.6. (n=1, 2, ⋯, 20).

The blue solid and broken lines show the KCRV and expanded uncertainty, respectively, in Loop 2.

This is an enlarged version of Fig. 3.n.4. (n=1, 2, ⋯, 20).

i) Table of the reduced dimensional DoE with respect to KCRV (Loop 1).

Table 3.n.3. (n=1, 2, ⋯, 20).

j) Table of the reduced dimensional DoE with respect to KCRV (Loop 2).

Table 3.n.4. (n=1, 2, ⋯, 20).

k) Figure of the reduced dimensional DoE with respect to KCRV.

Fig. 3.n.7. (n=1, 2, ⋯, 20).

l) Figure of the reduced dimensional DoE with respect to KCRV.

Fig. 3.n.8. (n=1, 2, ⋯, 20).

This is an enlarged version of Fig. 3.n.7. (n=1, 2, ⋯, 20).

In the tables of the reported results and KCRV (a and b), inconsistent data are written in *Italics*. The data were excluded from the determination of the KCRV. The criteria for determination of outliers is discussed in Appendix 1.

In the tables of the reported results and KCRV (a and b), the reported values were rounded to two significant figures. However, the analysis was conducted using the results as reported by the participants with no rounding.

The KCRVs were calculated using the reported results by the CCEM GT-RF members. CMI, GUM, and NMISA were excluded in the KCRV determinations.

In the figures of the reported values and KCRV (c, d, e, f, g, and h), the solid and broken lines show the KCRV and expanded uncertainty with the coverage factor of 2, respectively. The black dots and bars represent the reported values and expanded uncertainty with the coverage factor of 2, respectively.

According to the figures of the DoE (k and l), only reduced dimensional DoEs and confidence indicators are shown to assist in the graphical representation. Because the reduced dimensional DoEs are always positive values, the confidence indicators are shown only on one side in the figures.

The measurement uncertainty budgets and detailed information about each participant's measurements are found in Appendixes 2 and 3, respectively.

The pin depth measurement results of the travelling standards are provided in Appendix 4.

The stability monitoring data of the travelling standards during this comparison are given in Appendix 5.

K5c.CL/1 at 0.1 GHz

Table 3.1.1. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 1) at 0.1 GHz.

Laboratory	K5c.CL/1 (Loop 1) Measurement and combined uncertainty of S_{21} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.99767	0.00072	-0.0601	0.0011	
NMC, A*STAR	0.9978	0.0028	-0.0599	0.0028	
UME	0.99825	0.00073	-0.05973	0.00073	0.86
NMISA	0.9973	0.0017	-0.0590	0.0017	
NRC	0.999	0.014	-0.059	0.014	
NMIJ	0.9963	0.0018	-0.0605	0.0018	
SNIIM	0.9977	0.0033	-0.0602	0.0033	
NPL	0.997475	0.000059	-0.060124	0.000059	
KCRV	0.997481	0.000059	-0.060120	0.000059	

Table 3.1.2. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 2) at 0.1 GHz.

Laboratory	K5c.CL/1 (Loop 2) Measurement and combined uncertainty of S_{21} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.99758	0.00072	-0.0602	0.0011	
CMI	0.99756	0.00025	-0.06016	0.00022	-0.019
GUM	0.9978	0.0020	-0.0605	0.0020	
INRIM	0.9975	0.0025	-0.0603	0.0050	0.094
PTB	0.9976	0.0050	-0.0605	0.0050	
SP	0.9975	0.0015	-0.0602	0.0015	
NMIJ	0.9970	0.0018	-0.0599	0.0018	
VSL	0.99762	0.00062	-0.0602	0.0012	
LNE	0.99740	0.00041	-0.06030	0.00041	
NPL	0.997308	0.000082	-0.060182	0.000082	
KCRV	0.997319	0.000079	-0.060186	0.000079	

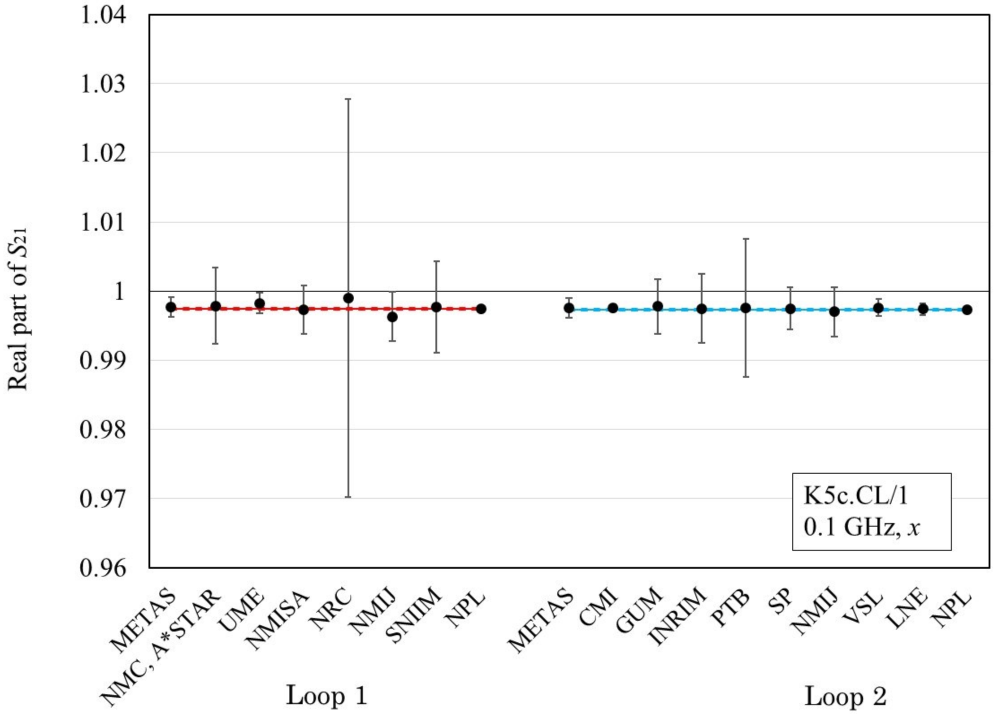

Fig. 3.1.1. Reported results and KCRV for ReS_{21} of K5c.CL/1 at 0.1 GHz.

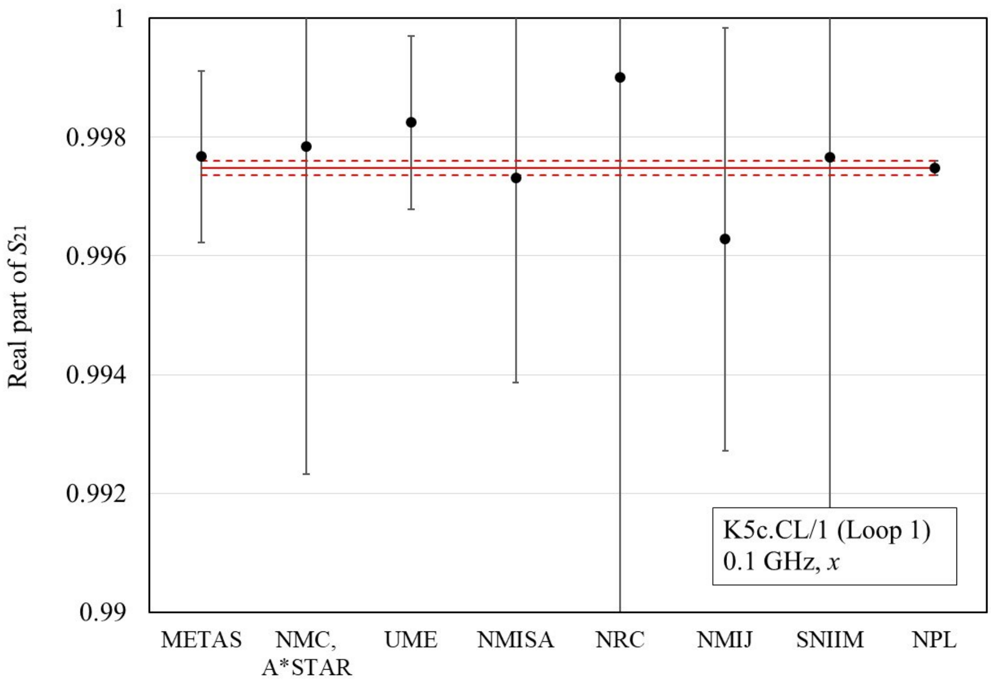

Fig. 3.1.2. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.1.1.).

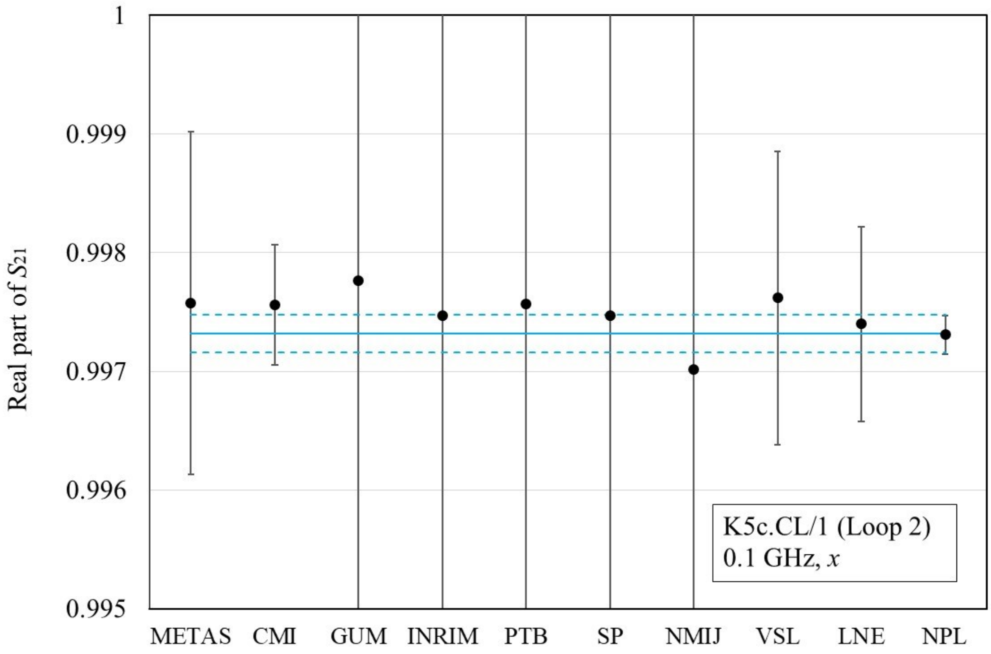

Fig. 3.1.3. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.1.1.).

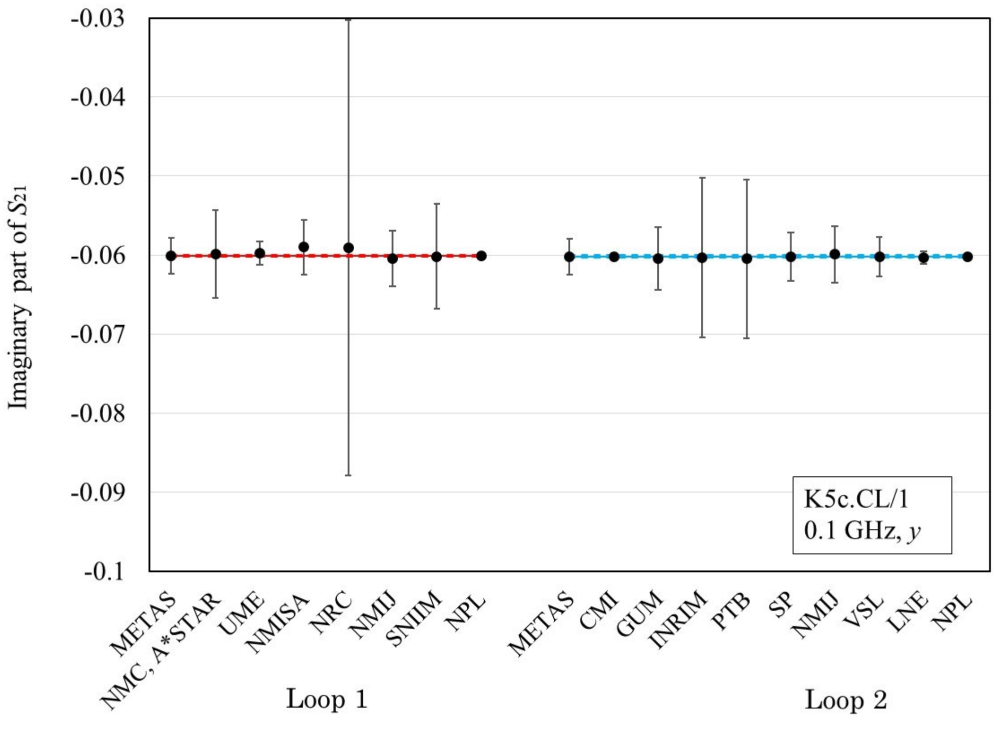

Fig. 3.1.4. Reported results and KCRV for ImS_{21} of K5c.CL/1 at 0.1 GHz.

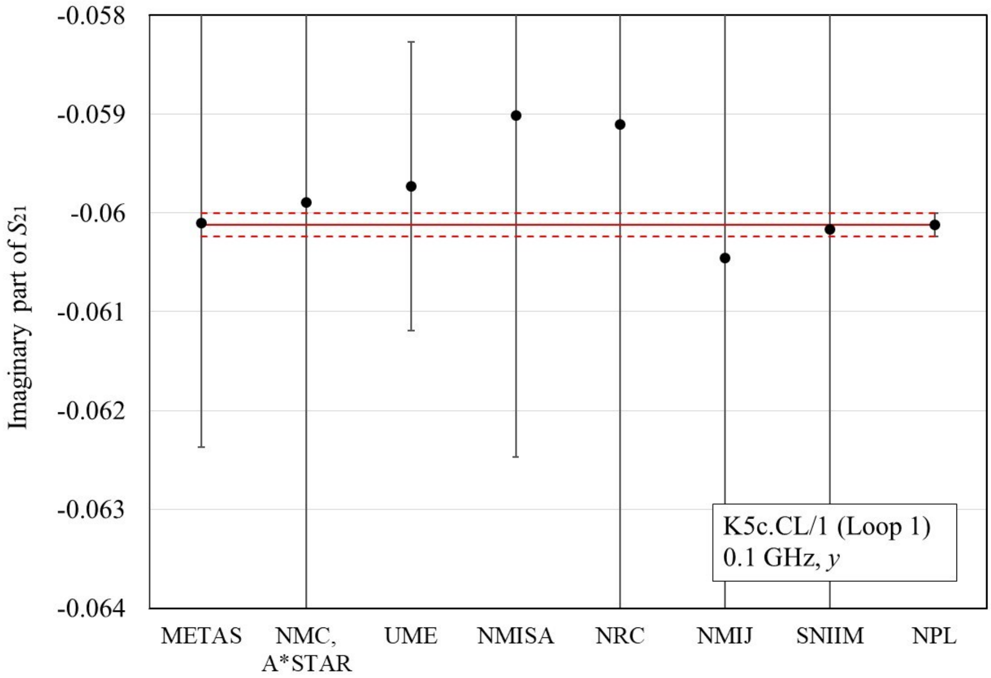

Fig. 3.1.5. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.1.4.).

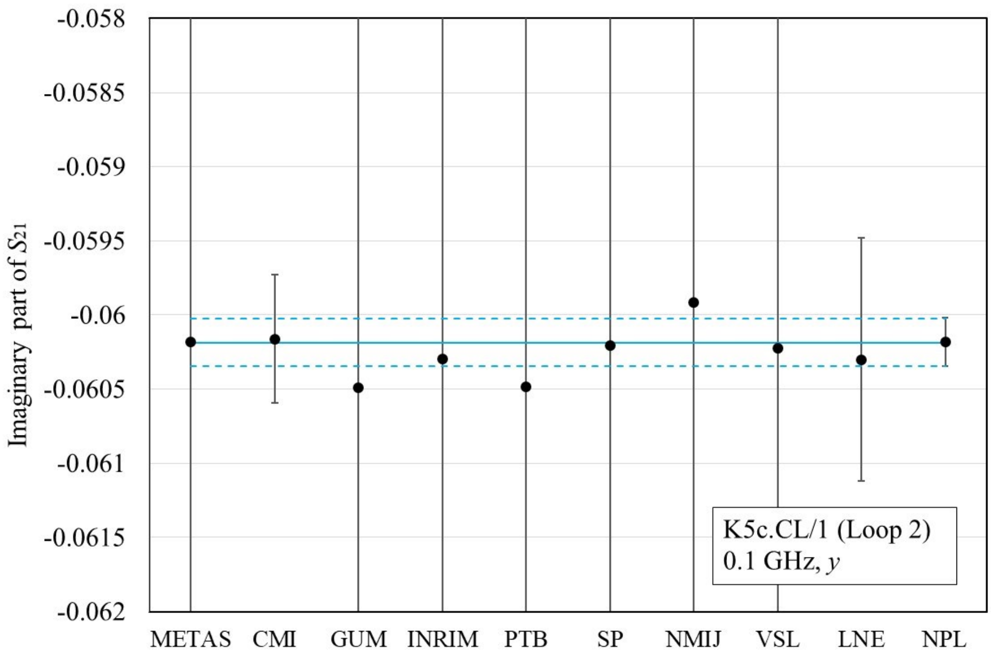

Fig. 3.1.6. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.1.4.).

Table 3.1.3. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 1) at 0.1 GHz.

	KCRV (Loop 1)	
	q_{1iM}	dq_{1iM}
METAS	0.0002	0.0018
NMC, A*STAR	0.0004	0.0068
UME	0.0009	0.0018
NMISA	0.0011	0.0042
NRC	0.002	0.035
NMIJ	0.0012	0.0044
SNIIM	0.0002	0.0081
NPL	0.000006	0.000017

Table 3.1.4. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 2) at 0.1 GHz.

	KCRV (Loop 2)	
	q_{2iM}	dq_{2iM}
METAS	0.0003	0.0018
CMI	0.00024	0.00065
GUM	0.0005	0.0049
INRIM	0.0002	0.0071
PTB	0.000	0.012
SP	0.0002	0.0037
NMIJ	0.0004	0.0044
VSL	0.0003	0.0015
LNE	0.0001	0.0010
NPL	0.000012	0.000051

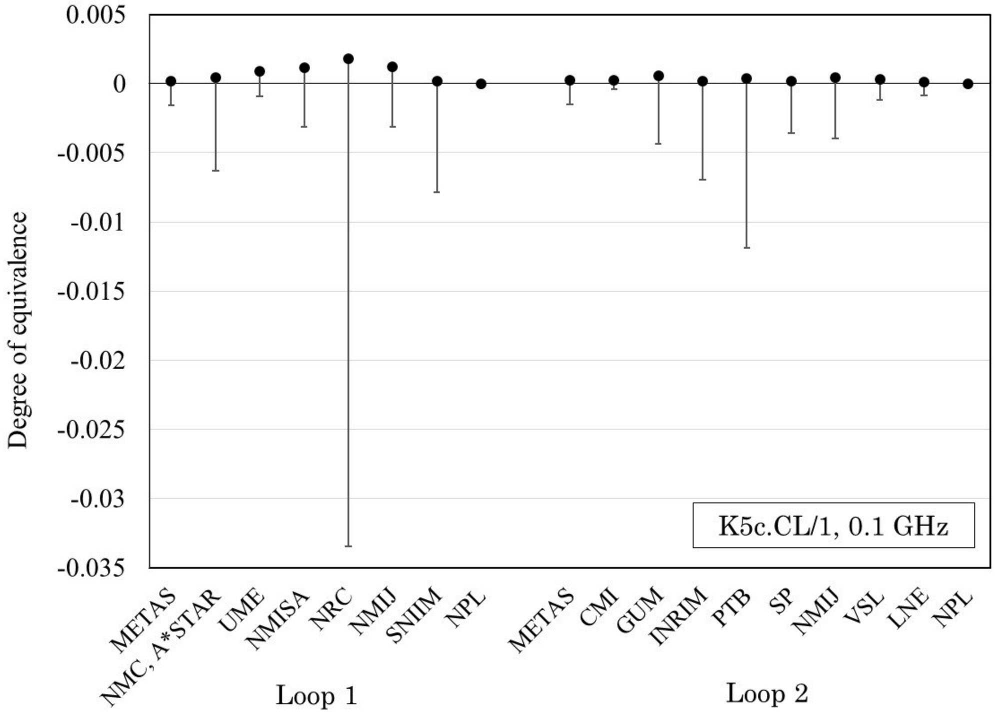

Fig. 3.1.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 0.1 GHz.

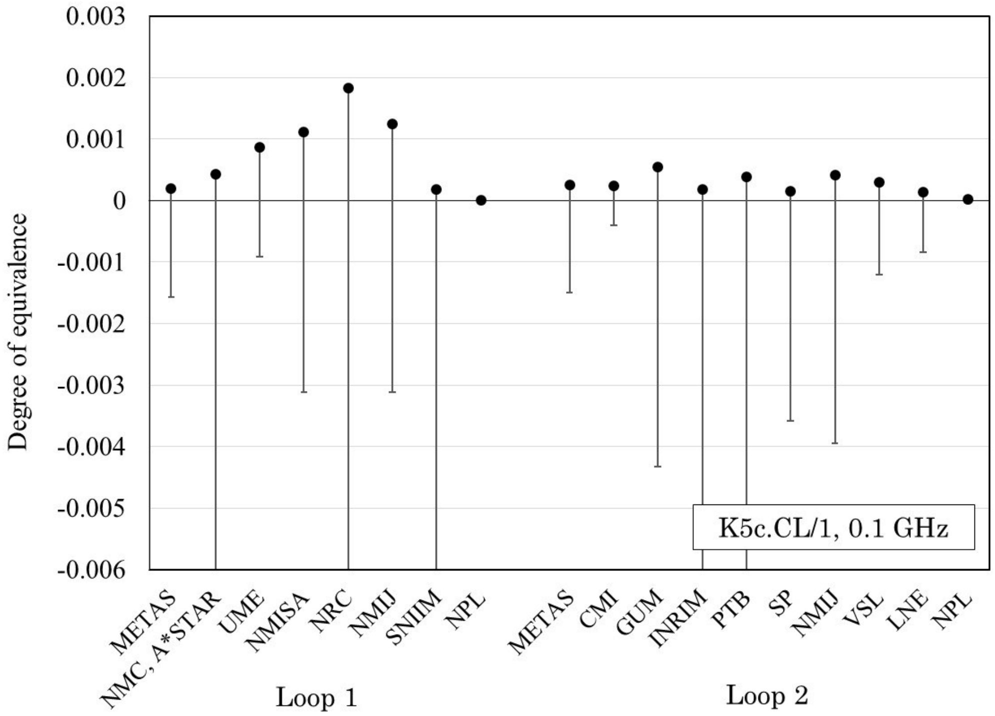

Fig. 3.1.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 0.1 GHz (enlarged view of Fig. 3.1.7.).

K5c.CL/1 at 12.4 GHz

Table 3.2.1. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 1) at 12.4 GHz.

Laboratory	K5c.CL/1 (Loop 1) Measurement and combined uncertainty of S_{21} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.43639	0.00063	-0.89161	0.00063	
NMC, A*STAR	0.4371	0.0076	-0.8914	0.0076	
UME	*0.43872*	*0.00087*	*-0.88967*	*0.00087*	*0.94*
NMISA	0.4324	0.0080	-0.8898	0.0080	
NRC	0.438	0.014	-0.893	0.014	
NMIJ	0.4321	0.0023	-0.8889	0.0023	
SNIIM	0.4365	0.0054	-0.8914	0.0054	
NPL	0.43551	0.00038	-0.89159	0.00038	
KCRV	0.43567	0.00032	-0.89155	0.00032	

Table 3.2.2. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 2) at 12.4 GHz.

Laboratory	K5c.CL/1 (Loop 2) Measurement and combined uncertainty of S_{21} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	*0.43757*	*0.00064*	*-0.89033*	*0.00064*	
CMI	0.4372	0.0022	-0.8901	0.0012	0.85
GUM	0.4358	0.0023	-0.8902	0.0023	
INRIM	0.4408	0.0167	-0.8884	0.0085	0.95
PTB	0.4387	0.0050	-0.8891	0.0050	
SP	0.4398	0.0028	-0.8890	0.0028	
NMIJ	0.4382	0.0024	-0.8872	0.0024	
VSL	0.4394	0.0042	-0.8891	0.0021	
LNE	0.43770	0.00080	-0.88840	0.00080	
NPL	0.43902	0.00045	-0.88903	0.00045	
KCRV	0.43869	0.00039	-0.88884	0.00038	

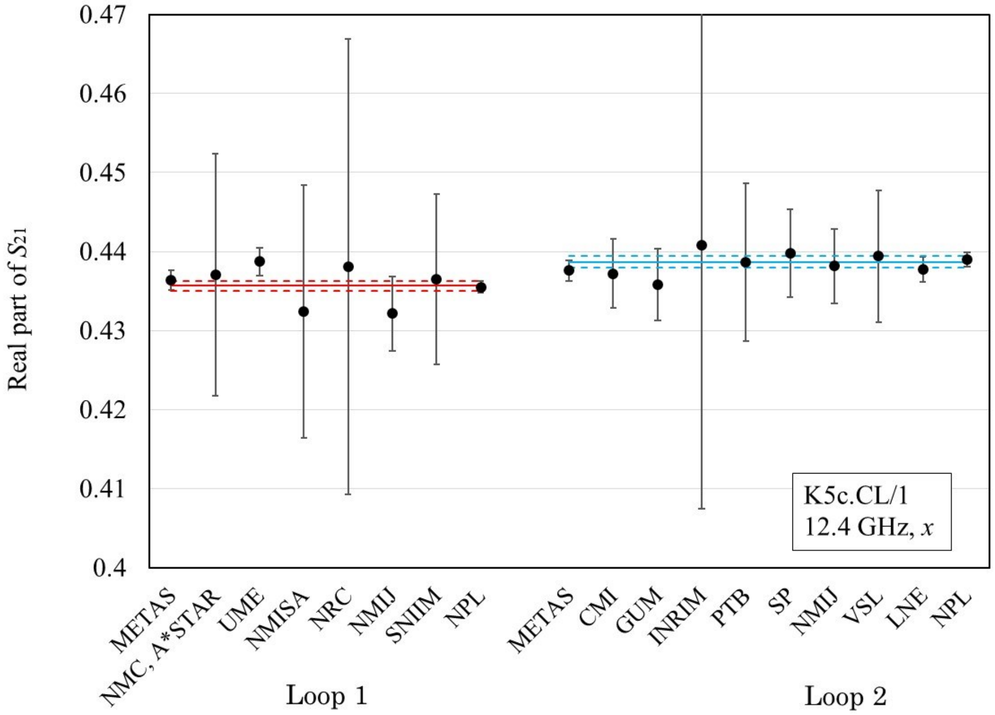

Fig. 3.2.1. Reported results and KCRV for ReS_{21} of K5c.CL/1 at 12.4 GHz.

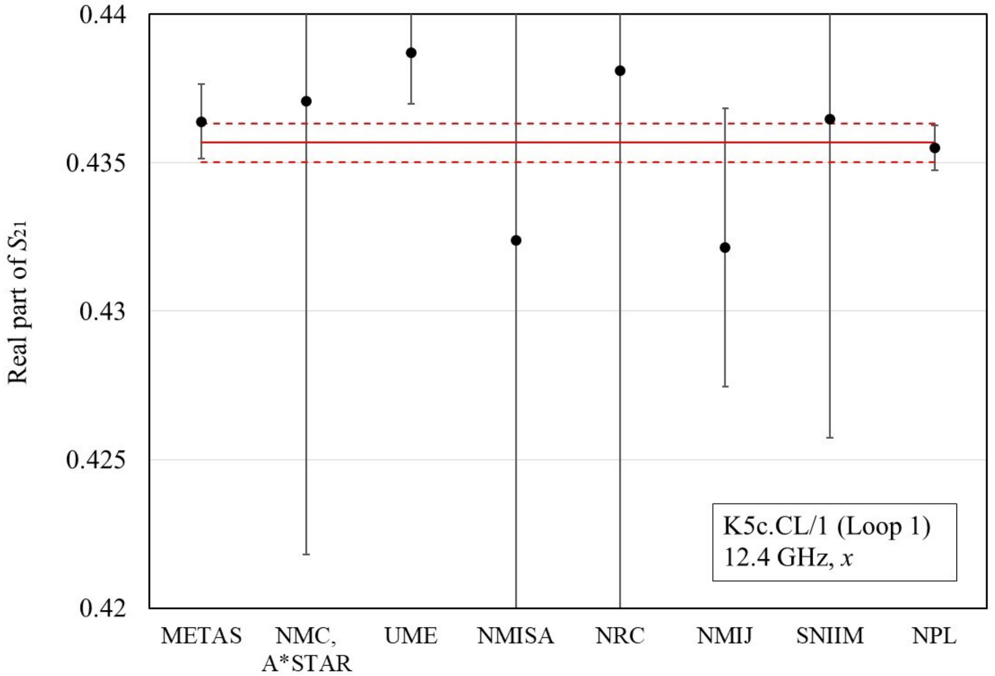

Fig. 3.2.2. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.2.1.).

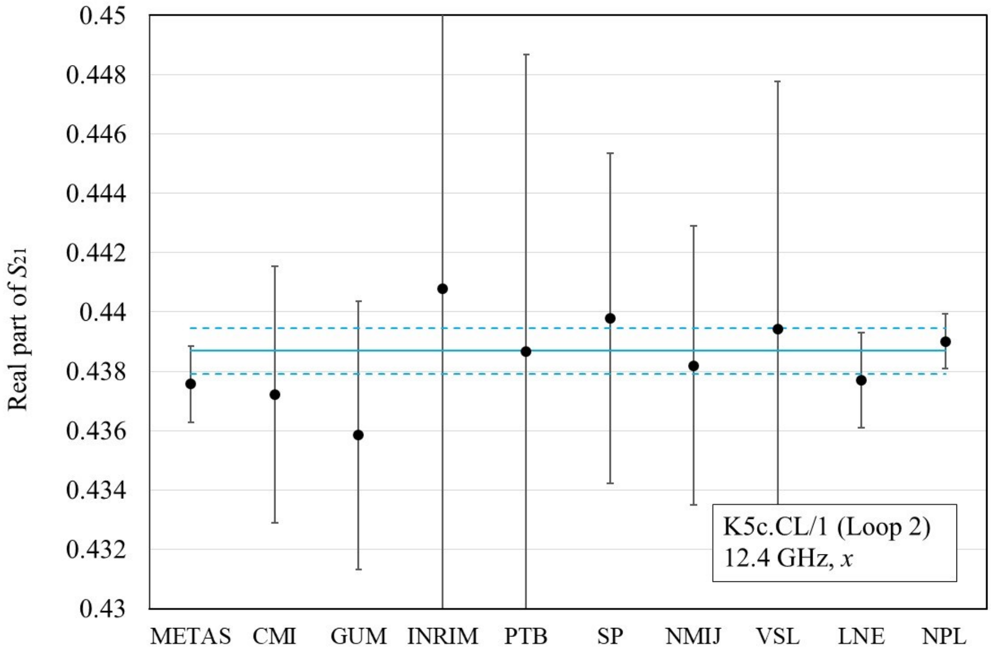

Fig. 3.2.3. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.2.1.).

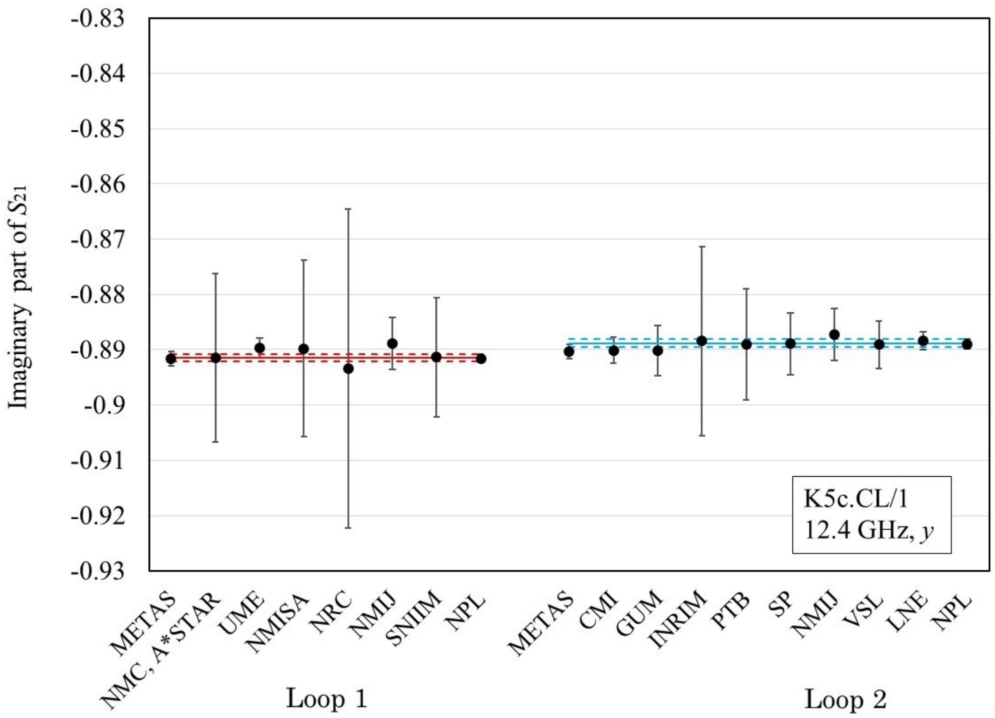

Fig. 3.2.4. Reported results and KCRV for ImS_{21} of K5c.CL/1 at 12.4 GHz.

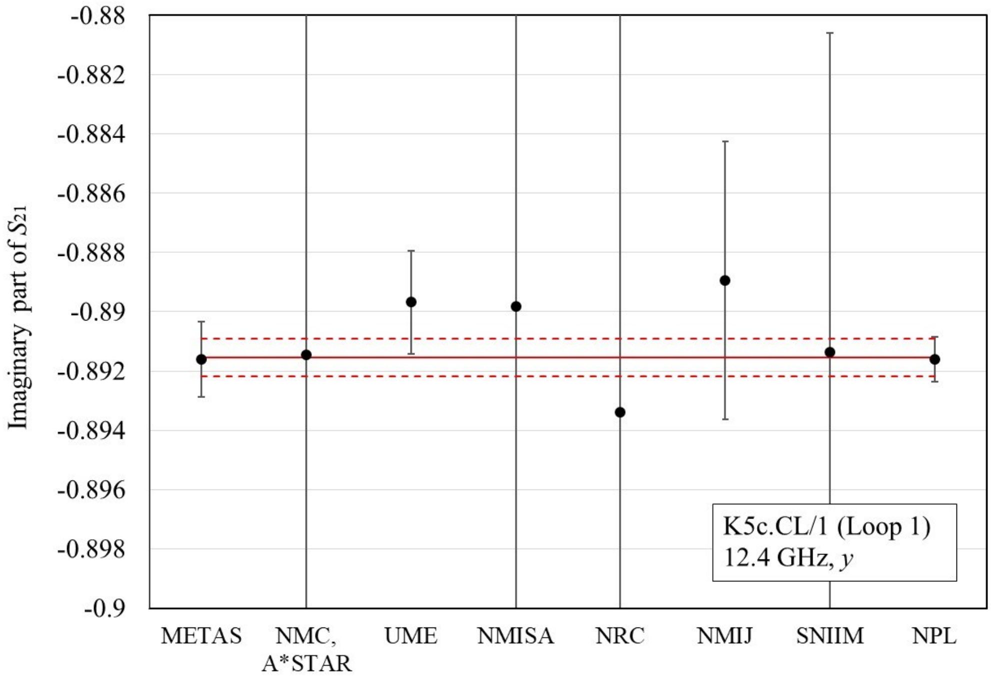

Fig. 3.2.5. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.2.4.).

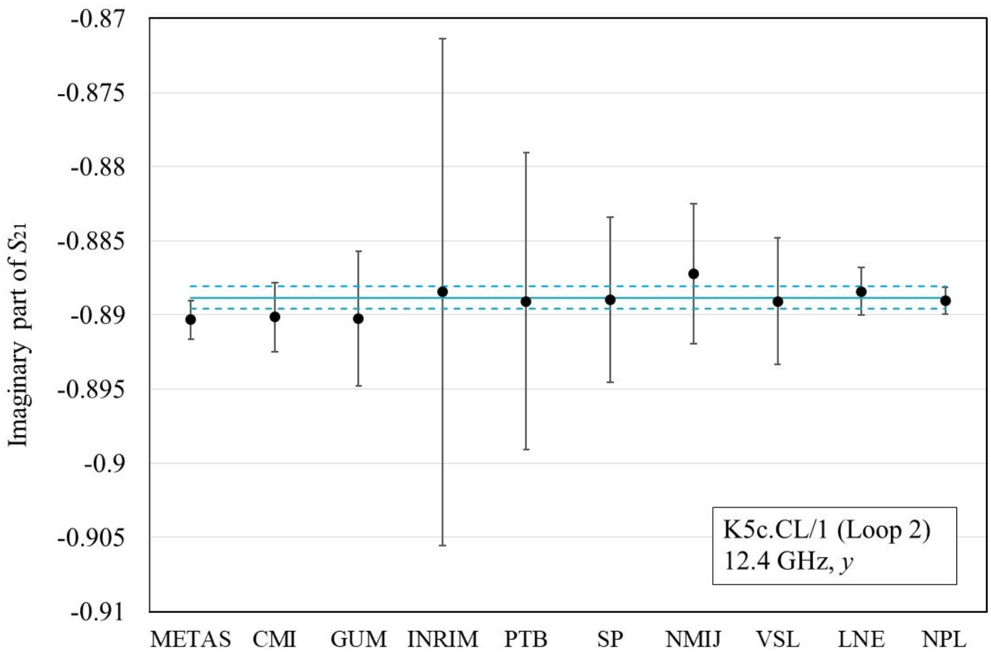

Fig. 3.2.6. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.2.4.).

Table 3.2.3. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 1) at 12.4 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0007	0.0013
NMC, A*STAR	0.001	0.019
UME	0.0036	0.0023
NMISA	0.004	0.020
NRC	0.003	0.035
NMIJ	0.0044	0.0057
SNIIM	0.001	0.013
NPL	0.00017	0.00049

Table 3.2.4. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 2) at 12.4 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0019	0.0018
CMI	0.0020	0.0038
GUM	0.0032	0.0056
INRIM	0.002	0.039
PTB	0.000	0.012
SP	0.0011	0.0069
NMIJ	0.0017	0.0057
VSL	0.0008	0.0090
LNE	0.0011	0.0017
NPL	0.00038	0.00059

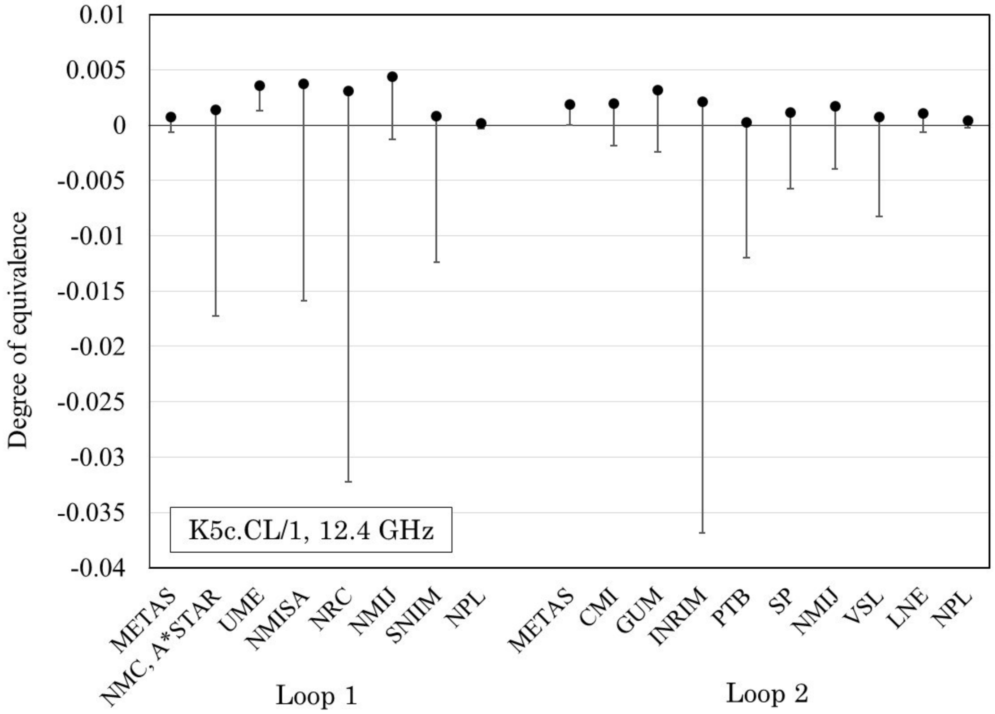

Fig. 3.2.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 12.4 GHz.

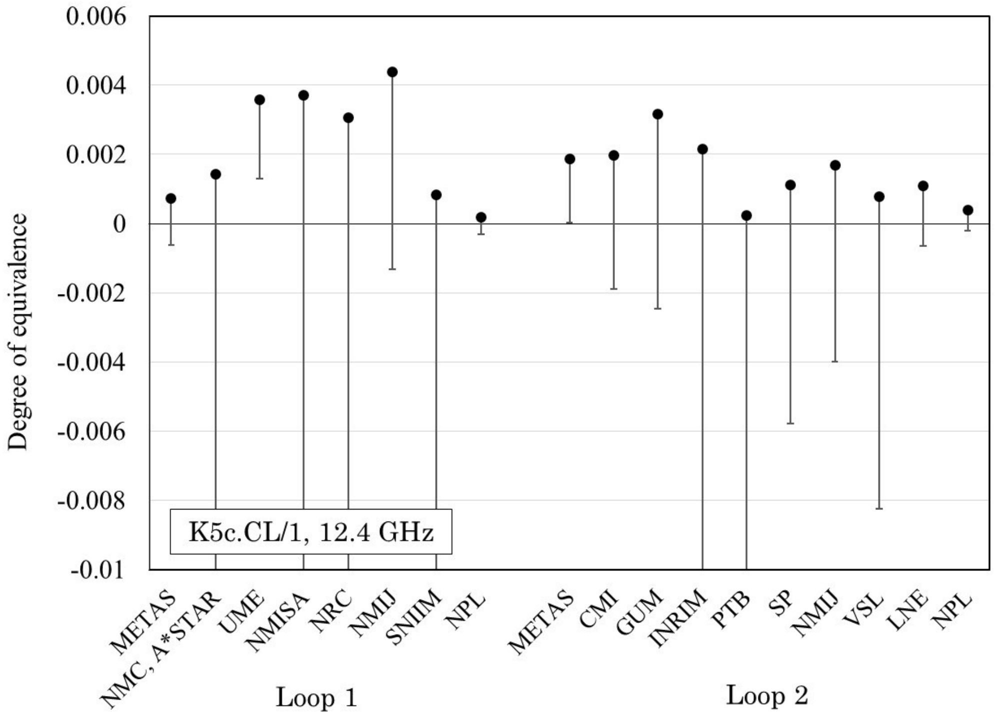

Fig. 3.2.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 12.4 GHz (enlarged view of Fig. 3.2.7.).

K5c.CL/1 at 26.5 GHz

Table 3.3.1. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 1) at 26.5 GHz.

Laboratory	K5c.CL/1 (Loop 1) Measurement and combined uncertainty of S_{21} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.98293	0.00072	0.10147	0.00089	
NMC, A*STAR	-0.9833	0.0082	0.1004	0.0082	
UME	*-0.9835*	*0.0012*	*0.0940*	*0.0012*	*0.98*
NMISA	-0.9847	0.0080	0.1007	0.0080	
NRC	-0.988	0.014	0.101	0.014	
NMIJ	-0.9771	0.0032	0.1047	0.0032	
SNIIM	-0.9827	0.0046	0.1006	0.0046	
NPL	-0.98212	0.00080	0.10288	0.00080	
KCRV	-0.98244	0.00053	0.10231	0.00058	

Table 3.3.2. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 2) at 26.5 GHz.

Laboratory	K5c.CL/1 (Loop 2) Measurement and combined uncertainty of S_{21} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	*-0.98261*	*0.00074*	*0.09723*	*0.00091*	
CMI	-0.9823	0.0013	0.0979	0.0051	0.38
GUM	-0.9809	0.0027	0.1000	0.0027	
INRIM	-0.9840	0.0040	0.091	0.034	0.79
PTB	-0.9809	0.0050	0.0955	0.0050	
SP	-0.9834	0.0049	0.0915	0.0049	
NMIJ	-0.9798	0.0032	0.0927	0.0032	
VSL	-0.9826	0.0011	0.0922	0.0088	
LNE	-0.9796	0.0017	0.0953	0.0017	
NPL	-0.9823	0.0010	0.0932	0.0010	
KCRV	-0.98191	0.00064	0.09375	0.00081	

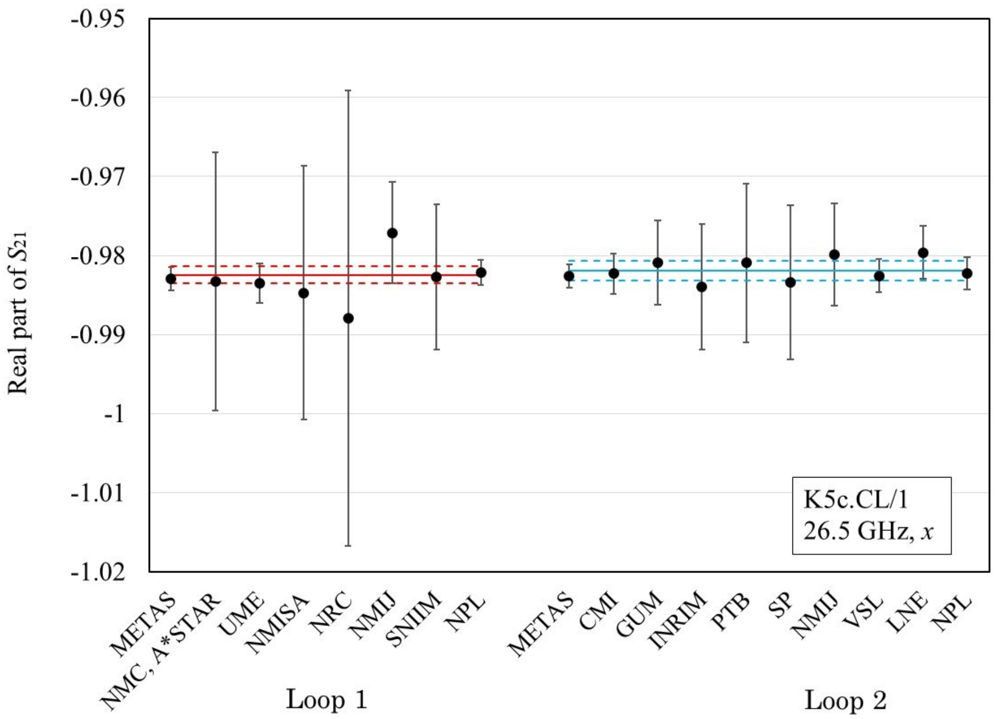

Fig. 3.3.1. Reported results and KCRV for ReS_{21} of K5c.CL/1 at 26.5 GHz.

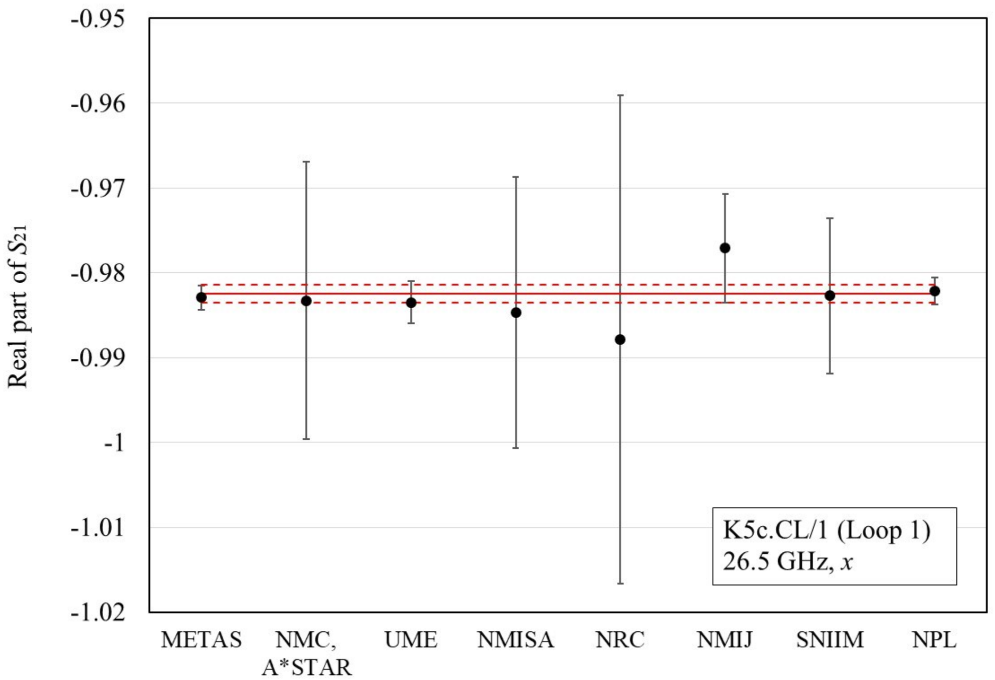

Fig. 3.3.2. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.3.1.).

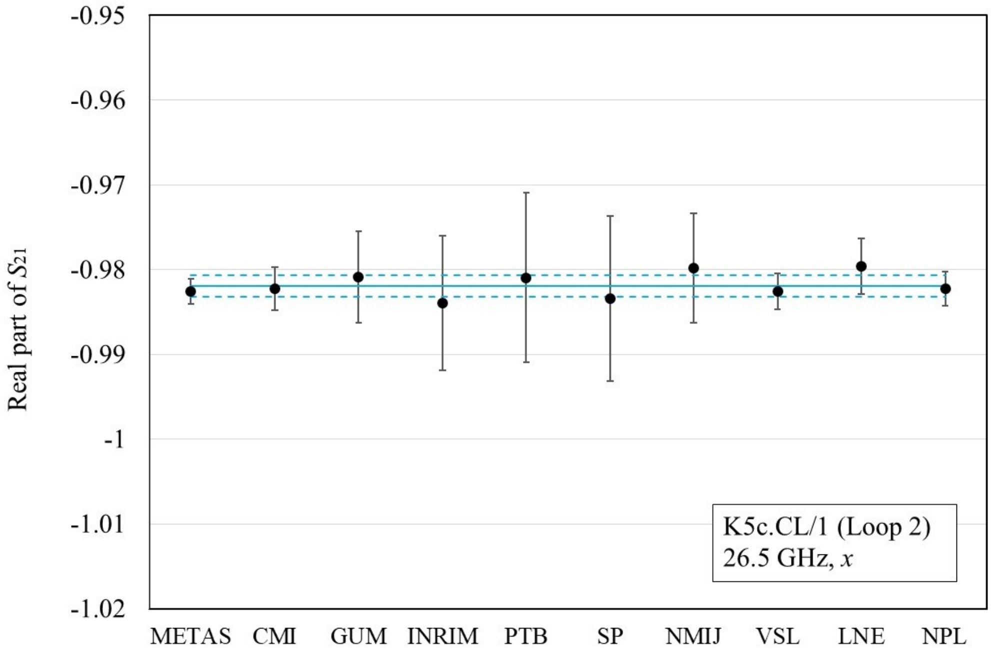

Fig. 3.3.3. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.3.1.).

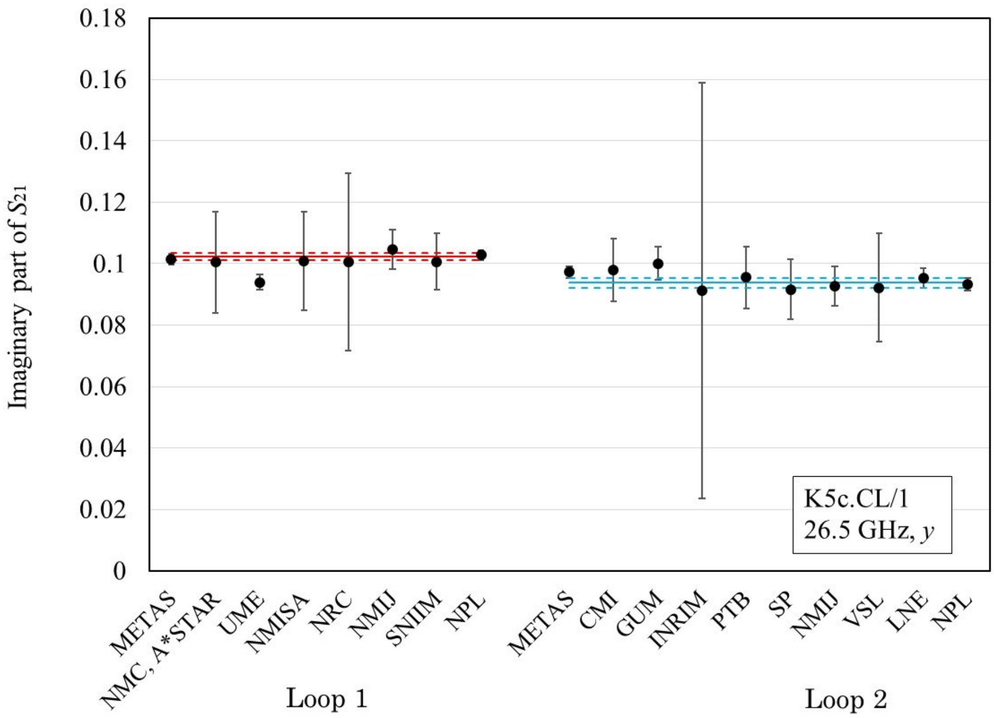

Fig. 3.3.4. Reported results and KCRV for ImS_{21} of K5c.CL/1 at 26.5 GHz.

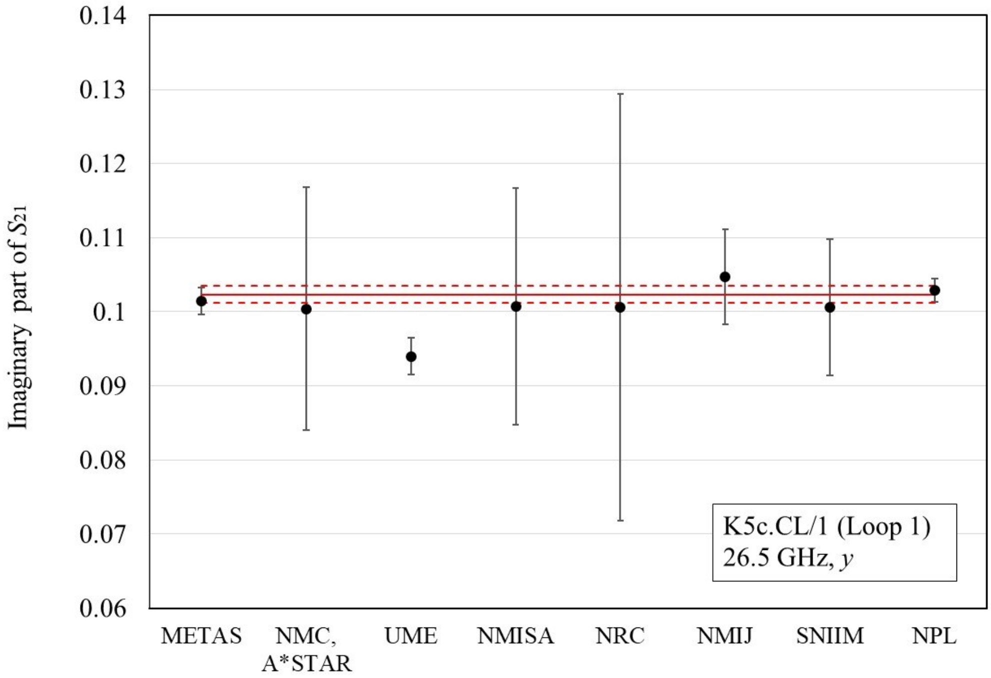

Fig. 3.3.5. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.3.4.).

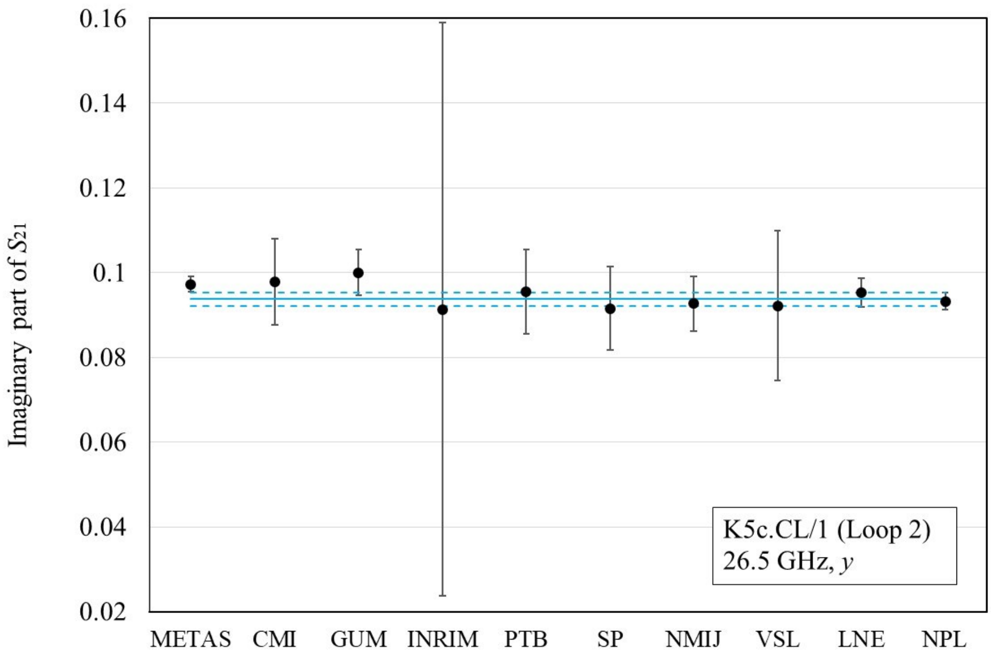

Fig. 3.3.6. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.3.4.).

Table 3.1.3. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 1) at 26.5 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0010	0.0015
NMC, A*STAR	0.002	0.020
UME	0.0084	0.0034
NMISA	0.003	0.020
NRC	0.006	0.035
NMIJ	0.0058	0.0078
SNIIM	0.002	0.011
NPL	0.0007	0.0014

Table 3.3.4. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 2) at 26.5 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0035	0.0030
CMI	0.004	0.012
GUM	0.0063	0.0069
INRIM	0.003	0.015
PTB	0.002	0.012
SP	0.003	0.012
NMIJ	0.0023	0.0077
VSL	0.0017	0.0052
LNE	0.0028	0.0037
NPL	0.0006	0.0016

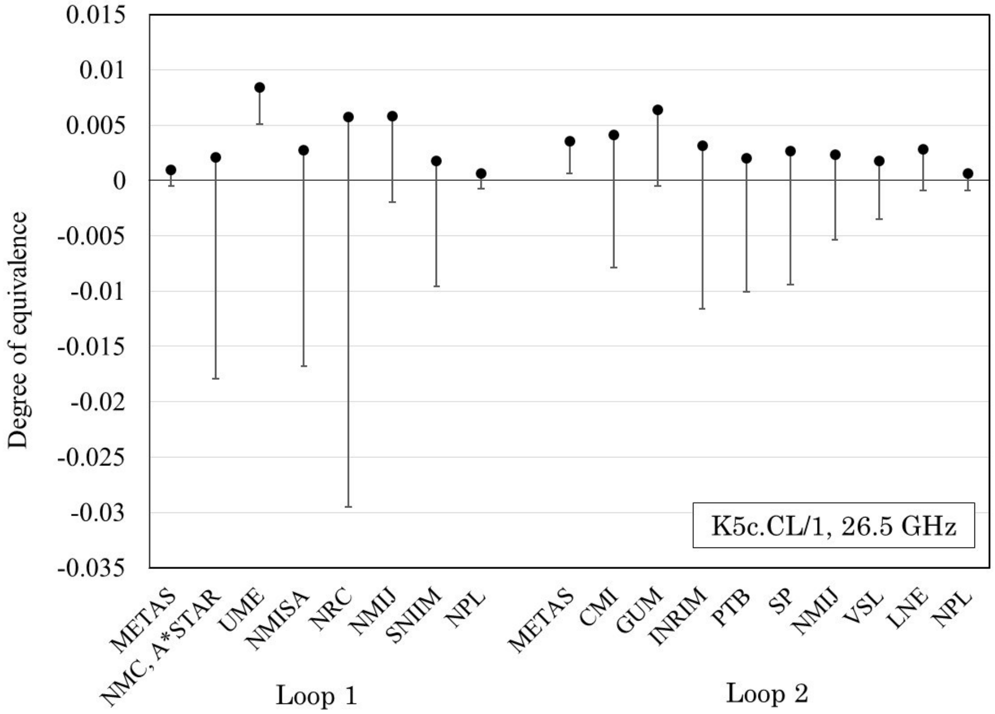

Fig. 3.3.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 26.5 GHz.

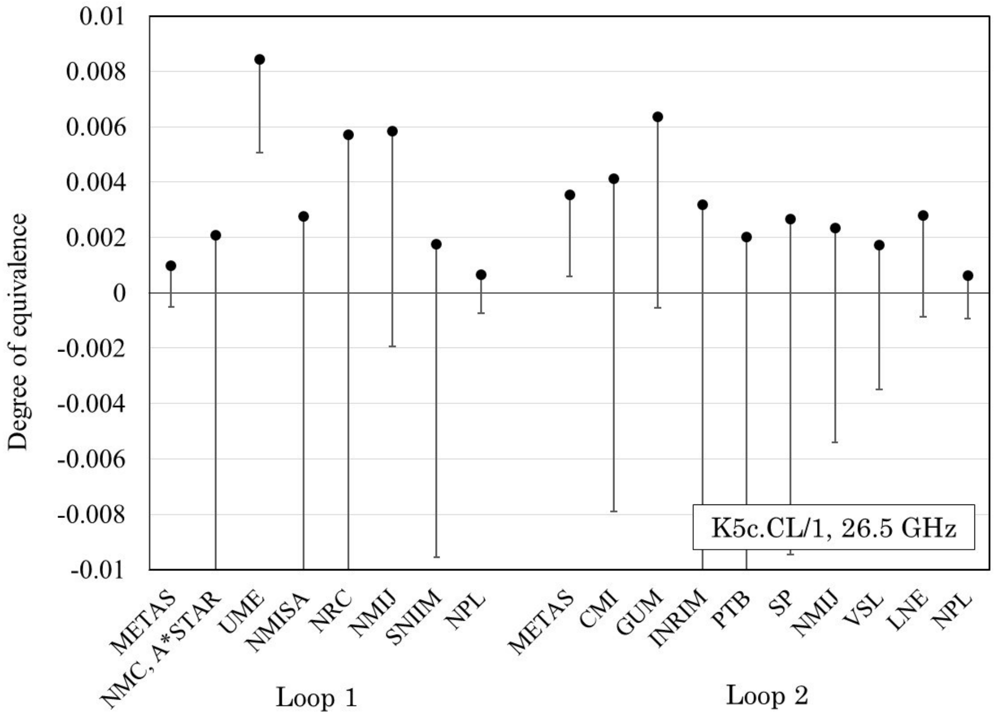

Fig. 3.3.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 26.5 GHz (enlarged view of Fig. 3.3.7.).

K5c.CL/1 at 33 GHz

Table 3.4.1. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 1) at 33 GHz.

Laboratory	K5c.CL/1 (Loop 1) Measurement and combined uncertainty of S_{21} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.65736	0.00092	-0.73513	0.00092	
NMC, A*STAR	0.6570	0.0085	-0.7366	0.0085	
UME	*0.6649*	*0.0012*	*-0.7284*	*0.0012*	*1.0*
NMISA					
NRC	0.661	0.014	-0.740	0.014	
NMIJ	0.6508	0.0036	-0.7339	0.0036	
SNIIM	0.6583	0.0072	-0.7340	0.0072	
NPL	0.6557	0.0010	-0.7356	0.0010	
KCRV	0.65640	0.00066	-0.73533	0.00066	

Table 3.4.2. Reported results and KCRV for S_{21} of K5c.CL/1 (Loop 2) at 33 GHz.

Laboratory	K5c.CL/1 (Loop 2) Measurement and combined uncertainty of S_{21} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	*0.66075*	*0.00093*	*-0.73123*	*0.00093*	
CMI	0.6602	0.0049	-0.7309	0.0044	0.91
GUM	0.6567	0.0027	-0.7326	0.0027	
INRIM	0.665	0.030	-0.725	0.028	0.99
PTB	0.6612	0.0050	-0.7263	0.0050	
SP	0.6667	0.0051	-0.7266	0.0051	
NMIJ	0.6629	0.0036	-0.7251	0.0036	
VSL	0.6653	0.0065	-0.7264	0.0060	
LNE	0.6590	0.0025	-0.7269	0.0025	
NPL	0.6641	0.0013	-0.7270	0.0013	
KCRV	0.6630	0.0010	-0.7268	0.0010	

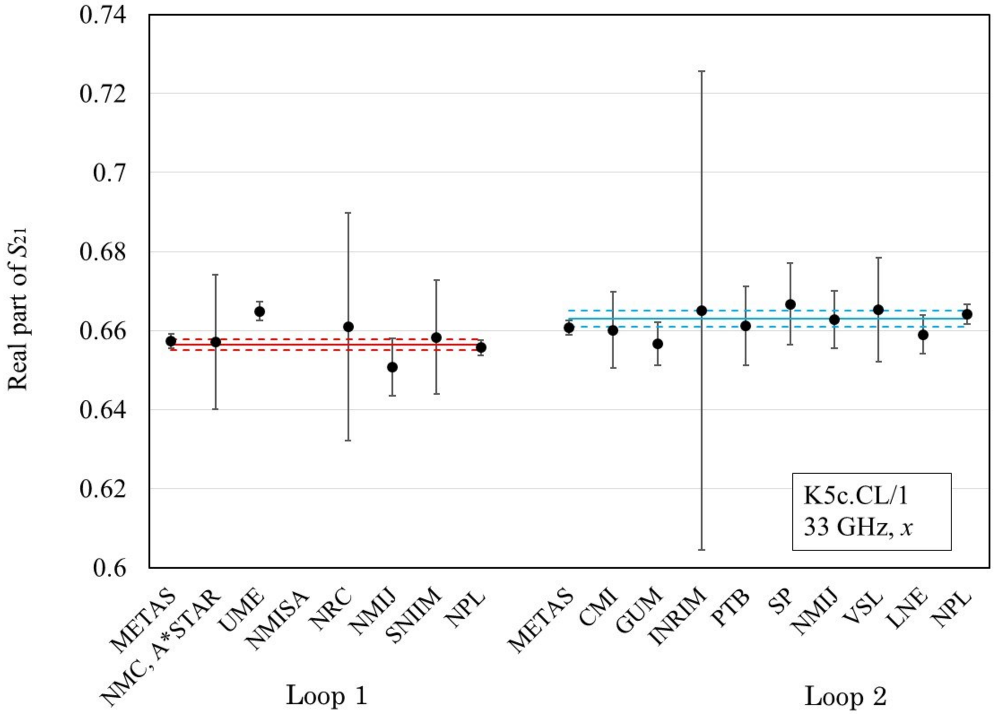

Fig. 3.4.1. Reported results and KCRV for ReS_{21} of K5c.CL/1 at 33 GHz.

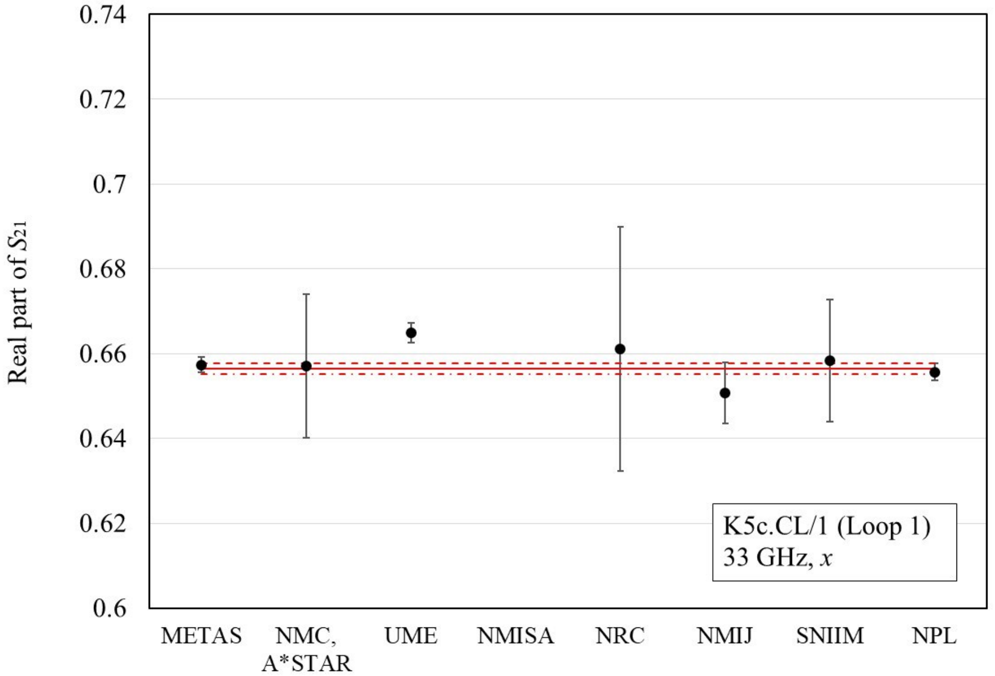

Fig. 3.4.2. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 1) at 33 GHz (enlarged view of Fig. 3.4.1.).

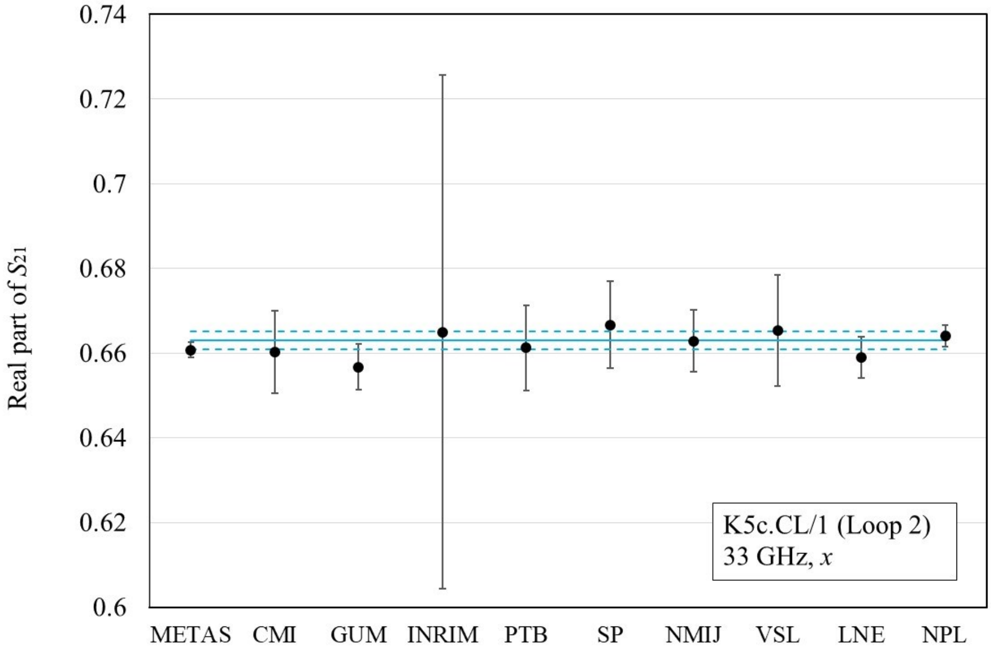

Fig. 3.4.3. Reported results and KCRV for ReS_{21} of K5c.CL/1 (Loop 2) at 33 GHz (enlarged view of Fig. 3.4.1.).

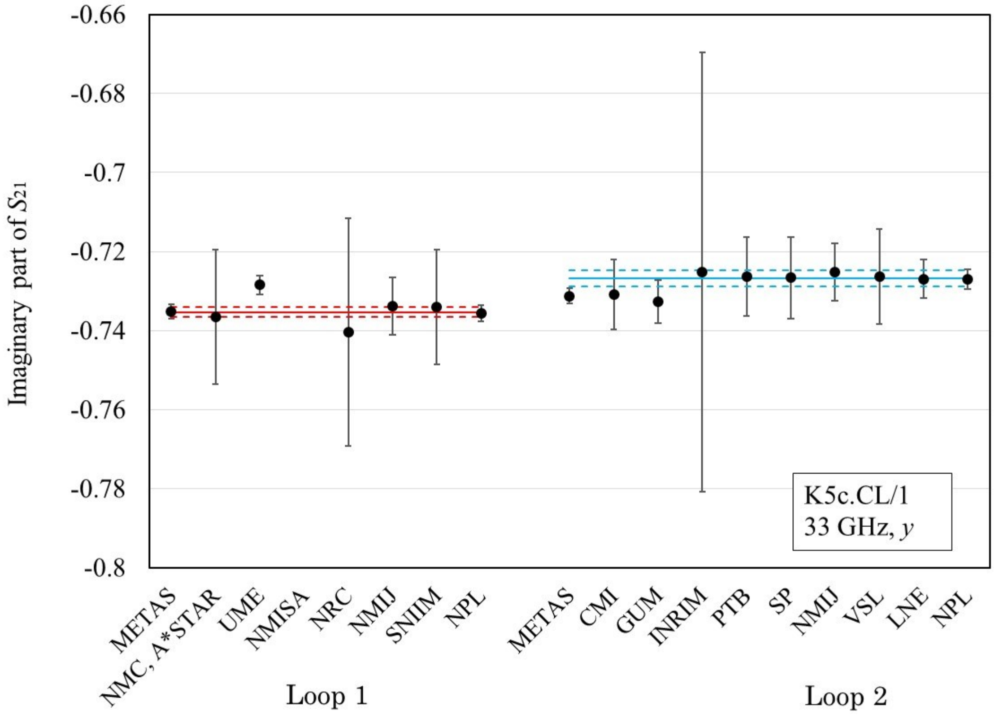

Fig. 3.4.4. Reported results and KCRV for ImS_{21} of K5c.CL/1 at 33 GHz.

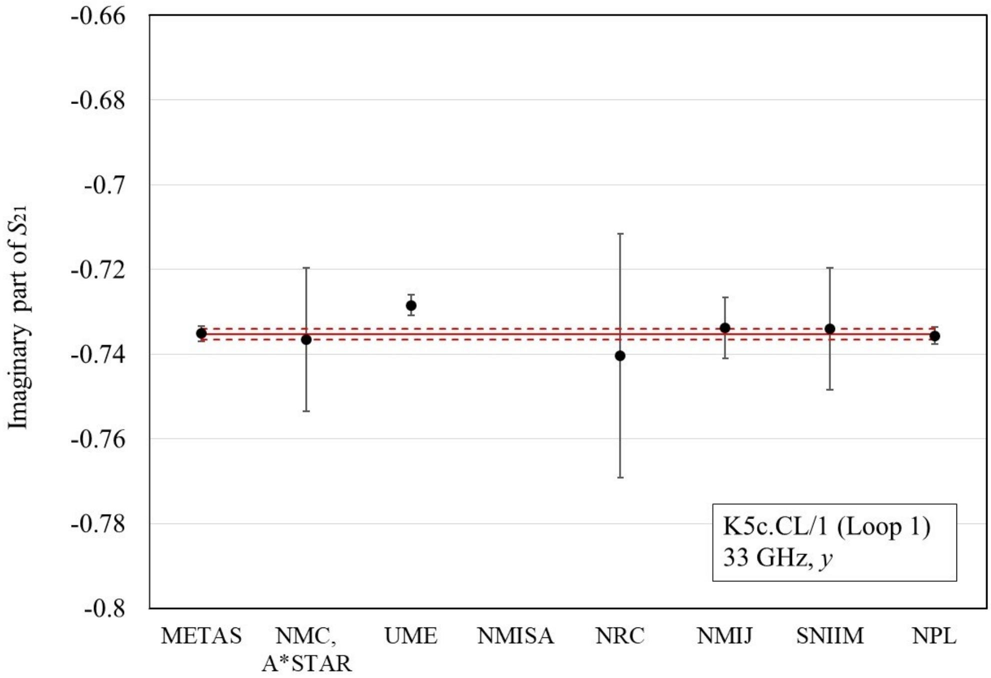

Fig. 3.4.5. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 1) at 33 GHz (enlarged view of Fig. 3.4.4.).

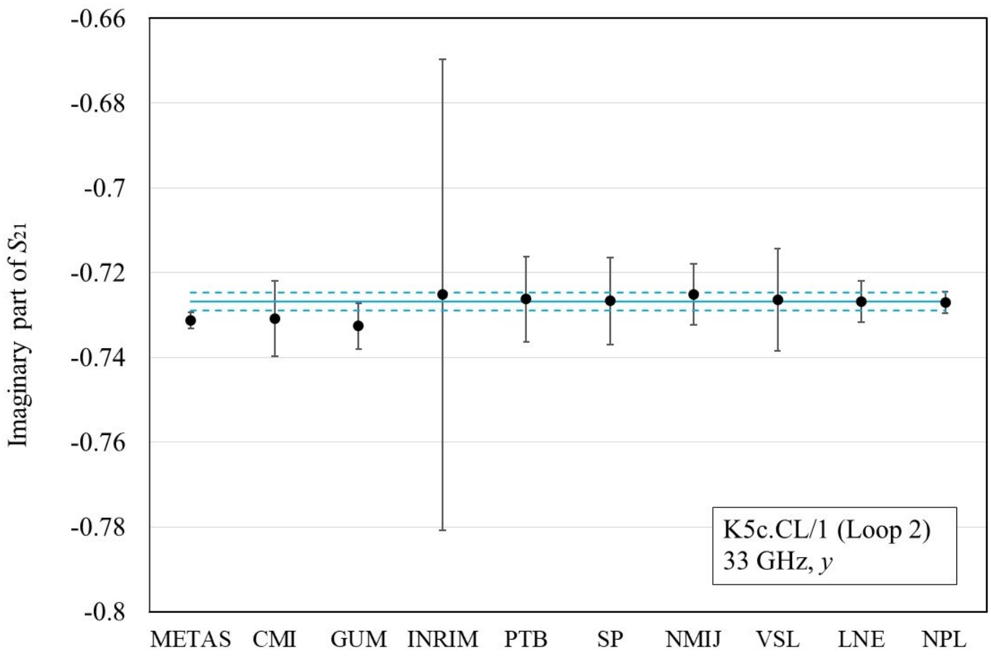

Fig. 3.4.6. Reported results and KCRV for ImS_{21} of K5c.CL/1 (Loop 2) at 33 GHz (enlarged view of Fig. 3.4.4.).

Table 3.4.3. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 1) at 33 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0010	0.0016
NMC, A*STAR	0.001	0.021
UME	0.0110	0.0033
NMISA		
NRC	0.007	0.035
NMIJ	0.0058	0.0087
SNIIM	0.002	0.018
NPL	0.0008	0.0018

Table 3.4.4. Reduced dimensional DoE for S_{21} of K5c.CL/1 (Loop 2) at 33 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0050	0.0034
CMI	0.005	0.011
GUM	0.0085	0.0071
INRIM	0.003	0.072
PTB	0.002	0.012
SP	0.004	0.013
NMIJ	0.0017	0.0085
VSL	0.002	0.016
LNE	0.0040	0.0054
NPL	0.0011	0.0018

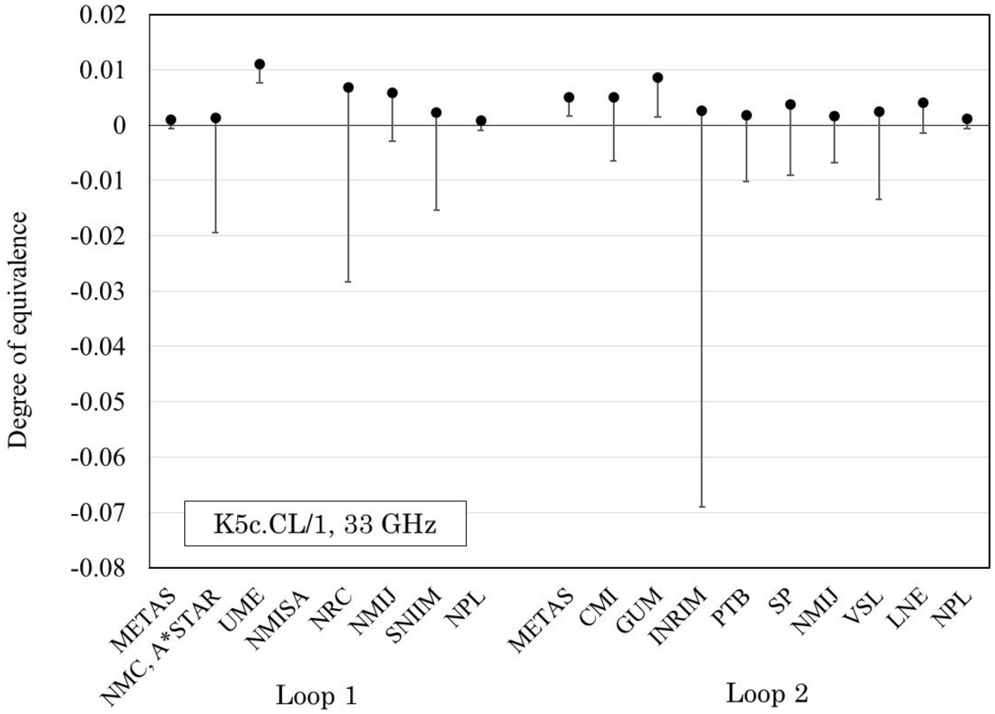

Fig. 3.4.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 33 GHz.

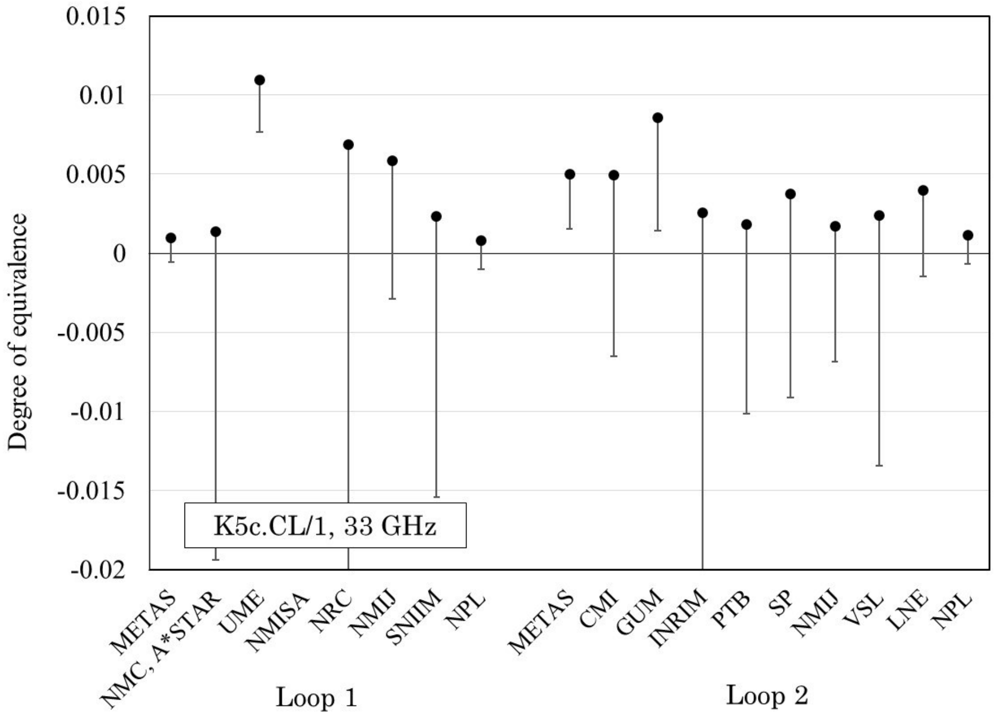

Fig. 3.4.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/1 at 33 GHz (enlarged view of Fig. 3.4.7.).

K5c.CL/2 at 0.1 GHz

Table 3.5.1. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 1) at 0.1 GHz.

Laboratory	K5c.CL/2 (Loop 1) Measurement and combined uncertainty of S_{21} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.099241	0.000072	-0.00711	0.00011	
NMC, A*STAR	0.0992	0.0040	-0.0070	0.0040	
UME	*0.099008*	*0.000080*	*-0.007225*	*0.000080*	*0.21*
NMISA	0.09926	0.00017	-0.00698	0.00017	
NRC	0.0994	0.0046	-0.0072	0.0046	
NMIJ	0.09915	0.00016	-0.00723	0.00016	
SNIIM	0.09922	0.00028	-0.00709	0.00028	
NPL	0.099228	0.000093	-0.007091	0.000093	
KCRV	0.099230	0.000051	-0.007102	0.000061	

Table 3.5.2. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 2) at 0.1 GHz.

Laboratory	K5c.CL/2 (Loop 2) Measurement and combined uncertainty of S_{21} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.099767	0.000073	-0.00716	0.00011	
CMI	0.09977	0.00023	-0.00720	0.00023	-0.00041
GUM	0.09981	0.00046	-0.00718	0.00046	
INRIM	0.09977	0.00025	-0.00715	0.00051	0.11
PTB	0.09975	0.00050	-0.00723	0.00050	
SP	0.09975	0.00015	-0.00714	0.00015	
NMIJ	0.09966	0.00016	-0.00720	0.00016	
VSL	0.09972	0.00012	-0.00716	0.00016	
LNE	0.09960	0.00011	-0.00710	0.00011	
NPL	0.099742	0.000094	-0.007146	0.000094	
KCRV	0.099720	0.000044	-0.007147	0.000053	

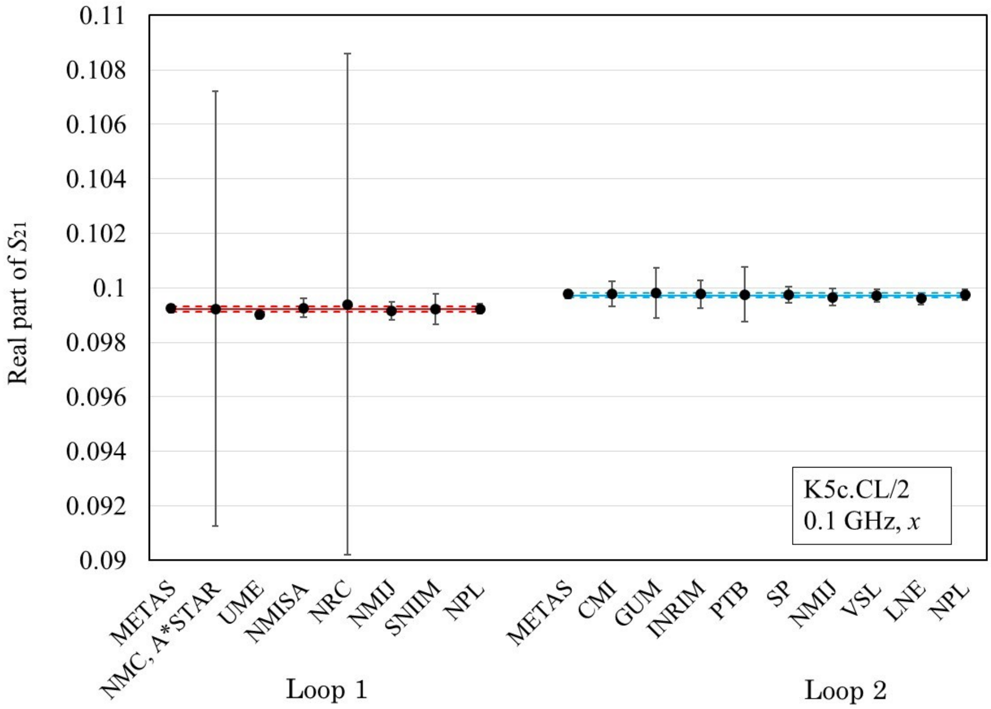

Fig. 3.5.1. Reported results and KCRV for ReS_{21} of K5c.CL/2 at 0.1 GHz.

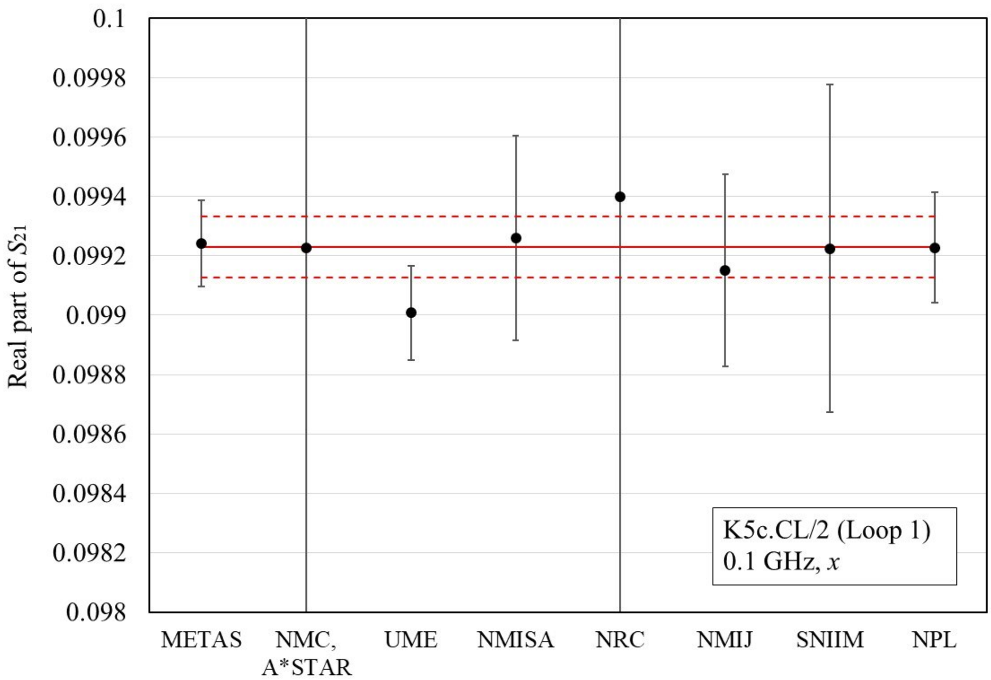

Fig. 3.5.2. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.5.1.).

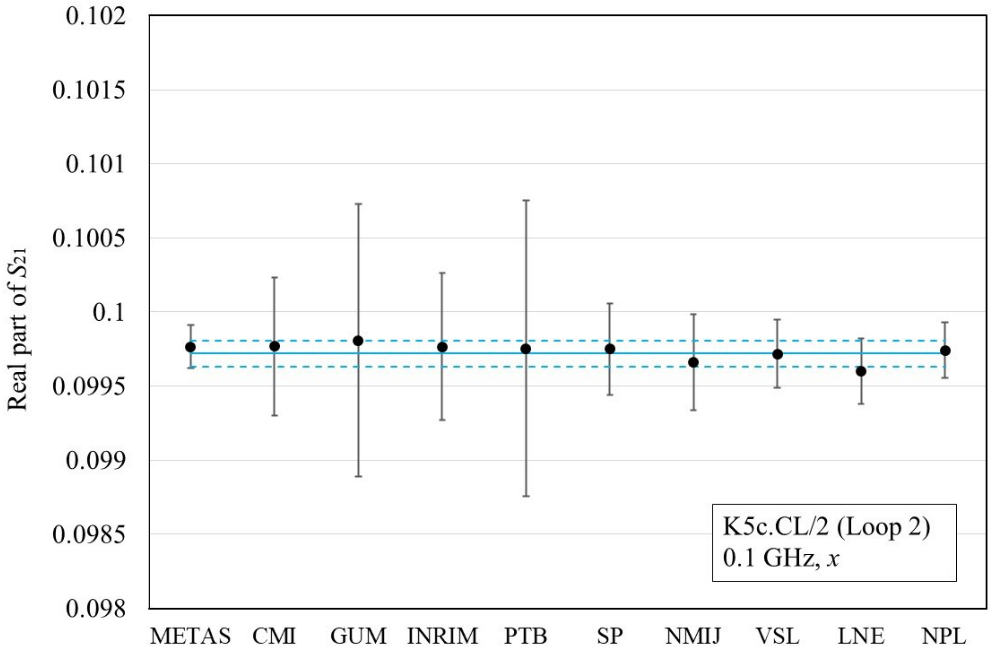

Fig. 3.5.3. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.5.1.).

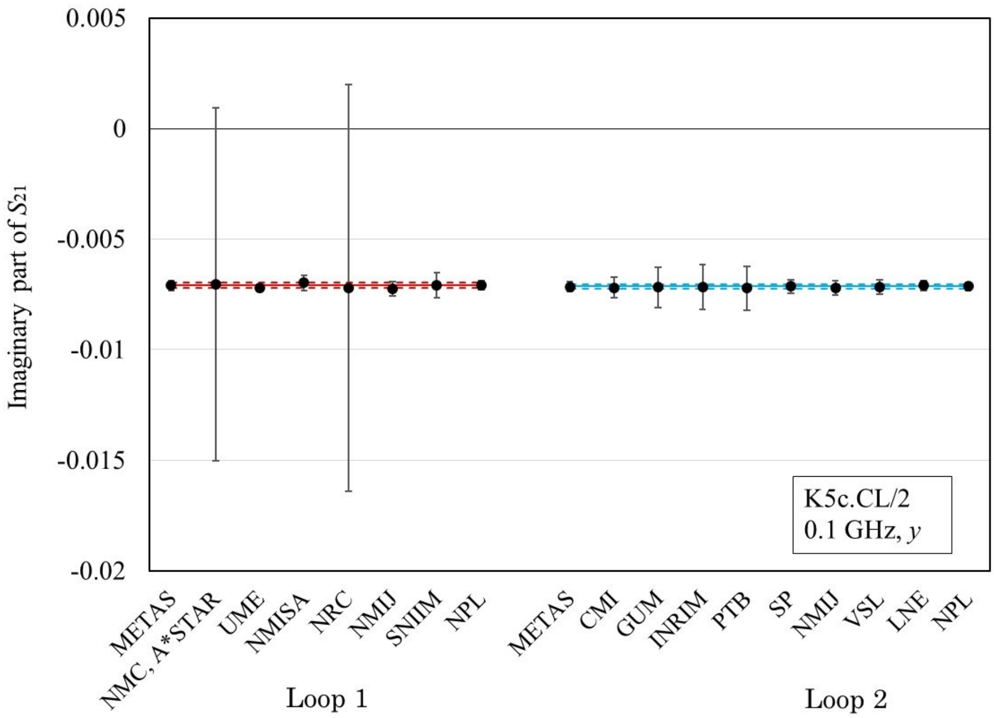

Fig. 3.5.4. Reported results and KCRV for ImS_{21} of K5c.CL/2 at 0.1 GHz.

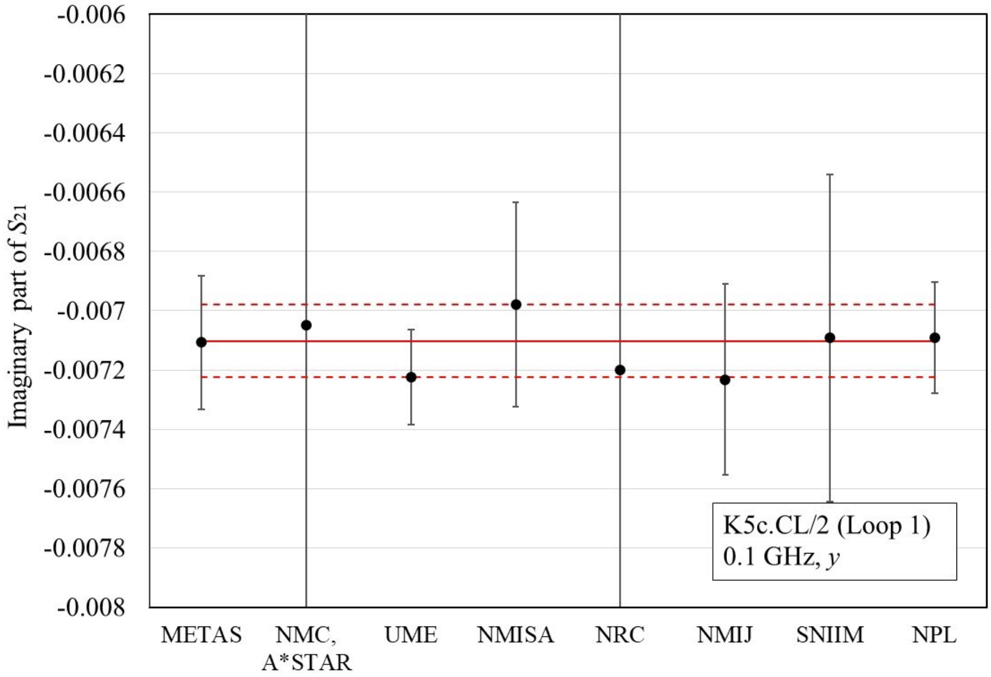

Fig. 3.5.5. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.5.4.).

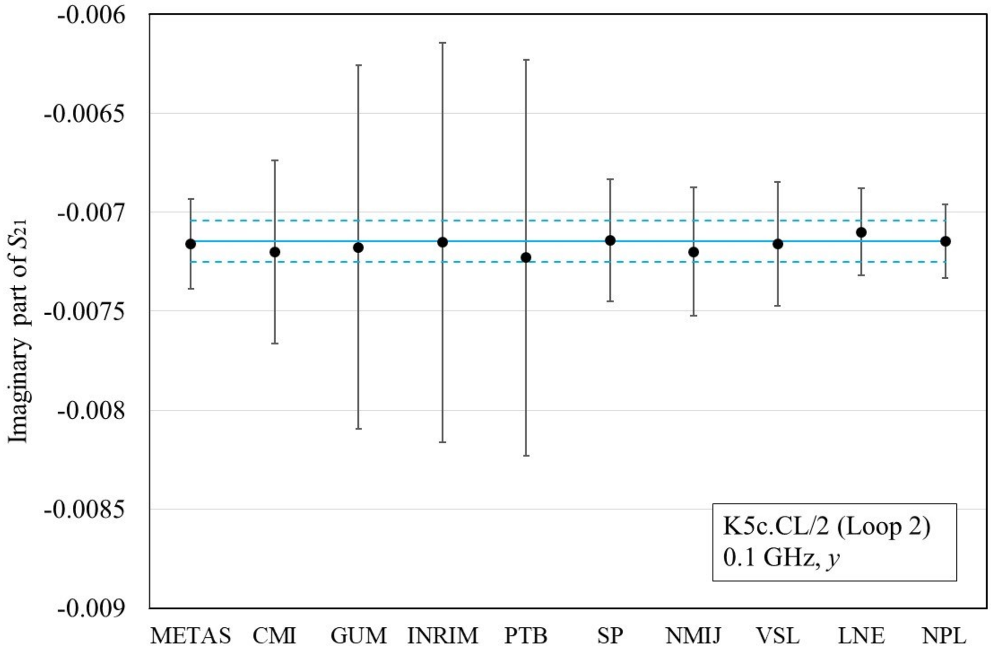

Fig. 3.5.6. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.5.4.).

Table 3.5.3. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 1) at 0.1 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.00001	0.00013
NMC, A*STAR	0.0001	0.0098
UME	0.00025	0.00024
NMISA	0.00013	0.00039
NRC	0.000	0.011
NMIJ	0.00015	0.00037
SNIIM	0.00001	0.00069
NPL	0.00001	0.00017

Table 3.5.4. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 2) at 0.1 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.00005	0.00015
CMI	0.00007	0.00058
GUM	0.0001	0.0011
INRIM	0.00005	0.00060
PTB	0.0001	0.0012
SP	0.00003	0.00039
NMIJ	0.00008	0.00038
VSL	0.00001	0.00035
LNE	0.00013	0.00025
NPL	0.00002	0.00020

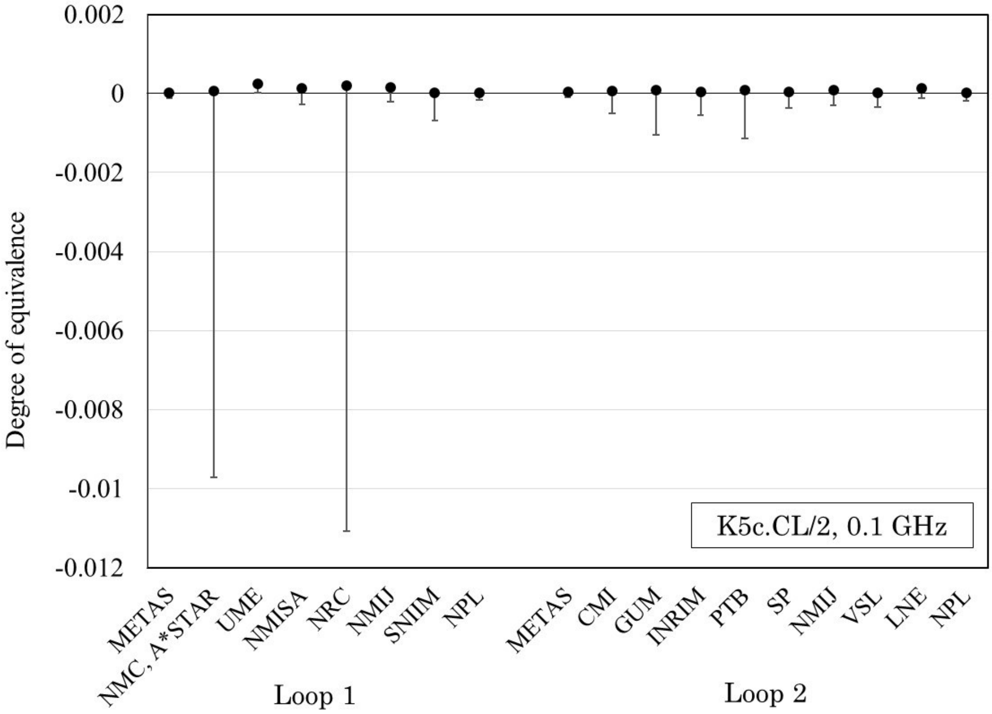

Fig. 3.5.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 0.1 GHz.

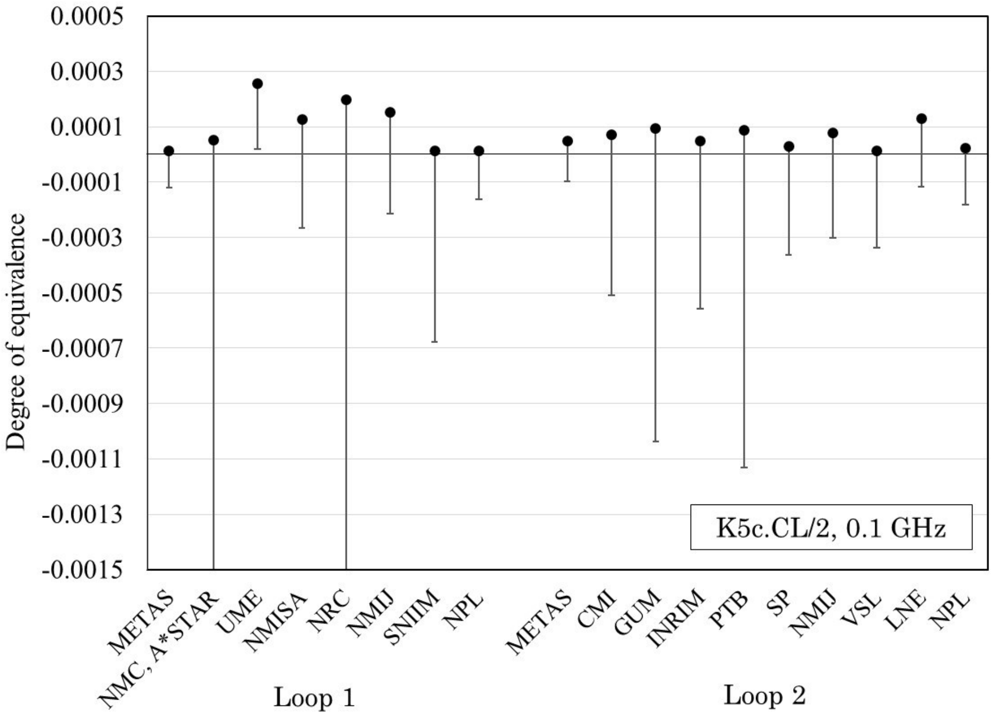

Fig. 3.5.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 0.1 GHz (enlarged view of Fig. 3.5.7.).

K5c.CL/2 at 12.4 GHz

Table 3.6.1. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 1) at 12.4 GHz.

Laboratory	K5c.CL/2 (Loop 1) Measurement and combined uncertainty of S_{21} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.075554	0.000065	-0.060911	0.000066	
NMC, A*STAR	-0.0758	0.0082	-0.0606	0.0082	
UME	-0.07544	0.00010	-0.06068	0.00010	-0.91
NMISA	-0.07563	0.00078	-0.06056	0.00078	
NRC	-0.0765	0.0046	-0.0609	0.0046	
NMIJ	*-0.07577*	*0.00023*	*-0.06023*	*0.00023*	
SNIIM	-0.07546	0.00045	-0.06108	0.00045	
NPL	*-0.07586*	*0.00010*	*-0.06048*	*0.00010*	
KCRV	-0.075517	0.000053	-0.060836	0.000054	

Table 3.6.2. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 2) at 12.4 GHz.

Laboratory	K5c.CL/2 (Loop 2) Measurement and combined uncertainty of S_{21} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.076761	0.000066	-0.060126	0.000067	
CMI	-0.07673	0.00026	-0.06025	0.00027	-0.20
GUM	-0.07681	0.00038	-0.06007	0.00038	
INRIM	-0.0765	0.0011	-0.0605	0.0014	-0.96
PTB	-0.07672	0.00050	-0.06009	0.00050	
SP	-0.07661	0.00027	-0.06035	0.00027	
NMIJ	-0.07673	0.00023	-0.05972	0.00023	
VSL	-0.07672	0.00030	-0.06008	0.00037	
LNE	-0.07650	0.00013	-0.06000	0.00013	
NPL	*-0.07701*	*0.00010*	*-0.05970*	*0.00010*	
KCRV	-0.076705	0.000055	-0.060076	0.000056	

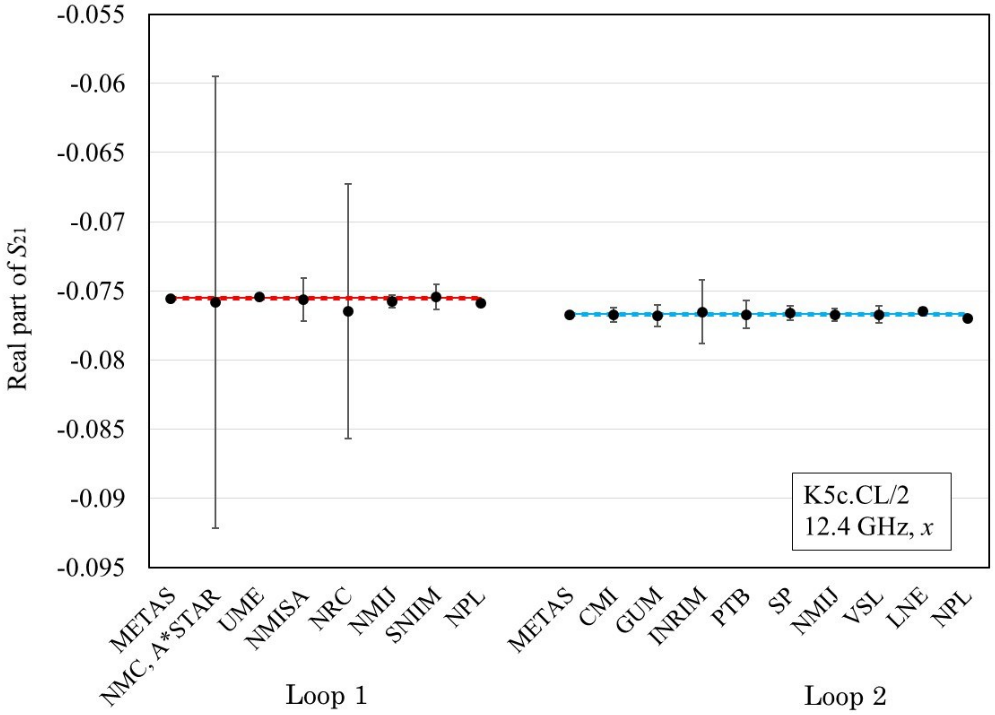

Fig. 3.6.1. Reported results and KCRV for ReS_{21} of K5c.CL/2 at 12.4 GHz.

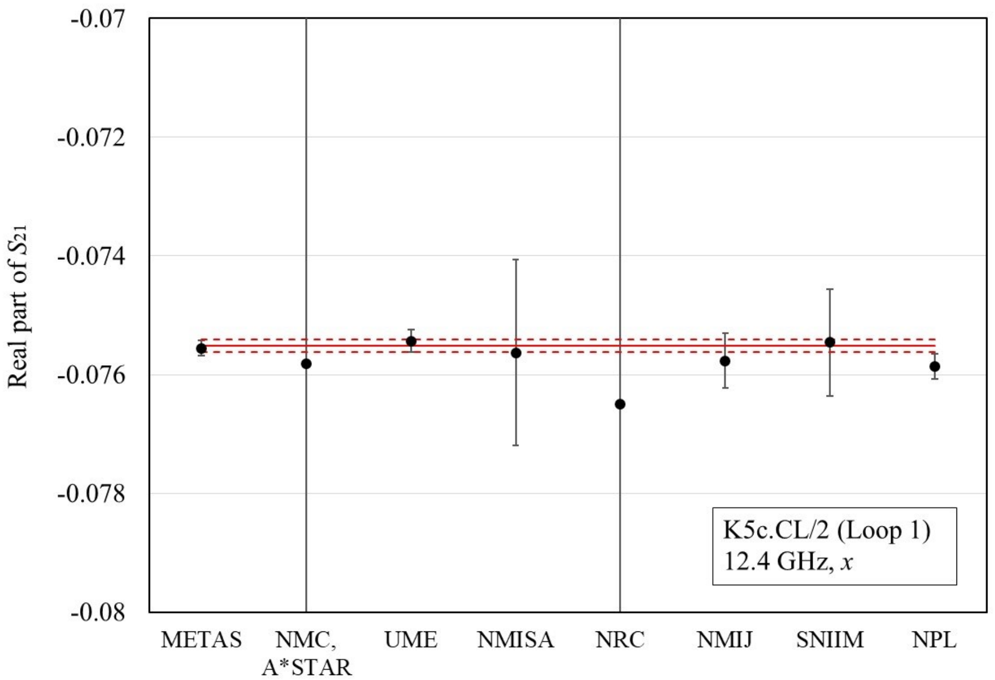

Fig. 3.6.2. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.6.1.).

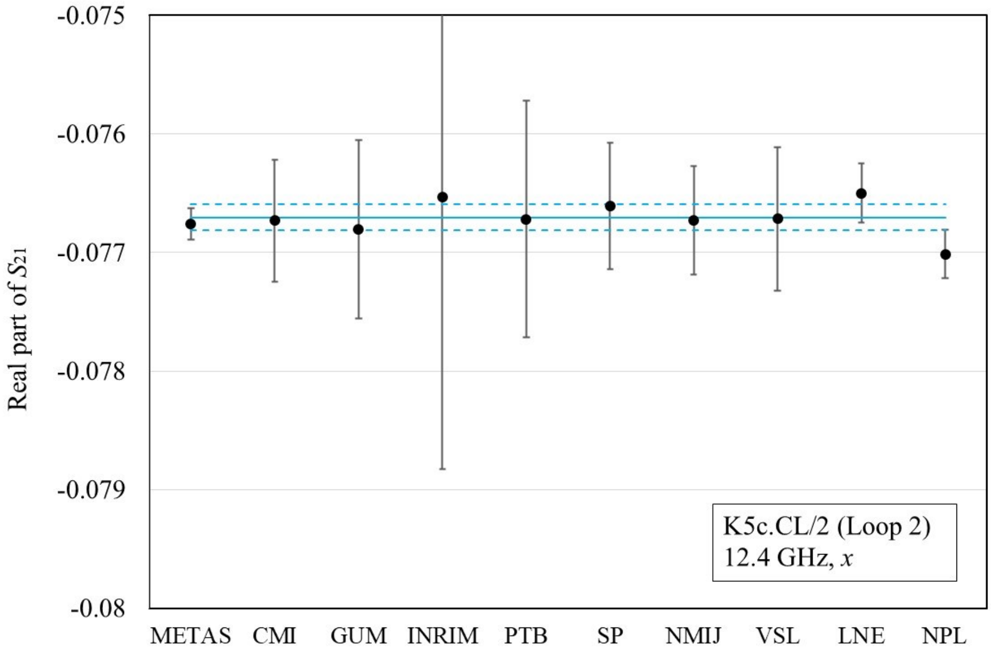

Fig. 3.6.3. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.6.1.).

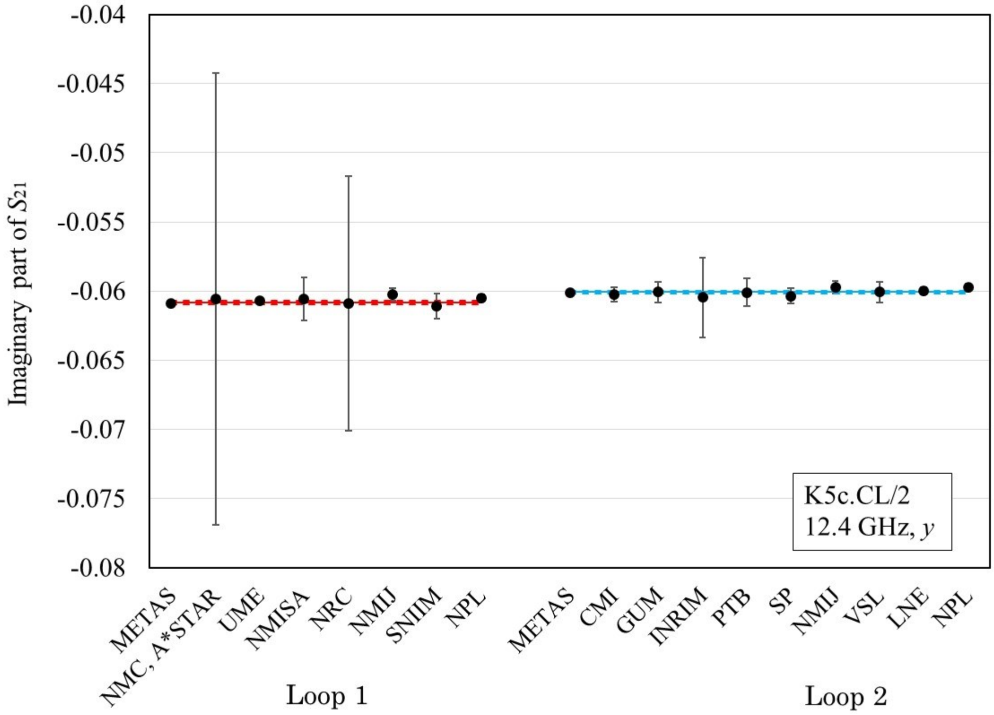

Fig. 3.6.4. Reported results and KCRV for ImS_{21} of K5c.CL/2 at 12.4 GHz.

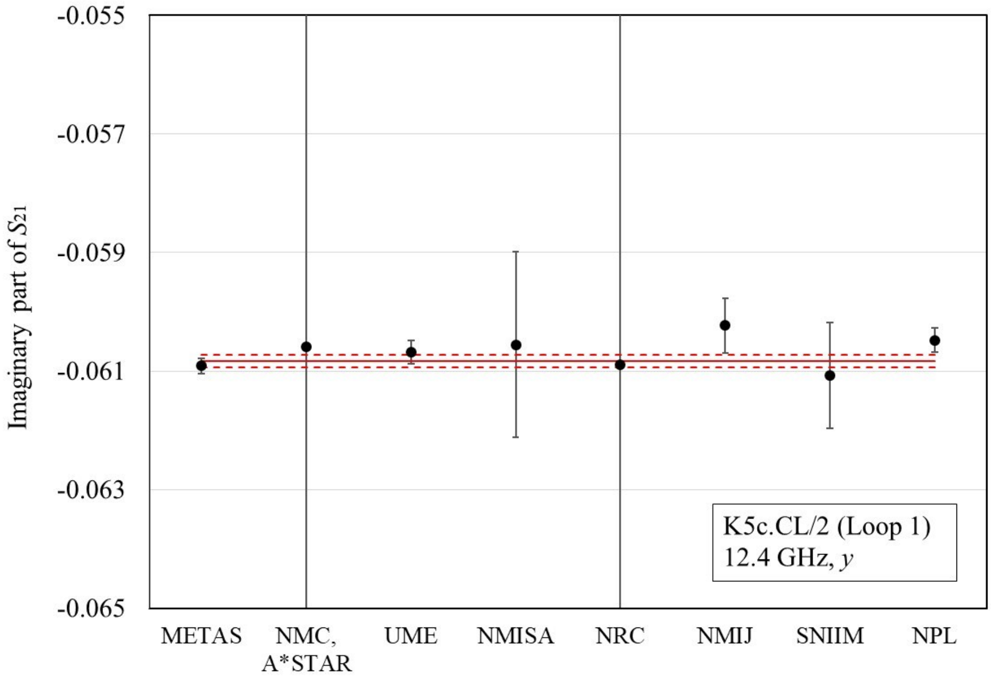

Fig. 3.6.5. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.6.4.).

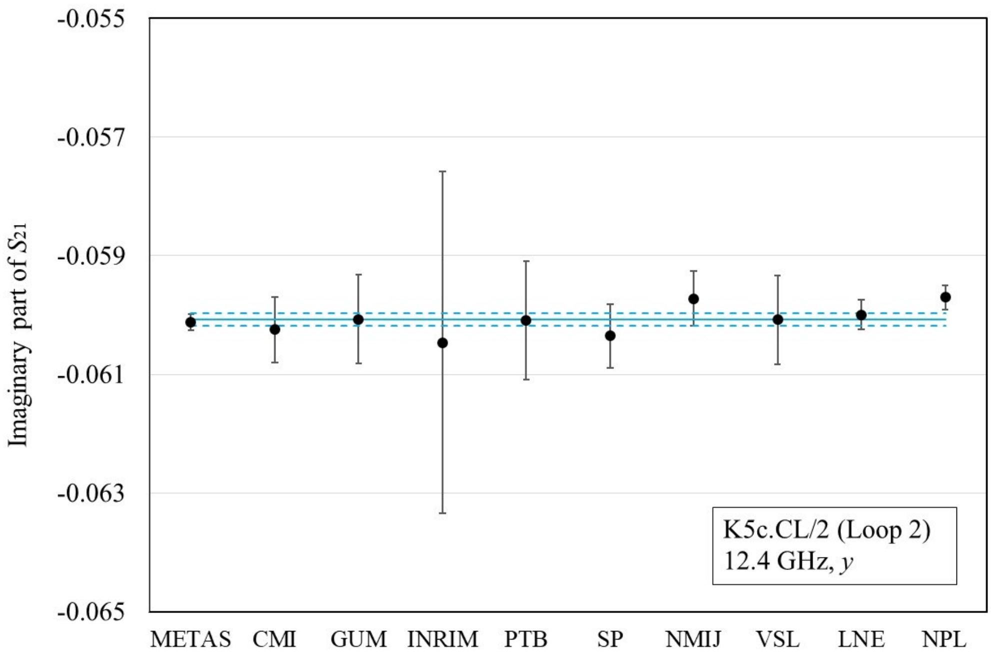

Fig. 3.6.6. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.6.4.).

Table 3.6.3. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 1) at 12.4 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.000084	0.000091
NMC, A*STAR	0.000	0.020
UME	0.00017	0.00019
NMISA	0.0003	0.0019
NRC	0.001	0.011
NMIJ	0.00065	0.00058
SNIIM	0.0002	0.0011
NPL	0.00050	0.00029

Table 3.6.4. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 2) at 12.4 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.000075	0.000089
CMI	0.00018	0.00068
GUM	0.00010	0.00093
INRIM	0.0004	0.0034
PTB	0.0000	0.0012
SP	0.00029	0.00067
NMIJ	0.00035	0.00055
VSL	0.00001	0.00076
LNE	0.00022	0.00027
NPL	0.00048	0.00028

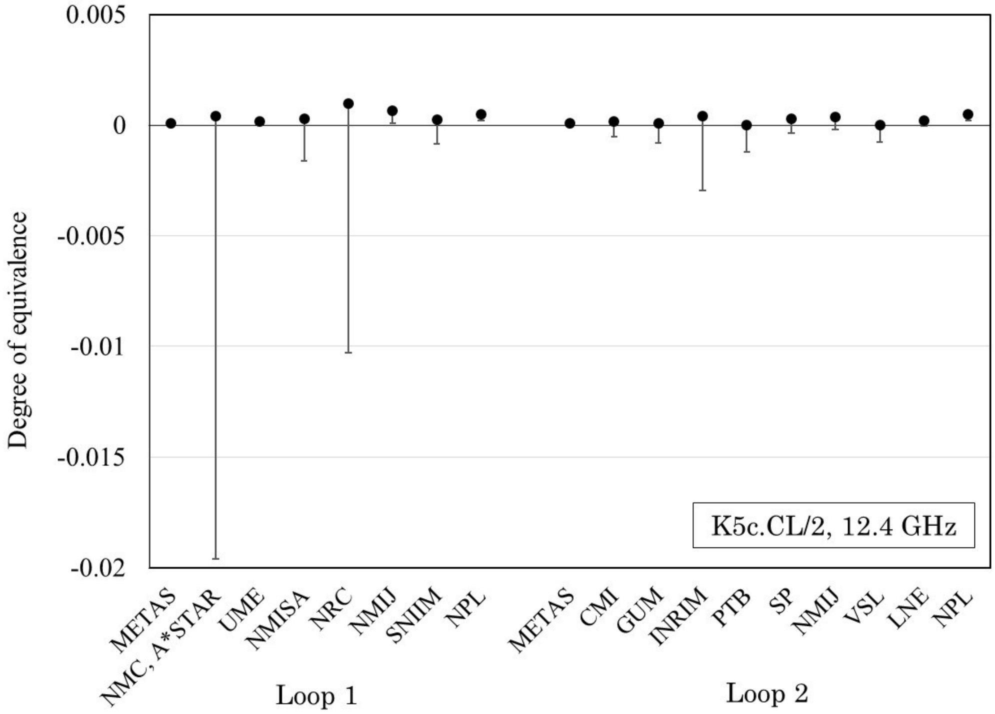

Fig. 3.6.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 12.4 GHz.

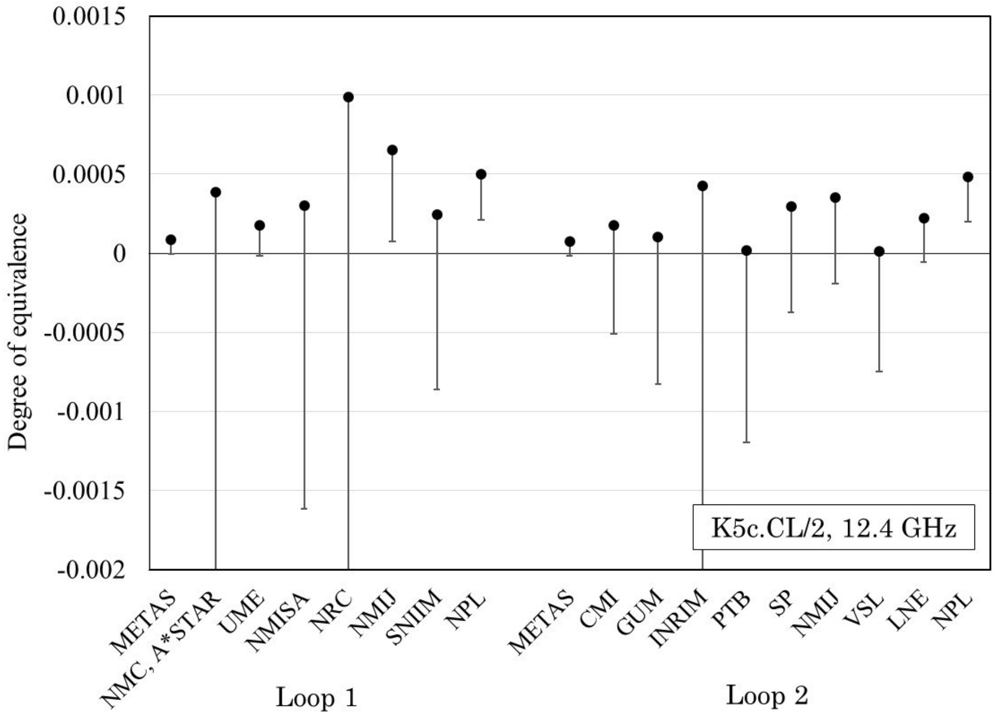

Fig. 3.6.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 12.4 GHz (enlarged view of Fig. 3.6.7.).

K5c.CL/2 at 26.5 GHz

Table 3.7.1. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 1) at 26.5 GHz.

Laboratory	K5c.CL/2 (Loop 1) Measurement and combined uncertainty of S_{21} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.094514	0.000077	0.014438	0.000093	
NMC, A*STAR	0.0946	0.0087	0.0136	0.0087	
UME	0.09427	0.00013	0.01457	0.00013	-0.91
NMISA	0.0946	0.0008	0.0143	0.0008	
NRC	0.0959	0.0046	0.0135	0.0046	
NMIJ	*0.09432*	*0.00031*	*0.01330*	*0.00031*	
SNIIM	0.09451	0.00047	0.01489	0.00047	
NPL	*0.09459*	*0.00014*	*0.01346*	*0.00014*	
KCRV	0.094450	0.000066	0.014483	0.000075	

Table 3.7.2. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 2) at 26.5 GHz.

Laboratory	K5c.CL/2 (Loop 2) Measurement and combined uncertainty of S_{21} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.096442	0.000080	0.011577	0.000096	
CMI	0.09650	0.00024	0.01192	0.00046	-0.14
GUM	0.09633	0.00045	0.01188	0.00045	
INRIM	0.09647	0.00049	0.0124	0.0033	-0.86
PTB	0.09637	0.00050	0.01160	0.00050	
SP	0.09648	0.00047	0.01216	0.00047	
NMIJ	0.09614	0.00032	0.01111	0.00032	
VSL	0.09636	0.00016	0.01162	0.00087	
LNE	*0.09580*	*0.00015*	*0.01180*	*0.00015*	
NPL	*0.09640*	*0.00013*	*0.01068*	*0.00013*	
KCRV	0.096411	0.000068	0.011542	0.000090	

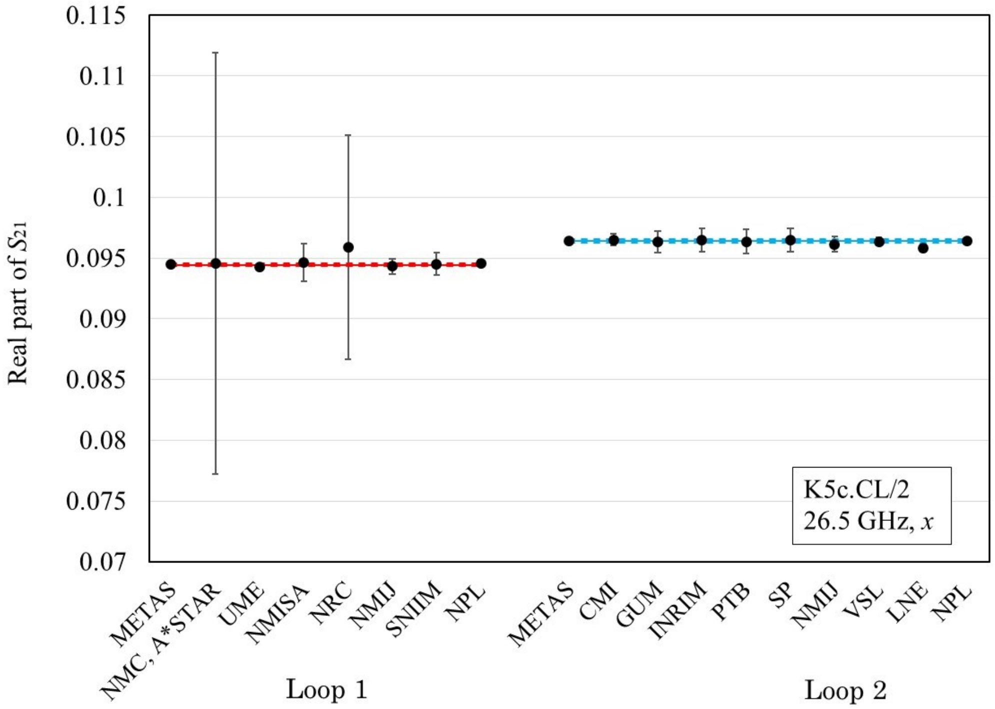

Fig. 3.7.1. Reported results and KCRV for ReS_{21} of K5c.CL/2 at 26.5 GHz.

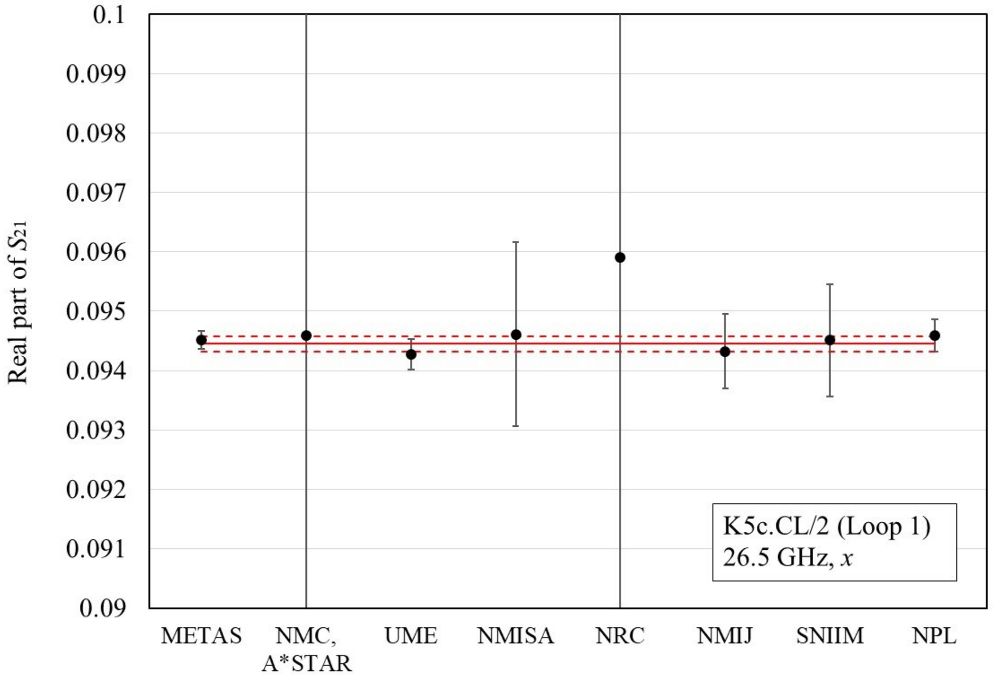

Fig. 3.7.2. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.7.1.).

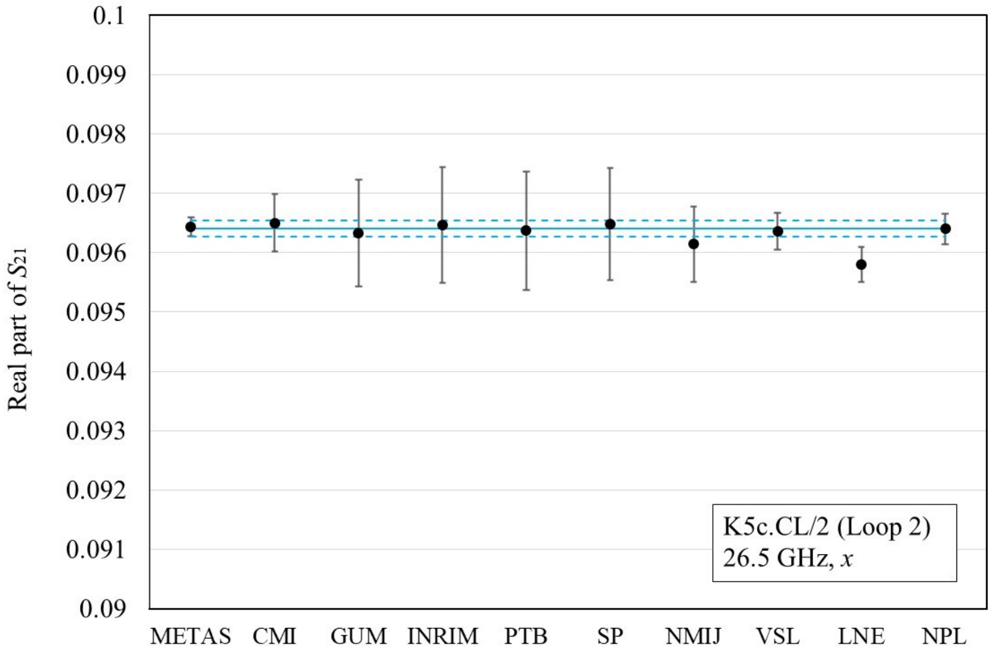

Fig. 3.7.3. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.7.1.).

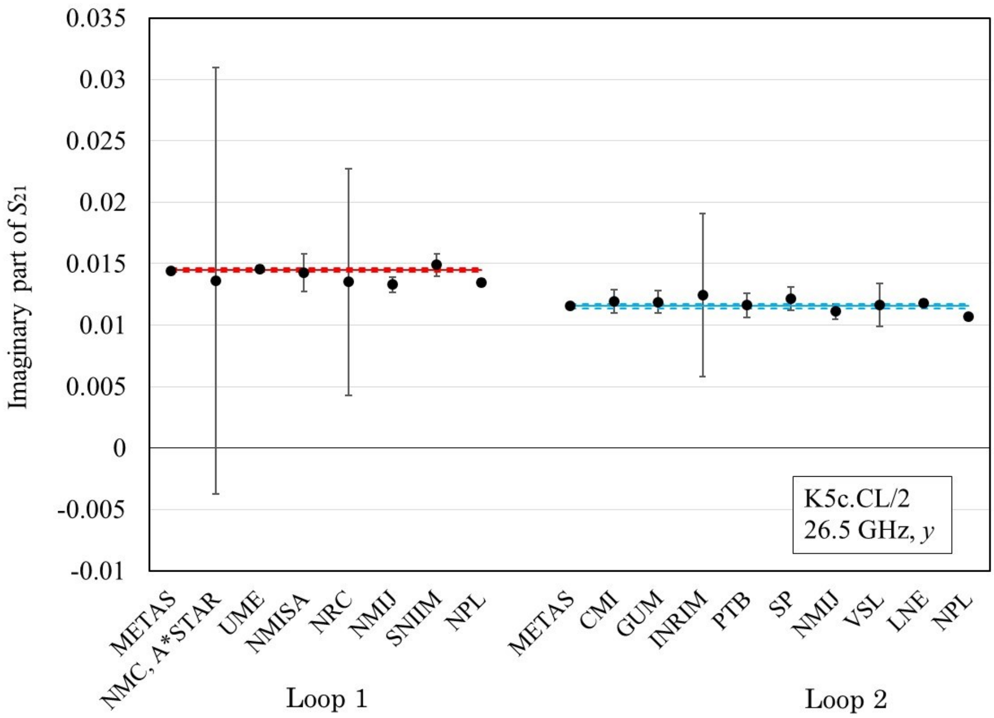

Fig. 3.7.4. Reported results and KCRV for ImS_{21} of K5c.CL/2 at 26.5 GHz.

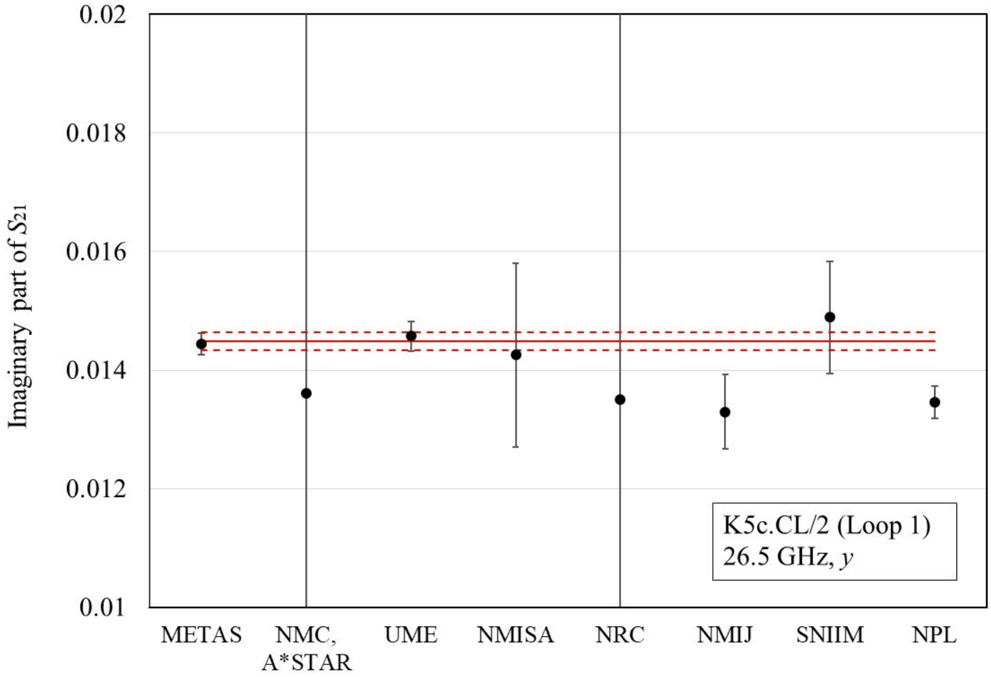

Fig. 3.7.5. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.7.4.).

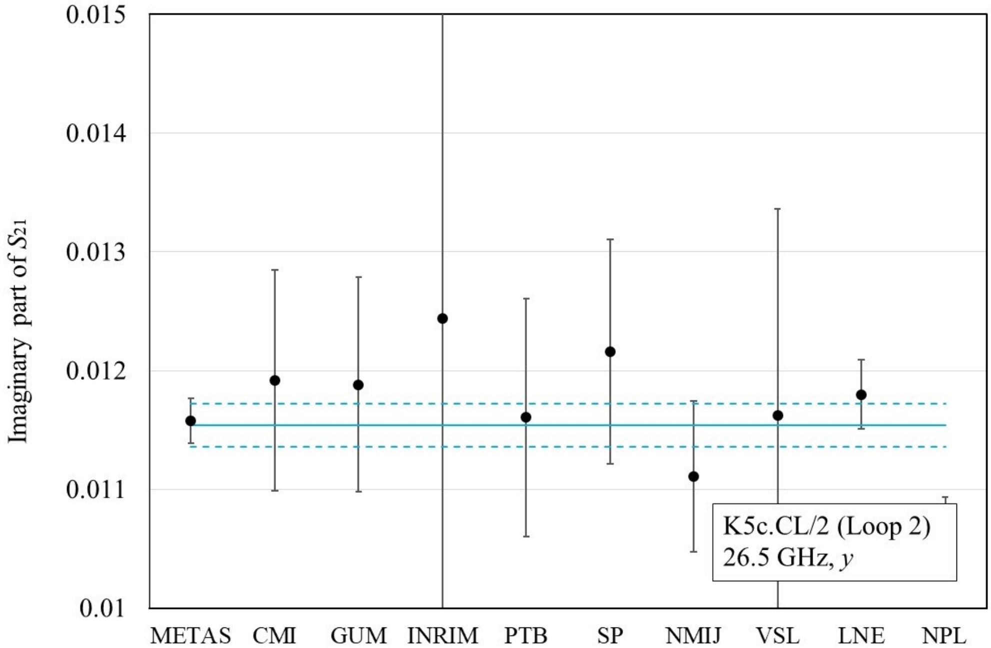

Fig. 3.7.6. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.7.4.).

Table 3.7.3. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 1) at 26.5 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.00008	0.00011
NMC, A*STAR	0.001	0.021
UME	0.00020	0.00026
NMISA	0.0003	0.0019
NRC	0.002	0.011
NMIJ	0.00119	0.00079
SNIIM	0.0004	0.0012
NPL	0.00103	0.00038

Table 3.7.4. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 2) at 26.5 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.000047	0.000090
CMI	0.0004	0.0011
GUM	0.0004	0.0011
INRIM	0.0009	0.0075
PTB	0.0001	0.0012
SP	0.0006	0.0012
NMIJ	0.00051	0.00075
VSL	0.00009	0.00060
LNE	0.00066	0.00040
NPL	0.00086	0.00038

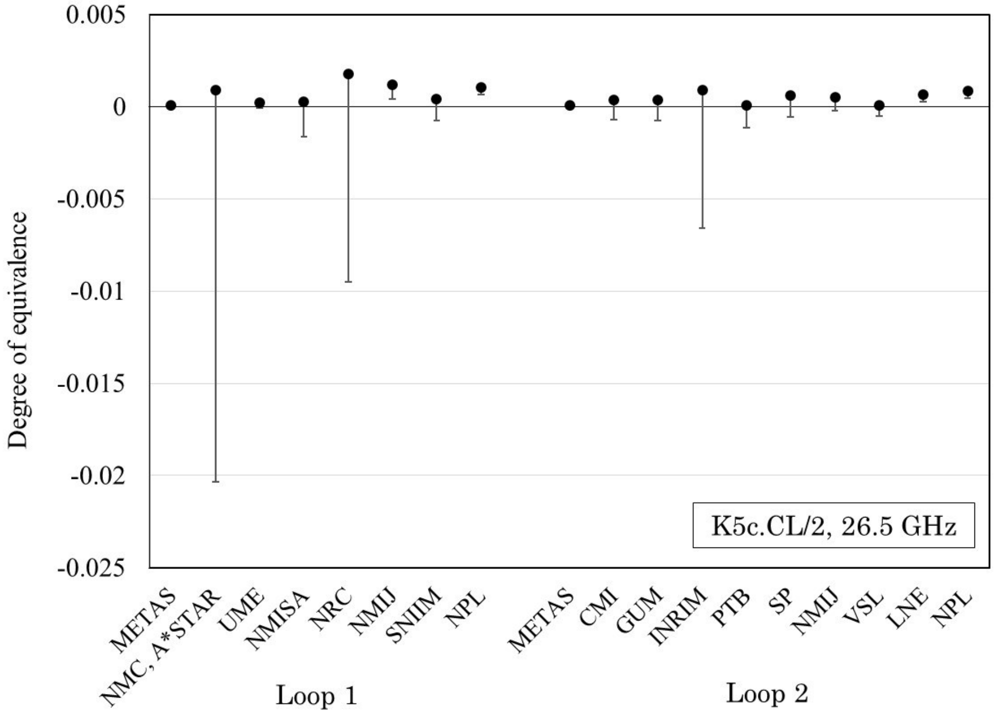

Fig. 3.7.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 26.5 GHz.

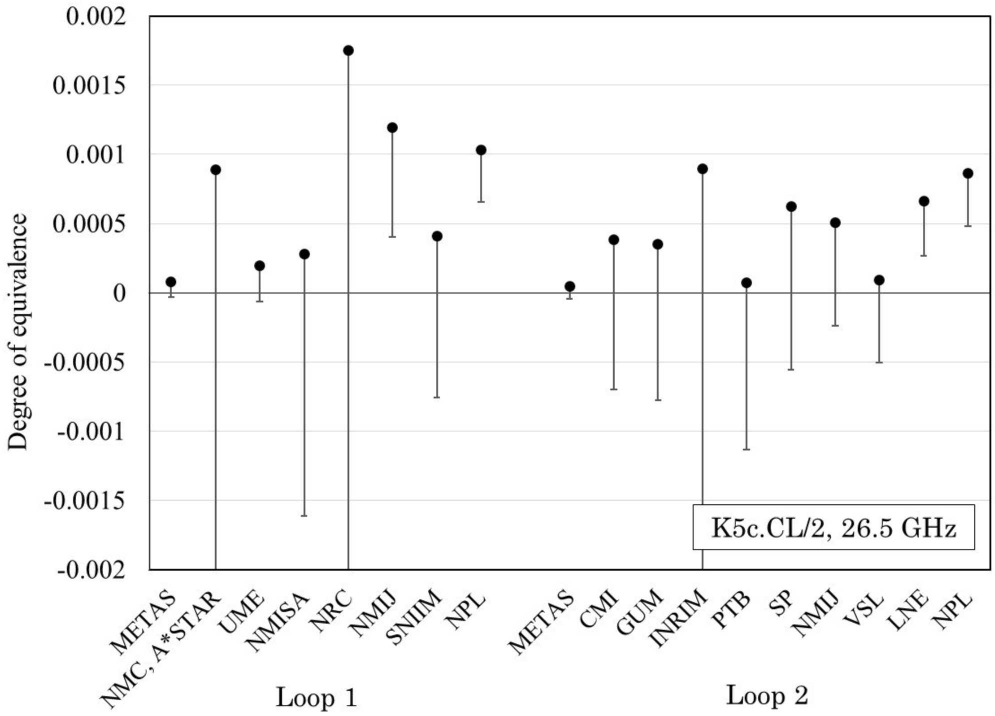

Fig. 3.7.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 26.5 GHz (enlarged view of Fig. 3.7.7.).

K5c.CL/2 at 33 GHz

Table 3.8.1. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 1) at 33 GHz.

Laboratory	K5c.CL/2 (Loop 1) Measurement and combined uncertainty of S_{21} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.02170	0.00010	0.09450	0.00010	
NMC, A*STAR	-0.0206	0.0090	0.0947	0.0090	
UME	*-0.02215*	*0.00018*	*0.09415*	*0.00018*	*0.94*
NMISA					
NRC	-0.0208	0.0046	0.0961	0.0046	
NMIJ	*-0.02035*	*0.00036*	*0.09451*	*0.00036*	
SNIIM	-0.02236	0.00077	0.09451	0.00077	
NPL	*-0.02058*	*0.00016*	*0.09475*	*0.00016*	
KCRV	-0.02170	0.00010	0.09451	0.00010	

Table 3.8.2. Reported results and KCRV for S_{21} of K5c.CL/2 (Loop 2) at 33 GHz.

Laboratory	K5c.CL/2 (Loop 2) Measurement and combined uncertainty of S_{21} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.01703	0.00010	0.09885	0.00010	
CMI	-0.01734	0.00056	0.09873	0.00028	0.24
GUM	-0.01729	0.00052	0.09888	0.00052	
INRIM	-0.0182	0.0041	0.09864	0.00084	0.92
PTB	-0.01710	0.00050	0.09876	0.00050	
SP	-0.01780	0.00056	0.09895	0.00056	
NMIJ	-0.01654	0.00037	0.09863	0.00037	
VSL	-0.01714	0.00089	0.09873	0.00019	
LNE	-0.01710	0.00024	0.09840	0.00024	
NPL	*-0.01594*	*0.00015*	*0.09889*	*0.00015*	
KCRV	-0.017018	0.000090	0.098761	0.000081	

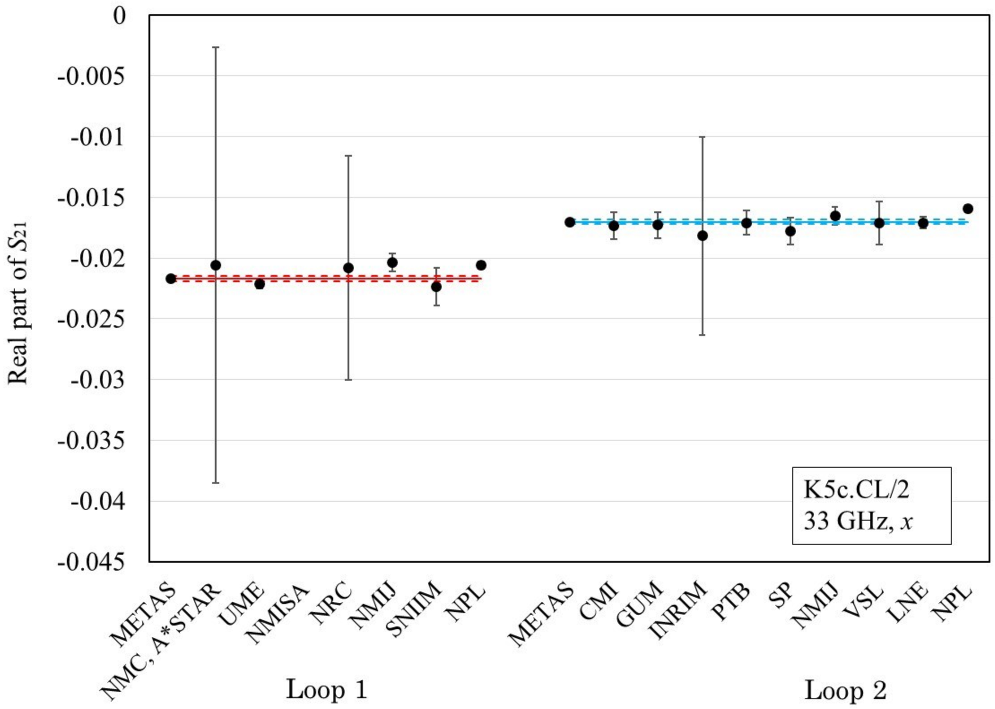

Fig. 3.8.1. Reported results and KCRV for ReS_{21} of K5c.CL/2 at 33 GHz.

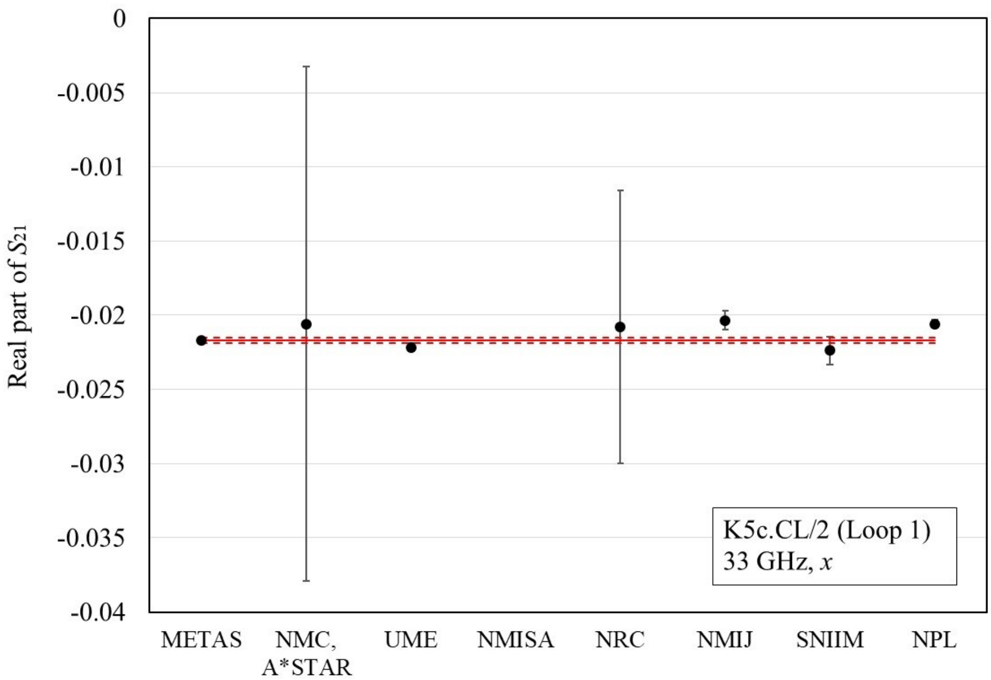

Fig. 3.8.2. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 1) at 33 GHz (enlarged view of Fig. 3.8.1.).

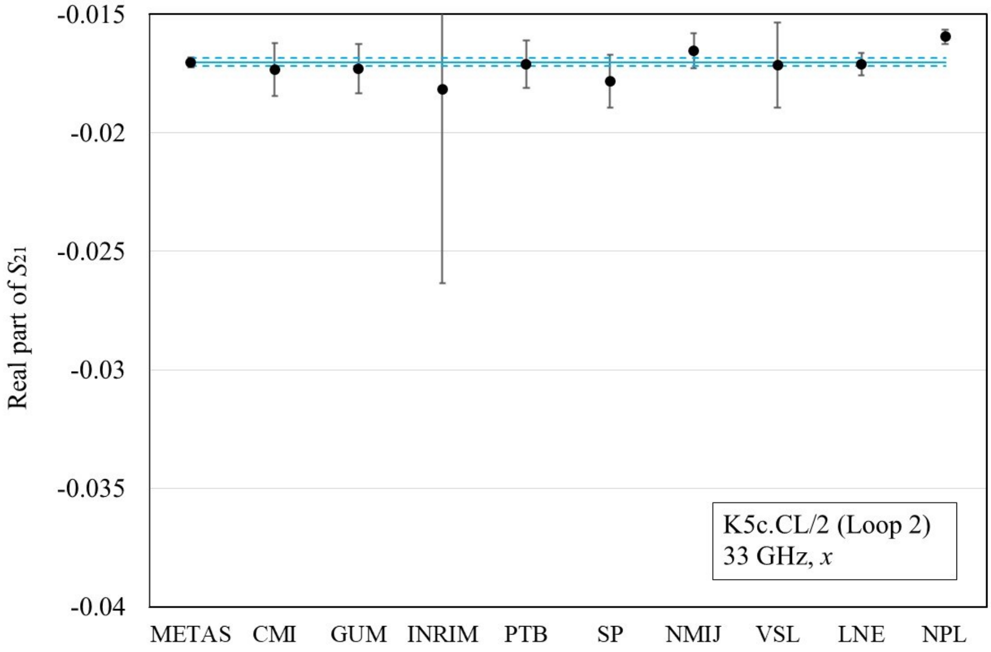

Fig. 3.8.3. Reported results and KCRV for ReS_{21} of K5c.CL/2 (Loop 2) at 33 GHz (enlarged view of Fig. 3.8.1.).

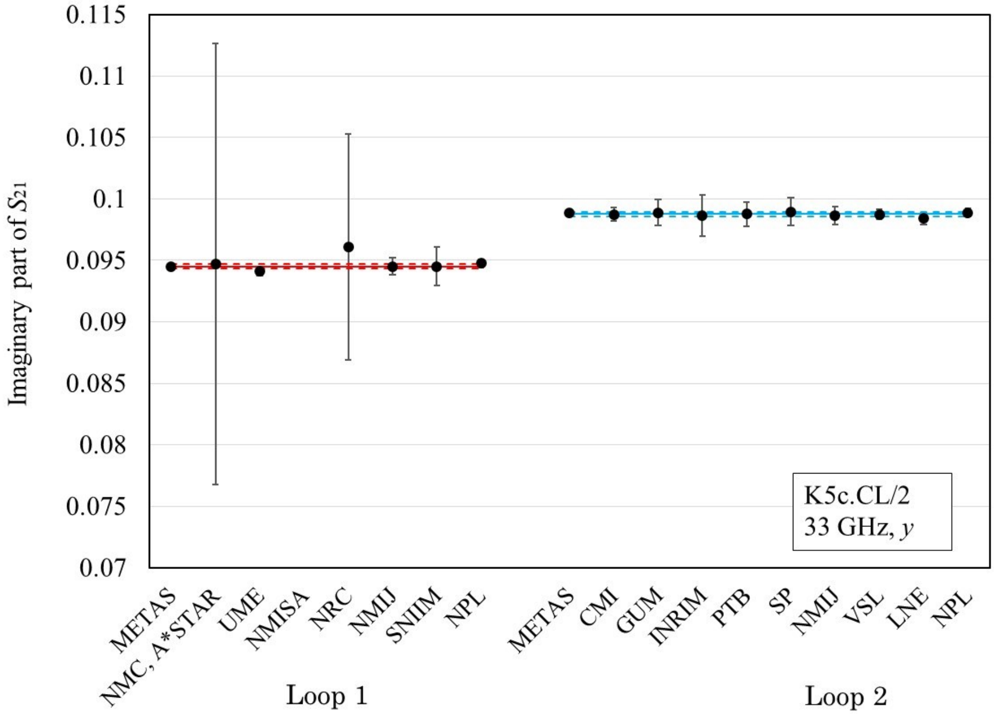

Fig. 3.8.4. Reported results and KCRV for ImS_{21} of K5c.CL/2 at 33 GHz.

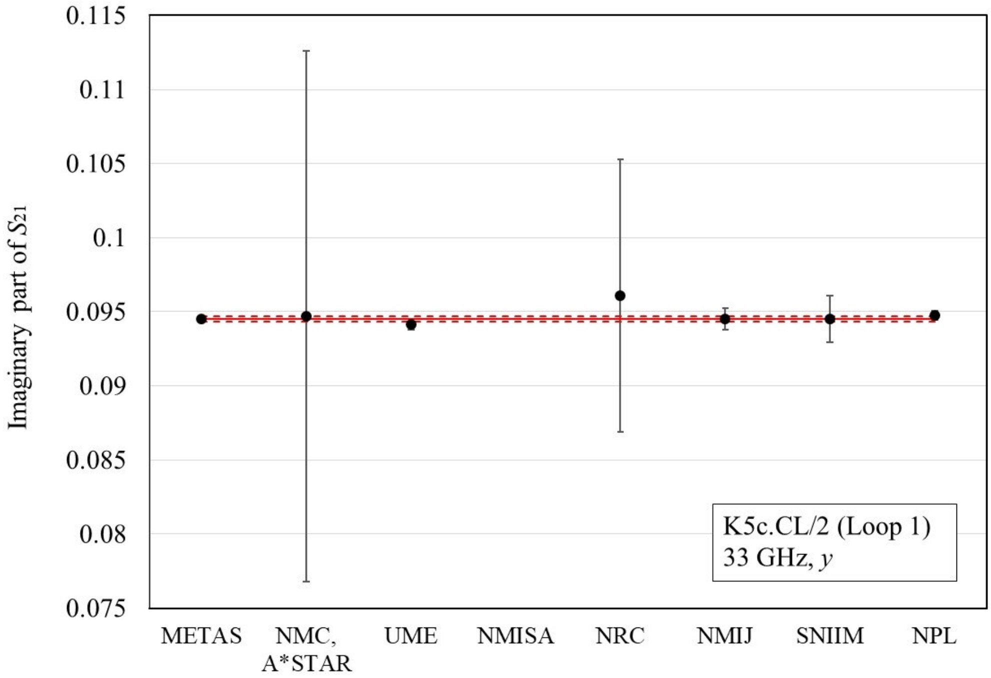

Fig. 3.8.5. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 1) at 33 GHz (enlarged view of Fig. 3.8.4.).

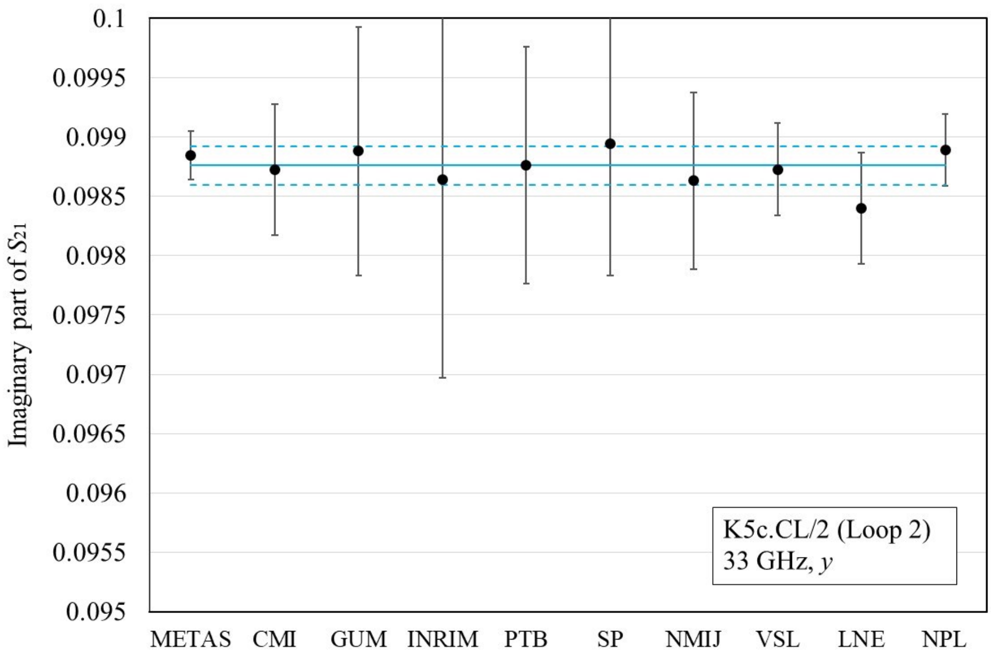

Fig. 3.8.6. Reported results and KCRV for ImS_{21} of K5c.CL/2 (Loop 2) at 33 GHz (enlarged view of Fig. 3.8.4.).

Table 3.8.3. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 1) at 33 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0000009	0.0000057
NMC, A*STAR	0.001	0.022
UME	0.00058	0.00050
NMISA		
NRC	0.002	0.011
NMIJ	0.00136	0.00091
SNIIM	0.0007	0.0019
NPL	0.00115	0.00046

Table 3.8.4. Reduced dimensional DoE for S_{21} of K5c.CL/2 (Loop 2) at 33 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.00009	0.00015
CMI	0.0003	0.0014
GUM	0.0003	0.0013
INRIM	0.0012	0.0090
PTB	0.0001	0.0012
SP	0.0008	0.0014
NMIJ	0.00050	0.00088
VSL	0.0001	0.0013
LNE	0.00037	0.00054
NPL	0.00108	0.00043

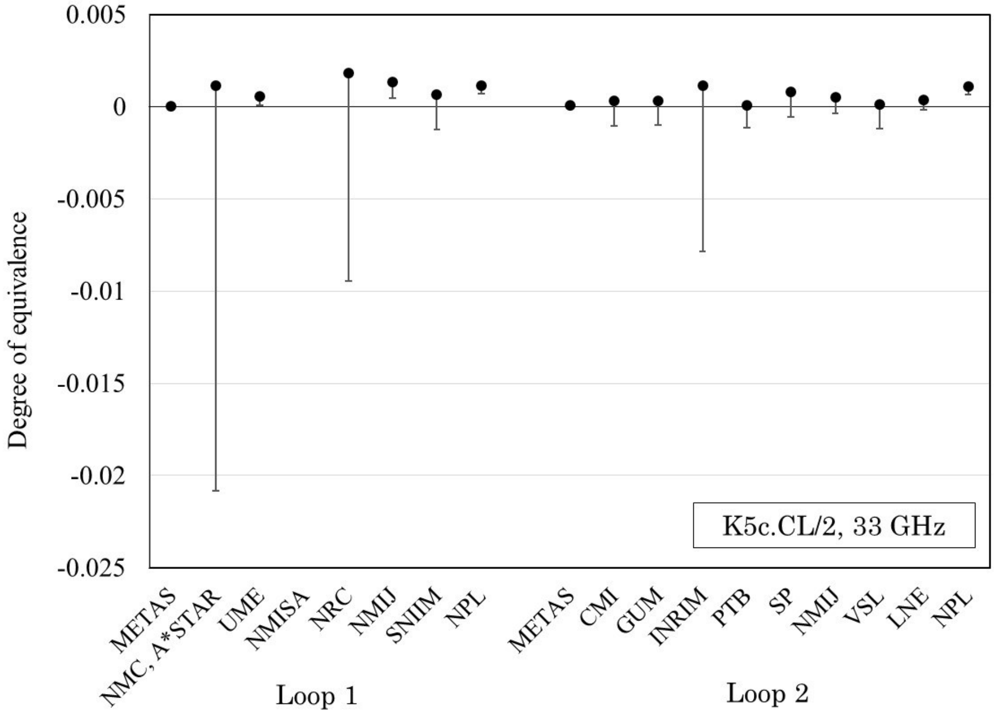

Fig. 3.8.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 33 GHz.

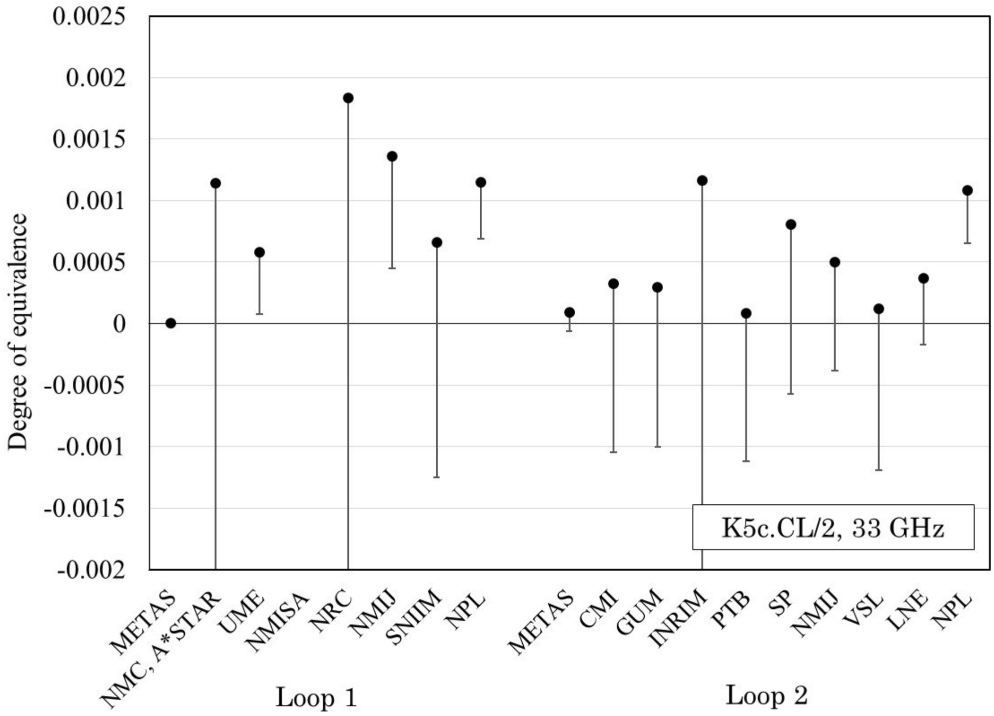

Fig. 3.8.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/2 at 33 GHz (enlarged view of Fig. 3.8.7.).

K5c.CL/3 at 0.1 GHz

Table 3.9.1. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 1) at 0.1 GHz.

Laboratory	K5c.CL/3 (Loop 1) Measurement and combined uncertainty of S_{21} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.0099517	0.0000073	-0.000758	0.000011	
NMC, A*STAR	0.0099	0.0067	-0.0007	0.0067	
UME	0.009941	0.000017	-0.000778	0.000017	0.58
NMISA	0.009955	0.000023	-0.000733	0.000023	
NRC	0.0100	0.0045	-0.0008	0.0045	
NMIJ	0.009935	0.000016	-0.000767	0.000016	
SNIIM	0.009953	0.000036	-0.000765	0.000036	
NPL	0.009950	0.000020	-0.000755	0.000020	
KCRV	0.0099484	0.0000057	-0.0007607	0.0000071	

Table 3.9.2. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 2) at 0.1 GHz.

Laboratory	K5c.CL/3 (Loop 2) Measurement and combined uncertainty of S_{21} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.0102139	0.0000075	-0.000780	0.000012	
CMI	0.010224	0.000048	-0.000790	0.000048	-0.00011
GUM	0.01022	0.00029	-0.00078	0.00029	
INRIM	0.010209	0.000027	-0.000783	0.000053	0.11
PTB	0.01021	0.00012	-0.00078	0.00012	
SP	0.010204	0.000035	-0.000770	0.000035	
NMIJ	0.010194	0.000016	-0.000784	0.000016	
VSL	0.010207	0.000022	-0.000790	0.000025	
LNE	0.010200	0.000033	-0.000800	0.000033	
NPL	0.010205	0.000020	-0.000781	0.000020	
KCRV	0.0102093	0.0000059	-0.0007833	0.0000078	

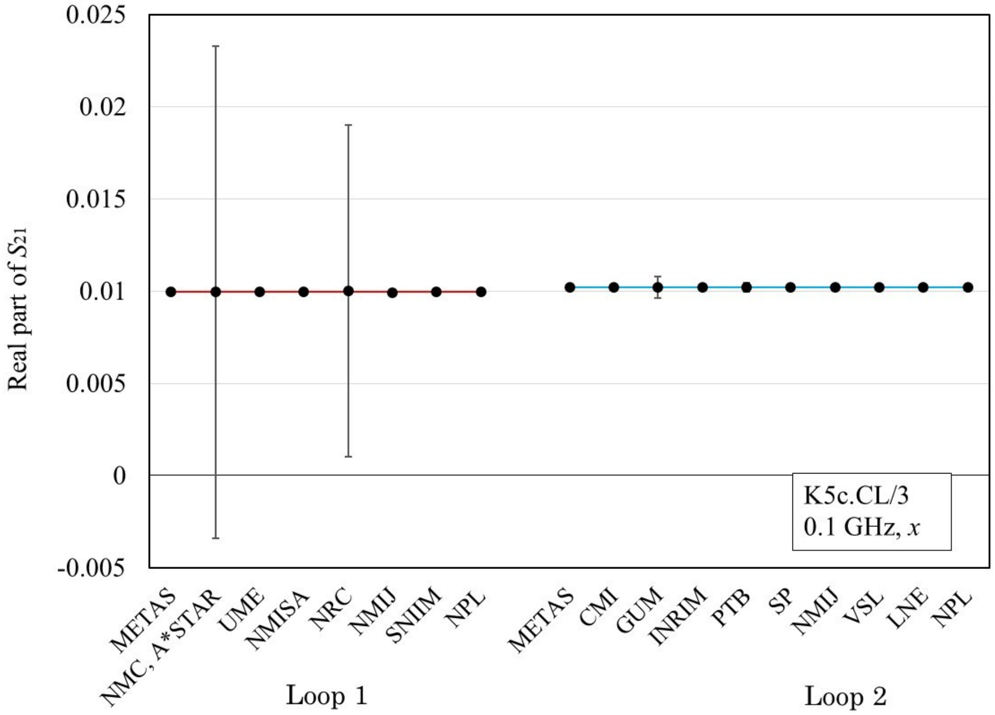

Fig. 3.9.1. Reported results and KCRV for ReS_{21} of K5c.CL/3 at 0.1 GHz.

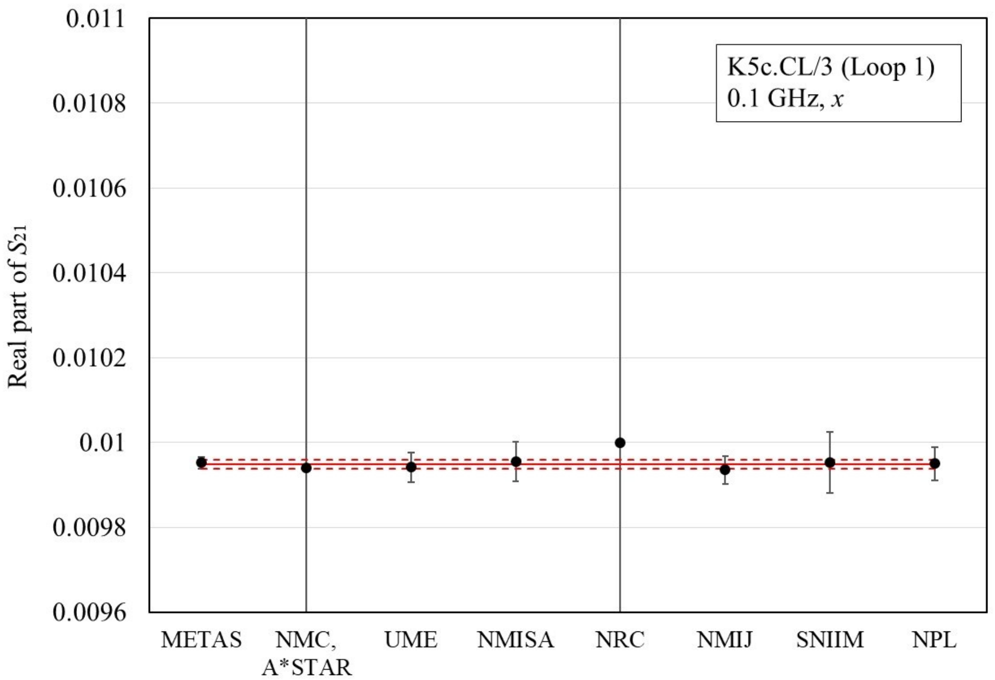

Fig. 3.9.2. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.9.1.).

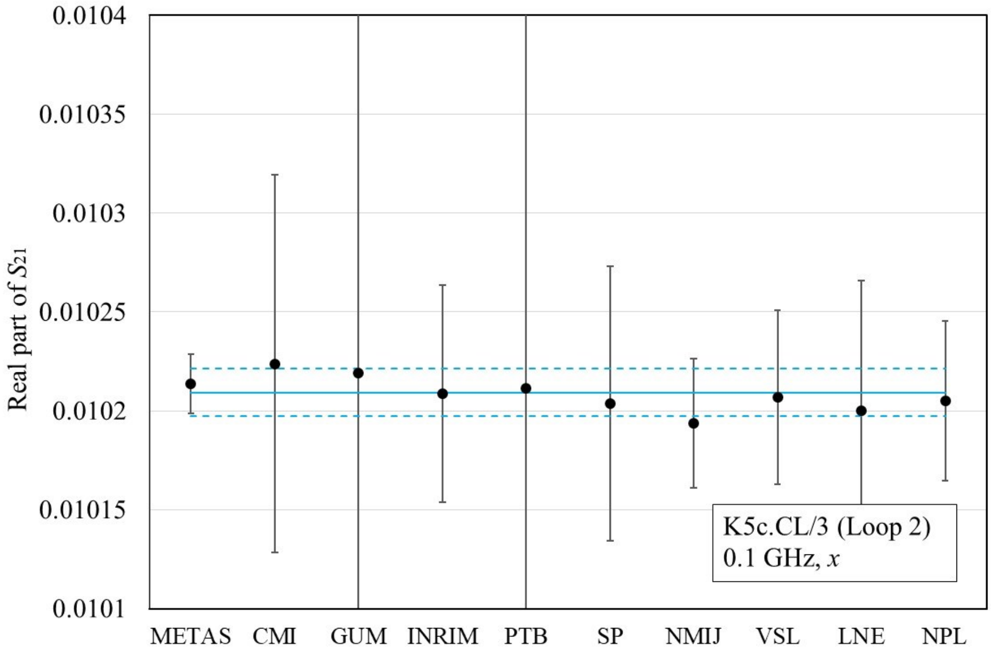

Fig. 3.9.3. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.9.1.).

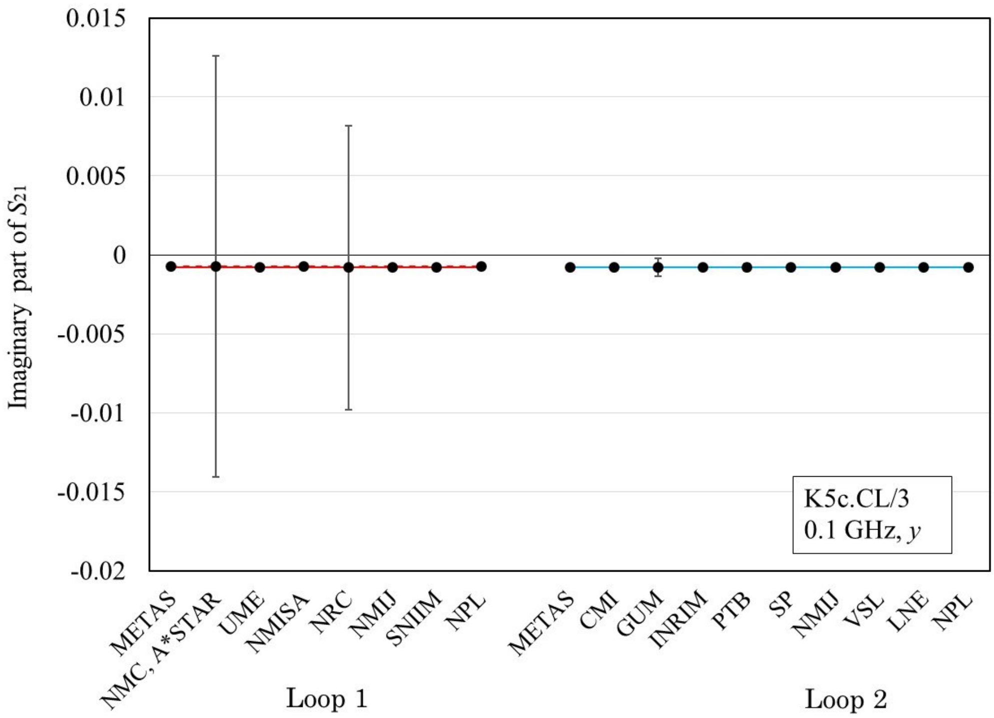

Fig. 3.9.4. Reported results and KCRV for ImS_{21} of K5c.CL/3 at 0.1 GHz.

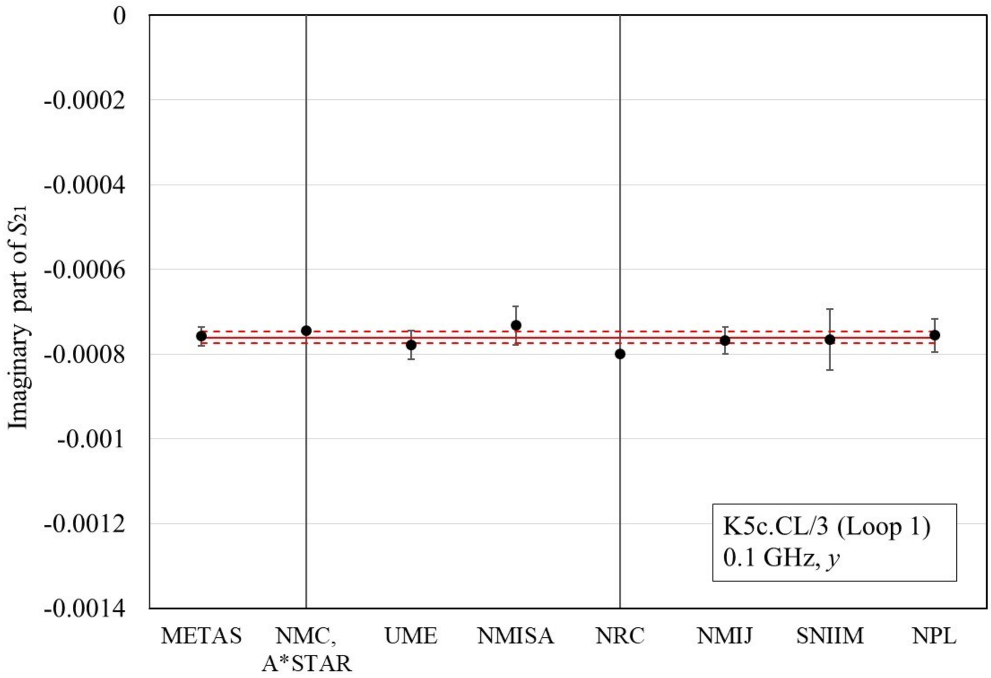

Fig. 3.9.5. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.9.4.).

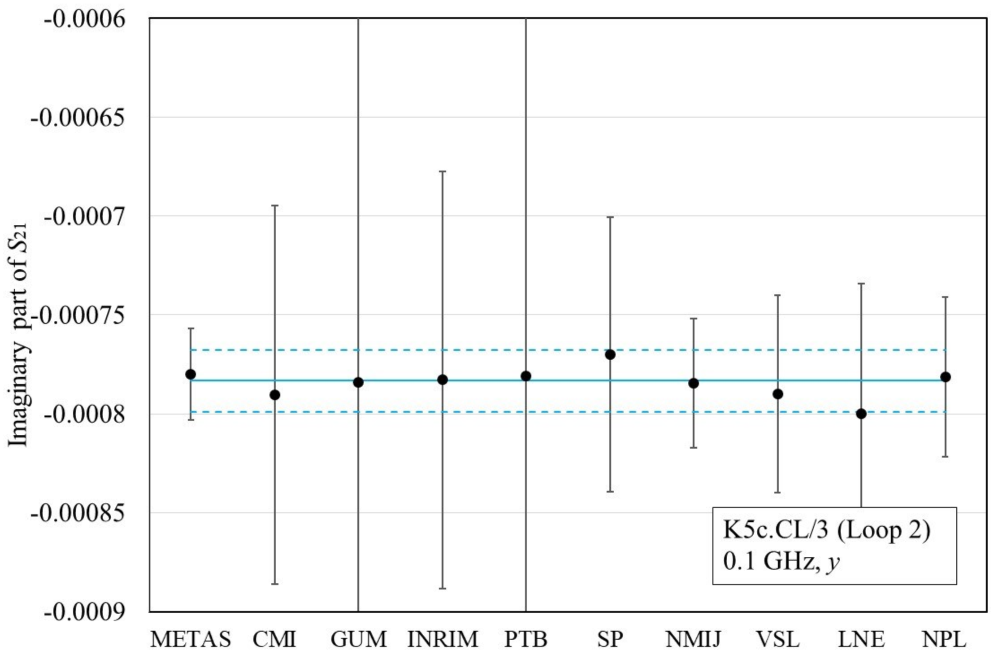

Fig. 3.9.6. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.9.4.).

Table 3.9.3. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 1) at 0.1 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.000004	0.000013
NMC, A*STAR	0.000	0.016
UME	0.000019	0.000038
NMISA	0.000029	0.000054
NRC	0.000	0.011
NMIJ	0.000015	0.000036
SNIIM	0.000006	0.000090
NPL	0.000006	0.000045

Table 3.9.4. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 2) at 0.1 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.000006	0.000013
CMI	0.00002	0.00012
GUM	0.00001	0.00071
INRIM	0.000001	0.000080
PTB	0.00000	0.00029
SP	0.000015	0.000087
NMIJ	0.000016	0.000037
VSL	0.000007	0.000057
LNE	0.000019	0.000079
NPL	0.000005	0.000047

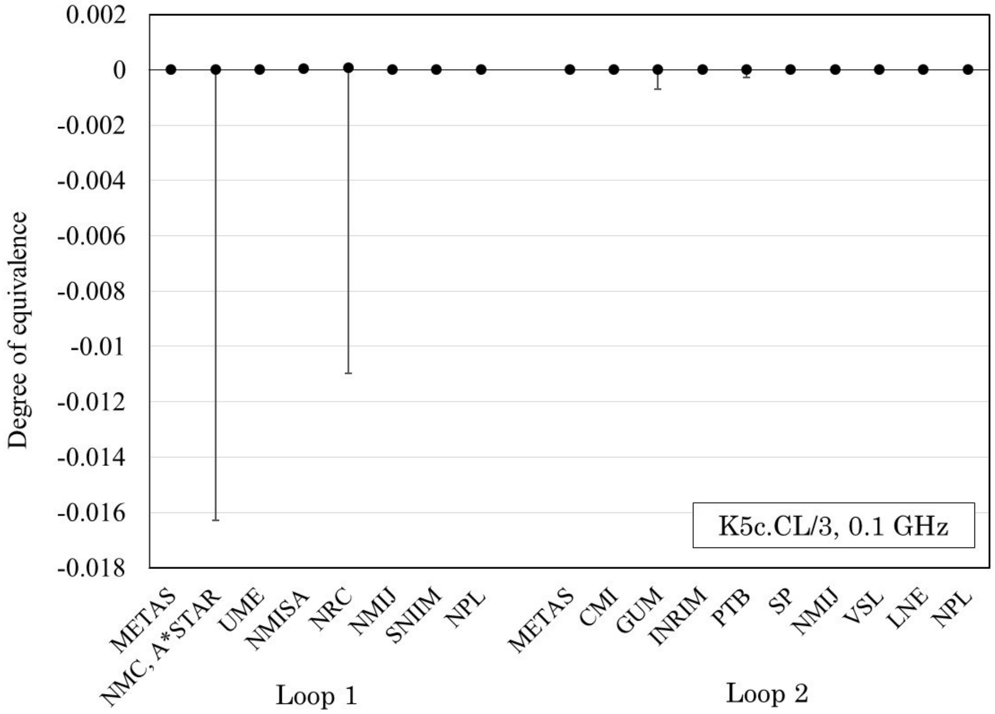

Fig. 3.9.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 0.1 GHz.

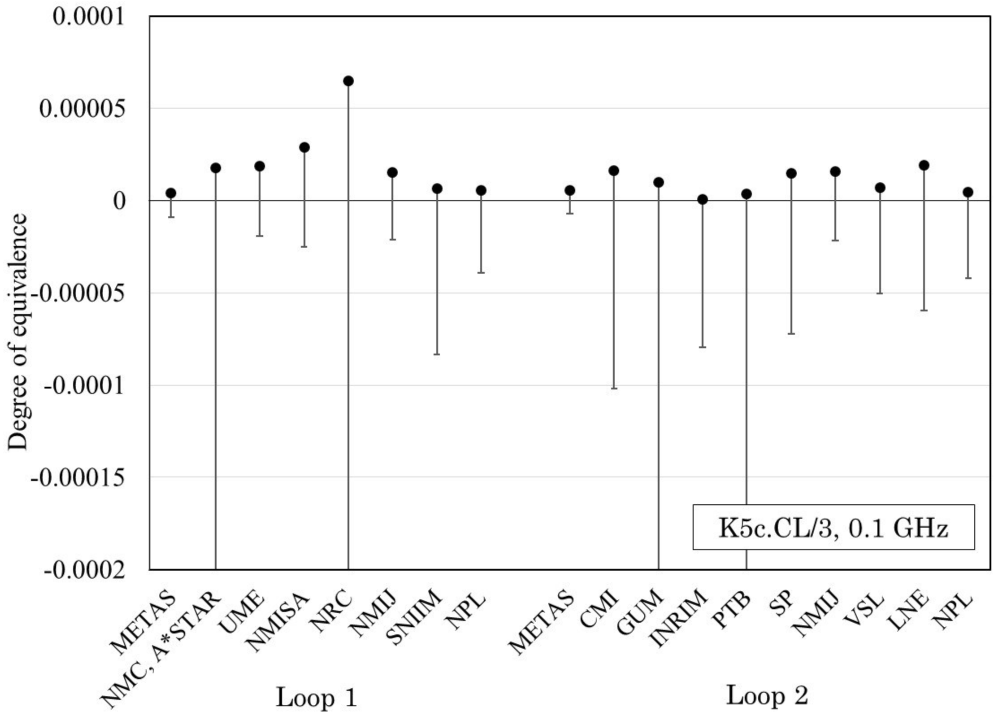

Fig. 3.9.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 0.1 GHz (enlarged view of Fig. 3.9.7.).

K5c.CL/3 at 12.4 GHz

Table 3.10.1. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 1) at 12.4 GHz.

Laboratory	K5c.CL/3 (Loop 1) Measurement and combined uncertainty of S_{21} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	*-0.0095700*	*0.0000067*	*-0.0011090*	*0.0000067*	
NMC, A*STAR	-0.0096	0.0094	-0.0011	0.0094	
UME	-0.009534	0.000025	-0.001050	0.000025	0.71
NMISA	-0.00956	0.00011	-0.00108	0.00011	
NRC	-0.0097	0.0045	-0.0011	0.0045	
NMIJ	-0.009546	0.000028	-0.001037	0.000028	
SNIIM	-0.009567	0.000044	-0.001131	0.000044	
NPL	-0.009572	0.000020	-0.001056	0.000020	
KCRV	-0.009555	0.000013	-0.001050	0.000013	

Table 3.10.2. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 2) at 12.4 GHz.

Laboratory	K5c.CL/3 (Loop 2) Measurement and combined uncertainty of S_{21} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.0097825	0.0000070	-0.0009613	0.0000070	
CMI	-0.009788	0.000046	-0.000961	0.000051	-0.012
GUM	-0.009786	0.000058	-0.000942	0.000058	
INRIM	-0.009778	0.000031	-0.00099	0.00018	-0.59
PTB	-0.00978	0.00012	-0.00095	0.00012	
SP	-0.009788	0.000027	-0.000979	0.000027	
NMIJ	-0.009754	0.000028	-0.000914	0.000028	
VSL	-0.009775	0.000018	-0.000952	0.000049	
LNE	-0.009800	0.000037	-0.001000	0.000037	
NPL	*-0.009784*	*0.000020*	*-0.000896*	*0.000020*	
KCRV	-0.0097806	0.0000061	-0.0009597	0.0000066	

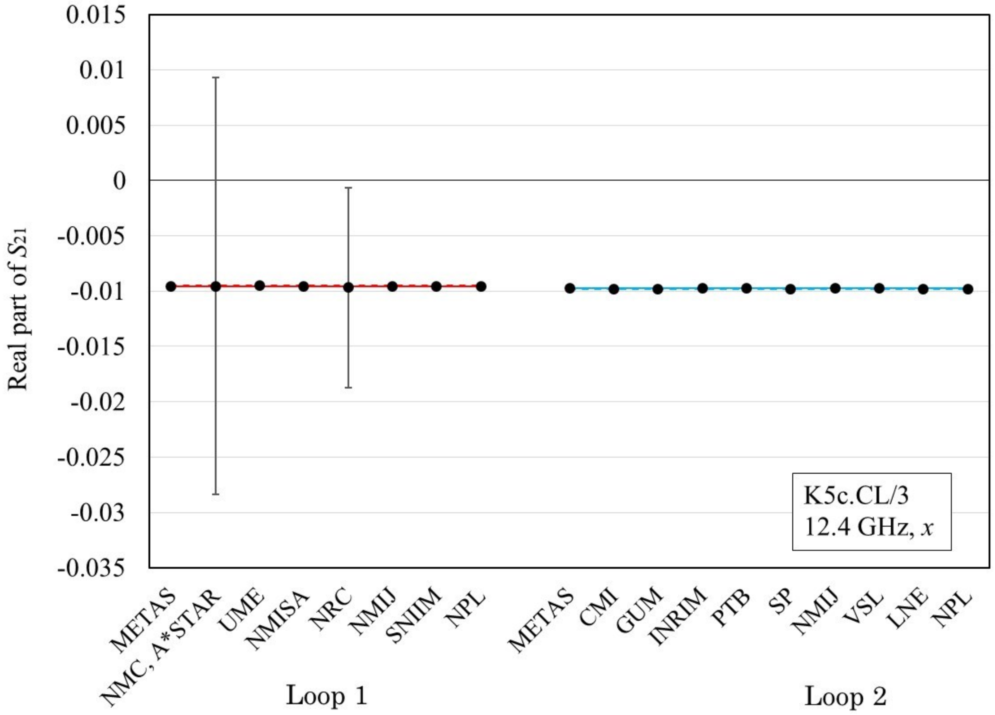

Fig. 3.10.1. Reported results and KCRV for ReS_{21} of K5c.CL/3 at 12.4 GHz.

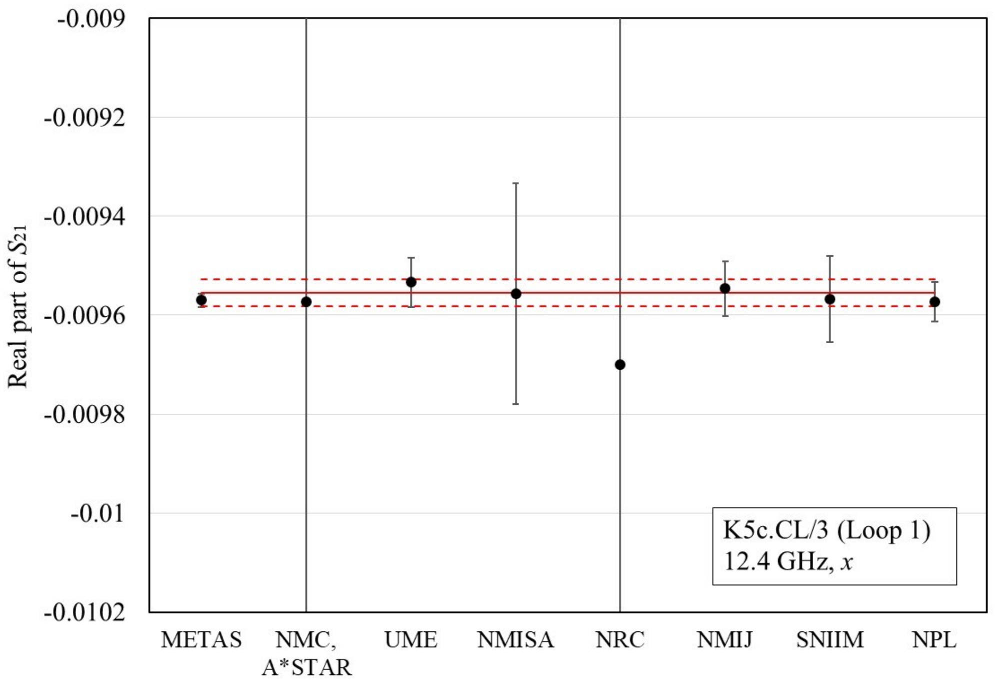

Fig. 3.10.2. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.10.1.).

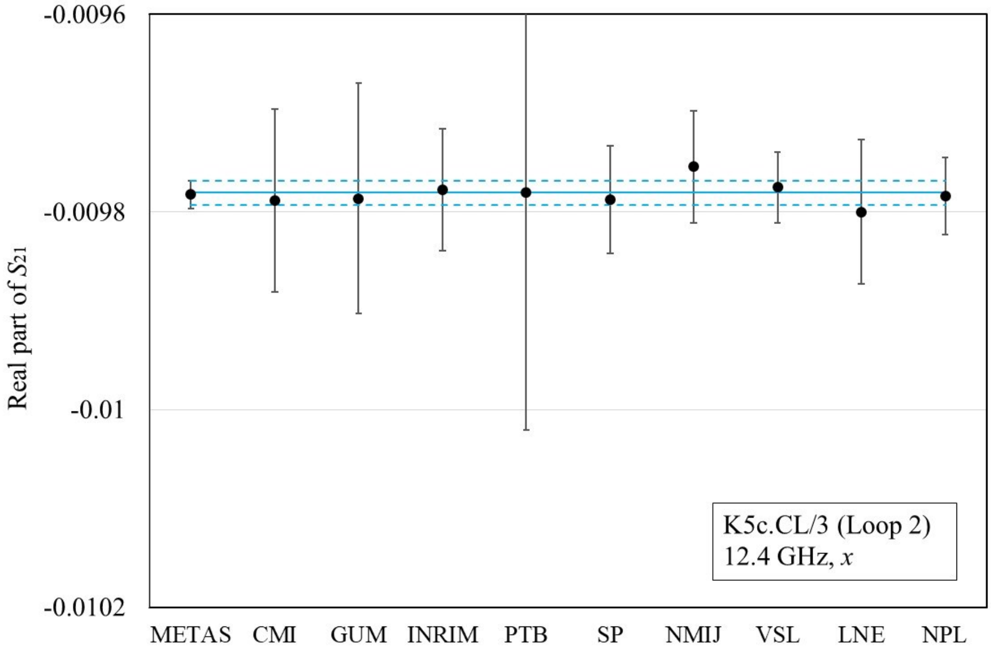

Fig. 3.10.3. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.10.1.).

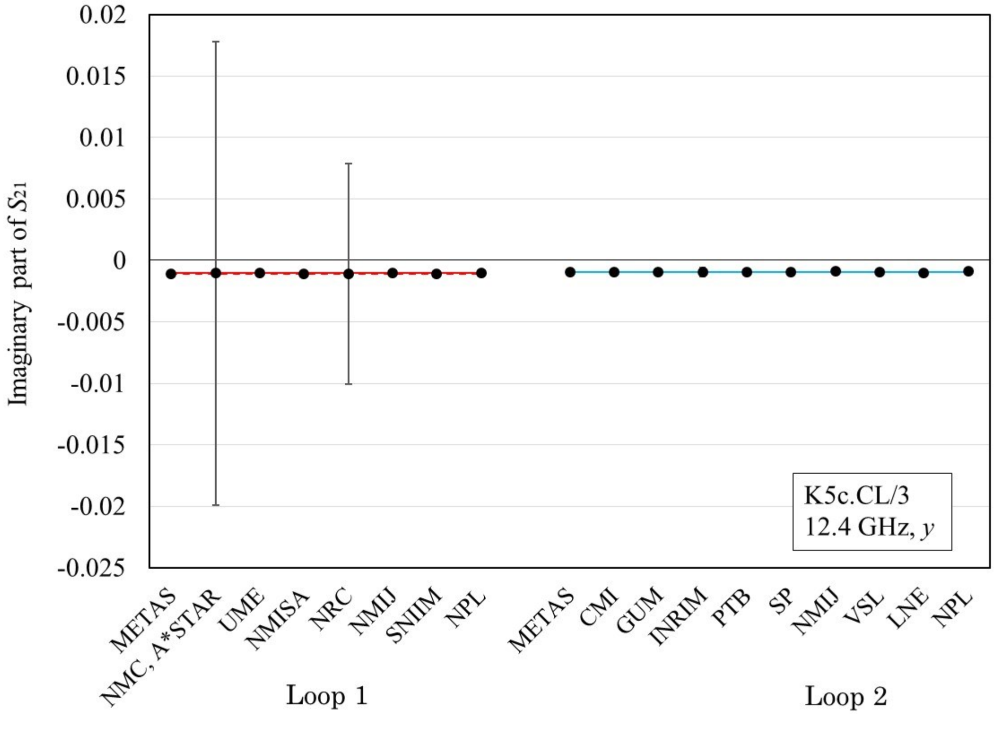

Fig. 3.10.4. Reported results and KCRV for ImS_{21} of K5c.CL/3 at 12.4 GHz.

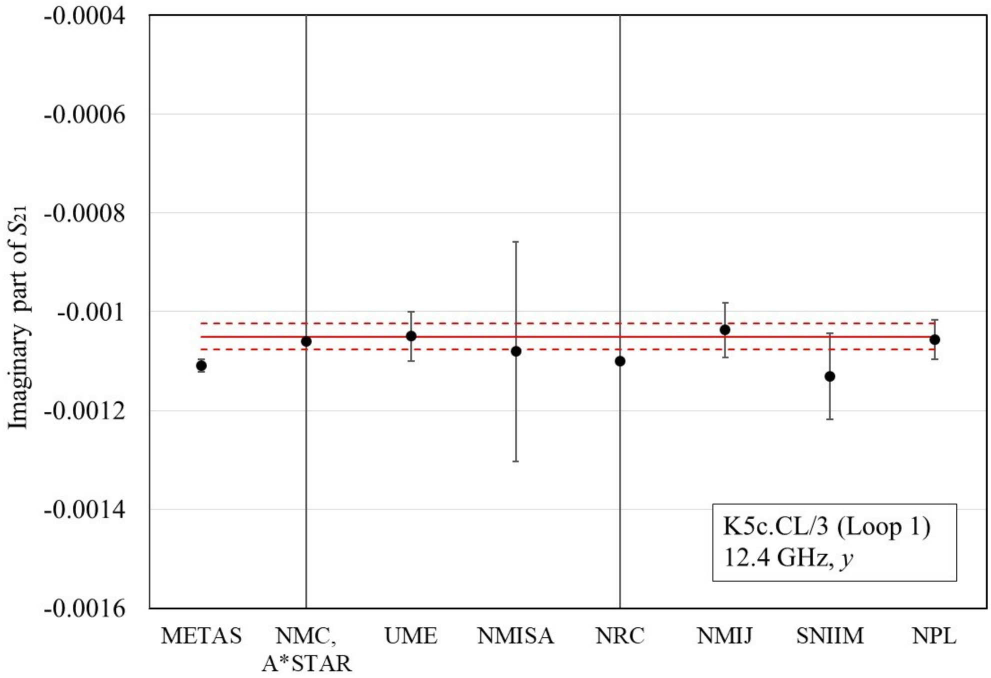

Fig. 3.10.5. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.10.4.).

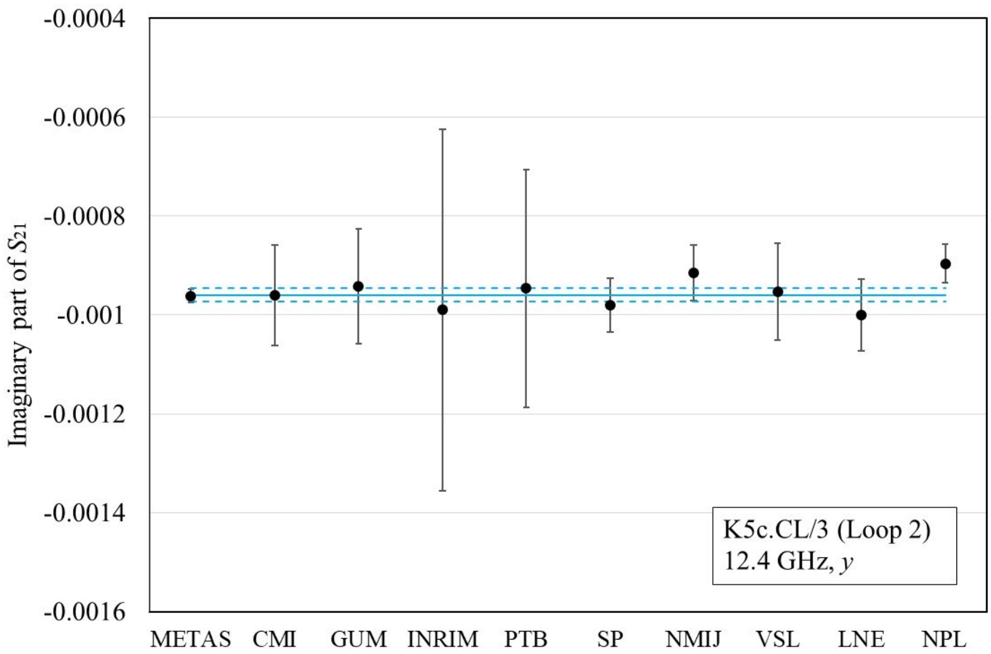

Fig. 3.10.6. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.10.4.).

Table 3.10.3. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 1) at 12.4 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.000061	0.000037
NMC, A*STAR	0.000	0.023
UME	0.000021	0.000051
NMISA	0.00003	0.00027
NRC	0.000	0.011
NMIJ	0.000016	0.000060
SNIIM	0.00008	0.00011
NPL	0.000019	0.000036

Table 3.10.4. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 2) at 12.4 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0000024	0.0000070
CMI	0.00001	0.00011
GUM	0.00002	0.00014
INRIM	0.00003	0.00039
PTB	0.00001	0.00029
SP	0.000021	0.000068
NMIJ	0.000053	0.000067
VSL	0.000010	0.000064
LNE	0.000045	0.000088
NPL	0.000064	0.000051

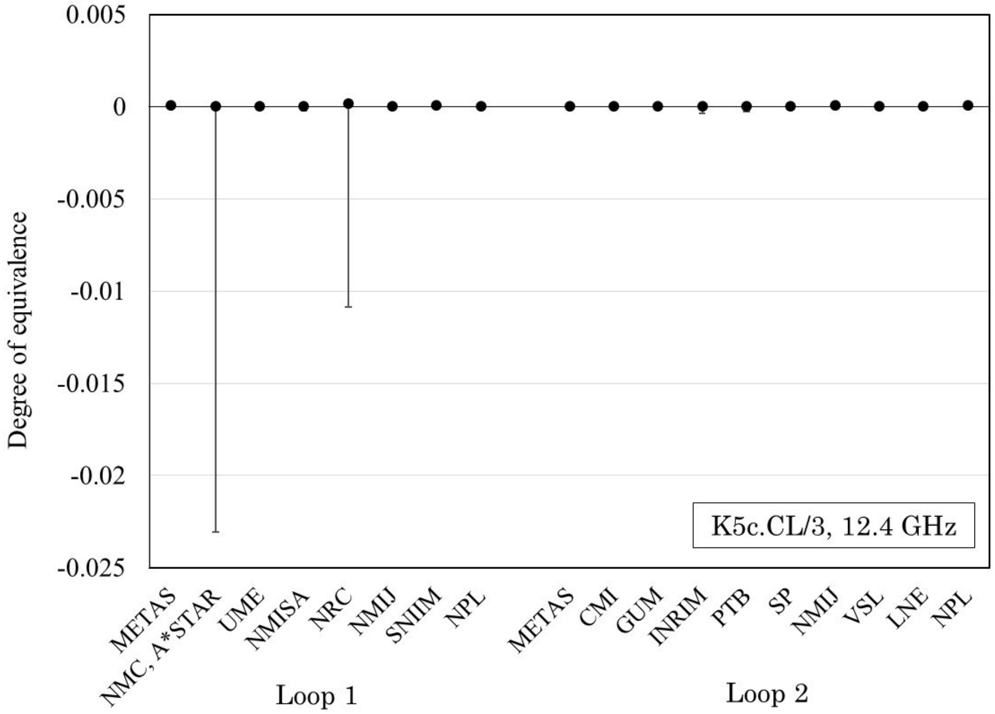

Fig. 3.10.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 12.4 GHz.

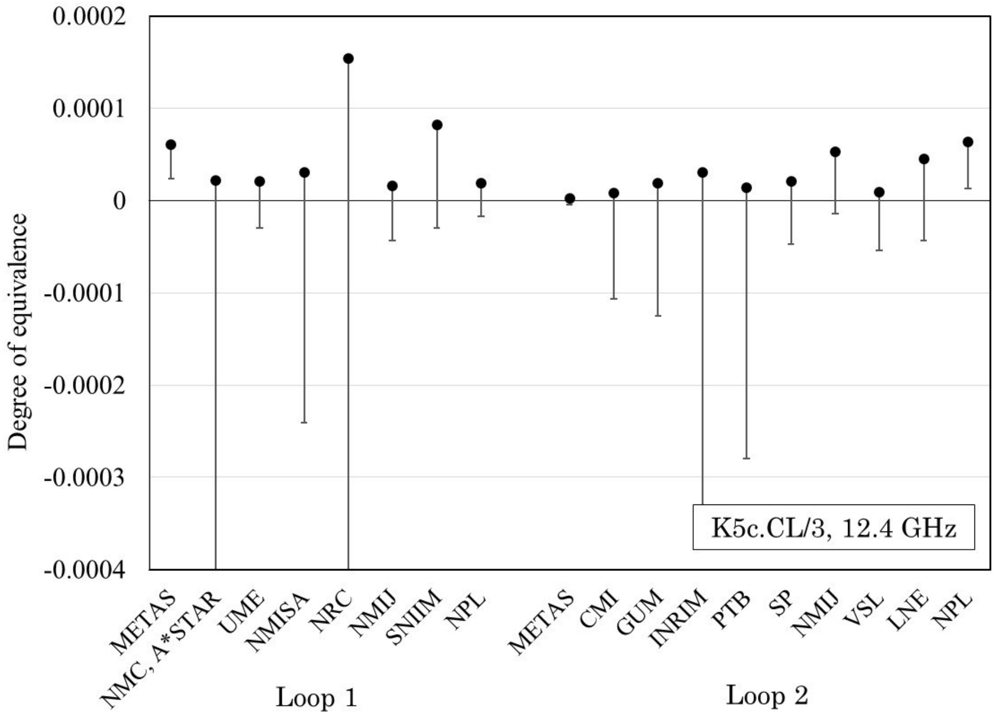

Fig. 3.10.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 12.4 GHz (enlarged view of Fig. 3.10.7.).

K5c.CL/3 at 24.5 GHz

Table 3.11.1. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 1) at 26.5 GHz.

Laboratory	K5c.CL/3 (Loop 1) Measurement and combined uncertainty of S_{21} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.005081	0.000010	-0.0084650	0.0000088	
NMC, A*STAR	0.0050	0.0099	-0.0085	0.0099	
UME	0.005035	0.000032	-0.008456	0.000032	-0.070
NMISA	0.00511	0.00011	-0.00850	0.00011	
NRC	0.0051	0.0045	-0.0086	0.0045	
NMIJ	*0.004951*	*0.000039*	*-0.008486*	*0.000039*	
SNIIM	0.005129	0.000081	-0.008441	0.000081	
NPL	*0.004988*	*0.000022*	*-0.008508*	*0.000022*	
KCRV	0.0050774	0.0000092	-0.0084645	0.0000084	

Table 3.11.2. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 2) at 26.5 GHz.

Laboratory	K5c.CL/3 (Loop 2) Measurement and combined uncertainty of S_{21} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.004909	0.000010	-0.0086646	0.0000091	
CMI	0.004917	0.000065	-0.008668	0.000054	0.16
GUM	0.004898	0.000069	-0.008656	0.000069	
INRIM	0.00497	0.00030	-0.00864	0.00017	0.98
PTB	0.00490	0.00012	-0.00864	0.00012	
SP	0.004943	0.000051	-0.008652	0.000051	
NMIJ	0.004829	0.000039	-0.008661	0.000039	
VSL	0.004893	0.000081	-0.008659	0.000048	
LNE	0.004900	0.000046	-0.008600	0.000046	
NPL	*0.004793*	*0.000021*	*-0.008717*	*0.000021*	
KCRV	0.0049037	0.0000095	-0.0086618	0.0000086	

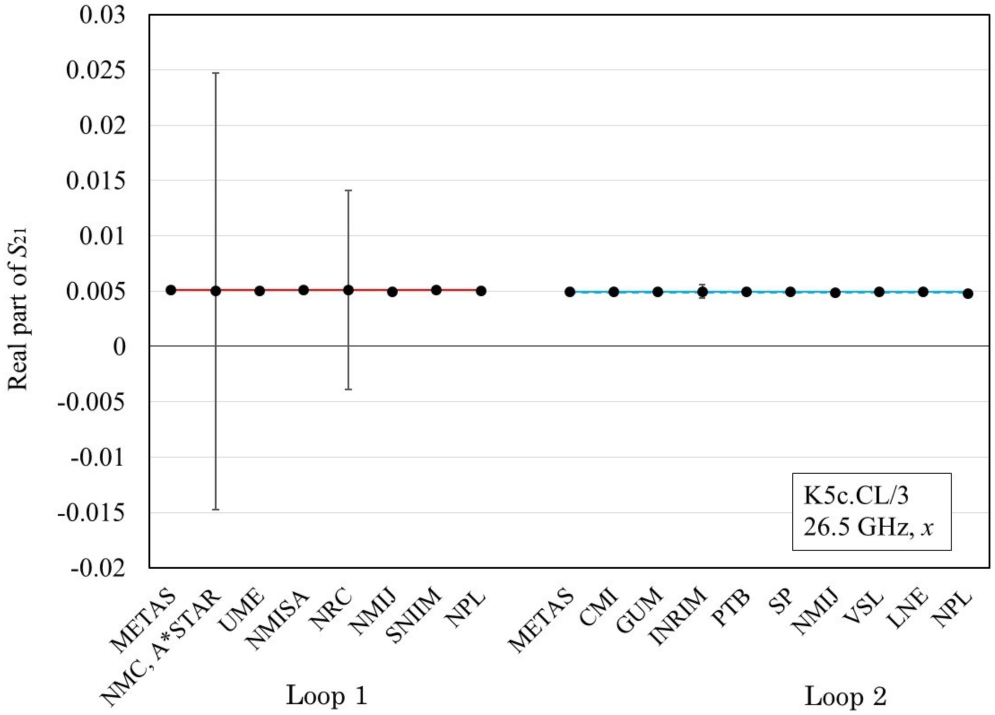

Fig. 3.11.1. Reported results and KCRV for ReS_{21} of K5c.CL/3 at 26.5 GHz.

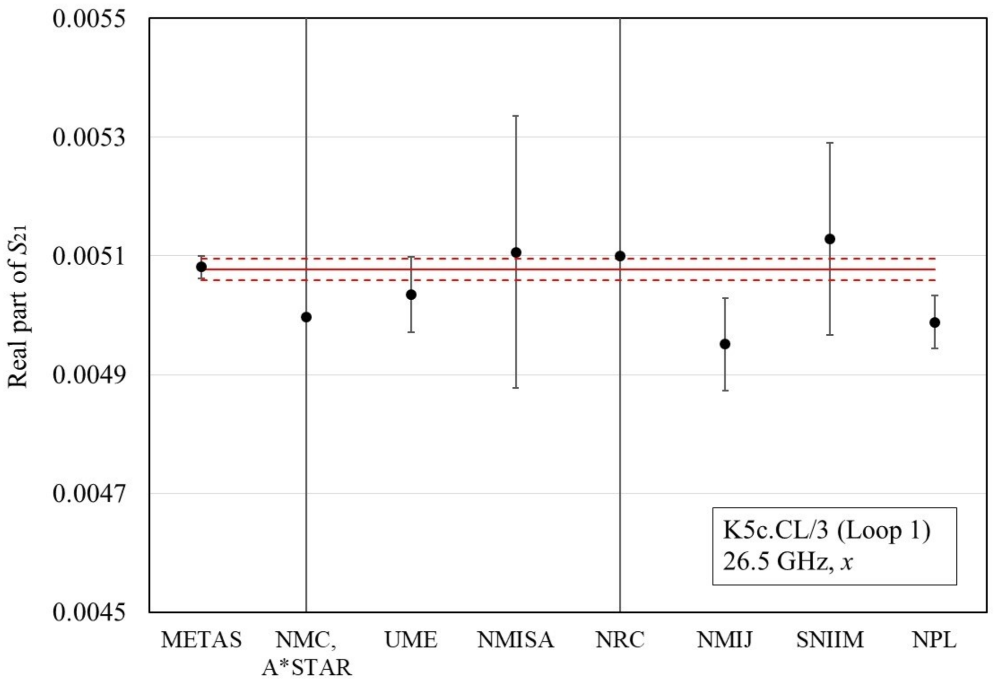

Fig. 3.11.2. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.11.1.).

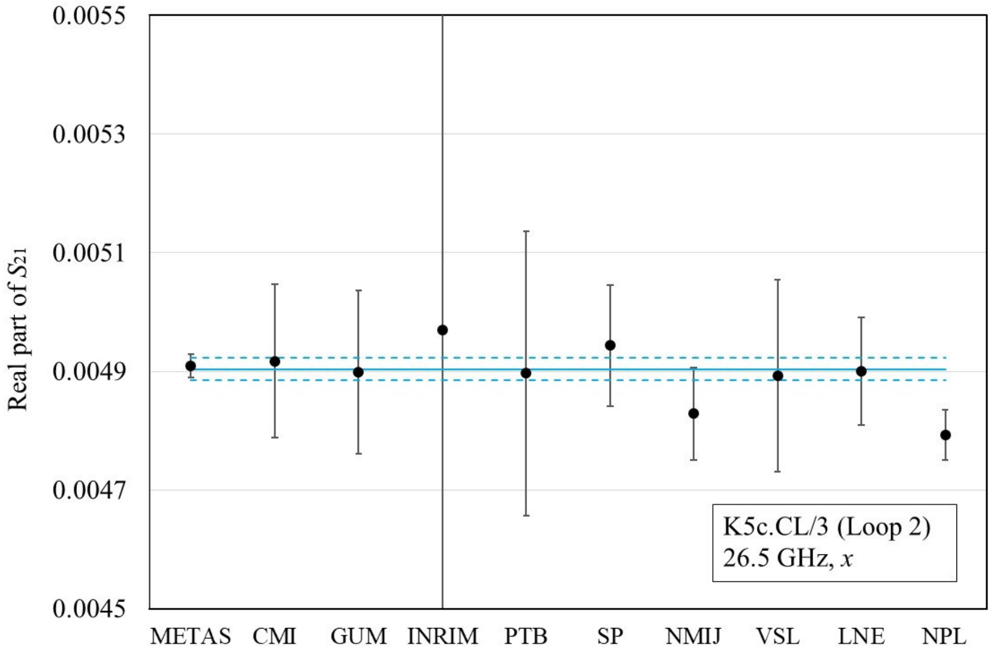

Fig. 3.11.3. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.11.1.).

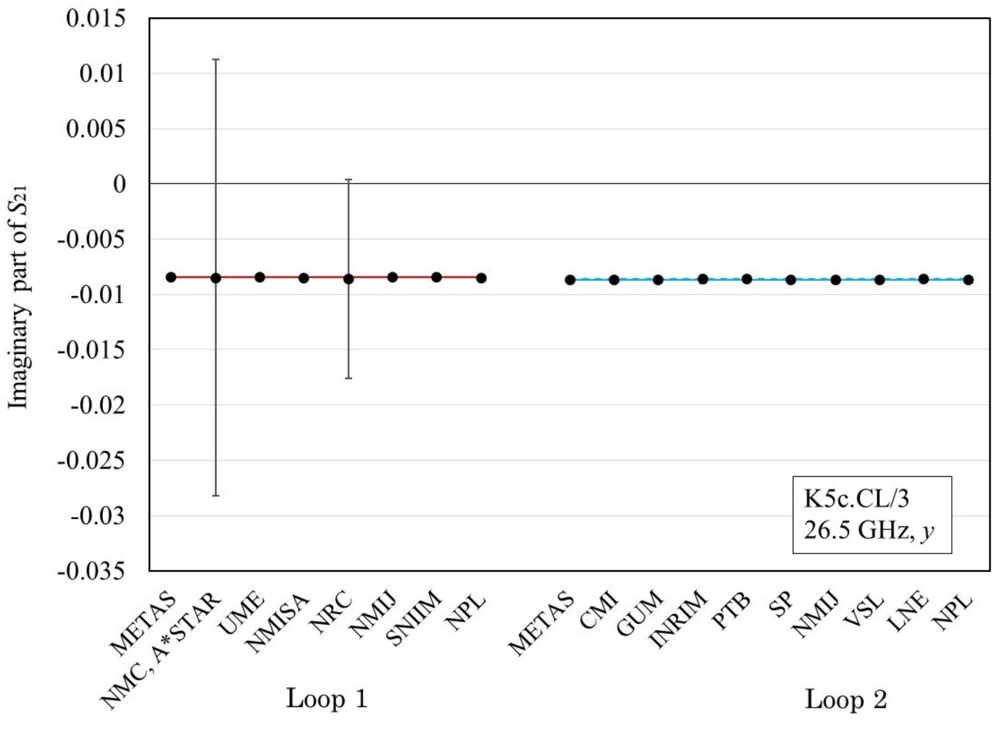

Fig. 3.11.4. Reported results and KCRV for ImS_{21} of K5c.CL/3 at 26.5 GHz.

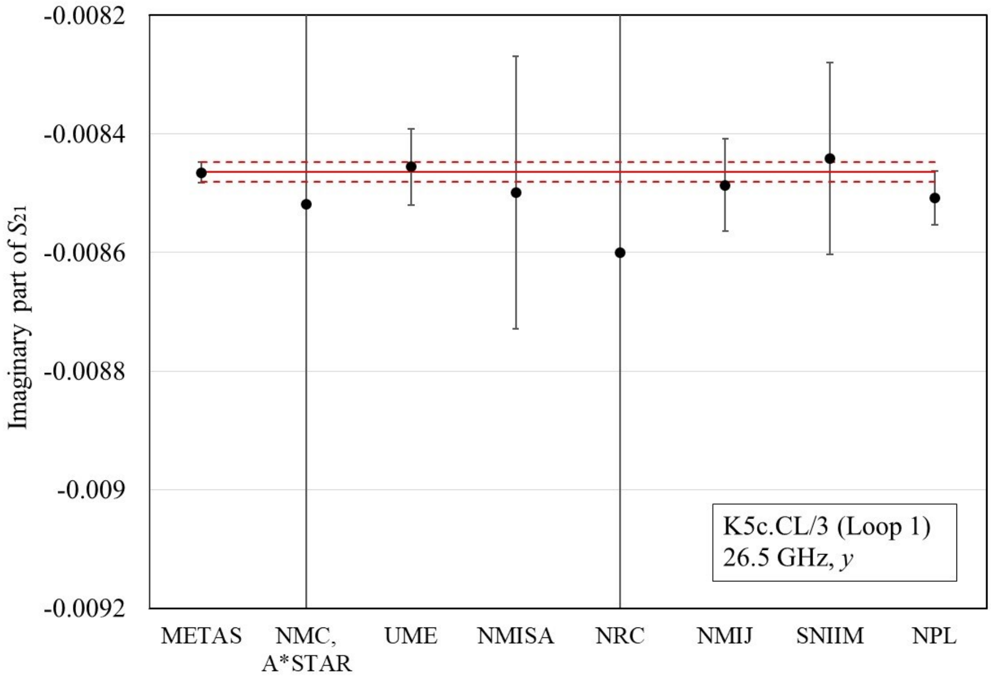

Fig. 3.11.5. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.11.4.).

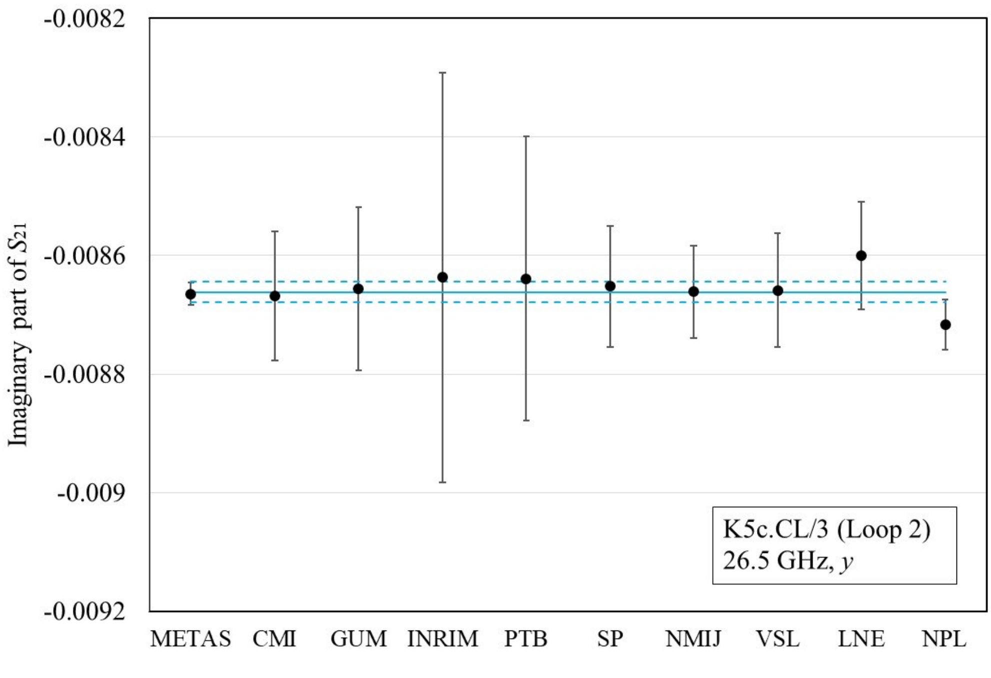

Fig. 3.11.6. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.11.4.).

Table 3.11.3. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 1) at 26.5 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0000037	0.0000071
NMC, A*STAR	0.000	0.024
UME	0.000043	0.000075
NMISA	0.00005	0.00028
NRC	0.000	0.011
NMIJ	0.00013	0.00010
SNIIM	0.00006	0.00020
NPL	0.000099	0.000059

Table 3.11.4. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 2) at 26.5 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0000061	0.0000085
CMI	0.00002	0.00015
GUM	0.00001	0.00017
INRIM	0.00007	0.00065
PTB	0.00002	0.00029
SP	0.00004	0.00013
NMIJ	0.000075	0.000093
VSL	0.00001	0.00019
LNE	0.00006	0.00011
NPL	0.000124	0.000057

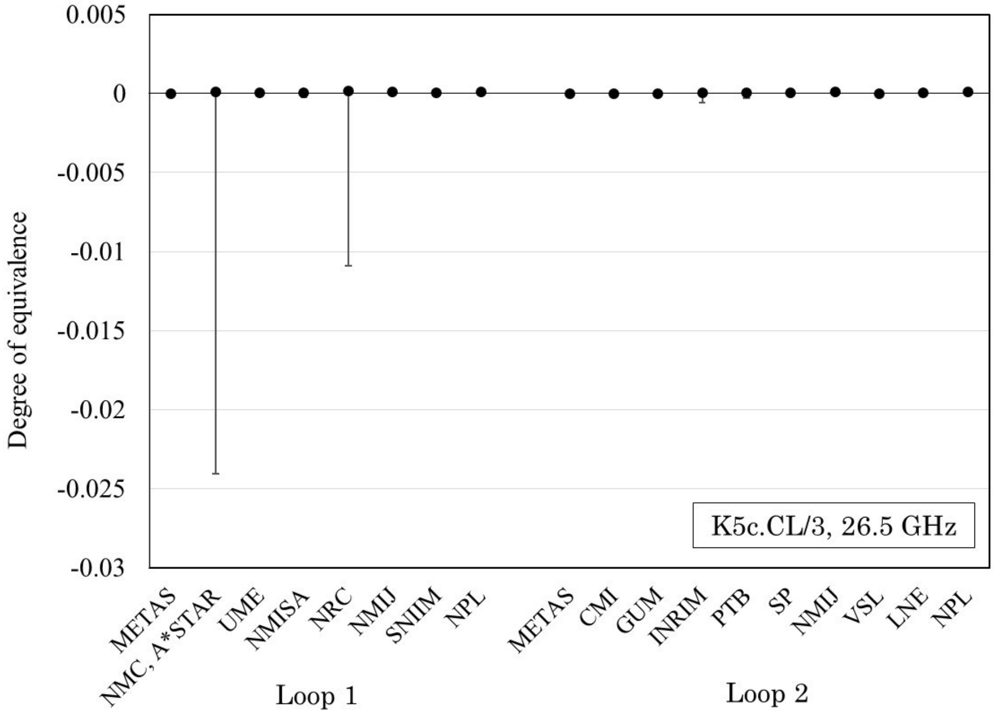

Fig. 3.11.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 26.5 GHz.

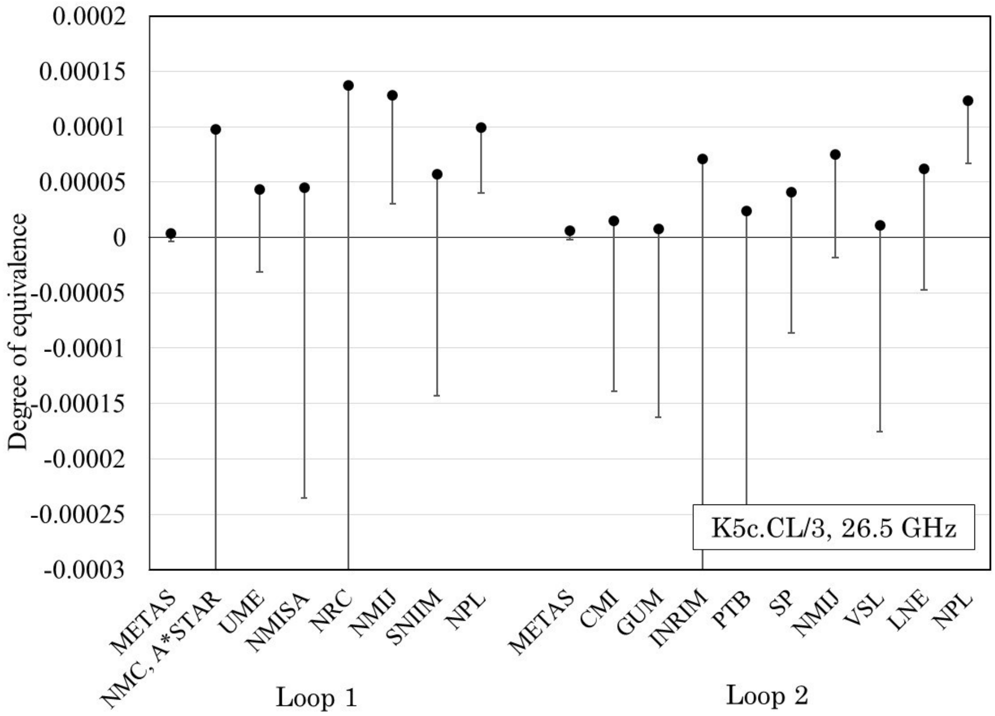

Fig. 3.11.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 26.5 GHz (enlarged view of Fig. 3.11.7.).

K5c.CL/3 at 33 GHz

Table 3.12.1. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 1) at 33 GHz.

Laboratory	K5c.CL/3 (Loop 1) Measurement and combined uncertainty of S_{21} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.010379	0.000011	0.002211	0.000011	
NMC, A*STAR	0.010	0.010	0.002	0.010	
UME	0.010355	0.000054	0.002163	0.000054	0.42
NMISA					
NRC	0.0106	0.0045	0.0021	0.0045	
NMIJ	*0.010377*	*0.000046*	*0.002066*	*0.000046*	
SNIIM	0.010376	0.000098	0.002295	0.000098	
NPL	*0.010399*	*0.000026*	*0.002098*	*0.000026*	
KCRV	0.010378	0.000011	0.002209	0.000011	

Table 3.12.2. Reported results and KCRV for S_{21} of K5c.CL/3 (Loop 2) at 33 GHz.

Laboratory	K5c.CL/3 (Loop 2) Measurement and combined uncertainty of S_{21} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.010576	0.000012	0.001898	0.000012	
CMI	0.010578	0.000055	0.001887	0.000079	-0.094
GUM	0.010574	0.000079	0.001859	0.000079	
INRIM	0.010539	0.000092	0.00198	0.00044	-0.87
PTB	0.01055	0.00012	0.00190	0.00012	
SP	0.010578	0.000068	0.001949	0.000068	
NMIJ	0.010547	0.000046	0.001813	0.000046	
VSL	0.010561	0.000026	0.001876	0.000097	
LNE	0.010500	0.000050	0.001900	0.000050	
NPL	*0.010586*	*0.000024*	*0.001736*	*0.000024*	
KCRV	0.010569	0.000010	0.001893	0.000011	

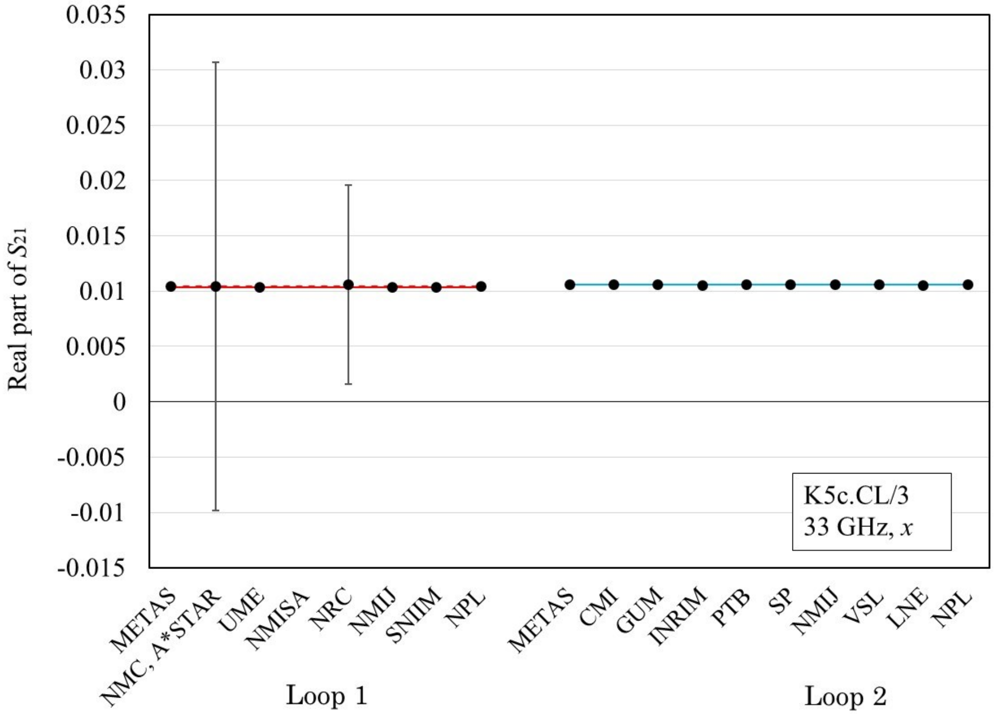

Fig. 3.12.1. Reported results and KCRV for ReS_{21} of K5c.CL/3 at 33 GHz.

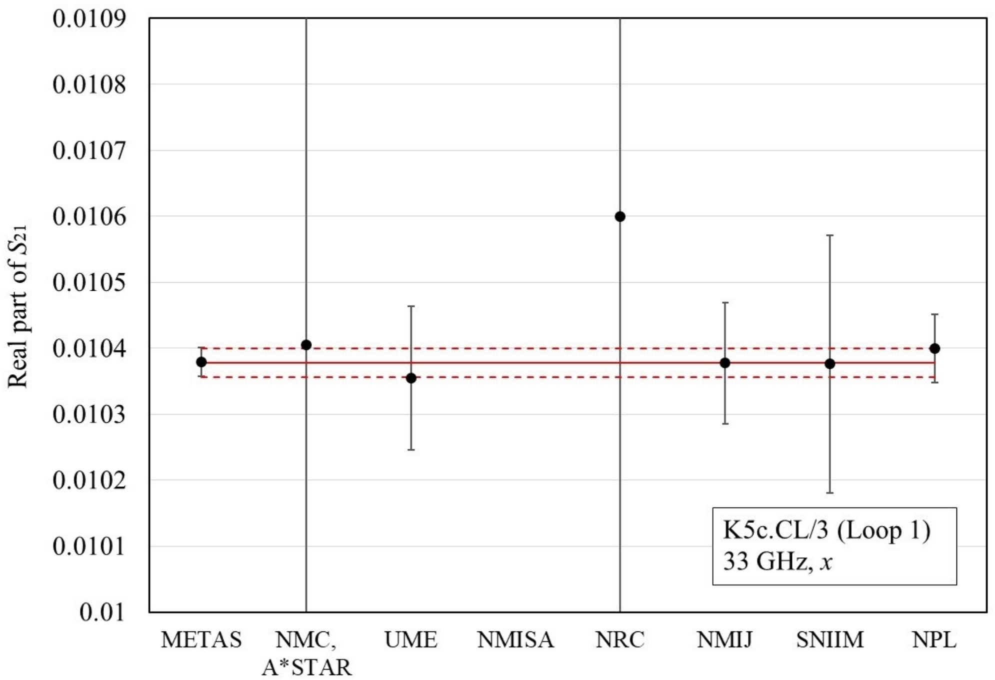

Fig. 3.12.2. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 1) at 33 GHz (enlarged view of Fig. 3.12.1.).

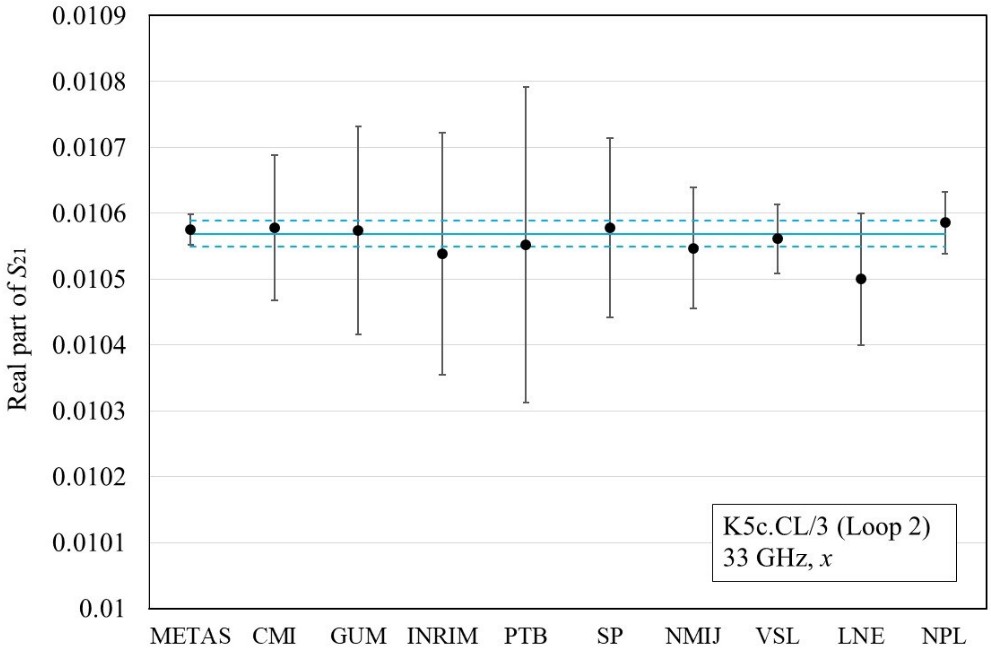

Fig. 3.12.3. Reported results and KCRV for ReS_{21} of K5c.CL/3 (Loop 2) at 33 GHz (enlarged view of Fig. 3.12.1.).

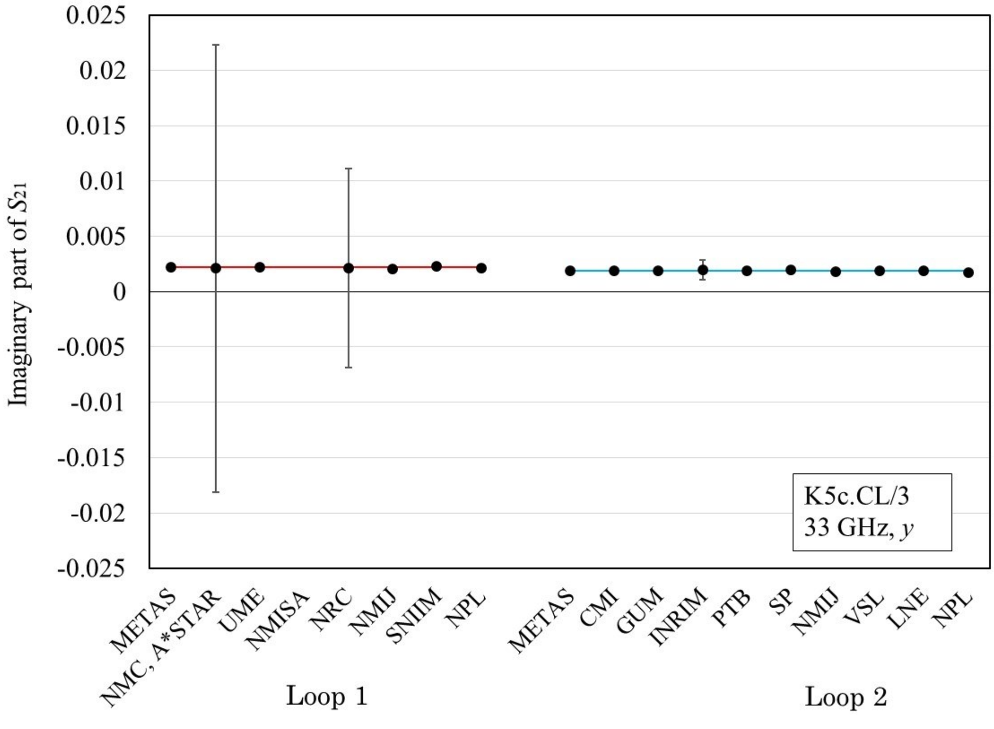

Fig. 3.12.4. Reported results and KCRV for ImS_{21} of K5c.CL/3 at 33 GHz.

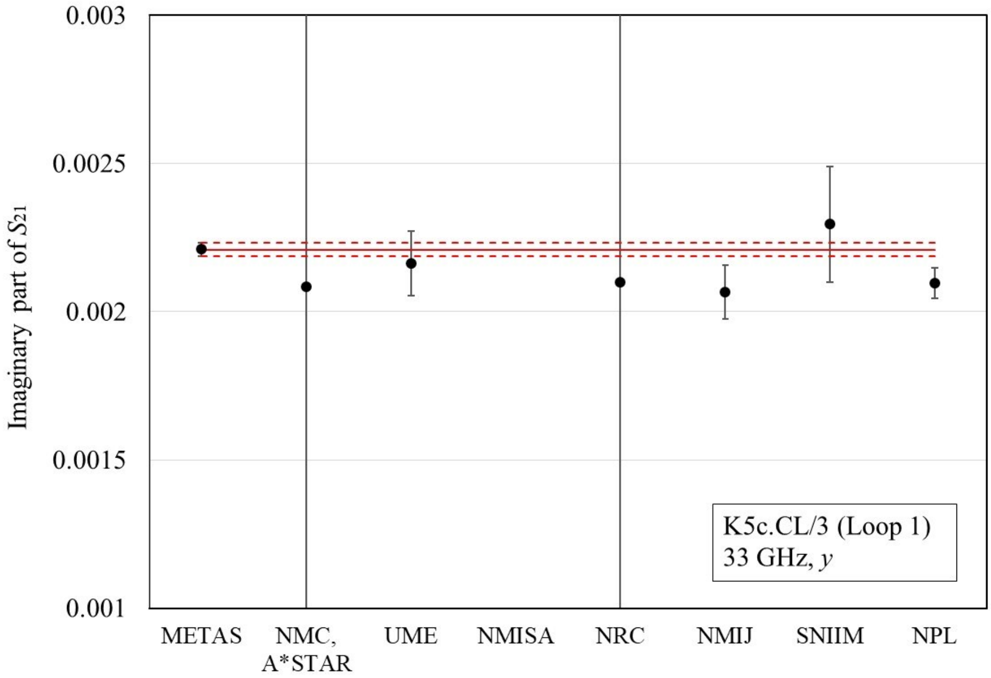

Fig. 3.12.5. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 1) at 33 GHz (enlarged view of Fig. 3.12.4.).

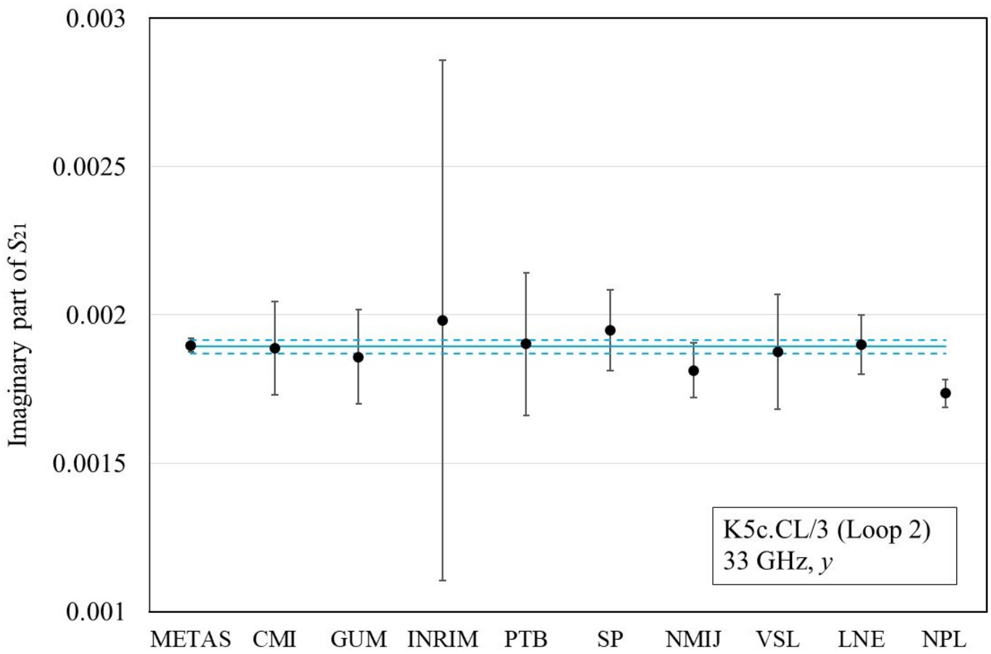

Fig. 3.12.6. Reported results and KCRV for ImS_{21} of K5c.CL/3 (Loop 2) at 33 GHz (enlarged view of Fig. 3.12.4.).

Table 3.12.3. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 1) at 33 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0000022	0.0000056
NMC, A*STAR	0.000	0.025
UME	0.00005	0.00013
NMISA		
NRC	0.000	0.011
NMIJ	0.00014	0.00012
SNIIM	0.00009	0.00024
NPL	0.000113	0.000069

Table 3.12.4. Reduced dimensional DoE for S_{21} of K5c.CL/3 (Loop 2) at 33 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.000009	0.000012
CMI	0.00001	0.00015
GUM	0.00003	0.00020
INRIM	0.00009	0.00060
PTB	0.00002	0.00029
SP	0.00006	0.00017
NMIJ	0.00008	0.00011
VSL	0.00002	0.00013
LNE	0.00007	0.00012
NPL	0.000158	0.000064

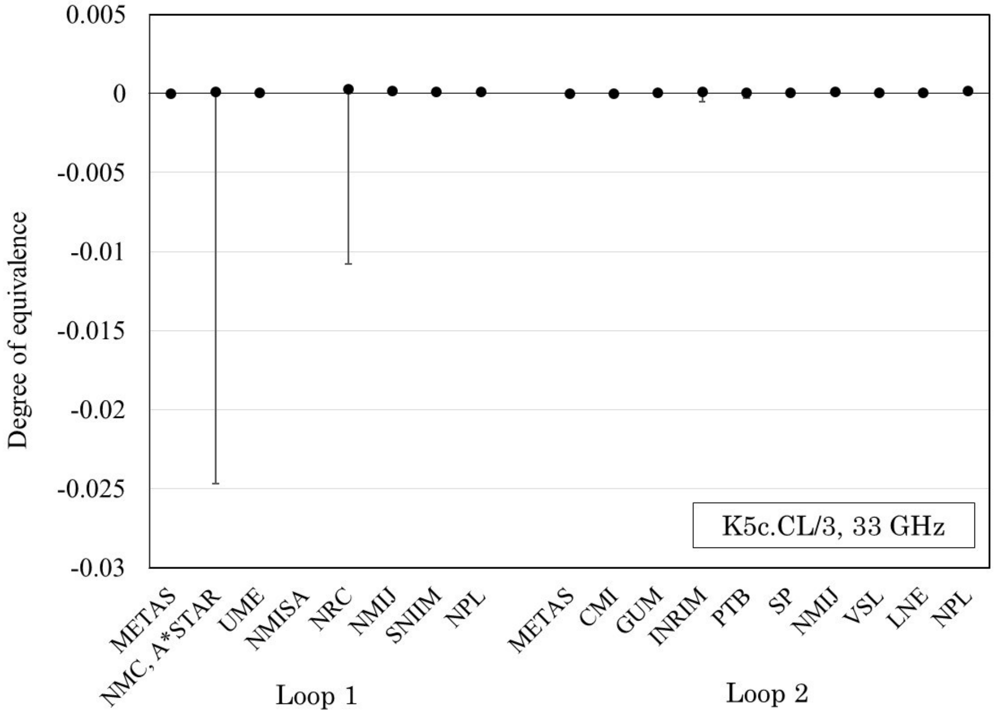

Fig. 3.12.7. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 33 GHz.

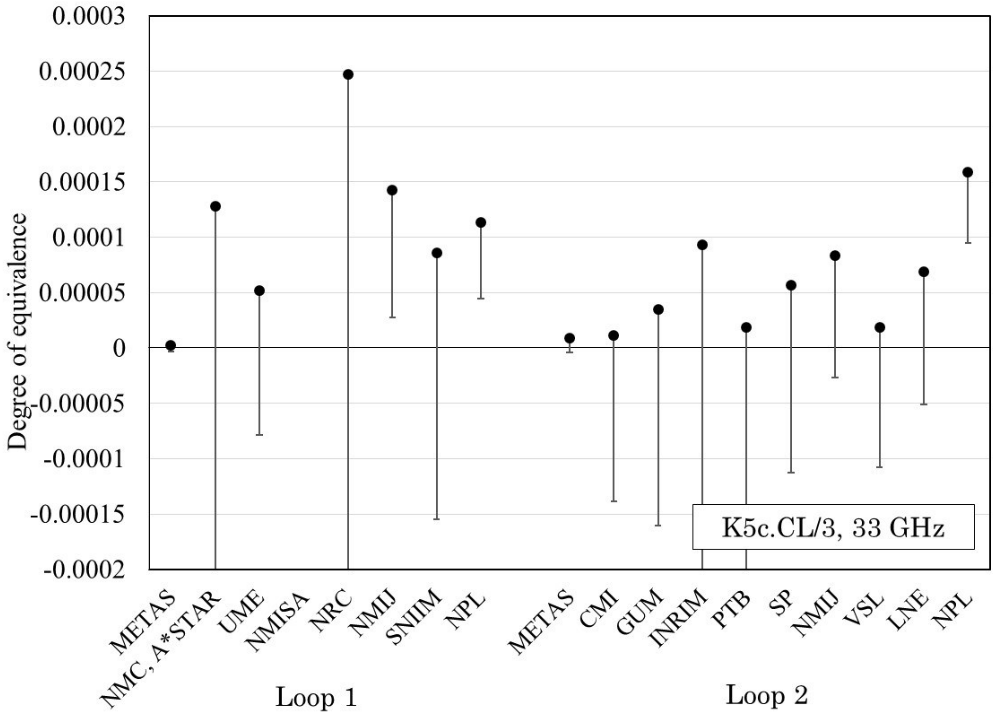

Fig. 3.12.8. Reduced dimensional DoE from KCRV for S_{21} of K5c.CL/3 at 33 GHz (enlarged view of Fig. 3.12.7.).

K5c.CL/4 at 0.1 GHz

Table 3.13.1. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 1) at 0.1 GHz.

Laboratory	K5c.CL/4 (Loop 1) Measurement and combined uncertainty of S_{11} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.00028	0.00052	0.00017	0.00052	
NMC, A*STAR	-0.0013	0.0041	0.0003	0.0041	
UME	-0.0004	0.0014	0.0001	0.0014	-0.12
NMISA	-0.0048	0.0065	0.0014	0.0065	
NRC	-0.0002	0.0067	-0.0013	0.0067	
NMIJ	-0.0007	0.0016	0.0001	0.0016	
SNIIM	-0.0005	0.0014	0.0000	0.0014	
NPL	-0.0002	0.0018	0.0004	0.0018	
KCRV	-0.00036	0.00044	0.00017	0.00044	

Table 3.13.2. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 2) at 0.1 GHz.

Laboratory	K5c.CL/4 (Loop 2) Measurement and combined uncertainty of S_{11} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.00221	0.00052	-0.00006	0.00052	
CMI	0.0024	0.0014	0.0003	0.0014	0.050
GUM	0.0020	0.0029	-0.0002	0.0029	
INRIM	0.0023	0.0025	-0.0004	0.0025	0.0000000055
PTB	0.0012	0.0025	0.0015	0.0025	
SP	0.0011	0.0035	0.0002	0.0035	
NMIJ	0.0019	0.0016	-0.0001	0.0016	
VSL	0.0022	0.0011	0.0000	0.0011	
LNE	0.0011	0.0017	-0.0001	0.0017	
NPL	0.0024	0.0018	0.0001	0.0018	
KCRV	0.00211	0.00041	-0.00001	0.00041	

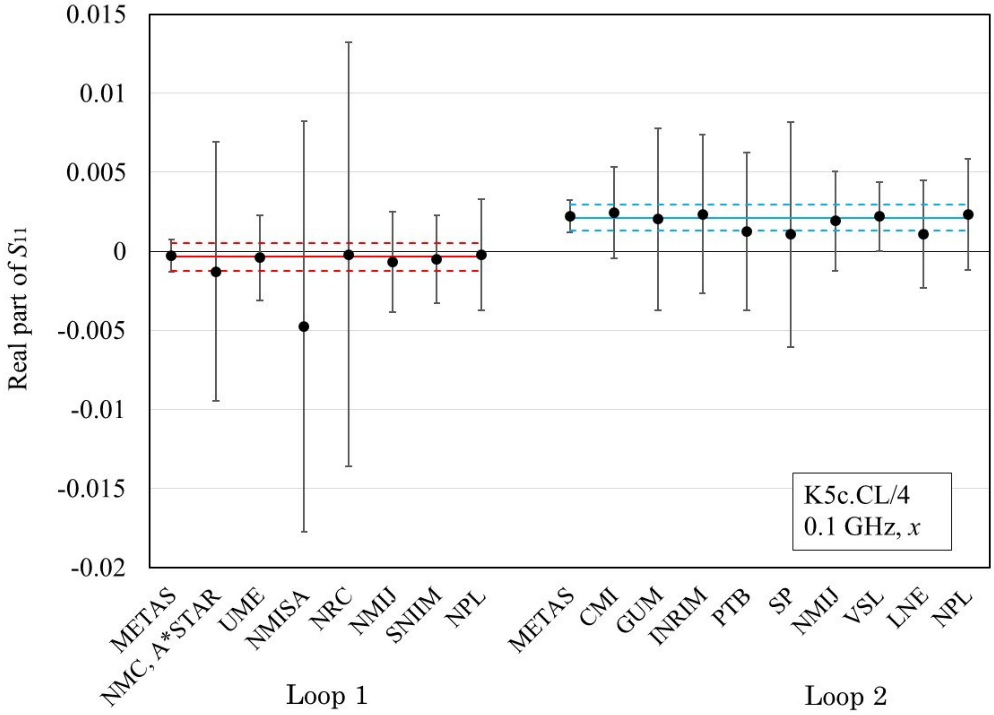

Fig. 3.13.1. Reported results and KCRV for ReS_{11} of K5c.CL/4 at 0.1 GHz.

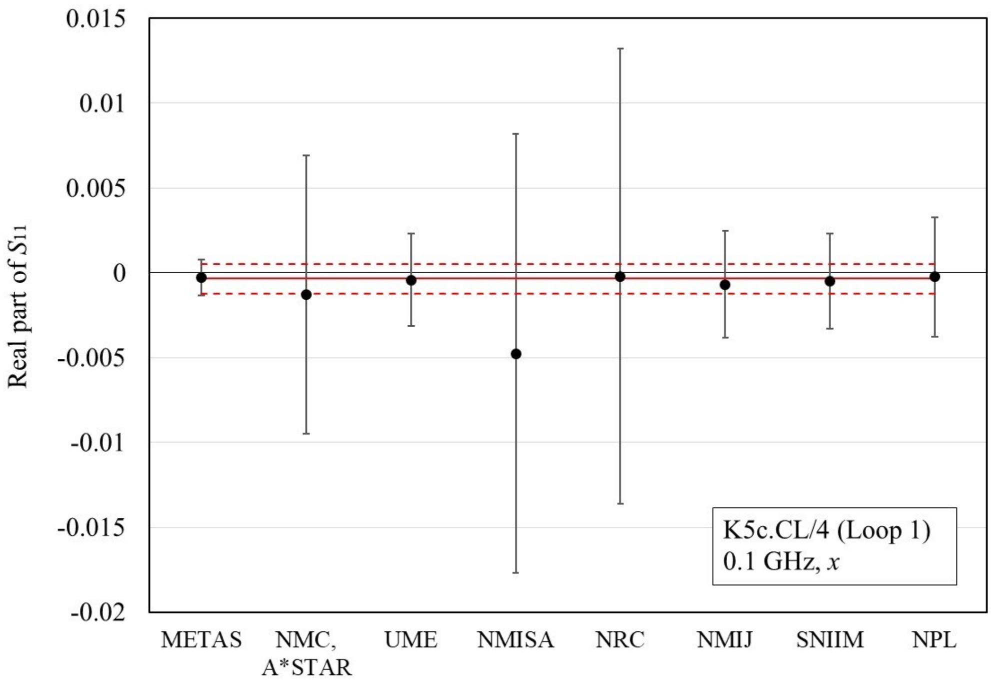

Fig. 3.13.2. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.13.1.).

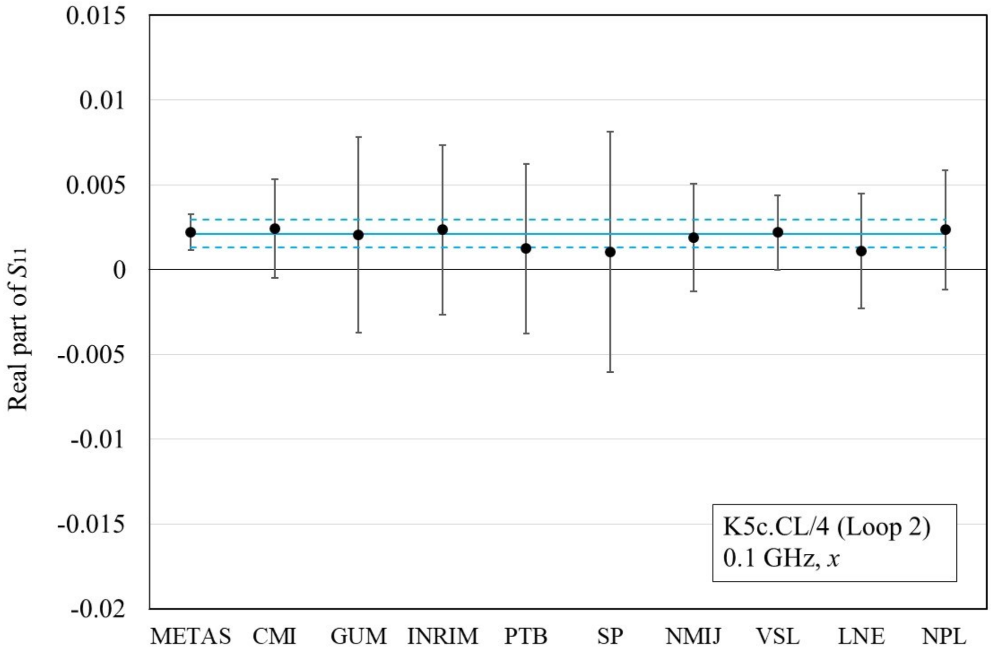

Fig. 3.13.3. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.13.1.).

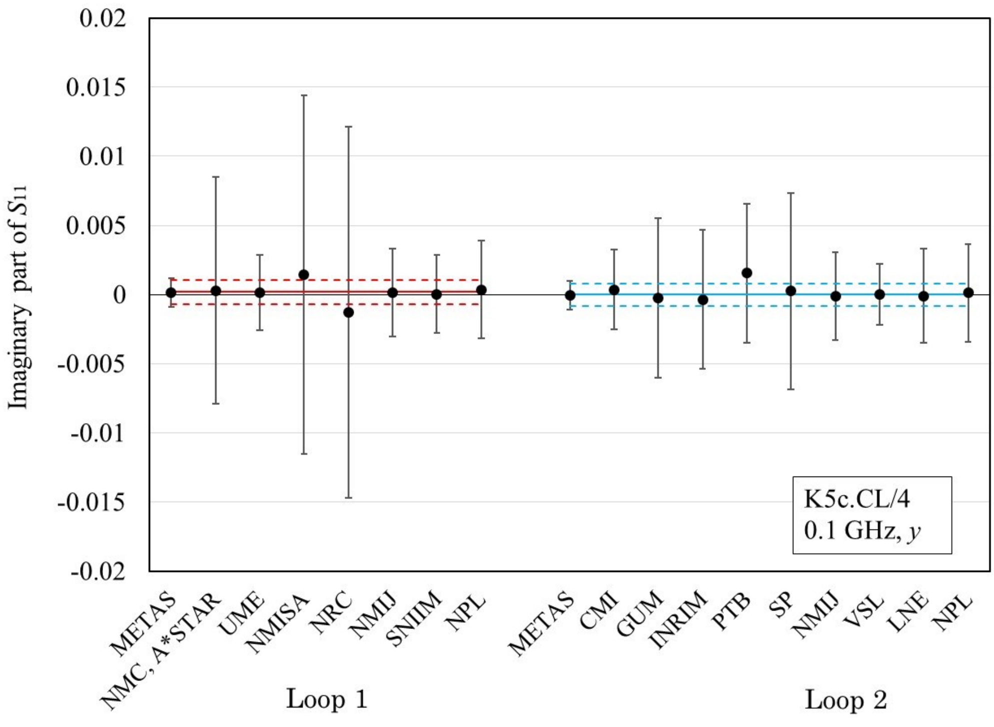

Fig. 3.13.4. Reported results and KCRV for ImS_{11} of K5c.CL/4 at 0.1 GHz.

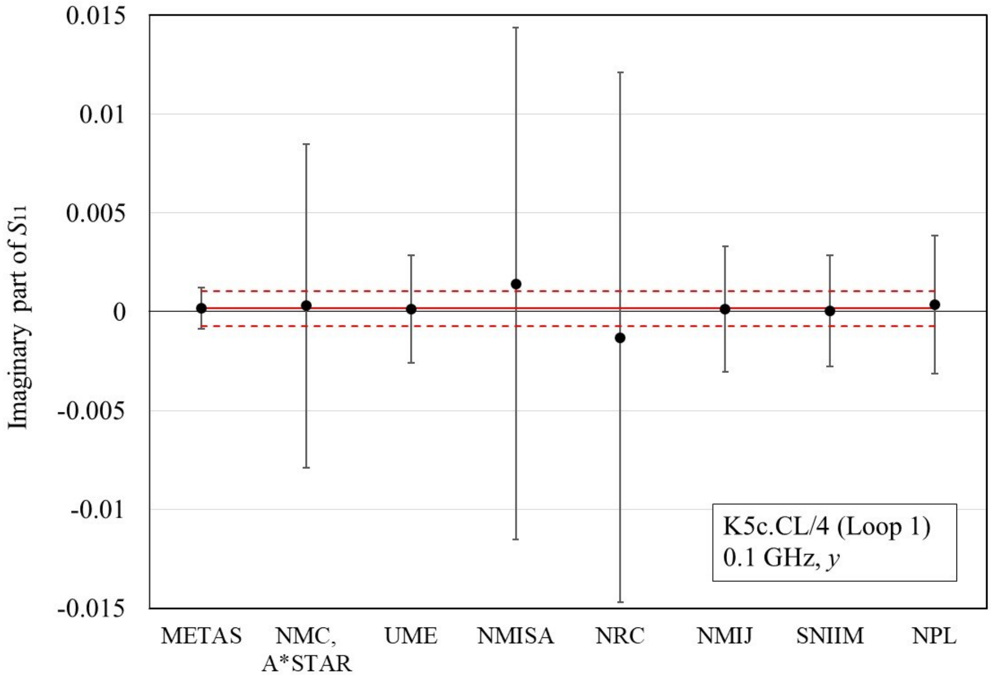

Fig. 3.13.5. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.13.4.).

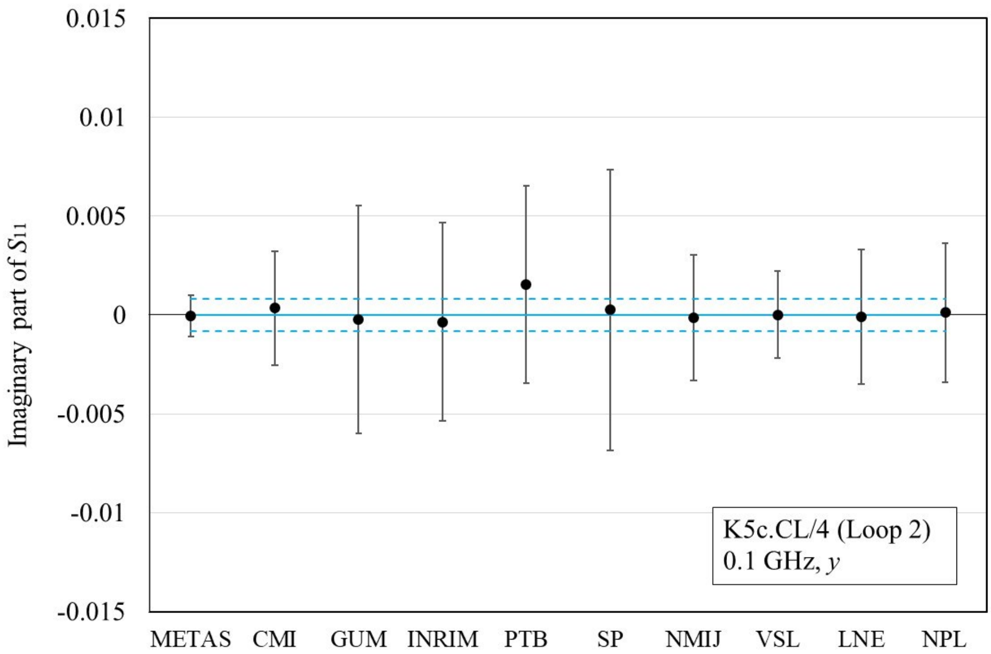

Fig. 3.13.6. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.13.4.).

Table 3.13.3. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 1) at 0.1 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.00008	0.00066
NMC, A*STAR	0.001	0.010
UME	0.0001	0.0031
NMISA	0.005	0.016
NRC	0.001	0.016
NMIJ	0.0003	0.0037
SNIIM	0.0002	0.0036
NPL	0.0002	0.0042

Table 3.13.4. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 2) at 0.1 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.00011	0.00078
CMI	0.0005	0.0037
GUM	0.0002	0.0071
INRIM	0.0004	0.0061
PTB	0.0018	0.0060
SP	0.0011	0.0088
NMIJ	0.0002	0.0037
VSL	0.0001	0.0025
LNE	0.0010	0.0040
NPL	0.0003	0.0042

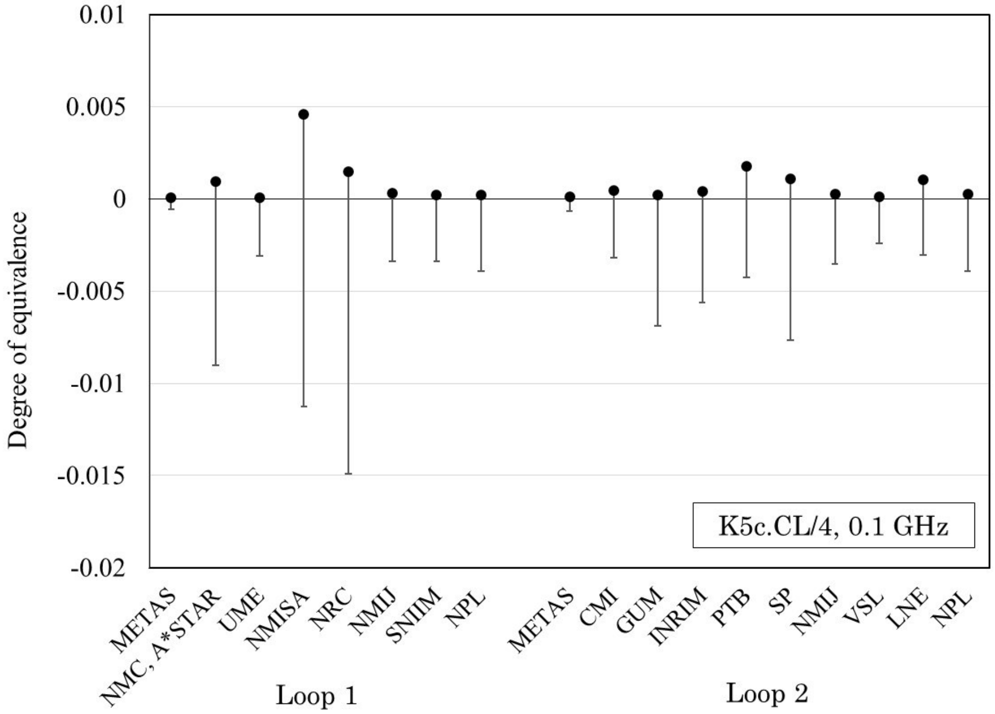

Fig. 3.13.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 0.1 GHz.

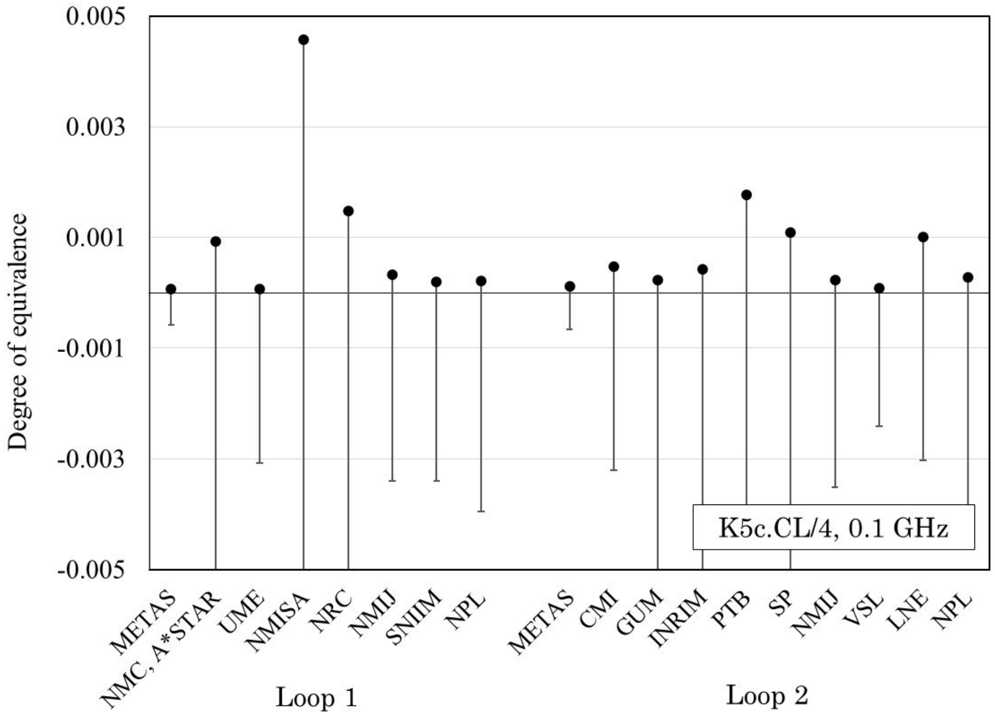

Fig. 3.13.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 0.1 GHz (enlarged view of Fig. 3.13.7.).

K5c.CL/4 at 12.4 GHz

Table 3.14.1. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 1) at 12.4 GHz.

Laboratory	K5c.CL/4 (Loop 1) Measurement and combined uncertainty of S_{11} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.00639	0.00055	-0.00694	0.00055	
NMC, A*STAR	-0.0064	0.0054	-0.0051	0.0054	
UME	-0.0069	0.0033	-0.0073	0.0033	-0.53
NMISA	-0.0051	0.0065	-0.0072	0.0065	
NRC	-0.0062	0.0067	-0.0059	0.0067	
NMIJ	-0.0062	0.0020	-0.0059	0.0020	
SNIIM	-0.0068	0.0026	-0.0053	0.0026	
NPL	-0.0060	0.0018	-0.0064	0.0018	
KCRV	-0.00635	0.00050	-0.00683	0.00050	

Table 3.14.2. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 2) at 12.4 GHz.

Laboratory	K5c.CL/4 (Loop 2) Measurement and combined uncertainty of S_{11} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.00495	0.00055	-0.00115	0.00056	
CMI	0.00519	0.00089	-0.0005	0.0010	-0.15
GUM	0.0050	0.0025	0.0007	0.0025	
INRIM	0.0052	0.0032	-0.0006	0.0032	0.00
PTB	0.0049	0.0025	0.0015	0.0025	
SP	0.0039	0.0058	0.0007	0.0058	
NMIJ	0.0052	0.0020	0.0004	0.0020	
VSL	0.0048	0.0011	-0.0013	0.0011	
LNE	*-0.0013*	*0.0036*	*-0.0127*	*0.0036*	
NPL	0.0054	0.0018	-0.0005	0.0018	
KCRV	0.00497	0.00045	-0.00096	0.00046	

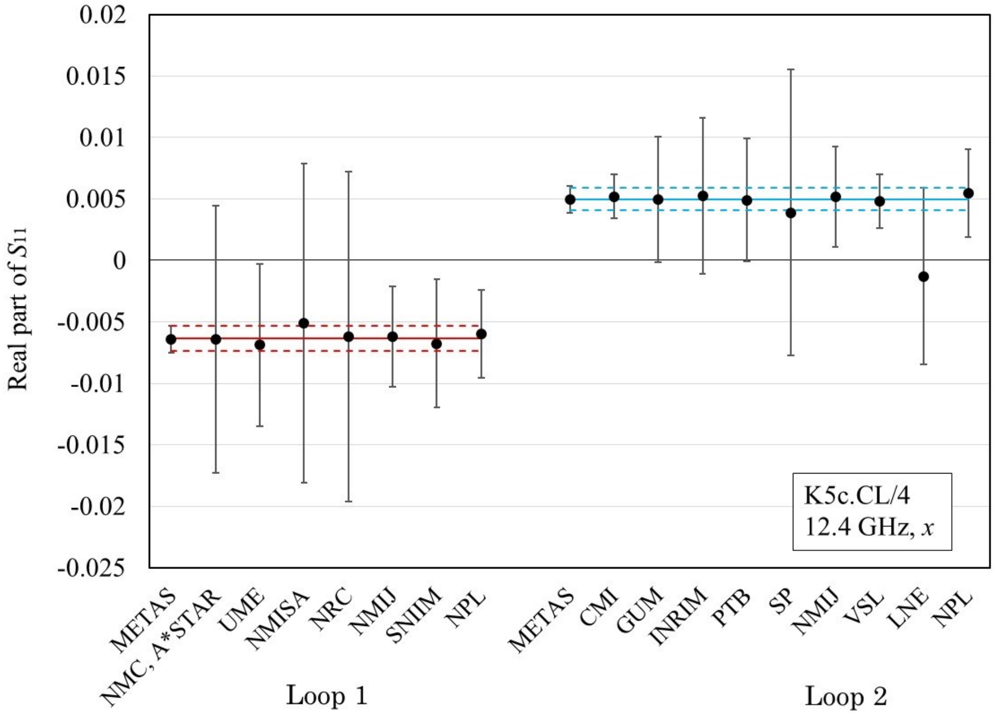

Fig. 3.14.1. Reported results and KCRV for ReS_{11} of K5c.CL/4 at 12.4 GHz.

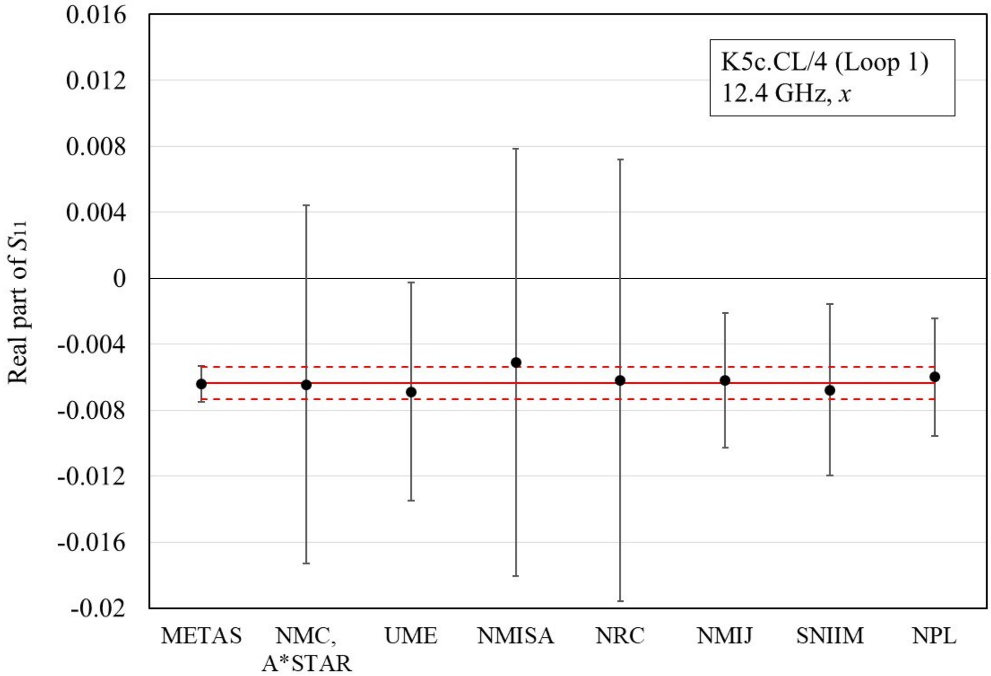

Fig. 3.14.2. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.14.1.).

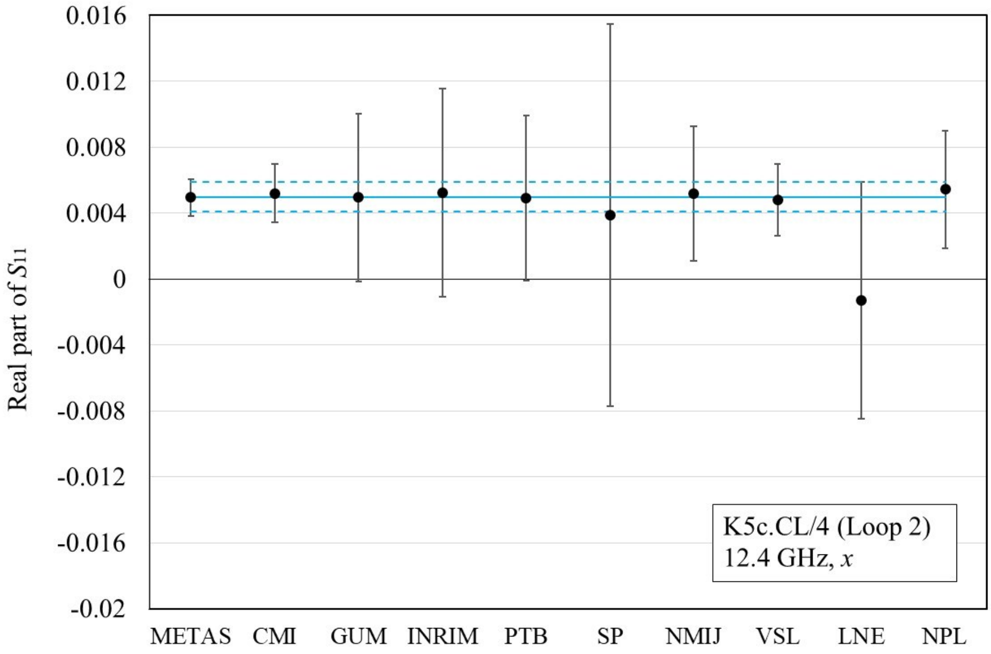

Fig. 3.14.3. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.14.1.).

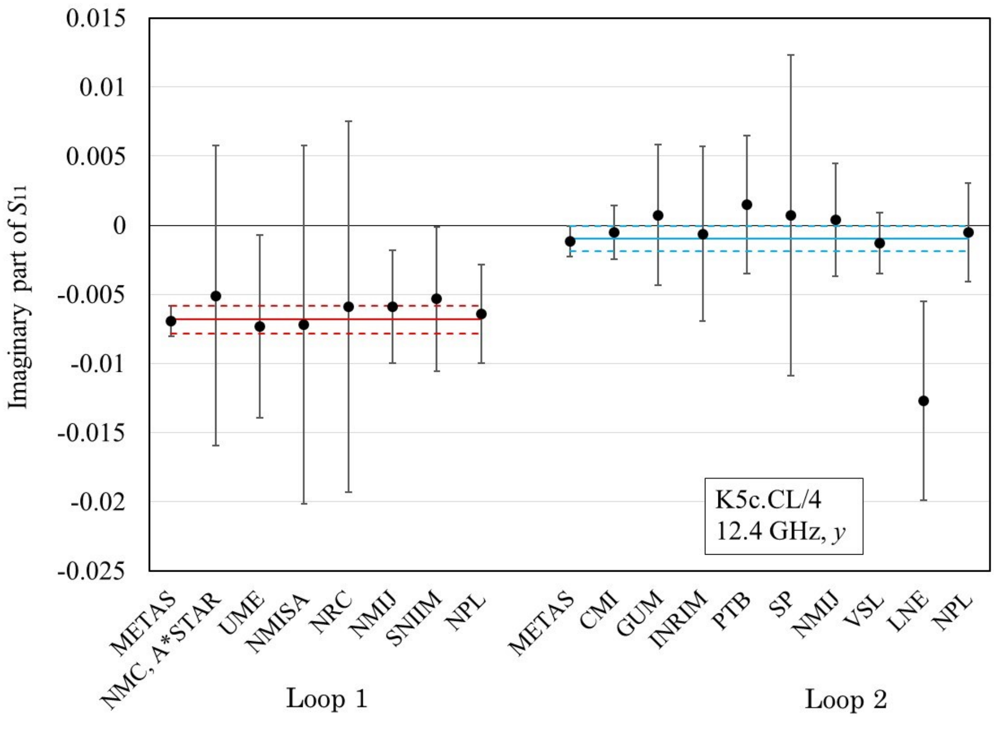

Fig. 3.14.4. Reported results and KCRV for ImS_{11} of K5c.CL/4 at 12.4 GHz.

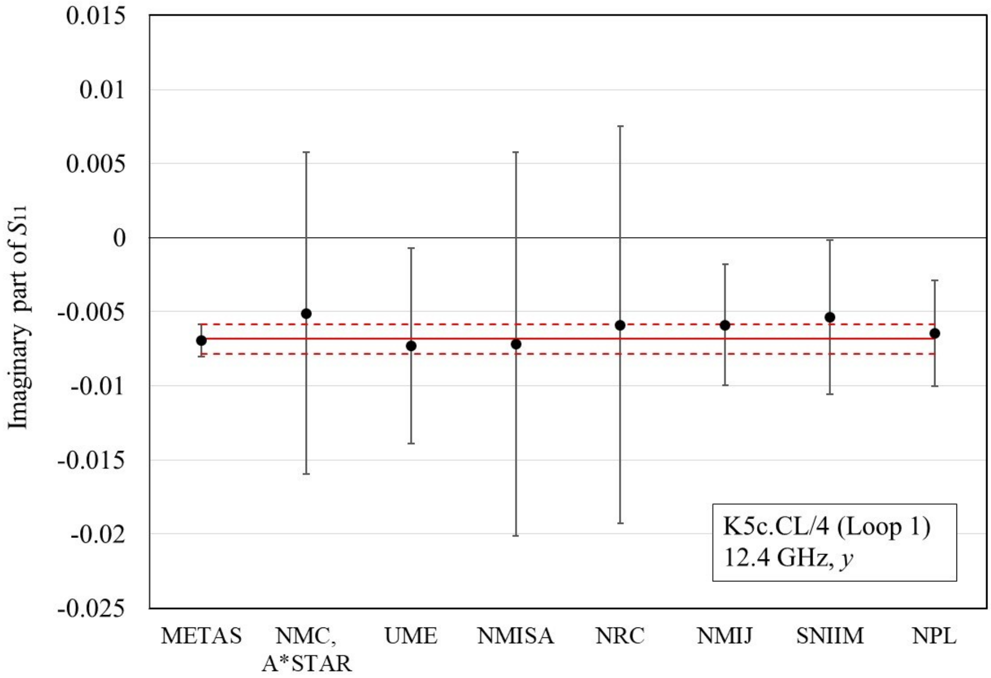

Fig. 3.14.5. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.14.4.).

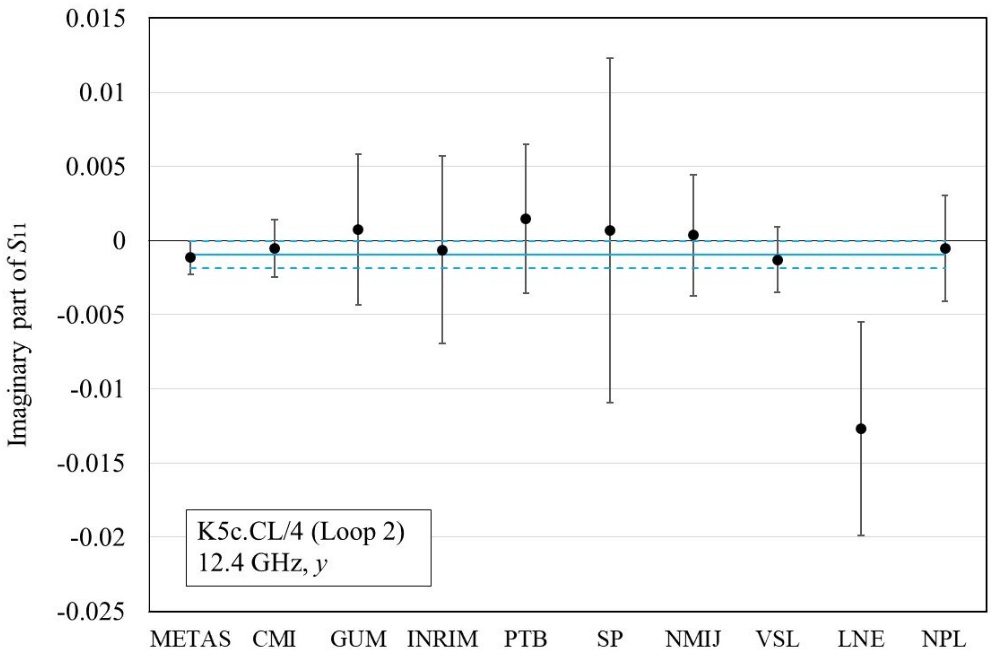

Fig. 3.14.6. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.14.4.).

Table 3.14.3. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 1) at 12.4 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.00012	0.00058
NMC, A*STAR	0.002	0.013
UME	0.0007	0.0080
NMISA	0.001	0.016
NRC	0.001	0.016
NMIJ	0.0009	0.0048
SNIIM	0.0015	0.0065
NPL	0.0005	0.0042

Table 3.14.4. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 2) at 12.4 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.00019	0.00080
CMI	0.0005	0.0026
GUM	0.0017	0.0063
INRIM	0.0004	0.0077
PTB	0.0024	0.0060
SP	0.002	0.014
NMIJ	0.0013	0.0049
VSL	0.0004	0.0025
LNE	0.0133	0.0089
NPL	0.0006	0.0042

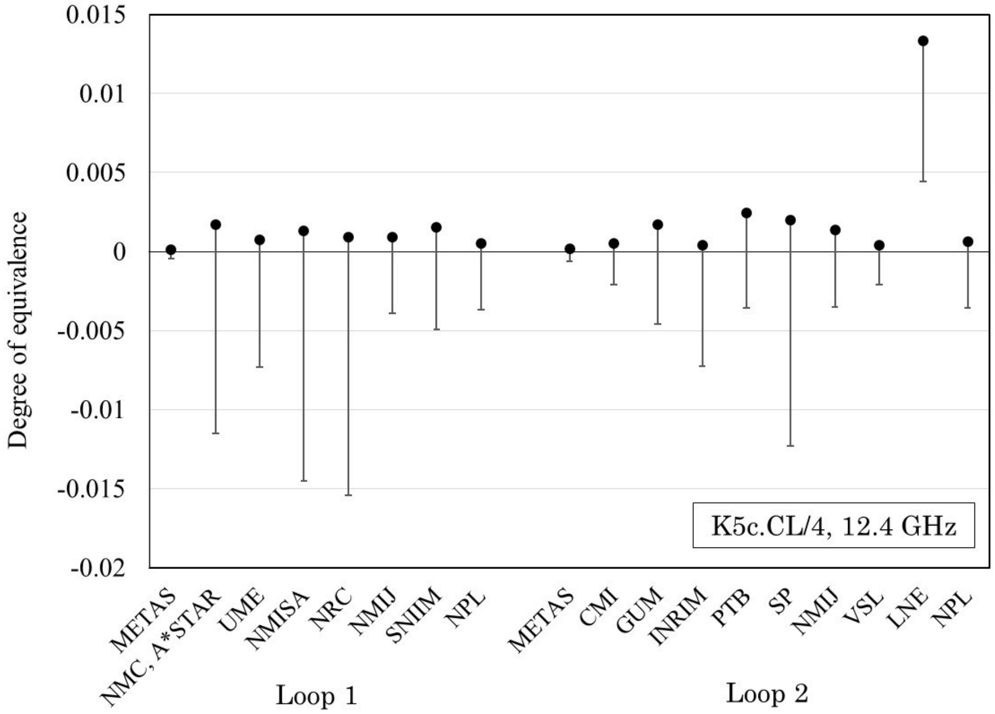

Fig. 3.14.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 12.4 GHz.

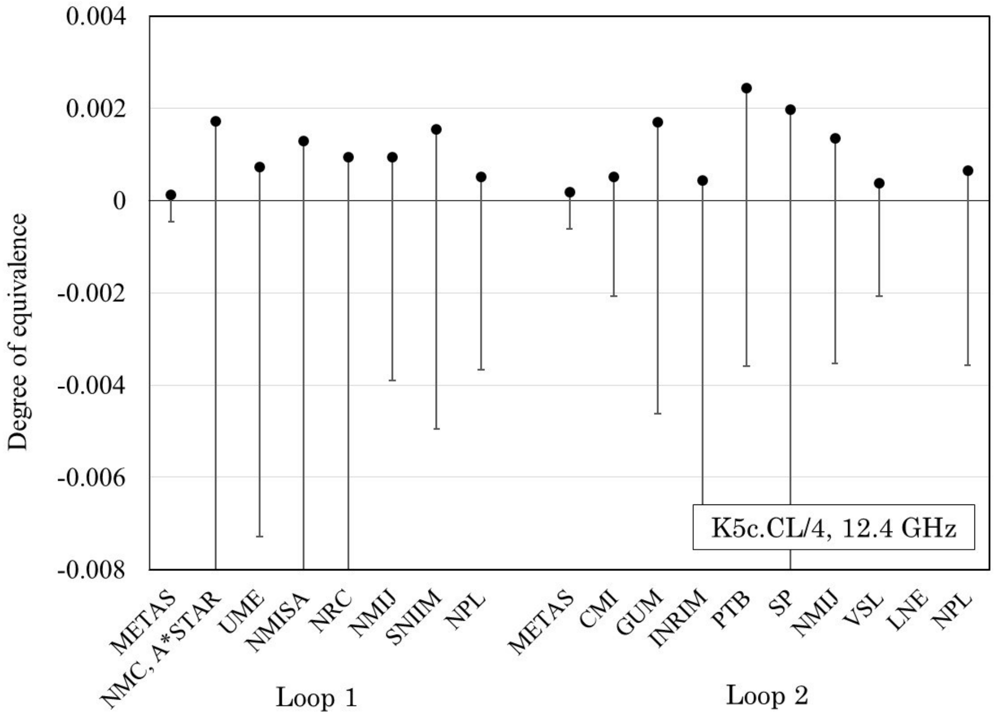

Fig. 3.14.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 12.4 GHz (enlarged view of Fig. 3.14.7.).

K5c.CL/4 at 26.5 GHz

Table 3.15.1. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 1) at 26.5 GHz.

Laboratory	K5c.CL/4 (Loop 1) Measurement and combined uncertainty of S_{11} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.00133	0.00091	0.01166	0.00091	
NMC, A*STAR	-0.0011	0.0059	0.0148	0.0059	
UME	-0.0030	0.0033	0.0100	0.0033	0.91
NMISA	-0.0023	0.0085	0.0090	0.0085	
NRC	-0.0007	0.0097	0.0121	0.0097	
NMIJ	-0.0003	0.0028	0.0135	0.0028	
SNIIM	-0.0009	0.0040	0.0146	0.0040	
NPL	-0.0009	0.0018	0.0132	0.0018	
KCRV	-0.00126	0.00075	0.01201	0.00075	

Table 3.15.2. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 2) at 26.5 GHz.

Laboratory	K5c.CL/4 (Loop 2) Measurement and combined uncertainty of S_{11} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.00181	0.00091	0.00564	0.00091	
CMI	-0.0014	0.0022	0.0072	0.0018	0.46
GUM	-0.0014	0.0027	0.0095	0.0027	
INRIM	-0.0033	0.0032	0.0072	0.0032	0.00019
PTB	-0.0015	0.0025	0.0097	0.0025	
SP	-0.0021	0.0091	0.0092	0.0091	
NMIJ	-0.0014	0.0028	0.0085	0.0028	
VSL	-0.0020	0.0022	0.0054	0.0022	
LNE	*-0.0147*	*0.0039*	*0.0280*	*0.0039*	
NPL	-0.0012	0.0018	0.0072	0.0018	
KCRV	-0.00176	0.00069	0.00640	0.00069	

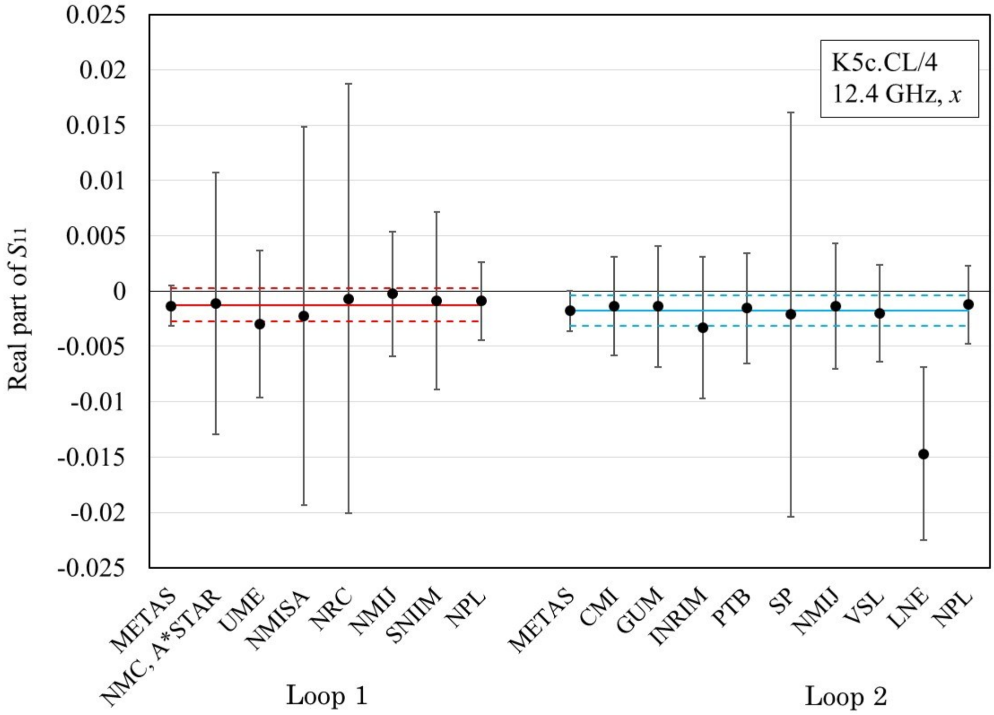

Fig. 3.15.1. Reported results and KCRV for ReS_{11} of K5c.CL/4 at 26.5 GHz.

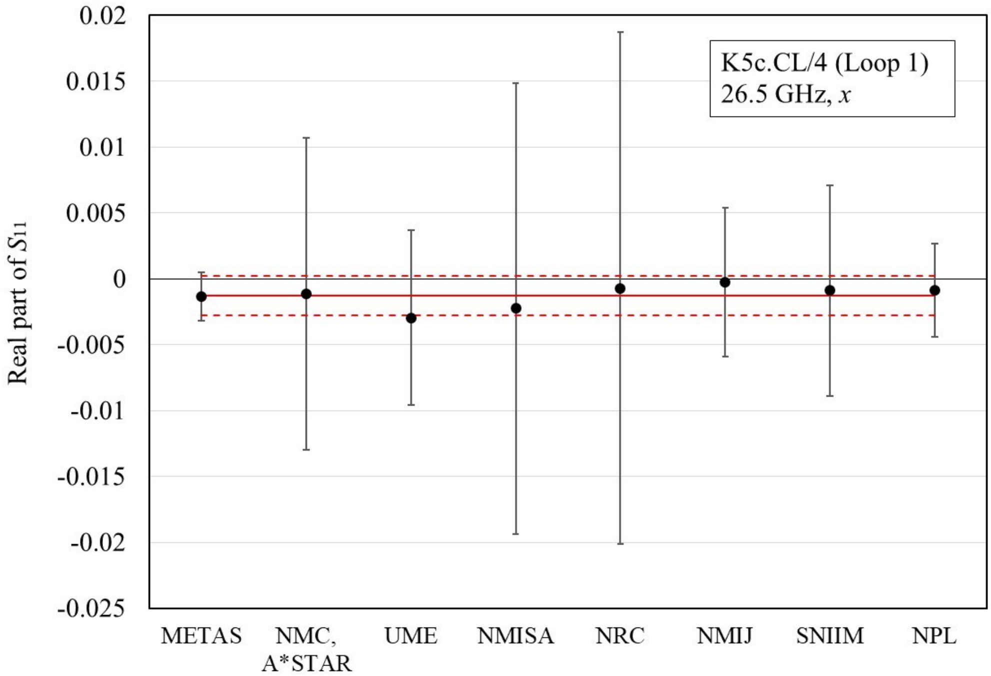

Fig. 3.15.2. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.15.1.).

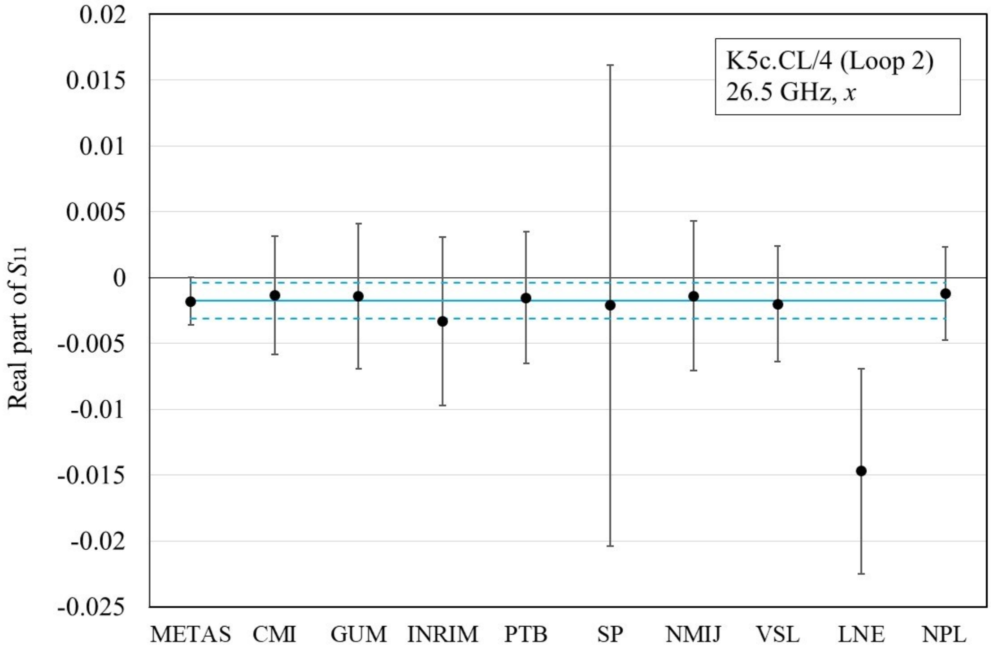

Fig. 3.15.3. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.15.1.).

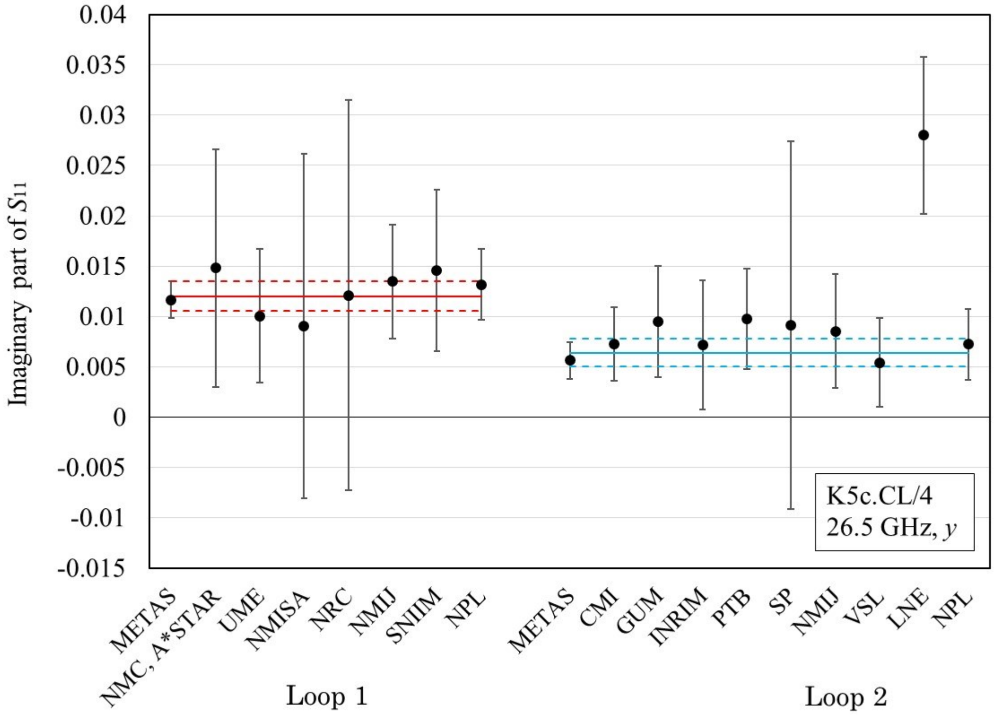

Fig. 3.15.4. Reported results and KCRV for ImS_{11} of K5c.CL/4 at 26.5 GHz.

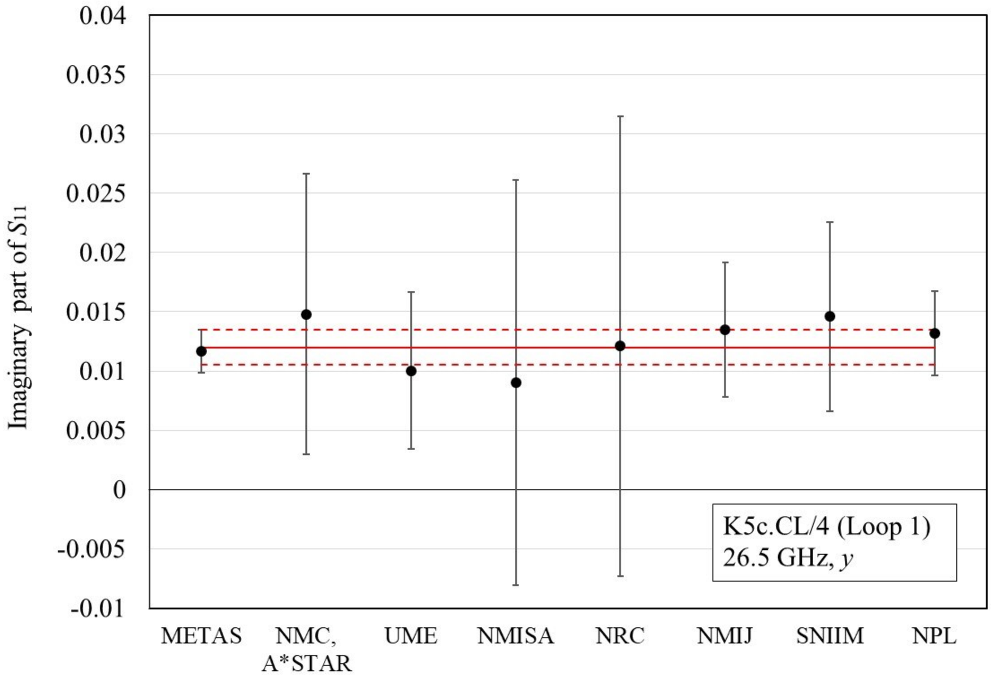

Fig. 3.15.5. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.15.4.).

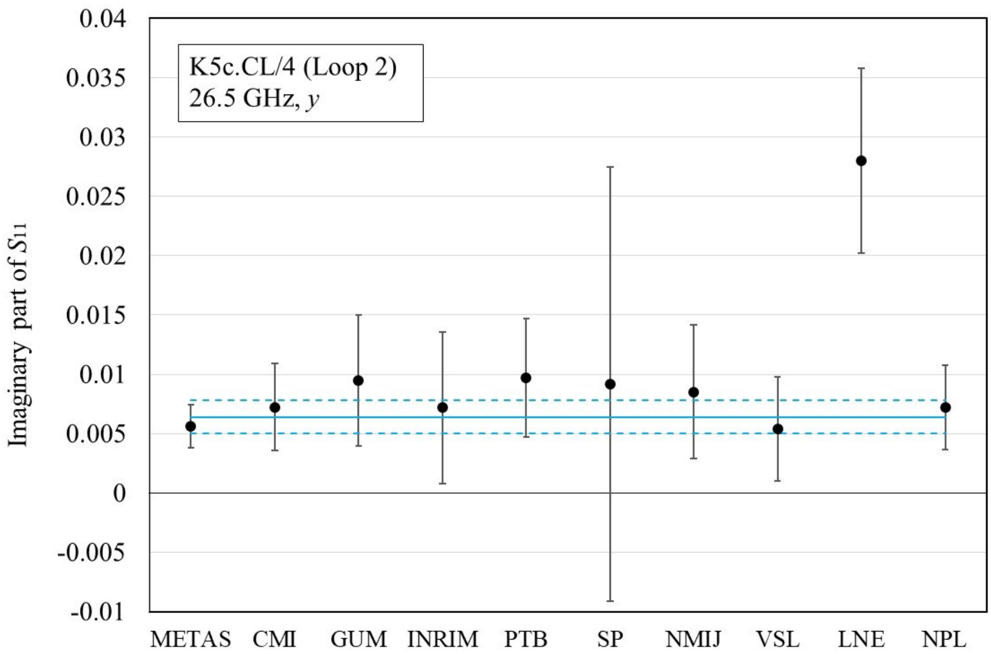

Fig. 3.15.6. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.15.4.).

Table 3.15.3. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 1) at 26.5 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0004	0.0013
NMC, A*STAR	0.003	0.014
UME	0.0026	0.0079
NMISA	0.003	0.021
NRC	0.001	0.024
NMIJ	0.0018	0.0067
SNIIM	0.003	0.010
NPL	0.0012	0.0039

Table 3.15.4. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 2) at 26.5 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0008	0.0015
CMI	0.0009	0.0049
GUM	0.0031	0.0069
INRIM	0.0017	0.0076
PTB	0.0033	0.0059
SP	0.003	0.022
NMIJ	0.0022	0.0067
VSL	0.0010	0.0051
LNE	0.0252	0.0097
NPL	0.0010	0.0040

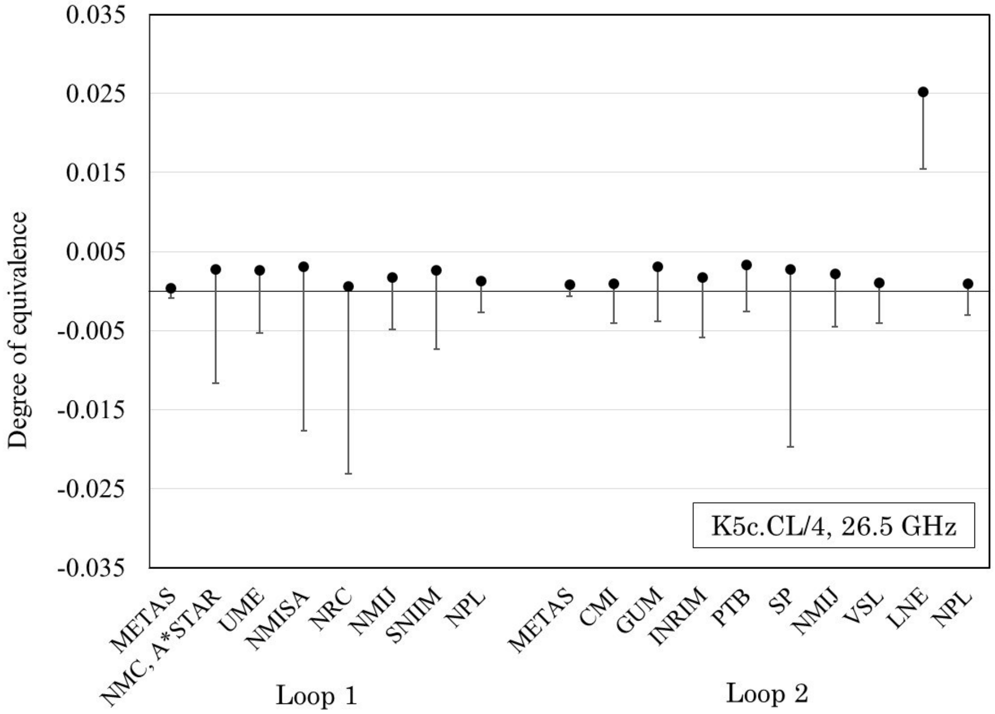

Fig. 3.15.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 26.5 GHz.

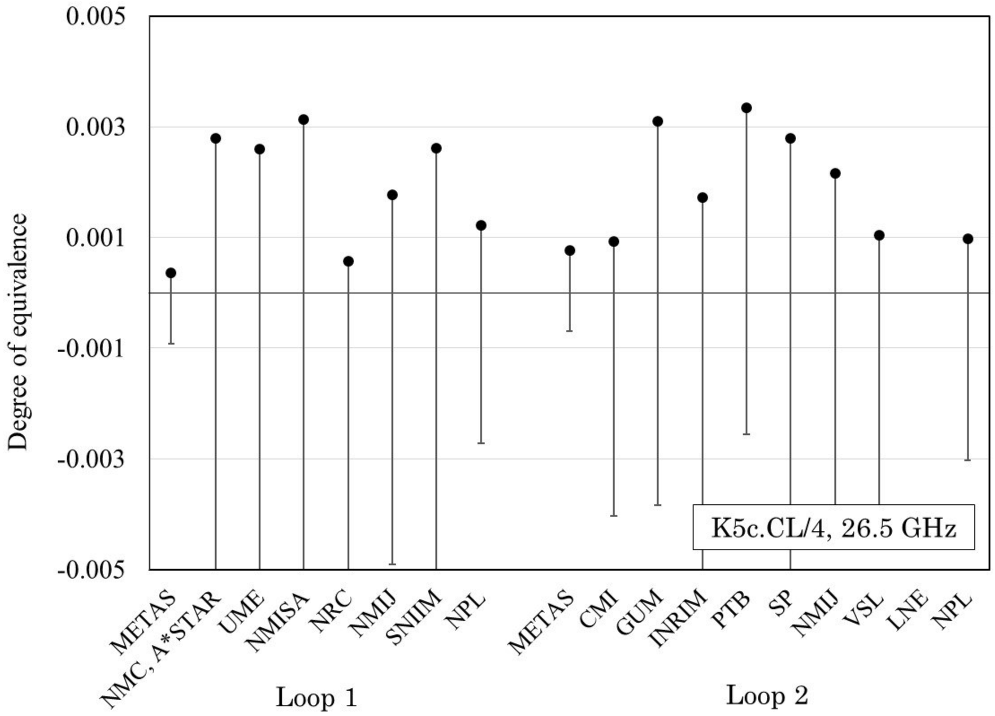

Fig. 3.15.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 26.5 GHz (enlarged view of Fig. 3.15.7.).

K5c.CL/4 at 33 GHz

Table 3.16.1. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 1) at 33 GHz.

Laboratory	K5c.CL/4 (Loop 1) Measurement and combined uncertainty of S_{11} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	0.0061	0.0017	-0.0246	0.0017	
NMC, A*STAR	0.0103	0.0066	-0.0249	0.0066	
UME	0.0039	0.0049	-0.0273	0.0049	0.996
NMISA					
NRC	0.007	0.023	-0.023	0.023	
NMIJ	0.0136	0.0030	-0.0249	0.0030	
SNIIM	0.0064	0.0056	-0.0217	0.0056	
NPL	0.0101	0.0019	-0.0238	0.0019	
KCRV	0.0086	0.0011	-0.0245	0.0011	

Table 3.16.2. Reported results and KCRV for S_{11} of K5c.CL/4 (Loop 2) at 33 GHz.

Laboratory	K5c.CL/4 (Loop 2) Measurement and combined uncertainty of S_{11} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.0001	0.0017	0.0000	0.0017	
CMI	0.0004	0.0026	0.0000	0.0027	0.51
GUM	0.0008	0.0027	0.0039	0.0027	
INRIM	-0.0026	0.0050	-0.0005	0.0050	4.2E-20
PTB	0.0057	0.0025	0.0023	0.0025	
SP	0.007	0.010	0.004	0.010	
NMIJ	0.0024	0.0030	0.0024	0.0030	
VSL	-0.0011	0.0022	-0.0010	0.0022	
LNE	*0.0267*	*0.0043*	*-0.0174*	*0.0043*	
NPL	0.0033	0.0019	0.0005	0.0019	
KCRV	0.00154	0.00094	0.00049	0.00094	

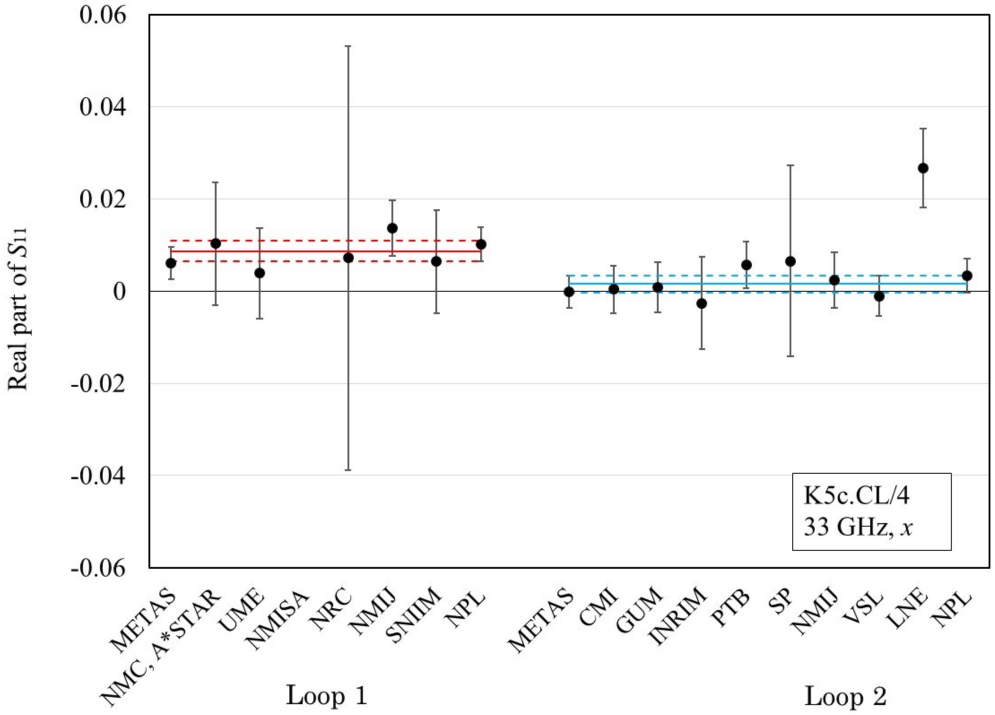

Fig. 3.16.1. Reported results and KCRV for ReS_{11} of K5c.CL/4 at 33 GHz.

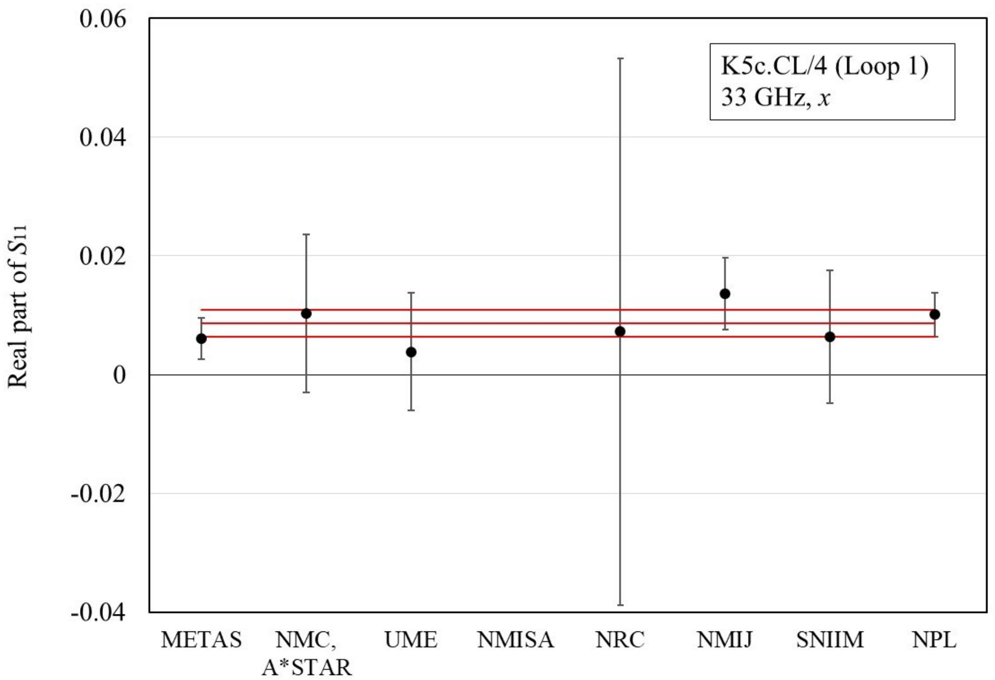

Fig. 3.16.2. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 1) at 33 GHz (enlarged view of Fig. 3.16.1.).

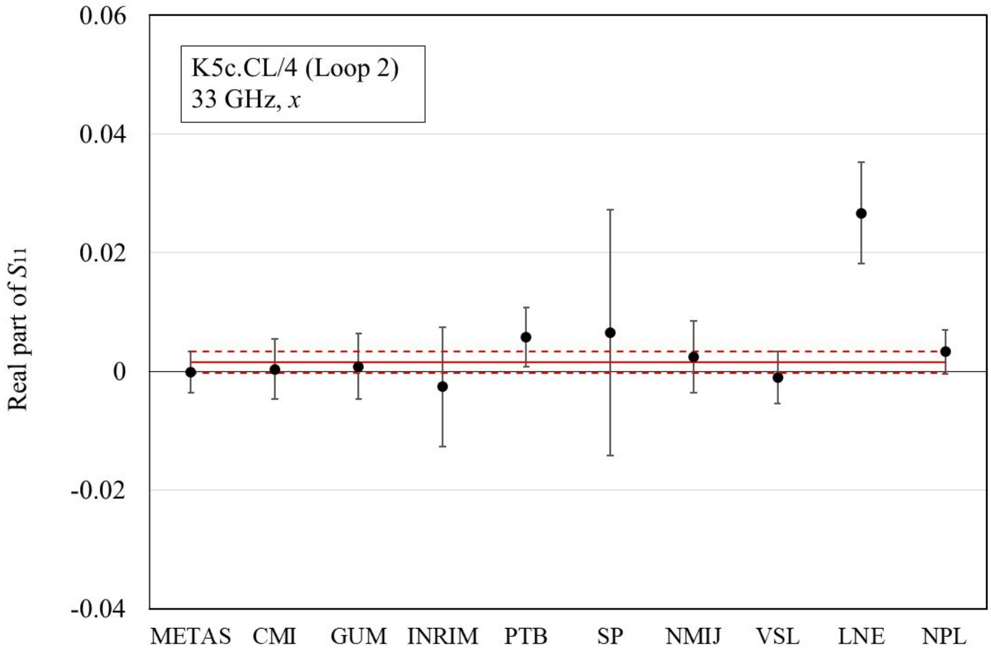

Fig. 3.16.3. Reported results and KCRV for ReS_{11} of K5c.CL/4 (Loop 2) at 33 GHz (enlarged view of Fig. 3.16.1.).

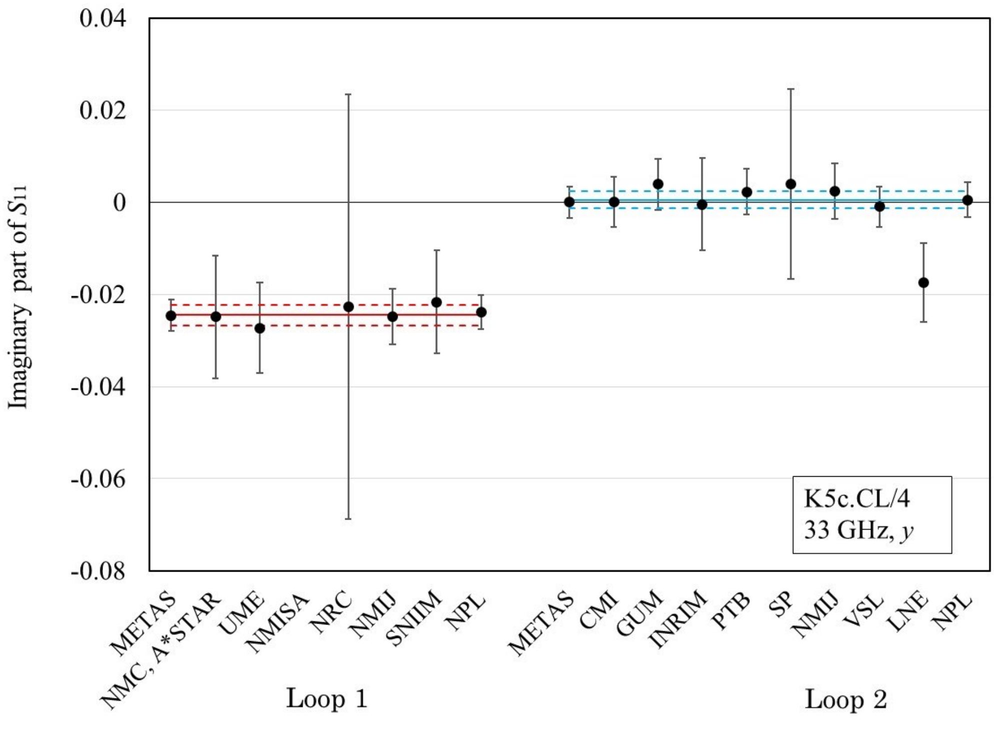

Fig. 3.16.4. Reported results and KCRV for ImS_{11} of K5c.CL/4 at 33 GHz.

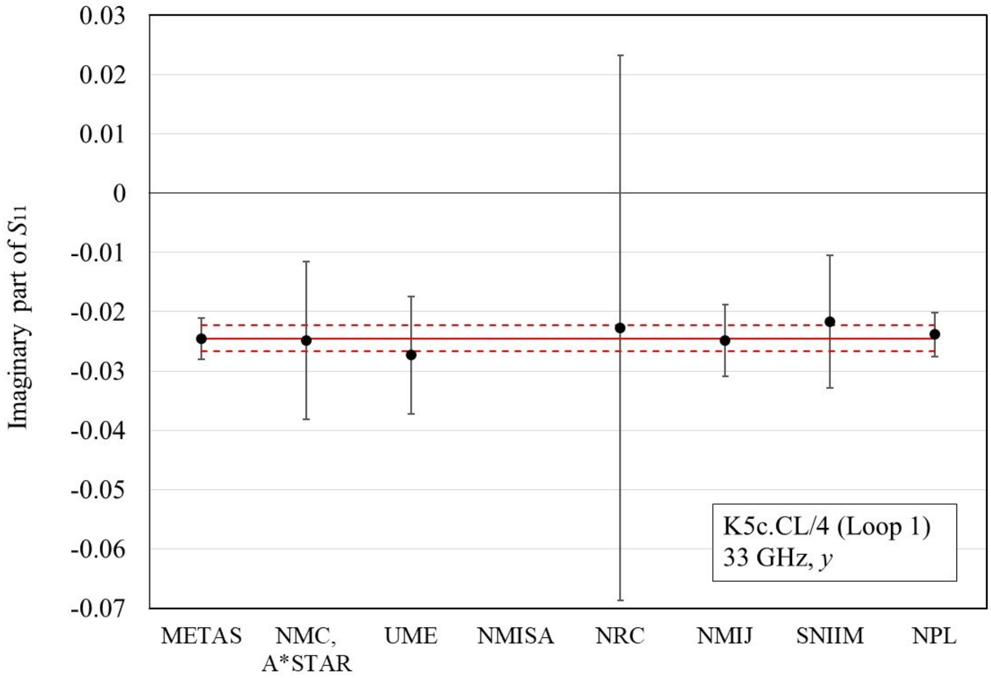

Fig. 3.16.5. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 1) at 33 GHz (enlarged view of Fig. 3.16.4.).

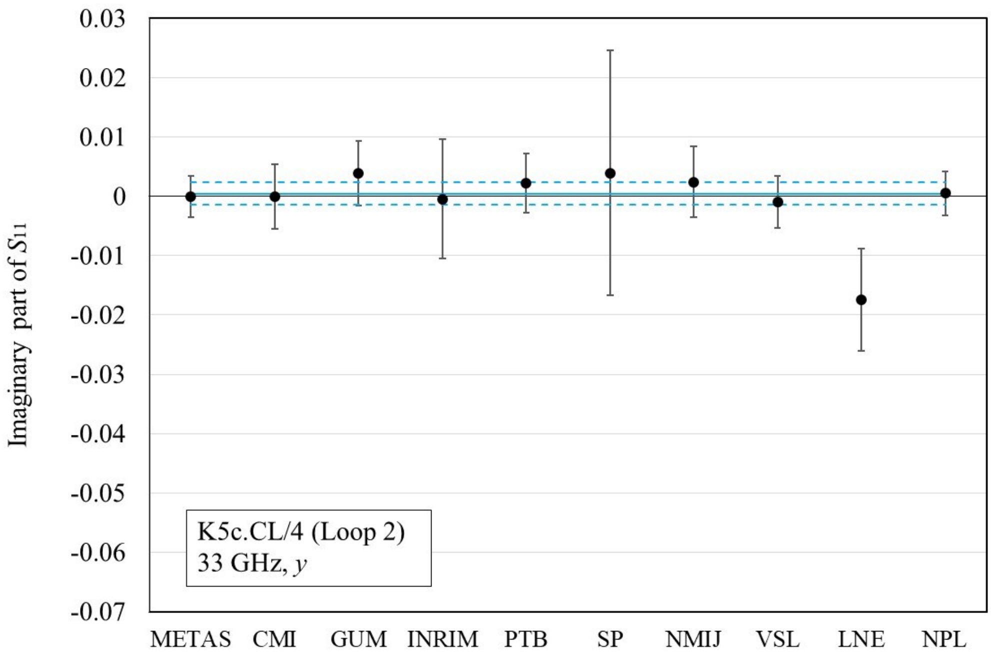

Fig. 3.16.6. Reported results and KCRV for ImS_{11} of K5c.CL/4 (Loop 2) at 33 GHz (enlarged view of Fig. 3.16.4.).

Table 3.16.3. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 1) at 33 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0025	0.0033
NMC, A*STAR	0.002	0.016
UME	0.006	0.012
NMISA		
NRC	0.002	0.056
NMIJ	0.0050	0.0069
SNIIM	0.004	0.014
NPL	0.0016	0.0036

Table 3.16.4. Reduced dimensional DoE for S_{11} of K5c.CL/4 (Loop 2) at 33 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0017	0.0036
CMI	0.0013	0.0067
GUM	0.0035	0.0071
INRIM	0.004	0.012
PTB	0.0045	0.0057
SP	0.006	0.025
NMIJ	0.0022	0.0070
VSL	0.0030	0.0049
LNE	0.031	0.011
NPL	0.0018	0.0040

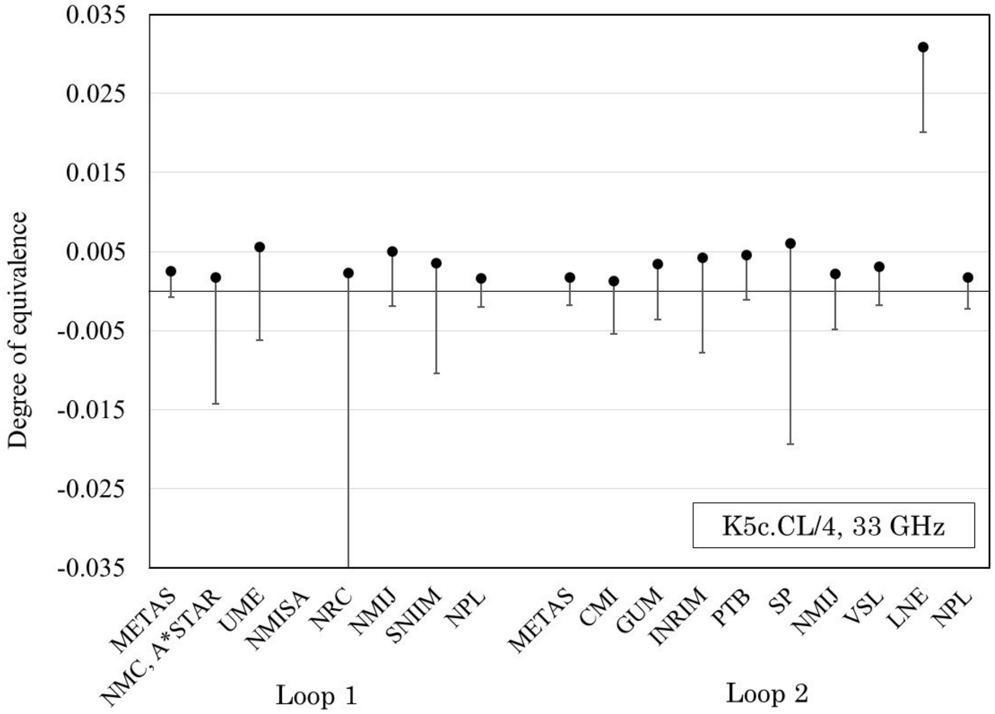

Fig. 3.16.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 33 GHz.

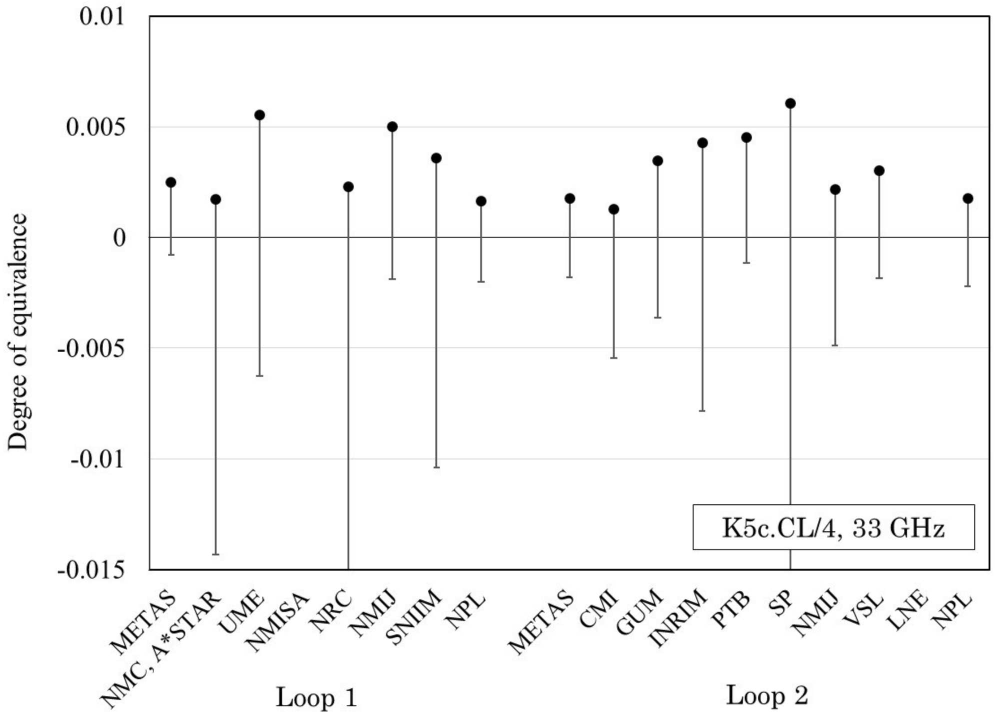

Fig. 3.16.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/4 at 33 GHz (enlarged view of Fig. 3.16.7.).

K5c.CL/7 at 0.1 GHz

Table 3.17.1. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 1) at 0.1 GHz.

Laboratory	K5c.CL/7 (Loop 1) Measurement and combined uncertainty of S_{11} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9999	0.0012	0.0000	0.0015	
NMC, A*STAR	-1.000	0.010	-0.001	0.010	
UME	-0.9995	0.0049	0.0003	0.0049	0.56
NMISA	-0.999	0.011	0.000	0.011	
NRC	-1.001	0.015	0.000	0.015	
NMIJ	-0.9980	0.0032	0.0003	0.0032	
SNIIM	-0.9998	0.0026	-0.0003	0.0026	
NPL	-0.9995	0.0018	0.0002	0.0018	
KCRV	-0.99966	0.00090	0.00012	0.00103	

Table 3.17.2. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 2) at 0.1 GHz.

Laboratory	K5c.CL/7 (Loop 2) Measurement and combined uncertainty of S_{11} at 0.1 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-1.0000	0.0012	0.0000	0.0015	
CMI	-1.00006	0.00025	0.00003	0.00027	0.0000055
GUM	-1.000	0.010	0.000	0.010	
INRIM	-1.0000	0.0035	0.0001	0.0072	-0.000067
PTB	-0.9997	0.0050	0.0003	0.0050	
SP	-1.0003	0.0071	-0.0003	0.0071	
NMIJ	-0.9987	0.0032	0.0000	0.0032	
VSL	-1.0000	0.0025	0.0001	0.0025	
LNE	-1.0006	0.0035	0.0005	0.0035	
NPL	-0.9995	0.0018	0.0002	0.0018	
KCRV	-0.99982	0.00081	0.00012	0.00092	

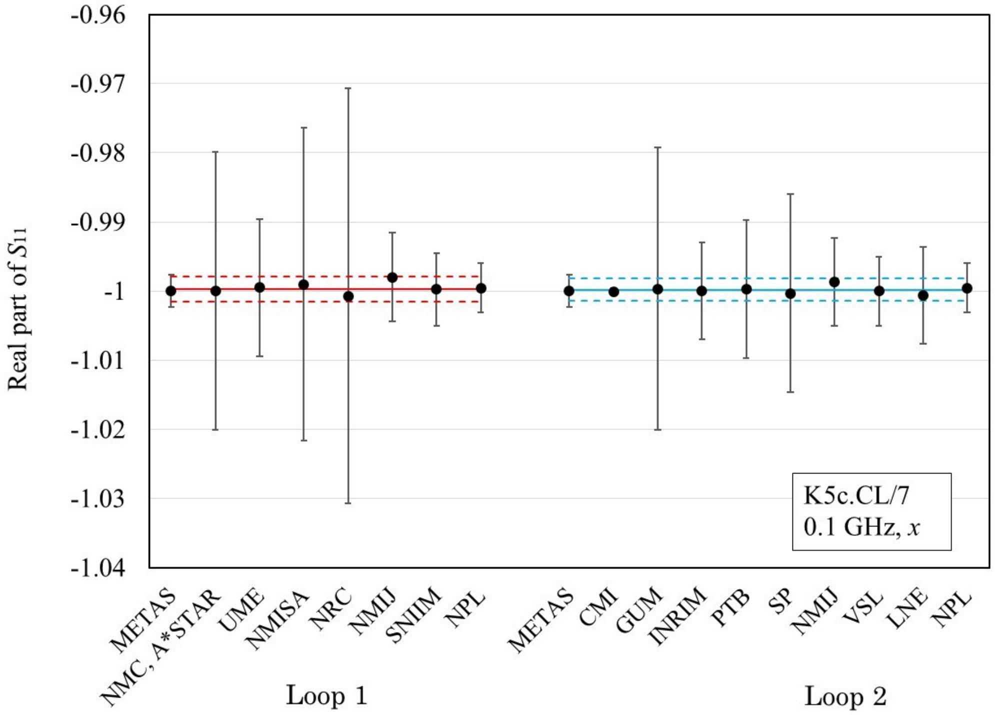

Fig. 3.17.1. Reported results and KCRV for ReS_{11} of K5c.CL/7 at 0.1 GHz.

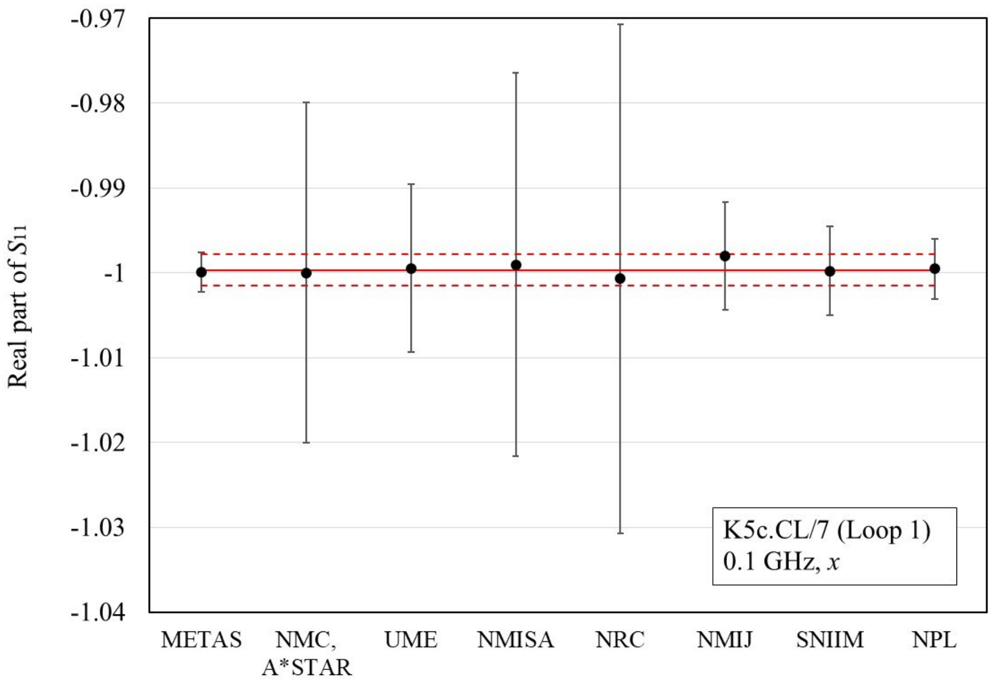

Fig. 3.17.2. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.17.1.).

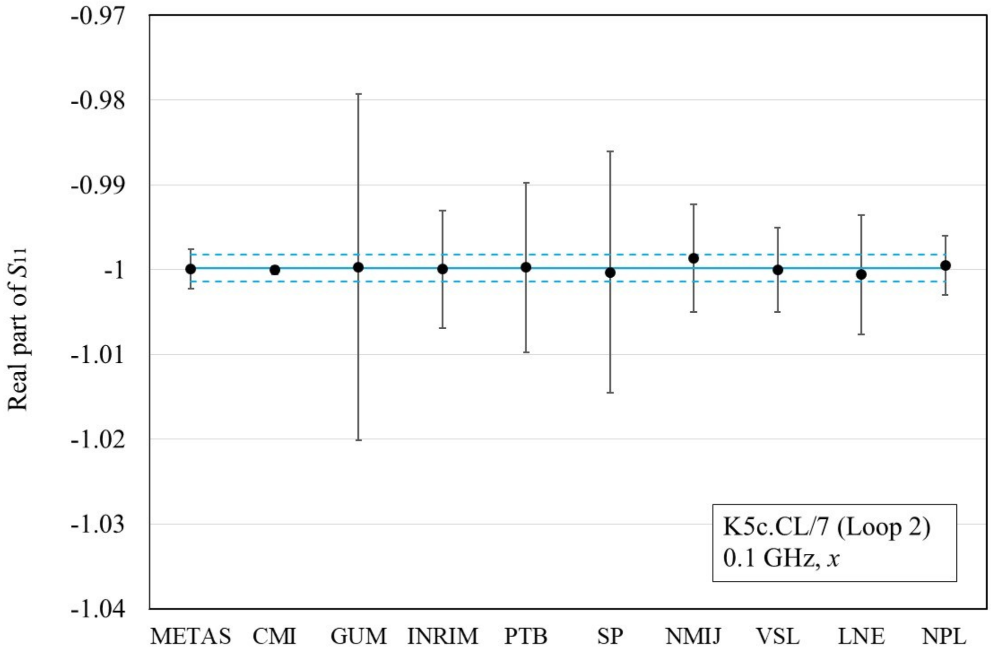

Fig. 3.17.3. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.17.1.).

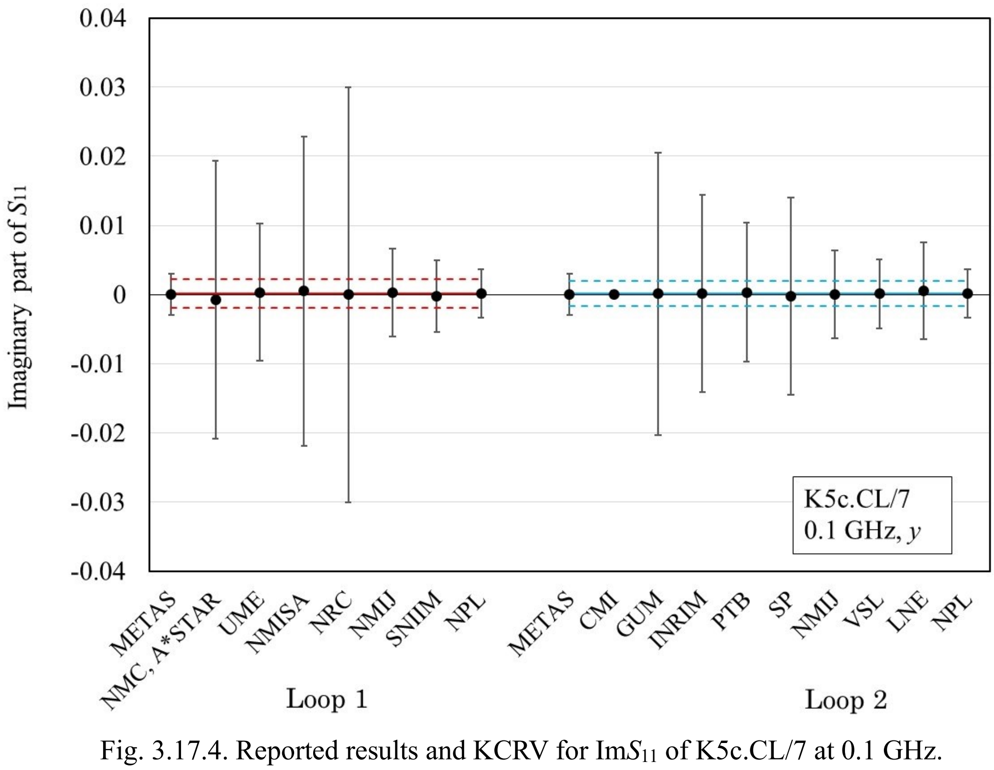

Fig. 3.17.4. Reported results and KCRV for ImS_{11} of K5c.CL/7 at 0.1 GHz.

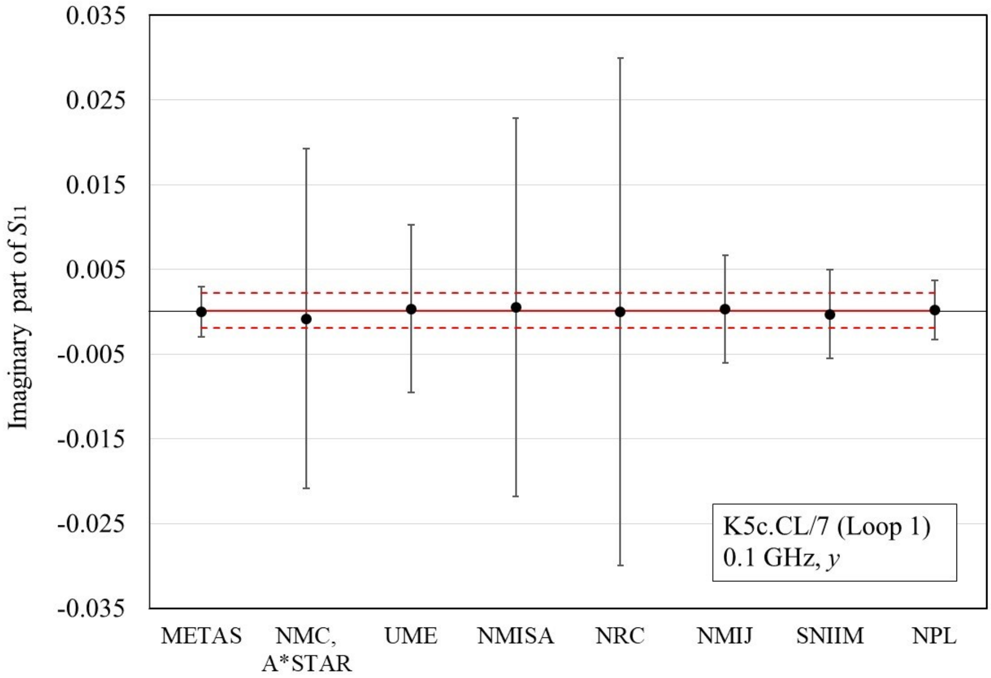

Fig. 3.17.5. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 1) at 0.1 GHz (enlarged view of Fig. 3.17.4.).

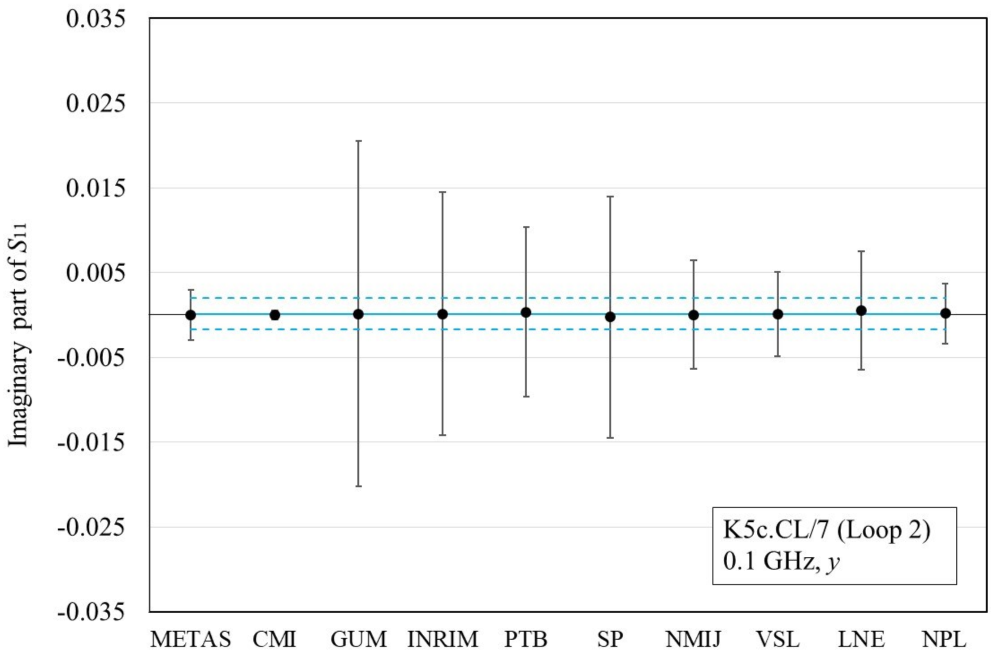

Fig. 3.17.6. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 2) at 0.1 GHz (enlarged view of Fig. 3.17.4.).

Table 3.17.3. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 1) at 0.1 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0003	0.0018
NMC, A*STAR	0.001	0.024
UME	0.000	0.012
NMISA	0.001	0.028
NRC	0.001	0.037
NMIJ	0.0017	0.0075
SNIIM	0.0004	0.0068
NPL	0.0001	0.0037

Table 3.17.4. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 2) at 0.1 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0002	0.0022
CMI	0.0003	0.0021
GUM	0.000	0.025
INRIM	0.0002	0.0084
PTB	0.000	0.012
SP	0.001	0.018
NMIJ	0.0012	0.0076
VSL	0.0002	0.0058
LNE	0.0009	0.0083
NPL	0.0003	0.0038

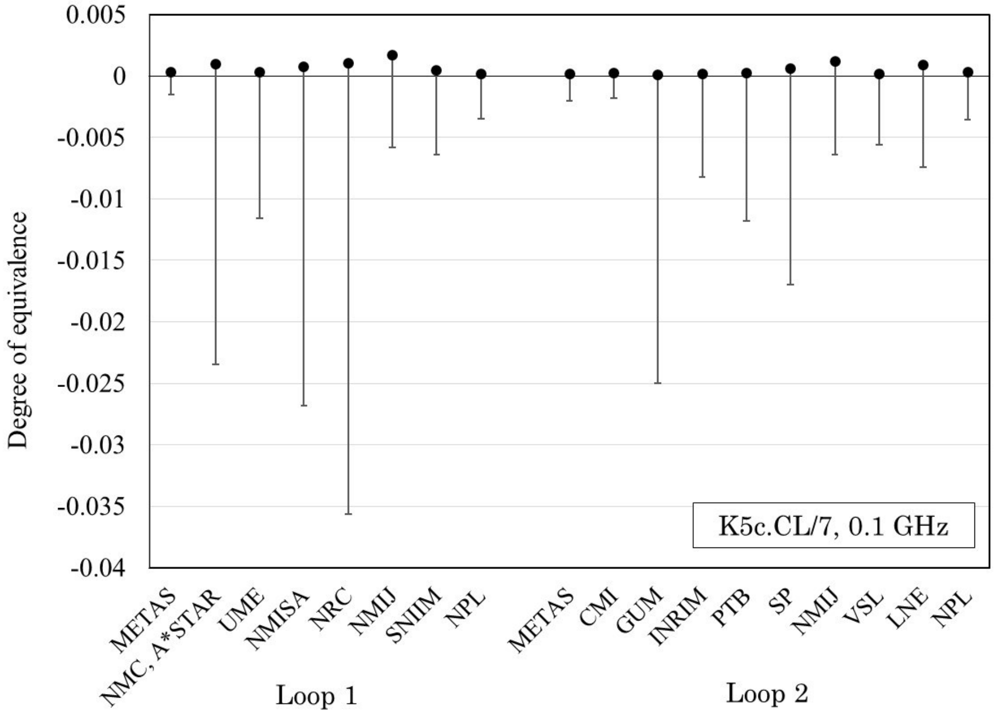

Fig. 3.17.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 0.1 GHz.

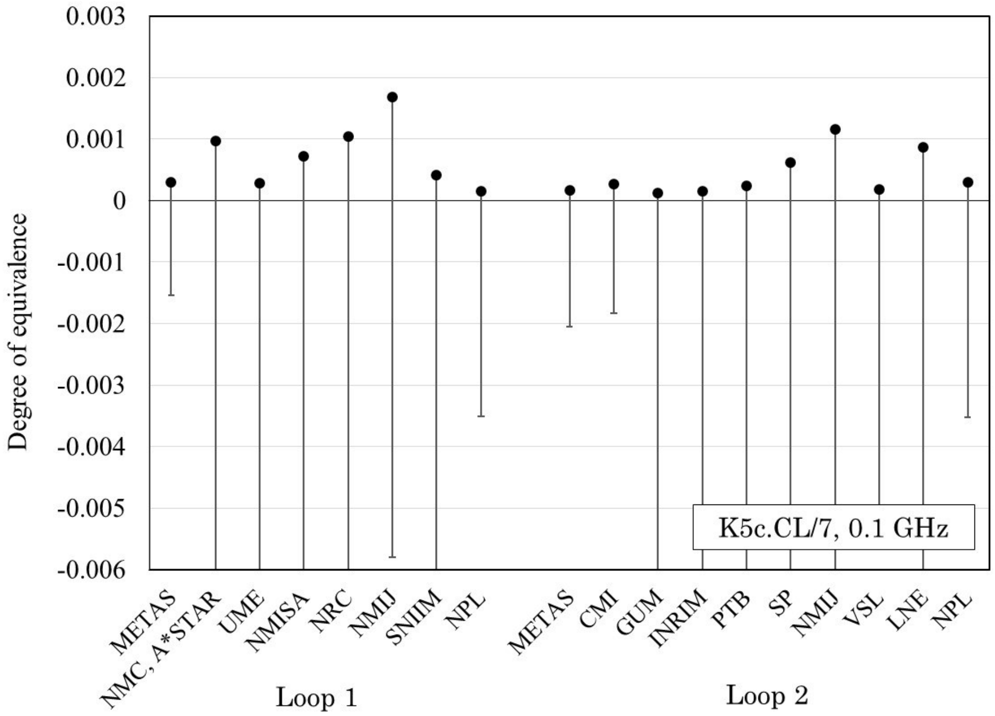

Fig. 3.17.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 0.1 GHz (enlarged view of Fig. 3.17.7.).

K5c.CL/7 at 12.4 GHz

Table 3.18.1. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 1) at 12.4 GHz.

Laboratory	K5c.CL/7 (Loop 1) Measurement and combined uncertainty of S_{11} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9993	0.0014	0.0025	0.0030	
NMC, A*STAR	-1.000	0.010	0.001	0.010	
UME	-0.998	0.011	-0.001	0.011	0.34
NMISA	-1.002	0.011	-0.002	0.011	
NRC	-0.998	0.015	0.004	0.015	
NMIJ	-0.9935	0.0042	0.0095	0.0042	
SNIIM	-0.9993	0.0066	0.0011	0.0066	
NPL	-0.9980	0.0019	0.0050	0.0019	
KCRV	-0.9986	0.0010	0.0047	0.0014	

Table 3.18.2. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 2) at 12.4 GHz.

Laboratory	K5c.CL/7 (Loop 2) Measurement and combined uncertainty of S_{11} at 12.4 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9994	0.0014	0.0025	0.0030	
CMI	-0.99926	0.00076	0.0021	0.0023	0.0058
GUM	-0.9986	0.0059	0.0047	0.0059	
INRIM	-1.002	0.014	-0.005	0.030	-0.0080
PTB	-0.9984	0.0050	0.0020	0.0050	
SP	-0.9997	0.0118	0.0039	0.0118	
NMIJ	-0.9954	0.0042	0.0073	0.0042	
VSL	-0.9991	0.0025	0.0038	0.0048	
LNE	-1.0029	0.0076	0.0037	0.0076	
NPL	-0.9981	0.0019	0.0042	0.0019	
KCRV	-0.99883	0.00095	0.00397	0.00135	

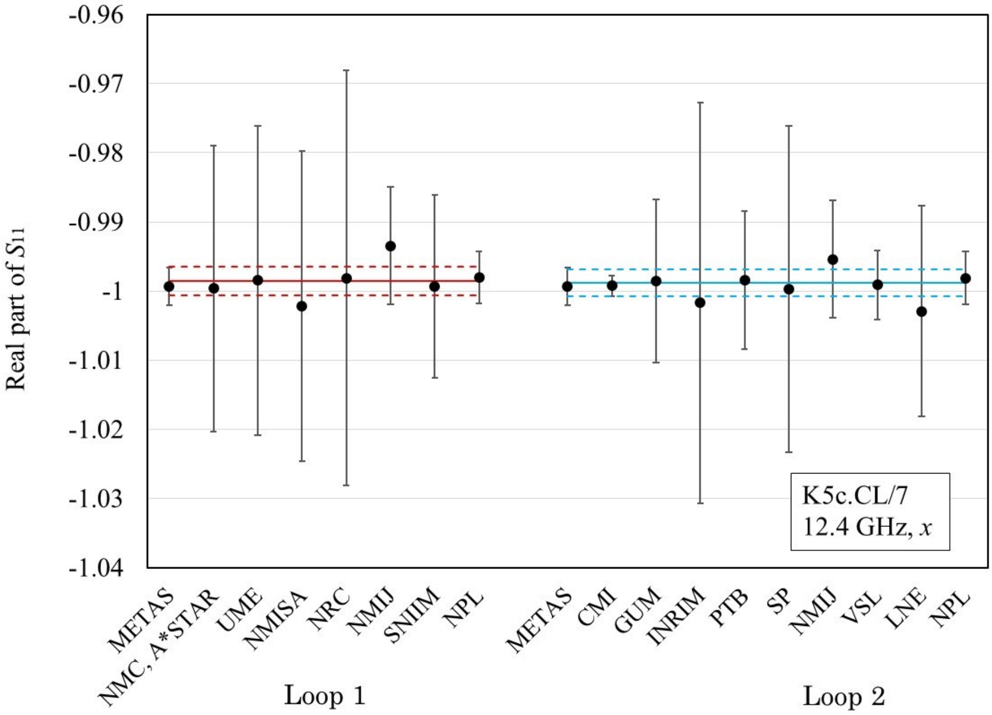

Fig. 3.18.1. Reported results and KCRV for ReS_{11} of K5c.CL/7 at 12.4 GHz.

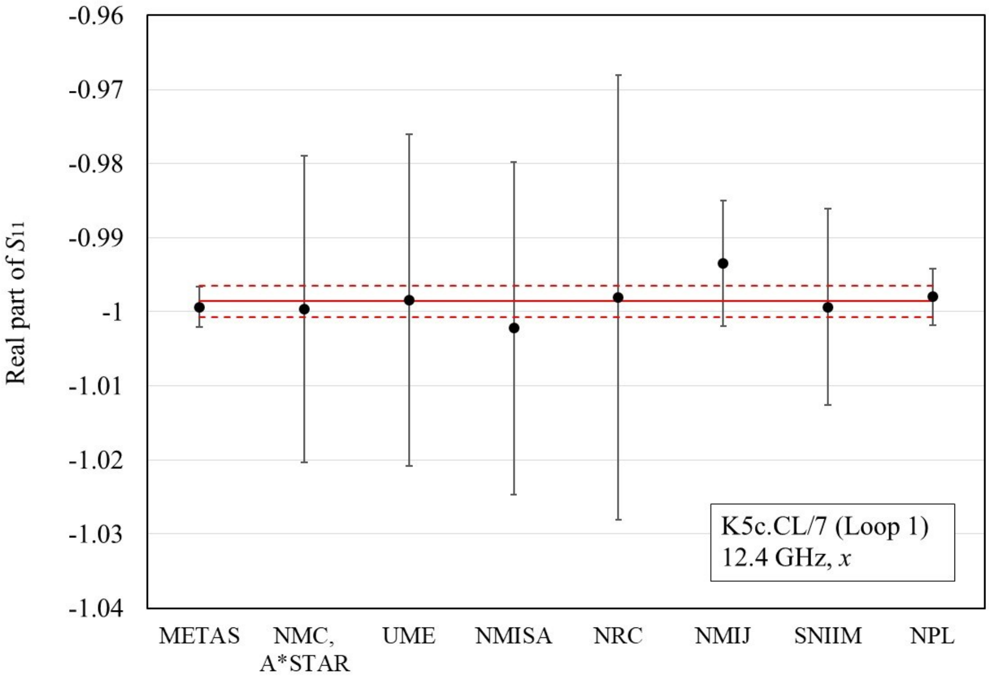

Fig. 3.18.2. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.18.1.).

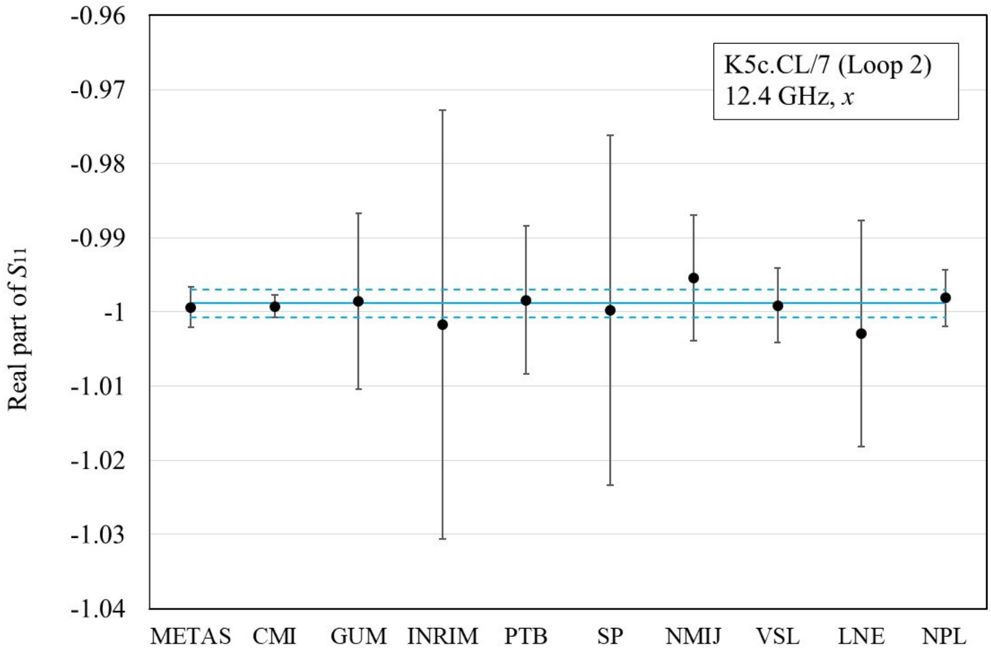

Fig. 3.18.3. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.18.1.).

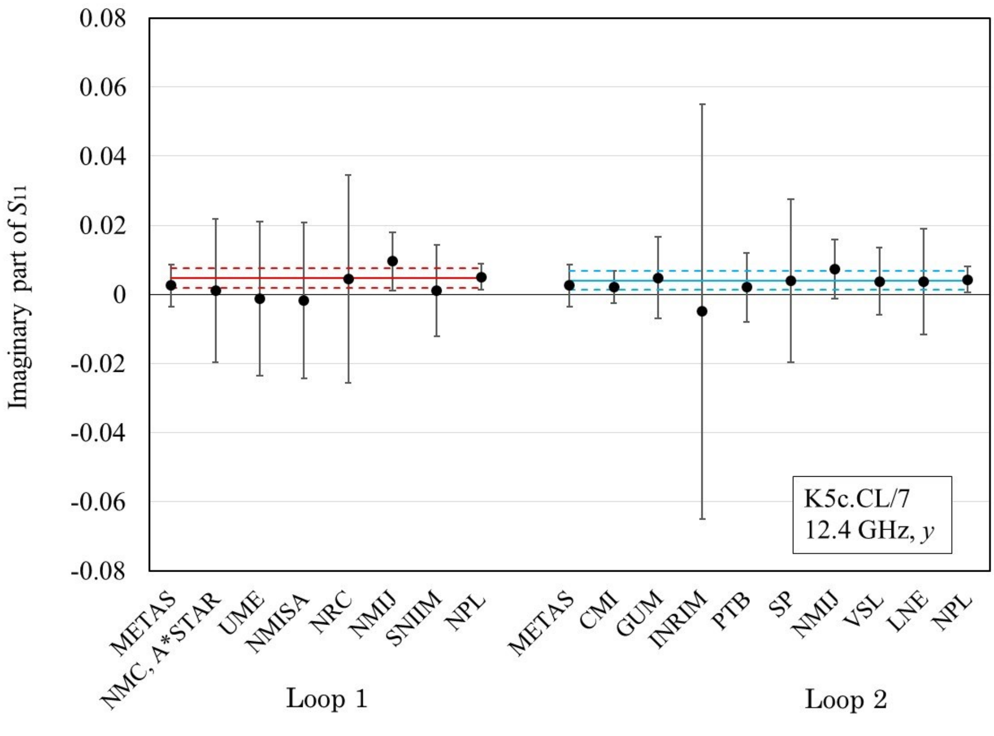

Fig. 3.18.4. Reported results and KCRV for ImS_{11} of K5c.CL/7 at 12.4 GHz.

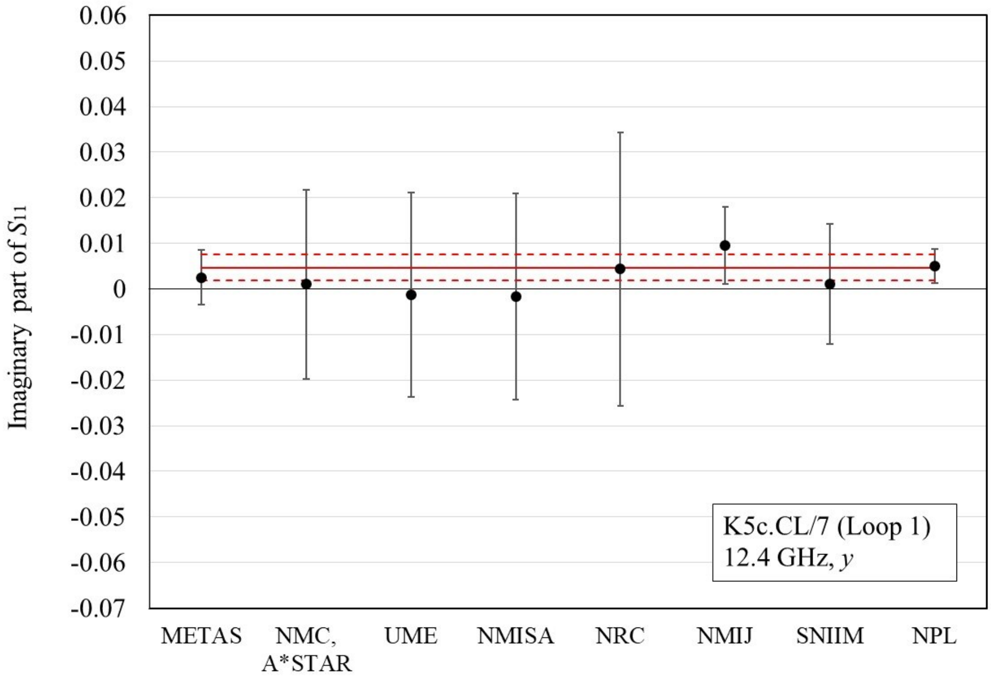

Fig. 3.18.5. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 1) at 12.4 GHz (enlarged view of Fig. 3.18.4.).

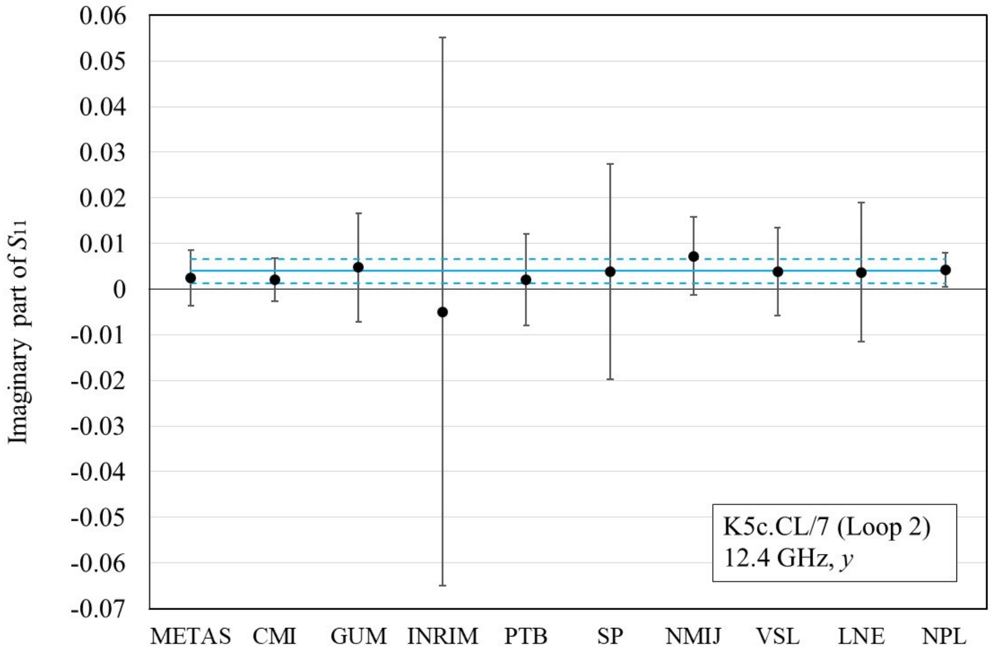

Fig. 3.18.6. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 2) at 12.4 GHz (enlarged view of Fig. 3.18.4.).

Table 3.18.3. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 1) at 12.4 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.0023	0.0047
NMC, A*STAR	0.004	0.025
UME	0.006	0.027
NMISA	0.007	0.027
NRC	0.001	0.037
NMIJ	0.007	0.010
SNIIM	0.004	0.017
NPL	0.0007	0.0035

Table 3.18.4. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 2) at 12.4 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0015	0.0050
CMI	0.0019	0.0060
GUM	0.001	0.015
INRIM	0.009	0.064
PTB	0.002	0.012
SP	0.001	0.029
NMIJ	0.005	0.010
VSL	0.0003	0.0064
LNE	0.004	0.018
NPL	0.0008	0.0039

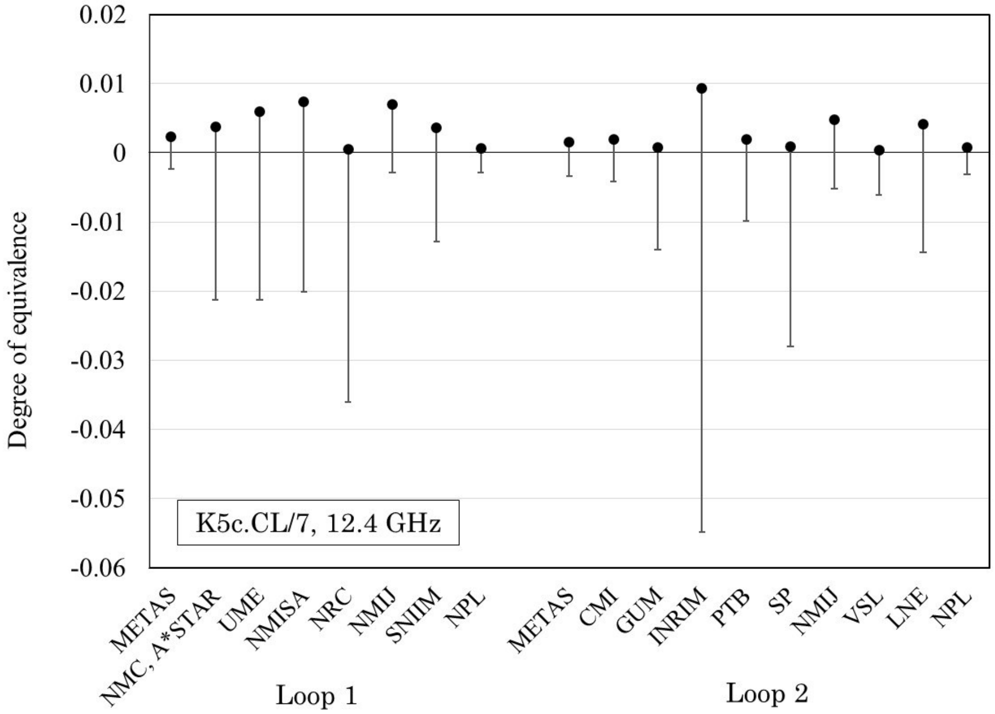

Fig. 3.18.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 12.4 GHz.

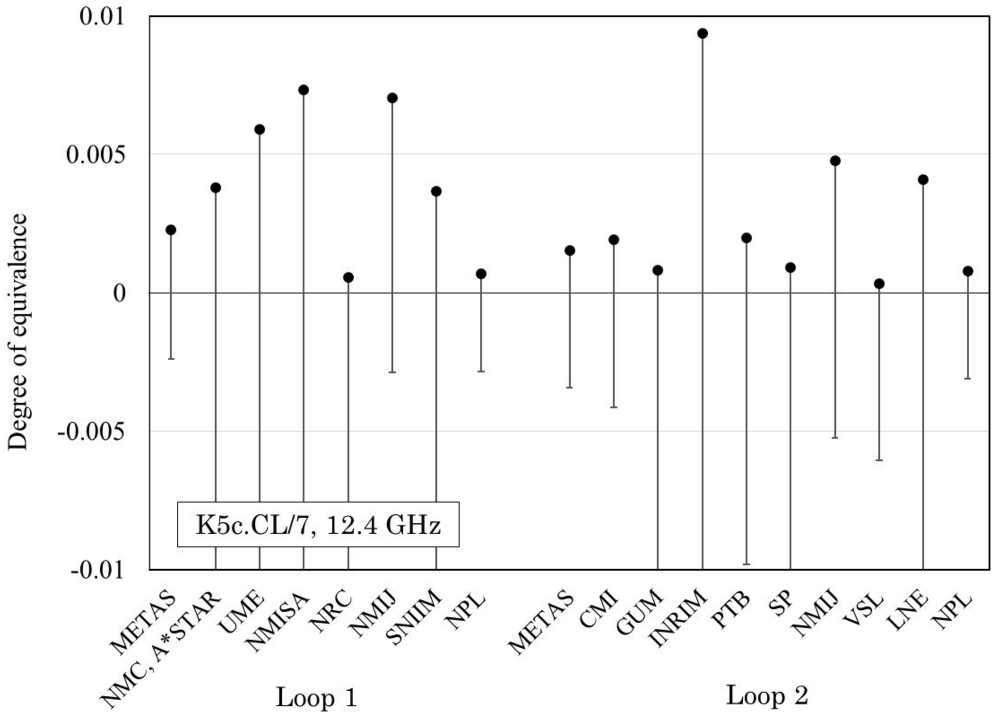

Fig. 3.18.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 12.4 GHz (enlarged view of Fig. 3.18.7.).

K5c.CL/7 at 26.5 GHz

Table 3.19.1. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 1) at 26.5 GHz.

Laboratory	K5c.CL/7 (Loop 1) Measurement and combined uncertainty of S_{11} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9986	0.0022	0.0053	0.0060	
NMC, A*STAR	-0.999	0.012	-0.003	0.012	
UME	-1.007	0.011	0.007	0.011	-0.69
NMISA	-1.007	0.029	-0.002	0.029	
NRC	-0.998	0.015	0.011	0.015	
NMIJ	-0.9916	0.0059	0.0118	0.0059	
SNIIM	-0.999	0.011	0.002	0.011	
NPL	-0.9971	0.0023	0.0095	0.0023	
KCRV	-0.9977	0.0015	0.0088	0.0020	

Table 3.19.2. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 2) at 26.5 GHz.

Laboratory	K5c.CL/7 (Loop 2) Measurement and combined uncertainty of S_{11} at 26.5 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9986	0.0022	0.0054	0.0060	
CMI	-0.9985	0.0012	0.0041	0.0052	0.018
GUM	-0.9974	0.0067	0.0097	0.0067	
INRIM	-1.012	0.022	-0.002	0.054	-0.0039
PTB	-0.9970	0.0050	0.0071	0.0050	
SP	-0.998	0.018	0.006	0.018	
NMIJ	-0.9954	0.0059	0.0038	0.0059	
VSL	-0.9984	0.0043	0.0072	0.0092	
LNE	-1.0008	0.0088	0.0100	0.0088	
NPL	-0.9973	0.0023	0.0082	0.0023	
KCRV	-0.9980	0.0014	0.0074	0.0018	

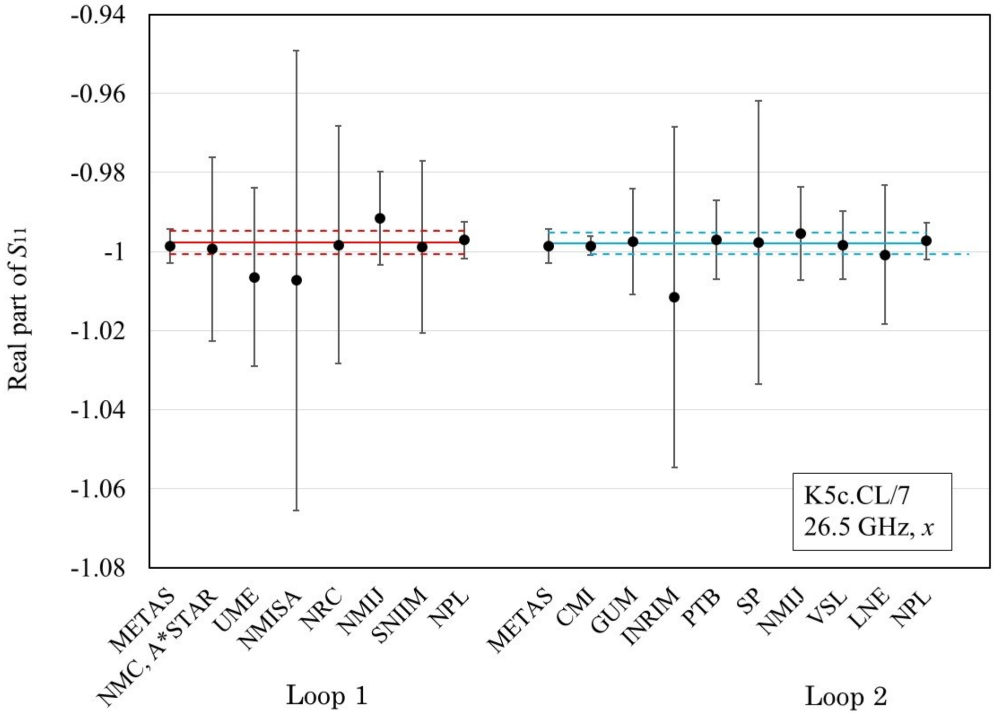

Fig. 3.19.1. Reported results and KCRV for ReS_{11} of K5c.CL/7 at 26.5 GHz.

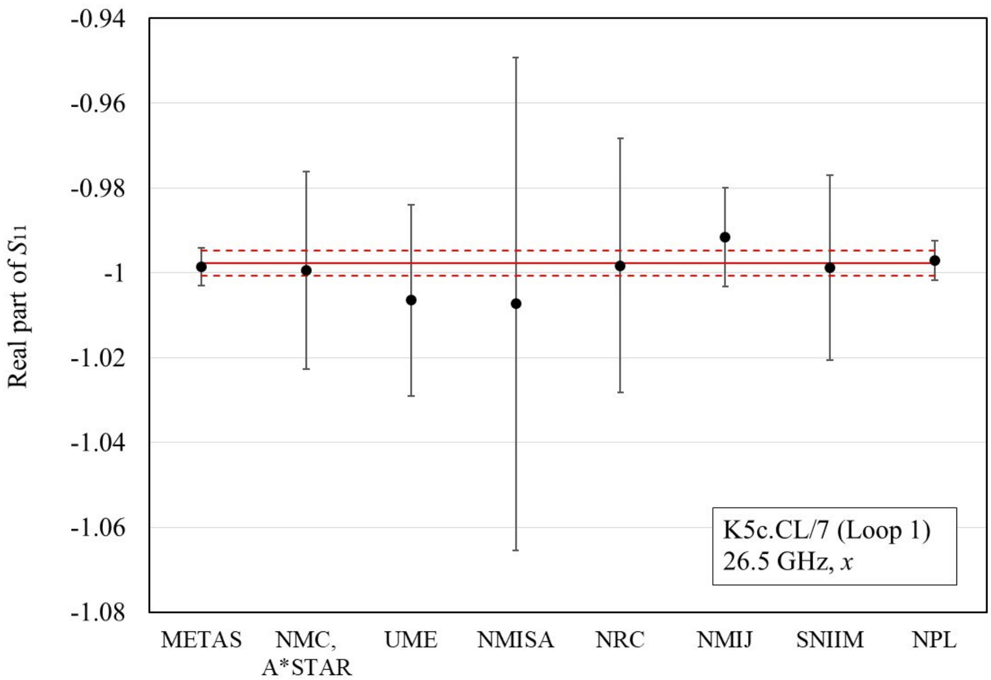

Fig. 3.19.2. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.19.1.).

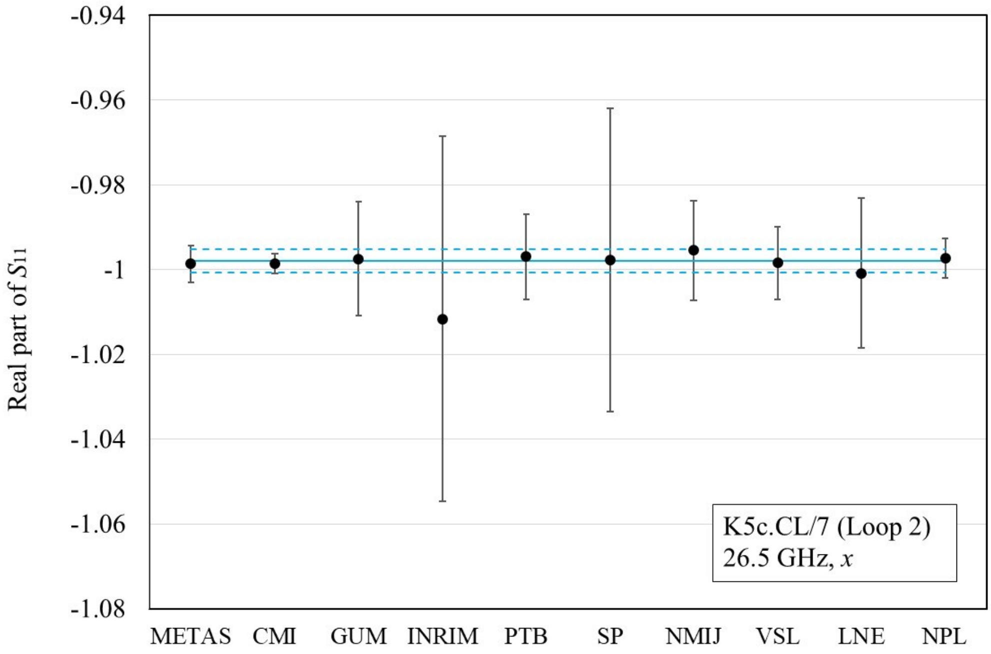

Fig. 3.19.3. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.19.1.).

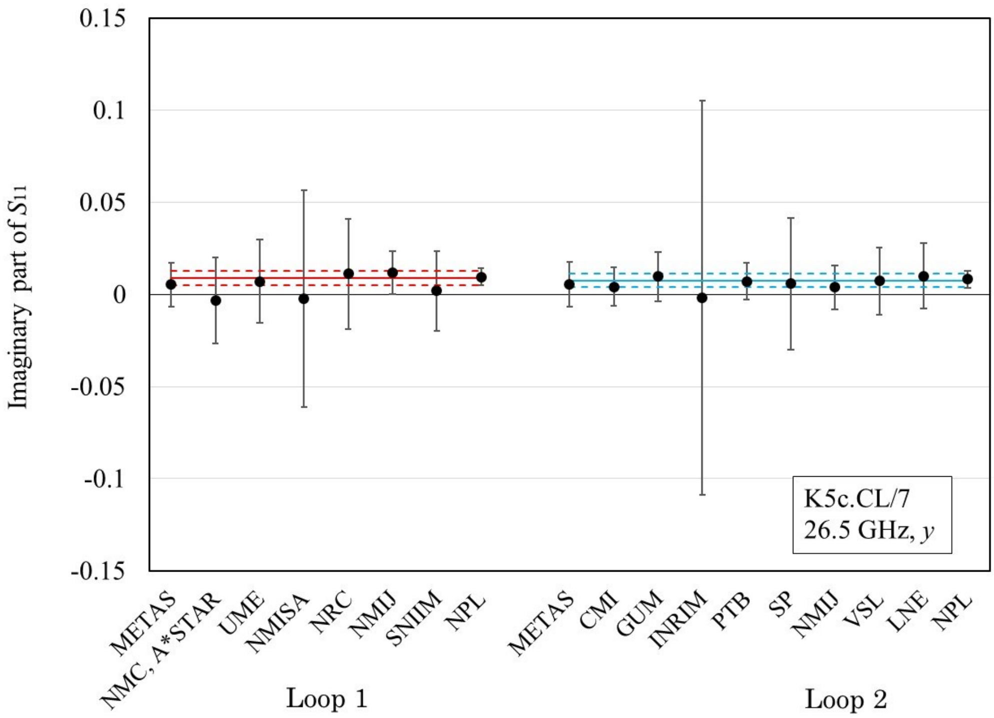

Fig. 3.19.4. Reported results and KCRV for ImS_{11} of K5c.CL/7 at 26.5 GHz.

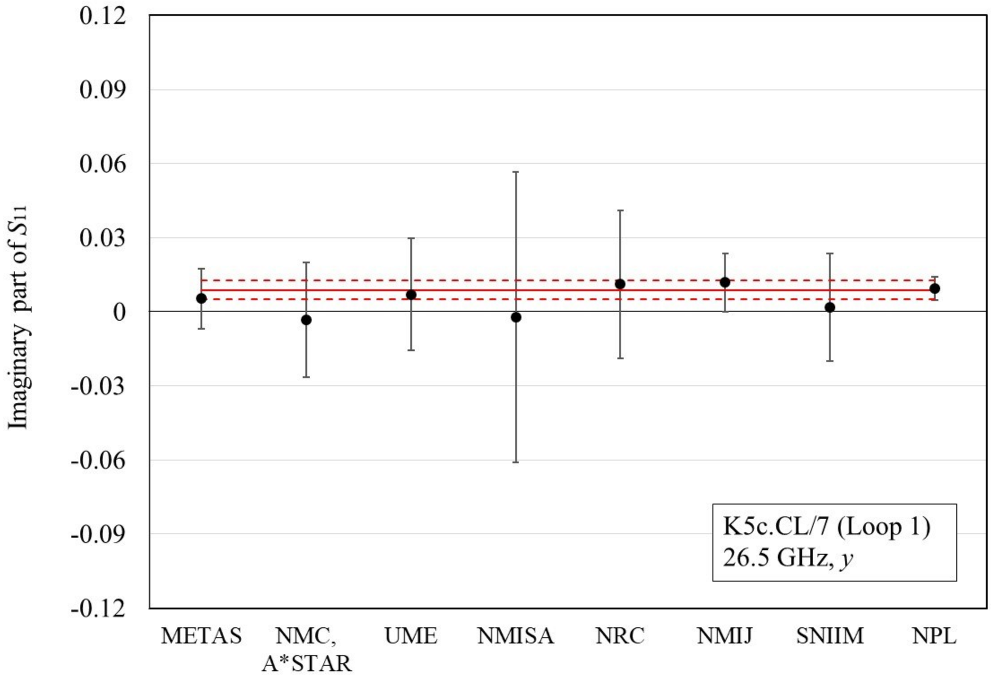

Fig. 3.19.5. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 1) at 26.5 GHz (enlarged view of Fig. 3.19.4.).

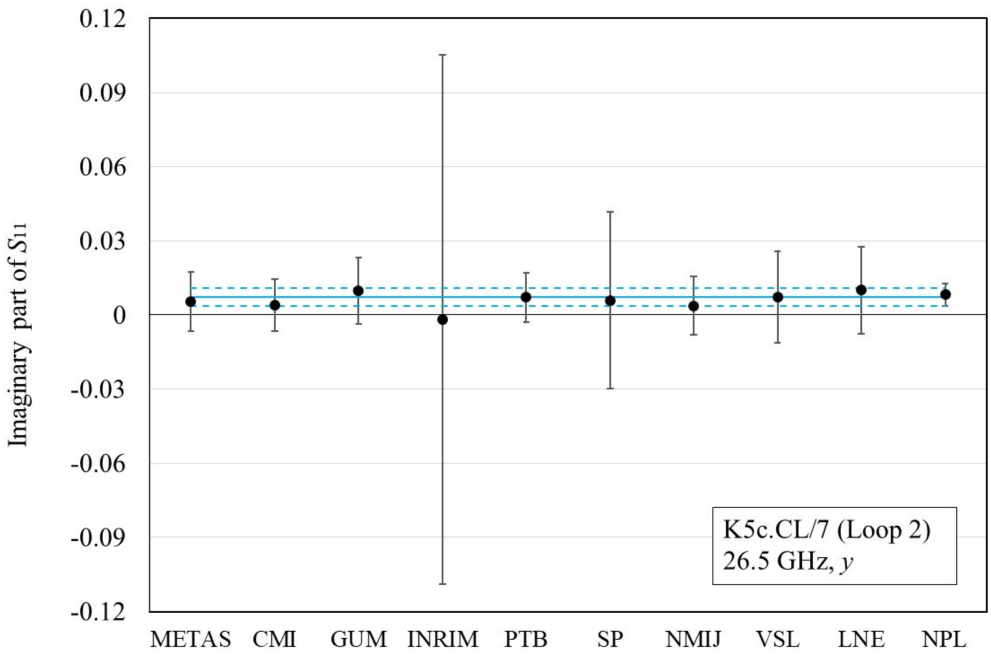

Fig. 3.19.6. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 2) at 26.5 GHz (enlarged view of Fig. 3.19.4.).

Table 3.19.3. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 1) at 26.5 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.004	0.011
NMC, A*STAR	0.012	0.028
UME	0.009	0.027
NMISA	0.015	0.072
NRC	0.002	0.036
NMIJ	0.007	0.014
SNIIM	0.007	0.027
NPL	0.0009	0.0035

Table 3.19.4. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 2) at 26.5 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.0021	0.0098
CMI	0.003	0.012
GUM	0.002	0.017
INRIM	0.016	0.061
PTB	0.001	0.012
SP	0.002	0.044
NMIJ	0.004	0.014
VSL	0.000	0.011
LNE	0.004	0.021
NPL	0.0010	0.0039

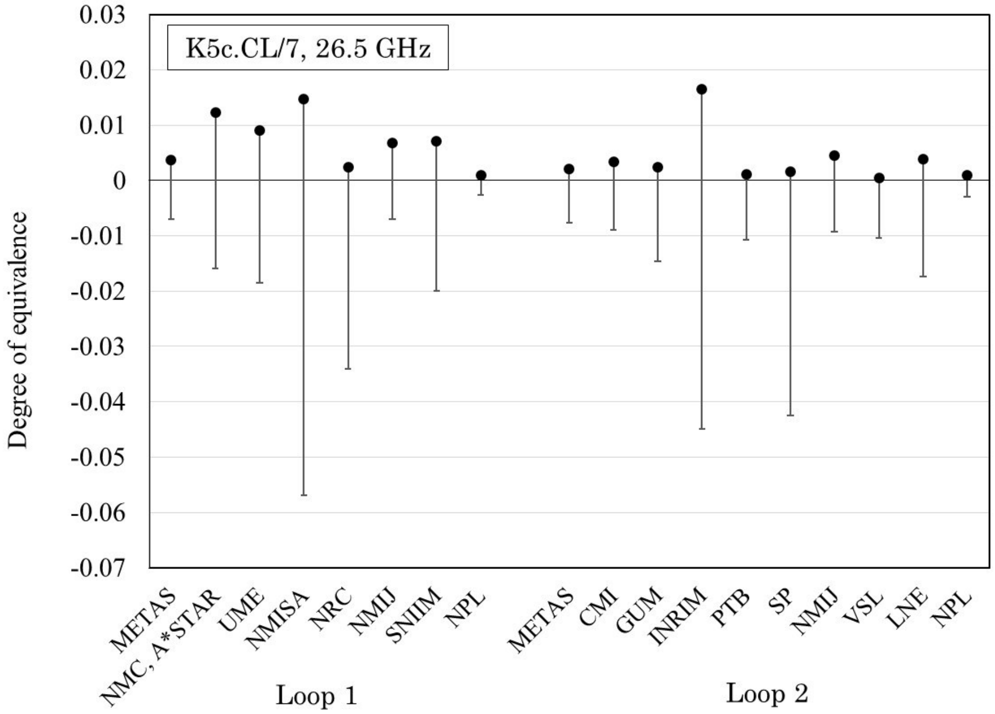

Fig. 3.19.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 26.5 GHz.

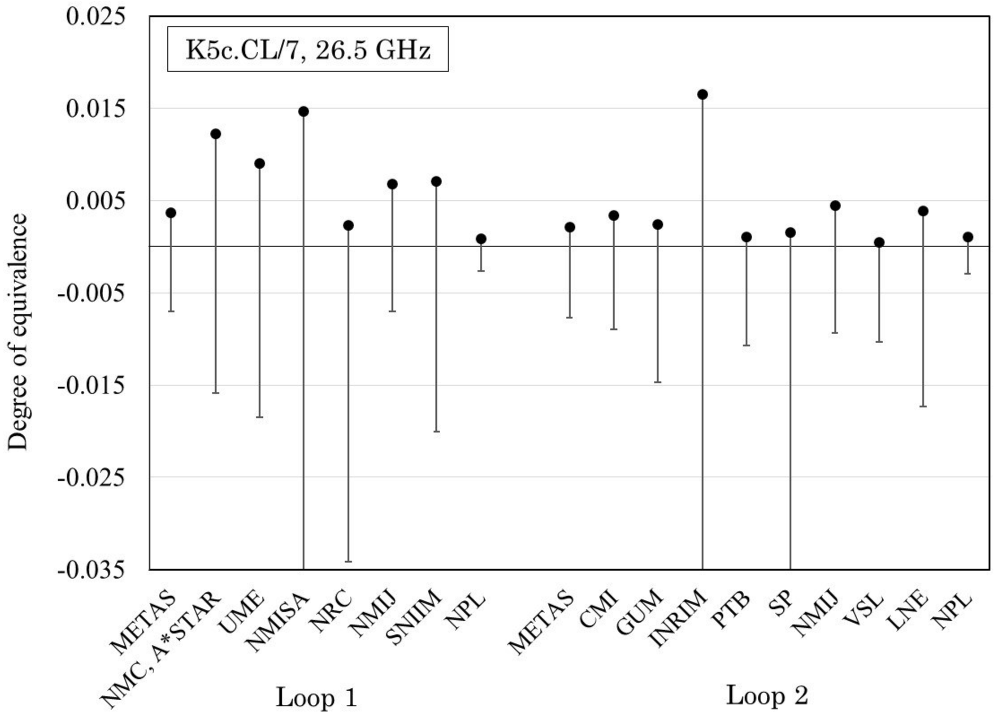

Fig. 3.19.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 26.5 GHz (enlarged view of Fig. 3.19.7.).

K5c.CL/7 at 33 GHz

Table 3.20.1. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 1) at 33 GHz.

Laboratory	K5c.CL/7 (Loop 1) Measurement and combined uncertainty of S_{11} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9984	0.0032	0.0068	0.0076	
NMC, A*STAR	-0.996	0.013	-0.003	0.013	
UME	-1.002	0.013	-0.010	0.013	-0.22
NMISA					
NRC	-1.000	0.022	0.013	0.022	
NMIJ	-0.9898	0.0066	0.0232	0.0066	
SNIIM	-0.999	0.013	0.003	0.013	
NPL	-0.9969	0.0024	0.0107	0.0024	
KCRV	-0.9969	0.0018	0.0108	0.0021	

Table 3.20.2. Reported results and KCRV for S_{11} of K5c.CL/7 (Loop 2) at 33 GHz.

Laboratory	K5c.CL/7 (Loop 2) Measurement and combined uncertainty of S_{11} at 33 GHz				
	x	$u(x)$	y	$u(y)$	$r(x,y)$
METAS	-0.9984	0.0032	0.0069	0.0076	
CMI	-0.9982	0.0014	0.0054	0.0068	0.025
GUM	-0.9968	0.0067	0.0212	0.0067	
INRIM	-0.997	0.024	-0.018	0.063	-0.041
PTB	-0.9959	0.0050	0.0089	0.0050	
SP	-0.999	0.021	0.007	0.021	
NMIJ	-0.9934	0.0067	0.0173	0.0067	
VSL	-0.9978	0.0044	0.0087	0.0104	
LNE	-0.9954	0.0099	-0.0093	0.0099	
NPL	-0.9971	0.0024	0.0091	0.0024	
KCRV	-0.9972	0.0016	0.0089	0.0019	

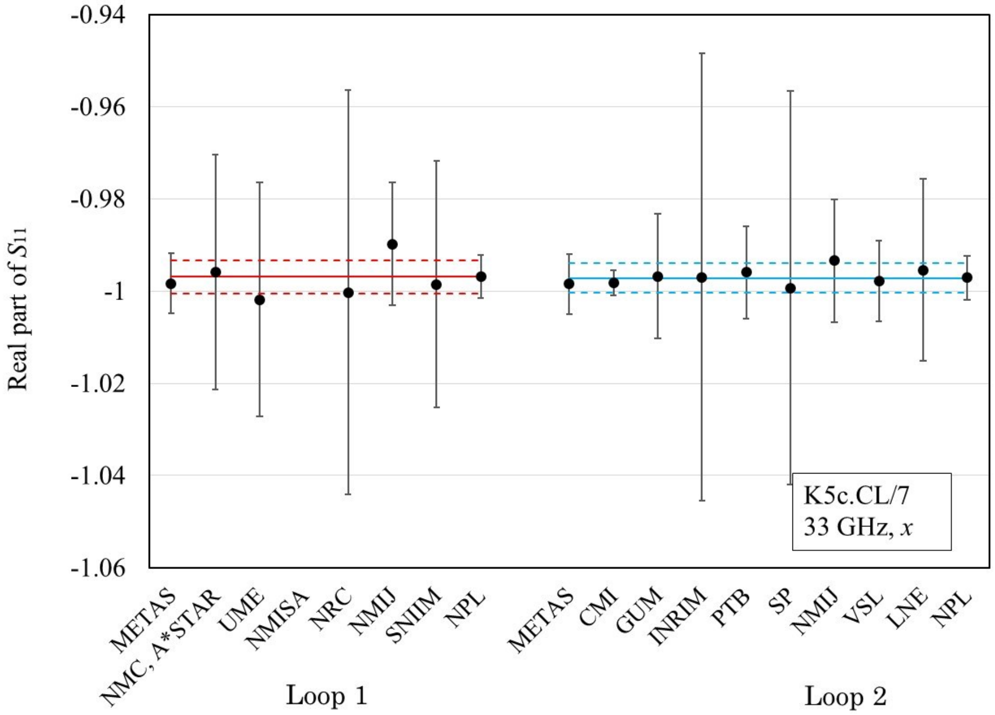

Fig. 3.20.1. Reported results and KCRV for ReS_{11} of K5c.CL/7 at 33 GHz.

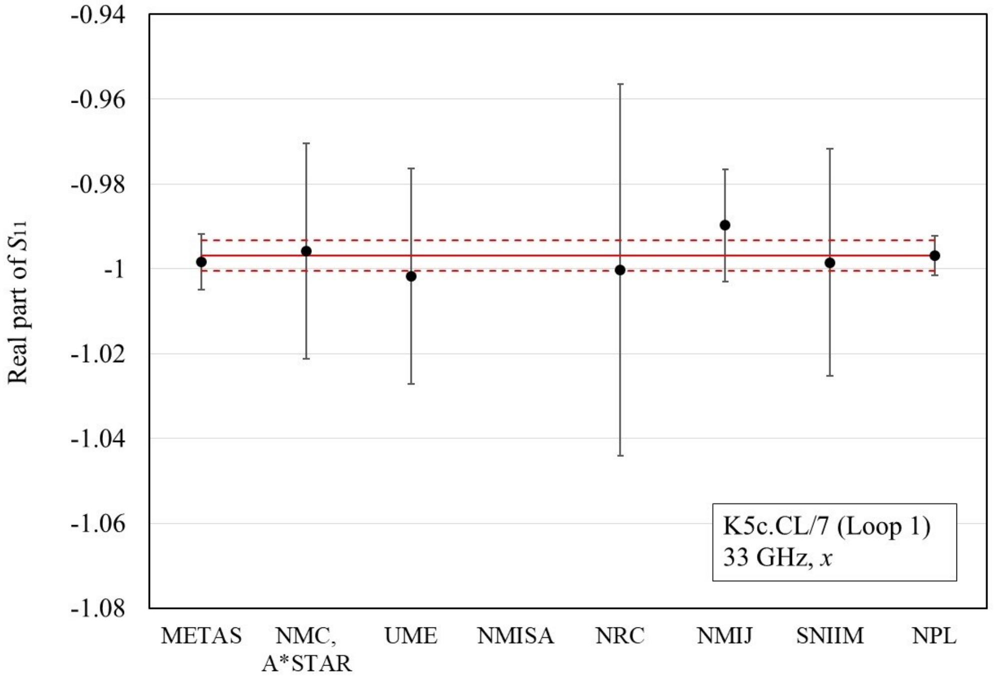

Fig. 3.20.2. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 1) at 33 GHz (enlarged view of Fig. 3.20.1.).

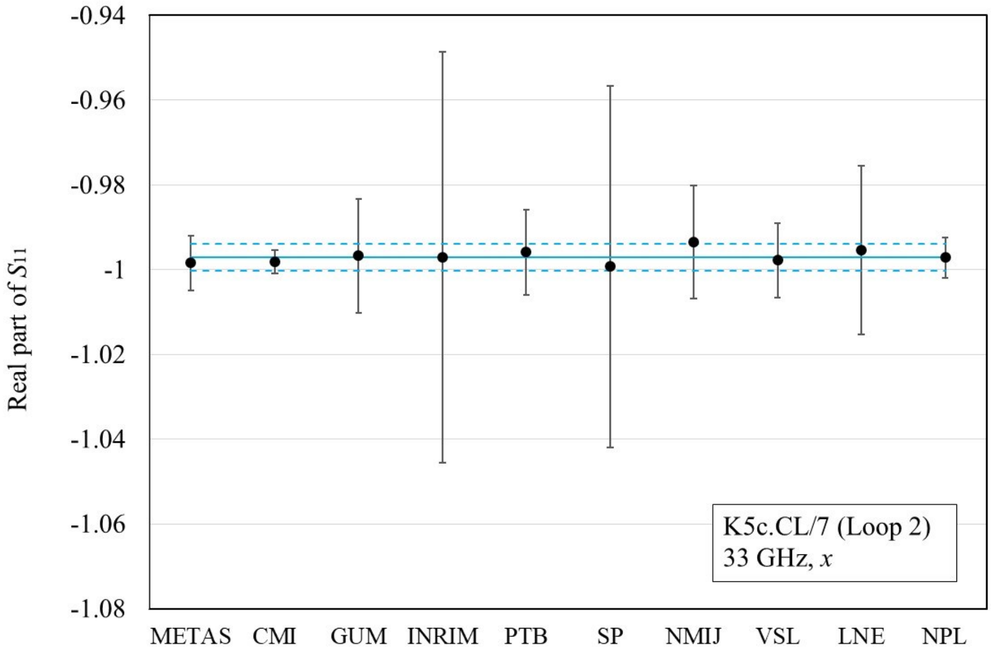

Fig. 3.20.3. Reported results and KCRV for ReS_{11} of K5c.CL/7 (Loop 2) at 33 GHz (enlarged view of Fig. 3.20.1.).

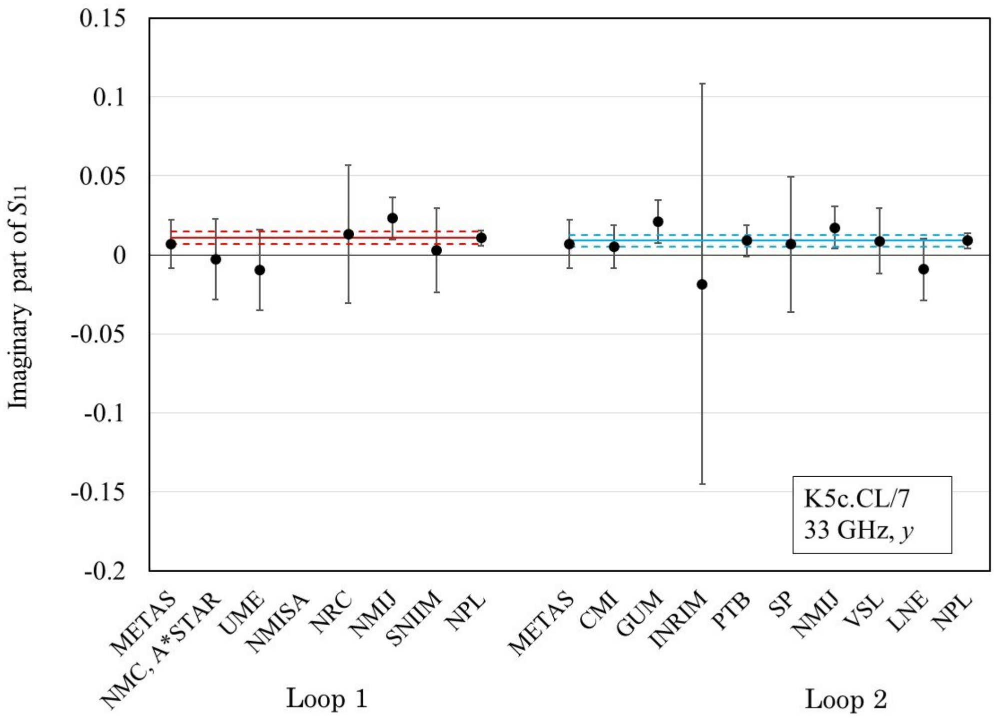

Fig. 3.20.4. Reported results and KCRV for ImS_{11} of K5c.CL/7 at 33 GHz.

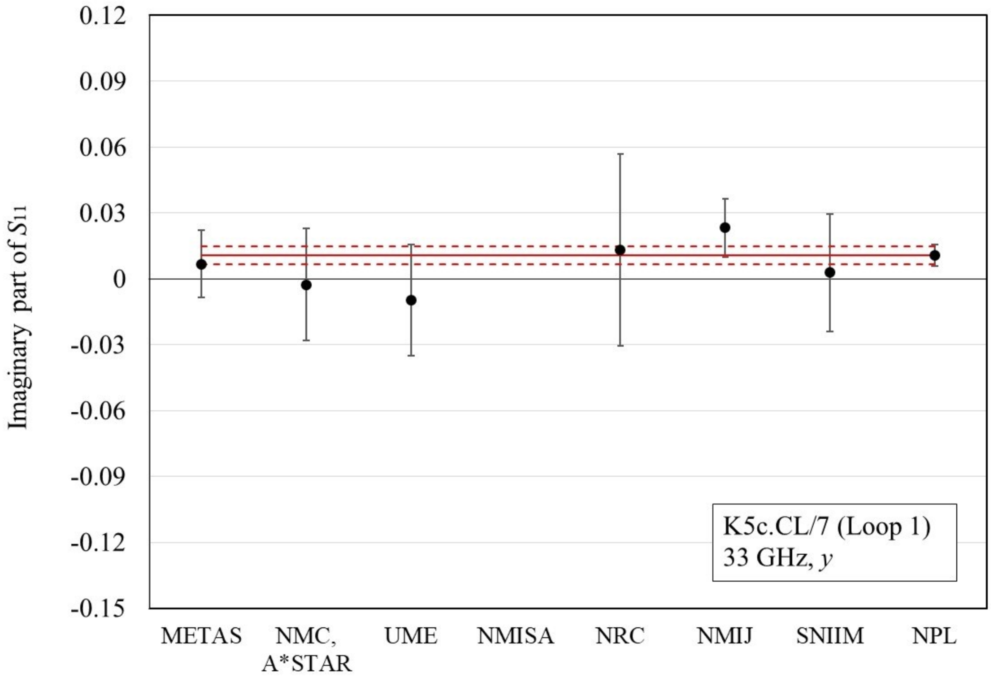

Fig. 3.20.5. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 1) at 33 GHz (enlarged view of Fig. 3.20.4.).

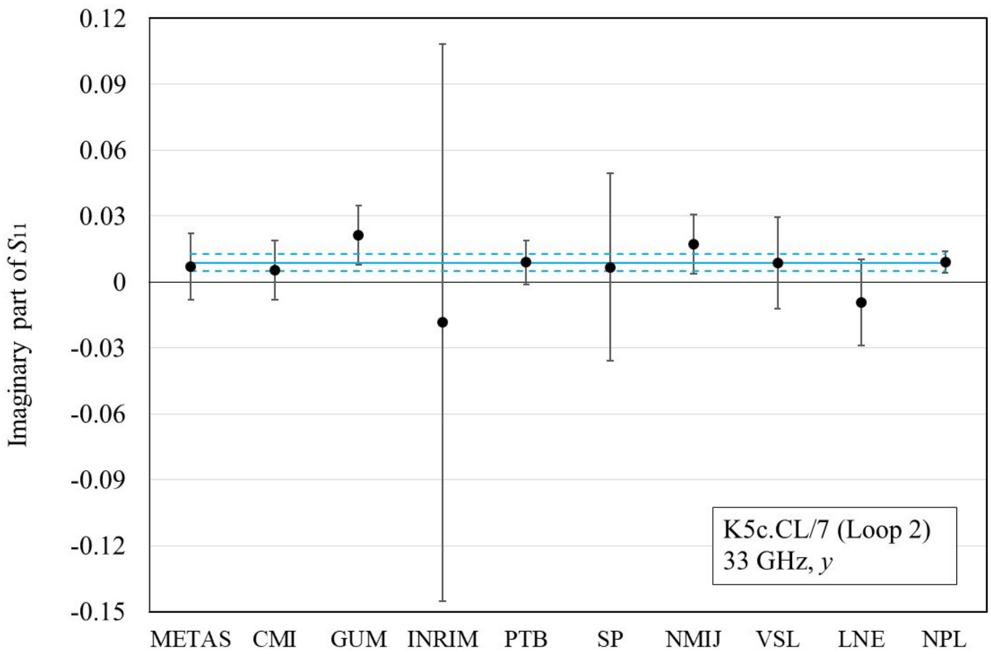

Fig. 3.20.6. Reported results and KCRV for ImS_{11} of K5c.CL/7 (Loop 2) at 33 GHz (enlarged view of Fig. 3.20.4.).

Table 3.20.3. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 1) at 33 GHz.

	KCRV (Loop 1)	
	q1iM	*dq1iM*
METAS	0.004	0.014
NMC, A*STAR	0.013	0.031
UME	0.021	0.031
NMISA		
NRC	0.004	0.053
NMIJ	0.014	0.015
SNIIM	0.008	0.033
NPL	0.0001	0.0030

Table 3.20.4. Reduced dimensional DoE for S_{11} of K5c.CL/7 (Loop 2) at 33 GHz.

	KCRV (Loop 2)	
	q2iM	*dq2iM*
METAS	0.002	0.011
CMI	0.004	0.013
GUM	0.012	0.017
INRIM	0.03	0.16
PTB	0.001	0.012
SP	0.003	0.052
NMIJ	0.009	0.016
VSL	0.001	0.010
LNE	0.018	0.024
NPL	0.0002	0.0035

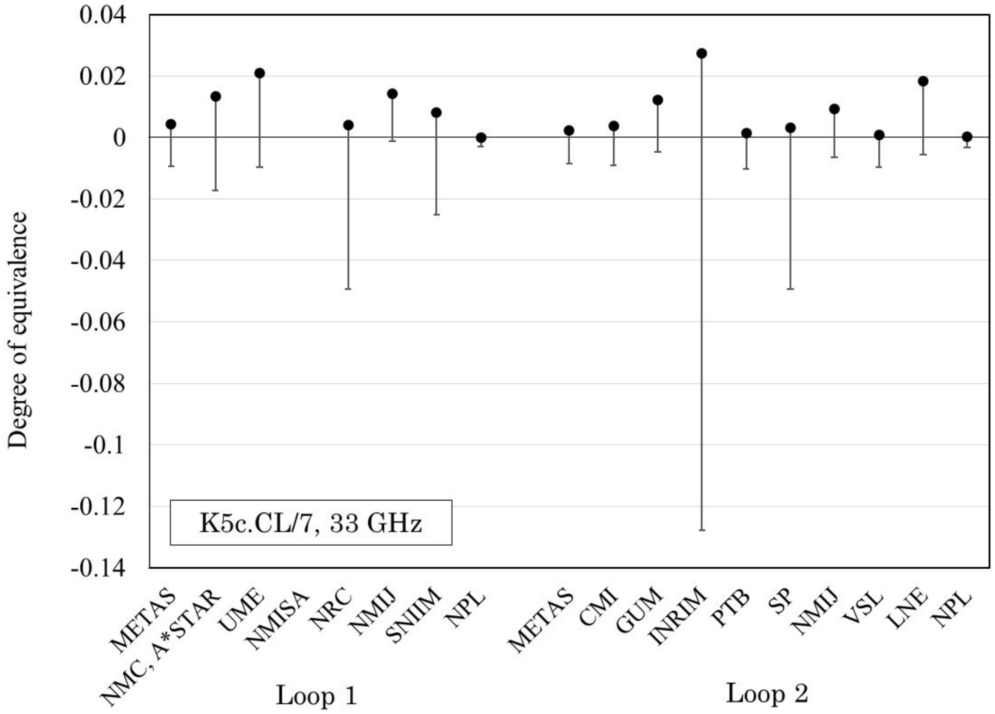

Fig. 3.20.7. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 33 GHz.

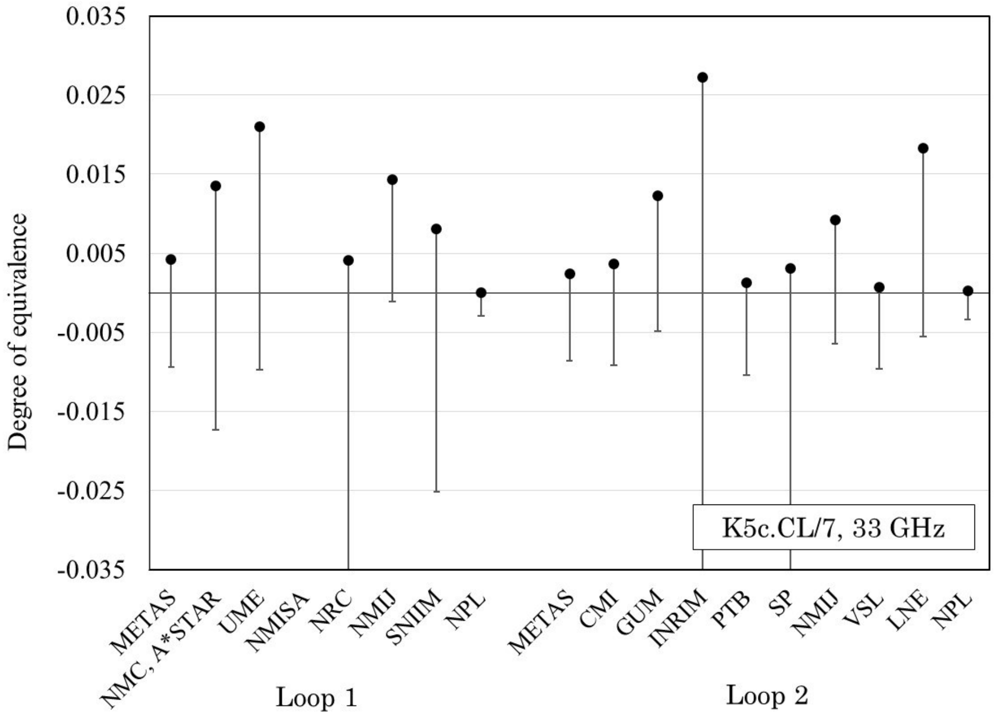

Fig. 3.20.8. Reduced dimensional DoE from KCRV for S_{11} of K5c.CL/7 at 33 GHz (enlarged view of Fig. 3.20.7.).

4: Discussion

To prove the effectiveness of the KCRVs and DoEs obtained in this comparison, the pilot laboratory, NMIJ, measured the travelling standards 7 times for both Loops 1 and 2. The stability monitoring data are shown in Appendix 5. According to the comparison between the uncertainties of the travelling standards' stability and the measurement uncertainty by NMIJ, the travelling standards have been stable during the comparison program except for K5c.CL/7 (Loop 2) at 33 GHz. There was an unidentified change between the first and second measurements by NMIJ. The measurement result of K5c.CL/7 (Loop 2) at 33 GHz from METAS was consistent with the second measurement result from NMIJ, so a step change has occurred between NMIJ's first measurement and METAS's measurement. In summary, the data reported by the participants were considered to be effective after the METAS's measurement.

Only 30 outliers were found from the total 355 reported S-parameters. Most of the data were generally consistent.

5: Problems during the Comparison and Recommendations

There were two technical problems during CCEM.RF-K5c.CL: calculation methods for KCRVs and treatment of the correlation of the traceability source.

The first problem was about the selection of a calculation method for KCRVs. In this report, the weighted-mean method was selected based on the technical protocol. However, a calculation method for KCRVs should basically be selected considering the distribution of reported measurement data by all participants [8]. In principle, it is not preferable to determine a calculation method before starting measurements.

Hence, the author recommends that some possible calculation methods be listed as candidates in a technical protocol and that the pilot and supporting laboratories select a suitable method from the candidates after completing all measurements.

The second problem was the treatment of the correlation of the measurement traceability source. Some participants were provided their traceability sources from other participants or laboratories. The data were considered to be correlated. However, the correlation was neglected in this report because the detailed traceability route and propagation analysis were unknown. A method which can include the effects of the correlation is therefore necessary.

6: Conclusion

CCEM.RF-K5c.CL is a key comparison of the S-parameters by broad-band methods. The comparison was performed by the initiative of CCEM GT-RF. The travelling standards are seven devices with 3.5 mm connectors: an adapter, 20 dB attenuator, 40 dB attenuator, matched termination with a female interface, matched termination with a male interface, flush short termination with a female interface, and flush short termination with a male interface. The compared frequency range was 0.1 GHz to 33 GHz. Before this comparison, two related key comparisons, CCEM.RF-K5a.CL and CCEM.RF-K5b.CL, were performed.

The purpose of CCEM.RF-K5c.CL was to compare the measurement results from all participants and to provide the DoEs. The DoEs will be used to establish the CMC of the S-parameter.

There were some differences in the magnitudes of the reported measurement uncertainties, but the analyzed results were generally consistent with a small number of outlying values especially at high frequencies.

The analyzed results support that this comparison was successfully performed and that the DoEs of participants with respect to KCRV can reliably be used to establish the CMC of each of the participating laboratories.

References

[1] J. P. Ide, “International Comparison GT-RF/83-4: Measurement of Scattering Coefficient Over the Band 2 – 18 GHz,” NPL Report CEM 15, July 1999.

[2] C. Eiø, “CCEM KEY COMPARISON CCEM.RF-K5b.CL (GT-RF/92-3), Scattering Coefficients by Broad-Band Methods, 2 – 18 GHz, Type N connector,” National Physical Laboratory, 2010.

[3] M. Horibe, “CCEM.RF-K5c.CL Technical Protocol, Scattering Coefficients by Broad-Band Methods, 100 MHz – 33 GHz – 3.5 mm connector,” National Metrology Institute of Japan, 2012.

[4] “CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons,” CCEM 2007.

[5] IEEE Standard for Precision Coaxial Connectors (DC to 100 GHz), IEEE Std. 287-2007, Sep. 2007.

[6] Radio-frequency connectors – Part 23: Pin and socket connector for use with 3.5 mm rigid precision coaxial lines with inner diameter of outer conductor of 3.5 mm (0.1378 in), IEC 60169-23, Dec. 1991.

[7] “Guidelines on the Evaluation of Vector Network Analysers (VNA),” EURAMET/cg-12/v.01, Jul. 2007.

[8] “CCQM Guideline note: Estimation of a consensus KCRV and associated Degree of Equivalence,” ver. 10, Apr. 2013.

[9] M. Zeier, “On the Analysis of Multidimensional Quantities in Measurement Comparisons,” CPEM 2006 Conference Digest, Torino, Jul 2006.

[10] N. M. Ridler and M. J. Salter, “An approach to the treatment of uncertainty in complex S-parameter measurements,” Metrologia, vol.39, no.3, 2002.

[11] K. V. Mardia, J. T. Kent, and J. M. Bibby, “MULTIVAROATE ANALYSIS,” Academic Press, 1995.

Acknowledgement

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Appendix 1: Analysis Method

In this appendix, the detailed analysis method for the comparison is discussed. First, the definition of the values used in this appendix is shown. Then, the analysis method for KCRV and DoE is described. Finally, the method for handling inconsistent data is shown.

$x_{\alpha i}$: Measurement result of the real component of S-parameter from laboratory i in Loop α.

$u(x_{\alpha i})$: Combined standard uncertainty of $x_{\alpha i}$.

$y_{\alpha i}$: Measurement result of the imaginary component of S-parameter from laboratory i in Loop α.

$u(y_{\alpha i})$: Combined standard uncertainty of $y_{\alpha i}$.

$z_{\alpha i} = x_{\alpha i} + jy_{\alpha i}$

$u(x_{\alpha i}, y_{\alpha i})$: Covariance of $z_{\alpha i}$.

$\boldsymbol{V}_{\alpha i} = \begin{pmatrix} u(x_{\alpha i})^2 & u(x_{\alpha i}, y_{\alpha i}) \\ u(x_{\alpha i}, y_{\alpha i}) & u(y_{\alpha i})^2 \end{pmatrix}$: Covariance matrix of $z_{\alpha i}$

$x_{\alpha M}$: Real component of KCRV for Loop α.

$y_{\alpha M}$: Imaginary component of KCRV for Loop α.

$z_{\alpha M} = x_{\alpha M} + jy_{\alpha M}$

$\boldsymbol{V}_{\alpha M} = \begin{pmatrix} u(x_{\alpha M})^2 & u(x_{\alpha M}, y_{\alpha M}) \\ u(x_{\alpha M}, y_{\alpha M}) & u(y_{\alpha M})^2 \end{pmatrix}$: Covariance matrix of $z_{\alpha M}$.

$r(x_{\alpha M}, y_{\alpha M})$: Correlation coefficient of $z_{\alpha M}$.

N_α: The number of laboratories in Loop α.

$\boldsymbol{\Delta}_{\alpha iM}$: DoE of laboratory i in Loop α with respect to KCRV for Loop α.

$\boldsymbol{V}_{\Delta\alpha iM}$: Covariance matrix of $\boldsymbol{\Delta}_{\alpha iM}$.

$q_{\alpha iM}$: Reduced dimensional DoE of laboratory i in Loop α with respect to KCRV for Loop α.

$dq_{\alpha iM}$: Confidence indicator of $q_{\alpha iM}$.

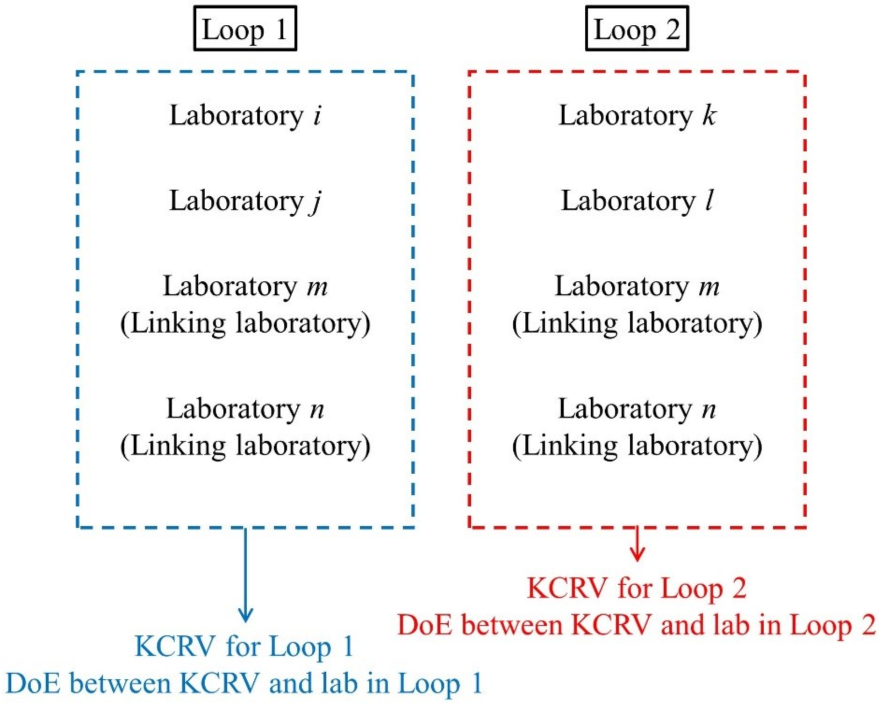


Fig. A1.1. Schematic explanation of analysis conducted in this report.

A1.1: KCRV

The calculation method for the KCRV in CCEM.RF-K5c.CL is shown in Fig. A1.1. In this report, the KCRV was calculated based on the uncertainty-weighted mean. Using the reported measurement results only from the laboratories belonging to Loop α, the KCRV for Loop α, $z_{\alpha M}$, is given as followings:

$$\boldsymbol{z}_{\alpha M} = \boldsymbol{V}_{\alpha T}^{-1} \sum_{i} \boldsymbol{V}_{\alpha i}^{-1} \boldsymbol{z}_{\alpha i} \tag{A1.1}$$

$$\boldsymbol{V}_{\alpha T} := \sum_{i} \boldsymbol{V}_{\alpha i}^{-1}. \tag{A1.2}$$

In this comparison, the correlation between the real and imaginary components of the S-parameter was not a quantity that must be reported. So, by neglecting the correlation in eqs. (A1.1) and (A1.2), the equations are transformed to eqs. (A1.3) and (A1.4). The obtained two equations are same as the one-dimensional expression.

$$x_{\alpha M} = \frac{\sum_i \frac{1}{u(x_{\alpha i})^2} x_{\alpha i}}{\sum_j \frac{1}{u(x_{\alpha j})^2}} \tag{A1.3}$$

$$y_{\alpha M} = \frac{\sum_i \frac{1}{u(y_{\alpha i})^2} y_{\alpha i}}{\sum_j \frac{1}{u(y_{\alpha j})^2}} \tag{A1.4}$$

The associated covariance matrix, $\boldsymbol{V}_{\alpha M}$, is given below.

$$\boldsymbol{V}_{\alpha M} = \left(\sum_i \boldsymbol{V}_{\alpha i}{}^{-1} \right)^{-1} \tag{A1.5}$$

If the correlation between the real and imaginary parts of the S-parameter is null, the components of $\boldsymbol{V}_{\alpha M}$ is transformed to the below equations.

$$\frac{1}{u(x_{\alpha M})^2} = \sum_i \frac{1}{u(x_{\alpha i})^2} \tag{A1.6}$$

$$\frac{1}{u(y_{\alpha M})^2} = \sum_i \frac{1}{u(y_{\alpha i})^2} \tag{A1.7}$$

The KCRVs were calculated using the results reported by the CCEM GT-RF members only. Hence, the measurement results by CMI, GUM, and NMISA were not included in the KCRV calculations. Moreover, measurement results by outliers were excluded when calculating the KCRVs. The criteria to determine outliers is discussed in A1.3.

A1.2: DoE of Each Laboratory with Respect to KCRV

The DoE of each laboratory with respect to the KCRV was calculated based on the uncertainty-weighted mean analysis. The DoEs for Loop1 and 2 were independently obtained shown in Fig. A1.1.

The DoE of each laboratory in Loop α with respect to the KCRV for Loop α is defined as the difference between the S-parameter of the reported value and the KCRV as follows:

$$\boldsymbol{\Delta}_{\alpha iM} = \boldsymbol{z}_{\alpha i} - \boldsymbol{z}_{\alpha M} \tag{A1.8}$$

The covariance matrix for the laboratories which contributes to the calculation of the KCRV is given as follows:

$$\boldsymbol{V}_{\boldsymbol{\Delta}_{\alpha iM}} = \boldsymbol{V}_{\alpha i} - \boldsymbol{V}_{\alpha M} \tag{A1.9}$$

The covariance matrix for an outlier is as follows:

$$\boldsymbol{V}_{\boldsymbol{\Delta}_{\alpha iM}} = \boldsymbol{V}_{\alpha M} + \boldsymbol{V}_{\alpha i} \tag{A1.10}$$

Because the DoE shown in Eq. (A1.8) is a two-dimensional value and the associated uncertainty is distributed on the two-dimensional plane, independent calculations for the real and imaginary components are not suitable. It is possible that one component (real or imaginary component) may be larger than its expanded uncertainty while the other is not. Hence, the number of dimensions is reduced [2][9]-[11]. $q_{\alpha iM}$ is the reduced dimensional DoE and $dq_{\alpha iM}$ is the confidence indicator of $q_{\alpha iM}$. $dq_{\alpha iM}$ is defined as the distance between $q_{\alpha iM}$ and the boundary through the origin (Fig. A1.2). Here the coverage factor, k, is 2.45 for two dimensional data.

$$q_{\alpha iM} = |\boldsymbol{\Delta}_{\alpha i}| = |\boldsymbol{z}_{\alpha i} - \boldsymbol{z}_{\alpha M}| \tag{A1.11}$$

$$dq_{\alpha iM} = q_{\alpha iM} k \sqrt{\left(\boldsymbol{\Delta}_{\alpha i}{}^{\mathrm{T}} \boldsymbol{V}_{\boldsymbol{\Delta}_{\alpha iM}}^{-1} \boldsymbol{\Delta}_{\alpha i}\right)^{-1}} \tag{A1.12}$$

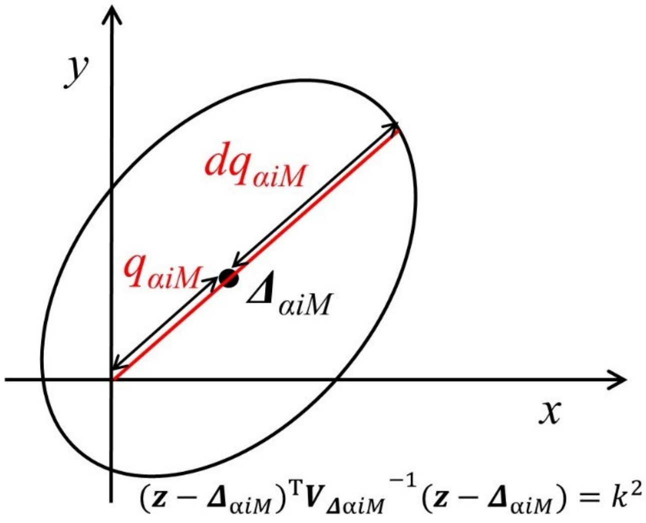


Fig. A1.2. Schematic drawing of reduced dimensional DoE and the confidence indicator.

A1.3: Outlier for Calculation of KCRV

When the KCRVs were calculated, inconsistent data were excluded. This process is also the same as that of CCEM.RF-K5b.CL [2].

If $q_{\alpha iM}$ was larger than $dq_{\alpha iM}$, the laboratory i in Loop α was regarded as an outlier and excluded from the calculation of the KCRV. The most discrepant data, i.e., the element for which $q_{\alpha iM} - dq_{\alpha iM}$ was most positive, was removed first, the vector mean was re-calculated and, if still inconsistent, the then most discrepant element was excluded. This process was repeated until a set of consistent data was obtained.

Appendix 2: Uncertainty Budget

The participating laboratories were asked to submit the uncertainty budgets. The reported uncertainty budgets are shown below.

A2.1: NMIJ

Table A2.1.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000637
Cable stability	0.0007058
Connection repeatability	0.0014182
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0008089
Overall Combined Uncertainty:	0.0018

Table A2.1.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000219
Cable stability	0.000699
Connection repeatability	0.002213
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000287
Overall Combined Uncertainty:	0.0023

Table A2.1.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000266
Cable stability	0.000695
Connection repeatability	0.003121
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000246
Overall Combined Uncertainty:	0.0032

Table A2.1.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000281
Cable stability	0.000694
Connection repeatability	0.003539
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000298
Overall Combined Uncertainty:	0.0036

Table A2.1.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00000672
Cable stability	0.00007030
Connection repeatability	0.00014126
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00003203
Overall Combined Uncertainty:	0.00016

Table A2.1.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000268
Cable stability	0.0000685
Connection repeatability	0.0002167
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0000121
Overall Combined Uncertainty:	0.00023

Table A2.1.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000337
Cable stability	0.0000674
Connection repeatability	0.0003026
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0000205
Overall Combined Uncertainty:	0.00031

Table A2.1.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000365
Cable stability	0.0000685
Connection repeatability	0.0003495
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0000236
Overall Combined Uncertainty:	0.00036

Table A2.1.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000002313
Cable stability	0.000007046
Connection repeatability	0.000014158
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000000597
Overall Combined Uncertainty:	0.000016

Table A2.1.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00001619
Cable stability	0.00000679
Connection repeatability	0.00002150
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00000121
Overall Combined Uncertainty:	0.000028

Table A2.1.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00002207
Cable stability	0.00000695
Connection repeatability	0.00003122
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00000214
Overall Combined Uncertainty:	0.000039

Table A2.1.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00002416
Cable stability	0.00000749
Connection repeatability	0.00003821
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00000241
Overall Combined Uncertainty:	0.000046

Table A2.1.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000002224
Cable stability	0.000500000
Connection repeatability	0.001004701
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001117897
Overall Combined Uncertainty:	0.0016

Table A2.1.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000016157
Cable stability	0.000500073
Connection repeatability	0.001583032
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001188107
Overall Combined Uncertainty:	0.0020

Table A2.1.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000022206
Cable stability	0.000500182
Connection repeatability	0.002251067
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001635343
Overall Combined Uncertainty:	0.0028

Table A2.1.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000025296
Cable stability	0.000500804
Connection repeatability	0.002555100
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001532609
Overall Combined Uncertainty:	0.0030

Table A2.1.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000063679
Cable stability	0.001222289
Connection repeatability	0.002456066
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001623496
Overall Combined Uncertainty:	0.0032

Table A2.1.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000220530
Cable stability	0.001224937
Connection repeatability	0.003851947
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001267050
Overall Combined Uncertainty:	0.0042

Table A2.1.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000268043
Cable stability	0.001251162
Connection repeatability	0.005454589
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001709751
Overall Combined Uncertainty:	0.0059

Table A2.1.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000283290
Cable stability	0.001268816
Connection repeatability	0.006186666
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001989452
Overall Combined Uncertainty:	0.0066

Table A2.1.21. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000637
Cable stability	0.0007063
Connection repeatability	0.0014192
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0008091
Overall Combined Uncertainty:	0.0018

Table A2.1.22. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000220
Cable stability	0.000700
Connection repeatability	0.002215
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000288
Overall Combined Uncertainty:	0.0024

Table A2.1.23. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000266
Cable stability	0.000696
Connection repeatability	0.003126
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000246
Overall Combined Uncertainty:	0.0032

Table A2.1.24. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000281
Cable stability	0.000695
Connection repeatability	0.003544
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000298
Overall Combined Uncertainty:	0.0036

Table A2.1.25. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00000675
Cable stability	0.00007066
Connection repeatability	0.00014198
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00003233
Overall Combined Uncertainty:	0.00016

Table A2.1.26. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000268
Cable stability	0.0000688
Connection repeatability	0.0002177
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0000122
Overall Combined Uncertainty:	0.00023

Table A2.1.27. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000341
Cable stability	0.0000685
Connection repeatability	0.0003075
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0000209
Overall Combined Uncertainty:	0.00032

Table A2.1.28. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000372
Cable stability	0.0000709
Connection repeatability	0.0003615
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0000243
Overall Combined Uncertainty:	0.00037

Table A2.1.29. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000002317
Cable stability	0.000007229
Connection repeatability	0.000014527
VNA system (directivity, matching, tracking, linearity, and resolution)	0.000000611
Overall Combined Uncertainty:	0.000016

Table A2.1.30. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00001619
Cable stability	0.00000693
Connection repeatability	0.00002193
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00000123
Overall Combined Uncertainty:	0.000028

Table A2.1.31. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00002207
Cable stability	0.00000702
Connection repeatability	0.00003152
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00000216
Overall Combined Uncertainty:	0.000039

Table A2.1.32. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00002416
Cable stability	0.00000757
Connection repeatability	0.00003864
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00000241
Overall Combined Uncertainty:	0.000046

Table A2.1.33. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00000223
Cable stability	0.00050000
Connection repeatability	0.00100471
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00111790
Overall Combined Uncertainty:	0.0016

Table A2.1.34. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.00001609
Cable stability	0.00050003
Connection repeatability	0.00158289
VNA system (directivity, matching, tracking, linearity, and resolution)	0.00118811
Overall Combined Uncertainty:	0.0020

Table A2.1.35. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000220
Cable stability	0.0005001
Connection repeatability	0.0022458
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0016406
Overall Combined Uncertainty:	0.0028

Table A2.1.36. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000240
Cable stability	0.0005000
Connection repeatability	0.0025511
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0015326
Overall Combined Uncertainty:	0.0030

Table A2.1.37. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.0000637
Cable stability	0.0012231
Connection repeatability	0.0024577
VNA system (directivity, matching, tracking, linearity, and resolution)	0.0016242
Overall Combined Uncertainty:	0.0032

Table A2.1.38. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000221
Cable stability	0.001227
Connection repeatability	0.003859
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001268
Overall Combined Uncertainty:	0.0042

Table A2.1.39. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000269056
Cable stability	0.001255896
Connection repeatability	0.005475241
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001710684
Overall Combined Uncertainty:	0.0059

Table A2.1.40. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
VNA noise	0.000284
Cable stability	0.001273
Connection repeatability	0.006209
VNA system (directivity, matching, tracking, linearity, and resolution)	0.001995
Overall Combined Uncertainty:	0.0067

A2.2: METAS

Table A2.2.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000327902	20.577	0.000968760	73.163
Calibration Standards	0.000000926	0.000	0.000003289	0.001
VNA Drift (correlated)	0.000042943	0.353	0.000044198	0.152
VNA Linearity	0.000642758	79.067	0.000585049	26.684
VNA Noise	0.000004018	0.003	0.000002179	0.000
Overall Combined Uncertainty:	0.000722855		0.001132585	
Expanded Uncertainty (k=2):	**0.001445709**		**0.002265169**	
measurement value ***x:***	0.997671932	***y*** :	-0.060105575	

Table A2.2.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000343617	29.484	0.000320225	25.636
Connector Repeatability	0.000070530	1.242	0.000071276	1.270
Calibration Standards	0.000281999	19.858	0.000274926	18.896
VNA Drift (correlated)	0.000120348	3.617	0.000111240	3.094
VNA Linearity	0.000427706	45.680	0.000451687	51.005
VNA Noise	0.000021873	0.119	0.000019877	0.099
Overall Combined Uncertainty:	0.000632823		0.000632455	
Expanded Uncertainty (k=2):	**0.001265647**		**0.001264910**	
measurement value ***x:***	0.436393041	***y*** :	-0.891611056	

Table A2.2.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000402463	30.849	0.000614219	47.204
Connector Repeatability	0.000126146	3.031	0.000156611	3.069
Calibration Standards	0.000320246	19.532	0.000423012	22.389
VNA Drift (correlated)	0.000179705	6.151	0.000188572	4.449
VNA Linearity	0.000460340	40.360	0.000424163	22.511
VNA Noise	0.000020210	0.078	0.000054865	0.377
Overall Combined Uncertainty:	0.000724611		0.000893988	
Expanded Uncertainty (k=2):	**0.001449223**		**0.001787977**	
measurement value ***x:***	-0.982929468	***y*** :	0.101472196	

Table A2.2.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000647360	49.989	0.000642240	49.055
Connector Repeatability	0.000143231	2.447	0.000144505	2.483
Calibration Standards	0.000405030	19.568	0.000406082	19.612
VNA Drift (correlated)	0.000179289	3.834	0.000189457	4.269
VNA Linearity	0.000448354	23.978	0.000453141	24.420
VNA Noise	0.000039177	0.183	0.000036764	0.161
Overall Combined Uncertainty:	0.000915609		0.000916973	
Expanded Uncertainty (k=2):	**0.001831218**		**0.001833945**	
measurement value ***x:***	0.657359651	***y*** :	-0.735125156	

Table A2.2.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000032826	20.645	0.000096367	72.997
Connector Repeatability	0.000000234	0.001		
Calibration Standards	0.000002784	0.149	0.000000286	0.001
VNA Drift (correlated)	0.000005977	0.684	0.000006139	0.296
VNA Linearity	0.000064017	78.518	0.000058288	26.705
VNA Noise	0.000000428	0.004	0.000000217	0.000
Overall Combined Uncertainty:	0.000072245		0.000112791	
Expanded Uncertainty (k=2):	**0.000144490**		**0.000225583**	
measurement value ***x*** :	0.099241374	***y*** :	-0.007107090	

Table A2.2.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000032071	24.458	0.000032817	24.994
Connector Repeatability	0.000006852	1.116	0.000006896	1.104
Calibration Standards	0.000027082	17.440	0.000027433	17.466
VNA Drift (correlated)	0.000022563	12.105	0.000024789	14.261
VNA Linearity	0.000043387	44.763	0.000042569	42.056
VNA Noise	0.000002209	0.116	0.000002269	0.120
Overall Combined Uncertainty:	0.000064849		0.000065641	
Expanded Uncertainty (k=2):	**0.000129697**		**0.000131282**	
measurement value ***x*** :	-0.075554121	***y*** :	-0.060911418	

Table A2.2.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000039514	26.261	0.000059231	40.693
Connector Repeatability	0.000012193	2.501	0.000015359	2.736
Calibration Standards	0.000031283	16.460	0.000040954	19.454
VNA Drift (correlated)	0.000035493	21.188	0.000038467	17.163
VNA Linearity	0.000044632	33.506	0.000041127	19.618
VNA Noise	0.000002238	0.084	0.000005374	0.335
Overall Combined Uncertainty:	0.000077107		0.000092852	
Expanded Uncertainty (k=2):	**0.000154213**		**0.000185704**	
measurement value ***x***:	0.094514072	***y***:	0.014438031	

Table A2.2.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000065146	43.417	0.000061388	40.010
Connector Repeatability	0.000016764	2.875	0.000017075	3.095
Calibration Standards	0.000042733	18.682	0.000041521	18.303
VNA Drift (correlated)	0.000039846	16.243	0.000038656	15.865
VNA Linearity	0.000042504	18.482	0.000046106	22.569
VNA Noise	0.000005424	0.301	0.000003861	0.158
Overall Combined Uncertainty:	0.000098869		0.000097052	
Expanded Uncertainty (k=2):	**0.000197737**		**0.000194103**	
measurement value ***x***:	-0.021703514	***y***:	0.094504957	

Table A2.2.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000003300	20.531	0.000009663	72.676
Connector Repeatability	0.000000024	0.001		
Calibration Standards	0.000000250	0.118	0.000000049	0.002
VNA Drift (correlated)	0.000000915	1.577	0.000000938	0.685
VNA Linearity	0.000006421	77.709	0.000005847	26.611
VNA Noise	0.000000184	0.064	0.000000181	0.026
Overall Combined Uncertainty:	0.000007284		0.000011335	
Expanded Uncertainty (k=2):	**0.000014568**		**0.000022670**	
measurement value ***x***:	0.009951652	***y***:	-0.000758199	

Table A2.2.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000003033	20.419	0.000003400	25.553
Connector Repeatability	0.000000695	1.072	0.000000676	1.010
Calibration Standards	0.000002656	15.653	0.000002748	16.689
VNA Drift (correlated)	0.000002882	18.430	0.000002965	19.429
VNA Linearity	0.000004448	43.912	0.000004080	36.788
VNA Noise	0.000000481	0.514	0.000000491	0.532
Overall Combined Uncertainty:	0.000006713		0.000006727	
Expanded Uncertainty (k=2):	**0.000013426**		**0.000013454**	
measurement value ***x***:	-0.009569994	***y***:	-0.001109020	

Table A2.2.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000005648	34.056	0.000004680	28.508
Connector Repeatability	0.000001479	2.336	0.000001275	2.117
Calibration Standards	0.000004018	17.237	0.000003526	16.182
VNA Drift (correlated)	0.000004930	25.950	0.000004490	26.244
VNA Linearity	0.000004328	19.997	0.000004516	26.553
VNA Noise	0.000000629	0.423	0.000000552	0.397
Overall Combined Uncertainty:	0.000009679		0.000008765	
Expanded Uncertainty (k=2):	**0.000019357**		**0.000017529**	
measurement value ***x***:	0.005081129	***y***:	-0.008464981	

Table A2.2.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000006685	36.543	0.000007102	39.581
Connector Repeatability	0.000001609	2.116	0.000001570	1.934
Calibration Standards	0.000004424	16.001	0.000004577	16.434
VNA Drift (correlated)	0.000005270	22.708	0.000005447	23.284
VNA Linearity	0.000005054	20.885	0.000004653	16.989
VNA Noise	0.000001462	1.747	0.000001505	1.778
Overall Combined Uncertainty:	0.000011059		0.000011289	
Expanded Uncertainty (k=2):	**0.000022118**		**0.000022578**	
measurement value ***x***:	0.010379213	***y***:	0.002211180	

Table A2.2.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000035824	0.477	0.000036090	0.481
Calibration Standards	0.000511870	97.480	0.000513013	97.110
VNA Drift (correlated)	0.000029668	0.327	0.000029942	0.331
VNA Linearity	0.000067401	1.690	0.000074580	2.052
VNA Noise	0.000008246	0.025	0.000008522	0.027
Overall Combined Uncertainty:	0.000518445		0.000520592	
Expanded Uncertainty (k=2):	**0.001036890**		**0.001041185**	
measurement value ***x***:	-0.000281495	***y***:	0.000166654	

Table A2.2.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000183156	11.206	0.000182656	10.859
Calibration Standards	0.000507155	85.917	0.000514913	86.293
VNA Drift (correlated)	0.000033627	0.378	0.000034689	0.392
VNA Linearity	0.000086441	2.496	0.000086787	2.451
VNA Noise	0.000003532	0.004	0.000003962	0.005
Overall Combined Uncertainty:	0.000547144		0.000554301	
Expanded Uncertainty (k=2):	**0.001094289**		**0.001108602**	
measurement value ***x***:	-0.006390699	***y***:	-0.006938987	

Table A2.2.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000292091	10.269	0.000292944	10.313
Calibration Standards	0.000846149	86.176	0.000845925	85.995
VNA Drift (correlated)	0.000101276	1.235	0.000104077	1.302
VNA Linearity	0.000138426	2.306	0.000140341	2.367
VNA Noise	0.000010815	0.014	0.000014141	0.024
Overall Combined Uncertainty:	0.000911494		0.000912213	
Expanded Uncertainty (k=2):	**0.001822987**		**0.001824427**	
measurement value ***x***:	-0.001334718	***y***:	0.011659198	

Table A2.2.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000629694	12.994	0.000628417	13.274
Calibration Standards	0.001621411	86.155	0.001598037	85.839
VNA Drift (correlated)	0.000113471	0.422	0.000115373	0.447
VNA Linearity	0.000113890	0.425	0.000114146	0.438
VNA Noise	0.000010513	0.004	0.000006472	0.001
Overall Combined Uncertainty:	0.001746839		0.001724822	
Expanded Uncertainty (k=2):	**0.003493678**		**0.003449644**	
measurement value ***x***:	0.006103465	***y***:	-0.024555617	

Table A2.2.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000056386	0.235	0.000056356	0.143
Calibration Standards	0.001064172	83.559	0.001425434	91.660
VNA Drift (correlated)	0.000048124	0.171	0.000044188	0.088
VNA Linearity	0.000465315	15.976	0.000423313	8.084
VNA Noise	0.000028301	0.059	0.000023290	0.024
Overall Combined Uncertainty:	0.001164164		0.001488868	
Expanded Uncertainty (k=2):	**0.002328327**		**0.002977736**	
measurement value ***x***:	-0.999949828	***y***:	0.000027858	

Table A2.2.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000353411	6.778	0.000353739	1.365
Calibration Standards	0.001220369	80.821	0.002974972	96.557
VNA Drift (correlated)	0.000061312	0.204	0.000061253	0.041
VNA Linearity	0.000473727	12.179	0.000431544	2.032
VNA Noise	0.000018669	0.019	0.000021529	0.005
Overall Combined Uncertainty:	0.001357470		0.003027546	
Expanded Uncertainty (k=2):	**0.002714939**		**0.006055092**	
measurement value ***x***:	-0.999348919	***y***:	0.002549598	

Table A2.2.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000558900	6.514	0.000565100	0.882
Calibration Standards	0.002067924	89.175	0.005975143	98.621
VNA Drift (correlated)	0.000106285	0.236	0.000106129	0.031
VNA Linearity	0.000441553	4.066	0.000407048	0.458
VNA Noise	0.000021857	0.010	0.000052641	0.008
Overall Combined Uncertainty:	0.002189845		0.006016760	
Expanded Uncertainty (k=2):	**0.004379690**		**0.012033519**	
measurement value ***x***:	-0.998605524	***y***:	0.005277583	

Table A2.2.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.001129523	12.102	0.001137501	2.261
Calibration Standards	0.002994369	85.049	0.007461471	97.284
VNA Drift (correlated)	0.000122411	0.142	0.000134577	0.032
VNA Linearity	0.000533502	2.700	0.000489513	0.419
VNA Noise	0.000028046	0.007	0.000053505	0.005
Overall Combined Uncertainty:	0.003246916		0.007564922	
Expanded Uncertainty (k=2):	**0.006493831**		**0.015129845**	
measurement value ***x***:	-0.998355472	***y***:	0.006817015	

Table A2.2.21. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000327886	20.600	0.000968670	73.195
Calibration Standards	0.000000928	0.000	0.000003265	0.001
VNA Drift (correlated)	0.000036095	0.250	0.000037149	0.108
VNA Linearity	0.000642700	79.147	0.000584997	26.696
VNA Noise	0.000004018	0.003	0.000002179	0.000
Overall Combined Uncertainty:	0.000722421		0.001132227	
Expanded Uncertainty (k=2):	**0.001444842**		**0.002264454**	
measurement value ***x***:	0.997577330	***y***:	-0.060183777	

Table A2.2.22. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000343317	28.723	0.000320040	25.083
Connector Repeatability	0.000070373	1.207	0.000071105	1.238
Calibration Standards	0.000281820	19.354	0.000274777	18.490
VNA Drift (correlated)	0.000157896	6.075	0.000145893	5.212
VNA Linearity	0.000427443	44.524	0.000451312	49.880
VNA Noise	0.000021854	0.116	0.000019867	0.097
Overall Combined Uncertainty:	0.000640592		0.000639019	
Expanded Uncertainty (k=2):	**0.001281184**		**0.001278038**	
measurement value ***x***:	0.437572128	***y***:	-0.890332022	

Table A2.2.23. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000401993	29.538	0.000613913	45.773
Connector Repeatability	0.000126026	2.903	0.000156615	2.979
Calibration Standards	0.000319962	18.713	0.000422783	21.709
VNA Drift (correlated)	0.000234772	10.075	0.000246065	7.354
VNA Linearity	0.000460115	38.697	0.000423866	21.820
VNA Noise	0.000020143	0.074	0.000054854	0.365
Overall Combined Uncertainty:	0.000739653		0.000907404	
Expanded Uncertainty (k=2):	**0.001479305**		**0.001814808**	
measurement value ***x***:	-0.982614440	***y***:	0.097230880	

Table A2.2.24. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000646492	48.496	0.000641758	47.460
Connector Repeatability	0.000142178	2.346	0.000143488	2.373
Calibration Standards	0.000404802	19.014	0.000405957	18.991
VNA Drift (correlated)	0.000239412	6.651	0.000253601	7.411
VNA Linearity	0.000448279	23.317	0.000452637	23.609
VNA Noise	0.000039049	0.177	0.000036861	0.157
Overall Combined Uncertainty:	0.000928347		0.000931555	
Expanded Uncertainty (k=2):	**0.001856694**		**0.001863110**	
measurement value ***x***:	0.660752215	***y***:	-0.731227301	

Table A2.2.25. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000033015	20.644	0.000096891	72.969
Connector Repeatability	0.000000198	0.001		
Calibration Standards	0.000002641	0.132	0.000000800	0.005
VNA Drift (correlated)	0.000006460	0.790	0.000006635	0.342
VNA Linearity	0.000064351	78.430	0.000058592	26.684
VNA Noise	0.000000430	0.003	0.000000218	0.000
Overall Combined Uncertainty:	0.000072663		0.000113427	
Expanded Uncertainty (k=2):	**0.000145327**		**0.000226853**	
measurement value ***x***:	0.099766673	***y***:	-0.007162071	

Table A2.2.26. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000032165	23.769	0.000033019	24.348
Connector Repeatability	0.000006876	1.086	0.000006917	1.069
Calibration Standards	0.000027211	17.010	0.000027585	16.994
VNA Drift (correlated)	0.000024924	14.271	0.000027371	16.731
VNA Linearity	0.000043640	43.752	0.000042713	40.743
VNA Noise	0.000002213	0.112	0.000002282	0.116
Overall Combined Uncertainty:	0.000065976		0.000066917	
Expanded Uncertainty (k=2):	**0.000131952**		**0.000133834**	
measurement value ***x***:	-0.076760530	***y***:	-0.060126226	

Table A2.2.27. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000039973	24.909	0.000060395	39.409
Connector Repeatability	0.000012422	2.405	0.000015607	2.632
Calibration Standards	0.000031865	15.829	0.000041790	18.868
VNA Drift (correlated)	0.000039743	24.623	0.000042909	19.892
VNA Linearity	0.000045418	32.157	0.000041797	18.875
VNA Noise	0.000002225	0.077	0.000005482	0.325
Overall Combined Uncertainty:	0.000080092		0.000096206	
Expanded Uncertainty (k=2):	**0.000160184**		**0.000192413**	
measurement value ***x***:	0.096441816	***y***:	0.011577236	

Table A2.2.28. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000067540	42.118	0.000063649	38.935
Connector Repeatability	0.000017368	2.785	0.000017501	2.943
Calibration Standards	0.000044017	17.889	0.000042828	17.628
VNA Drift (correlated)	0.000045554	19.160	0.000043744	18.390
VNA Linearity	0.000043858	17.760	0.000047800	21.959
VNA Noise	0.000005587	0.288	0.000003867	0.144
Overall Combined Uncertainty:	0.000104071		0.000102005	
Expanded Uncertainty (k=2):	**0.000208142**		**0.000204010**	
measurement value ***x***:	-0.017033128	***y***:	0.098849006	

Table A2.2.29. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000003388	20.512	0.000009918	72.636
Connector Repeatability	0.000000023	0.001		
Calibration Standards	0.000000263	0.123	0.000000043	0.001
VNA Drift (correlated)	0.000000979	1.713	0.000001005	0.745
VNA Linearity	0.000006590	77.590	0.000006001	26.593
VNA Noise	0.000000185	0.061	0.000000181	0.024
Overall Combined Uncertainty:	0.000007482		0.000011637	
Expanded Uncertainty (k=2):	**0.000014963**		**0.000023275**	
measurement value ***x***:	0.010213889	***y***:	-0.000779933	

Table A2.2.30. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000003094	19.398	0.000003472	24.293
Connector Repeatability	0.000000710	1.021	0.000000689	0.958
Calibration Standards	0.000002710	14.880	0.000002804	15.847
VNA Drift (correlated)	0.000003329	22.454	0.000003414	23.500
VNA Linearity	0.000004540	41.777	0.000004162	34.914
VNA Noise	0.000000482	0.471	0.000000492	0.488
Overall Combined Uncertainty:	0.000007025		0.000007043	
Expanded Uncertainty (k=2):	**0.000014049**		**0.000014087**	
measurement value ***x***:	-0.009782507	***y***:	-0.000961251	

Table A2.2.31. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000005746	32.079	0.000004672	26.195
Connector Repeatability	0.000001492	2.162	0.000001273	1.944
Calibration Standards	0.000004090	16.254	0.000003551	15.128
VNA Drift (correlated)	0.000005618	30.665	0.000005113	31.37
VNA Linearity	0.000004357	18.447	0.000004564	25.002
VNA Noise	0.000000635	0.392	0.000000549	0.362
Overall Combined Uncertainty:	0.000010145		0.000009129	
Expanded Uncertainty (k=2):	**0.000020291**		**0.000018257**	
measurement value ***x***:	0.004909096	***y***:	-0.008664610	

Table A2.2.32. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Cable Stability	0.000006767	34.554	0.000007204	37.332
Connector Repeatability	0.000001593	1.916	0.000001552	1.733
Calibration Standards	0.000004422	14.756	0.000004592	15.171
VNA Drift (correlated)	0.000006024	27.378	0.000006262	28.205
VNA Linearity	0.000005121	19.789	0.000004706	15.929
VNA Noise	0.000001460	1.607	0.000001506	1.631
Overall Combined Uncertainty:	0.000011513		0.000011790	
Expanded Uncertainty (k=2):	**0.000023025**		**0.000023580**	
measurement value ***x***:	0.010575681	***y***:	0.001898088	

Table A2.2.33. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000035840	0.476	0.000036113	0.479
Calibration Standards	0.000512656	97.396	0.000513739	97.016
VNA Drift (correlated)	0.000032701	0.396	0.000032952	0.399
VNA Linearity	0.000067865	1.707	0.000075194	2.078
VNA Noise	0.000008273	0.025	0.000008541	0.027
Overall Combined Uncertainty:	0.000519465		0.000521579	
Expanded Uncertainty (k=2):	**0.001038930**		**0.001043159**	
measurement value ***x***:	0.002212908	***y***:	-0.000055312	

Table A2.2.34. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000183754	11.070	0.000183228	10.696
Calibration Standards	0.000512211	86.018	0.000520867	86.436
VNA Drift (correlated)	0.000035200	0.406	0.000036110	0.415
VNA Linearity	0.000087348	2.501	0.000087640	2.447
VNA Noise	0.000003538	0.004	0.000004011	0.005
Overall Combined Uncertainty:	0.000552274		0.000560246	
Expanded Uncertainty (k=2):	**0.001104548**		**0.001120491**	
measurement value ***x***:	0.004953278	***y***:	-0.001154163	

Table A2.2.35. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000291875	10.313	0.000292661	10.295
Calibration Standards	0.000842915	86.014	0.000845536	85.937
VNA Drift (correlated)	0.000105786	1.355	0.000107996	1.402
VNA Linearity	0.000137976	2.305	0.000139580	2.342
VNA Noise	0.000010702	0.014	0.000014115	0.024
Overall Combined Uncertainty:	0.000908867		0.000912100	
Expanded Uncertainty (k=2):	**0.001817735**		**0.001824199**	
measurement value ***x***:	-0.001807250	***y***:	0.005635286	

Table A2.2.36. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000631427	13.373	0.000630297	13.342
Calibration Standards	0.001598270	85.680	0.001597353	85.692
VNA Drift (correlated)	0.000123656	0.513	0.000125388	0.528
VNA Linearity	0.000113273	0.430	0.000113923	0.436
VNA Noise	0.000010449	0.004	0.000006637	0.001
Overall Combined Uncertainty:	0.001726672		0.001725560	
Expanded Uncertainty (k=2):	**0.003453345**		**0.003451119**	
measurement value ***x***:	-0.000137064	***y***:	-0.000003225	

Table A2.2.37. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 0.1 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000056386	0.235	0.000056357	0.143
Calibration Standards	0.001064180	83.546	0.001425448	91.650
VNA Drift (correlated)	0.000050288	0.187	0.000046965	0.099
VNA Linearity	0.000465321	15.974	0.000423318	8.083
VNA Noise	0.000028302	0.059	0.000023290	0.024
Overall Combined Uncertainty:	0.001164265		0.001488967	
Expanded Uncertainty (k=2):	**0.002328529**		**0.002977934**	
measurement value ***x***:	-0.999958262	***y***:	0.000025885	

Table A2.2.38. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 12.4 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000353418	6.780	0.000353746	1.365
Calibration Standards	0.001220379	80.842	0.002974995	96.564
VNA Drift (correlated)	0.000057048	0.177	0.000055928	0.034
VNA Linearity	0.000473737	12.182	0.000431553	2.032
VNA Noise	0.000018669	0.019	0.000021529	0.005
Overall Combined Uncertainty:	0.001357298		0.003027467	
Expanded Uncertainty (k=2):	**0.002714596**		**0.006054935**	
measurement value ***x***:	-0.999356589	***y***:	0.002519434	

Table A2.2.39. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 26.5 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.000558895	6.516	0.000565089	0.882
Calibration Standards	0.002067958	89.214	0.005975385	98.633
VNA Drift (correlated)	0.000096051	0.192	0.000083789	0.019
VNA Linearity	0.000441544	4.067	0.000407044	0.458
VNA Noise	0.000021858	0.010	0.000052638	0.008
Overall Combined Uncertainty:	0.002189402		0.006016646	
Expanded Uncertainty (k=2):	**0.004378803**		**0.012033292**	
measurement value ***x***:	-0.998647184	***y***:	0.005405191	

Table A2.2.40. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 33 GHz.

Uncertainty contribution	**Estimated value**			
	u(x)	***u(x)*** percentage	***u(y)***	***u(y)*** percentage
Connector Repeatability	0.001129672	12.108	0.001137650	2.261
Calibration Standards	0.002994617	85.082	0.007462126	97.295
VNA Drift (correlated)	0.000103697	0.102	0.000107548	0.020
VNA Linearity	0.000533573	2.701	0.000489578	0.419
VNA Noise	0.000028050	0.007	0.000053512	0.005
Overall Combined Uncertainty:	0.003246557		0.007565163	
Expanded Uncertainty (k=2):	**0.006493113**		**0.015130326**	
measurement value ***x***:	-0.998443034	***y***:	0.006877426	

A2.3: NPL

Table A2.3.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000000
Isolation	0.000006
Mismatch	0.000004
Random	0.000059
Overall Combined Uncertainty:	0.000059

Table A2.3.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.0000031
Isolation	0.0000058
Mismatch	0.0000106
Random	0.0003794
Overall Combined Uncertainty:	0.000380

Table A2.3.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 26.5 GHz.

	Estimated value
Linearity	0.000005
Isolation	0.000006
Mismatch	0.000046
Random	0.000801
Overall Combined Uncertainty:	0.000802

Table A2.3.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000006
Isolation	0.000006
Mismatch	0.000033
Random	0.000992
Overall Combined Uncertainty:	0.000993

Table A2.3.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000093
Isolation	0.000006
Mismatch	0.000001
Random	0.000005
Overall Combined Uncertainty:	0.000093

Table A2.3.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000091
Isolation	0.000006
Mismatch	0.000005
Random	0.000049
Overall Combined Uncertainty:	0.000104

Table A2.3.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 26.5 GHz.

	Estimated value
Linearity	0.000091
Isolation	0.000006
Mismatch	0.000005
Random	0.000101
Overall Combined Uncertainty:	0.000136

Table A2.3.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000091
Isolation	0.000006
Mismatch	0.000017
Random	0.000131
Overall Combined Uncertainty:	0.000161

Table A2.3.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000019
Isolation	0.000006
Mismatch	0.000000
Random	0.000003
Overall Combined Uncertainty:	0.000020

Table A2.3.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000018
Isolation	0.000006
Mismatch	0.000000
Random	0.000006
Overall Combined Uncertainty:	0.000020

Table A2.3.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 26.5 GHz.

	Estimated value
Linearity	0.000018
Isolation	0.000006
Mismatch	0.000001
Random	0.000011
Overall Combined Uncertainty:	0.000022

Table A2.3.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000019
Isolation	0.000006
Mismatch	0.000001
Random	0.000016
Overall Combined Uncertainty:	0.000026

Table A2.3.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0000
Random effects	0.0014
Overall Combined Uncertainty:	0.0018

Table A2.3.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0000
Random effects	0.0014
Overall Combined Uncertainty:	0.0018

Table A2.3.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0000
Random effects	0.0015
Overall Combined Uncertainty:	0.0018

Table A2.3.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0000
Random effects	0.0016
Overall Combined Uncertainty:	0.0019

Table A2.3.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 0.1 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0014
Random effects	0.0002
Overall Combined Uncertainty:	0.0018

Table A2.3.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 12.4 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0014
Random effects	0.0007
Overall Combined Uncertainty:	0.0019

Table A2.3.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 26.5 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0014
Random effects	0.0016
Overall Combined Uncertainty:	0.0023

Table A2.3.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 1) at 33 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0014
Random effects	0.0016
Overall Combined Uncertainty:	0.0024

Table A2.3.21. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000000
Isolation	0.000006
Mismatch	0.000005
Random	0.000081
Overall Combined Uncertainty:	0.000082

Table A2.3.22. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000003
Isolation	0.000006
Mismatch	0.000006
Random	0.000454
Overall Combined Uncertainty:	0.000454

Table A2.3.23. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 26.5 GHz.

	Estimated value
Linearity	0.000005
Isolation	0.000006
Mismatch	0.000042
Random	0.001005
Overall Combined Uncertainty:	0.001005

Table A2.3.24. Uncertainty budget in S_{21} measurement of K5c.CL/1 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000006
Isolation	0.000006
Mismatch	0.000022
Random	0.001274
Overall Combined Uncertainty:	0.001274

Table A2.3.25. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000093
Isolation	0.000006
Mismatch	0.000002
Random	0.000009
Overall Combined Uncertainty:	0.000094

Table A2.3.26. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000092
Isolation	0.000006
Mismatch	0.000005
Random	0.000042
Overall Combined Uncertainty:	0.000101

Table A2.3.27. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 26.5 GHz.

	Estimated value
Linearity	0.000091
Isolation	0.000006
Mismatch	0.000007
Random	0.000088
Overall Combined Uncertainty:	0.000127

Table A2.3.28. Uncertainty budget in S_{21} measurement of K5c.CL/2 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000093
Isolation	0.000006
Mismatch	0.000017
Random	0.000118
Overall Combined Uncertainty:	0.000151

Table A2.3.29. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000019
Isolation	0.000006
Mismatch	0.000000
Random	0.000004
Overall Combined Uncertainty:	0.000020

Table A2.3.30. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000018
Isolation	0.000006
Mismatch	0.000000
Random	0.000004
Overall Combined Uncertainty:	0.000020

Table A2.3.31. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 26.5 GHz.

	Estimated value
Linearity	0.000019
Isolation	0.000006
Mismatch	0.000001
Random	0.000008
Overall Combined Uncertainty:	0.000021

Table A2.3.32. Uncertainty budget in S_{21} measurement of K5c.CL/3 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.000020
Isolation	0.000006
Mismatch	0.000001
Random	0.000012
Overall Combined Uncertainty:	0.000024

Table A2.3.33. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
	0.0010
Air line deviations from nominal	0.0001
Resistivity	0.0000
Test port match	0.0014
Random effects	
Overall Combined Uncertainty:	0.0018

Table A2.3.34. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0000
Random effects	0.0014
Overall Combined Uncertainty:	0.0018

Table A2.3.35. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0000
Random effects	0.0015
Overall Combined Uncertainty:	0.0018

Table A2.3.36. Uncertainty budget in S_{11} measurement of K5c.CL/4 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0000
Random effects	0.0016
Overall Combined Uncertainty:	0.0019

Table A2.3.37. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 0.1 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0014
Random effects	0.0002
Overall Combined Uncertainty:	0.0018

Table A2.3.38. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 12.4 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0001
Test port match	0.0014
Random effects	0.0007
Overall Combined Uncertainty:	0.0019

Table A2.3.39. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 26.5 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0014
Random effects	0.0016
Overall Combined Uncertainty:	0.0023

Table A2.3.40. Uncertainty budget in S_{11} measurement of K5c.CL/7 (Loop 2) at 33 GHz.

Uncertainty contribution	Estimated value
Air line deviations from nominal	0.0010
Resistivity	0.0000
Test port match	0.0014
Random effects	0.0017
Overall Combined Uncertainty:	0.0024

A2.4: NMC, A*STAR

Table A2.4.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0015	
Transmission Tracking	0.0219	
Cross Talk	0.0002	
Mismatch	0.0091	
System Repeatability	0.0012	
	0.0238	0.0027
Repeatability		0.0003
Overall Combined Uncertainty:	0.0028	

Table A2.4.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0015	
Transmission Tracking	0.0652	
Cross Talk	0.0001	
Mismatch	0.0108	
System Repeatability	0.0012	
	0.0661	0.0076
Repeatability		0.0001
Overall Combined Uncertainty:	0.0076	

Table A2.4.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0015	
Transmission Tracking	0.0699	
Cross Talk	0.0001	
Mismatch	0.0108	
System Repeatability	0.0012	
	0.0708	0.0082
Repeatability		0.0002
Overall Combined Uncertainty:	0.0082	

Table A2.4.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0015	
Transmission Tracking	0.0725	
Cross Talk	0.0001	
Mismatch	0.0108	
System Repeatability	0.0020	
	0.0733	0.0085
Repeatability		0.0005
Overall Combined Uncertainty:	0.0085	

Table A2.4.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0250	
Transmission Tracking	0.0219	
Cross Talk	0.0025	
Mismatch	0.0091	
System Repeatability	0.0012	
	0.0346	0.0040
Repeatability		0.0000
Overall Combined Uncertainty:	0.0040	

Table A2.4.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0250	
Transmission Tracking	0.0652	
Cross Talk	0.0002	
Mismatch	0.0108	
System Repeatability	0.0012	
	0.0707	0.0082
Repeatability		0.0000
Overall Combined Uncertainty:	0.0082	

Table A2.4.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0250	
Transmission Tracking	0.0699	
Cross Talk	0.0004	
Mismatch	0.0108	
System Repeatability	0.0012	
	0.0750	0.0087
Repeatability		0.0000
Overall Combined Uncertainty:	0.0087	

Table A2.4.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0250	
Transmission Tracking	0.0725	
Cross Talk	0.0004	
Mismatch	0.0108	
System Repeatability	0.0020	
	0.0775	0.0090
Repeatability		0.0001
Overall Combined Uncertainty:	0.0090	

Table A2.4.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0475	
Transmission Tracking	0.0219	
Cross Talk	0.0225	
Mismatch	0.0091	
System Repeatability	0.0012	
	0.0577	0.0067
Repeatability		0.0000
Overall Combined Uncertainty:	0.0067	

Table A2.4.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0475	
Transmission Tracking	0.0652	
Cross Talk	0.0015	
Mismatch	0.0108	
System Repeatability	0.0012	
	0.0814	0.0094
Repeatability		0.0000
Overall Combined Uncertainty:	0.0094	

Table A2.4.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0475	
Transmission Tracking	0.0699	
Cross Talk	0.0032	
Mismatch	0.0108	
System Repeatability	0.0012	
	0.0853	0.0099
Repeatability		0.0000
Overall Combined Uncertainty:	0.0099	

Table A2.4.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value (dB)	Linear
Linearity	0.0475	
Transmission Tracking	0.0725	
Cross Talk	0.0032	
Mismatch	0.0108	
System Repeatability	0.0020	
	0.0874	0.0101
Repeatability		0.0000
Overall Combined Uncertainty:	0.0101	

Table A2.4.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0035
Linearity	0.0015
Reflection Track	0.0001
System Repeatability	0.0015
Repeatability	0.0000
Overall Combined Uncertainty:	0.0041

Table A2.4.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0050
Linearity	0.0015
Reflection Track	0.0001
System Repeatability	0.0015
Repeatability	0.0000
Overall Combined Uncertainty:	0.0054

Table A2.4.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0055
Linearity	0.0015
Reflection Track	0.0001
System Repeatability	0.0016
Repeatability	0.0001
Overall Combined Uncertainty:	0.0059

Table A2.4.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0060
Linearity	0.0020
Reflection Track	0.0001
System Repeatability	0.0020
Repeatability	0.0002
Overall Combined Uncertainty:	0.0066

Table A2.4.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0099
Linearity	0.0005
Reflection Track	0.0005
System Repeatability	0.0015
Repeatability	0.0002
Overall Combined Uncertainty:	0.0100

Table A2.4.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0102
Linearity	0.0005
Reflection Track	0.0005
System Repeatability	0.0015
Repeatability	0.0005
Overall Combined Uncertainty:	0.0103

Table A2.4.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0115
Linearity	0.0005
Reflection Track	0.0005
System Repeatability	0.0016
Repeatability	0.0007
Overall Combined Uncertainty:	0.0117

Table A2.4.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value
Directivity & Source Match	0.0125
Linearity	0.0010
Reflection Track	0.0005
System Repeatability	0.0020
Repeatability	0.0008
Overall Combined Uncertainty:	0.0127

A2.5: UME

Table A2.5.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value
Repetability	4.66E-05
Reproducibility	1.07E-04
Linearity	5.41E-05
Isolation	1.86E-05
Noise	1.37E-04
Mismatch	1.47E-05
Cable flexture	7.09E-04
Overall Combined Uncertainty:	0.00073

Table A2.5.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value
Repetability	4.62E-05
Reproducibility	4.76E-04
Linearity	5.37E-05
Isolation	3.03E-05
Noise	1.60E-04
Mismatch	9.82E-05
Cable flexture	7.04E-04
Overall Combined Uncertainty:	0.00087

Table A2.5.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value
Repetability	2.33E-05
Reproducibility	9.36E-04
Linearity	5.35E-05
Isolation	5.32E-05
Noise	1.84E-04
Mismatch	3.44E-04
Cable flexture	7.01E-04
Overall Combined Uncertainty:	0.0012

Table A2.5.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value
Repetability	9.12E-05
Reproducibility	8.97E-04
Linearity	5.34E-05
Isolation	9.10E-05
Noise	2.23E-04
Mismatch	1.75E-04
Cable flexture	7.00E-04
Overall Combined Uncertainty:	0.0012

Table A2.5.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value
Repetability	9.37E-06
Reproducibility	1.90E-05
Linearity	5.37E-06
Isolation	1.12E-05
Noise	2.82E-05
Mismatch	3.43E-06
Cable flexture	7.06E-05
Overall Combined Uncertainty:	0.000080

Table A2.5.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value
Repetability	4.60E-06
Reproducibility	4.80E-05
Linearity	5.24E-06
Isolation	1.74E-05
Noise	2.58E-05
Mismatch	3.17E-05
Cable flexture	6.87E-05
Overall Combined Uncertainty:	0.000095

Table A2.5.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value
Repetability	9.57E-06
Reproducibility	9.92E-05
Linearity	5.16E-06
Isolation	2.33E-05
Noise	2.34E-05
Mismatch	2.16E-05
Cable flexture	6.77E-05
Overall Combined Uncertainty:	0.00013

Table A2.5.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value
Repetability	1.99E-05
Reproducibility	1.99E-05
Linearity	1.99E-05
Isolation	1.99E-05
Noise	1.99E-05
Mismatch	1.99E-05
Cable flexture	1.99E-05
Overall Combined Uncertainty:	0.00018

Table A2.5.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value
Repetability	5.86E-06
Reproducibility	4.92E-06
Linearity	5.40E-07
Isolation	1.22E-05
Noise	5.46E-06
Mismatch	3.65E-07
Cable flexture	7.08E-06
Overall Combined Uncertainty:	0.000017

Table A2.5.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value
Repetability	3.07E-06
Reproducibility	1.32E-05
Linearity	5.19E-07
Isolation	1.75E-05
Noise	9.27E-06
Mismatch	1.73E-06
Cable flexture	6.81E-06
Overall Combined Uncertainty:	0.000025

Table A2.5.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value
Repetability	9.17E-06
Reproducibility	1.63E-05
Linearity	5.33E-07
Isolation	2.29E-05
Noise	1.13E-05
Mismatch	6.41E-06
Cable flexture	6.98E-06
Overall Combined Uncertainty:	0.000033

Table A2.5.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value
Repetability	1.71E-05
Reproducibility	1.99E-05
Linearity	5.72E-07
Isolation	4.27E-05
Noise	1.82E-05
Mismatch	8.13E-06
Cable flexture	7.51E-06
Overall Combined Uncertainty:	0.000054

Table A2.5.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
Repeatability	5.65E-06
Reproducibility	6.86E-06
Linearity	2.40E-08
Effective uncertainty	1.36E-03
Tracking	2.56E-07
Cable flexure	3.15E-07
Overall Combined Uncertainty:	0.0014

Table A2.5.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
Repeatability	4.07E-06
Reproducibility	2.25E-04
Linearity	5.43E-07
Effective uncertainty	3.30E-03
Tracking	5.80E-06
Cable flexure	7.13E-06
Overall Combined Uncertainty:	0.0033

Table A2.5.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
Repeatability	1.02E-05
Reproducibility	3.80E-04
Linearity	5.66E-07
Effective uncertainty	3.30E-03
Tracking	6.04E-06
Cable flexure	7.43E-06
Overall Combined Uncertainty:	0.0033

Table A2.5.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value
Repeatability	1.15E-05
Reproducibility	6.14E-04
Linearity	1.49E-06
Effective uncertainty	4.89E-03
Tracking	1.59E-05
Cable flexure	1.96E-05
Overall Combined Uncertainty:	0.0049

Table A2.5.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
Repeatability	3.84E-05
Reproducibility	8.54E-05
Linearity	5.41E-05
Effective uncertainty	4.86E-03
Tracking	5.77E-04
Cable flexure	7.09E-04
Overall Combined Uncertainty:	0.0049

Table A2.5.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
Repeatability	1.99E-05
Reproducibility	1.68E-04
Linearity	5.40E-05
Effective uncertainty	1.11E-02
Tracking	5.76E-04
Cable flexure	7.09E-04
Overall Combined Uncertainty:	0.011

Table A2.5.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
Repeatability	3.60E-05
Reproducibility	1.91E-04
Linearity	5.45E-05
Effective uncertainty	1.13E-02
Tracking	5.81E-04
Cable flexure	7.14E-04
Overall Combined Uncertainty:	0.011

Table A2.5.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value
Repeatability	4.50E-05
Reproducibility	2.56E-04
Linearity	5.42E-05
Effective uncertainty	1.27E-02
Tracking	5.78E-04
Cable flexure	7.11E-04
Overall Combined Uncertainty:	0.013

A2.6: NMISA

Table A2.6.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	**Estimated value**	
magnitude	0.999056292	-0.008200813
port 1 match	0.0023	
port 2 match	0.0041	
s11	0.0011	
s22	0.0024	
mismatch	0.0002	
linearity	0.0100	
isolation	0.0001	
ambience	0.0008	
cable flex	0.00100000	
repeatabilty	0.000370	
combined uncertainty	0.0059	
Veff	127936.3703	
coverage factor	2.000021985	
Overall Combined Uncertainty (dB and lin):	0.0118	0.0014
Accredited CMC (dB and lin)	0.015	0.0017

Table A2.6.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value	
magnitude	0.989305741	-0.093389409
port 1 match	0.0023	
port 2 match	0.0041	
s11	0.0041	
s22	0.0060	
mismatch	0.0004	
linearity	0.0100	
isolation	0.0001	
ambience	0.0008	
cable flex	0.001	
repeatabilty	0.000417	
combined uncertainty	0.0059	
Veff	80301.29632	
coverage factor	2.000033577	
Overall Combined Uncertainty (dB and lin):	0.0118	0.0013
Accredited CMC (dB and lin)	0.070	0.0080

Table A2.6.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value	
magnitude	0.989838288	-0.088715025
port 1 match	0.0100	
port 2 match	0.0123	
s11	0.0178	
s22	0.0171	
mismatch	0.0044	
linearity	0.0100	
isolation	0.0001	
ambience	0.0008	
cable flex	0.001	
repeatabilty	0.000579	
combined uncertainty	0.0064	
Veff	30595.81282	
coverage factor	2.00008416	
Overall Combined Uncertainty (dB and lin):	0.0129	0.0015
Accredited CMC (dB and lin)	0.070	0.0080

Table A2.6.4. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	**Estimated value**	
magnitude	0.099505393	-20.04306763
port 1 match	0.0023	
port 2 match	0.0041	
s11	0.0117	
s22	0.0040	
mismatch	0.0004	
linearity	0.0100	
isolation	0.0009	
ambience	0.0008	
cable flex	0.00100000	
repeatabilty	0.002867	
combined uncertainty	0.0066	
Veff	54.87101189	
coverage factor	2.04736751	
Overall Combined Uncertainty (dB and lin):	0.0134	0.0002
Accredited CMC (dB and lin)	0.015	0.0017

Table A2.6.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value	
magnitude	0.09688649	-20.27473556
port 1 match	0.0023	
port 2 match	0.0041	
s11	0.0220	
s22	0.0161	
mismatch	0.0010	
linearity	0.0100	
isolation	0.0009	
ambience	0.0008	
cable flex	0.001	
repeatabilty	0.001267	
combined uncertainty	0.0061	
Veff	1048.302518	
coverage factor	2.002390739	
Overall Combined Uncertainty (dB and lin):	0.0121	0.0001
Accredited CMC (dB and lin)	0.070	0.0080

Table A2.6.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value	
magnitude	0.095681712	-20.38342121
port 1 match	0.0100	
port 2 match	0.0123	
s11	0.0211	
s22	0.0228	
mismatch	0.0043	
linearity	0.0100	
isolation	0.0009	
ambience	0.0008	
cable flex	0.001	
repeatabilty	0.001894	
combined uncertainty	0.0067	
Veff	307.4564297	
coverage factor	2.008178385	
Overall Combined Uncertainty (dB and lin):	0.0134	0.0001
Accredited CMC (dB and lin)	0.070	0.0080

Table A2.6.7. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	**Estimated value**	
magnitude	0.009982014	-40.01563658
port 1 match	0.0023	
port 2 match	0.0041	
s11	0.0082	
s22	0.0097	
mismatch	0.0005	
linearity	0.0100	
isolation	0.0087	
ambience	0.0008	
cable flex	0.00100000	
repeatabilty	0.001162	
combined uncertainty	0.0078	
Veff	4095.102986	
coverage factor	2.000613129	
Overall Combined Uncertainty (dB and lin):	0.0156	0.0000
Accredited CMC (dB and lin)	0.015	0.0000

Table A2.6.8. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value	
magnitude	0.009617086	-40.33912978
port 1 match	0.0023	
port 2 match	0.0041	
s11	0.0116	
s22	0.0065	
mismatch	0.0005	
linearity	0.0100	
isolation	0.0087	
ambience	0.0008	
cable flex	0.001	
repeatabilty	0.001534	
combined uncertainty	0.0079	
Veff	1392.158173	
coverage factor	2.001800008	
Overall Combined Uncertainty (dB and lin):	0.0158	0.0000
Accredited CMC (dB and lin)	0.070	0.0001

Table A2.6.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value	
magnitude	0.009915165	-40.07400085
port 1 match	0.0100	
port 2 match	0.0123	
s11	0.0352	
s22	0.0407	
mismatch	0.0074	
linearity	0.0100	
isolation	0.0087	
ambience	0.0008	
cable flex	0.001	
repeatabilty	0.008455	
combined uncertainty	0.0122	
Veff	8.735882718	
coverage factor	2.3664195	
Overall Combined Uncertainty (dB and lin):	0.0289	0.0000
Accredited CMC (dB and lin)	0.070	0.0001

Table A2.6.10. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
	x
magnitude	0.0050
measured directivity (dir)	0.0044
measured test port match (TPM)	0.0023
correlated (dir & TPM)	0.0044
linearity	0.0010
other (cable, ambience, noise)	0.0007
repeatability	0.0000213
combined unc	0.00324099
Veff	1064562405.55
coverage factor	2.0000
Overall Combined Uncertainty:	0.0065
Accredited CMC	0.006 + 0.006 *ρ^2

Table A2.6.11. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
	x
magnitude	0.0088
measured directivity (dir)	0.0044
measured test port match (TPM)	0.0032
correlated (dir & TPM)	0.0044
linearity	0.0010
other (cable, ambience, noise)	0.0007
repeatability	0.0000109
combined unc	0.00324107
Veff	15502895252.49
coverage factor	2.0000
Overall Combined Uncertainty:	0.0065
Accredited CMC	0.006 + 0.006 *ρ^2

able A2.6.12. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
	x
magnitude	0.0093
measured directivity (dir)	0.0059
measured test port match (TPM)	0.0100
correlated (dir & TPM)	0.0059
linearity	0.0010
other (cable, ambience, noise)	0.0007
repeatability	0.0001822
combined unc	0.00427395
Veff	605932.80
coverage factor	2.0000
Overall Combined Uncertainty:	0.0085
Accredited CMC	0.006 + 0.006 *ρ^2

Table A2.6.13. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
	x
magnitude	0.9990
measured directivity (dir)	0.0037
measured test port match (TPM)	0.0041
correlated (dir & TPM)	0.0078
linearity	0.0010
other (cable, ambience, noise)	0.0007
repeatability	0.0008634
combined unc	0.00565048
Veff	3669.18
coverage factor	2.0007
Overall Combined Uncertainty:	0.0113
Accredited CMC	0.006 + 0.006 *ρ^2

Table A2.6.14. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
	x
magnitude	1.0022
measured directivity (dir)	0.0037
measured test port match (TPM)	0.0041
correlated (dir & TPM)	0.0078
linearity	0.0010
other (cable, ambience, noise)	0.0007
repeatability	0.0002150
combined unc	0.00560654
Veff	925468.08
coverage factor	2.0000
Overall Combined Uncertainty:	0.0112
Accredited CMC	0.006 + 0.006 *ρ^2

Table A2.6.15. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
	x
magnitude	1.0073
measured directivity (dir)	0.0080
measured test port match (TPM)	0.0123
correlated (dir & TPM)	0.0205
linearity	0.0010
other (cable, ambience, noise)	0.0007
repeatability	0.0009530
combined unc	0.01454222
Veff	108458.22
coverage factor	2.0000
Overall Combined Uncertainty:	0.0291
Accredited CMC	0.006 + 0.006 *ρ^2

A2.7: NRC

Table A2.7.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeat	0.0141
Overall Combined Uncertainty:	0.0144

Table A2.7.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeat	0.0141
Overall Combined Uncertainty:	0.0144

Table A2.7.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeat	0.0141
Overall Combined Uncertainty:	0.0144

Table A2.7.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeat	0.0141
Overall Combined Uncertainty:	0.0144

Table A2.7.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0046

Table A2.7.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0046

Table A2.7.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0046

Table A2.7.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0046

Table A2.7.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0045

Table A2.7.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0045

Table A2.7.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0045

Table A2.7.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value
Linearity/Noise	0.0006
Cable Flexure	0.0020
Connector repeat.	0.001000
Reference std.	0.001400
System repeatability	0.0035
Overall Combined Uncertainty:	0.0045

Table A2.7.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System Repeatability	0.0035
Cable Flex.	0.0020
Reference Load	0.001400
Overall Combined Uncertainty:	0.0067

Table A2.7.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System Repeatability	0.0035
Cable Flex.	0.0020
Reference Load	0.001400
Overall Combined Uncertainty:	0.0067

Table A2.7.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System Repeatability	0.0070
Cable Flex.	0.0040
Reference Load	0.001400
Overall Combined Uncertainty:	0.0097

Table A2.7.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System Repeatability	0.0210
Cable Flex.	0.0060
Reference Load	0.001400
Overall Combined Uncertainty:	0.0230

Table A2.7.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System repeatability	0.0140
Cable Flexure	0.002000
Reference	0.001400
Overall Combined Uncertainty:	0.0150

Table A2.7.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System repeatability	0.0140
Cable Flexure	0.002000
Reference	0.001400
Overall Combined Uncertainty:	0.0150

Table A2.7.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0050
System repeatability	0.0140
Cable Flexure	0.0020
Reference	0.001400
Overall Combined Uncertainty:	0.0150

Table A2.7.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value
Directivity	0.0120
System repeatability	0.0140
Cable Flexure	0.0060
Reference	0.002800
Overall Combined Uncertainty:	0.0219

A2.8: SNIIM

Table A2.8.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.001500
Cable Stability	0.001211
Connector Repeatability	0.000354
VNA Drift	0.000005
VNA Linearity	0.000209
VNA Noise	0.000014
Overall Combined Uncertainty:	0.003292

Table A2.8.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.002449
Cable Stability	0.001977
Connector Repeatability	0.000578
VNA Drift	0.000008
VNA Linearity	0.000341
VNA Noise	0.000022
Overall Combined Uncertainty:	0.005376

Table A2.8.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.002087
Cable Stability	0.001684
Connector Repeatability	0.000492
VNA Drift	0.000006
VNA Linearity	0.000290
VNA Noise	0.000019
Overall Combined Uncertainty:	0.004579

Table A2.8.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.003291
Cable Stability	0.002656
Connector Repeatability	0.000777
VNA Drift	0.000010
VNA Linearity	0.000458
VNA Noise	0.000030
Overall Combined Uncertainty:	0.007222

Table A2.8.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.000064
Cable Stability	0.000157
Connector Repeatability	0.000030
VNA Drift	0.000000
VNA Linearity	0.000023
VNA Noise	0.000003
Overall Combined Uncertainty:	0.000276

Table A2.8.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.000103
Cable Stability	0.000255
Connector Repeatability	0.000048
VNA Drift	0.000001
VNA Linearity	0.000037
VNA Noise	0.000004
Overall Combined Uncertainty:	0.000449

Table A2.8.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.000108
Cable Stability	0.000267
Connector Repeatability	0.000050
VNA Drift	0.000001
VNA Linearity	0.000039
VNA Noise	0.000004
Overall Combined Uncertainty:	0.000470

Table A2.8.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.000179
Cable Stability	0.000439
Connector Repeatability	0.000083
VNA Drift	0.000001
VNA Linearity	0.000065
VNA Noise	0.000007
Overall Combined Uncertainty:	0.000774

Table A2.8.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.000448
Cable Stability	0.000643
Connector Repeatability	0.000349
VNA Drift	0.000011
VNA Linearity	0.000426
VNA Noise	0.001415
Overall Combined Uncertainty:	0.003292

Table A2.8.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.002449
Cable Stability	0.001977
Connector Repeatability	0.000578
VNA Drift	0.000008
VNA Linearity	0.000341
VNA Noise	0.000022
Overall Combined Uncertainty:	0.005376

Table A2.8.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.002087
Cable Stability	0.001684
Connector Repeatability	0.000492
VNA Drift	0.000006
VNA Linearity	0.000290
VNA Noise	0.000019
Overall Combined Uncertainty:	0.004579

Table A2.8.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.003291
Cable Stability	0.002656
Connector Repeatability	0.000777
VNA Drift	0.000010
VNA Linearity	0.000458
VNA Noise	0.000030
Overall Combined Uncertainty:	0.007222

Table A2.8.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.001155
Cable Stability	0.000013
Connector Repeatability	0.000210
VNA Drift	0.000000
VNA Linearity	0.000000
VNA Noise	0.000021
Overall Combined Uncertainty:	0.001400

Table A2.8.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.002145
Cable Stability	0.000024
Connector Repeatability	0.000391
VNA Drift	0.000000
VNA Linearity	0.000001
VNA Noise	0.000039
Overall Combined Uncertainty:	0.002600

Table A2.8.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.003301
Cable Stability	0.000036
Connector Repeatability	0.000601
VNA Drift	0.000000
VNA Linearity	0.000001
VNA Noise	0.000060
Overall Combined Uncertainty:	0.004000

Table A2.8.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.004621
Cable Stability	0.000051
Connector Repeatability	0.000842
VNA Drift	0.000001
VNA Linearity	0.000002
VNA Noise	0.000084
Overall Combined Uncertainty:	0.005600

Table A2.8.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.002145
Cable Stability	0.000024
Connector Repeatability	0.000391
VNA Drift	0.000000
VNA Linearity	0.000001
VNA Noise	0.000039
Overall Combined Uncertainty:	0.002600

Table A2.8.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.005446
Cable Stability	0.000060
Connector Repeatability	0.000992
VNA Drift	0.000001
VNA Linearity	0.000002
VNA Noise	0.000099
Overall Combined Uncertainty:	0.006600

Table A2.8.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.008994
Cable Stability	0.000099
Connector Repeatability	0.001638
VNA Drift	0.000001
VNA Linearity	0.000003
VNA Noise	0.000164
Overall Combined Uncertainty:	0.010900

Table A2.8.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value
Calibration Standard	0.011057
Cable Stability	0.000122
Connector Repeatability	0.002014
VNA Drift	0.000001
VNA Linearity	0.000004
VNA Noise	0.000202
Overall Combined Uncertainty:	0.013400

A2.9: CMI

Table A2.9.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	re	im
cal. standards	0.00000	0.00000
trace noise	0.00023	0.00021
connectors	0.00004	0.00000
drift	0.00000	0.00002
overall repeatability	0.00010	0.00005
Overall Combined Uncertainty:	0.00025	0.00022

Table A2.9.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	re	im
cal. standards	0.00050	0.00050
trace noise	0.00021	0.00022
connectors	0.00039	0.00021
drift	0.00196	0.00096
overall repeatability	0.00063	0.00031
Overall Combined Uncertainty:	0.00217	0.00117

Table A2.9.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

	Estimated value	
	re	im
cal. standards	0.00107	0.00108
trace noise	0.00023	0.00021
connectors	0.00017	0.00091
drift	0.00046	0.00463
overall repeatability	0.00044	0.00160
Overall Combined Uncertainty:	0.00127	0.00510

Table A2.9.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value	
	re	im
cal. standards	0.00133	0.00133
trace noise	0.00022	0.00022
connectors	0.00085	0.00077
drift	0.00429	0.00387
overall repeatability	0.00167	0.00151
Overall Combined Uncertainty:	0.00487	0.00444

Table A2.9.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000231	0.000231
noise and isolation	0.000007	0.000007
connector (cal./meas.)	0.000004	0.000000
cable flexure (cal./meas.)	0.000018	0.000002
mismatch	0.000003	0.000003
overall repeatability	0.000019	0.000009
Overall Combined Uncertainty:	0.00023	0.00023

Table A2.9.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000227	0.000227
noise and isolation	0.000007	0.000007
connector (cal./meas.)	0.000027	0.000034
cable flexure (cal./meas.)	0.000115	0.000143
mismatch	0.000010	0.000010
overall repeatability	0.000021	0.000042
Overall Combined Uncertainty:	0.00026	0.00027

Table A2.9.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000227	0.000227
noise and isolation	0.000018	0.000018
connector (cal./meas.)	0.000018	0.000089
cable flexure (cal./meas.)	0.000078	0.000379
mismatch	0.000012	0.000012
overall repeatability	0.000013	0.000109
Overall Combined Uncertainty:	0.00024	0.00046

Table A2.9.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000231	0.000231
noise and isolation	0.000018	0.000018
connector (cal./meas.)	0.000114	0.000026
cable flexure (cal./meas.)	0.000484	0.000114
mismatch	0.000026	0.000026
overall repeatability	0.000117	0.000091
Overall Combined Uncertainty:	0.00056	0.00028

Table A2.9.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000047	0.000047
noise and isolation	0.000007	0.000007
connector (cal./meas.)	0.000000	0.000000
cable flexure (cal./meas.)	0.000002	0.000000
mismatch	0.000000	0.000000
overall repeatability	0.000004	0.000004
Overall Combined Uncertainty:	0.000048	0.000048

Table A2.9.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000046	0.000046
noise and isolation	0.000007	0.000007
connector (cal./meas.)	0.000001	0.000004
cable flexure (cal./meas.)	0.000004	0.000018
mismatch	0.000000	0.000000
overall repeatability	0.000002	0.000011
Overall Combined Uncertainty:	0.000046	0.000051

Table A2.9.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000046	0.000046
noise and isolation	0.000018	0.000018
connector (cal./meas.)	0.000008	0.000005
cable flexure (cal./meas.)	0.000034	0.000020
mismatch	0.000002	0.000002
overall repeatability	0.000023	0.000008
Overall Combined Uncertainty:	0.000065	0.000054

Table A2.9.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value	
	re	im
test set linearity	0.000049	0.000049
noise and isolation	0.000018	0.000018
connector (cal./meas.)	0.000003	0.000012
cable flexure (cal./meas.)	0.000012	0.000052
mismatch	0.000002	0.000002
overall repeatability	0.000014	0.000026
Overall Combined Uncertainty:	0.000055	0.000079

Table A2.9.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference line	0.00142	0.00142
connectors	0.00016	0.00016
overall repeatability	0.00026	0.00021
Overall Combined Uncertainty:	0.00145	0.00144

Table A2.9.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference line	0.00068	0.00068
connectors	0.00056	0.00056
overall repeatability	0.00010	0.00039
Overall Combined Uncertainty:	0.00089	0.00097

Table A2.9.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference line	0.00110	0.00110
connectors	0.00101	0.00101
overall repeatability	0.00168	0.00107
Overall Combined Uncertainty:	0.00225	0.00184

Table A2.9.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference line	0.00135	0.00135
connectors	0.00122	0.00122
overall repeatability	0.00179	0.00201
Overall Combined Uncertainty:	0.00255	0.00271

Table A2.9.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference short	0.00006	0.00001
trace noise	0.00023	0.00021
connectors	0.00004	0.00000
drift	0.00000	0.00001
overall repeatability	0.00005	0.00017
Overall Combined Uncertainty:	0.00025	0.00027

Table A2.9.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference short	0.00069	0.00164
trace noise	0.00023	0.00021
connectors	0.00009	0.00043
drift	0.00000	0.00126
overall repeatability	0.00019	0.00098
Overall Combined Uncertainty:	0.00076	0.00234

Table A2.9.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference short	0.00101	0.00350
trace noise	0.00023	0.00021
connectors	0.00015	0.00092
drift	0.00001	0.00269
overall repeatability	0.00049	0.00265
Overall Combined Uncertainty:	0.00115	0.00523

Table A2.9.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value	
	re	im
reference short	0.00112	0.00436
trace noise	0.00023	0.00021
connectors	0.00017	0.00115
drift	0.00002	0.00335
overall repeatability	0.00075	0.00378
Overall Combined Uncertainty:	0.00138	0.00677

A2.10: INRIM

Table A2.10.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.002454957	0.005036843
Calibration Standard	0.000014985	0.000014713
VNA Drift	0.000003690	
VNA Linearity	0.000325428	0.000320706
VNA Noise	0.000084154	0.000088745
Overall Combined Uncertainty:	0.002477910	0.005047844

Table A2.10.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.016657615	0.008525621
Calibration Standard	0.000535363	0.000535363
Connector Repeatability		0.000020535
VNA Drift	0.000046980	0.000035221
VNA Linearity	0.000318667	0.000321510
VNA Noise	0.000162854	0.000121765
Overall Combined Uncertainty:	0.016670123	0.008549426

Table A2.10.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

	Estimated value	
	Re	Im
Cable Stability	0.003961025	0.033841556
Calibration Standard	0.000233130	0.000230039
Connector Repeatability	0.000012565	
VNA Drift	0.000176950	
VNA Linearity	0.000321055	0.000314976
VNA Noise	0.000127313	0.000589490
Overall Combined Uncertainty:	0.003986831	0.033848937

Table A2.10.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.030218391	0.027704642
Calibration Standard	0.002194742	0.002194742
Connector Repeatability	0.000179222	0.000179222
VNA Drift	0.000242837	
VNA Linearity	0.000317109	0.000317470
VNA Noise	0.000505166	0.000469082
Overall Combined Uncertainty:	0.030305360	0.027797788

Table A2.10.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.000246267	0.000503795
Calibration Standard	0.000011498	0.000011495
VNA Drift	0.000001589	0.000001156
VNA Linearity	0.000032972	0.000032522
VNA Noise	0.000013000	0.000013297
Overall Combined Uncertainty:	0.000249075	0.000505150

Table A2.10.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.001145756	0.001438581
Calibration Standard	0.000050345	0.000050345
VNA Drift	0.000002772	0.000005236
VNA Linearity	0.000032310	0.000032212
VNA Noise	0.000013457	0.000014988
Overall Combined Uncertainty:	0.001147399	0.001439910

Table A2.10.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

	Estimated value	
	Re	Im
Cable Stability	0.000484059	0.003315885
Calibration Standard	0.000052157	0.000052087
Connector Repeatability	0.000003731	
VNA Drift	0.000017289	0.000006674
VNA Linearity	0.000032869	0.000032221
VNA Noise	0.000013780	0.000058051
Overall Combined Uncertainty:	0.000488484	0.003316966

Table A2.10.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.004081005	0.000807623
Calibration Standard	0.000216072	0.000216108
Connector Repeatability	0.000021724	0.000022913
VNA Drift	0.000033268	0.000029493
VNA Linearity	0.000033323	0.000033708
VNA Noise	0.000068540	0.000016740
Overall Combined Uncertainty:	0.004087625	0.000837716

Table A2.10.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.000025246	0.000051569
Calibration Standard	0.000000837	0.000000837
VNA Drift	0.000001562	0.000001560
VNA Linearity	0.000003774	0.000003754
VNA Noise	0.000009984	0.000009989
Overall Combined Uncertainty:	0.000027467	0.000052691

Table A2.10.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.000030250	0.000182945
Calibration Standard	0.000003319	0.000003319
Connector Repeatability	0.000000089	
VNA Drift	0.000003181	0.000003153
VNA Linearity	0.000003622	0.000003603
VNA Noise	0.000001986	0.000002409
Overall Combined Uncertainty:	0.000030875	0.000183054

Table A2.10.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

	Estimated value	
	Re	Im
Cable Stability	0.000296941	0.000172741
Calibration Standard	0.000006315	0.000006315
VNA Drift	0.000005538	0.000005548
VNA Linearity	0.000003658	0.000003668
VNA Noise	0.000006504	0.000004967
Overall Combined Uncertainty:	0.000297153	0.000173056

Table A2.10.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.000084830	0.000437646
Calibration Standard	0.000023512	0.000023507
Connector Repeatability	0.000001032	0.000000679
VNA Drift	0.000026448	0.000026514
VNA Linearity	0.000003952	0.000003932
VNA Noise	0.000003495	0.000007911
Overall Combined Uncertainty:	0.000092073	0.000439168

Table A2.10.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Calibration Standard	0.002505929	0.002505929
Connector Repeatability	0.000028124	0.000028124
VNA Linearity	0.000008703	0.000008706
VNA Noise	0.000014088	0.000014088
Overall Combined Uncertainty:	0.002506141	0.002506141

Table A2.10.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Calibration Standard	0.003155550	0.003155550
Connector Repeatability	0.000223615	0.000223615
VNA Linearity	0.000018374	0.000018959
VNA Noise	0.000007874	0.000004735
Overall Combined Uncertainty:	0.003163526	0.003163523

Table A2.10.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Calibration Standard	0.003155904	0.003155904
Connector Repeatability	0.000500576	0.000500576
VNA Linearity	0.000041263	0.000037392
VNA Noise	0.000043679	0.000060416
Overall Combined Uncertainty:	0.003195922	0.003196147

Table A2.10.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Calibration Standard	0.004999847	0.004999847
Connector Repeatability	0.000561654	0.000561654
Overall Combined Uncertainty:	0.005031295	0.005031295

Table A2.10.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.003453751	0.007138136
Calibration Standard	0.000251022	0.000250966
Connector Repeatability	0.000112247	0.000112154
VNA Drift	0.000007229	
VNA Linearity	0.000312528	0.000307899
VNA Noise	0.000080702	0.000085281
Overall Combined Uncertainty:	0.003479691	0.007150568

Table A2.10.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.003462216	0.026504107
Calibration Standard	0.013355869	0.013355869
Connector Repeatability	0.004399558	0.004399530
VNA Drift	0.000077104	0.000093788
VNA Linearity	0.000328153	0.000325919
VNA Noise	0.000127362	0.000162113
Overall Combined Uncertainty:	0.014486274	0.030005734

Table A2.10.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.003495224	0.049173261
Calibration Standard	0.018183153	0.018183153
Connector Repeatability	0.011008058	0.011008058
VNA Drift	0.000404974	0.000220531
VNA Linearity	0.000324535	0.000322076
VNA Noise	0.000316932	0.000523012
Overall Combined Uncertainty:	0.021549727	0.053574620

Table A2.10.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value	
	Re	Im
Cable Stability	0.003610049	0.058642838
Calibration Standard	0.022125424	0.022125424
Connector Repeatability	0.009247966	0.009247966
VNA Drift	0.000061603	0.000609295
VNA Linearity	0.000361064	0.000355697
VNA Noise	0.000224804	0.000737708
Overall Combined Uncertainty:	0.024254411	0.063364688

A2.11: PTB

Table A2.11.1. Example of uncertainty contributions for reflection measurements (S11 and S22), ex. S11=1 when S12=S21=0, at 26.5 GHz.

Uncertainty Contribution	Typical values (expressed as standard uncertainties)	Distribution	Contributions	Divisor	S11 uncertainty
TRL line standard (δSii)	0.003	Standard	f(S11, Γ, $e^{-\gamma l}$)	1	0.0030
Calibration repeatability	0.005	U-shape	1	√2	0.0036
Noise floor	0.001	Standard	1	√N, N=6	0.00041
Connection Repeatability	0.001	Standard	1	√N, N=6	0.00041
	Combined Standard uncertainty				0.0047
	Expanded uncertainty (k=2)				0.0095

Table A2.11.2. Example of uncertainty contributions for transmission measurements (S21 and S12), ex. S21=1, at 26.5 GHz.

Uncertainty Contribution	Typical values (expressed as standard uncertainties)	Distribution	Contributions	Divisor	S21 uncertainty
TRL line standard (δSii)	0.003	Standard	f(S11, S22, $e^{-\gamma l}$)	1	0.0030
Calibration repeatability	0.005	Standard	1	√N, N=6	0.0021

Test set linearity	0.003	Uninform	S21	√3	0.0017
Test set isolation	0.003	Uniform	1	√3	0.0017
	Combined Standard uncertainty				0.0044
	Expanded uncertainty (k=2)				0.0088

A2.12: SP

Table A2.12.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000040000
Reference frequency error	0.000000270
Isolation	0.000000660
Linearity	0.000600000
Residual match male	0.000001400
Residual match female	0.000002200
Repeatability	0.000083000
Residual tracking	0.000140000
Overall Combined Uncertainty:	0.000620000

Table A2.12.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000380000
Reference frequency error	0.000033000
Isolation	0.000000099
Linearity	0.000600000
Residual match male	0.000013000
Residual match female	0.000021000
Repeatability	0.000530000
Residual tracking	0.000710000
Overall Combined Uncertainty:	0.001100000

Table A2.12.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000760000
Reference frequency error	0.000069000
Isolation	0.000000200
Linearity	0.000590000
Residual match male	0.000150000
Residual match female	0.000150000
Repeatability	0.000780000
Residual tracking	0.001500000
Overall Combined Uncertainty:	0.002000000

Table A2.12.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000930000
Reference frequency error	0.000086000
Isolation	0.000000340
Linearity	0.000590000
Residual match male	0.000043000
Residual match female	0.000088000
Repeatability	0.000870000
Residual tracking	0.001500000
Overall Combined Uncertainty:	0.002100000

Table A2.12.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000004000
Reference frequency error	0.000000027
Isolation	0.000000660
Linearity	0.000060000
Residual match male	0.000002200
Residual match female	0.000001500
Repeatability	0.000013000
Residual tracking	0.000014000
Overall Combined Uncertainty:	0.000063000

Table A2.12.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000037000
Reference frequency error	0.000003200
Isolation	0.000000099
Linearity	0.000059000
Residual match male	0.000013000
Residual match female	0.000016000
Repeatability	0.000042000
Residual tracking	0.000070000
Overall Combined Uncertainty:	0.000110000

Table A2.12.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000074000
Reference frequency error	0.000006800
Isolation	0.000000200
Linearity	0.000058000
Residual match male	0.000033000
Residual match female	0.000015000
Repeatability	0.000061000
Residual tracking	0.000150000
Overall Combined Uncertainty:	0.000190000

Table A2.12.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000095000
Reference frequency error	0.000008800
Isolation	0.000000340
Linearity	0.000060000
Residual match male	0.000079000
Residual match female	0.000051000
Repeatability	0.000074000
Residual tracking	0.000160000
Overall Combined Uncertainty:	0.000230000

Table A2.12.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000000410
Reference frequency error	0.000000003
Isolation	0.000000660
Linearity	0.000006100
Residual match male	0.000000160
Residual match female	0.000000120
Repeatability	0.000013000
Residual tracking	0.000001400
Overall Combined Uncertainty:	0.000014000

Table A2.12.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000003700
Reference frequency error	0.000000320
Isolation	0.000000099
Linearity	0.000005900
Residual match male	0.000000650
Residual match female	0.000000380
Repeatability	0.000004800
Residual tracking	0.000007100
Overall Combined Uncertainty:	0.000011000

Table A2.12.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000007600
Reference frequency error	0.000000700
Isolation	0.000000200
Linearity	0.000006000
Residual match male	0.000004100
Residual match female	0.000003900
Repeatability	0.000007900
Residual tracking	0.000016000
Overall Combined Uncertainty:	0.000021000

Table A2.12.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value
Cable flex	0.000010000
Reference frequency error	0.000000940
Isolation	0.000000340
Linearity	0.000006500
Residual match male	0.000004600
Residual match female	0.000003500
Repeatability	0.000018000
Residual tracking	0.000017000
Overall Combined Uncertainty:	0.000028000

Table A2.12.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.00350000
Residual tracking	0.00000005
Residual match	0.00000000
Cable flex	0.00000000
Reference frequency error	0.00000000
Linearity	0.00000022
Repeatability	0.00000790
Overall Combined Uncertainty:	0.00350000

Table A2.12.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.00580000
Residual tracking	0.00000300
Residual match	0.00000010
Cable flex	0.00000000
Reference frequency error	0.00000001
Linearity	0.00000250
Repeatability	0.00002400
Overall Combined Uncertainty:	0.00580000

Table A2.12.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.00880000
Residual tracking	0.00001400
Residual match	0.00000070
Cable flex	0.00000000
Reference frequency error	0.00000004
Linearity	0.00000530
Repeatability	0.00007100
Overall Combined Uncertainty:	0.00880000

Table A2.12.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.01000000
Residual tracking	0.00001600
Residual match	0.00000110
Cable flex	0.00000000
Reference frequency error	0.00000006
Linearity	0.00000610
Repeatability	0.00012000
Overall Combined Uncertainty:	0.01000000

Table A2.12.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.003500000
Residual tracking	0.000140000
Residual match	0.003600000
Cable flex	0.000000000
Reference frequency error	0.000000000
Linearity	0.000600000
Repeatability	0.000025000
Overall Combined Uncertainty:	0.007100000

Table A2.12.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.005800000
Residual tracking	0.000720000
Residual match	0.006000000
Cable flex	0.000000000
Reference frequency error	0.000000000
Linearity	0.000600000
Repeatability	0.000150000
Overall Combined Uncertainty:	0.012000000

Table A2.12.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.009100000
Residual tracking	0.001600000
Residual match	0.009000000
Cable flex	0.000000000
Reference frequency error	0.000000000
Linearity	0.000600000
Repeatability	0.000340000
Overall Combined Uncertainty:	0.018000000

Table A2.12.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value
Residual directivity	0.010000000
Residual tracking	0.001600000
Residual match	0.010000000
Cable flex	0.000000000
Reference frequency error	0.000000000
Linearity	0.000600000
Repeatability	0.000440000
Overall Combined Uncertainty:	0.021000000

A2.13: VSL

Table A2.13.1. Uncertainty in one-port reflection measurements for a matched termination with female connector (With $S_{11}(x) = 0.005$, $S_{11}(y) = 0.005$) at 33 GHz.

Uncertainty Contribution **S_{11}(x-part)**	Estimate	Uncertainty for $\lvert x \rvert = 0.005$ $\lvert y \rvert = 0.005$	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0014	0.0000			
Sum of correlated quantities		0.0020	U-shaped	□2	0.0014
Tracking	0.0002	0.0000	rectangular	□3	0.0000
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0002	0.0000	gaussian	2	0.0000
Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0014
Expanded Uncertainty (k = 2)					0.0028

Uncertainty Contribution **S_{11}(y-part)**	Estimate	Uncertainty for $\lvert x \rvert = 0.005$ $\lvert y \rvert = 0.005$	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0015	0.0000			
Sum of correlated quantities		0.0020	U-shaped	□2	0.0014
Tracking	0.0002	0.0000	rectangular	□3	0.0000
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0002	0.0000	gaussian	2	0.0000

Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0014
Expanded Uncertainty (k = 2)					0.0028

Table A2.13.2. Uncertainty in one-port reflection measurements for a short termination with female connector (With $S_{11}(x) = -0.9999$, $S_{11}(y) = 0.0150$) at 33 GHz.

Uncertainty Contribution **S_{11}(x-part)**	Estimate	Uncertainty for $\lvert x \rvert = -0.9999$ $\lvert y \rvert = 0.0150$	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0022	0.0022			
Sum of correlated quantities		0.0042	U-shaped	$\sqrt{2}$	0.0030
Tracking	0.0001	0.0001	rectangular	$\sqrt{3}$	0.0001
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0001	0.0001	gaussian	2	0.0001
Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0030
Expanded Uncertainty (k = 2)					0.0060

Uncertainty Contribution **S_{11}(y-part)**	Estimate	Uncertainty for $\lvert x \rvert = -0.9999$ $\lvert y \rvert = 0.0150$	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0115	0.0115			
Sum of correlated quantities		0.0135	U-shaped	$\sqrt{2}$	0.0096
Tracking	0.0002	0.0002	rectangular	$\sqrt{3}$	0.0001

System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0002	0.0002	gaussian	2	0.0001
Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0096
Expanded Uncertainty (*k* = 2)					0.0191

Table A2.13.3. Uncertainty in transmission measurement for a 20 dB attenuator ($S_{21}(x)$ = -0.017135 , $S_{21}(y)$ = -0.098728 with $|S_{11}|$ = 0.050 and $|S_{22}|$ = 0.050) at 33 GHz.

Uncertainty Contribution S_{21}(x-part)	Estimate	Uncertainty	Distribution	Divisor	Standard Uncertainty
Linearity	0.000194	0.000194	gaussian	□2	0.000137
Mismatch calculated		0.000021	gaussian	□2	0.000015
Cross-talk	0.000006	0.000006	rectangular	□3	0.000004
Noise	0.000039	0.000039	gaussian	2	0.000020
Cable Flexure	0.001274	0.001274	gaussian	□2	0.000901
Connector Repeatability	0.000100	0.000000	gaussian	*2*	0.000050
Combined Standard Uncertainty					0.000913
Expanded Uncertainty (*k* = 2)					0.001826

Uncertainty Contribution S_{21}(y-part)	Estimate	Uncertainty	Distribution	Divisor	Standard Uncertainty
Linearity	0.000194	0.000194	gaussian	□2	0.000137
Mismatch calculated		0.000021	gaussian	□2	0.000015
Cross-talk	0.000008	0.000008	rectangular	□3	0.000004
Noise	0.000039	0.000039	gaussian	2	0.000020

Cable Flexure	0.000112	0.000112	gaussian	□2	0.000079
Connector Repeatability	0.000100	0.050000	gaussian	*2*	0.000050
Combined Standard Uncertainty					0.000168
Expanded Uncertainty (k = 2)					0.000336

A2.14: LNE

Table A2.14.1. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0
Mismatch	0.000779982
Isolation	0.000223998
Noise	0.001
Cable	0.0005
Ambient conditions	0.00057735
Connector	0.0005
Overall Combined Uncertainty:	0.001578569

Table A2.14.2. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0
Mismatch	0.001584461
Isolation	0.000251329
Noise	0.002
Cable	0.0015
Ambient conditions	0.00057735
Connector	0.0015
Overall Combined Uncertainty:	0.003377427

Table A2.14.3. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 26.5 GHz.

Uncertainty contribution	Estimated value
Linearity	0
Mismatch	0.001903765
Isolation	0.000281995
Noise	0.0025
Cable	0.002
Ambient conditions	0.00057735
Connector	0.002
Overall Combined Uncertainty:	0.004276351

Table A2.14.4. Uncertainty budget in S_{21} measurement of K5c.CL/1 at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0
Mismatch	0.001903765
Isolation	0.000316403
Noise	0.0025
Cable	0.002
Ambient conditions	0.00057735
Connector	0.002
Overall Combined Uncertainty:	0.004278757

Table A2.14.5. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.015
Mismatch	0.000773847
Isolation	0.007078596
Noise	0.001
Cable	0.0005
Ambient conditions	0.00057735
Connector	0.0005
Overall Combined Uncertainty:	0.016659493

Table A2.14.6. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.015
Mismatch	0.001559924
Isolation	0.007941632
Noise	0.002
Cable	0.0005
Ambient conditions	0.00057735
Connector	0.0015
Overall Combined Uncertainty:	0.01724344

Table A2.14.7. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 26.5 GHz.

Uncertainty contribution	Estimated value
Linearity	0.015
Mismatch	0.001873096
Isolation	0.008909797
Noise	0.0025
Cable	0.002
Ambient conditions	0.00057735
Connector	0.002
Overall Combined Uncertainty:	0.017957625

Table A2.14.8. Uncertainty budget in S_{21} measurement of K5c.CL/2 at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.015
Mismatch	0.001873096
Isolation	0.009995874
Noise	0.0025
Cable	0.002
Ambient conditions	0.00057735
Connector	0.002
Overall Combined Uncertainty:	0.018520511

Table A2.14.9. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 0.1 GHz.

Uncertainty contribution	Estimated value
Linearity	0.025
Mismatch	0.000773841
Isolation	0.070340313
Noise	0.001
Cable	0.0005
Ambient conditions	0.00057735
Connector	0.0005
Overall Combined Uncertainty:	0.074667207

Table A2.14.10. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 12.4 GHz.

Uncertainty contribution	Estimated value
Linearity	0.025
Mismatch	0.0015599
Isolation	0.078855981
Noise	0.002
Cable	0.0015
Ambient conditions	0.00057735
Connector	0.0015
Overall Combined Uncertainty:	0.082792104

Table A2.14.11. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 26.5 GHz.

Uncertainty contribution	Estimated value
Linearity	0.025
Mismatch	0.001873066
Isolation	0.088393536
Noise	0.0025
Cable	0.002
Ambient conditions	0.00057735
Connector	0.002
Overall Combined Uncertainty:	0.091959278

Table A2.14.12. Uncertainty budget in S_{21} measurement of K5c.CL/3 at 33 GHz.

Uncertainty contribution	Estimated value
Linearity	0.025
Mismatch	0.001873066
Isolation	0.099073297
Noise	0.0025
Cable	0.002
Ambient conditions	0.00057735
Connector	0.002
Overall Combined Uncertainty:	0.102267345

Table A2.14.13. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 0.1 GHz.

Uncertainty contribution	Estimated value
Error model	0.001624176
Linearity	0.000208534
Noise	0.0001365
Cable	0.0001365
Ambient conditions	0.000157617
Connector	0.0005
Overall Combined Uncertainty:	0.001730186

Table A2.14.14. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 12.4 GHz.

Uncertainty contribution	Estimated value
Error model	0.003174462
Linearity	0.000208534
Noise	0.000273
Cable	0.0004095
Ambient conditions	0.000157617
Connector	0.0015
Overall Combined Uncertainty:	0.003554962

Table A2.14.15. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 26.5 GHz.

Uncertainty contribution	Estimated value
Error model	0.003236727
Linearity	0.000208534
Noise	0.0004095
Cable	0.000546
Ambient conditions	0.000157617
Connector	0.002
Overall Combined Uncertainty:	0.003874344

Table A2.14.16. Uncertainty budget in S_{11} measurement of K5c.CL/4 at 33 GHz.

Uncertainty contribution	Estimated value
Error model	0.003353127
Linearity	0.000208534
Noise	0.0004095
Cable	0.000546
Ambient conditions	0.000157617
Connector	0.0025
Overall Combined Uncertainty:	0.004245892

Table A2.14.17. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 0.1 GHz.

Uncertainty contribution	Estimated value
Error model	0.002871112
Linearity	0
Noise	0.000005
Cable	0.000005
Ambient conditions	5.7735E-06
Connector	0.002
Overall Combined Uncertainty:	0.003499052

Table A2.14.18. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 12.4 GHz.

Uncertainty contribution	Estimated value
Error model	0.00567844
Linearity	0
Noise	0.00001
Cable	0.000015
Ambient conditions	5.7735E-06
Connector	0.005
Overall Combined Uncertainty:	0.007566045

Table A2.14.19. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 26.5 GHz.

Uncertainty contribution	Estimated value
Error model	0.006385546
Linearity	0
Noise	0.000015
Cable	0.00002
Ambient conditions	5.7735E-06
Connector	0.006
Overall Combined Uncertainty:	0.008762183

Table A2.14.20. Uncertainty budget in S_{11} measurement of K5c.CL/7 at 33 GHz.

Uncertainty contribution	Estimated value
Error model	0.006504373
Linearity	0
Noise	0.000015
Cable	0.00002
Ambient conditions	5.7735E-06
Connector	0.0075
Overall Combined Uncertainty:	0.009927614

Appendix 3: Detailed Information about Each Measurement

The participants were asked to report their detailed measurement information. The items in the template of the report were traceability source, laboratory temperature, measurement system (VNA, port-1 cables, port-2 cables, pin depth in test port-1, pin depth of test port-2), calibration kit (calibration method, characterization method), and device pin recession information. The pin recession is summarized in Appendix 4 and the others are summarized in this section.

A3.1: NMIJ

Traceability source	Own primary standard
Laboratory temperature	23 ± 1 degrees
Measurement system	
VNA	E8364B PNA Series Network Analyzer by Agilent Technologies.
Port-1 cables	No cable
Port-2 cables	FE0BN0BM025.0 by Gore and 8946C38 by Maury Microwave.
Pin depth on test port 1	85052-60034 by Agilent Technologies. -2.2 μm
Pin depth on test port 2	85052-60032 by Agilent Technologies. -0.7 μm
Calibration kit	85052C 3.5 mm precision calibration kit by Agilent Technologies.
Calibration method	TRL calibration
Characterized by	Masahiro Horibe
Other comments	**Measurement system**

	The measurement conditions of the VNA, E8364B, are as follows: Sweep type: Segment sweep IF bandwidth: 10 Hz Averaging: 1 Test port power: -9 dBm **Measurement method** Six times connection and disconnection processes were performed to estimate connection repeatability for each device under measurement. VNA error corrections are based on firmware with the original definition parameters. After device s are measured, the residual errors are corrected. The residuals are calculated using airlines with several lengths in advance. **Traceability** The dimensions of airlines were measured and the characteristic impedance of the airlines were theoretically evaluated. The traceability to the length (SI base unit) was established.

A3.2: METAS

Traceability source	METAS
Laboratory temperature	23.0 degrees ± 0.5 degrees
Measurement system	
VNA	E5061B (used up to 900 MHz) and N5227A Opt210 using a special cable fixture developed at METAS
Port-1 cables	Agilent, 85133F, NMD2.4 mm(f) to NMD2.4 mm(m) with adapter 85130F NMD2.4 mm(f) to NMD3.5 mm(m). This side was always kept fixed. Adapter shimmed to larger pin depth (avoid near field effects).
Port-2 cables	Gore, RMJ083107-01, NMD1.85 mm(f) to NMD1.85 mm(m) with adapter 85130F NMD2.4 mm(f) to NMD3.5 mm(m). Adapter shimmed to larger pin depth (avoid near field effects).
Pin depth on test port 1	-0.0195 mm
Pin depth on test port 2	-0.0147 mm
Calibration kit	Prototype LRL cal kit from Maury (6 airlines) with additional components from Agilent (Open, Short, Load and Flush Short)
Calibration method	The VNA was error corrected with an over-determined calibration technique including Offset-Opens, Offset-Shorts, Flush-Shorts and Loads. The used calibration standards were characterised with a \`Line-Reflect-Line\` calibration technique that implements corrections due to imperfections of the connector interface.
Characterized by	METAS
Other comments	For additional information two data sets for each comparison component have been supmitted. 1) the offical METAS measurements which should be used for the k5c comparison. This data does include corrections due to imperfections of the connector interface.

	2) The data files with the ending "Agilent" are representing the measurement results based from the same raw measurements but using the 85052B Agilent cal kit definitions and a SOLT calibration including (Open, Short. Load and Sliding Load). This method does not account for possible systematic connector influences. The idea is to be able to compare our results with other participants which have used a 85052B calibration kit and the definitions provided by Agilent (ignoring connector effects). For each component two different data file formats have been delivered: a) *.sdatcv format (official comparison format), containing uncertainties and correlations between all S-parameter components at a single frequencies (no correlations between frequencies and no dependencies). b) *.sdatb formate used by VNA Tools II including all dependencies, correlations and the individual uncertainty contributions down to mechanical and electrical quantities of the METAS primary calibration. The attached MD5 Checksum Excel files are showing the file name, size and the MD5 checksum for each of the provided measurement files. Additional comments to the uncertainty contributions listed in the work sheets that follow: - VNA Drift summarizes drift contributions from: Switch Terms, Directivity, Tracking, Match and Isolation. - VNA Noise summarizes contributions from Trace Noise and Noise Floor.

	- DUT Repeatability contains the repeatability uncertainty of a DUT if it shows greater variations than the standard connector repeatability specs. - Calibration Standards summarizes uncertainty contributions from the definitions of the calibration standards (derived from METAS primary calibration). - Connector repeatability summerizes uncertainty contributions from connections made during calibration and DUT measurements. The repeatability uncertainty is computed from at least 8 measurements using different connector orientations. - Cable stability summerizes uncertainty contributions from cable movements during calibration and DUT measurements. - VNA Linearity contains the uncertainty due to linearity deviations of the recievers in the VNA. The uncertainties are computed with linear uncertainty propagation using METAS UncLib. More Information about the applied measurement model can be found in the VNA Tools II - Math Reference V1.0 which can be downlaoded from www.metas.ch/vnatools References - M. Wollensack, J. Hoffmann, J. Rüfenacht and M. Zeier, VNA Tools II: S-parameter uncertainty calculation (paper), 79th ARFTG conference, Montreal, June 2012 - J. Hoffmann, P. Leuchtmann, R. Vahldieck, Pin Gap Investigations for the 1.85 mm Coaxial Connector, IEEE European Microwave Week, Munich, Proceedings, pp. 388-391,October 2007

	- J. Hoffmann, J. Ruefenacht, M. Wollensack, M. Zeier, Comparison of 1.85 mm Line Reflect Line and Offset Short Calibration, 76th ARFTG Conference, Clearwater Beach, Florida, Conference Digest, vol. 76, Dec. 2011

A3.3: NPL

Traceability source	Own primary standard (See summary document RFK5c UK_report.docx for details)
Laboratory temperature	23 degrees ± 2 degrees
Measurement system	
VNA	Agilent E8364C PNA
Port-1 cables	Agilent 85130-60011 rugadised 2.4 mm (f) to 3.5 mm (f) Adaptor then HP 85052-60033 rugadised test port adaptor 3.5 mm (m) to 3.5 mm (m).
Port-2 cables	Gore FE0BN0BM038.0 2.4 mm (f) to 2.4 mm (m) cable then Keysight 85130-60011 rugadised 2.4 mm (f) to 3.5 mm (f) Adaptor
Pin depth on test port 1	-7.6
Pin depth on test port 2	-25.4
Calibration kit	
Calibration method	TRL
Characterized by	James Skinner and Daniel Stokes
Other comments	For comments and measurement details please see RFK5c UK_report.docx

MEASUREMENTS

The items were measured using a Vector Network Analyser (VNA) configured with an external TRL (Thru-Reflect-Line) type calibration algorithm, implemented by NPL, using calibration items traceable to SI units via their mechanical properties. The calibration was verified using traceably calibrated audit standards which consisted of a 20 dB attenuator and a set of offset short circuits.

For each measurement run the VNA was calibrated with 3 airline standards all of which were characterised using NPL's air gauge systems. This is used to determine each lines characteristic impedance and establish traceability to the SI via the unit of the metre (last calibration of these items was 7th March 2017). The length of each airline is also measured by a 3rd party using systems calibrated with artefacts traceable to national standards (last calibration date was 6th May 2016). The calibrated VNA was then used to make a measurement of each of the verification standards and Devices under Test (DUT). Each of these items were measured with an averaging factor of 8 applied. Once each item was measured the VNA was re-calibrated and repeat measurements of each device made, this was done a minimum of 8 times.

The VNA used for all of the measurements is calibrated for linearity and isolation (last calibration date was 12th April 2016). The linearity measurement was made using a calibrated attenuator traceable to NPLs primary Attenuation systems.

All measurements were taken with the female end of the items attached to port 1 of the network analyser. Thus S_{11} refers to the voltage reflection coefficient of the female end of the items with the other scattering parameters designated accordingly.

All of NPL's VNA measurements are traceable to national standards and meet the requirements of section 5.6.2.1 of ISO 17025-2005 regarding the calibration of equipment.

The measurements for both the loop 1 and 2 items were made concurrently using the same experimental setup.

The ambient laboratory temperature during the measurements was (23 ± 2) °C.

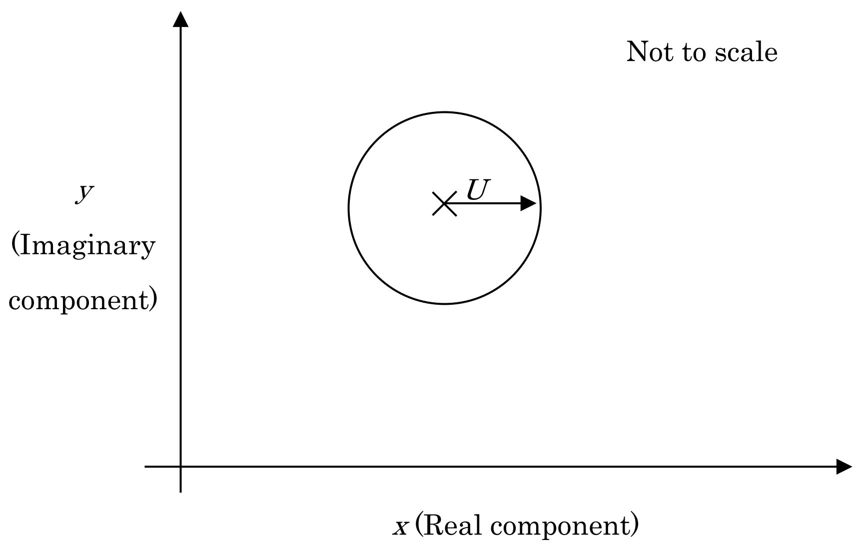
The uncertainty in the frequency is better than 0.1 ppm.

RESULTS

The results given in the excel workbooks [1] [2] are the values of the real and imaginary components of the complex voltage reflection and transmission coefficients of the items, at each given frequency, referred to 50 **Ω**. The random effects contribution in the uncertainty budget is assessed as a Type A uncertainty through the repeated measurements of the DUTs. This Type A uncertainty is used to account for the contributions associated with the noise, drift, connector repeatability and cable movements.

In the uncertainty budgets for transmission coefficients the mismatch uncertainty contribution is derived from the value and uncertainty of S11 and S22 of that item.
The example uncertainty budgets are for indication only and were compiled separately from the data and reported uncertainty as given in the results.

The uncertainties quoted in the reports can be represented by a circle with radius U around the real, x, and the imaginary, y, values plotted on a Cartesian plane (as illustrated below). Therefore only U(x) is given as U(x) = U(y).



All of the uncertainties reported are the combined standard uncertainty not the expanded uncertainty, therefore all given uncertainties have a coverage factor k =1.

The results and uncertainties relate to the on the day values and make no allowance for drift or operation under other environmental conditions.

No value for the correlation coefficient between the real and imaginary components r(x,y) is given in the reports.

Reference

[1] RFK5c UK Loop 1.xls

[2] RFK5c UK Loop 2.xls

A3.4: NMC, A*STAR

Traceability source	Trace to own primary standard and NPL's
Laboratory temperature	23 ± 2 ℃, 55 ± 10 % relative humidity
Measurement system	
VNA	
Port-1 cables	
Port-2 cables	
Pin depth on test port 1	
Pin depth on test port 2	
Calibration kit	
Calibration method	
Characterized by	
Other comments	

A3.5: UME

Traceability source	Verification kit traceable to the NPL and attenuator set traceable to PTB.
Laboratory temperature	23 degrees ± 1 degrees
Measurement system	
VNA	HP 8510C with 8517B test set. Special cable fixture produced at UME was used.
Port-1 cables	Gore FE0BL0HB025.0 male, length 25”, phase-stable VNA cable.
Port-2 cables	Gore FE0BL0HB025.0 female, length 25”, phase-stable VNA cable.
Pin depth on test port 1	-23.6 ± 3.1
Pin depth on test port 2	-17.5 ± 3.2
Calibration kit	Agilent 85052B
Calibration method	SOLT
Characterized by	It is characterized using VNA verification.
Other comments	The travelling standards have two ports were measured using full-two port calibrated VNA. The travelling standards have one port were measured using one port calibrated VNA. The standards were disconnected, rotated about 120 ° and connected to the VNA for each frequency. The uncertainty of the standards were calculated according to the EURAMET VNA guide. Pin depth of the travelling standards and VNA cables were measured with analog gages.

A3.6: NMISA

Traceability source	Own primary standard – ATTENUATION Trace to other NMI(s) – VRC
Laboratory temperature	(23 ± 2) ℃
Measurement system	
VNA	
Port-1 cables	
Port-2 cables	
Pin depth on test port 1	
Pin depth on test port 2	
Calibration kit	
Calibration method	
Characterized by	
Other comments	Instrument pin recession information: Port 1 at end of cable: 2.54 ± 4.5 um Port 2 at adapter: 20.32 ± 4.5 um Measurement plane between cable on Port 1 and adapter on Port2

Measurement Technique

The following instruments were employed for the measurements of the travelling standards:

PNA vector network analyzer, model E8361C

Adapter on port 1, model 85130F, 2.4 mm to 3.5 mm (male)

Cable on port 1, model 85131-60012

Adapter on port 2, model 85130F, 2.4 mm – 3.5 mm (female)

40 dB attenuator (for system verification), model 85053-60002

Calibration kit, model 85052B

Dial test indicator & master setting gauge, models 11752-60020 & 11752-60022

Dial test indicator & master setting gauge, models 11752-60021 & 11752-60023

Frequency range: 100 MHz to 26.5 GHz, the limiting factor being the calibration kit used.

The PNA ports have 1.85 mm connectors. A 2.4 mm adapter was inserted between the 3.5 mm cable and the network analyzer. The measurement plane was between the cable on port 1 and the adapter on port 2. Only full-two port calibrations were done with the calibration kit, and all standards (one- and two-port devices) were measured. A known artifact, namely, a 40 dB attenuator, was measured alongside the travelling standards in order to verify the system. For each device three measurements were taken at different positions.

Two sets of calibrations were done per device. For the first set, after calibration of the network analyzer, normalization was done in order to remove noise. For the second set, normalization was not done. Results were taken in real and imaginary format and converted to magnitude for comparison. Comparing results of the known attenuator to previous results, hence this set was used for reporting results.

The attenuation of the known artefact and all two-port travelling standards were further measured with the FSMR measuring receiver to establish confidence in the results. This was done only at frequencies 100 MHz, 12.4 GHz and 26.5 GHz.

Measurement uncertainties

Uncertainty budgets are included in the excel spreadsheet for the chosen frequencies. The uncertainty budget for attenuation is done using dB as units, and the final values of uncertainty is converted to linear. Uncertainty contributors are linearity, port match, directivity and connector repeatability. Linearity is determined by using a calibrated step attenuator at 1 GHz up to 70 dB on the PNA. The results of the step attenuator are traceable to a Techtest WBCO piston attenuator standard. Directivity and port match were measured using reference airlines and the ripple extraction methd.

Pin depth

Pin depth was measured with a dial test indicator and a master setting gauge for each of the device ports and instrument ports. Factors contributing to the uncertainty are certified uncertainties of standards, resolution and repeatability.

Reference

1. EA Guidelines on the Evaluation of Vector Network Analysers (VNA), "Publication Reference EA-10/12, European co-operation for accreditation, May 2000.

A3.7: NRC

Traceability source	Own primary standard
Laboratory temperature	23 Deg+/- 1
Measurement system	
VNA	
Port-1 cables	
Port-2 cables	
Pin depth on test port 1	
Pin depth on test port 2	
Calibration kit	
Calibration method	
Characterized by	
Other comments	Total of 7 calibration/measurements. Best one was used. TRL 2 port using 85052C Cal kit. E8364C (50 Ghz) analyzer. Custom built patch cables.

the artifacts (loop 1) for the K5c comparison have arrived to NRC Canada today. I have measured the pin position for the connectors. Here is the result for the measurements:

F type connectors:

Short # 7 0

Load #1123 -3

(1dB) THRU #84240 -4

20dB #2715 -14

40 dB #2871 -16

M type connectors:

SHORT #31	0
Load #11728	-5
(1dB) THRU #84240	-7
20dB #2715	-13
40 dB #2871	-20

The gage is HP model: 11750

The units are 'minor divisions': 1 unit = 0.0001 inch

The torque is 8 lb.in (90 N-cm)

Each result above is the result of seven different measurements. Four different orientations were used. We saw NO significant change with the orientation. All the readings for one connector were whitin one unit. We also assume one unit uncertainty due to to the instrument.

The result and overall expanded uncertainty (95 %) follows:

F type connectors:

Short # 7	0.000 mm (+/- 0.005 mm, 95 %)
Load #1123	-0.008 mm (+/- 0.005 mm, 95 %)
(1dB) THRU #84240	-0.010 mm (+/- 0.005 mm, 95 %)
20dB #2715	-0.030 mm (+/- 0.005 mm, 95 %)
40 dB #2871	-0.040 mm (+/- 0.005 mm, 95 %)

M type connectors:

SHORT #31	0.000 mm (+/- 0.005 mm, 95 %)
Load #11728	-0.012 mm (+/- 0.005 mm, 95 %)

(1dB) THRU #84240	-0.018 mm (+/- 0.005 mm, 95 %)
20dB #2715	-0.032 mm (+/- 0.005 mm, 95 %)
40 dB #2871	-0.050 mm (+/- 0.005 mm, 95 %)

A3.8: SNIIM

Traceability source	Own primary standard
Laboratory temperature	22 degrees ± 0.5 degrees
Measurement system	
VNA	Agilent E8361C
Port-1 cables	N4697F Flexible Cable 1.85 mm and 85130F Test Port Adapter 2.4 mm to 3.5 mm
Port-2 cables	N4697F Flexible Cable 1.85 mm and 85130F Test Port Adapter 2.4 mm to 3.5 mm
Pin depth on test port 1	10 um
Pin depth on test port 2	12 um
Calibration kit	85052C, air Line 75 mm
Calibration method	LRL, OSLT
Characterized by	SNIIM
Other comments	

At the SNIIM measurements were performed using measurement system, incorporating:

- Agilent E8361C VNA;
- N4697F Flexible Cable 1.85 mm and 85130F Test Port Adapter 2.4 mm to 3.5 mm at Port1;
- N4697F Flexible Cable 1.85 mm and 85130F Test Port Adapter 2.4 mm to 3.5 mm at Port2.

The measurements are done with an OSLT method using characterized standards. These calibration standards are characterized prior by means of a LRL optimization method using Metas VNA Tools II software. Three different Air Lines were used in calibration – two Air Lines from 85052C 3.5 mm Precision Calibration Kit and additional 75 mm Air line.

Air Lines and two Offset Short are measured dimensionally, traceable to the SI base unit of length (m), at SNIIM. Then Air lines and Offset Short were modeling to obtain S-parameters.

Measurements are made on every device using 4 disconnects with approximately 90 degrees of rotation.

The laboratory condition was 22 ± 0.5 °C and 50 ± 10 % rel. humidity.

A3.9: CMI

Traceability source	Own primary standard
Laboratory temperature	23 ℃ ± 1 ℃
Measurement system	
VNA	
Port-1 cables	
Port-2 cables	
Pin depth on test port 1	
Pin depth on test port 2	
Calibration kit	
Calibration method	
Characterized by	
Other comments	

Vector network analyzer Agilent E8364B was used for measurements.

Impedance measurements are traceable via the calibration of dimensions of four reference coaxial standards to the SI base unit of length at CMI.

Used calculable reference standards are as follows:

Air line with the length of 75 mm (used mostly in the frequency range up to 1 GHz)

Air line with the length of 16 mm (used mostly in the frequency range from 1 GHz to 5 GHz)

Air line with the length of 3.9 mm (used mostly in the frequency range above 5 GHz)

Flush coaxial male short

Note that electrical parameters of the 75 mm long air line cannot be fully calculated from dimensional measurements because of dielectric support being at one end of the line. However, measured reflections of this line (after TRL calibration of the VNA using 3.9 mm air line) are not greater than 0.003 up to 14 GHz, which indicates that the effect of the dielectric support can be neglected at low frequencies.

Lowband loads used for TRM calibration are traceable thru measurements with the 75 mm long air line and measurement at DC.

In most cases a TRL (TRM up to 1 GHz) calibration method was used utilising algorithm implemented in VNA. For the matched loads, the accuracy was enhanced on basis of the additional measurements of the loads connected to the test port through reference air lines.

Changes of the characteristic impedance and phase constant of air lines due to skineffect were taken in the account in the calculations.

Simplified uncertainty evaluation approach was used. Excepting measurements of low reflections, uncertainty contributions from assumed dominant sources were evaluated separately for magnitude and phase, combined and recalculated to uncertainties in real and imaginary part.

A3.10: GUM

Traceability source	National Physical Laboratory United Kingdom
Laboratory temperature	23 ± 2 ℃
Measurement system	
VNA	
Port-1 cables	
Port-2 cables	
Pin depth on test port 1	
Pin depth on test port 2	
Calibration kit	
Calibration method	
Characterized by	
Other comments	

A3.11: INRIM

Traceability source	Trace to other NMI(s)
Laboratory temperature	23 degrees ± 0.5 degrees
Measurement system	Vector Network Analyzer – VNA
VNA	Agilent E8364C OPT: 010-014-080-081-H11-UNL-P02
Port-1 cables	APC3.5 mm (m) HP 85134D 85134-60001 sn. 00299
Port-2 cables	APC3.5 mm (f) HP 85134D 85134-60001 sn. 00202
Pin depth on test port 1	0 um (0”)
Pin depth on test port 2	-5 um (-0.0002”)
Calibration kit	HP 85052B 3.5 mm
Calibration method	SOLT
Characterized by	
Other comments	- Pin depth has been measured using the gauge contained into the 85052B calibration kit used for the calibration. Gauges express pin depth in inches, the resolution is 0.0001”, the conversion in um has been computed as 1e04” = 2.54 um. A rounding has been done at the 0.1 um level. Uncertainty considered is ±2.5 um. - Visual inspection has been conducted using a lens. - The VNA present male connector at port1 and female connector at port2. Due to this, standards RF-K5c.CL4 and RF-K5c.CL5 have been measured together, and the same account for RF-K5c.CL6 and RF-K5c.CL7. For this reason the S parameter taken into account for RF-K5c.CL5 and RF-K5c.CL7 is actually S22 and not S11. - Nominal power level for both ports: -17 dBm

CCEM.RF.K5c.CL INRIM Measurement Procedure

1. Instrumentation used

- Vector Network Analyzer: Agilent E8364C OPT: 010-014-080-081-H11-UNL-P02
- Port 1 Cable: APC3.5 mm (m) HP 85134D 85134-60001 sn. 00299
- Port 2 Cable: APC3.5 mm (f) HP 85134D 85134-60001 sn. 00202
- Calibration kit: HP 85052B 3.5 mm
- Calibration method: SOLT

Impedance measurements are traceable, via other NMI, to the SI base unit of length (meter).

2. Procedure

All the measurements have been conducted using the VNA Tools II software developed by METAS. Each device has been measured twelve times disconnecting and reconnection it after each measurement, and repeating all the calibration process four times. This means that there are four groups of three measurements of the same device that differs in terms of the calibration process and the connections of the standards.

The average of all the twelve series of raw data of each standard has then been computed. Since the VNA Tools II applies the calibration procedure to the raw data “offline” (separately from the algorithm implemented directly into the PNA), the average computed has been fed to the software to evaluate the corrected S-parameters that are the measurands of the international comparison.

The repeated measurements have been used also to evaluate the uncertainty sources defined “repeatability” as explained in the next section.

3. Uncertainty source

The software considers as uncertainty sources the following ones:

1. Cable stability – expressed in magnitude (dB) and phase (°).
2. Calibration standard – expressed according to the Agilent Model
3. Connector repeatability (dB)
4. VNA Noise
5. VNA Linearity
6. VNA Drift.

All the characteristics parameters of the uncertainty sources are inserted into the VNA Tools II database and used to evaluate the final uncertainty on the measured scattering parameters (S-parameters).

3.1 Cable Stability

The Cable Stability contribution is the one provided by the manufacture according to the document "Agilent Technologies 85134C/D/G NMD-2.4 mm –f- to 3.5 mm Semi-Rigid Test Port Return – Operating and Service Manual" (http://literature.cdn.keysight.com/litweb/pdf/85133-90011.pdf).

3.2 Calibration standard

The calibration standard characteristic data are taken from the Agilent specifications and are inserted in the database as they appear in the manual.

3.3 Connector repeatability

Usually in the VNA tools II the connector repeatability is considered as a quantity related to the type of connector. Since one of the requirements of the international comparison was to take into account the repeatability of the executed measurements, we decided to insert this quantity into the database with a specific procedure.

The standard deviation of the twelve repeated measurements acquired for each device has been computed and then converted in dB format. This standard deviation has been computed on the corrected S-parameters, since the repeatability of interest is applied in the corrected data. Among the standard deviations of all the four S-parameters, the only the ones of the reflection parameters S_{11} and S_{22} have been considered, in particular evaluating the average of the two.

This process has been conducted for all the devices to evaluate the specific repeatability of each object. In the repeatability section of the database, for each device its specific repeatability has been inserted.

3.4 VNA Noise

The VNA noise has been evaluated for the actual PNA used for the comparison with a specific procedure. The technique required to perform repeated measurements on the two ports, which are connected alternately to a short and a load. On the collected data a specific algorithm is applied that allows to evaluate the required noise.

3.5 VNA Linearity

The VNA Linearity has been evaluated measuring the states of a step attenuator calibrated against a waveguide below cutoff (WBCO) and then comparing the incremental attenuation obtained with the certificate provided with the step attenuator.

3.6 VNA Drift

The drift (one hour drift and 24 hours drift) has been evaluated performing a full two port calibration and then measuring a thru connection immediately after the calibration, then after one hour and 24 hours. Since all the measurements and the calibration process last less than one hour, therefore, the one hour drift data has been inserted into the database.

A3.12: PTB

Traceability source	Own primary standard
Laboratory temperature	23 degrees C ± 0.5 degrees C
Measurement system	
VNA	
Port-1 cables	
Port-2 cables	
Pin depth on test port 1	6
Pin depth on test port 2	4.3
Calibration kit	
Calibration method	
Characterized by	
Other comments	

Example of uncertainty contributions for reflection measurements (S11 and S22), ex. S11=1 when S12=S21=0, at 26.5 GHz.

Uncertainty Contribution	Typical values (expressed as standard uncertainties)	Distribution	Contributions	Divisor	S11 uncertainty
TRL line standard (δSii)	0.003	Standard	f(S11, Γ, $e^{-\gamma l}$)	1	0.0030
Calibration repeatability	0.005	U-shape	1	$\sqrt{2}$	0.0036
Noise floor	0.001	Standard	1	$\sqrt{N}$, N=6	0.00041
Connection Repeatability	0.001	Standard	1	$\sqrt{N}$, N=6	0.00041
	Combined Standard uncertainty				0.0047

	Expanded uncertainty (k=2)	0.0095

Example of uncertainty contributions for transmission measurements (S21 and S12), ex. S21=1, at 26.5 GHz.

Uncertainty Contribution	Typical values (expressed as standard uncertainties)	Distribution	Contributions	Divisor	S21 uncertainty
TRL line standard (δSii)	0.003	Standard	f(S11, S22, $e^{-\gamma l}$)	1	0.0030
Calibration repeatability	0.005	Standard	1	√N, N=6	0.0021
Test set linearity	0.003	Uninform	S21	√3	0.0017
Test set isolation	0.003	Uniform	1	√3	0.0017
	Combined Standard uncertainty				0.0044
	Expanded uncertainty (k=2)				0.0088

A3.13: SP

Traceability source	NPL Air line impedance METAS Linearity from stepattenuator
Laboratory temperature	22.9 ± 1 degrees
Measurement system	
VNA	PNA N5227A Metrology option, US51270331, A.09.80.20
Port-1 cables	NMD 2.4 mm Maury 8946C38 SP602813, SN112
Port-2 cables	NMD 2.4 mm Maury 8946C38 SP603208, SN112
Pin depth on test port 1	23 um
Pin depth on test port 2	23 um
Calibration kit	Agilent 85052B SP503385
Calibration method	Unknown thru
Characterized by	SP
Other comments	-

Measurement technique

The DUTs were measured using a Vector Network Analyzer (VNA) Agilent PNA N5227A Metrology option, US51270331. The measurements were performed according to the standard procedure for S-parameter measurements at SP [1-3]. The VNA was calibrated using the unknown thru technique with a female connector on port 1 and male connector on port 2 of the VNA. The complex S-parameters were measured. The one-port devices were measured with adapters according to Table 2 and the two-port devices were measured using both test port cables and adapters according to Table 2.

The SOLT standards and DUTs were connected 6 times each in order to estimate connector repeatability. The SOLT standards were previously characterized using a TRL calibration kit and the residual errors were estimated using the two-port ripple technique [4, 5] with additions to include uncertainty in air-line impedance.

Results are reported on the complex S-parameters of each devices. The results can be found in the appended excel document.

Instrumentation

The instrumentation used us found in Table 2.

Table 2 Instrumentation used for the measurements

Item	Identification number
PNA N5227A Metrology option	BX33663
3.5 mm calibration kit HP 85052B	SP503385
Test port cables port 1 Maury 8496C38	SP602813
Test port cables port 2 Maury 8496C38	SP603208
Adapter NMD 2.4 mm → 3.5 mm female	BX33583
Adapter NMD 2.4 mm → 3.5 mm male	BX33583
Torque wrench	SP602332
Torque wrench	SP503384
Maury connector gage kit A034E	SP602812

Inspection on arrival and before dispatch

The connectors of the DUTs were inspected, cleaned and the pin depth was measured both on arrival and before dispatch to the next lab. The pin-depth was found to be ok on arrival and before dispatch to the next lab.

Uncertainty

Traceability

VNA microwave impedance is traced to calibrated airline impedance standards. VNA linearity is evaluated with calibrated step attenuators. See Table 3 for details on devices used.

Table 3 Traceability table

Device	Identification number	Traceability
Agilent 75 mm airline	SP602340	NPL

Maury 150 mm airline		NPL
Agilent 84904L step attenuator	SP602845	METAS
Agilent 84906L step attenuator	SP602844	METAS

Environmental conditions

During measurement the temperature and humidity were measured at the VNA. The temperature was 22.0±1 ℃. And the relative humidity was 32 %±10 %.

Reference

[1] J. Stenarson and K. Yhland, "One and two-port measurement with vector network analyser," SP-Metod 2925, 2004.

[2] J. Stenarson and K. Yhland, "OSL/SOLT Vector Network Analyzer calibration," SP Sveriges Provnings- och Forsknings Institut, Borås SP-AR 2002:24, 2002.

[3] J. Stenarson and K. Yhland, "Uncertainty in VNA measurements," SP Sveriges Provnings- och Forsknings Institut, Borås SP-AR 2003:04, 2003.

[4] J. Stenarson and K. Yhland, "Residual error models for the SOLT and SOLR VNA calibration algorithms," in *69th ARFTG Conference*, Honolulu Hawaii, 2007.

[5] J. Stenarson and K. Yhland, "A new assessment method for the residual errors in SOLT and SOLR calibrated VNAs," in *69th ARFTG Conference*, Honolulu Hawaii, 2007.

A3.14: VSL

Summary

The results of the VSL measurements for the GT-RF key comparison are described. The Sparameters of one adapter, two attenuators and four terminations are measured in the frequency range 100 MHz to 33 GHz with 100 MHz steps.

1. Introduction

It is a function of the Mutual Recognition Arrangement (MRA) of the Bureau International des Poids et Mesures (BIPM) that the equivalence of signatory National Metrology Institutes (NMI) standards should be established by means of international comparison exercises. In order to establish such equivalence in complex-impedance measurement, it was decided to initiate a BIPM Key Comparison designated CCEM.RF-K5c.CL, Scattering Coefficients by Broad-Band Methods 100 MHz - 33 GHz with 3.5 mm connector. VSL is one of the last laboratories to carry out the requested measurements. The last measurements by the coordinating laboratory are scheduled for 2015.

2. Measurement set-up

The measurements were performed using a Vector Network Analyzer (VNA) set-up suitable for different connector types with a maximum frequency of 50 GHz. The VNA system owned by VSL is an Agilent metrology VNA system of the type PNA5225A for the frequency range 10 MHz up to 50 GHz.

The VNA is calibrated using a precision 3.5 mm coaxial calibration kit and the VSL software for S-parameter measurements. The calibration method for one-port artifacts is based on the well known SOL (short-open-load) method and calibration method for the two-port artifacts is the SOLT (short-open-load-through) method. The calibration is conducted by VSL S-parameter software.

The one-port SOL calibration devices used for calibration the VNA are characterized using the VSL primary multi-line calibration in 3.5 mm connector. **The calibration method accounts for connector effects, such as the well known pin-gap effect by using special recessed test-port adapters, Kapton offset discs, and short standards**. Validation of the measurements is performed using a verification kit comprising two attenuators, a 50 Ω precision airline and a 25 Ω precision airline.

On each port of the VNA a 1.85 mm GORE flexible precision cable is attached with a suitable test-port adapter (2.4 mm (f) – 3.5 mm) from a dedicated precision adapter kit which results in an effective test-port 1 having a 3.5 mm male connector and an effective test-port 2 having a 3.5 mm slotless female connector. This set-up was used for calibration of the two-port artifacts. All oneport artifacts are calibrated on port-1 of the VNA with suitable test-port adapter.

The VSL software is written in LabView and Matlab. The software is used for data correction, uncertainty analysis and uncertainty calculations.

The power setting of the VNA source is set at -10 dBm level with IF bandwidth of 3 Hz and no averaging was used. The measurements were conducted from 100 MHz up to 33 GHz with 100 MHz step. The results from these measurements are presented in the main text.

3. Traceability

The characteristic impedance standard of 50 ohm is based upon the mechanical dimensions of the beadles airlines part of the calibration and verification kit. These are measured in the Department of Length (Dimensional Measurements) of the VSL. The linearity of the system has been checked using a step attenuator, equipped with type-N 50 ohm connectors and calibrated by NPL, UK, at 50 MHz and 1 GHz. This scheme is presented in figure 1.

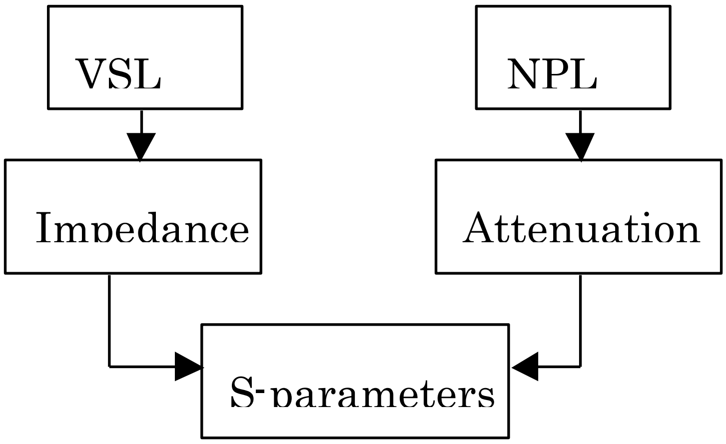


Figure 1: Traceability scheme for S-parameters with type-3.5 mm connector

4. Measurement conditions

The measurements were performed in November 2014.

The ambient conditions during the measurements were:

Temperature: (23.0 ± 0.5) °C

Relative air humidity: (41 ± 5) %

5. Devices under test

A set of 7 travelling standards (Loop 2) are included in the comparison. The DUTs (Devices under test) were selected by the coordinating laboratory NMIJ. They are normal commercial devices. The identification of the DUTs together with the intake measurements are presented in Annex-A.

The pin-depth measurement results of the DUTs and of the VNA test-port connectors are presented in Annex-B. The pin-depth measurements are conducted using precision screw-on coaxial gauges.

6. Measurement results

6.1 General information

The results are presented in the complex $x + jy$ format, as requested by the piloting laboratory. The coordinating laboratory asked for a different presentation in real and imaginary terms, along with standard uncertainties for the results. VSL decided to submit measurement results in magnitude & phase format as well, however, these results will not be considered in the comparison analysis.

Each artifact is measured in a series of three independent measurements, each with different orientation of the DUT rotated in steps of 120°. The submitted results are based on a series of three independent measurements.

6.2 Measurements on one-port devices

In total four one-port devices are measured, two nominal 50 ohm terminations (one male and one female) and two flush short devices (one male and one female). In order to give a good representation of the electrical behavior as function of frequency and the associated uncertainties, the results are presented in the complex $x + jy$ format and magnitude & phase format. From our standard set of frequencies a subset is selected for presentation: 100 MHz, 12.4 GHz, 26.5 GHz and 33 GHz. The combined standard uncertainties (k=1) are presented in the relevant tables of the measured artifacts.

6.2.1 Matched termination (female) sn.11575

Table 6.2.1

Frequency	S11	S11	S11	S11
(GHz)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.0022	0.0011	0.0000	0.0011
12.4	0.0048	0.0011	-0.0013	0.0011
26.5	-0.0020	0.0015	0.0054	0.0015
33.0	-0.0011	0.0015	-0.0010	0.0015

Frequency	S11	S11	S11	S11
(GHz)	Magnitude	Unc(Mag)	Phase (º)	Unc(Phase) (º)
0.1	0.0022	0.0011	-0	36
12.4	0.0050	0.0011	-15	15
26.5	0.0058	0.0015	110	20
33.0	0.0015	0.0015	-139	90

6.2.2 Matched termination (male) sn.11655

Table 6.2.2

Frequency	S11	S11	S11	S11
(GHz)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.0007	0.0011	-0.0001	0.0011
12.4	0.0025	0.0011	-0.0031	0.0011
26.5	-0.0088	0.0015	0.0009	0.0015
33.0	0.0050	0.0015	0.0099	0.0015

Frequency	S11	S11	S11	S11
(GHz)	Magnitude	Unc(Mag)	Phase (º)	Unc(Phase) (º)
0.1	0.0007	0.0011	-11	89
12.4	0.0040	0.0011	-51	19
26.5	0.0088	0.0015	174	13

33.0	0.0111	0.0015	63	10

6.2.3 Flush Short Termination (female) sn.9

Table 6.2.3

Frequency	S11	S11	S11	S11
(GHz)	x-part	Unc(x)	y-part	Unc(y)
0.1	-1.0001	0.0018	0.0011	0.0011
12.4	-0.9995	0.0018	0.0049	0.0042
26.5	-0.9992	0.0030	0.0092	0.0080
33.0	-0.9992	0.0030	0.0143	0.0096

Frequency	S11	S11	S11	S11
(GHz)	Magnitude	Unc(Mag)	Phase (º)	Unc(Phase) (º)
0.1	1.0001	0.0018	179.93	0.07
12.4	0.9996	0.0018	179.72	0.19
26.5	0.9993	0.0029	179.46	0.39
33.0	0.9993	0.0029	179.18	0.48

6.2.4 Flush Short Termination (male) sn.032

Table 6.2.4

Frequency	S11	S11	S11	S11
(GHz)	x-part	Unc(x)	y-part	Unc(y)
0.1	-1.0000	0.0018	0.0001	0.0011
12.4	-0.9991	0.0018	0.0038	0.0042
26.5	-0.9984	0.0030	0.0072	0.0080
33.0	-0.9978	0.0030	0.0087	0.0096

Frequency	S11	S11	S11	S11

(GHz)	Magnitude	Unc(Mag)	Phase (º)	Unc(Phase) (º)
0.1	1.0000	0.0018	179.99	0.07
12.4	0.9991	0.0018	179.78	0.19
26.5	0.9984	0.0029	179.58	0.39
33.0	0.9978	0.0029	179.50	0.48

6.3. Measurements on two port devices

In total three two-port devices are measured, all three nominal 50 ohm devices with male and female connectors comprising of a through adapter, a 20 dB attenuator and a 40 dB attenuator. In order to give a good representation of the electrical behavior as function of frequency and the associated uncertainties, the results are presented in the complex $x + jy$ format as requested by the pilot laboratory. VSL decided also to submit measurements results in magnitude & phase format as well. From our standard set of frequencies a subset is selected for presentation: 100 MHz, 12.4 GHz, 26.5 GHz and 33 GHz. The combined standard uncertainties (k=1) are presented in the relevant tables of the measured artifacts.

6.3.1 Adapter sn. 84242

Table 6.3.1. Reflection coefficients and transmission coefficients

Frequency	S11	S11	S11	S11	S22	S22	S22	S22
(GHz)	x-part	Unc(x)	y-part	Unc(y)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.0007	0.0016	0.0007	0.0016	0.0007	0.0016	0.0006	0.0016
12.4	-0.0015	0.0015	-0.0021	0.0015	-0.0016	0.0015	-0.0015	0.0015
26.5	0.0050	0.0020	0.0159	0.0021	0.0022	0.0020	0.0165	0.0021
33.0	0.0058	0.0020	-0.0083	0.0020	-0.0041	0.0020	0.0082	0.0020
Frequency	S21	S21	S21	S21	S12	S12	S12	S12
(GHz)	x-part	Unc(x)	y-part	Unc(y)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.997617	0.001069	-0.060222	0.002479	0.997394	0.001069	-0.060244	0.002479

12.4	0.439419	0.004754	-0.889074	0.001523	0.439386	0.004754	-0.888992	0.001523
26.5	-0.982578	0.001616	0.092161	0.007519	-0.982610	0.001616	0.092182	0.007519
33.0	0.665326	0.007113	-0.726402	0.005453	0.665441	0.007113	-0.726217	0.005453

Frequency	S11	S11	S11	S11	S22	S22	S22	S22
(GHz)	Mag	Unc(Mag)	Phase (º)	Unc (º)	Mag	Unc(Mag)	Phase (º)	Unc (º)
0.1	0.0010	0.0015	43	120	0.0010	0.0015	40	120
12.4	0.0025	0.0015	-126	47	0.0022	0.0015	-137	47
26.5	0.0167	0.0020	73	10	0.0167	0.0020	82	10
33.0	0.0101	0.0020	-55	17	0.0092	0.0020	117	17
Frequency	S21	S21	S21	S21	S12	S12	S12	S12
(GHz)	Mag (dB)	Unc (dB)	Phase (º)	Unc (º)	Mag (dB)	Unc (dB)	Phase (º)	Unc (º)
0.1	-0.0049	0.0091	-3.45	0.03	-0.0068	0.0091	-3.45	0.03
12.4	-0.0721	0.0091	-63.69	0.17	-0.0728	0.0091	-63.69	0.17
26.5	-0.1146	0.0091	174.64	0.37	-0.1143	0.0091	174.64	0.37
33.0	-0.1309	0.0091	-47.51	0.46	-0.1314	0.0091	-47.50	0.46

6.3.2 20 dB Attenuator sn. 02793

Table 6.3.2. Reflection coefficients and transmission coefficients

Frequency	S11	S11	S11	S11	S22	S22	S22	S22
(GHz)	x-part	Unc(x)	y-part	Unc(y)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.0054	0.0011	-0.0002	0.0011	0.0072	0.0011	-0.0009	0.0011
12.4	-0.0263	0.0011	0.0010	0.0011	-0.0207	0.0011	-0.0010	0.0011
26.5	0.0169	0.0015	-0.0010	0.0015	0.0368	0.0015	0.0055	0.0015
33.0	-0.0397	0.0015	0.0288	0.0015	-0.0371	0.0016	0.0714	0.0015
Frequency	S21	S21	S21	S21	S12	S12	S12	S12

(GHz)	x-part	Unc(x)	y-part	Unc(y)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.099716	0.000141	-0.007159	0.000263	0.099709	0.000141	-0.007156	0.000263
12.4	-0.076717	0.000254	-0.060083	0.000438	-0.076695	0.000254	-0.060094	0.000438
26.5	0.096359	0.000099	0.011620	0.000759	0.096354	0.000099	0.011621	0.000759
33.0	-0.017135	0.000907	0.098728	0.000129	-0.017147	0.000907	0.098787	0.000129

Frequency	S11	S11	S11	S11	S22	S22	S22	S22
(GHz)	Mag	Unc(Mag)	Phase (º)	Unc (º)	Mag	Unc(Mag)	Phase (º)	Unc (º)
0.1	0.0054	0.0011	-2	14	0.0073	0.0011	-7	10
12.4	0.0263	0.0011	178	3	0.0207	0.0011	-177	4
26.5	0.0170	0.0015	-4	7	0.0372	0.0015	9	3
33.0	0.0490	0.0015	144	2	0.0805	0.0015	117	2
Frequency	S21	S21	S21	S21	S12	S12	S12	S12
(GHz)	Mag (dB)	Unc (dB)	Phase (º)	Unc (º)	Mag (dB)	Unc (dB)	Phase (º)	Unc (º)
0.1	-20.0024	0.0140	-4.10	0.07	-20.0030	0.0140	-4.10	0.07
12.4	-20.2249	0.0140	-141.93	0.19	-20.2258	0.0140	-141.91	0.19
26.5	-20.2595	0.0141	6.87	0.38	-20.2599	0.0141	6.87	0.38
33.0	-19.9823	0.0142	99.84	0.47	-19.9771	0.0142	99.84	0.47

6.3.3 40 dB Attenuator sn. 02870

Table 6.3.3. Reflection coefficients and transmission coefficients

Frequency	S11	S11	S11	S11	S22	S22	S22	S22
(GHz)	x-part	Unc(x)	y-part	Unc(y)	x-part	Unc(x)	y-part	Unc(y)
0.1	-0.0020	0.0011	0.0006	0.0011	-0.0035	0.0011	0.0005	0.0011
12.4	-0.0038	0.0011	0.0011	0.0011	-0.0004	0.0011	0.0113	0.0011
26.5	-0.0430	0.0015	-0.0070	0.0015	-0.0445	0.0015	0.0080	0.0015
33.0	-0.0334	0.0015	-0.0186	0.0015	-0.0310	0.0015	-0.0266	0.0015

Frequency	S21	S21	S21	S21	S12	S12	S12	S12
(GHz)	x-part	Unc(x)	y-part	Unc(y)	x-part	Unc(x)	y-part	Unc(y)
0.1	0.010207	0.000021	-0.000790	0.000031	0.010236	0.000021	-0.000780	0.000031
12.4	-0.009775	0.000017	-0.000952	0.000052	-0.009775	0.000017	-0.000951	0.000052
26.5	0.004893	0.000074	-0.008659	0.000036	0.004891	0.000074	-0.008662	0.000036
33.0	0.010561	0.000020	0.001876	0.000098	0.010563	0.000020	0.001881	0.000098

Frequency	S11	S11	S11	S11	S22	S22	S22	S22
(GHz)	Mag	Unc(Mag)	Phase (º)	Unc (º)	Mag	Unc(Mag)	Phase (º)	Unc (º)
0.1	0.0021	0.0011	163	39	0.0035	0.0011	172	21
12.4	0.0039	0.0011	164	19	0.0113	0.0011	92	6
26.5	0.0436	0.0015	-171	3	0.0452	0.0015	170	3
33.0	0.0382	0.0015	-151	3	0.0408	0.0015	-139	3
Frequency	S21	S21	S21	S21	S12	S12	S12	S12
(GHz)	Mag (dB)	Unc (dB)	Phase (º)	Unc (º)	Mag (dB)	Unc (dB)	Phase (º)	Unc (º)
0.1	-39.7965	0.0231	-4.42	0.14	-39.7725	0.0231	-4.35	0.14
12.4	-40.1565	0.0220	-174.43	0.22	-40.1566	0.0220	-174.44	0.22
26.5	-40.0470	0.0221	-60.53	0.39	-40.0455	0.0221	-60.54	0.39
33.0	-39.3913	0.0220	10.07	0.48	-39.3884	0.0220	10.09	0.48

7. Uncertainty calculation

Two examples of uncertainty budgets are presented for one-port S-parameter measurements of one-port matched and highly mismatched devices. A one example of uncertainty budget is provided for transmission measurement of a two-port 20 dB attenuator. VSL uncertainty budget follows the uncertainty assessment philosophy as outlined in [1]. Uncertainty measurement and assessment techniques are modified to include connector effects.

7.2 Reflection measurement

Uncertainty in one-port reflection measurements for a matched termination with female connector (With $S_{11}(x) = 0.005$, $S_{11}(y) = 0.005$) at 33 GHz.

Uncertainty Contribution **S_{11}(x-part)**	Estimate	Uncertainty for |x | = 0.005 |y | = 0.005	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0014	0.0000			
Sum of correlated quantities		0.0020	U-shaped	$\sqrt{2}$	0.0014
Tracking	0.0002	0.0000	rectangular	$\sqrt{3}$	0.0000
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0002	0.0000	gaussian	2	0.0000
Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0014
Expanded Uncertainty (k = 2)					0.0028

Uncertainty Contribution **S_{11}(y-part)**	Estimate	Uncertainty for |x | = 0.005 |y | = 0.005	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0015	0.0000			
Sum of correlated quantities		0.0020	U-shaped	$\sqrt{2}$	0.0014
Tracking	0.0002	0.0000	rectangular	$\sqrt{3}$	0.0000
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0002	0.0000	gaussian	2	0.0000

Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0014
Expanded Uncertainty (k = 2)					0.0028

Uncertainty in one-port reflection measurements for a short termination with female connector (With $S_{11}(x) = -0.9999$, $S_{11}(y) = 0.0150$) at 33 GHz.

Uncertainty Contribution **S_{11}(x-part)**	Estimate	Uncertainty for |x | = -0.9999 |y | = 0.0150	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0022	0.0022			
Sum of correlated quantities		0.0042	U-shaped	□2	0.0030
Tracking	0.0001	0.0001	rectangular	□3	0.0001
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0001	0.0001	gaussian	2	0.0001
Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0030
Expanded Uncertainty (k = 2)					0.0060

Uncertainty Contribution **S_{11}(y-part)**	Estimate	Uncertainty for |x | = -0.9999 |y | = 0.0150	Distribution	Divisor	Standard Uncertainty
Effective Directivity	0.0020	0.0020			
Effective Test Port Match	0.0115	0.0115			
Sum of correlated quantities		0.0135	U-shaped	□2	0.0096

Tracking	0.0002	0.0002	rectangular	□3	0.0001
System Repeatability	0.0000	0.0000	gaussian	2	0.0000
Cable Flexure	0.0002	0.0002	gaussian	2	0.0001
Connector Repeatability	0.0001	0.0001	gaussian	2	0.0001
Combined Standard Uncertainty					0.0096
Expanded Uncertainty (k = 2)					0.0191

7.3 Transmission measurement

Uncertainty in transmission measurement for a 20 dB attenuator ($S_{21}(x)$ = -0.017135 , $S_{21}(y)$ = -0.098728 with $|S_{11}|$ = 0.050 and $|S_{22}|$ = 0.050) at 33 GHz

Uncertainty Contribution S_{21}(x-part)	Estimate	Uncertainty	Distribution	Divisor	Standard Uncertainty
Linearity	0.000194	0.000194	gaussian	□2	0.000137
Mismatch calculated		0.000021	gaussian	□2	0.000015
Cross-talk	0.000006	0.000006	rectangular	□3	0.000004
Noise	0.000039	0.000039	gaussian	2	0.000020
Cable Flexure	0.001274	0.001274	gaussian	□2	0.000901
Connector Repeatability	0.000100	0.000000	gaussian	*2*	0.000050
Combined Standard Uncertainty					0.000913
Expanded Uncertainty (k = 2)					0.001826

Uncertainty Contribution S_{21}(y-part)	Estimate	Uncertainty	Distribution	Divisor	Standard Uncertainty
Linearity	0.000194	0.000194	gaussian	□2	0.000137

Mismatch calculated		0.000021	gaussian	□2	0.000015
Cross-talk	0.000008	0.000008	rectangular	□3	0.000004
Noise	0.000039	0.000039	gaussian	2	0.000020
Cable Flexure	0.000112	0.000112	gaussian	□2	0.000079
Connector Repeatability	0.000100	0.050000	gaussian	*2*	0.000050
Combined Standard Uncertainty					0.000168
Expanded Uncertainty (k = 2)					0.000336

8. Conclusion

The artifacts connector pin-depth is measured at start and end of VSL calibration measurements. All pin-depth measurement results are considered within specification limits. No artifact exhibited protrusion on any connector. Furthermore, connector stability as function of device orientation is good for all artifacts. VSL measurements were conducted within 3 week duration. All measurement results are supplied in the x+jy format together with the combined standard uncertainty. Three examples of the uncertainty budgets are included, two budgets for one-port reflection coefficient measurements and one uncertainty budget for two-port attenuation measurement.

9. References

[1] EURAMET Technical Committee for Electricity and Magnetism, "Guidelines on the evaluations of Vector Network Analyzers (VNA)", EURAMET cg-12, Version 2.0 (03/2011). Online available via www.euramet.org.

[2] BIPM website: www.bipm.org

Annex A – Measurement Artefacts

Identification of the DUTs measured by VSL in loop 2 of the comparison.

Identifier	Device	Manufacturer	Model	Serial number	Connector
K5c.CL/1	Adapter	Agilent	85052-60013	84242	Male / female
K5c.CL/2	Attenuator	Agilent	85053-60001	02793	Male / female
K5c.CL/3	Attenuator	Agilent	85053-60002	02870	Male / female
K5c.CL/4	Matched termination	Agilent	00902-60004	11575	Female
K5c.CL/5	Matched termination	Agilent	00902-60003	11655	Male
K5c.CL/6	Flush short termination	Agilent	85052BK25	9	Female
K5c.CL/7	Flush short termination	Agilent	85052BK26	032	Male

Annex B – Connector Pin-dept Measurement Results

The coordinating requested a pin-depth (pin recession) measurements to be performed at the start and end of the official measurements. Its main purpose is to ascertain that the DUTs are still in good condition. The measurements of the pin depth are done using gauges with an indication in μm and the uncertainty (k=2) is 4 μm.

Measurement date		**Start of VSL measurements (2014-11-9)**		**End of VSL measurements (2014-11-25)**	
Device	**SN**	**“120 deg” pindepth readings (□m)**	**Final Pin-depth averaged (□m)**	**“120 deg” pindepth readings (□m)**	**Final Pindepth averaged (□m)**

Adapter (**female** connector)	84242	-42 -42 -42	**-42**	- - -	**-**
Adapter (**male** connector)	84242	-22 -21 -20	**-21**	-18 -20 -20	**-19**
20 dB Attenuator (**female** connector)	02797	-39 -39 -38	**-39**	-40 -39 -39	**-39**
20 dB Attenuator (**male** connector)	02797	-43 -40 -44	**-42**	-41 -40 -41	**-41**
40 dB Attenuator (**female** connector)	02870	-40 -42 -42	**-41**	-42 -42 -43	**-42**
40 dB Attenuator (**male** connector)	02870	-56 -53 -56	**-55**	-53 -51 -56	**-53**
Matched term. (**female** connector)	11575	-10 -10 -10	**-10**	-11 -11 -11	**-11**
Matched term. (**male** connector)	11655	-11 -13 -14	**-13**	-8 -12 -11	**-10**
Flush short		0 0		-1	

(**female** connector)	9	-1	**0**	-1 0	**-1**
Flush short (**male** connector)	032	-3 -3 -3	**-3**	-1 0 -1	**-1**

Device	**SN**	**"120 deg" pin-depth readings (□m)**	**Final Pin-depth averaged (□m)**
2.4 mm NMD (female) to 3.5 mm (male) **Adapter (VNA Test-port)** (**male** connector)	44	-23 -22 -24	**-23**
2.4 mm NMD (female) to 3.5 mm (female) **Adapter (VNA Test-port)** (fe**male** connector)	55	-12 -13 -13	**-13**

A3.15: LNE

Traceability source	Own primary standard
Laboratory temperature	23 degrees ± 0.5 degrees
Measurement system	
VNA	Agilent Technologies, N5227 010 020 410.
Port-1 cables	Agilent Technologies, 1.85 mm N4697-60200, adapter 2.4 mm to 3.5 mm.
Port-2 cables	Agilent Technologies, 1.85 mm N4697-60100, adapter 2.4 mm to 3.5 mm.
Pin depth on test port 1	-0.44
Pin depth on test port 2	-0.23
Calibration kit	–
Calibration method	SOLT
Characterized by	Alexis Litwin
Other comments	–

Appendix 4: Pin Depth Measurement

The participants should measure the pin depth of the travelling standards before connecting them to their test ports. The reported pin depth results are listed in Table A4.1. and Table A4.2.

The unit of the values is micrometer. The pin depth is expressed as a positive values when the center conductor is recessed below the reference plane of the outer conductor.

Table A4.1. The pin depth measurement results reported by laboratories in Loop 1.

	K5c.CL/1		K5c.CL/2		K5c.CL/3		K5c.CL/4	K5c.CL/5	K5c.CL/6	K5c.CL/7
	Female	**Male**	**Female**	**Male**	**Female**	**Male**				
METAS	10.4	19.8	36.1	34.0	40.1	51.6	8.9	14.0	0.0	0.0
NMC, A*STAR	12.1	19.9	38.1	35.0	41.8	52.5	10.8	15.6	1.4	1.7
UME	12.2	17.8	38.3	33.6	42.9	51.5	10.2	13.9	0.8	-1.1
NMISA	10.2	20.3	43.2	35.6	48.3	53.3	10.2	15.2	0.0	0.0
NRC	10.0	18.0	32.0	30.0	40.0	50.0	8.0	12.0	0.0	0.0
NMIJ	9.9	17.0	35.2	31.7	39.1	47.6	5.9	12.2	-0.5	-0.4
SNIIM	15.2	19.1	40.6	33.0	45.7	50.8	9.4	15.2	0.0	0.0
NPL	12.7	22.9	40.6	40.6	45.7	58.4	15.2	17.8	2.5	2.5

Table A.4.2. The pin depth measurement results reported by laboratories in Loop 2.

	K5c.CL/1		**K5c.CL/2**		**K5c.CL/3**		**K5c.CL/4**	**K5c.CL/5**	**K5c.CL/6**	**K5c.CL/7**
	Female	**Male**	**Female**	**Male**	**Female**	**Male**				
METAS	8.1	16.3	37.9	39.4	40.6	50.8	8.4	9.1	0.0	0.0
CMI	8.3	17.5	38.0	39.2	40.9	51.6	8.6	10.0	0.0	0.2
GUM	7.6	17.8	40.6	40.6	41.9	52.1	10.2	10.2	0.0	0.0
INRIM (29/3/2014)	5.1	17.8	40.6	38.1	43.2	50.8	10.2	10.2	0	0
(15/4/2014)	2.6	17.8	38.1	38.1	43.2	50.8	7.6	7.6	0	0
PTB	5.75	20.00	38.00	41.00	41.00	53.75	10.00	9.75	0.00	0.00
SP	5.1	19.5	38.1	38.9	42.3	50.8	10.2	8.5	-1.7	0
NMIJ	1.4	18.3	36.0	35.6	38.7	48.4	8.8	7.7	-0.4	-0.4
VSL (Start of measurement)	42	21	39	42	41	55	10	13	0	3
(End of measurement)	-	19	39	41	42	53	11	10	1	1
LNE	0.2	0.7	1.7	1.5	1.8	1.9	0.3	0.3	-0.1	-0.1
NPL	7.6	25.4	40.6	43.2	45.7	48.3	12.7	12.7	0.0	2.5

Appendix 5: Stability of Travelling Standards

To monitor the stability of the travelling standards, the pilot laboratory, NMIJ, measured the devices 7 times for both Loops 1 and 2 during the comparison measurements.

Table A5.1 shows the results of the stability monitoring measurements. The uncertainties of stability defined as Eq. (A5.1) are compared with the combined standard uncertainties of the 4th measurement by NMIJ. Here *N* describes the number of stability monitoring measurements.

$$\frac{1}{\sqrt{N(N-1)}}\sqrt{\sum_{i=1}^{N}\left(X_i-\frac{1}{N}\sum_{j=1}^{N}X_j\right)^2} \qquad (X=x,y). \qquad \text{(A5.1)}$$

Except for the data for the imaginary component of K5c.CL/7 for Loop 2 at 33 GHz, the stability uncertainties are smaller than the combined standard uncertainties. The result shows that the travelling standards have been stable during the comparison.

Figure A5.1 shows the 6-time stability monitoring measurement data of the imaginary part of K5c.CL/7 for Loop 2 at 33 GHz. According to the figure, a significant step change has occurred between the first and second measurements. Reasons for why the change occurred are unidentified.

Tables A5.2 and A5.3 show the stability of the pin depth. The sixth measurement for Loop 2 has been missed. The unit of the values is micrometer. The pin depth is expressed as a positive value when the center conductor is recessed below the reference plane of the outer conductor.

Table A5.1. Comparison between uncertainty of stability and standard measurement uncertainty of travelling standards.

Device	**Frequency**	**Component**	**Uncertainty of stability**	**Combined standard uncertainty of measurements (4th times)**
Loop 1				
K5c.CL/1	0.1GHz	x	0.00034	0.0018
		y	0.000057	0.0018
	12.4 GHz	x	0.00099	0.0023
		y	0.00086	0.0023
	26.5 GHz	x	0.0015	0.0032
		y	0.00077	0.0032

	33 GHz	x	0.0015	0.0036
		y	0.00081	0.0036
K5c.CL/2	0.1GHz	x	0.000033	0.00016
		y	0.000018	0.00016
	12.4 GHz	x	0.000057	0.00023
		y	0.00010	0.00023
	26.5 GHz	x	0.00012	0.00031
		y	0.00011	0.00031
	33 GHz	x	0.00017	0.00036
		y	0.00010	0.00036
K5c.CL/3	0.1GHz	x	0.0000046	0.000016
		y	0.0000027	0.000016
	12.4 GHz	x	0.000011	0.000028
		y	0.0000095	0.000028
	26.5 GHz	x	0.000017	0.000039
		y	0.000012	0.000039
	33 GHz	x	0.000011	0.000046
		y	0.000021	0.000046
K5c.CL/4	0.1GHz	x	0.0000047	0.0016
		y	0.0000019	0.0016
	12.4 GHz	x	0.000096	0.0020
		y	0.00019	0.0020
	26.5 GHz	x	0.00027	0.0028
		y	0.00040	0.0028
	33 GHz	x	0.00055	0.0030
		y	0.00079	0.0030
K5c.CL/7	0.1GHz	x	0.00039	0.0032
		y	0.00010	0.0032
	12.4 GHz	x	0.0014	0.0042
		y	0.00045	0.0042
	26.5 GHz	x	0.0017	0.0059
		y	0.0013	0.0059
	33 GHz	x	0.0041	0.0066

		y	0.0061	0.0066
Loop 2				
K5c.CL/1	0.1GHz	*x*	0.00029	0.0018
		y	0.00012	0.0018
	12.4 GHz	*x*	0.00075	0.0024
		y	0.00057	0.0024
	26.5 GHz	*x*	0.0011	0.0032
		y	0.0015	0.0032
	33 GHz	*x*	0.0022	0.0036
		y	0.0016	0.0036
K5c.CL/2	0.1GHz	*x*	0.000026	0.00016
		y	0.000018	0.00016
	12.4 GHz	*x*	0.000070	0.00023
		y	0.000074	0.00023
	26.5 GHz	*x*	0.000093	0.00032
		y	0.00021	0.00032
	33 GHz	*x*	0.00036	0.00037
		y	0.000069	0.00037
K5c.CL/3	0.1GHz	*x*	0.0000031	0.000016
		y	0.0000011	0.000016
	12.4 GHz	*x*	0.0000063	0.000028
		y	0.000011	0.000028
	26.5 GHz	*x*	0.000023	0.000039
		y	0.0000083	0.000039
	33 GHz	*x*	0.0000090	0.000046
		y	0.000037	0.000046
K5c.CL/4	0.1GHz	*x*	0.0000079	0.0016
		y	0.0000030	0.0016
	12.4 GHz	*x*	0.000077	0.0020
		y	0.00023	0.0020
	26.5 GHz	*x*	0.00044	0.0028
		y	0.00066	0.0028
	33 GHz	*x*	0.0021	0.0030

		y	0.0021	0.0030
K5c.CL/7	0.1GHz	x	0.00024	0.0032
		y	0.000050	0.0032
	12.4 GHz	x	0.00094	0.0043
		y	0.0011	0.0043
	26.5 GHz	x	0.0021	0.0059
		y	0.0031	0.0059
	33 GHz	x	0.0036	0.0067
		y	0.0072	0.0067

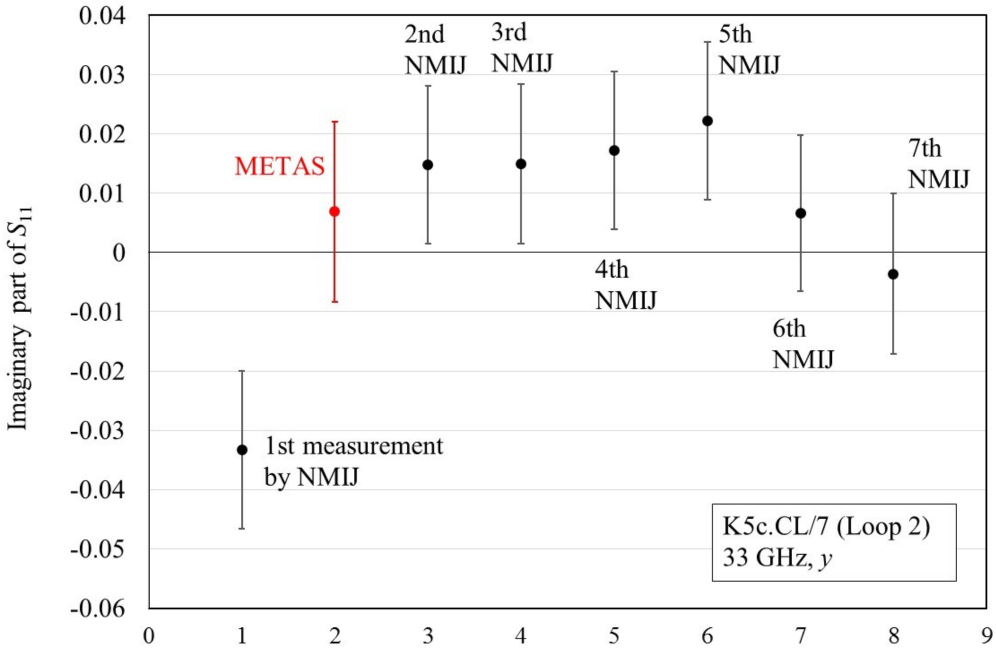


Fig. A5.1. Stability monitoring data of imaginary part of L5c.CL/7 (Loop 2) at 33 GHz.

Table A5.2. Stability of pin depth of travelling standards (Loop 1).

	K5c.CL/1		K5c.CL/2		K5c.CL/3		K5c.CL/4	K5c.CL/5	K5c.CL/6	K5c.CL/7
	Female	**Male**	**Female**	**Male**	**Female**	**Male**				
1st	8.5	17.7	34.5	32.3	38.6	48.5	7.9	13.4	-0.6	-0.5
2nd	9.5	18.2	34.9	32.8	38.6	49.4	8.7	14.3	-0.7	0.1
3rd	9.5	17.0	35.1	31.1	39.4	47.8	8.9	12.5	-1.4	-2.4
4th	9.9	17.0	35.2	31.7	39.1	47.6	5.9	12.2	-0.5	-0.4
5th	10.3	16.9	31.7	34.6	38.5	47.7	7.5	11.9	-0.8	-0.3
6th	8.0	15.5	34.6	31.2	38.6	47.6	7.3	12.9	-0.6	-0.8

Table A5.3. Stability of pin depth of travelling standards (Loop 2).

	K5c.CL/1		K5c.CL/2		K5c.CL/3		K5c.CL/4	K5c.CL/5	K5c.CL/6	K5c.CL/7
	Female	**Male**	**Female**	**Male**	**Female**	**Male**				
1st	7.1	15.5	35.6	35.9	38.7	48.3	8.3	8.1	-0.6	-0.6
2nd	7.3	15.8	35.8	37.2	39.2	49.2	7.9	8.5	-0.7	-0.0
3rd	6.8	15.5	39.8	36.6	42.6	48.8	12.0	8.3	1.5	-1.0
4th	1.4	18.3	36.0	35.6	38.7	48.4	8.8	7.7	-0.4	-0.4
5th	1.7	18.5	35.2	35.8	39.0	49.3	8.6	7.1	-0.4	-0.4
7th	-0.5	17.9	35.4	35.3	38.6	47.8	8.1	7.3	-0.5	-1.3