CCEM KEY COMPARISON CCEM.RF-K19.CL (GT-RF/00-2)

Attenuation at 60 MHz and 5 GHz using a Type N step attenuator

Final Report of the Pilot Laboratory

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This report is dedicated to the memory of Dr. Johannes (Jan) Petrus Maria de Vreede (1945 – 2007), metrologist, colleague and friend.

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[1] As of 1 Jan 2008, the National Metrology Centre moved from SPRING to the Agency for Science, Technology and Research (A*STAR). For the purposes of this report, they will still be referred to as SPRING.

1 Introduction

It is over ten years since the last CCEM (Consultative Committee on Electricity and Magnetism) RF / Microwave attenuation Intercomparison between National Metrology Institutions. The GT-RF Working Group meeting of 12 September 2000 approved a CIPM Key Comparison of Attenuation to be piloted by the National Physical Laboratory. It has been given the reference number CCEM-RF-K19.CL (previously GT-RF-00-02).

Participation in this Key Comparison was open to all CCEM members and, additionally, Signatories of the Metre Convention. A list of participants is given at the start of this report.

The travelling standards were two commercially available coaxial switched attenuators, terminated in precision Type N connectors. The measurement values and frequencies were selected to maximise the potential participants and to permit the participants to demonstrate fully the dynamic range of their measurement facilities.

2 Travelling Standards

Two travelling standards were used in this intercomparison: an HP 84907L (serial no. 2936A00473), which has a range of 0 to 70 dB in 10 dB steps (designated K19.CL/1); and an HP 8496H (serial no. 3247A12679), which has a range of 0 to 110 dB in 10 dB steps (designated K19.CL/2).

The HP 84907L is fitted with in-line connector adaptors to precision Type N (female) connectors. The attenuator body and the adaptors are mounted on an aluminium alloy base. The connections between the adaptors and the attenuator are covered in copper tape to reduce leakage. The measurement ports are identified by self adhesive labels.

Both standards are driven by a control unit (model HP11713A) that provides both manual and computer control. Both attenuators are used extensively by laboratories world wide, and many of the participants should already have been familiar with their operation and already own suitable control software to integrate them into their measurement systems. Should this not have been the case, programming and operational instructions were supplied with the standards. The attenuator dimensions do not exceed 79 mm by 48 mm by 168 mm and they weigh less than 1 kg each.

The specific devices were chosen for stability and repeatability prior to the start of the comparison.

3 Comparison Protocol and Schedule

The travelling standards were circulated to the participants, who were asked to provide the following measurements:

- Nominal attenuation steps 20 dB, 40 dB, 60 dB and 70 dB of standard K.19/CL1
- Nominal attenuation steps 20 dB, 40 dB, 60 dB, 80 dB, 100 dB and 110 dB of standard K19.CL/2

These measurements were to be made at 60 MHz and 5 GHz.

Attenuation (dB)	**SOCKET 'X' or 'Y'**			
	1	**2**	**3**	**4**
0				
20		X		
40			X	
60		X	X	
70	X	X	X	
80			X	X
100		X	X	X
110	X	X	X	X

Table 1 – Attenuator switch positions for use in this intercomparison

Each attenuator contains two separate 40 dB steps; there are therefore two possible combinations for the nominal 40 dB, 60 dB and 70 dB steps. So that the same step was measured throughout this intercomparison, the protocol [1] outlined the switch settings for each step as shown in Table 1.

Laboratory	Date of Measurement
PTB (Germany)	January 2002
VNIIFTRI (Russia)	June 2002
SIQ (Slovenia)	August 2002
CSIR (South Africa)	October 2002
NPL (UK)	December 2002
NRC (Canada)	February 2003
NIST (USA)	April 2003
NMIJ (Japan)	May 2003
NIM (China)	July 2003
CMI (Czech Republic)	August 2003
SP (Sweden)	September 2003
INRIM (Italy)	October 2003
NMi-VSL (Netherlands)	November 2003
METAS (Switzerland)	December 2003
LNE (France)	February 2004
UME (Turkey)	March 2004
KRISS (South Korea)	May 2004
MIKES (Finland)	October 2004
SPRING (Singapore)	March 2005
INRIM (Italy) repeat	October 2006
NMIA (Australia)	January 2007

Table 2 – Dates of measurements for this intercomparison

Table 3 – Summary of the measurement techniques used by each participant

Laboratory	Method: 60 MHz	Standard: 60 MHz	Method: 5 GHz	Standard: 5 GHz
NPL	Voltage ratio / AF substitution	Inductive voltage divider	Voltage ratio / AF substitution	Inductive voltage divider
NIST	Six-port	Airline length	Commercial VNA	Airline length
LNE	Power ratio / IF substitution		Power ratio / IF substitution	
PTB	Power ratio / DC substitution (to 30 dB) RF series substitution (above 30 dB)	DC voltage	Power ratio / DC substitution (to 30 dB) RF series substitution (above 30 dB)	DC voltage
NMIJ	Voltage ratio / IF substitution	Inductive voltage divider	Voltage ratio / IF substitution	Inductive voltage divider
CMI	Measuring Receiver		Measuring Receiver	
CSIR	Measuring Receiver	WBCO attenuator	Measuring Receiver & Microwave Mixer	WBCO attenuator
NRC	AF substitution	Inductive voltage divider	AF substitution	Inductive voltage divider
NMi-VSL	Commercial VNA	Calibrated attenuator	Commercial VNA	Calibrated attenuator
METAS	IF substitution	WBCO attenuator	IF substitution	WBCO attenuator
SP	Commercial VNA	Calibrated airline and attenuator	Commercial VNA	Calibrated airline and attenuator
UME	Commerical VNA	Calibrated airline and attenuator	Commercial VNA	Calibrated airline and attenuator
SPRING	Voltage ratio / IF substitution	Inductive voltage divider	Voltage ratio / IF substitution	Inductive voltage divider
NIM	AF substitution	Inductive voltage divider	AF substitution	Inductive voltage divider
SIQ	Measuring Receiver	Reference attenuator		
MIKES	Commercial VNA	Calibrated attenuator	Commercial VNA	Calibrated attenuator
KRISS	RF substitution	DC voltage	RF substitution	DC voltage
INRIM	Commercial VNA	Length standards	Commercial VNA	Length standards
VNIIFTRI	Series substitution RF attenuation on low IF	Inductive voltage divider	Parallel substitution RF attenuation on IF	Resistive attenuator on IF
NMIA	IF substitution	WBCO attenuator	IF substitution	WBCO attenuator

The majority of measurements were made between January 2002 and March 2005, with initial and final measurements made at NPL in October 2001 and January 2006 respectively. These measurements were performed to monitor any drift in the standards over the period of the comparison and, in line with the protocol, NPL's only other measurement, which was performed in December 2002, is considered in the analysis of the results. INRIM performed a repeat measurement towards the end of 2006 after the first Draft A review. NMIA expressed interest in participation after NPL had performed the third measurement and, since the comparison was still at Draft A reporting stage, it was felt that NMIA should be allowed to participate. Table 2 gives an indication of the dates when the measurements took place at each laboratory. The original timetable was not strictly adhered to, owing to delays in customs and shipping.

4 Summary of Measurement Techniques

Table 3 gives a brief summary of the measurement techniques employed by each participant. A full description of the methods, as provided by each participant, can be found in Appendix B.

5 Discussion of the Results

The results were presented to the pilot laboratory in the format of the logarithmic dB value of the various attenuation values of the two travelling standards.

Although several attenuation step values were measured and reported to the pilot laboratory, only a selection are presented for analysis in this section of the report. The chosen measurands are:

- Measurement of the nominal 20 dB step on both standards at 60 MHz and 5 GHz
- Measurement of the nominal 60 dB step on both standards at 60 MHz and 5 GHz
- Measurement of the nominal 100 dB step on standard K19.CL/2 at 60 MHz and 5 GHz

These values were chosen to provide a measurement at low, medium and high values of attenuation.

Participants were also asked to provide estimates of the Type A and Type B uncertainties and the combined standard uncertainty (at one standard deviation) for the aforementioned measurands.

The measurement results and associated standard uncertainties together with the reference values and associated standard uncertainties (rounded to three decimal places) can be found in Tables 4 – 13.

It is interesting to note that there is a large variation in the reported uncertainties from each participant. The best explanation for this would be due to the different types of measurement system used by the participants.

Particularly at the higher attenuation steps, those participants with dedicated attenuation measurement systems (IF substitution, voltage ratio, etc.) report lower uncertainties than those choosing to use a network analyser to perform the measurement.

Due to this stark contrast in the reported uncertainties, there are two graphs in each of Figs 1 – 8 for each of the reported attenuation measurements: (a) measurements performed on dedicated attenuation systems; and (b) measurements performed on network analysers. Figs 9 and 10 contain only one graph as participants using network analysers did not make a measurement of the 100 dB step[2].

The results on the graphs are plotted as they were reported, i.e., they are not rounded in any way (some participants reported results to four decimal places), so there may be a slight difference between some of the graphs and the corresponding tables of results.

INRIM is included twice in Tables 4 – 11 after a request during the first Draft A review to perform a repeat measurement; both sets of measurements have been included. The graphs and degree of equivalence tables contain only INRIM's second reported measurements.

INRIM requested this repeat because it was felt that the first measurement was performed

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[2] With the exception of NMi-VSL, who are not included on the graph due to their relatively high reported uncertainty.

incorrectly. It was agreed to report the results in this way as this was more efficient than performing a subsequent bilateral comparison. This does not affect the KCRV in any way as INRIM's results are not used due to the measurements having been performed using a network analyser.

Appendix A describes the methods used to determine the key comparison reference value, and its associated uncertainty, along with the degrees of equivalence with respect to the key comparison reference value (KCRV) and between participants for the measurands described above. Only those measurements from participants who are CCEM members contribute to the calculation of the KCRV. Results from participants with traceability to other laboratories within this comparison were not used to calculate the key comparison reference value, neither were those from participants whose measurements were made on network analysers, regardless of their traceability path, due to their higher uncertainties[3].

All uncertainty budgets provided by the participants can be found in Appendix C. Appendix D contains the full set of reported results (i.e., all reported attenuation steps at both frequencies for both devices).

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[3] CMI is not a member of CCEM, but is an observer; therefore CMI's results are not included in the calculation of the KCRV. SIQ and UME are not members either (UME is an observer) but would be excluded from the KCRV anyway due to traceability to another participant and use of a network analyser to perform the measurement, respectively.

Table 4a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/1 at 60 MHz	
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)
NPL	19.953	0.001
LNE	19.950	0.010
PTB	19.953	0.001
NMIJ	19.950	0.001
CSIR	19.951	0.009
NRC	19.950	0.011
METAS	19.954	0.003
NIM	19.952	0.002
KRISS	19.953	0.002
VNIIFTRI	19.953	0.001
	A_{20_R} (dB)	$u(A_{20\_R})$ (dB)
Reference value	19.952	0.002

Table 4b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/1 at 60 MHz		
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)	Reason for exclusion
NIST	19.952	0.007	VNA measurement
CMI	19.948	0.012	Non-CCEM member
NMi-VSL	19.953	0.025	VNA measurement
SP	19.942	0.007	VNA measurement
UME	19.951	0.032	VNA measurement / Non-CCEM member
SPRING	19.952	0.002	Traceable to other participant
SIQ	19.954	0.016	Traceable to other participant / Non-CCEM member
MIKES	19.947	0.013	VNA measurement
INRIM	19.964	0.011	Replaced by repeat
INRIM repeat	19.952	0.022	VNA measurement
NMIA	19.944	0.003	Statistical outlier[4]

All uncertainties are given for coverage factor $k = 1$.

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[4] The term 'outlier' used here does not necessarily mean a measurement that is bad in the sense that the assigned uncertainty is underestimated due to unrecognised systematic effects, rather a value that lies outside a statistically derived interval used to determine the KCRV. In this case, it is a suspected drift within the attenuator that may have caused this statistical anomaly – see Appendix E for more details.

Table 5a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/1 at 5 GHz	
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)
NPL	19.956	0.001
LNE	19.950	0.012
PTB	19.951	0.001
NMIJ	19.947	0.001
CSIR	19.951	0.020
NRC	19.951	0.011
METAS	19.947	0.004
NIM	19.947	0.003
KRISS	19.958	0.005
VNIIFTRI	19.956	0.001
	A_{20_R} (dB)	$u(A_{20\_R})$ (dB)
Reference value	19.951	0.003

Table 5b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/1 at 5 GHz		
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)	Reason for exclusion
NIST	19.939	0.010	VNA measurement
CMI	19.942	0.013	Non-CCEM member
NMi-VSL	19.931	0.024	VNA measurement
SP	19.942	0.025	VNA measurement
UME	19.947	0.032	VNA measurement / Non-CCEM member
SPRING	19.947	0.003	Traceable to other participant
SIQ	Not provided	Not provided	
MIKES	19.940	0.020	VNA measurement
INRIM	19.909	0.002	Replaced by repeat
INRIM repeat	19.943	0.008	VNA measurement
NMIA	19.937	0.004	Statistical outlier[5]

All uncertainties are given for coverage factor *k* = 1.

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[5] Again, this statistical anomaly is probably due to a drift within the attenuator itself – see Appendix E for more details.

Table 6a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/1 at 60 MHz	
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)
NPL	60.070	0.002
LNE	60.070	0.024
PTB	60.071	0.002
NMIJ	60.069	0.002
NRC	60.080	0.024
METAS	60.075	0.004
NIM	60.068	0.003
KRISS	60.069	0.004
VNIIFTRI	60.070	0.001
NMIA	60.060	0.006
	A_{60_R} (dB)	$u(A_{60\_R})$ (dB)
Reference value	60.070	0.004

Table 6b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/1 at 60 MHz		
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)	Reason for exclusion
NIST	60.055	0.086	VNA measurement
CMI	60.053	0.023	Non-CCEM member
NMi-VSL	60.070	0.066	VNA measurement
SP	60.076	0.018	VNA measurement
UME	60.070	0.258	VNA measurement / Non-CCEM member
SPRING	60.072	0.007	Traceable to other participant
SIQ	60.058	0.027	Traceable to other participant / Non-CCEM member
MIKES	60.065	0.037	VNA measurement
INRIM	60.138	0.086	Replaced by repeat
INRIM repeat	60.059	0.096	VNA measurement
CSIR	60.044	0.013	Statistical outlier

All uncertainties are given for coverage factor $k = 1$.

Table 7a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/1 at 5 GHz	
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)
NPL	60.069	0.002
LNE	60.070	0.027
PTB	60.059	0.005
NMIJ	60.058	0.002
CSIR	60.053	0.020
NRC	60.060	0.024
METAS	60.063	0.006
NIM	60.062	0.004
KRISS	60.074	0.007
VNIIFTRI	60.074	0.002
NMIA	60.049	0.007
	A_{60_R} (dB)	$u(A_{60\_R})$ (dB)
Reference value	60.063	0.004

Table 7b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/1 at 5 GHz		
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)	Reason for exclusion
NIST	60.037	0.081	VNA measurement
CMI	60.037	0.024	Non-CCEM member
NMi-VSL	60.032	0.071	VNA measurement
SP	59.996	0.085	VNA measurement
UME	60.044	0.258	VNA measurement / Non-CCEM member
SPRING	60.063	0.006	Traceable to other participant
SIQ	Not provided	Not provided	
MIKES	60.058	0.040	VNA measurement
INRIM	60.491	0.058	Replaced by repeat
INRIM repeat	60.060	0.058	VNA measurement

All uncertainties are given for coverage factor $k = 1$.

Table 8a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/2 at 60 MHz	
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)
NPL	19.945	0.001
LNE	19.940	0.010
PTB	19.944	0.001
NMIJ	19.944	0.001
METAS	19.945	0.003
NIM	19.944	0.002
KRISS	19.943	0.002
VNIIFTRI	19.944	0.001
	A_{20_R} (dB)	$u(A_{20\_R})$ (dB)
Reference value	19.944	0.001

Table 8b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/2 at 60 MHz		
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)	Reason for exclusion
CSIR	19.938	0.008	Statistical outlier
NRC	19.934	0.011	Statistical outlier
NIST	19.944	0.007	VNA measurement
CMI	19.939	0.012	Non-CCEM member
NMi-VSL	19.958	0.023	VNA measurement
SP	19.942	0.007	VNA measurement
UME	19.947	0.032	VNA measurement / Non-CCEM member
SPRING	19.943	0.002	Traceable to other participant
SIQ	19.946	0.016	Traceable to other participant / Non-CCEM member
MIKES	19.937	0.013	VNA measurement
INRIM	19.990	0.011	Replaced by repeat
INRIM repeat	19.944	0.022	VNA measurement
NMIA	19.938	0.002	Statistical outlier

All uncertainties are given for coverage factor $k = 1$.

Table 9a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/2 at 5 GHz	
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)
NPL	19.931	0.003
LNE	19.930	0.016
PTB	19.938	0.003
NMIJ	19.931	0.002
CSIR	19.913	0.040
NRC	19.933	0.010
METAS	19.940	0.006
NIM	19.939	0.006
KRISS	19.938	0.006
VNIIFTRI	19.948	0.002
NMIA	19.927	0.006
	A_{20_R} (dB)	$u(A_{20\_R})$ (dB)
Reference value	19.933	0.004

Table 9b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 20 dB attenuation step of K19.CL/2 at 5 GHz		
	A_{20_i} (dB)	$u(A_{20\_i})$ (dB)	Reason for exclusion
NIST	19.922	0.010	VNA measurement
CMI	19.918	0.014	Non-CCEM member
NMi-VSL	20.024	0.063	VNA measurement
SP	19.936	0.025	VNA measurement
UME	19.934	0.032	VNA measurement / Non-CCEM member
SPRING	19.933	0.003	Traceable to other participant
SIQ	Not provided	Not provided	
MIKES	19.925	0.021	VNA measurement
INRIM	19.791	0.002	Replaced by repeat
INRIM repeat	19.930	0.007	VNA measurement

All uncertainties are given for coverage factor $k = 1$.

Table 10a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/2 at 60 MHz	
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)
NPL	60.140	0.001
LNE	60.140	0.025
PTB	60.138	0.003
NMIJ	60.138	0.002
NRC	60.138	0.024
METAS	60.140	0.004
NIM	60.135	0.003
KRISS	60.132	0.004
VNIIFTRI	60.136	0.001
	A_{60_R} (dB)	$u(A_{60\_R})$ (dB)
Reference value	60.138	0.004

Table 10b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/2 at 60 MHz		
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)	Reason for exclusion
CSIR	60.124	0.012	Statistical outlier
NIST	60.127	0.083	VNA measurement
CMI	60.111	0.025	Non-CCEM member
NMi-VSL	60.150	0.065	VNA measurement
SP	60.143	0.018	VNA measurement
UME	60.134	0.258	VNA measurement / Non-CCEM member
SPRING	60.137	0.007	Traceable to other participant
SIQ	60.144	0.027	Traceable to other participant / Non-CCEM member
MIKES	60.132	0.037	VNA measurement
INRIM	60.244	0.088	Replaced by repeat
INRIM repeat	60.141	0.098	VNA measurement
NMIA	60.125	0.006	Statistical outlier

All uncertainties are given for coverage factor $k = 1$.

Table 11a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/2 at 5 GHz	
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)
NPL	60.098	0.004
LNE	60.100	0.035
PTB	60.108	0.007
NMIJ	60.099	0.003
NRC	60.096	0.024
METAS	60.111	0.007
NIM	60.106	0.007
KRISS	60.103	0.007
VNIIFTRI	60.115	0.005
NMIA	60.083	0.009
	A_{60_R} (dB)	$u(A_{60\_R})$ (dB)
Reference value	60.102	0.005

Table 11b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 60 dB attenuation step of K19.CL/2 at 5 GHz		
	A_{60_i} (dB)	$u(A_{60\_i})$ (dB)	Reason for exclusion
CSIR	60.076	0.050	Statistical outlier
NIST	60.082	0.081	VNA measurement
CMI	60.061	0.026	Non-CCEM member
NMi-VSL	60.200	0.071	VNA measurement
SP	60.171	0.088	VNA measurement
UME	60.109	0.258	VNA measurement / Non-CCEM member
SPRING	60.098	0.007	Traceable to other participant
SIQ	Not provided	Not provided	
MIKES	60.091	0.041	VNA measurement
INRIM	60.099	0.010	Replaced by repeat
INRIM repeat	60.095	0.015	VNA measurement

All uncertainties are given for coverage factor $k = 1$.

Table 12a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 100 dB attenuation step of K19.CL/2 at 60 MHz	
	A_{100_i} (dB)	$u(A_{100\_i})$ (dB)
NPL	100.277	0.002
LNE	100.280	0.040
PTB	100.277	0.004
NMIJ	100.274	0.008
METAS	100.278	0.007
NIM	100.270	0.008
VNIIFTRI	100.273	0.002
	A_{100_R} (dB)	$u(A_{100\_R})$ (dB)
Reference value	100.276	0.006

Table 12b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 100 dB attenuation step of K19.CL/2 at 60 MHz		
	A_{100_i} (dB)	$u(A_{100\_i})$ (dB)	Reason for exclusion
CSIR	100.260	0.040	Statistical outlier
NIST	Not provided	Not provided	
CMI	100.240	0.221	Non-CCEM member
NMi-VSL	100.303	0.907	VNA measurement
SP	Not provided	Not provided	
UME	Not provided	Not provided	
SPRING	100.294	0.018	Traceable to other participant
SIQ	100.263	0.091	Traceable to other participant / Non-CCEM member
MIKES	Not provided	Not provided	
INRIM	Not provided	Not provided	
NRC	Not provided	Not provided	
KRISS	Not provided	Not provided	
NMIA	Not provided	Not provided	

All uncertainties are given for coverage factor $k = 1$.

Table 13a – Reported measurements used to calculate the KCRV

Lab *i*	Measurement and Combined Uncertainty of 100 dB attenuation step of K19.CL/2 at 5 GHz	
	A_{100_i} (dB)	$u(A_{100\_i})$ (dB)
NPL	100.246	0.006
LNE	100.230	0.052
PTB	100.260	0.030
NMIJ	100.241	0.007
METAS	100.234	0.034
NIM	100.243	0.010
	A_{100_R} (dB)	$u(A_{100\_R})$ (dB)
Reference value	100.242	0.012

Table 13b – Other reported measurements not used in the determination of the KCRV

Lab *i*	Measurement and Combined Uncertainty of 100 dB attenuation step of K19.CL/2 at 5 GHz		
	A_{100_i} (dB)	$u(A_{100\_i})$ (dB)	Reason for exclusion
CSIR	100.200	0.060	Statistical outlier
NIST	Not provided	Not provided	
CMI	100.150	0.145	Non-CCEM member
NMi-VSL	100.447	2.824	VNA measurement
SP	Not provided	Not provided	
UME	Not provided	Not provided	
SPRING	100.233	0.011	Traceable to other participant
SIQ	Not provided	Not provided	
MIKES	Not provided	Not provided	
INRIM	Not provided	Not provided	
NRC	Not provided	Not provided	
KRISS	Not provided	Not provided	
VNIIFTRI	100.331	0.030	Statistical outlier
NMIA	Not provided	Not provided	

All uncertainties are given for coverage factor $k = 1$.

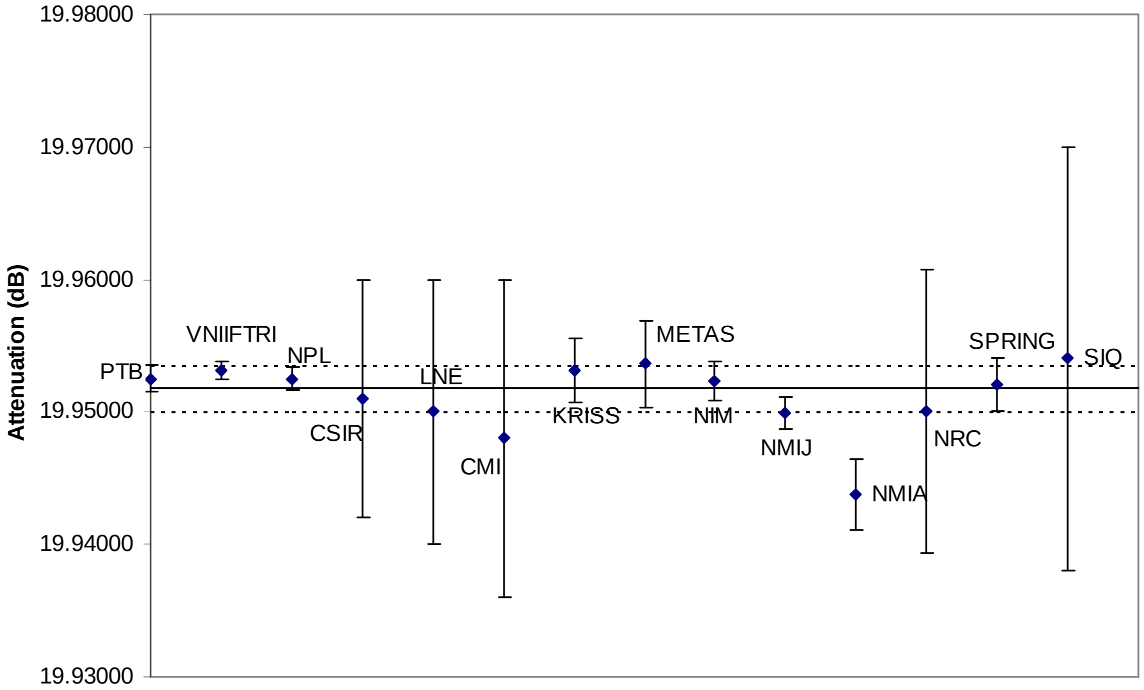

Fig 1a – K19.CL/1 device 20 dB step at 60 MHz: participants using attenuation systems

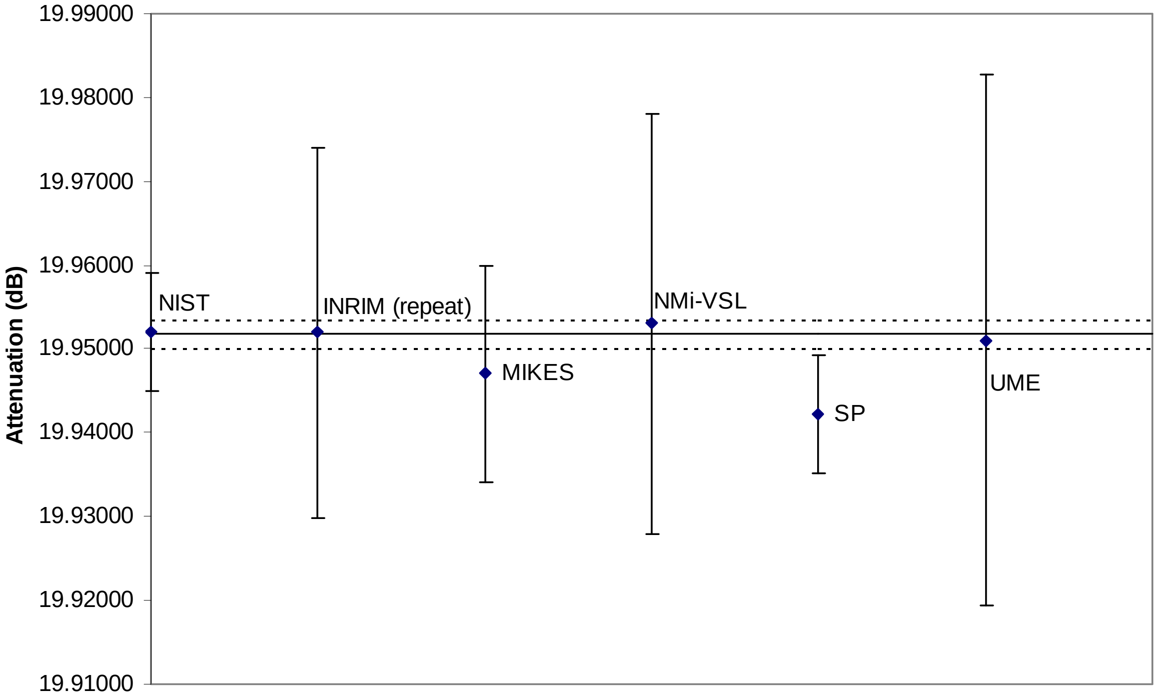

Fig 1b – K19.CL/1 device 20 dB step at 60 MHz: particpants using network analysers

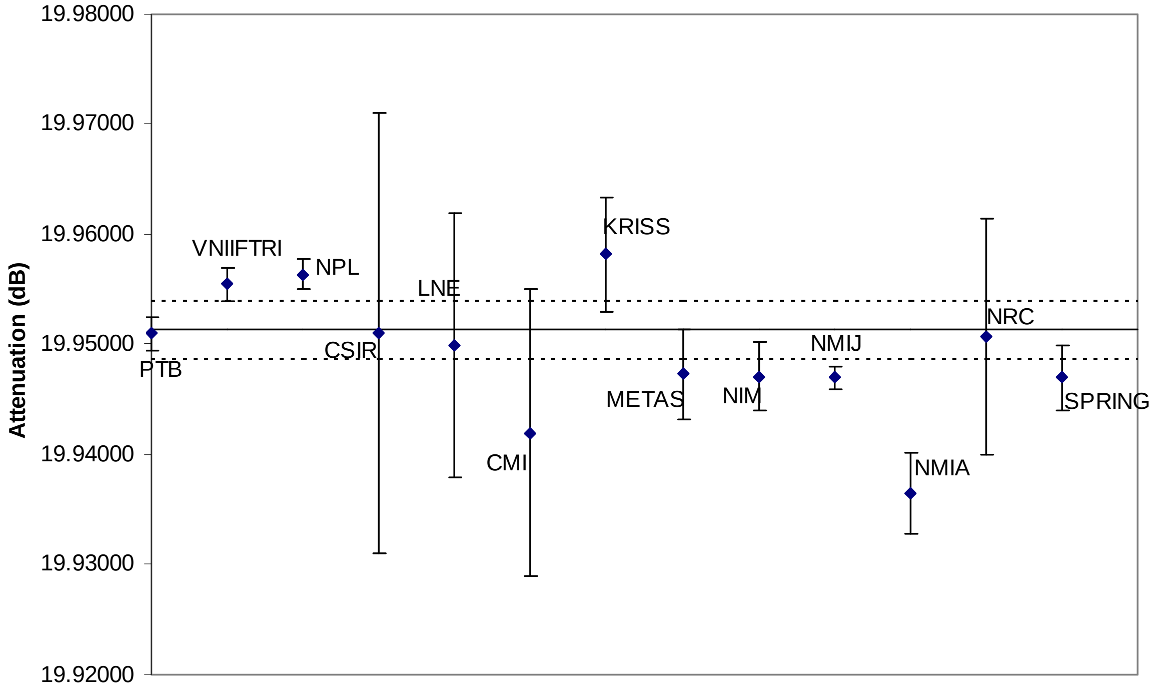

Fig 2a – K19.CL/1 device 20 dB step at 5 GHz: participants using attenuation systems

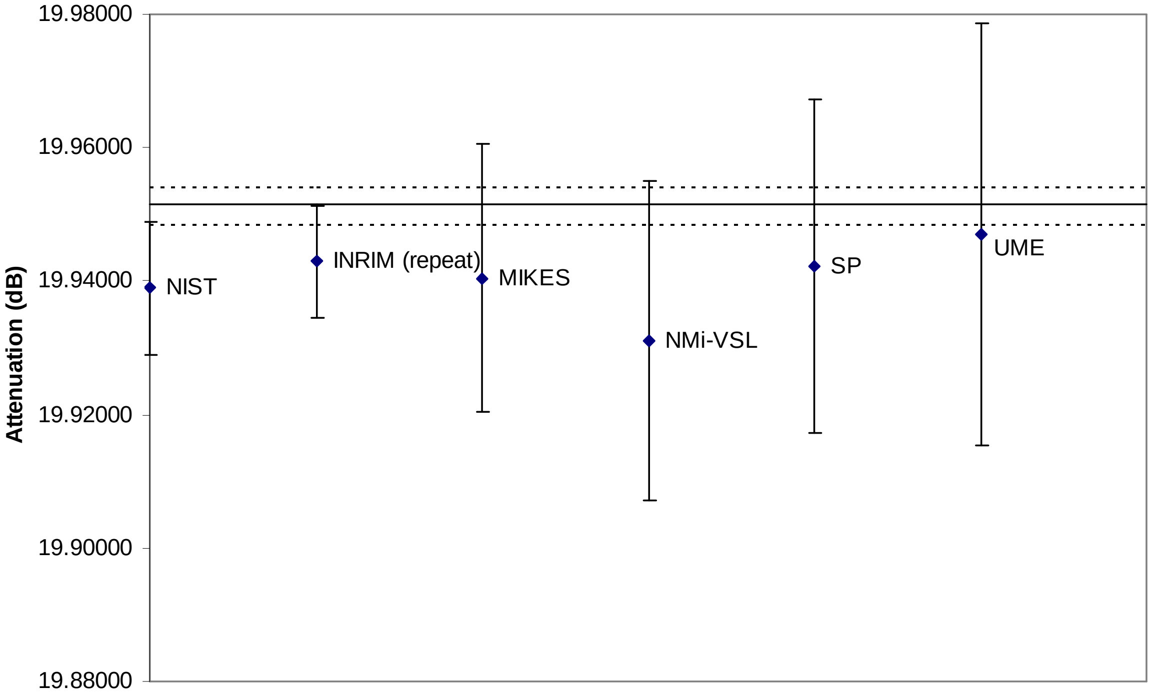

Fig 2b – K19.CL/1 device 20 dB step at 5 GHz: particpants using network analysers

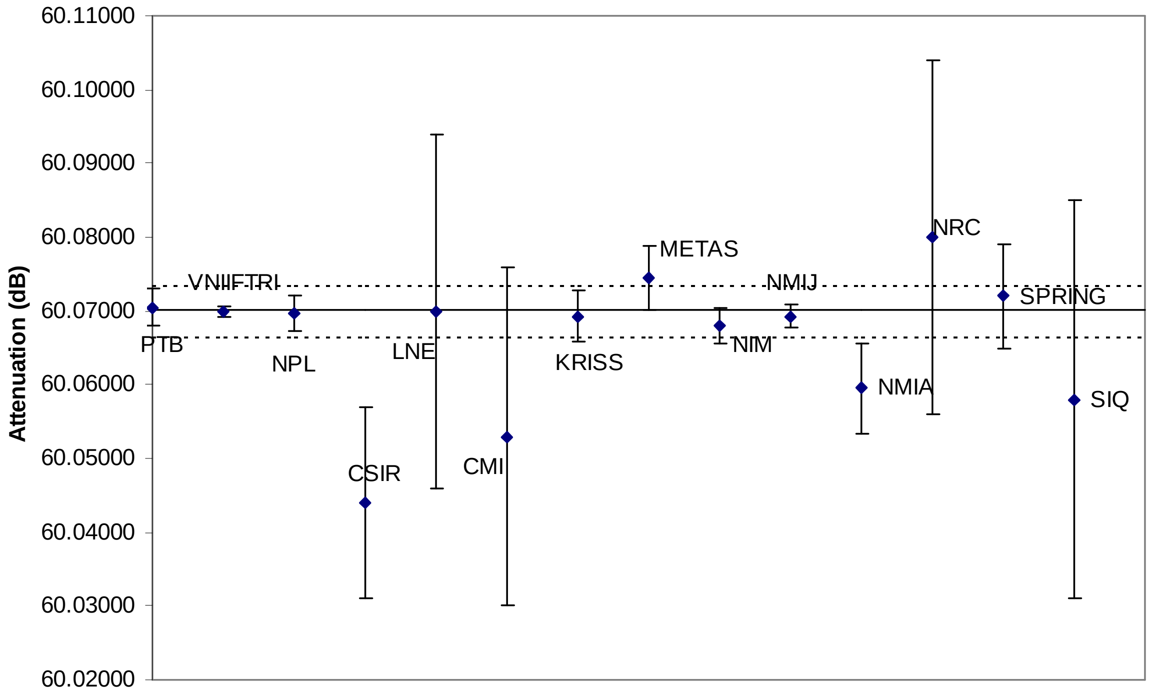

Fig 3a – K19.CL/1 device 60 dB step at 60 MHz: participants using attenuation systems

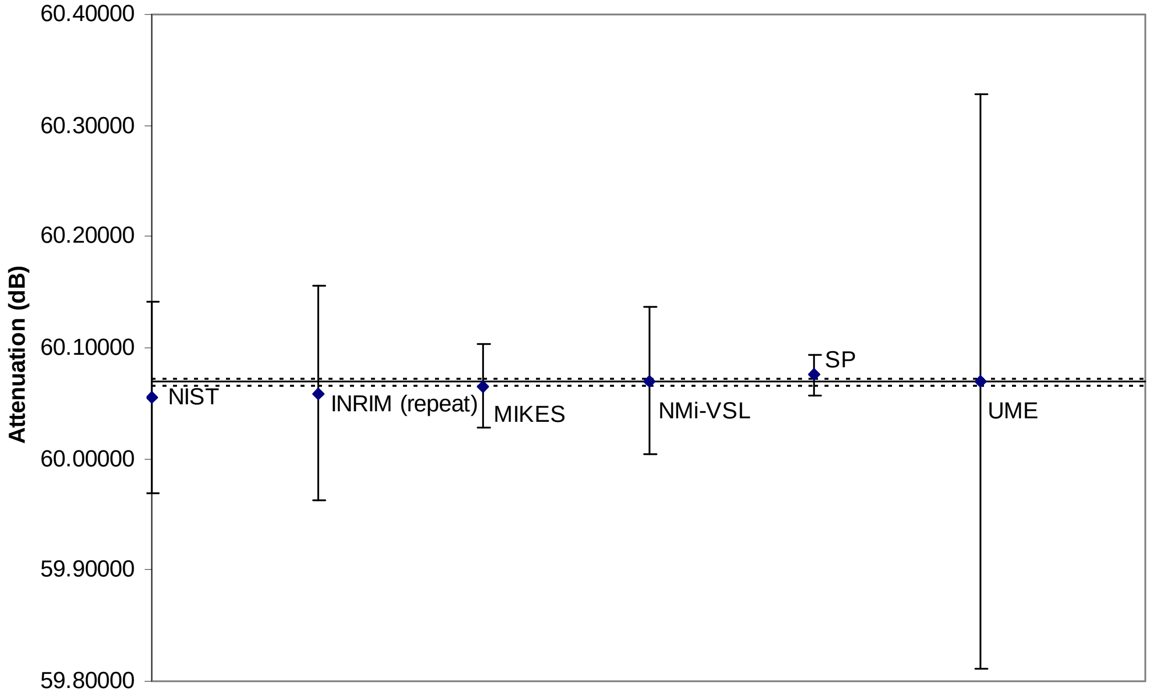

Fig 3b – K19.CL/1 device 60 dB step at 60 MHz: participants using network analysers

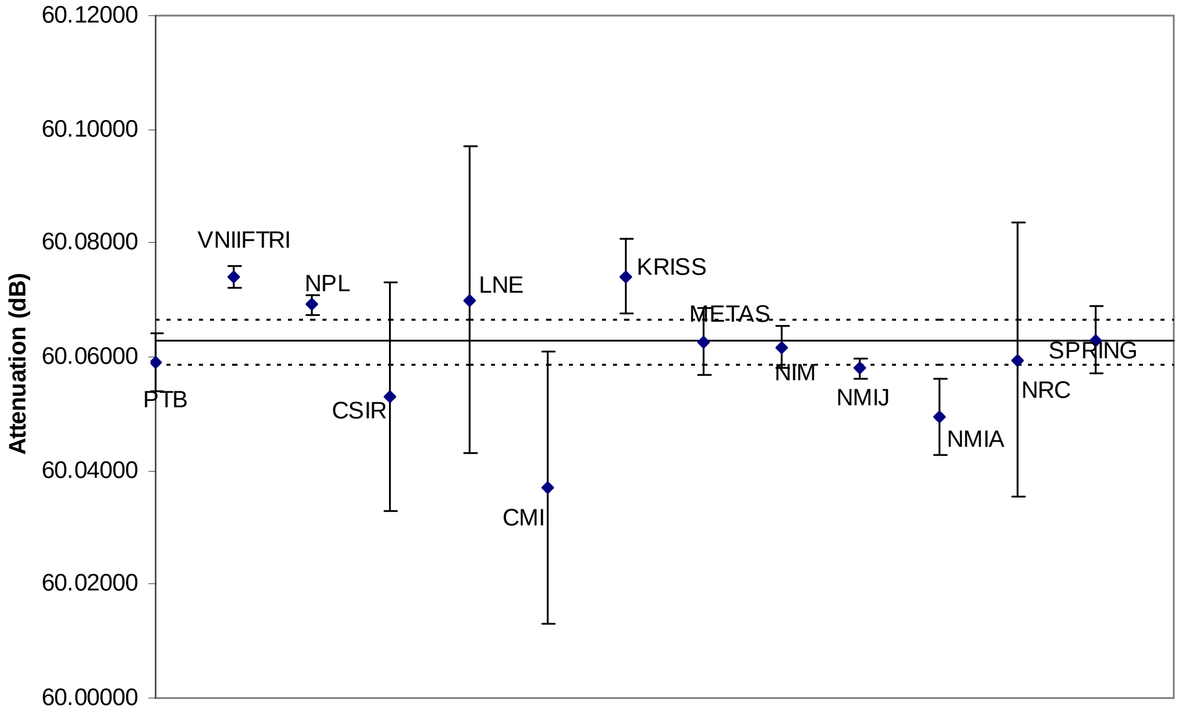

Fig 4a – K19.CL/1 device 60 dB step at 5 GHz: participants using attenuation systems

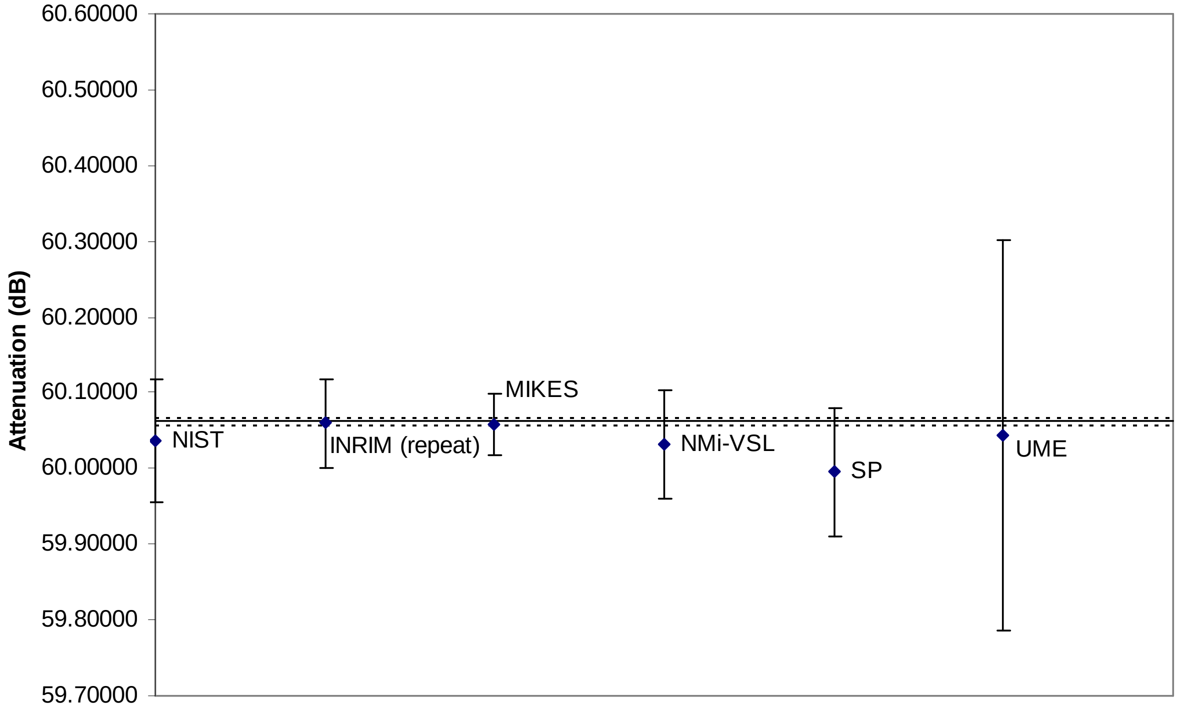

Fig 4b – K19.CL/1 device 60 dB step at 5 GHz: participants using network analysers

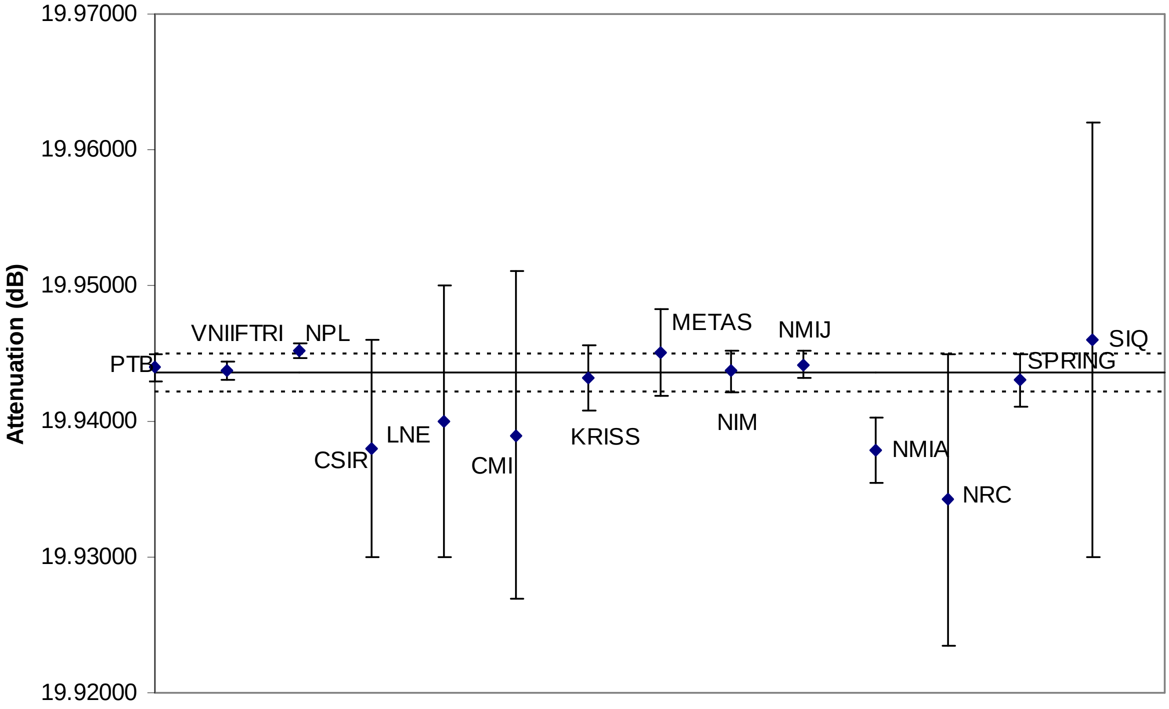

Fig 5a – K19.CL/2 device 20 dB step at 60 MHz: participants using attenuation systems

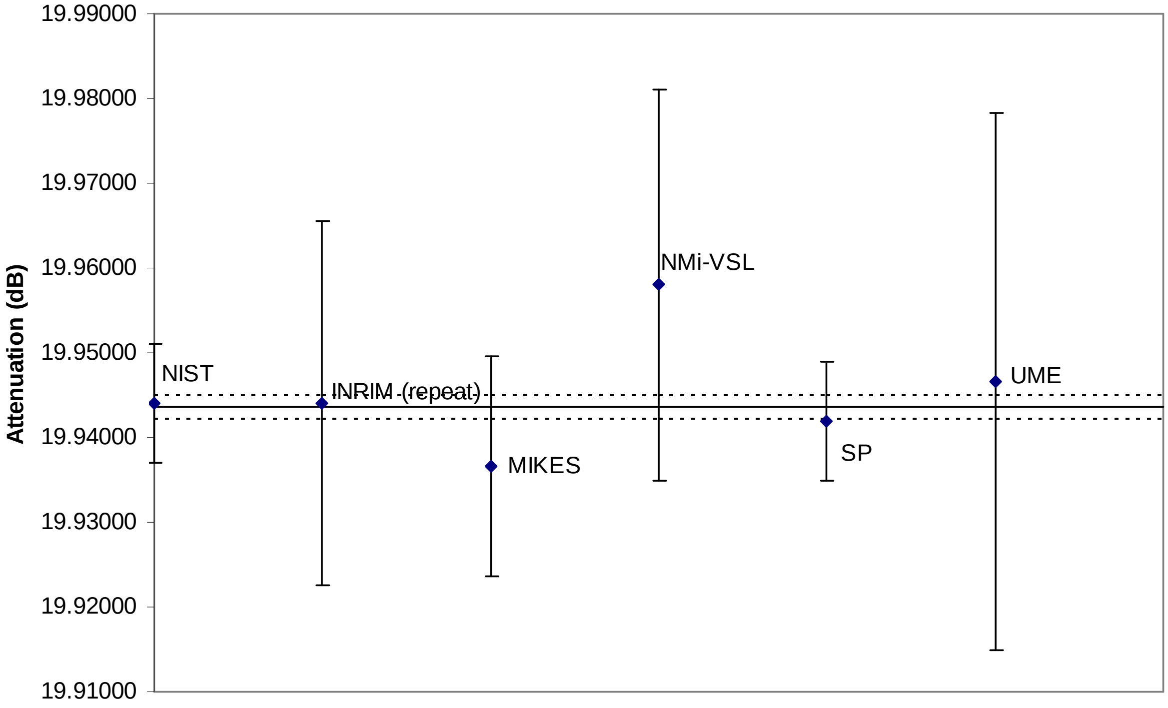

Fig 5b – K19.CL/2 device 20 dB step at 60 MHz: participants using network analysers

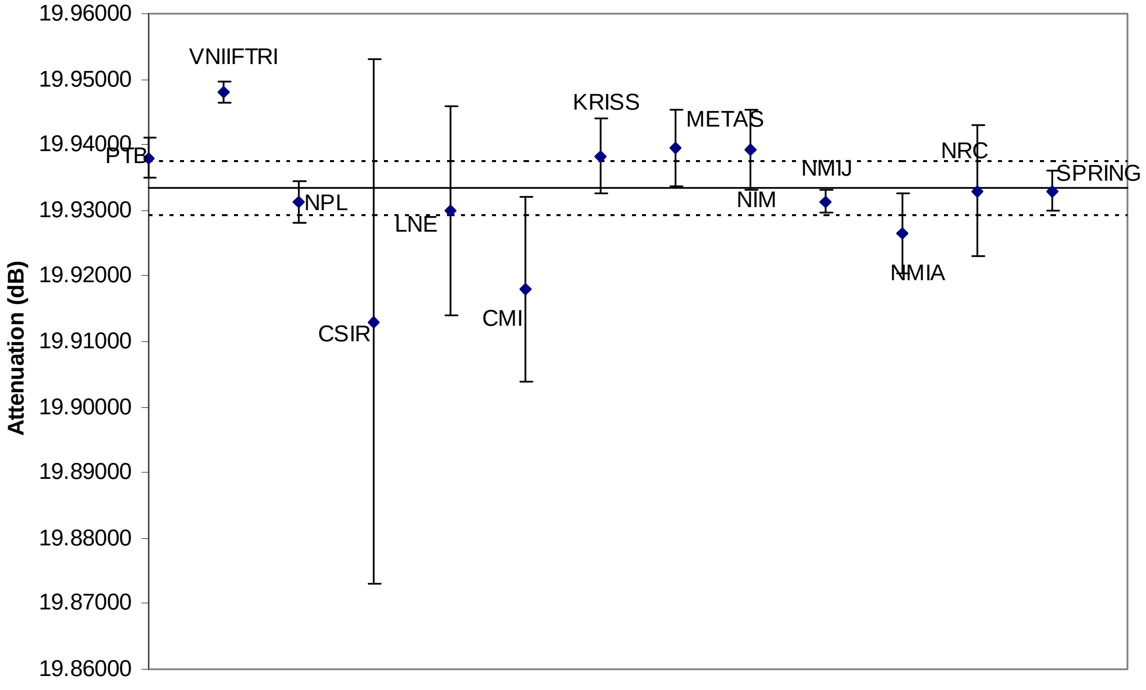

Fig 6a – K19.CL/2 device 20 dB step at 5 GHz: participants using attenuation systems

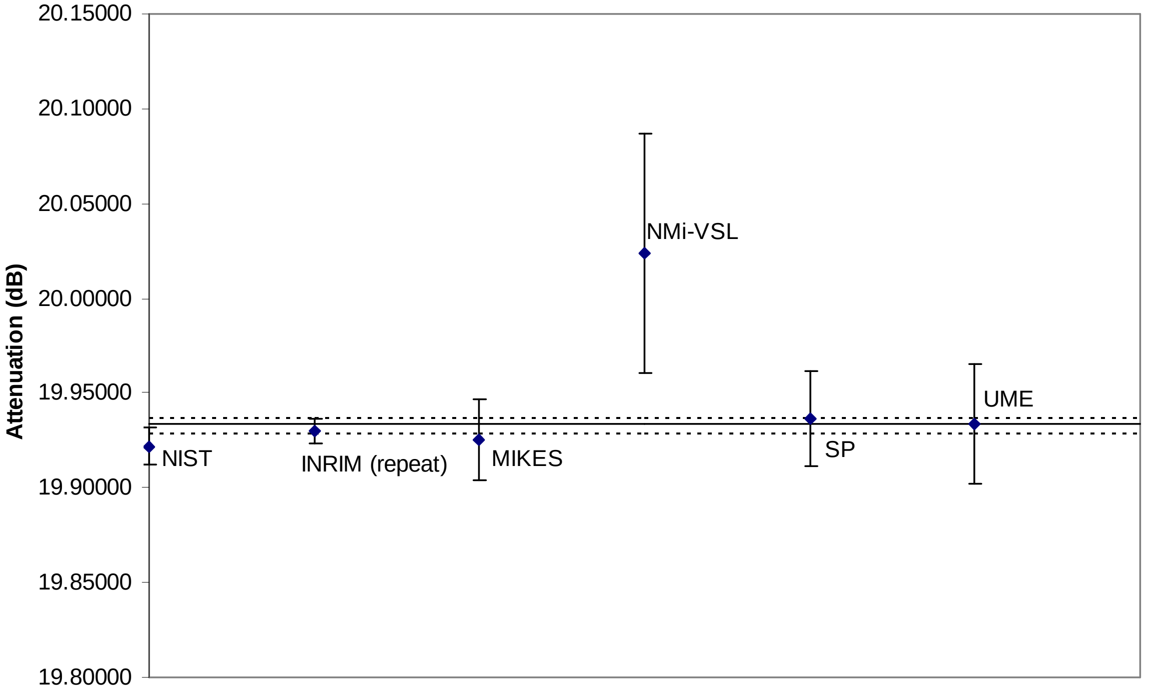

Fig 6b – K19.CL/2 device 20 dB step at 5 GHz: participants using network analysers

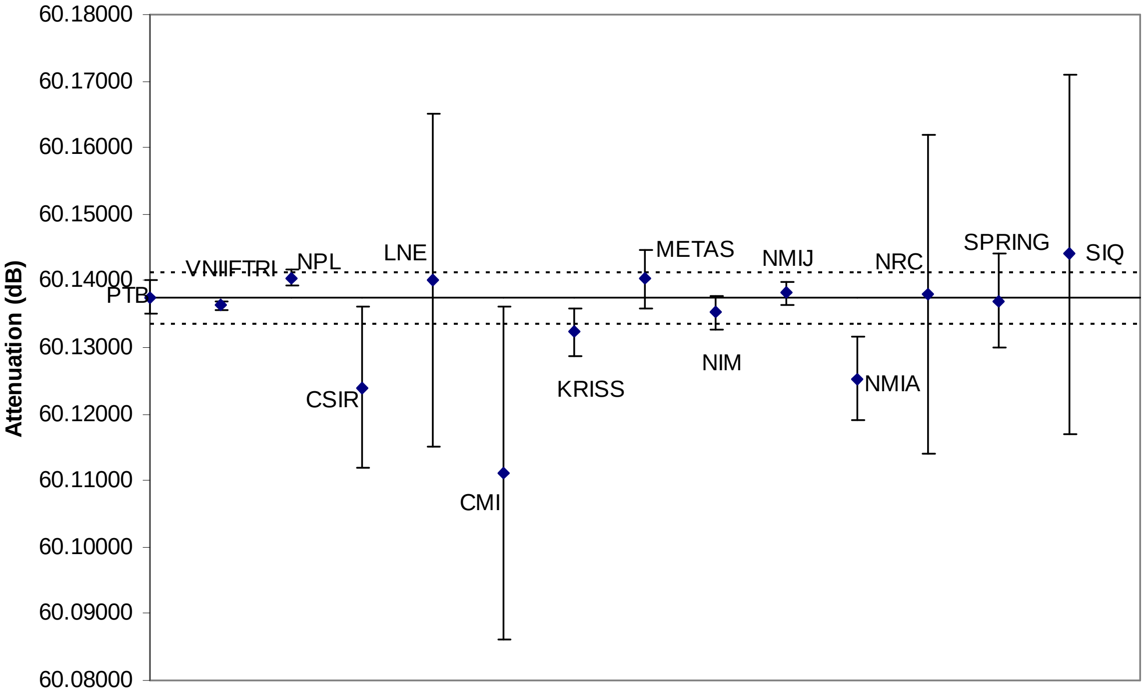

Fig 7a – K19.CL/2 device 60 dB step at 60 MHz: participants using attenuation systems

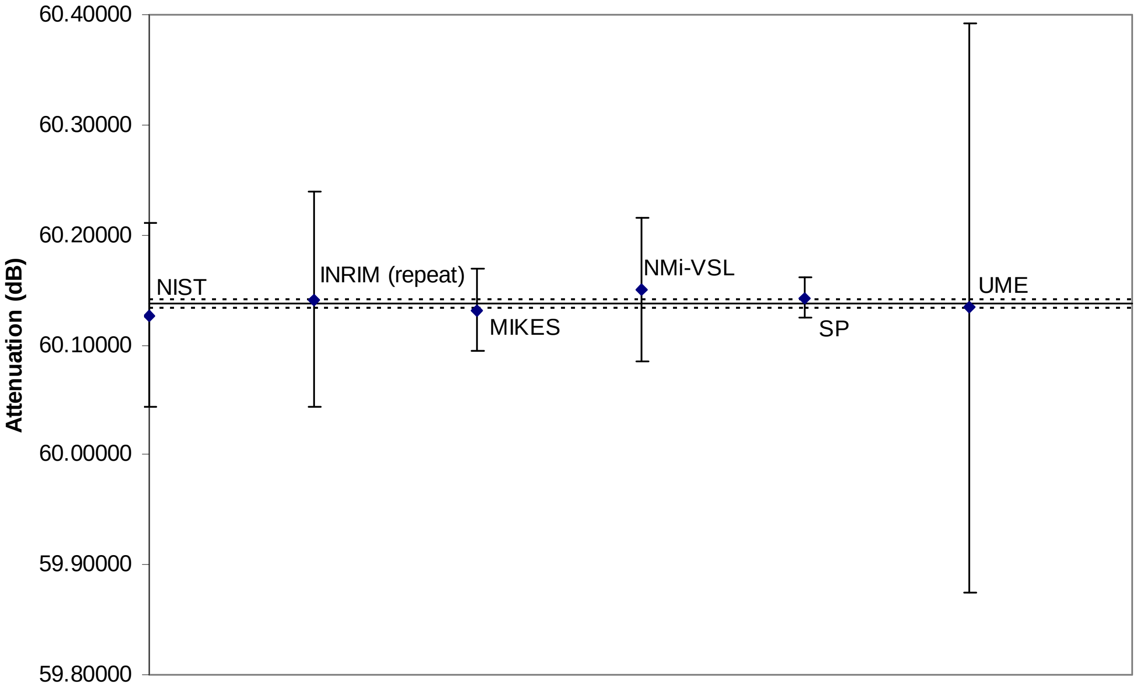

Fig 7b – K19.CL/2 device 60 dB step at 60 MHz: participants using network analysers

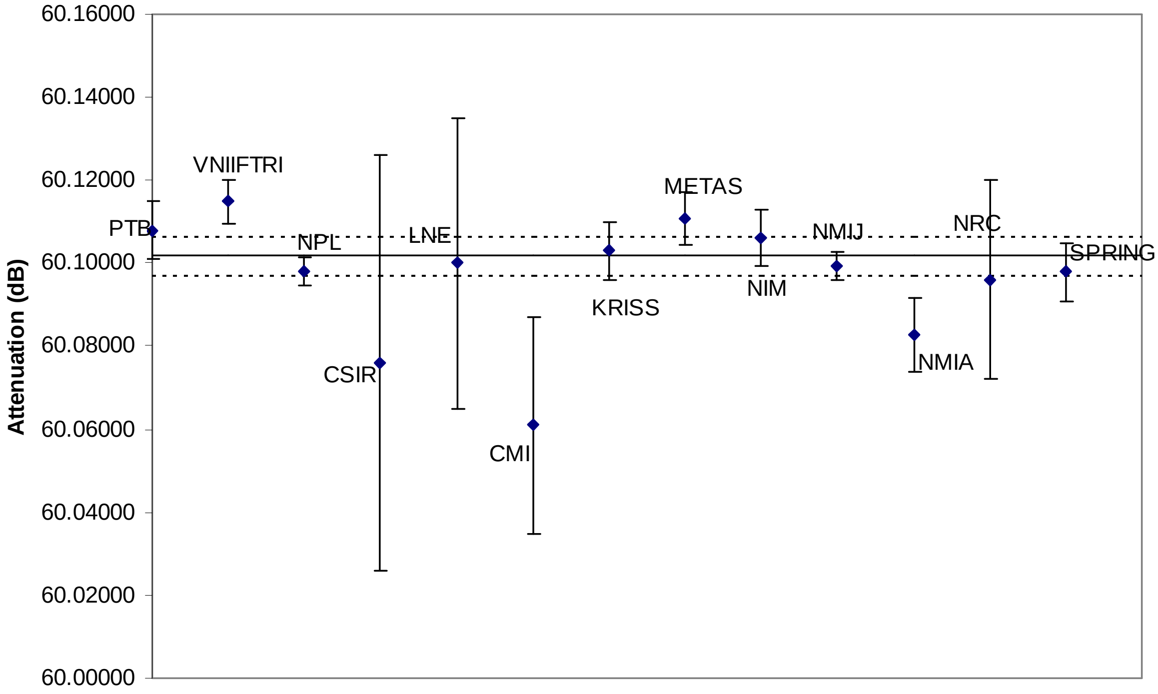

Fig 8a – K19.CL/2 device 60 dB step at 5 GHz: participants using attenuation systems

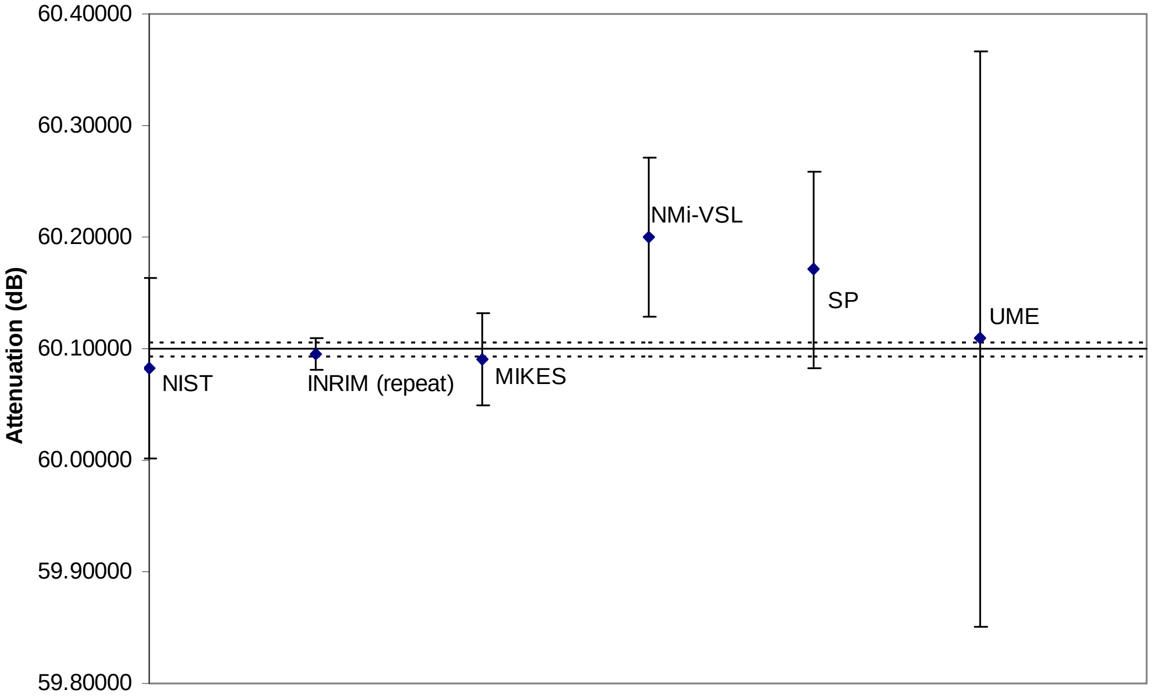

Fig 8b – K19.CL/2 device 60 dB step at 5 GHz: participants using network analysers

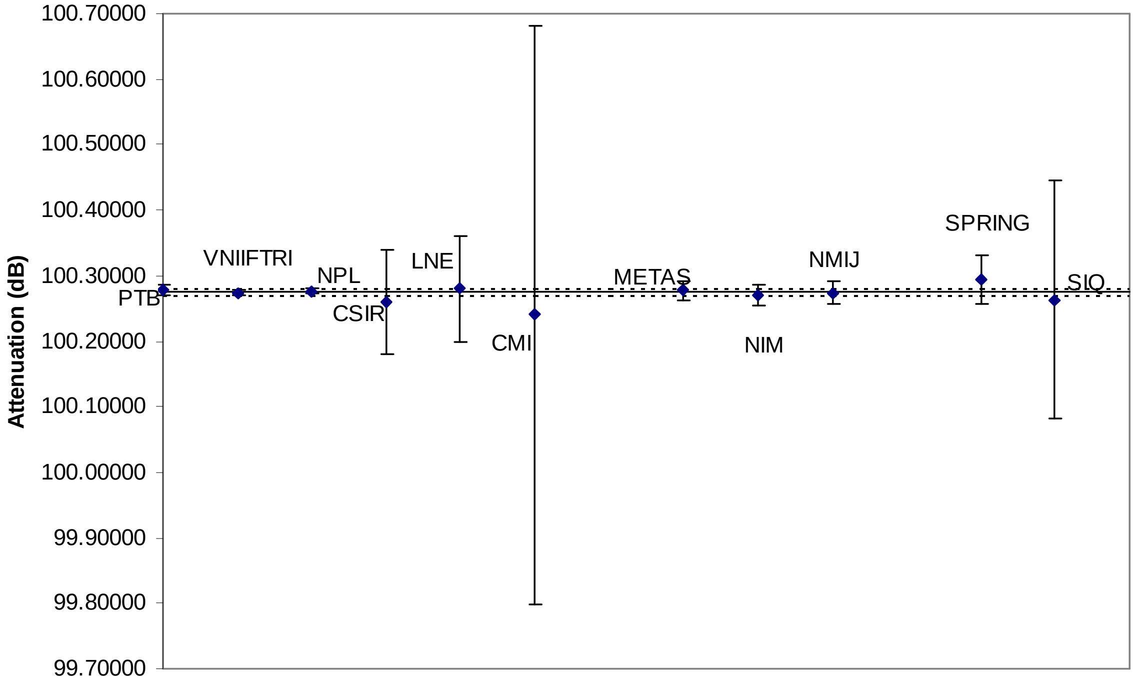

Fig 9 – K19.CL/2 device 100 dB step at 60 MHz: participants using attenuation systems

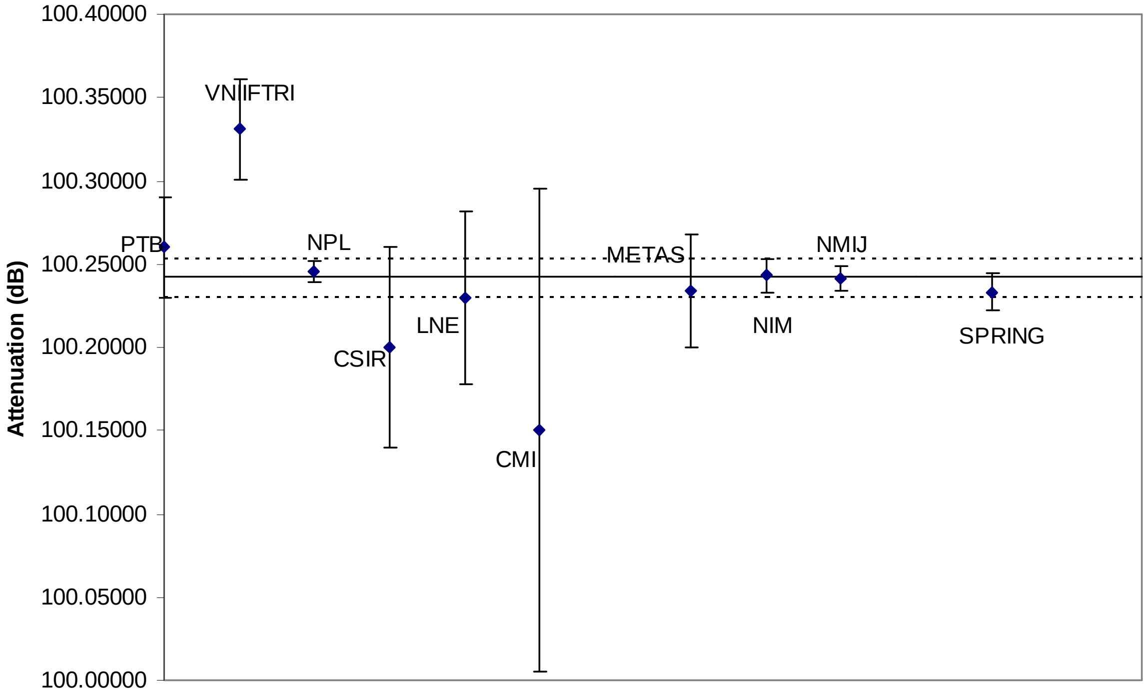

Fig 10 – K19.CL/2 device 100 dB step at 5 GHz: participants using attenuation systems

6 References

[1] CCEM.RF-K19.CL Technical Protocol Version 3.8, May 2004

[2] J. RANDA, “Proposal for KCRV & Degree of Equivalence for GT-RF Key Comparisons”, *GT-RF/00-12,* August 2000

[3] J. RANDA, “Update to Proposal for KCRV & Degree of Equivalence for GT-RF Key Comparisons”, *GT-RF/05-04,* March 2005

[4] T. J. WITT, “Some statistical formulas used in the analysis of key comparisons”, *GT-RF/2001-25*, BIPM, July 2001

[5] L. NIELSEN, “Identification and handling of discrepant measurements in key comparisons”, *Technical report DFM-02-R28*, Dansk Fundamental Metrologi, Kongens Lyngby, Denmark, 2002

[6] M. G. COX, “The evaluation of key comparison data”, *Metrologia*, 2002, **vol 39**, pp. 589-595

[7] M. G. COX, C. EIØ, G. MANA & F. PENNECCHI, “The generalized weighted mean of correlatied quantities”, *Metrologia*, 2006, **vol 43**, pp S268-S275

Appendix A – Treatment of the results

Key comparison **CCEM.RF-K19.CL**

MEASURANDS: Attenuation

Pilot Laboratory: NPL (UK)

A_{20_i}	result of measurement of 20 dB attenuation step carried out by laboratory *i*.
$u(A_{20\_i})$	combined uncertainty of A_{20_i} reported by laboratory *i*.
A_{60_i}	result of measurement of 60 dB attenuation step carried out by laboratory *i*.
$u(A_{60\_i})$	combined uncertainty of A_{60_i} reported by laboratory *i*.
A_{100_i}	result of measurement of 100 dB attenuation step carried out by laboratory *i*.
$u(A_{100\_i})$	combined uncertainty of A_{100_i} reported by laboratory *i*.

Outlying results were excluded in obtaining the key comparison reference value (KCRV). Outliers were identified using the Median of Absolute Deviations [2], defined by

$$\sigma \approx S(MAD) \equiv k_1 median_j \left\{ \left| Y_j - Y_{med} \right| \right\}, \tag{1}$$

where k_1 is a multiplier determined by simulation and Y_{med} is the median of the sample $\{Y_i\}$. According to [3], the value of k_1 for 20 participants is 1.544. A value of Y_j, which differs from the median by more than $2.5S(MAD)$, is considered an outlier, and this criterion may be used to test each point:

$$\left|Y_i - Y_{med}\right| > 2.5 \times S(MAD)\,. \tag{2}$$

Should the inequality (2) be true for any point Y_i, this point is identified as an outlier.

The KCRVs, A_{x_R}, for this comparison are calculated using the unweighted mean[6] from the results of the participants as follows:

$$A_{x\_R} = \frac{1}{N'}\sum_{i=1}^{N'} A_{x\_i}\,, \tag{3}$$

where x = 20, 60 or 100 and N' is the number of participants after inconsistent data has been identified and discarded.

The combined uncertainties associated with the KCRV were obtained using [4]

$$u(A_{x\_R}) = \sqrt{\frac{1}{N'^2}\sum_i u^2(A_{x\_i})}\,. \tag{4}$$

The degrees of equivalence of each laboratory with respect to the reference value are given by

$$\Delta_{Ax\_i} = A_{x\_i} - A_{x\_R}\,. \tag{5}$$

If A_{x_i} is not used in the calculation of the KCRV, then the expanded uncertainty in Δ_{Ax_i} is given by

$$U(\Delta_{Ax\_i}) = k\sqrt{u^2(A_{x\_i}) + u^2(A_{x\_R})}\,, \tag{6}$$

where k is the coverage factor used to give the uncertainty at 95 % confidence (usually, k = 2).

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[6] Due to the large variation in reported uncertainties, even amongst the participants using dedicated attenuation systems, an unweighted mean is the preferred option over a weighted mean to avoid any unwanted biasing towards results with the lowest reported uncertainties.

If A_{x_i} is not an outlier, then the expanded uncertainty in Δ_{Ax_i} is given by

$$U(\Delta_{Ax\_i}) = 2.0\sqrt{u^2(A_{x\_R}) + \left(1 - \frac{2}{N}\right)u^2\left(A_{x\_i}\right)} \tag{7}$$

owing to the existence of correlation between the KCRV and the measured value A_{x_i}.

The degrees of equivalence between laboratories, Δ_{Ax_ij}, are given by

$$\Delta_{Ax\_ij} = A_{x\_i} - A_{x\_j} \, . \tag{8}$$

The associated expanded uncertainty, $U(\Delta_{Ax\_ij})$, was determined using equation (6), replacing $u^2(A_{x\_R})$ with $u^2(A_{x\_j})$.

Equation (6) cannot be used to derive the uncertainty in the degree of equivalence between participants with a common traceability path (e.g., NPL and MIKES) owing to the presence of correlation. If correlation is to be considered, the correlated data must be consistent and a correlation coefficient known [5, 6, 7]. Determination of such correlation coefficients is difficult given the available data and therefore it is decided not to include a degree of equivalence between labs where this occurs.

Degree of equivalence with respect to the reference value and between each of the participants can be found in Tables A.1 to A.10.

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A20_i}	$U(\Delta_{A20\_i})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.001	0.004			0.000	0.003	0.000	0.002	0.002	0.018	0.001	0.014	0.003	0.020	0.005	0.024
PTB	0.001	0.004	0.000	0.003			0.000	0.002	0.002	0.018	0.001	0.014	0.003	0.020	0.005	0.024
VNIIFTRI	0.001	0.004	0.000	0.002	0.000	0.002			0.002	0.018	0.001	0.014	0.003	0.020	0.005	0.024
CSIR	-0.001	0.017	-0.002	0.018	-0.002	0.018	-0.002	0.018			-0.001	0.023	0.001	0.027	0.003	0.030
NIST	0.000	0.015	-0.001	0.014	-0.001	0.014	-0.001	0.014	0.001	0.023			0.002	0.024	0.004	0.028
LNE	-0.002	0.019	-0.003	0.020	-0.003	0.020	-0.003	0.020	-0.001	0.027	-0.002	0.024			0.002	0.031
CMI	-0.004	0.022	-0.005	0.024	-0.005	0.024	-0.005	0.024	-0.003	0.030	-0.004	0.028	-0.002	0.031		
INRIM	0.000	0.044	-0.001	0.044	-0.001	0.044	-0.001	0.044	0.001	0.046	0.000	0.046	0.002	0.048	0.004	0.050
KRISS	0.001	0.006	0.000	0.005	0.000	0.005	0.000	0.005	0.002	0.019	0.001	0.015	0.003	0.021	0.005	0.025
METAS	0.002	0.007	0.001	0.007	0.001	0.007	0.001	0.007	0.003	0.019	0.002	0.016	0.004	0.021	0.006	0.025
MIKES	-0.005	0.026			-0.006	0.026	-0.006	0.026	-0.004	0.032	-0.005	0.030	-0.003	0.033	-0.001	0.035
NIM	0.000	0.005	-0.001	0.004	-0.001	0.004	-0.001	0.003	0.001	0.018	0.000	0.014	0.002	0.020	0.004	0.024
NMIJ	-0.002	0.005	-0.003	0.003	-0.003	0.003	-0.003	0.003	-0.001	0.018	-0.002	0.014	0.000	0.020	0.002	0.024
NMi-VSL	0.001	0.050			0.000	0.050	0.000	0.050	0.002	0.053	0.001	0.052	0.003	0.054	0.005	0.056
NRC	-0.002	0.020	-0.003	0.022	-0.003	0.022	-0.003	0.021	-0.001	0.028	-0.002	0.026	0.000	0.029	0.002	0.032
SPRING	0.000	0.006			-0.001	0.005	-0.001	0.004	0.001	0.018	0.000	0.015	0.002	0.020	0.004	0.024
SIQ	0.002	0.032			0.001	0.032	0.001	0.032	0.003	0.037	0.002	0.035	0.004	0.038	0.006	0.040
SP	-0.010	0.015			-0.011	0.014	-0.011	0.014	-0.009	0.023	-0.010	0.020	-0.008	0.024	-0.006	0.028
UME	-0.001	0.064			-0.002	0.063	-0.002	0.063	0.000	0.066	-0.001	0.065	0.001	0.067	0.003	0.068
NMIA	-0.008	0.006	-0.009	0.006	-0.009	0.006	-0.009	0.006	-0.007	0.019	-0.008	0.015	-0.006	0.021	-0.004	0.025

Table A.1a – Degrees of equivalence for 20 dB step measurements of device K19.CL/1 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.001	0.044	0.000	0.005	-0.001	0.007			0.001	0.004	0.003	0.003		
PTB	0.001	0.044	0.000	0.005	-0.001	0.007	0.006	0.026	0.001	0.004	0.003	0.003	0.000	0.050
VNIIFTRI	0.001	0.044	0.000	0.005	-0.001	0.007	0.006	0.026	0.001	0.003	0.003	0.003	0.000	0.050
CSIR	-0.001	0.046	-0.002	0.019	-0.003	0.019	0.004	0.032	-0.001	0.018	0.001	0.018	-0.002	0.053
NIST	0.000	0.046	-0.001	0.015	-0.002	0.016	0.005	0.030	0.000	0.014	0.002	0.014	-0.001	0.052
LNE	-0.002	0.048	-0.003	0.021	-0.004	0.021	0.003	0.033	-0.002	0.020	0.000	0.020	-0.003	0.054
CMI	-0.004	0.050	-0.005	0.025	-0.006	0.025	0.001	0.035	-0.004	0.024	-0.002	0.024	-0.005	0.056
INRIM			-0.001	0.044	-0.002	0.045	0.005	0.051	0.000	0.044	0.002	0.044	-0.001	0.067
KRISS	0.001	0.044			-0.001	0.008	0.006	0.026	0.001	0.006	0.003	0.005	0.000	0.050
METAS	0.002	0.045	0.001	0.008			0.007	0.027	0.002	0.007	0.004	0.007	0.001	0.050
MIKES	-0.005	0.051	-0.006	0.026	-0.007	0.027			-0.005	0.026	-0.003	0.026		
NIM	0.000	0.044	-0.001	0.006	-0.002	0.007	0.005	0.026			0.002	0.004	-0.001	0.050
NMIJ	-0.002	0.044	-0.003	0.005	-0.004	0.007	0.003	0.026	-0.002	0.004			-0.003	0.050
NMi-VSL	0.001	0.067	0.000	0.050	-0.001	0.050			0.001	0.050	0.003	0.050		
NRC	-0.002	0.049	-0.003	0.022	-0.004	0.022	0.003	0.034	-0.002	0.022	0.000	0.022	-0.003	0.054
SPRING	0.000	0.044	-0.001	0.006	-0.002	0.008			0.000	0.005	0.002	0.005		
SIQ	0.002	0.055	0.001	0.032	0.000	0.033			0.002	0.032	0.004	0.032		
SP	-0.010	0.046	-0.011	0.015	-0.012	0.016			-0.010	0.014	-0.008	0.014		
UME	-0.001	0.077	-0.002	0.064	-0.003	0.064			-0.001	0.064	0.001	0.063		
NMIA	-0.008	0.044	-0.009	0.007	-0.010	0.009	-0.003	0.026	-0.008	0.006	-0.006	0.006	-0.009	0.050

Table A.1b – Degrees of equivalence for 20 dB step measurements of device K19.CL/1 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.003	0.022									0.009	0.006
PTB	0.003	0.022	0.001	0.005	-0.001	0.032	0.011	0.014	0.002	0.063	0.009	0.006
VNIIFTRI	0.003	0.021	0.001	0.004	-0.001	0.032	0.011	0.014	0.002	0.063	0.009	0.006
CSIR	0.001	0.028	-0.001	0.018	-0.003	0.037	0.009	0.023	0.000	0.066	0.007	0.019
NIST	0.002	0.026	0.000	0.015	-0.002	0.035	0.010	0.020	0.001	0.065	0.008	0.015
LNE	0.000	0.029	-0.002	0.020	-0.004	0.038	0.008	0.024	-0.001	0.067	0.006	0.021
CMI	-0.002	0.032	-0.004	0.024	-0.006	0.040	0.006	0.028	-0.003	0.068	0.004	0.025
INRIM	0.002	0.049	0.000	0.044	-0.002	0.055	0.010	0.046	0.001	0.077	0.008	0.044
KRISS	0.003	0.022	0.001	0.006	-0.001	0.032	0.011	0.015	0.002	0.064	0.009	0.007
METAS	0.004	0.022	0.002	0.008	0.000	0.033	0.012	0.016	0.003	0.064	0.010	0.009
MIKES	-0.003	0.034									0.003	0.026
NIM	0.002	0.022	0.000	0.005	-0.002	0.032	0.010	0.014	0.001	0.064	0.008	0.006
NMIJ	0.000	0.022	-0.002	0.005	-0.004	0.032	0.008	0.014	-0.001	0.063	0.006	0.006
NMi-VSL	0.003	0.054									0.009	0.050
NRC			-0.002	0.022	-0.004	0.039	0.008	0.026	-0.001	0.067	0.006	0.022
SPRING	0.002	0.022									0.008	0.007
SIQ	0.004	0.039									0.010	0.032
SP	-0.008	0.026									-0.002	0.015
UME	0.001	0.067									0.007	0.064
NMIA	-0.006	0.022	-0.008	0.007	-0.010	0.032	0.002	0.015	-0.007	0.064		

Table A.1c – Degrees of equivalence for 20 dB step measurements of device K19.CL/1 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A20_i}	$U(\Delta_{A20\_i})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.005	0.006			0.005	0.004	0.000	0.004	0.005	0.040	0.017	0.020	0.006	0.024	0.014	0.026
PTB	0.000	0.006	-0.005	0.004			-0.005	0.004	0.000	0.040	0.012	0.020	0.001	0.024	0.009	0.026
VNIIFTRI	0.005	0.006	0.000	0.004	0.005	0.004			0.005	0.040	0.017	0.020	0.006	0.024	0.014	0.026
CSIR	0.000	0.037	-0.005	0.040	0.000	0.040	-0.005	0.040			0.012	0.045	0.001	0.047	0.009	0.048
NIST	-0.012	0.021	-0.017	0.020	-0.012	0.020	-0.017	0.020	-0.012	0.045			-0.011	0.031	-0.003	0.033
LNE	-0.001	0.022	-0.006	0.024	-0.001	0.024	-0.006	0.024	-0.001	0.047	0.011	0.031			0.008	0.035
CMI	-0.009	0.024	-0.014	0.026	-0.009	0.026	-0.014	0.026	-0.009	0.048	0.003	0.033	-0.008	0.035		
INRIM	-0.008	0.018	-0.013	0.017	-0.008	0.017	-0.013	0.017	-0.008	0.043	0.004	0.026	-0.007	0.029	0.001	0.031
KRISS	0.007	0.011	0.002	0.011	0.007	0.011	0.002	0.011	0.007	0.041	0.019	0.023	0.008	0.026	0.016	0.028
METAS	-0.004	0.009	-0.009	0.009	-0.004	0.009	-0.009	0.009	-0.004	0.041	0.008	0.022	-0.003	0.025	0.005	0.027
MIKES	-0.011	0.041			-0.010	0.040	-0.015	0.040	-0.010	0.057	0.002	0.045	-0.009	0.047	-0.001	0.048
NIM	-0.004	0.008	-0.009	0.007	-0.004	0.007	-0.009	0.007	-0.004	0.041	0.008	0.021	-0.003	0.025	0.005	0.027
NMIJ	-0.004	0.006	-0.009	0.003	-0.004	0.004	-0.009	0.004	-0.004	0.040	0.008	0.020	-0.003	0.024	0.005	0.026
NMi-VSL	-0.020	0.048			-0.020	0.048	-0.025	0.048	-0.020	0.063	-0.008	0.052	-0.019	0.054	-0.011	0.055
NRC	0.000	0.020	-0.005	0.022	0.000	0.022	-0.005	0.022	0.000	0.045	0.012	0.029	0.001	0.032	0.009	0.034
SPRING	-0.004	0.008			-0.004	0.007	-0.009	0.007	-0.004	0.040	0.008	0.021	-0.003	0.025	0.005	0.027
SIQ																
SP	-0.009	0.050			-0.009	0.050	-0.014	0.050	-0.009	0.064	0.003	0.054	-0.008	0.056	0.000	0.056
UME	-0.004	0.064			-0.004	0.064	-0.009	0.064	-0.004	0.075	0.008	0.067	-0.003	0.068	0.005	0.069
NMIA	-0.014	0.009	-0.019	0.008	-0.014	0.008	-0.019	0.008	-0.014	0.041	-0.002	0.021	-0.013	0.025	-0.005	0.027

Table A.2a – Degrees of equivalence for 20 dB step measurements of device K19.CL/1 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.013	0.017	-0.002	0.011	0.009	0.009			0.009	0.007	0.009	0.003		
PTB	0.008	0.017	-0.007	0.011	0.004	0.009	0.010	0.040	0.004	0.007	0.004	0.004	0.020	0.048
VNIIFTRI	0.012	0.017	-0.002	0.011	0.009	0.009	0.015	0.040	0.009	0.007	0.009	0.004	0.025	0.048
CSIR	0.008	0.043	-0.007	0.041	0.004	0.041	0.010	0.057	0.004	0.041	0.004	0.040	0.020	0.063
NIST	-0.004	0.026	-0.019	0.023	-0.008	0.022	-0.002	0.045	-0.008	0.021	-0.008	0.020	0.008	0.052
LNE	0.007	0.029	-0.008	0.026	0.003	0.025	0.009	0.047	0.003	0.025	0.003	0.024	0.019	0.054
CMI	-0.001	0.031	-0.016	0.028	-0.005	0.027	0.001	0.048	-0.005	0.027	-0.005	0.026	0.011	0.055
INRIM			-0.015	0.020	-0.004	0.019	0.003	0.044	-0.004	0.018	-0.004	0.017	0.012	0.051
KRISS	0.015	0.020			0.011	0.013	0.017	0.042	0.011	0.012	0.011	0.011	0.027	0.049
METAS	0.004	0.019	-0.011	0.013			0.006	0.041	0.000	0.010	0.000	0.008	0.016	0.049
MIKES	-0.003	0.044	-0.017	0.042	-0.006	0.041			-0.006	0.041	-0.006	0.040		
NIM	0.004	0.018	-0.011	0.012	0.000	0.010	0.006	0.041			0.000	0.007	0.016	0.048
NMIJ	0.004	0.017	-0.011	0.011	0.000	0.008	0.006	0.040	0.000	0.007			0.016	0.048
NMi-VSL	-0.012	0.051	-0.027	0.049	-0.016	0.049			-0.016	0.048	-0.016	0.048		
NRC	0.008	0.027	-0.007	0.024	0.004	0.023	0.010	0.046	0.004	0.022	0.004	0.022	0.020	0.053
SPRING	0.004	0.018	-0.011	0.012	0.000	0.010			0.000	0.009	0.000	0.006		
SIQ														
SP	-0.001	0.053	-0.016	0.051	-0.005	0.051			-0.005	0.050	-0.005	0.050		
UME	0.004	0.066	-0.011	0.064	0.000	0.064			0.000	0.064	0.000	0.063		
NMIA	-0.006	0.018	-0.021	0.013	-0.010	0.011	-0.003	0.041	-0.010	0.010	-0.010	0.008	0.006	0.049

Table A.2b – Degrees of equivalence for 20 dB step measurements of device K19.CL/1 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.005	0.022									0.019	0.008
PTB	0.000	0.022	0.004	0.007			0.009	0.050	0.004	0.064	0.014	0.008
VNIIFTRI	0.005	0.022	0.009	0.007			0.014	0.050	0.009	0.064	0.019	0.008
CSIR	0.000	0.045	0.004	0.040			0.009	0.064	0.004	0.075	0.014	0.041
NIST	-0.012	0.029	-0.008	0.021			-0.003	0.054	-0.008	0.067	0.002	0.021
LNE	-0.001	0.032	0.003	0.025			0.008	0.056	0.003	0.068	0.013	0.025
CMI	-0.009	0.034	-0.005	0.027			0.000	0.056	-0.005	0.069	0.005	0.027
INRIM	-0.008	0.027	-0.004	0.018			0.001	0.053	-0.004	0.066	0.006	0.018
KRISS	0.007	0.024	0.011	0.012			0.016	0.051	0.011	0.064	0.021	0.013
METAS	-0.004	0.023	0.000	0.010			0.005	0.051	0.000	0.064	0.010	0.011
MIKES	-0.010	0.046									0.003	0.041
NIM	-0.004	0.022	0.000	0.009			0.005	0.050	0.000	0.064	0.010	0.010
NMIJ	-0.004	0.022	0.000	0.006			0.005	0.050	0.000	0.063	0.010	0.008
NMi-VSL	-0.020	0.053	-0.016	0.048							-0.006	0.049
NRC			0.004	0.022			0.009	0.054	0.004	0.067	0.014	0.023
SPRING	-0.004	0.022									0.010	0.010
SIQ												
SP	-0.009	0.054									0.005	0.051
UME	-0.004	0.067									0.010	0.064
NMIA	-0.014	0.023	-0.010	0.010			-0.005	0.051	-0.010	0.064		

Table A.2c – Degrees of equivalence for 20 dB step measurements of device K19.CL/1 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A60_i}	$U(\Delta_{A60\_i})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.000	0.009			-0.001	0.007	0.000	0.005	0.026	0.026	0.015	0.172	0.000	0.048	0.017	0.046
PTB	0.001	0.009	0.001	0.007			0.001	0.005	0.027	0.027	0.016	0.172	0.001	0.048	0.018	0.046
VNIIFTRI	0.000	0.008	0.000	0.005	-0.001	0.005			-0.026	0.026	0.015	0.172	0.000	0.048	0.017	0.046
CSIR	-0.026	0.027	-0.026	0.026	-0.027	0.027	-0.026	0.026			-0.011	0.174	-0.026	0.055	-0.009	0.053
NIST	-0.015	0.172	-0.015	0.172	-0.016	0.172	-0.015	0.172	0.011	0.174			-0.015	0.179	0.002	0.178
LNE	0.000	0.043	0.000	0.048	-0.001	0.048	0.000	0.048	0.026	0.055	0.015	0.179			0.017	0.067
CMI	-0.017	0.047	-0.017	0.046	-0.018	0.046	-0.017	0.046	0.009	0.053	-0.002	0.178	-0.017	0.067		
INRIM	-0.011	0.193	-0.011	0.193	-0.012	0.193	-0.011	0.193	0.015	0.195	0.004	0.258	-0.011	0.199	0.006	0.198
KRISS	-0.001	0.010	-0.001	0.009	-0.002	0.009	-0.001	0.007	0.025	0.027	0.014	0.172	-0.001	0.049	0.016	0.047
METAS	0.005	0.011	0.005	0.010	0.004	0.010	0.005	0.009	0.031	0.027	0.020	0.172	0.005	0.049	0.022	0.047
MIKES	-0.005	0.075			-0.006	0.075	-0.005	0.075	0.021	0.079	0.010	0.188	-0.005	0.089	0.012	0.088
NIM	-0.002	0.009	-0.002	0.007	-0.003	0.007	-0.002	0.005	0.024	0.027	0.013	0.172	-0.002	0.048	0.015	0.046
NMIJ	-0.001	0.008	-0.001	0.006	-0.002	0.006	-0.001	0.004	0.025	0.026	0.014	0.172	-0.001	0.048	0.016	0.046
NMi-VSL	0.000	0.132			-0.001	0.132	0.000	0.132	0.026	0.135	0.015	0.217	0.000	0.141	0.017	0.140
NRC	0.010	0.043	0.010	0.048	0.009	0.048	0.010	0.048	0.036	0.055	0.025	0.179	0.010	0.068	0.027	0.067
SPRING	0.002	0.016			0.001	0.015	0.002	0.014	0.028	0.030	0.017	0.173	0.002	0.050	0.019	0.048
SIQ	-0.012	0.055			-0.013	0.054	-0.012	0.054	0.014	0.060	0.003	0.180	-0.012	0.072	0.005	0.071
SP	0.006	0.037			0.005	0.036	0.006	0.036	0.032	0.044	0.021	0.176	0.006	0.060	0.023	0.058
UME	0.000	0.516			-0.001	0.516	0.000	0.516	0.026	0.516	0.015	0.544	0.000	0.518	0.017	0.518
NMIA	-0.010	0.013	-0.010	0.013	-0.011	0.013	-0.010	0.012	0.016	0.029	0.005	0.172	-0.010	0.050	0.007	0.048

Table A.3a – Degrees of equivalence for 60 dB step measurements of device K19.CL/1 at 60 MHz

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.011	0.193	0.001	0.009	-0.005	0.010			0.002	0.007	0.001	0.006		
PTB	0.012	0.193	0.002	0.009	-0.004	0.010	0.006	0.075	0.003	0.007	0.002	0.006	0.001	0.132
VNIIFTRI	0.011	0.193	0.001	0.007	-0.005	0.009	0.005	0.075	0.002	0.005	0.001	0.004	0.000	0.132
CSIR	-0.015	0.195	-0.025	0.027	-0.031	0.027	-0.021	0.079	-0.024	0.027	-0.025	0.026	-0.026	0.135
NIST	-0.004	0.258	-0.014	0.172	-0.020	0.172	-0.010	0.188	-0.013	0.172	-0.014	0.172	-0.015	0.217
LNE	0.011	0.199	0.001	0.049	-0.005	0.049	0.005	0.089	0.002	0.048	0.001	0.048	0.000	0.141
CMI	-0.006	0.198	-0.016	0.047	-0.022	0.047	-0.012	0.088	-0.015	0.046	-0.016	0.046	-0.017	0.140
INRIM			-0.010	0.193	0.016	0.193	-0.006	0.207	-0.009	0.193	-0.010	0.193	-0.011	0.234
KRISS	0.010	0.193			-0.006	0.011	0.004	0.075	0.001	0.009	0.000	0.008	-0.001	0.132
METAS	0.016	0.193	0.006	0.011			0.010	0.075	0.007	0.010	0.006	0.009	0.005	0.132
MIKES	0.006	0.207	-0.004	0.075	-0.010	0.075			-0.003	0.075	-0.004	0.075		
NIM	0.009	0.193	-0.001	0.009	-0.007	0.010	0.003	0.075			-0.001	0.006	-0.002	0.132
NMIJ	0.010	0.193	0.000	0.008	-0.006	0.009	0.004	0.075	0.001	0.006			-0.001	0.132
NMi-VSL	0.011	0.234	0.001	0.132	-0.005	0.132			0.002	0.132	0.001	0.132		
NRC	0.021	0.199	0.011	0.049	0.005	0.049	0.015	0.089	0.012	0.048	0.011	0.048	0.010	0.141
SPRING	0.013	0.193	0.003	0.016	-0.003	0.017			0.004	0.015	0.003	0.014		
SIQ	-0.001	0.200	-0.011	0.055	-0.017	0.055			-0.010	0.054	-0.011	0.054		
SP	0.017	0.196	0.007	0.037	0.001	0.037			0.008	0.036	0.007	0.036		
UME	0.011	0.550	0.001	0.516	-0.005	0.516			0.002	0.516	0.001	0.516		
NMIA	0.001	0.193	-0.009	0.014	-0.015	0.015	-0.005	0.076	-0.008	0.013	-0.009	0.013	-0.010	0.133

Table A.3b – Degrees of equivalence for 60 dB step measurements of device K19.CL/1 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	-0.010	0.048									0.010	0.013
PTB	-0.009	0.048	-0.001	0.015	0.013	0.054	-0.005	0.036	0.001	0.516	0.011	0.013
VNIIFTRI	-0.010	0.048	-0.002	0.014	0.012	0.054	-0.006	0.036	0.000	0.516	0.010	0.012
CSIR	-0.036	0.055	-0.028	0.030	-0.014	0.060	-0.032	0.044	-0.026	0.516	-0.016	0.029
NIST	-0.025	0.179	-0.017	0.173	-0.003	0.180	-0.021	0.176	-0.015	0.544	-0.005	0.172
LNE	-0.010	0.068	-0.002	0.050	0.012	0.072	-0.006	0.060	0.000	0.518	0.010	0.050
CMI	-0.027	0.067	-0.019	0.048	-0.005	0.071	-0.023	0.058	-0.017	0.518	-0.007	0.048
INRIM	-0.021	0.199	-0.013	0.193	0.001	0.200	-0.017	0.196	-0.011	0.550	-0.001	0.193
KRISS	-0.011	0.049	-0.003	0.016	0.011	0.055	-0.007	0.037	-0.001	0.516	0.009	0.014
METAS	-0.005	0.049	0.003	0.017	0.017	0.055	-0.001	0.037	0.005	0.516	0.015	0.015
MIKES	-0.015	0.089									0.005	0.076
NIM	-0.012	0.048	-0.004	0.015	0.010	0.054	-0.008	0.036	-0.002	0.516	0.008	0.013
NMIJ	-0.011	0.048	-0.003	0.014	0.011	0.054	-0.007	0.036	-0.001	0.516	0.009	0.013
NMi-VSL	-0.010	0.141									0.010	0.133
NRC			0.008	0.050	0.022	0.072	0.004	0.060	0.010	0.518	0.020	0.050
SPRING	-0.008	0.050									0.012	0.019
SIQ	-0.022	0.072									-0.002	0.055
SP	-0.004	0.060									0.016	0.038
UME	-0.010	0.518									0.010	0.516
NMIA	-0.020	0.050	-0.012	0.019	0.002	0.055	-0.016	0.038	-0.010	0.516		

Table A.3c – Degrees of equivalence for 60 dB step measurements of device K19.CL/1 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A60_i}	$U(\Delta_{A60\_i})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.006	0.009			0.010	0.011	-0.005	0.005	0.016	0.040	0.032	0.162	-0.001	0.054	0.032	0.048
PTB	-0.004	0.013	-0.010	0.011			-0.015	0.011	0.006	0.041	0.022	0.162	-0.011	0.055	0.022	0.049
VNIIFTRI	0.011	0.010	0.005	0.005	0.015	0.011			0.021	0.040	0.037	0.162	0.004	0.054	0.037	0.048
CSIR	-0.010	0.037	-0.016	0.040	-0.006	0.041	-0.021	0.040			0.016	0.167	-0.017	0.067	0.016	0.063
NIST	-0.026	0.162	-0.032	0.162	-0.022	0.162	-0.037	0.162	-0.016	0.167			-0.033	0.171	0.000	0.169
LNE	0.007	0.050	0.001	0.054	0.011	0.055	-0.004	0.054	0.017	0.067	0.033	0.171			0.033	0.072
CMI	-0.026	0.044	-0.032	0.048	-0.022	0.049	-0.037	0.048	-0.016	0.063	0.000	0.169	-0.033	0.072		
INRIM	-0.003	0.117	-0.009	0.117	0.001	0.117	-0.014	0.117	0.007	0.124	0.023	0.200	-0.010	0.129	0.023	0.126
KRISS	0.011	0.015	0.005	0.013	0.015	0.016	0.000	0.014	0.021	0.042	0.037	0.163	0.004	0.056	0.037	0.050
METAS	0.000	0.014	-0.006	0.012	0.004	0.015	-0.011	0.012	0.010	0.042	0.026	0.162	-0.007	0.055	0.026	0.049
MIKES	-0.005	0.081			-0.001	0.081	-0.016	0.081	0.005	0.090	0.021	0.181	-0.012	0.097	0.021	0.094
NIM	-0.001	0.011	-0.007	0.008	0.003	0.012	-0.012	0.008	0.009	0.041	0.025	0.162	-0.008	0.055	0.025	0.049
NMIJ	-0.005	0.009	-0.011	0.005	-0.001	0.011	-0.016	0.005	0.005	0.040	0.021	0.162	-0.012	0.054	0.021	0.048
NMi-VSL	-0.031	0.142			-0.027	0.142	-0.042	0.142	-0.021	0.148	-0.005	0.215	-0.038	0.152	-0.005	0.150
NRC	-0.003	0.044	-0.009	0.048	0.001	0.049	-0.014	0.048	0.007	0.063	0.023	0.169	-0.010	0.072	0.023	0.068
SPRING	0.000	0.015			0.004	0.016	-0.011	0.013	0.010	0.042	0.026	0.162	-0.007	0.055	0.026	0.050
SIQ																
SP	-0.067	0.170			-0.063	0.170	-0.078	0.170	-0.057	0.175	-0.041	0.235	-0.074	0.178	-0.041	0.177
UME	-0.019	0.517			-0.015	0.517	-0.030	0.516	-0.009	0.518	0.007	0.541	-0.026	0.519	0.007	0.519
NMIA	-0.014	0.014	-0.020	0.014	-0.010	0.017	-0.025	0.014	-0.004	0.042	0.012	0.163	-0.021	0.056	0.012	0.050

Table A.4a – Degrees of equivalence for 60 dB step measurements of device K19.CL/1 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.009	0.117	-0.005	0.013	0.006	0.012			0.007	0.008	0.011	0.005		
PTB	-0.001	0.117	-0.015	0.016	-0.004	0.015	0.001	0.081	-0.003	0.012	0.001	0.011	0.027	0.142
VNIIFTRI	0.014	0.117	0.000	0.014	0.011	0.012	0.016	0.081	0.012	0.008	0.016	0.005	0.042	0.142
CSIR	-0.007	0.124	-0.021	0.042	-0.010	0.042	-0.005	0.090	-0.009	0.041	-0.005	0.040	0.021	0.148
NIST	-0.023	0.200	-0.037	0.163	-0.026	0.162	-0.021	0.181	-0.025	0.162	-0.021	0.162	0.005	0.215
LNE	0.010	0.129	-0.004	0.056	0.007	0.055	0.012	0.097	0.008	0.055	0.012	0.054	0.038	0.152
CMI	-0.023	0.126	-0.037	0.050	-0.026	0.049	-0.021	0.094	-0.025	0.049	-0.021	0.048	0.005	0.150
INRIM			-0.014	0.118	-0.003	0.117	0.002	0.142	-0.002	0.117	0.002	0.117	0.028	0.184
KRISS	0.014	0.118			0.011	0.017	0.016	0.081	0.012	0.015	0.016	0.013	0.042	0.143
METAS	0.003	0.117	-0.011	0.017			0.005	0.081	0.001	0.014	0.005	0.012	0.031	0.143
MIKES	-0.002	0.142	-0.016	0.081	-0.005	0.081			-0.004	0.081	0.000	0.081		
NIM	0.002	0.117	-0.012	0.015	-0.001	0.014	0.004	0.081			0.004	0.008	0.030	0.142
NMIJ	-0.002	0.117	-0.016	0.013	-0.005	0.012	0.000	0.081	-0.004	0.008			0.026	0.142
NMi-VSL	-0.028	0.184	-0.042	0.143	-0.031	0.143			-0.030	0.142	-0.026	0.142		
NRC	0.000	0.126	-0.014	0.050	-0.003	0.049	0.002	0.094	-0.002	0.049	0.002	0.048	0.028	0.150
SPRING	0.003	0.117	-0.011	0.018	0.000	0.017			0.001	0.014	0.005	0.013		
SIQ														
SP	-0.064	0.206	-0.078	0.171	-0.067	0.170			-0.066	0.170	-0.062	0.170		
UME	-0.016	0.529	-0.030	0.517	-0.019	0.517			-0.018	0.517	-0.014	0.516		
NMIA	-0.011	0.118	-0.025	0.019	-0.014	0.018	-0.009	0.082	-0.013	0.015	-0.009	0.014	0.017	0.143

Table A.4b – Degrees of equivalence for 60 dB step measurements of device K19.CL/1 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.009	0.048									0.020	0.014
PTB	-0.001	0.049	-0.004	0.016			0.063	0.170	0.015	0.517	0.010	0.017
VNIIFTRI	0.014	0.048	0.011	0.013			0.078	0.170	0.030	0.516	0.025	0.014
CSIR	-0.007	0.063	-0.010	0.042			0.057	0.175	0.009	0.518	0.004	0.042
NIST	-0.023	0.169	-0.026	0.162			0.041	0.235	-0.007	0.541	-0.012	0.163
LNE	0.010	0.072	0.007	0.055			0.074	0.178	0.026	0.519	0.021	0.056
CMI	-0.023	0.068	-0.026	0.050			0.041	0.177	-0.007	0.519	-0.012	0.050
INRIM	0.000	0.126	-0.003	0.117			0.064	0.206	0.016	0.529	0.011	0.118
KRISS	0.014	0.050	0.011	0.018			0.078	0.171	0.030	0.517	0.025	0.019
METAS	0.003	0.049	0.000	0.017			0.067	0.170	0.019	0.517	0.014	0.018
MIKES	-0.002	0.094									0.009	0.082
NIM	0.002	0.049	-0.001	0.014			0.066	0.170	0.018	0.517	0.013	0.015
NMIJ	-0.002	0.048	-0.005	0.013			0.062	0.170	0.014	0.516	0.009	0.014
NMi-VSL	-0.028	0.150									-0.017	0.143
NRC			-0.003	0.050			0.064	0.177	0.016	0.519	0.011	0.050
SPRING	0.003	0.050									0.014	0.018
SIQ												
SP	-0.064	0.177									-0.053	0.171
UME	-0.016	0.519									-0.005	0.517
NMIA	-0.011	0.050	-0.014	0.018			0.053	0.171	0.005	0.517		

Table A.4c – Degrees of equivalence for 60 dB step measurements of device K19.CL/1 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A20_i}	$U(\Delta_{A20\_i})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.001	0.003			0.001	0.002	0.001	0.002	0.007	0.016	0.001	0.014	0.005	0.020	0.006	0.024
PTB	0.000	0.003	-0.001	0.002			0.000	0.002	0.006	0.016	0.000	0.014	0.004	0.020	0.005	0.024
VNIIFTRI	0.000	0.003	-0.001	0.002	0.000	0.002			0.006	0.016	0.000	0.014	0.004	0.020	0.005	0.024
CSIR	-0.006	0.016	-0.007	0.016	-0.006	0.016	-0.006	0.016			-0.006	0.021	-0.002	0.026	-0.001	0.029
NIST	0.000	0.014	-0.001	0.014	0.000	0.014	0.000	0.014	0.006	0.021			0.004	0.024	0.005	0.028
LNE	-0.004	0.018	-0.005	0.020	-0.004	0.020	-0.004	0.020	0.002	0.026	-0.004	0.024			0.001	0.031
CMI	-0.005	0.024	-0.006	0.024	-0.005	0.024	-0.005	0.024	0.001	0.029	-0.005	0.028	-0.001	0.031		
INRIM	0.000	0.043	-0.001	0.043	0.000	0.043	0.000	0.043	0.006	0.046	0.000	0.045	0.004	0.047	0.005	0.049
KRISS	-0.001	0.005	-0.002	0.005	-0.001	0.005	-0.001	0.005	0.005	0.017	-0.001	0.015	0.003	0.021	0.004	0.025
METAS	0.001	0.006	0.000	0.007	0.001	0.007	0.001	0.007	0.007	0.017	0.001	0.015	0.005	0.021	0.006	0.025
MIKES	-0.007	0.026			-0.007	0.026	-0.007	0.026	-0.001	0.030	-0.007	0.029	-0.003	0.033	-0.002	0.035
NIM	0.000	0.004	-0.001	0.003	0.000	0.004	0.000	0.003	0.006	0.016	0.000	0.014	0.004	0.020	0.005	0.024
NMIJ	0.000	0.003	-0.001	0.002	0.000	0.003	0.000	0.002	0.006	0.016	0.000	0.014	0.004	0.020	0.005	0.024
NMi-VSL	0.014	0.046			0.014	0.046	0.014	0.046	0.020	0.049	0.014	0.048	0.018	0.050	0.019	0.052
NRC	-0.010	0.022	-0.011	0.021	-0.010	0.022	-0.010	0.021	-0.004	0.027	-0.010	0.026	-0.006	0.029	-0.005	0.032
SPRING	-0.001	0.005			-0.001	0.005	-0.001	0.004	0.005	0.017	-0.001	0.015	0.003	0.020	0.004	0.024
SIQ	0.002	0.032			0.002	0.032	0.002	0.032	0.008	0.036	0.002	0.035	0.006	0.038	0.007	0.040
SP	-0.002	0.014			-0.002	0.014	-0.002	0.014	0.004	0.021	-0.002	0.020	0.002	0.024	0.003	0.028
UME	0.003	0.063			0.003	0.063	0.003	0.063	0.009	0.065	0.003	0.065	0.007	0.067	0.008	0.068
NMIA	-0.006	0.006	-0.007	0.005	-0.006	0.005	-0.006	0.005	0.000	0.017	-0.006	0.015	-0.002	0.021	-0.001	0.024

Table A.5a – Degrees of equivalence for 20 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.001	0.043	0.002	0.005	0.000	0.007			0.001	0.003	0.001	0.002		
PTB	0.000	0.043	0.001	0.005	-0.001	0.007	0.007	0.026	0.000	0.004	0.000	0.003	-0.014	0.046
VNIIFTRI	0.000	0.043	0.001	0.005	-0.001	0.007	0.007	0.026	0.000	0.003	0.000	0.002	-0.014	0.046
CSIR	-0.006	0.046	-0.005	0.017	-0.007	0.017	0.001	0.030	-0.006	0.016	-0.006	0.016	-0.020	0.049
NIST	0.000	0.045	0.001	0.015	-0.001	0.015	0.007	0.029	0.000	0.014	0.000	0.014	-0.014	0.048
LNE	-0.004	0.047	-0.003	0.021	-0.005	0.021	0.003	0.033	-0.004	0.020	-0.004	0.020	-0.018	0.050
CMI	-0.005	0.049	-0.004	0.025	-0.006	0.025	0.002	0.035	-0.005	0.024	-0.005	0.024	-0.019	0.052
INRIM			0.001	0.043	-0.001	0.044	0.007	0.050	0.000	0.043	0.000	0.043	-0.014	0.063
KRISS	-0.001	0.043			-0.002	0.008	0.006	0.026	-0.001	0.006	-0.001	0.005	-0.015	0.046
METAS	0.001	0.044	0.002	0.008			0.008	0.027	0.001	0.007	0.001	0.007	-0.013	0.046
MIKES	-0.007	0.050	-0.006	0.026	-0.008	0.027			-0.007	0.026	-0.007	0.026		
NIM	0.000	0.043	0.001	0.006	-0.001	0.007	0.007	0.026			0.000	0.004	-0.014	0.046
NMIJ	0.000	0.043	0.001	0.005	-0.001	0.007	0.007	0.026	0.000	0.004			-0.014	0.046
NMi-VSL	0.014	0.063	0.015	0.046	0.013	0.046			0.014	0.046	0.014	0.046		
NRC	-0.010	0.048	-0.009	0.022	-0.011	0.022	-0.003	0.034	-0.010	0.022	-0.010	0.022	-0.024	0.051
SPRING	-0.001	0.043	0.000	0.006	-0.002	0.008			-0.001	0.005	-0.001	0.005		
SIQ	0.002	0.054	0.003	0.032	0.001	0.033			0.002	0.032	0.002	0.032		
SP	-0.002	0.045	-0.001	0.015	-0.003	0.015			-0.002	0.014	-0.002	0.014		
UME	0.003	0.077	0.004	0.064	0.002	0.064			0.003	0.064	0.003	0.063		
NMIA	-0.006	0.043	-0.005	0.007	-0.007	0.008	0.001	0.026	-0.006	0.006	-0.006	0.005	-0.020	0.046

Table A.5b – Degrees of equivalence for 20 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.011	0.021									0.007	0.005
PTB	0.010	0.022	0.001	0.005	-0.002	0.032	0.002	0.014	-0.003	0.063	0.006	0.005
VNIIFTRI	0.010	0.021	0.001	0.004	-0.002	0.032	0.002	0.014	-0.003	0.063	0.006	0.005
CSIR	0.004	0.027	-0.005	0.017	-0.008	0.036	-0.004	0.021	-0.009	0.065	0.000	0.017
NIST	0.010	0.026	0.001	0.015	-0.002	0.035	0.002	0.020	-0.003	0.065	0.006	0.015
LNE	0.006	0.029	-0.003	0.020	-0.006	0.038	-0.002	0.024	-0.007	0.067	0.002	0.021
CMI	0.005	0.032	-0.004	0.024	-0.007	0.040	-0.003	0.028	-0.008	0.068	0.001	0.024
INRIM	0.010	0.048	0.001	0.043	-0.002	0.054	0.002	0.045	-0.003	0.077	0.006	0.043
KRISS	0.009	0.022	0.000	0.006	-0.003	0.032	0.001	0.015	-0.004	0.064	0.005	0.007
METAS	0.011	0.022	0.002	0.008	-0.001	0.033	0.003	0.015	-0.002	0.064	0.007	0.008
MIKES	0.003	0.034									-0.001	0.026
NIM	0.010	0.022	0.001	0.005	-0.002	0.032	0.002	0.014	-0.003	0.064	0.006	0.006
NMIJ	0.010	0.022	0.001	0.005	-0.002	0.032	0.002	0.014	-0.003	0.063	0.006	0.005
NMi-VSL	0.024	0.051									0.020	0.046
NRC			-0.009	0.022	-0.012	0.039	-0.008	0.026	-0.013	0.067	-0.004	0.022
SPRING	0.009	0.022									0.005	0.006
SIQ	0.012	0.039									0.008	0.032
SP	0.008	0.026									0.004	0.015
UME	0.013	0.067									0.009	0.064
NMIA	0.004	0.022	-0.005	0.006	-0.008	0.032	-0.004	0.015	-0.009	0.064		

Table A.5c – Degrees of equivalence for 20 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A20_i}	$U(\Delta_{A20\_i})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	-0.002	0.010			-0.007	0.009	-0.017	0.007	0.018	0.080	0.009	0.021	0.001	0.033	0.013	0.029
PTB	0.005	0.010	0.007	0.009			-0.010	0.007	0.025	0.080	0.016	0.021	0.008	0.033	0.020	0.029
VNIIFTRI	0.015	0.009	0.017	0.007	0.010	0.007			0.035	0.080	0.026	0.020	0.018	0.032	0.030	0.028
CSIR	-0.020	0.073	-0.018	0.080	-0.025	0.080	-0.035	0.080			-0.009	0.083	-0.017	0.086	-0.005	0.085
NIST	-0.011	0.022	-0.009	0.021	-0.016	0.021	-0.026	0.020	0.009	0.083			-0.008	0.038	0.004	0.034
LNE	-0.003	0.030	-0.001	0.033	-0.008	0.033	-0.018	0.032	0.017	0.086	0.008	0.038			0.012	0.043
CMI	-0.015	0.027	-0.013	0.029	-0.020	0.029	-0.030	0.028	0.005	0.085	-0.004	0.034	-0.012	0.043		
INRIM	-0.003	0.016	-0.001	0.015	-0.008	0.015	-0.018	0.014	0.017	0.081	0.008	0.024	0.000	0.035	0.012	0.031
KRISS	0.005	0.014	0.007	0.013	0.000	0.013	-0.010	0.012	0.025	0.081	0.016	0.023	0.008	0.034	0.020	0.030
METAS	0.007	0.014	0.009	0.013	0.002	0.013	-0.008	0.012	0.027	0.081	0.018	0.023	0.010	0.034	0.022	0.030
MIKES	-0.008	0.044			-0.013	0.043	-0.023	0.043	0.012	0.091	0.003	0.047	-0.005	0.054	0.007	0.051
NIM	0.006	0.014	0.008	0.014	0.001	0.014	-0.009	0.013	0.026	0.081	0.017	0.024	0.009	0.034	0.021	0.031
NMIJ	-0.002	0.009	0.000	0.007	-0.007	0.007	-0.017	0.005	0.018	0.080	0.009	0.020	0.001	0.032	0.013	0.028
NMi-VSL	0.091	0.126			0.086	0.126	0.076	0.126	0.111	0.149	0.102	0.128	0.094	0.130	0.106	0.129
NRC	0.000	0.020	0.002	0.021	-0.005	0.021	-0.015	0.020	0.020	0.083	0.011	0.028	0.003	0.038	0.015	0.034
SPRING	0.000	0.011			-0.005	0.009	-0.015	0.007	0.020	0.080	0.011	0.021	0.003	0.033	0.015	0.029
SIQ																
SP	0.003	0.051			-0.002	0.050	-0.012	0.050	0.023	0.094	0.014	0.054	0.006	0.059	0.018	0.057
UME	0.001	0.064			-0.004	0.064	-0.014	0.064	0.021	0.102	0.012	0.067	0.004	0.071	0.016	0.069
NMIA	-0.006	0.014	-0.004	0.014	-0.011	0.014	-0.021	0.013	0.014	0.081	0.005	0.024	-0.003	0.034	0.009	0.031

Table A.6a – Degrees of equivalence for 20 dB step measurements of device K19.CL/2 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	0.001	0.015	-0.007	0.013	-0.009	0.013			-0.008	0.014	0.000	0.007		
PTB	0.008	0.015	0.000	0.013	-0.002	0.013	0.013	0.043	-0.001	0.014	0.007	0.007	-0.086	0.126
VNIIFTRI	0.018	0.014	0.010	0.012	0.008	0.012	0.023	0.043	0.009	0.013	0.017	0.005	-0.076	0.126
CSIR	-0.017	0.081	-0.025	0.081	-0.027	0.081	-0.012	0.091	-0.026	0.081	-0.018	0.080	-0.111	0.149
NIST	-0.008	0.024	-0.016	0.023	-0.018	0.023	-0.003	0.047	-0.017	0.024	-0.009	0.020	-0.102	0.128
LNE	0.000	0.035	-0.008	0.034	-0.010	0.034	0.005	0.054	-0.009	0.034	-0.001	0.032	-0.094	0.130
CMI	-0.012	0.031	-0.020	0.030	-0.022	0.030	-0.007	0.051	-0.021	0.031	-0.013	0.028	-0.106	0.129
INRIM			-0.008	0.018	-0.010	0.018	0.005	0.045	-0.009	0.018	-0.001	0.014	-0.094	0.127
KRISS	0.008	0.018			-0.002	0.016	0.013	0.044	-0.001	0.017	0.007	0.012	-0.086	0.127
METAS	0.010	0.018	0.002	0.016			0.015	0.044	0.001	0.017	0.009	0.012	-0.084	0.127
MIKES	-0.005	0.045	-0.013	0.044	-0.015	0.044			-0.014	0.045	-0.006	0.043		
NIM	0.009	0.018	0.001	0.017	-0.001	0.017	0.014	0.045			0.008	0.013	-0.085	0.127
NMIJ	0.001	0.014	-0.007	0.012	-0.009	0.012	0.006	0.043	-0.008	0.013			-0.093	0.126
NMi-VSL	0.094	0.127	0.086	0.127	0.084	0.127			0.085	0.127	0.093	0.126		
NRC	0.003	0.024	-0.005	0.023	-0.007	0.023	0.008	0.047	-0.006	0.024	0.002	0.020	-0.091	0.128
SPRING	0.003	0.015	-0.005	0.013	-0.007	0.013			-0.006	0.014	0.002	0.007		
SIQ														
SP	0.006	0.052	-0.002	0.051	-0.004	0.051			-0.003	0.052	0.005	0.050		
UME	0.004	0.065	-0.004	0.064	-0.006	0.065			-0.005	0.065	0.003	0.064		
NMIA	-0.003	0.018	-0.011	0.017	-0.013	0.017	0.002	0.045	-0.012	0.018	-0.004	0.013	-0.097	0.127

Table A.6b – Degrees of equivalence for 20 dB step measurements of device K19.CL/2 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$	Δ_{A20_ij}	$U(\Delta_{A20\_ij})$
NPL	-0.002	0.021									0.004	0.014
PTB	0.005	0.021	0.005	0.009			0.002	0.050	0.004	0.064	0.011	0.014
VNIIFTRI	0.015	0.020	0.015	0.007			0.012	0.050	0.014	0.064	0.021	0.013
CSIR	-0.020	0.083	-0.020	0.080			-0.023	0.094	-0.021	0.102	-0.014	0.081
NIST	-0.011	0.028	-0.011	0.021			-0.014	0.054	-0.012	0.067	-0.005	0.024
LNE	-0.003	0.038	-0.003	0.033			-0.006	0.059	-0.004	0.071	0.003	0.034
CMI	-0.015	0.034	-0.015	0.029			-0.018	0.057	-0.016	0.069	-0.009	0.031
INRIM	-0.003	0.024	-0.003	0.015			-0.006	0.052	-0.004	0.065	0.003	0.018
KRISS	0.005	0.023	0.005	0.013			0.002	0.051	0.004	0.064	0.011	0.017
METAS	0.007	0.023	0.007	0.013			0.004	0.051	0.006	0.065	0.013	0.017
MIKES	-0.008	0.047									-0.002	0.045
NIM	0.006	0.024	0.006	0.014			0.003	0.052	0.005	0.065	0.012	0.018
NMIJ	-0.002	0.020	-0.002	0.007			-0.005	0.050	-0.003	0.064	0.004	0.013
NMi-VSL	0.091	0.128									0.097	0.127
NRC			0.000	0.021			-0.003	0.054	-0.001	0.067	0.006	0.024
SPRING	0.000	0.021									0.006	0.014
SIQ												
SP	0.003	0.054									0.009	0.052
UME	0.001	0.067									0.007	0.065
NMIA	-0.006	0.024	-0.006	0.014			-0.009	0.052	-0.007	0.065		

Table A.6c – Degrees of equivalence for 20 dB step measurements of device K19.CL/2 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A60_i}	$U(\Delta_{A60\_i})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.002	0.008			0.002	0.006	0.004	0.003	0.016	0.024	0.013	0.166	0.000	0.050	0.029	0.050
PTB	0.000	0.009	-0.002	0.006			0.002	0.005	0.014	0.025	0.011	0.166	-0.002	0.050	0.027	0.050
VNIIFTRI	-0.002	0.008	-0.004	0.003	-0.002	0.005			0.012	0.024	0.009	0.166	-0.004	0.050	0.025	0.050
CSIR	-0.014	0.025	-0.016	0.024	-0.014	0.025	-0.012	0.024			-0.003	0.168	-0.016	0.056	0.013	0.056
NIST	-0.011	0.166	-0.013	0.166	-0.011	0.166	-0.009	0.166	0.003	0.168			-0.013	0.173	0.016	0.173
LNE	0.002	0.045	0.000	0.050	0.002	0.050	0.004	0.050	0.016	0.056	0.013	0.173			0.029	0.071
CMI	-0.027	0.051	-0.029	0.050	-0.027	0.050	-0.025	0.050	-0.013	0.056	-0.016	0.173	-0.029	0.071		
INRIM	0.003	0.196	0.001	0.196	0.003	0.196	0.005	0.196	0.017	0.197	0.014	0.257	0.001	0.202	0.030	0.202
KRISS	-0.006	0.010	-0.008	0.007	-0.006	0.009	-0.004	0.007	0.008	0.025	0.005	0.166	-0.008	0.051	0.021	0.051
METAS	0.002	0.011	0.000	0.009	0.002	0.010	0.004	0.009	0.016	0.026	0.013	0.166	0.000	0.051	0.029	0.051
MIKES	-0.006	0.075			-0.006	0.075	-0.004	0.075	0.008	0.079	0.005	0.182	-0.008	0.090	0.021	0.090
NIM	-0.003	0.009	-0.005	0.006	-0.003	0.007	-0.001	0.005	0.011	0.025	0.008	0.166	-0.005	0.050	0.024	0.050
NMIJ	0.000	0.008	-0.002	0.004	0.000	0.006	0.002	0.004	0.014	0.024	0.011	0.166	-0.002	0.050	0.027	0.050
NMi-VSL	0.012	0.130			0.012	0.130	0.014	0.130	0.026	0.132	0.023	0.211	0.010	0.139	0.039	0.139
NRC	0.000	0.043	-0.002	0.048	0.000	0.048	0.002	0.048	0.014	0.054	0.011	0.173	-0.002	0.069	0.027	0.069
SPRING	-0.001	0.016			-0.001	0.015	0.001	0.014	0.013	0.028	0.010	0.167	-0.003	0.052	0.026	0.052
SIQ	0.006	0.055			0.006	0.054	0.008	0.054	0.020	0.059	0.017	0.175	0.004	0.074	0.033	0.074
SP	0.005	0.037			0.005	0.036	0.007	0.036	0.019	0.043	0.016	0.170	0.003	0.062	0.032	0.062
UME	-0.004	0.516			-0.004	0.516	-0.002	0.516	0.010	0.517	0.007	0.542	-0.006	0.519	0.023	0.519
NMIA	-0.013	0.015	-0.015	0.013	-0.013	0.013	-0.011	0.012	0.001	0.027	-0.002	0.166	-0.015	0.052	0.014	0.052

Table A.7a – Degrees of equivalence for 60 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	-0.001	0.196	0.008	0.007	0.000	0.009			0.005	0.006	0.002	0.004		
PTB	-0.003	0.196	0.006	0.009	-0.002	0.010	0.006	0.075	0.003	0.007	0.000	0.006	-0.012	0.130
VNIIFTRI	-0.005	0.196	0.004	0.007	-0.004	0.009	0.004	0.075	0.001	0.005	-0.002	0.004	-0.014	0.130
CSIR	-0.017	0.197	-0.008	0.025	-0.016	0.026	-0.008	0.079	-0.011	0.025	-0.014	0.024	-0.026	0.132
NIST	-0.014	0.257	-0.005	0.166	-0.013	0.166	-0.005	0.182	-0.008	0.166	-0.011	0.166	-0.023	0.211
LNE	-0.001	0.202	0.008	0.051	0.000	0.051	0.008	0.090	0.005	0.050	0.002	0.050	-0.010	0.139
CMI	-0.030	0.202	-0.021	0.051	-0.029	0.051	-0.021	0.090	-0.024	0.050	-0.027	0.050	-0.039	0.139
INRIM			0.009	0.196	0.001	0.196	0.009	0.210	0.006	0.196	0.003	0.196	-0.009	0.235
KRISS	-0.009	0.196			-0.008	0.011	0.000	0.075	-0.003	0.009	-0.006	0.008	-0.018	0.130
METAS	-0.001	0.196	0.008	0.011			0.008	0.075	0.005	0.010	0.002	0.009	-0.010	0.130
MIKES	-0.009	0.210	0.000	0.075	-0.008	0.075			-0.003	0.075	-0.006	0.075		
NIM	-0.006	0.196	0.003	0.009	-0.005	0.010	0.003	0.075			-0.003	0.006	-0.015	0.130
NMIJ	-0.003	0.196	0.006	0.008	-0.002	0.009	0.006	0.075	0.003	0.006			-0.012	0.130
NMi-VSL	0.009	0.235	0.018	0.130	0.010	0.130			0.015	0.130	0.012	0.130		
NRC	-0.003	0.202	0.006	0.049	-0.002	0.049	0.006	0.089	0.003	0.048	0.000	0.048	-0.012	0.139
SPRING	-0.004	0.196	0.005	0.016	-0.003	0.017			0.002	0.015	-0.001	0.014		
SIQ	0.003	0.203	0.012	0.055	0.004	0.055			0.009	0.054	0.006	0.054		
SP	0.002	0.199	0.011	0.037	0.003	0.037			0.008	0.036	0.005	0.036		
UME	-0.007	0.552	0.002	0.516	-0.006	0.516			-0.001	0.516	-0.004	0.516		
NMIA	-0.016	0.196	-0.007	0.014	-0.015	0.015	-0.007	0.076	-0.010	0.013	-0.013	0.013	-0.025	0.131

Table A.7b – Degrees of equivalence for 60 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.002	0.048									0.015	0.013
PTB	0.000	0.048	0.001	0.015	-0.006	0.054	-0.005	0.036	0.004	0.516	0.013	0.013
VNIIFTRI	-0.002	0.048	-0.001	0.014	-0.008	0.054	-0.007	0.036	0.002	0.516	0.011	0.012
CSIR	-0.014	0.054	-0.013	0.028	-0.020	0.059	-0.019	0.043	-0.010	0.517	-0.001	0.027
NIST	-0.011	0.173	-0.010	0.167	-0.017	0.175	-0.016	0.170	-0.007	0.542	0.002	0.166
LNE	0.002	0.069	0.003	0.052	-0.004	0.074	-0.003	0.062	0.006	0.519	0.015	0.052
CMI	-0.027	0.069	-0.026	0.052	-0.033	0.074	-0.032	0.062	-0.023	0.519	-0.014	0.052
INRIM	0.003	0.202	0.004	0.196	-0.003	0.203	-0.002	0.199	0.007	0.552	0.016	0.196
KRISS	-0.006	0.049	-0.005	0.016	-0.012	0.055	-0.011	0.037	-0.002	0.516	0.007	0.014
METAS	0.002	0.049	0.003	0.017	-0.004	0.055	-0.003	0.037	0.006	0.516	0.015	0.015
MIKES	-0.006	0.089									0.007	0.076
NIM	-0.003	0.048	-0.002	0.015	-0.009	0.054	-0.008	0.036	0.001	0.516	0.010	0.013
NMIJ	0.000	0.048	0.001	0.014	-0.006	0.054	-0.005	0.036	0.004	0.516	0.013	0.013
NMi-VSL	0.012	0.139									0.025	0.131
NRC			0.001	0.050	-0.006	0.072	-0.005	0.060	0.004	0.518	0.013	0.050
SPRING	-0.001	0.050									0.012	0.019
SIQ	0.006	0.072									0.019	0.055
SP	0.005	0.060									0.018	0.038
UME	-0.004	0.518									0.009	0.516
NMIA	-0.013	0.050	-0.012	0.019	-0.019	0.055	-0.018	0.038	-0.009	0.516		

Table A.7c – Degrees of equivalence for 60 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		NIST		LNE		CMI	
	Δ_{A60_i}	$U(\Delta_{A60\_i})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	-0.004	0.011			-0.010	0.016	-0.017	0.013	0.022	0.100	0.016	0.162	-0.002	0.070	0.037	0.053
PTB	0.006	0.016	0.010	0.016			-0.007	0.017	0.032	0.101	0.026	0.163	0.008	0.071	0.047	0.054
VNIIFTRI	0.013	0.013	0.017	0.013	0.007	0.017			0.039	0.101	0.033	0.162	0.015	0.071	0.054	0.053
CSIR	-0.026	0.100	-0.022	0.100	-0.032	0.101	-0.039	0.101			-0.006	0.190	-0.024	0.122	0.015	0.113
NIST	-0.020	0.162	-0.016	0.162	-0.026	0.163	-0.033	0.162	0.006	0.190			-0.018	0.177	0.021	0.170
LNE	-0.002	0.063	0.002	0.070	-0.008	0.071	-0.015	0.071	0.024	0.122	0.018	0.177			0.039	0.087
CMI	-0.041	0.053	-0.037	0.053	-0.047	0.054	-0.054	0.053	-0.015	0.113	-0.021	0.170	-0.039	0.087		
INRIM	-0.007	0.031	-0.003	0.030	-0.013	0.033	-0.020	0.031	0.019	0.104	0.013	0.165	-0.005	0.076	0.034	0.060
KRISS	0.001	0.016	0.005	0.016	-0.005	0.020	-0.012	0.017	0.027	0.101	0.021	0.163	0.003	0.071	0.042	0.054
METAS	0.009	0.015	0.013	0.015	0.003	0.019	-0.004	0.017	0.035	0.101	0.029	0.163	0.011	0.071	0.050	0.054
MIKES	-0.011	0.083			-0.017	0.083	-0.024	0.083	0.015	0.130	0.009	0.182	-0.009	0.108	0.030	0.097
NIM	0.004	0.015	0.008	0.016	-0.002	0.020	-0.009	0.017	0.030	0.101	0.024	0.163	0.006	0.071	0.045	0.054
NMIJ	-0.003	0.011	0.001	0.010	-0.009	0.016	-0.016	0.012	0.023	0.100	0.017	0.162	-0.001	0.070	0.038	0.052
NMi-VSL	0.098	0.142			0.092	0.143	0.085	0.142	0.124	0.174	0.118	0.215	0.100	0.158	0.139	0.151
NRC	-0.006	0.044	-0.002	0.049	-0.012	0.050	-0.019	0.049	0.020	0.111	0.014	0.169	-0.004	0.085	0.035	0.071
SPRING	-0.004	0.017			-0.010	0.020	-0.017	0.017	0.022	0.101	0.016	0.163	-0.002	0.071	0.037	0.054
SIQ																
SP	0.069	0.176			0.063	0.177	0.056	0.176	0.095	0.202	0.089	0.239	0.071	0.189	0.110	0.184
UME	0.007	0.516			0.001	0.517	-0.006	0.517	0.033	0.526	0.027	0.541	0.009	0.521	0.048	0.519
NMIA	-0.019	0.018	-0.015	0.019	-0.025	0.022	-0.032	0.020	0.007	0.102	0.001	0.163	-0.017	0.072	0.022	0.055

Table A.8a – Degrees of equivalence for 60 dB step measurements of device K19.CL/2 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	INRIM		KRISS		METAS		MIKES		NIM		NMIJ		NMi-VSL	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.003	0.030	-0.005	0.016	-0.013	0.015			-0.008	0.016	-0.001	0.010		
PTB	0.013	0.033	0.005	0.020	-0.003	0.019	0.017	0.083	0.002	0.020	0.009	0.016	-0.092	0.143
VNIIFTRI	0.020	0.031	0.012	0.017	0.004	0.017	0.024	0.083	0.009	0.017	0.016	0.012	-0.085	0.142
CSIR	-0.019	0.104	-0.027	0.101	-0.035	0.101	-0.015	0.130	-0.030	0.101	-0.023	0.100	-0.124	0.174
NIST	-0.013	0.165	-0.021	0.163	-0.029	0.163	-0.009	0.182	-0.024	0.163	-0.017	0.162	-0.118	0.215
LNE	0.005	0.076	-0.003	0.071	-0.011	0.071	0.009	0.108	-0.006	0.071	0.001	0.070	-0.100	0.158
CMI	-0.034	0.060	-0.042	0.054	-0.050	0.054	-0.030	0.097	-0.045	0.054	-0.038	0.052	-0.139	0.151
INRIM			-0.008	0.033	-0.016	0.032	0.004	0.087	-0.011	0.033	-0.004	0.030	-0.105	0.145
KRISS	0.008	0.033			-0.008	0.019	0.012	0.083	-0.003	0.020	0.004	0.016	-0.097	0.143
METAS	0.016	0.032	0.008	0.019			0.020	0.083	0.005	0.019	0.012	0.015	-0.089	0.143
MIKES	-0.004	0.087	-0.012	0.083	-0.020	0.083			-0.015	0.083	-0.008	0.083		
NIM	0.011	0.033	0.003	0.020	-0.005	0.019	0.015	0.083			0.007	0.015	-0.094	0.143
NMIJ	0.004	0.030	-0.004	0.016	-0.012	0.015	0.008	0.083	-0.007	0.015			-0.101	0.142
NMi-VSL	0.105	0.145	0.097	0.143	0.089	0.143			0.094	0.143	0.101	0.142		
NRC	0.001	0.056	-0.007	0.050	-0.015	0.050	0.005	0.095	-0.010	0.050	-0.003	0.049	-0.104	0.150
SPRING	0.003	0.033	-0.005	0.020	-0.013	0.019			-0.008	0.020	-0.001	0.016		
SIQ														
SP	0.076	0.178	0.068	0.177	0.060	0.177			0.065	0.177	0.072	0.176		
UME	0.014	0.517	0.006	0.517	-0.002	0.517			0.003	0.517	0.010	0.516		
NMIA	-0.012	0.034	-0.020	0.022	-0.028	0.022	-0.008	0.084	-0.023	0.022	-0.016	0.019	-0.117	0.143

Table A.8b – Degrees of equivalence for 60 dB step measurements of device K19.CL/2 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	NRC		SPRING		SIQ		SP		UME		NMIA	
	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$	Δ_{A60_ij}	$U(\Delta_{A60\_ij})$
NPL	0.002	0.049									0.015	0.019
PTB	0.012	0.050	0.010	0.020			-0.063	0.177	-0.001	0.517	0.025	0.022
VNIIFTRI	0.019	0.049	0.017	0.017			-0.056	0.176	0.006	0.517	0.032	0.020
CSIR	-0.020	0.111	-0.022	0.101			-0.095	0.202	-0.033	0.526	-0.007	0.102
NIST	-0.014	0.169	-0.016	0.163			-0.089	0.239	-0.027	0.541	-0.001	0.163
LNE	0.004	0.085	0.002	0.071			-0.071	0.189	-0.009	0.521	0.017	0.072
CMI	-0.035	0.071	-0.037	0.054			-0.110	0.184	-0.048	0.519	-0.022	0.055
INRIM	-0.001	0.056	-0.003	0.033			-0.076	0.178	-0.014	0.517	0.012	0.034
KRISS	0.007	0.050	0.005	0.020			-0.068	0.177	-0.006	0.517	0.020	0.022
METAS	0.015	0.050	0.013	0.019			-0.060	0.177	0.002	0.517	0.028	0.022
MIKES	-0.005	0.095									0.008	0.084
NIM	0.010	0.050	0.008	0.020			-0.065	0.177	-0.003	0.517	0.023	0.022
NMIJ	0.003	0.049	0.001	0.016			-0.072	0.176	-0.010	0.516	0.016	0.019
NMi-VSL	0.104	0.150									0.117	0.143
NRC			-0.002	0.050			-0.075	0.182	-0.013	0.519	0.013	0.051
SPRING	0.002	0.050									0.015	0.022
SIQ												
SP	0.075	0.182									0.088	0.177
UME	0.013	0.519									0.026	0.517
NMIA	-0.013	0.051	-0.015	0.022			-0.088	0.177	-0.026	0.517		

Table A.8c – Degrees of equivalence for 60 dB step measurements of device K19.CL/2 at 5 GHz

N.B. SIQ did not submit results at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		LNE		CMI	
	Δ_{A100_i}	$U(\Delta_{A100\_i})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$
NPL	0.002	0.013			0.000	0.009	0.004	0.006	0.017	0.080	-0.003	0.080	0.037	0.442
PTB	0.002	0.014	0.000	0.009			0.004	0.009	0.017	0.080	-0.003	0.080	0.037	0.442
VNIIFTRI	-0.002	0.013	-0.004	0.006	-0.004	0.009			0.013	0.080	-0.007	0.080	0.033	0.442
CSIR	-0.015	0.081	-0.017	0.080	-0.017	0.080	-0.013	0.080			-0.020	0.113	0.020	0.449
LNE	0.005	0.069	0.003	0.080	0.003	0.080	0.007	0.080	0.020	0.113			0.040	0.449
CMI	-0.035	0.442	-0.037	0.442	-0.037	0.442	-0.033	0.442	-0.020	0.449	-0.040	0.449		
METAS	0.003	0.017	0.001	0.015	0.001	0.017	0.005	0.015	0.018	0.081	-0.002	0.081	0.038	0.442
NIM	-0.005	0.018	-0.007	0.016	-0.007	0.017	-0.003	0.016	0.010	0.081	-0.010	0.081	0.030	0.442
NMIJ	-0.001	0.019	-0.003	0.017	-0.003	0.018	0.001	0.017	0.014	0.082	-0.006	0.082	0.034	0.442
NMi-VSL	0.028	1.814			0.026	1.814	0.030	1.814	0.043	1.816	0.023	1.816	0.063	1.867
SPRING	0.019	0.038	0.017	0.036	0.017	0.037	0.021	0.036	0.034	0.088	0.014	0.088	0.054	0.444
SIQ	-0.012	0.182			-0.014	0.182	-0.010	0.182	0.003	0.199	-0.017	0.199	0.023	0.478

Table A.9a – Degrees of equivalence for 100 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	METAS		NIM		NMIJ		NMi-VSL		SPRING		SIQ	
	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$
NPL	-0.001	0.015	0.007	0.016	0.003	0.017			-0.017	0.036		
PTB	-0.001	0.017	0.007	0.017	0.003	0.018	-0.026	1.814	-0.017	0.037	0.014	0.182
VNIIFTRI	-0.005	0.015	0.003	0.016	-0.001	0.017	-0.030	1.814	-0.021	0.036	0.010	0.182
CSIR	-0.018	0.081	-0.010	0.081	-0.014	0.082	-0.043	1.816	-0.034	0.088	-0.003	0.199
LNE	0.002	0.081	0.010	0.081	0.006	0.082	-0.023	1.816	-0.014	0.088	0.017	0.199
CMI	-0.038	0.442	-0.030	0.442	-0.034	0.442	-0.063	1.867	-0.054	0.444	-0.023	0.478
METAS			0.008	0.021	0.004	0.022	-0.025	1.814	-0.016	0.039	0.015	0.183
NIM	-0.008	0.021			-0.004	0.022	-0.033	1.814	-0.024	0.039	0.007	0.183
NMIJ	-0.004	0.022	0.004	0.022			-0.029	1.814	-0.020	0.040	0.011	0.183
NMi-VSL	0.025	1.814	0.033	1.814	0.029	1.814			0.009	1.814		
SPRING	0.016	0.039	0.024	0.039	0.020	0.040	-0.009	1.814			0.031	0.186
SIQ	-0.015	0.183	-0.007	0.183	-0.011	0.183			-0.031	0.186		

Table A.9b – Degrees of equivalence for 100 dB step measurements of device K19.CL/2 at 60 MHz

Lab *j* ⇒

Lab *i* ⇓	KCRV		NPL		PTB		VNIIFTRI		CSIR		LNE		CMI	
	Δ_{A100_i}	$U(\Delta_{A100\_i})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$
NPL	0.004	0.029			-0.014	0.061	-0.085	0.061	0.046	0.121	0.016	0.105	0.096	0.290
PTB	0.018	0.057	0.014	0.061			-0.071	0.085	0.060	0.134	0.030	0.120	0.110	0.296
VNIIFTRI	0.089	0.066	0.085	0.061	0.071	0.085			0.131	0.134	0.101	0.120	0.181	0.296
CSIR	-0.042	0.105	-0.046	0.121	-0.060	0.134	-0.131	0.134			-0.030	0.159	0.050	0.314
LNE	-0.012	0.092	-0.016	0.105	-0.030	0.120	-0.101	0.120	0.030	0.159			0.080	0.308
CMI	-0.092	0.291	-0.096	0.290	-0.110	0.296	-0.181	0.296	-0.050	0.314	-0.080	0.308		
METAS	-0.008	0.063	-0.012	0.069	-0.026	0.091	-0.097	0.091	0.034	0.138	0.004	0.124	0.084	0.298
NIM	0.001	0.031	-0.003	0.024	-0.017	0.063	-0.088	0.063	0.043	0.122	0.013	0.106	0.093	0.291
NMIJ	-0.001	0.029	-0.005	0.019	-0.019	0.062	-0.090	0.062	0.041	0.121	0.011	0.105	0.091	0.290
NMi-VSL	0.205	5.648			0.187	5.648	0.116	5.648	0.247	5.649	0.217	5.649	0.297	5.655
SPRING	-0.009	0.034	-0.013	0.026	-0.027	0.064	-0.098	0.064	0.033	0.122	0.003	0.106	0.083	0.291

Table A.10a – Degrees of equivalence for 100 dB step measurements of device K19.CL/2 at 5 GHz

Lab *j* ⇒

Lab *i* ⇓	METAS		NIM		NMIJ		NMi-VSL		SPRING	
	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$	Δ_{A100_ij}	$U(\Delta_{A100\_ij})$
NPL	0.012	0.069	0.003	0.024	0.005	0.019			0.013	0.026
PTB	0.026	0.091	0.017	0.063	0.019	0.062	-0.187	5.648	0.027	0.064
VNIIFTRI	0.097	0.091	0.088	0.063	0.090	0.062	-0.116	5.648	0.098	0.064
CSIR	-0.034	0.138	-0.043	0.122	-0.041	0.121	-0.247	5.649	-0.033	0.122
LNE	-0.004	0.124	-0.013	0.106	-0.011	0.105	-0.217	5.649	-0.003	0.106
CMI	-0.084	0.298	-0.093	0.291	-0.091	0.290	-0.297	5.655	-0.083	0.291
METAS			-0.009	0.071	-0.007	0.070	-0.213	5.648	0.001	0.072
NIM	0.009	0.071			0.002	0.025	-0.204	5.648	0.010	0.030
NMIJ	0.007	0.070	-0.002	0.025			-0.206	5.648	0.008	0.026
NMi-VSL	0.213	5.648	0.204	5.648	0.206	5.648			0.214	5.648
SPRING	-0.001	0.072	-0.010	0.030	-0.008	0.026	-0.214	5.648		

Table A.10b – Degrees of equivalence for 100 dB step measurements of device K19.CL/2 at 5 GHz

Appendix B – Technical Reports from participating laboratories

The following reports on the measurement techniques were received from the participating laboratories.

B.1 NPL Measurements (C. Purser, K. P. Holland, J. Howes)

MEASUREMENTS

The 60 MHz measurements were carried out using the NPL 0.5 to 100 MHz Attenuator Calibrator. The Voltage Ratio Method (described by FL Warner et al in IEEE Trans IM-32 pp 33-37, 1983) was used for attenuation values up to the 90 dB setting and the AF substitution method using phase sensitive detection for higher attenuation values. A 10 kHz calibrated inductive divider was used as the reference standard. This IVD was calibrated by the NPL DC and LF group against the National Standard of Voltage Ratio.

The device under test was inserted between a signal source and a tuned receiver. The reflection coefficients of the source, the receiver and the device under test were measured and used to calculate the mismatch uncertainty. Impedance traceability was provided by check standards measured by NPL Impedance Section.

The reference or datum for the measurement of incremental attenuation was defined by connecting the device under test into the measurement system and setting it to the minimum attenuation value.

The measured attenuation values relate to the performance of the device under test when connected into a transmission line system having a characteristic impedance of 50 Ω.

The 5.0 GHz measurements were carried out on the NPL 2 – 18 GHz Attenuator Calibrator. The Voltage Ratio Method was used up to 80 dB, with the AF substitution method using phase sensitive detection for higher attenuation values. Unlike the low frequency measurements the source and receiver were impedance tuned using coaxial stub tuners directly connected to coaxial isolators.

B.2 NIST Measurements (R. A. Ginley)

Measurement Technique:

Two different Vector Network Analyzer (VNA) systems were used for the measurement of the attenuation standards. A NIST Dual Six-Port System was used for the measurements at 60 MHz and a commercial VNA was used to obtain the results at 5 GHz. Both systems were calibrated using the TRL calibration technique. Thus, the measurements are traceable back to the physical dimensions of the airline standards which were determined by NIST dimensional metrology systems.

Uncertainties:

All uncertainties are listed as one standard deviation. The uncertainty component denoted by u_a is a Type A component that is associated with the calibration of the measurement system. This component is primarily due to connector variability, long-term system variations, power meter resolution, and system noise during calibration of the VNA. The uncertainty component denoted by u_d is a Type A component that is evaluated from the repeated measurements of the device under test. This component is primarily due to the connector nonrepeatability of the device under test. The uncertainty component denoted by u_b is a Type B component that is primarily due to imperfections in the airline standards and test ports on the measurement. The expanded uncertainty, U, is given by

$$U = \sqrt{u_a^2 + u_b^2 + \frac{u_d^2}{n}}$$

where n is the number of repeat measurements of the device under test (n=6 for all the measurements).

Description of Results:

The measurement results are presented in an Excel spread sheet with three worksheets. The first worksheet has the incremental attenuation results for all of the attenuation levels measured for both attenuators at both frequencies with all of the uncertainty components (as described above) and the total uncertainty listed. The second worksheet contains the reflection coefficient information for all measurements. The results contain the data for the magnitude and phase (in deg) of S_{11}, the magnitude and phase (in deg) of S_{22}, and the measured source match and load match values (the source and load match values were not used in the determination of incremental attenuation or reflection coefficients and there is no uncertainty values listed for them). The final worksheet contains our pin depth measurements.

B.3 LNE Measurements (B. Mellouet)

Two different methods were used for the measurements:

The residual attenuation of the devices at 0 dB position was measured by the power ratio technique. It means that the power was measured with and without the device. The attenuation is the ratio between the measured powers.

For the attenuation measurement of the different steps, the method used was a substitution method at intermediate frequency. We used a TEGAM VM7 attenuation measurement system. This system works at 30 MHz so mixers were used to reduce the frequency. The step attenuation values were measured by taking the reference point at the 0 dB position of the step attenuator. For 60 dB attenuation or higher, a fixed 50 dB coaxial attenuator is used to have more dynamic range.

The measurement systems are well matched by adding fixed attenuators in order to minimize the mismatch uncertainties.

The reflection factors were measured by the compensated reflectometer method and with a vector network analyser.

B.4 PTB Measurements (D. Stumpe)

Power Ratio

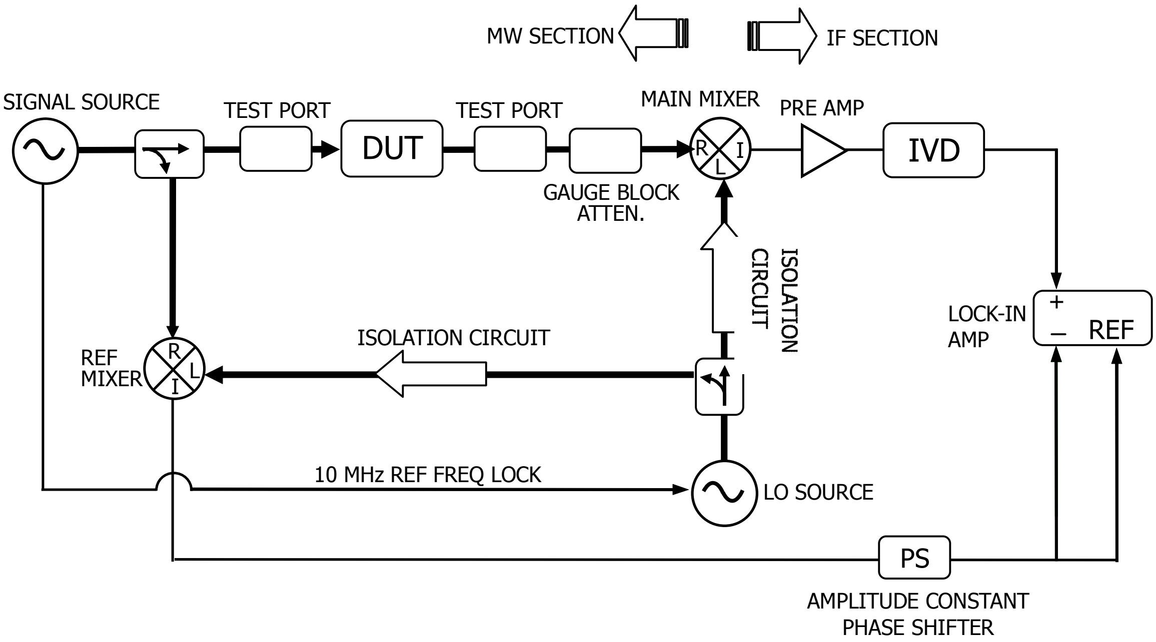
The PTB RF standard attenuation measuring equipment for attenuation values up to 30 dB is working with the power ratio method using DC substitution. A stabilized RF power of 10 mW is fed into the DUT. The power transmitted through the DUT is measured with a thermistor mount which is connected to a self-balancing bolometer bridge. The bridge voltages are measured using two digital voltmeters. The attenuation is calculated from two the two power levels which correspond to the ON and OFF settings of the DUT. Source and load side of the insertion point for the DUT are matched with tuners. Traceability to the German national standard for DC voltage is achieved by calibration of the digital voltmeters.

RF Series Substitution

The PTB RF standard attenuation measuring equipment for attenuation values above 30 dB is working with the RF series substitution method. A stabilized RF power of 10 mW is fed into the DUT. The power transmitted through the DUT is detected with a sensitive receiver. The attenuation of the DUT is measured by comparison with a chain of reference attenuators which are calibrated with the power ratio method. The small difference between DUT and reference chain is measured using the receivers synchronous detector only. The attenuation is calculated from the value of the reference chain and the measured difference between DUT and reference chain. Source and load side of the insertion point for the DUT are matched with tuners. Traceability to national standards is achieved by calibration of the synchronous detector and the components of the reference chain with the power ratio setup which again is traceable to the German national standard for DC voltage.

B.5 NMIJ Measurements (A. Widarta)

1. Principle of Measurement Technique



Block diagram of RF attenuation measurement system based on a dual-channel IF substitution method.

The above-mentioned figure shows a block diagram of the NMIJ RF attenuation measurement system [1], [2] used to make the measurements of this attenuation intercomparison. The system employs a traceable inductive voltage divider (IVD) at 1 kHz as a reference standard and dual-channel intermediate frequency substitution method. The RF attenuation of the DUT after converting to the IF attenuation is compared with attenuation of IVD by a null balance method. The signals are kept balanced by adjusting the IVD and phase shifter before and after setting of the DUT. The attenuation value then is determined from the ratio of the IVD values at initial and final setting. Single step measurement technique is used for measurements of attenuation up to 60 dB. However, double step measurement technique, which is switching the gauge block attenuator into and out from the circuit, is used for measurements of attenuation greater than 60 dB. The LED-fiber-PD assemblies and amplifier-attenuator assemblies are used as isolation circuits in 60 MHz and 5 GHz measurement system, respectively. Well impedance-matched isolators are used as test ports in 60 MHz attenuation system, though combination of isolators and stub tuner are used in 5 GHz. As for signal and local sources, two very stable crystal oscillators are used in 60 MHz system and two synthesizers which are locked by the same 10 MHz reference frequency are used in 5 GHz system.

2. Measurement Condition.

Any measurements were performed after full equilibration process of the transfer standards by placing them in the measurement room more than 48 hours. The room temperature and humidity are controlled to 23±1°C and 50±15%, respectively. The actual operating temperatures of the standards were measured by an infrared radiation thermometer with the specification accuracy in ±2 °C. The protrusion of the RF connector center pins of the test ports and traveling standards were checked before commencing measurements. Not any unsatisfied dimensions were found among them. The power incidents on the traveling standards were 1 mw and 10 mW in measurements at frequency 60 MHz and 5GHz, respectively. The attenuator controller was supplied by 100 V/50 Hz voltages.

3. Uncertainty Evaluation

The main sources of the uncertainty are listed in the following table together with typical values for measurements made of a 0-40 dB step of K19.CL/1 traveling standard at 5 GHz. Detail of each uncertainty source determination could be found in Reference 1 and 2. Mismatch uncertainties are evaluated following equation 29 of Reference 3 by making measurements of reflection coefficients of the travelling standards and the test port sets of the system using the HP-8510 network analyzer.

Uncertainty estimations for a typical 0-40 dB step of K19.CL/1 travelling standard at 5 GHz

Source of uncertainty	Type of uncertainty	Typical standard uncertainty
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.00005
Amplitude change of phase shifter	B	0.0003
Non linearity	B	0.0005
Leakage	B	$3\text{x}10^{-6}$
Stability	B	0.0001
Mismatch	B	0.0003
Gauge block calibration	B	-
Standard deviation of 10 measured values	A	0.0006

4. Traceability

The NMIJ RF attenuation measurements system is originally developed at NMIJ/AIST. The system is planned to be used as a national standard of attenuation from the fiscal year 2004. The IVD is traceable to the Japan national standard of AC voltage ratio at 1 kHz.

5. Results

See the attached completed measurements result spreadsheet.

6. References

[1] A.WIDARTA, T.KAWAKAMI, “Attenuation measurement system in frequency range of 10 to 100 MHz”, *IEEE Trans. IM*, Vol. 52, No.2, pp.302-305, April 2003.

[2] A.WIDARTA, T.KAWAKAMI, K. SUZUKI, “Dual channel IF substitution measurement system for microwave attenuation standard”, *IEICE Trans.Electron.*, Vol. E86, No.8, pp., August 2003.

[3] I.A. HARRIS, F.L. WARNER, “Re-examination of mismatch uncertainty when measuring microwave power and attenuation,” *IEE Proc.*, Vol.128.pt.h. no.1, pp.35-41, Feb.1981.

B.6 CMI Measurements (F. Hejsek)

Date of receipt

6th August 2003

List of equipment

Receiver VM–7, Lucas-Weinschel	ser. no.: 290
Mixer 8852, Lucas-Weinschel	ser. no.: 184
Calibrated by CMI traceable to hf. power standard. Calibrated on 26th May 2003, Calibration certificate no.: 113–KL–1728–03.	
Power splitter 11667A, Agilent	ser. no.: 19397
Attenuator set, Weinschel Corp.	ser. no.: 6147
VNA 8510SX (0.045–26.6) GHz, Hewlett—Packard	ser. no.: 3312A00583
Coaxial accessories	

Measuring method

The system VM7/8852 has been calibrated according to modified (A. Coster: Calibration of the Lucas Weinschel VM7 Attenuator and Signal Calibrator, BEMC, 1995, p.46-1) method. Instead of using IVD at 10 kHz we have used 30 MHz signal which has been simultaneously measured by the VM-7 and thermistor sensor. The differences between wattmeter and VM7 readings are less then 0.001 dB. To calibrate the mixer, we have used programmable attenuator 8494/6H and the applied (uncalibrated) step in signal power has been simultaneously measured by the VM-7 and thermistor sensor again.

Attenuation has been measured according to Fig. A.1 under routine laboratory condition. Reflection coefficients have been measured with the help of 8510SX network analyser.

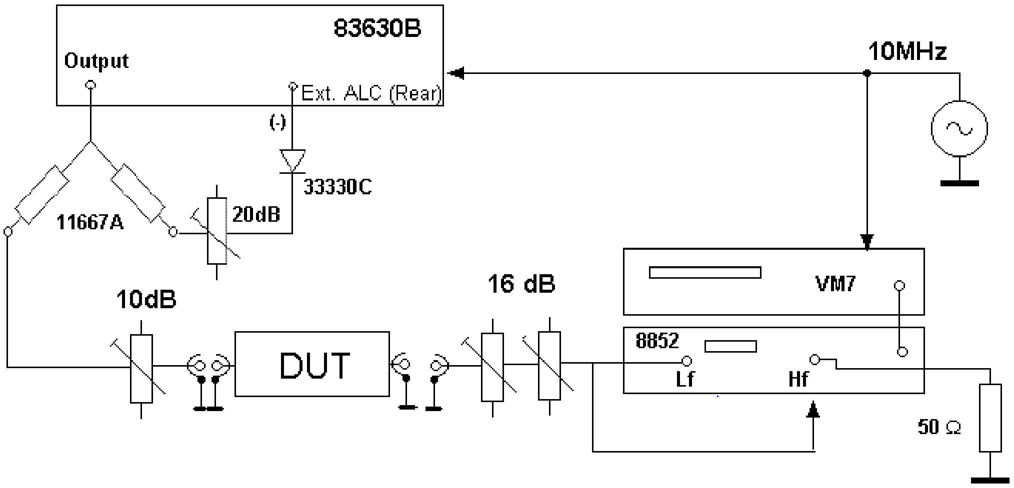


Fig. A.1 – Circuit diagram

B.7 CSIR Measurements (C. F. Matthee)

The 60 MHz attenuation measurements were performed by direct measurement against a calibrated Hewlett-Packard 8902A Measuring Receiver.

The 5 GHz attenuation measurements were performed using a microwave mixer and local oscillator to down-convert the RF signal to a 120,53 MHz IF signal. This IF signal was measured using the measuring receiver.

The measuring receiver was traceable to a Techtest 310 WBCO piston attenuator operating at 30 MHz. The WBCO is a primary standard with traceability to other parameters.

The reference or datum for the measurement of incremental attenuation was defined by connecting the device under test into the measurement system and setting it to the minimum attenuation value.

The voltage reflection coefficients (VRC) of the source and receiver were improved by using pre-selected attenuators with low reflection coefficients at the measurement points.

The voltage reflection coefficients of the device under test and receiver were determined by direct measurement against a vector network analyser. The reflection coefficient of the source was calculated using the VRC of the attenuator and the worst-case reflection coefficient of the source.

The uncertainty of the VNA was calculated using the EA document, “Assessment of calibrated vector network analysers (VNA)”. The accuracy was checked by comparison against two calibrated airlines from the VNA verification kit, calibrated by NPL.

B.8 NRC Measurements (A. Michaud, D. C. Paulusse)

Introduction

The purpose of this international comparison is to compare the ability of the national metrology institutes to measure RF-attenuation. We followed the guidelines of the *Technical Protocol.* [1]

In this report, we give a short description of the measurement methods and we present the results for the two devices that were submitted. One is a 0-70 dB device modified (*HP 8490L*) and the other one is a 0-110 dB device (*HP 8496H*). The DUTs were labelled: **K19.CL/1,** (0-70 dB) and **K19.CL/2** (0-110 dB) respectively.

Description specific to the INMS measurement

Date of receiving the attenuators: 27 January 2003

Date measurements commenced: 31 January 2003

Date measurements completed: 2 March 2003

Date of dispatch of attenuators: 3 March 2003

Measurement technique 60 MHz:

We use an AF substitution system similar to the one described in Warner [2, Chapter 8].

The source is a synthesized oscillator, (FLUKE 6060A) followed by an amplifier, a filter, a resistive tee power divider, and a fixed attenuator. This attenuator is selected in order to insure a good source match. The second port to the power divider is attached to a closed loop level controller.

The receiver is a double balanced mixer and a synthesized oscillator (HP 3325B). The front end is a fixed attenuator to insure a good match. The intermediate frequency of 10 KHz is then amplified and fed through an Inductive Voltage Divider (Gertsch/Singer 6 digits model) to a level detector.

Measurement technique 5 GHz:

The source is a synthesized oscillator, (HP 683620A) followed by an amplifier (HP 8349B), a directional coupler used as a power divider, some isolators and an impedance tuner. This tuner is adjusted "in situ" using a Vector Network Analyzer in order to insure a good impedance match. The side port of the power divider is attached to a closed loop amplitude controller.

The receiver is a double balanced mixer and a leveled controlled synthesized oscillator (Agilent 83650B) to drive its LO input. The front end is a tuner and some isolators to insure a good match. The intermediate frequency of 10 KHz is amplified and then fed to the AF receiver described above.

For both measurement frequencies, the source is contained on a wheeled table that can be moved in order to align to the connectors.

Results of the INMS measurement

Connector quality:

The connectors were inspected using a stereoscope and pin depths were measured. The results ware as follows:

K19.CL/1 Port 1: Some minor signs of wear on the outer edge of the centre pin. Some minor sign of wear on the step of outer. Pin recession: (0.0015" +/- 0.001") 40 µm +/- 25 µm. Overall condition quite good.

K19.CL/1 Port 2: Some minor signs of wear on the step of outer. Pin recession: (0.0005" +/- 0.001") 12 µm +/- 25 µm. Overall condition quite good.

K19.CL/2 Port 1: Signs of wear on the center pin. Some wear due to a rotation. Pin recession: (0.001" +/- 0.001") 25 µm +/- 25 µm. Overall condition quite good.

K19.CL/2 Port 2: Some minor compression points visible. Pin recession: (0.002” +/- 0.001”) 50 µm +/- 25 µm. Overall condition quite good.

Reflection Coefficient:

The reflection coefficient of the attenuator was also measured and its magnitude is reported in the **resultsINMS** file. The values were used for the evaluation of the mismatch factor and related uncertainties. These measurements were done using a Vector Network Analyzer, Hewlet Packard model 8510C. The reference standards are a set of airlines. The uncertainty of this measurement is described in reference [3].

Incremental Attenuation:

The measurement results are given in the file **resultsINMS.xls** in the standard format for the comparison. We summarise them in the table 1 shown below:

K19-CL/1 at 60 MHz			
Setting [dB]	**Reading [dB]**	**+/- [dB]**	**Degrees of Freedom**
0-20	**19.950**	**0.0107**	**3.9**
0-40	**40.120**	**0.0147**	**10.7**
0-60	**60.08**	**0.024**	**6.1**
0-70	**70.03**	**0.029**	**11.5**

Table 1: Reported values for the K19-CL/1 device measured at 60 MHz

The expressed uncertainty represents the standard uncertainty. The evaluation of the various contributions was done in the file **INMS-UNCERTAINTY-BUDGET.XLS** and is reported in the **ResultsINMS** file.

K19-CL/2 at 60 MHz			
Setting [dB]	**Reading [dB]**	**+/- [dB]**	**Degrees of Freedom**
0-20	**19.934**	**0.0107**	**3.9**
0-40	**40.189**	**0.0147**	**10.7**
0-60	**60.14**	**0.024**	**6.1**
0-80	**80.34**	**0.029**	**11.5**
0-100	**Not Measured**	**----**	**----**
0-110	**Not Measured**	**----**	**----**

Table 2: Reported values for the K19-CL/2 device measured at 60 MHz

Although it was not required, the file **INMS-UNCERTAINTY-BUDGET.XLS** also gives the expanded uncertainties and the coverage factor for a 95 % confidence interval.

The Tables **3** and **4** give the similar results for 5 GHz.

K19-CL/1 at 5 GHz			
Setting [dB]	**Reading [dB]**	**+/- [dB]**	**Degrees of Freedom**
0-20	**19.951**	**0.0107**	**3.9**
0-40	**40.110**	**0.0147**	**10.7**
0-60	**60.06**	**0.024**	**6.1**
0-70	**70.03**	**0.029**	**11.5**

Table 3: Reported values for the K19-CL/1 device measured at 5 GHz

K19-CL/2 at 5 GHz			
Setting [dB]	**Reading [dB]**	**+/- [dB]**	**Degrees of Freedom**
0-20	**19.933**	**0.0107**	**3.9**
0-40	**40.152**	**0.0147**	**10.7**
0-60	**60.10**	**0.024**	**6.1**
0-80	**80.29**	**0.029**	**11.5**
0-100	**Not Measured**	**----**	**----**
0-110	**Not Measured**	**----**	**----**

Table 4: Reported values for the K19-CL/2 device measured at 5 GHz

Environmental Conditions:

The temperature of the room during the measurement was **23 +/- 1 °C**. The relative humidity was **25 +/- 10 %**.

Discussion:

During the course of measurement, we found that an unusual high level of RF leakage was present. The consequence is that it was not possible to measure the device **K-19-CL/2** for the values above 80 dB. As a consequence, we do not want to report any value for those measurements (**100 dB** and **110 dB**). The appropriate entries in table 2 and table 4 were left blank.

References

[1] J. HOWES, "CIPM Key Comparison CCEM-RF-K19.CL (GT-RF-00-02) Attenuation at 60 MHz and 5 GHz using a 50 Ohm Type-N step attenuator: Technical Protocol (Version 3.3)", September 2001

[2] F. L. WARNER, "Microwave Attenuation Measurement", London, Peter Peregrinus, 1977.

[3] A. JURKUS, “Evaluation of a Wide-Band Method for the Measurement of the Reflection Coefficient of Microwave One-Port Networks”, *IEEE Trans. Instrum. Meas.*, Vol. IM-26, No. 3, September 1977, pp. 238-242.

B.9 NMi-VSL Measurements (J. P. M. de Vreede)

NMi-VSL operates two VNAs, one for low frequencies (50 kHz – 3 GHz) and one for higher frequencies (45 MHz – 50 GHz). To obtain a low noise level the first one is used for the measurements at 60 MHz.

For 60 MHz the HP 8753E with external test-set 85046A is calibrated using a calibration kit HP 85032B using firmware (SOLT calibration). A frequency set of 30 frequencies is used with a maximum average of 64 scans.

For 5 GHz an Agilent system containing the 8510C basic unit, a HP synthesizer 83651B as signal source and two S-parameter test sets is available. The test set 8515A (frequency range 45 MHz up to 26.5 GHz) is used and calibrated using firmware and a calibration kit 85054B (SOLT calibration with sliding loads). On each port of the test set an Agilent 85132F cable is attached together with an adapter PC7-N (male or female) which results in an effective test port 1 having a slotless female connector and an effective test port 2 having a male connector. An average of 128 measurements is used under normal circumstances, but for high attenuation (50 dB and isolation) this is increased up to 4096, the maximum number, still with an acceptable measuring time.

The insertion measurements and all step measurements are performed after changing the adapter on port 1 to effectively a male N-connector.

Measurements are performed at different power level, but corrections are made for non-linear behaviour due to power level. The linearity of the detectors is based upon measurements done using a step attenuator calibrated at 1 GHz by NPL, UK (range: 0-40 dB in steps of 5 dB). For higher attenuation a numerical calculation is used.

A software programme written in QuickBasic is used for control of the VNA and for obtaining the corrected data from the VNA. Further data analysis is done in spreadsheets written in Excel.

B.10 METAS Measurements (J. Furrer, M. Zeier)

1 Measurement Technique and Traceability

Measurements were performed with a parallel IF substitution system comprising a “Waveguide Below Cut-off” (WBCO) attenuation standard (Techtest Model 310). With this primary standard attenuation is determined through measurement of the longitudinal position of the WBCO piston via a laser interferometer. Results are thus traceable to national standards and to internationally supported realisations of SI units.

2 Measurements

Three measurement series were performed for each DUT/attenuation configuration at three different source powers (DUT branch). Each measurement series consisted of ten measurements.

To improve the matching conditions in the DUT branch a 10dB (before DUT) and a 20 dB (after DUT) matching pad were installed. For the 5GHz measurements additionally a tuner was inserted after the DUT.

The system in its current state is not able to measure attenuation above 80dB mostly due to limitations of the measurement receiver. For details see section 3 (Receiver noise and High attenuation).

It was found after the measurements that the feedback control of the WBCO RF source was not working properly and that during certain measurement periods the WBCO signal was unstable. This effect created an unusual large scatter in the data and also an additional Type B uncertainty contribution, which is under normal conditions not present. For details see section 3 (WBCO source stability).

3 Measurement Uncertainties

Uncertainty contributions are quantified for each configuration in the separate excel sheet. In the following each item is described in short. Quoted uncertainties are standard uncertainties. All Type B contributions are assumed to have infinite degrees of freedom.

Statistics (SU_C1)

The quoted value is the standard deviation of the mean calculated from the scatter of data points.

Attenuation standard (SU_C2)

The accuracy of the WBCO system is limited by the geometrical tolerances of the wave-guide. We quote a relative uncertainty of $5 \cdot 10^{-5} / dB$.

Environment (SU_C3)

Temperature, air pressure and humidity influence geometrical dimensions of the wave guide and laser wavelength. These quantities are permanently monitored during the measurements with a calibrated meteo station (Thommen HP 113 A-L5 W1F).

The measurement uncertainties of these quantities propagate to the attenuation results. Typical values and uncertainties for the environmental quantities and resulting relative uncertainties for attenuation values are listed in the following:

Temperature around wave-guide $T = 25°C$: $u(T)=1°C \rightarrow 1.6 \cdot 10^{-5} / dB$

Pressure around wave-guide $P = 950 mbar$: $u(P)=10 mbar \rightarrow 2.6 \cdot 10^{-6} / dB$

Excess Pressure in wave-guide $P_G = 5 mbar$: $u(P_G)=5 mbar \rightarrow 9.8 \cdot 10^{-11} / dB$

Humidity around wave-guide $H = 30\%$: $u(H)=10\% \rightarrow 1.4 \cdot 10^{-7} / dB$

The dominant (and only relevant) contribution is from the temperature around the wave-guide.

Mismatch (SU_C4)

Mismatch uncertainties are calculated according to equation 29 in *I.A. Harris and F.L. Warner, IEE Proc. 128 (1981) 35*. S-parameters of the DUT and source and load reflection coefficients of the measurement apparatus are determined with a Vector network analyser.

Non-linearity (Mixer and WBCO) (SU_C5)

Measurements were performed at different source power resulting in different maximum signal strength at the mixer (-21 dBm, -25 dBm, -30dBm) while the Local Oscillator power was kept constant (10dBm). This allows investigating the effects of mixer non-linearity. The observed effect is $(-1.4 \pm 0.2) \cdot 10^{-3} dB$ at –21dBm and neglible at –30dBm. The data is corrected for this effect and the remaining uncertainty is small (0.0001dB below 80dB and less than 0.001 for 80 dB and higher).

The WBCO non-linearity is known from calibration measurements done in the past. The calibration data is fitted with a smooth curve, which is used to correct the data for non-linearity of the WBCO. The correction is typically small (<0.004 dB). The uncertainty in the fit parameters is propagated to an uncertainty in attenuation, which turns out to be less than 0.0001dB except at 80 dB (0.0007dB).

WBCO source stability (SU_C6)

Due to the above-mentioned instability of the WBCO RF source some data sets show an unusual large scatter. We believe that the effect is primarily of statistical nature but we can‘t entirely exclude an overall bias due to e.g. long-term drifts of the WBCO source power. After the comparison measurements the behaviour of the WBCO source power was recorded over time. From observed typical drifts an uncertainty of 0.003 dB is determined. This is a dominant contribution at lower attenuation values.

Receiver noise (SU_C7)

The mixer introduces an additional source of noise in the DUT branch of the apparatus resulting in different noise floors in the receiver for the WBCO and DUT measurements. This additional noise introduces a bias in the receiver at low signal strength and limits the measurement capabilities of the system to a maximum of 80 dB. As a consequence data taken at the lowest source power is omitted for the 70 dB result and only data at maximum source power is taken into account for the 80 dB result. Additionally a correction of $-0.006 \pm 0.003\, dB$ is applied to the 80dB data.

High attenuation (100 and 110 dB) (SU_C8)

We are not able to measure 100 dB and 110 dB directly for reasons mentioned above. The results that are quoted for 100 and 110 dB are calculated sums of the measurements of single sections of the step attenuator, i.e. 100=20+40(1)+40(2) and 110=10+20+40(1)+40(2). The validity of this approach is tested for other attenuator settings that are calculable as sums of sections but can also be measured directly. From these comparisons we estimate an uncertainty of 0.004dB for 60 MHz and 0.033 dB for 5 GHz.

B.11 SP Measurements (J. Stenarson, K. Yhland, C. Wingqvist)

Background

The comparison contains two DUTs (Device Under Test), both manufactured by Agilent. They are of two different models. Their designations can be found in Table 2.

Table 2 DUT designations

DUT model	Designation
84907L	K19.CL/1
8496H	K19.CL/2

Results are reported on the incremental attenuation as well as the reflection coefficient of the devices.

Measurement technique

The DUTs (Device Under Test) were measured using a Vector Network Analyser (VNA) Agilent 8510 with an Agilent 8515 testset. The DUTs were non-insertable, both ports of the DUT had female connectors. The measurement was performed according to the standard procedure for attenuator measurements at SP [1]. The VNA was calibrated using the SOLT technique with a female connector on port 1 and male connector on port 2 of the VNA, this means the DUT was measured with a male-male adapter on the DUT, see Fig A.2. The incremental attenuation was computed by the ratio of the S_{21} values of the measurements of the S-parameters of the datum and set position of the DUT. No correction was made for the adapter that had to be used but it is included in the uncertainty budget.

The SOLT standards were connected 6 times each and the step attenuators were measured by first measuring the datum setting and then the desired setting of the attenuator, thus the datum is measured before each setting. All required settings are measured in sequence and this sequence was repeated 10 times.

To estimate the uncertainty contribution of the male-male adapter we measured the adapter connected with a female-female adapter.

Measurements are reported for 20, 40, 60, and 70dB for K19.CL/1 and 20, 40, 60, and 80dB for K19.CL/2.

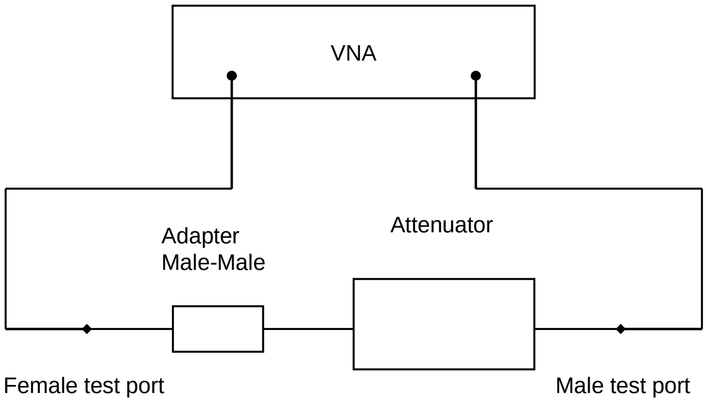


Fig A.2 Measurement set-up.

Instrumentation

Table 3 Instrumentation used for the measurements

Item	Inventory number
Agilent 8515A testset	SP602333
Agilent 8510C Network analyzer	SP602331
Agilent 83651B Synthesized sweeper	SP602343
Agilent 11713A attenuator switch	SP602726
Type N calibration kit HP 85054B	SP503388
Flexcable port 1 Maury	SP602814
Flexcable port 2 Agilent	SP602610
Adapter NMD 3.5mm->Type N female	SP602776
Adapter NMD 3.5mm->Type N male	SP602776
Type N adapter Male-Male	S/N 63713
Type N adapter Female-Female	S/N 59205

Uncertainty Traceability

VNA measurements are traced to airline impedance standards and calibrated step attenuators. See Table 4 for details on devices used. The calibration algorithm is described in [2], and the uncertainty calculation is described in detail in [3].

Table 4 Traceability table

Device	SP number	Tracebility
Agilent 125mm airline	SP503389	NPL
Maury 150mm airline	SP602571	NPL
Maury 300mm airline	SP602852	
Agilent 84904L step attenuator	SP602845	NPL
Agilent 84906L step attenuator	SP602844	NPL

Environmental conditions

The temperature and humidity was measured at the VNA. The temperature was 24.9±0.5 ºC.

Uncertainty contributions

In the uncertainty budget the different contributions are designated SU_C1…SU_C13, each contribution is described below. The uncertainty budget is evaluated in linear units.

The results for the comparison are to be reported in dB, so a conversion must be made. The estimated linear transmission, T, is converted to attenuation, A, in dB by

$$A = -20 * \log(T)$$

The relative standard uncertainty, $u(T)$, is converted to standard uncertainty, $u(A)$, in dB by

$$u(A) = -20 * \log(1 - u(T))$$

Experimental variation (SU_C1): The standard uncertainty in the mean of the incremental attenuation. This value is estimated using a bootstrap technique including all measurements of the SOLT standards as well as the 10 measurements of the datum and set positions.

Drift (SU_C2): Estimated uncertainty due to drift and ambient conditions estimated for the measurement setup.

Cable flex (SU_C3): Estimated uncertainty due to cable flexing between the calibration and connection to the DUT.

Frequency error (SU_C4): Estimated uncertainty due to frequency uncertainty.

Isolation (SU_C5): This is the estimated uncertainty contribution due to finite isolation.

Linearity (SU_C6): This is the estimated uncertainty contribution due to non-linearity.

Test port match (SU_C7-SU_C9): This is the estimated uncertainty contribution from residual test port match. There are two terms SU_C7 and SU_C8 for port 1 and 2 of the VNA. In the budget there is also contribution arising from the interaction between port 1 and 2. This is a small factor since it contains the product of M_1 and M_2 (SU_C9).

Adaptor (SU_C10-SU_C12): This is the estimated uncertainty contribution from the male-male adaptor on port one of the attenuator. Only the S-parameters S_{12}, S_{21} and S_{22} of the adaptor have an impact on the measurement of incremental attenuation. There is a first order contribution from $u(S_{22})$ (SU_C10) and second order contributions from $u(S_{22})u(S_{12})$ (SU_C11) and $u(S_{22})u(S_{21})$ (SU_C12).

Temperature coefficient of DUT (SU_C13): The attenuator has a temperature coefficient of 0.0001 dB/dB/C. A value of 0.0003 dB/dB was used to account for the 1.9±0.5ºC deviation from 23ºC.

Connector gauging

The connectors of the DUTs were inspected and the pin depth was measured both on arrival and before dispatch to the next lab.

The master gauge was used to adjust the dial indicator to show 0 mm. Thereafter three measurements were taken with the master gauge rotated to three different positions to ensure that the clock shows 0 mm. Table 5 and Table 7 shows the results of these procedures.

The measurement of each connector was repeated three times with the clock rotated to different positions. Table 6 and Table 8 show the result of these measurements. The results are within specification (0 – 0.076 mm).

Measurements on arrival

Table 5 Results of zero gauge for the measurements on arrival.

Master gauge position	Indication [mm]
1	0.0000
2	0.0000
3	0.0000

Table 6 Results of the pin-depth measurements on arrival.

	K19.CL/1		K19.CL/2	
	Port 1	Port 2	Port 1	Port 2
Visual inspection	OK	OK	OK	OK
Pin-depth [mm]	0.04826	0.01016	0.03048	0.06096
	0.04826	0.01270	0.03302	0.06350
	0.04318	0.01524	0.03048	0.06096
Pin-depth mean value [mm]	0.04657	0.01270	0.03133	0.06181

Measurements before dispatch

Table 7 Results of zero gauge for the measurements prior to dispatch.

Master gauge position	Indication [mm]
1	0.0000
2	0.0000
3	0.0000

Table 8 Results of the pin-depth measurements prior to dispatch.

	K19.CL/1		K19.CL/2	
	Port 1	Port 2	Port 1	Port 2
Visual inspection	OK	OK	OK	OK
Pin-depth [mm]	0.04826	0.01016	0.0432	0.06350
	0.04826	0.01270	0.0432	0.06096
	0.04064	0.01016	0.0381	0.06096
Pin-depth mean value [mm]	0.04572	0.01101	0.0415	0.06181

References

[1] J. STENARSON AND K. YHLAND, "S-parameter and incremental attenuation measurement," SP-Metod 2925, 2004.

[2] J. STENARSON, "SOL/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.

B.12 UME Measurements (S. Yaran)

1. MEASUREMENT PERIOD

24 March 2004 – 9 April 2004

2. ENVIRONMENTAL CONDITIONS

Temperature: (23±1) °C
Relative humidity: (45±10) %
Line voltage: (220±10) V
Line frequency: 50 Hz

3. REFERENCE USED IN THE MEASUREMENTS

HP 8510C Network Analyser with HP 8515A Test Set

The HP 85055A Verification Kit with Serial No 2815A00520 of the Network Analyser was calibrated by NMi-VSL.

4. MEASUREMENT FREQUENCIES

0.06 and 5 GHz

5. MEASUREMENT METHOD

The measurement standard used was HP8510C Netvork Analyser with a HP8515A Test Set. HP85132F cable pairs used at the port 1 and 2. The type of calibration is Short-Open-Load-Through (SOLT) with fixed loads below 2 GHz and sliding loads above 2 GHz.

B.13 SPRING Measurements (A. B. I. Teo, N. Hoon, Y. Shan)

Submitted by	:	National Metrology Centre SPRING Singapore 1 Science Park Drive Singapore 118221	Date : 2005-05-04 Page 1 of 11
Subject	:	Programmable Step Attenuators	Ambient Temperature : 23 ± 2^{o}C Relative Humidity : 55 ± 5% rh
Manufacturer	:	Hewlett Packard(CL1)/Agilent(CL2)	
Model	:	84907L//8496H	
Serial Number	:	2936A00473/3247A12679	
Range	:	0-70 dB/0-110 dB	
Date Measured	:	2005-04-22	

These Programmable Step Attenuators have been measured at the National Metrology Centre, SPRING Singapore, under the ambient conditions stated above.

Method of Measurement

The SPRING's RF/microwave attenuation measurement system employs an inductive voltage divider (IVD) calibrated at NPL, UK, as a reference. For both 60 MHz and 5 GHz measurement of the DUTs, the intermediate frequency substitution method and voltage ratio technique are used.

B.14 NIM Measurements (Q. Gao)

1. Principle of Measurement Technique

A low-medium frequency (10 kHz) series substitution method is used in the attenuation measurement system in NIM. An Inductive Voltage Divider (IVD) is used as the reference standard. The IVD is traceable to the AC voltage ratio standard (IVD standard) in NIM. A Lock-In Amplifier is used as a phase sensitive detector. The measurement system is shown in the fig. 1 as follows.

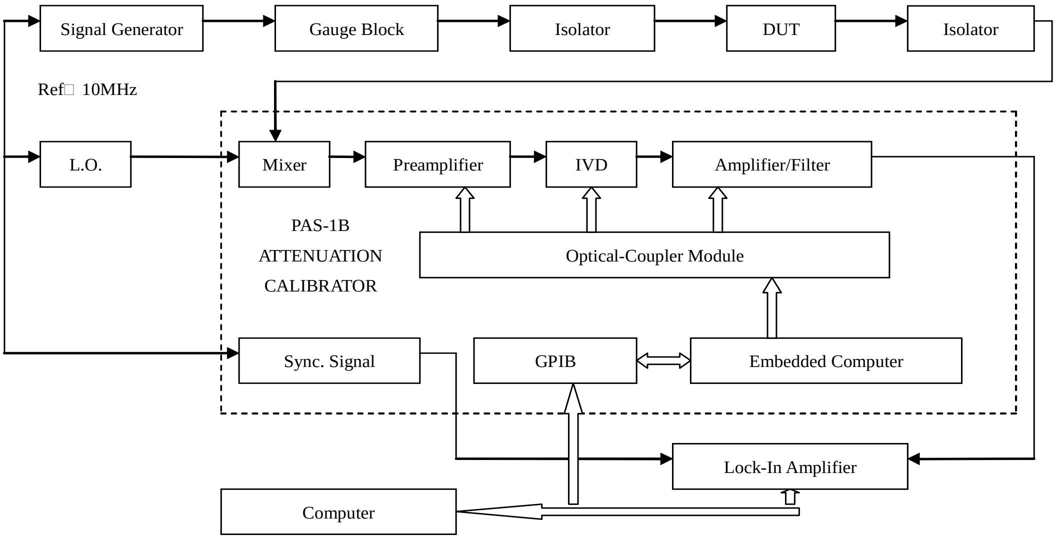


Fig. Attenuation Measurement System

The instrument, PAS-1B ATTENUATION CALIBRATOR, was designed and made by NIM. As shown in fig.1, the PAS-1 mainly consists of a switch/preamplifier, IVD and variable amplifier modules. The frequency ranges from 10 kHz to 18 GHz over a selection of 4 mixers, e.g. 10 kHz, 100 kHz – 30 MHz, 10 MHz – 1.5 GHz, and 1.5 GHz – 18 GHz. The band selection is done in the switch/preamplifier module. The purpose of this module is to provide about 38 dB gain and “zero” output impedance which IVDs need.

The IVD is used as a reference standard. It consists of an eight decade autotransformer to realise 0 – .99999999 ratio.

The variable amplifier module provides 0 dB – 100 dB variable gain with resolution of 0.1 dB. The variable gain is realised in two ways. One is to use five operational amplifiers with variable gain of 0 dB - 10 dB, and four with 0 dB - 20 dB respectively. The other is to use a D/A converter, which provides 0 dB - 10 dB variable gain with resolution of 0.1 dB. In addition, there are two band-pass filters in the module to improve the signal to noise ratio.

2. Measurement Method

In the intercomparison, in order to expand dynamic measurement range, RF substitution is used as well, and an attenuator (8496H) is used as a gauge block. Two 10 dB attenuators are used as isolators to improve the VSWR of the test ports at 60 MHz. Four circulators are used at 5 GHz for same purpose.

3. Uncertainty Evaluation

The uncertainty sources: reference standard, mismatch, system linearity, leakage, resolution, connector repeatability were considered in the uncertainty evaluation.

The reflection coefficients of the test ports and the travelling standard were calibrated by HP8722ES S-PARAMETER NETWORK ANALYSER.

B.15 SIQ Measurements (B. Pinter, Z. Svetik)

Measurement conditions

All measurements were performed in the period from 22 August, 2002 to 29 August, 2002 under following environmental conditions:

Temperature: 23 °C ± 1 °C

Relative humidity: 50 % ± 20 %

The actual temperature of the measured item is given along with the measurement results.

Before commencing the measurements, the connectors were inspected, cleaned and gauged.

Measurement method used

All measurements were performed using an internal IF substitution method of a calibrated tuned measuring receiver. A standard method published in the CMCs was used. No measurements have been performed at 5 GHz because SIQ does not have any equipment and procedures for traceable measurements at frequencies higher than 1.3 GHz.

Traceability

The tuned measuring receiver was calibrated using a laboratory reference 0 to 110 dB step attenuator HP 8496B (10 dB steps). The reference step attenuator was calibrated for all steps at the following frequencies:

10 MHz, 30 MHz, 100 MHz, 300 MHz, 500 MHz, 700 MHz, 1 GHz, 2 GHz, 8 GHz, 12 GHz, 18 GHz.

The calibration was performed by ASAP / SESC (UKAS accreditation number: 0029). The reference step attenuator is periodically calibrated at 2 year intervals.

Measurements at 60 MHz were performed using a calibrated receiver HP8902A. The measuring receiver specifications were taken as uncertainty of the standard.

IF substitution using a calibrated measuring receiver

An HP 8902A measuring receiver was used for measuring attenuations using tuned RF level measurement procedure. It covers RF level measurement from 0 dBm to -120 dBm in the frequency range from 2.5 MHz to 1300 MHz. Uncertainty due to measuring receiver was derived from manufacturer’s specifications. These were confirmed by calibration of the receiver through the measurement of tuned RF level, which is set by a reference step attenuator.

Calibration Setup

A block diagram for measurement of attenuation using tuned RF level is shown in Fig A.3.

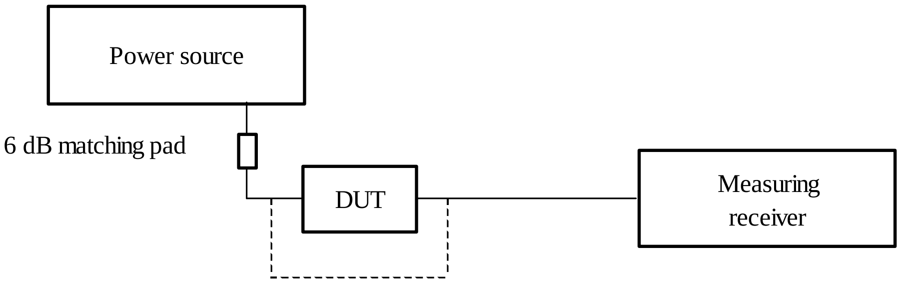


Fig A.3. Attenuation measurement setup using tuned RF level technique

The DUT was connected between the measuring receiver and a 6 dB matching pad and set to its 'zero' or 'datum' position. The power was selected so that input power to the measuring receiver was as close as possible to 0 dBm. Then a zero-reference was set on the measuring receiver at the current measurement level. The DUT was then set to the required attenuation value and measured with the measuring receiver. This relative power is equal to the insertion loss of the DUT.

Data acquisition and processing

The measurement procedure was automated through GPIB interface. Measurement results were recorded into an Excel worksheet.

Uncertainty budget

The uncertainty budget of the calibration factor measurement consists of the following components:

sU_C_1 Uncertainty due to measuring receiver relative power measurement error. This uncertainty is derived from measuring receiver specifications and is defined as

± 0.005 dB / 10 dB step ± 0.015 dB ± 1 digit for 0 dBm to –100 dBm range,

± 0.050 dB / 10 dB step ± 0.015 dB ± 1 digit for –100 dBm to –120 dBm range.

This uncertainty is assumed to have rectangular probability distribution. This uncertainty is verified through the calibration of the measuring receiver.

sU_C_2 Mismatch uncertainty. The following equation was used to calculate mismatch uncertainty:

$$M_s = \frac{8{,}686}{\sqrt{2}} \sqrt{|\Gamma_G|^2 (|s_{11a}|^2 + |s_{11b}|^2) + |\Gamma_L|^2 (|s_{22a}|^2 + |s_{22b}|^2) + |\Gamma_G|^2 \cdot |\Gamma_L|^2 (|s_{21a}|^4 + |s_{21b}|^4)}$$

where index *b* in the *s*-parameters denotes the values measured at a chosen attenuation setting and index *a* in the *s*-parameters indicates *s*-parameters for ‘zero’ or ‘datum’ position. In calculation only nominal values of s_{12} and s_{21} were taken and it was assumed that $s_{12} = s_{21}$. $s_{21\mathrm{a}}$ (insertion loss at zero position) was assumed to be zero, resulting in maximum uncertainty contribution.

A 6 dB matching pad was used at input connector of the measured item, while the receiver itself in tuned mode provides an input attenuation pad.

The uncertainties of the values of Γ_G and Γ_L and the scattering coefficients used in equation were considered in such a way, that they were added in quadrature to the measured or derived values of the reflection coefficients. A U-shaped probability distribution was applied in the calculation.

sU_C3 uncertainty due to leakage. It was assumed that leakage was controlled to better than 140 dB using high quality microwave cables and connectors at 60 MHz, and better than 120 dB at 5 GHz. The contribution of leakage was calculated from:

$$\Delta A_L = \frac{8{,}686}{\sqrt{2}} \cdot \left(10^{-\frac{(A_L - A_A)}{20}} \right)$$

A U-shaped probability distribution was applied in the calculation.

sU_C4 Type A uncertainty evaluation (1·σ) based on 10 repetitions (standard deviation of the mean).

B.16 MIKES Measurements (K. Ojasalo)

Incremental attenuation measurement was performed with VNA. After calibration of the instrument, twoport *S*-parameter uncertainty evaluation was carried out (according to EA-10/12). The S-parameters of the unknown DUT were measured after this. Finally, the *S*-parameters of a calibrated reference attenuator were measured with five closest settings to the unknown values (both datum and setting values). The reference had been calibrated at exact frequencies of the measurement (60 MHz, 5 GHz).

The incremental attenuation of the unknown DUTs were determined from the difference of the S_{21} parameters (dB) measured at the reference attenuation of the DUT and at datum value. The difference of reference attenuator S_{21} measurements and calibrated data were observed at both frequencies. These differences were used to estimate two uncertainties:

- uncertainty of the reference zero setting due to mismatch
- linearity uncertainty

Uncertainty of the zero setting is taken as a rectangular distribution, limit value taken from 20 dB – 0 dB measurement. Especially at the 5 GHz frequency this has considerable effect. Linearity is deduced from the trend in measurements beyond 20 dB. The temperature of the attenuators was measured with an environmental measurement probe close to the attenuator. There was no possibility to attach the probe directly to the case.

K19.CL/2 device was measured up to 80 dB attenuation level.

Description of the equipment used

VNA:
· Agilent PNA E8357A (300 kHz – 6 GHz) with option 015.

VNA Calkit:
· Agilent 85054D.

Calibration method:

· full 2 port SOLT with adapter removal.

Settings of the VNA:

· Segment sweep

· 1 Hz IF bandwith with 60 MHz and 5 GHz, other points with 10 Hz

· Two additional points measured around 60 MHz and 5 GHz with 1 Hz IF bandwith.

· Averaging was set to 10.

· Power level 0 dBm

Reference clock Rubidium accuracy 2.48×10-10.

Reference step attenuator:

Step attenuator combination consisting of:
Model 84904L, Range 0 – 90 dB connected to
Model 84906L, Range 0 – 11 dB.

The attenuator combination includes a 2.4 mm male to N-type male adapter and a 2.4 mm male to N-type female adapter to make the device insertable. The frequency range is therefore limited to 18 GHz. The attenuator has been calibrated using port 1 as input. The calibration was performed with 1 dB steps between 0 – 90 using 0-setting as reference. Last calibrated in July 2004, at NPL.

B.17 KRISS Measurements (J-G Lee, J-H Kim)

A brief description of measurement technique

We measure the attenuation of the intercomparison devices using an RF series substitution technique as shown in Figure A.5. A standard step attenuator, composed of 10 steps of build-up chain of power measurement and operating from 10 MHz to 18 GHz, is used as the attenuation standard. Its measurement scheme and uncertainty analysis at 30 MHz are described in reference 1. The overall system has a dynamic range over 90 dB.

The regulated RF source with amplifier provides a stable RF signal with its level monitored and leveled using thermistor mount and the power level control unit. The receiving system consists of a mixer and a 30 MHz receiver, and has a resolution of 0.001 dB. We attach a pad between the output of DUT and the input of receiving system to reduce the mismatch.

Initially, to measure attenuation of 40 dB, STD is set to its reference stage and DUT is set to nominal 40 dB. Reading at the receiving system is denoted as *A40*. Next, DUT is set to its 0 dB datum and the attenuation of the STD is approximately increased to around 40 dB. The signal level is adjusted and measured until the reading of the receiving system indicates the value measured beforehand (*A40*).

In order to compensate the mismatch factors, reflection coefficients and S-parameters of the DUT and the measurement system are measured using a vector network analyzer.

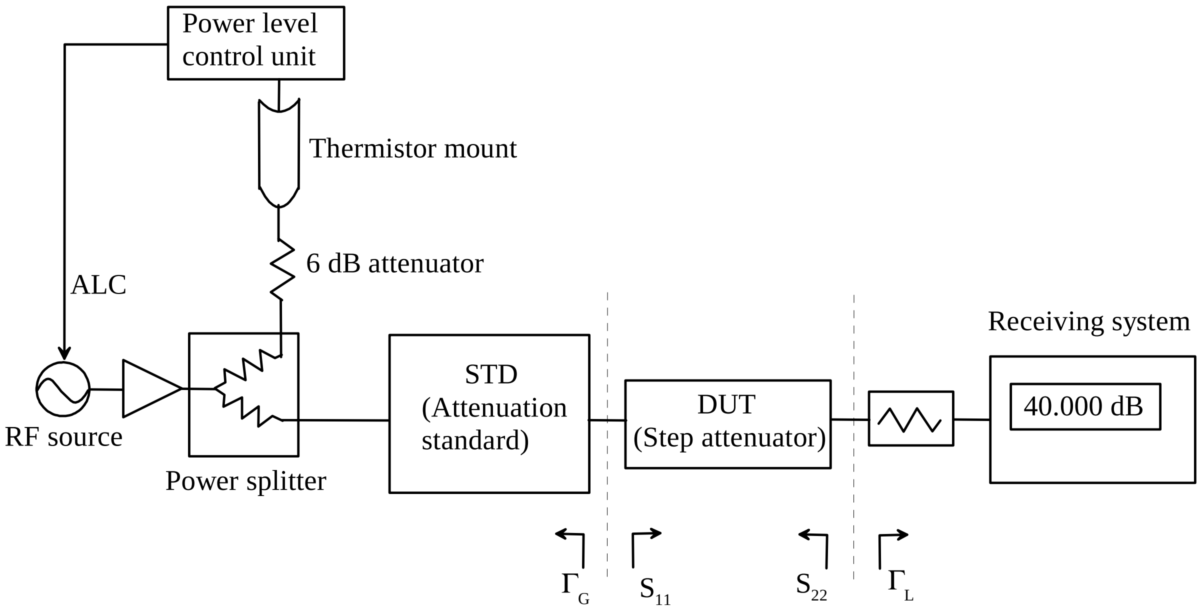


Figure A.5. Block diagram of the attenuation measurement system.

The traceability route for the attenuation measurements

The KRISS attenuation standards are traceable, via calibrated dc voltmeters, to the KRISS national standards for dc voltage.

References

[1] J. G. LEE ET AL, “A broadband attenuation standard,” *Measurement Science and Technology*, Vol. 15, No. 1, pp. 55-57, Jan. 2004.

B.18 INRIM Measurements (L. Brunetti)

The measurements on travelling standards KCL/1 and KCL/2 have been performed by means of the S-parameter measurement technique. Two Vectorial Network Analyzers (VNA), a HP8510C and a HP8753E have been used, but only measurements made with the HP8510C have been considered and reported to the Pilot laboratory. The VNA HP8753E, even though more suitable for high attenuation measurements, is not the primary INRIM system and it has been used only for performing supplementary checks on the HP8510C data. Attenuation measurements and the related accuracy assessment have been performed up to 110 dB, but are reported only up to 80 dB, being them not realistic beyond this level. For the HP8510C the accuracy becomes poor at 60 dB, but the data seems having sense up to 80 dB, at least for the frequency used.

The INRIM system (HP8510C) is traced to a set of impedance standards, which are defined and maintained through mechanical and electrical measurements. Basically, for each transmission line or connector type, a precision calibration kit and verification kit have been qualified for being the primary impedance standard set. Actually, the calibration kit component is only mechanical checked, while the verification kit components are dimensionally and electrically calibrated through independent sources and methods. In this manner traceability is assumed of the HP8510C to the primary standards of length and direct current, that is, to the SI fundamental quantities.

INRIM Official Data come from 10 sets of repeated measurements, which have been performed under well-controlled environment parameters, (23 ± 0.2) ˚C and (50±5)% RH. The HP8510C calibration process has been repeated two times always using a high number of averages (1024).

The incremental attenuation values have been measured subtracting at the total insertion loss associated to X-configuration the insertion loss associated to 0-configuration.

Accuracy assessment of the measurements has been performed according to the Guide Document EA-10/12, “EA Guidelines on the Evaluation of Vector Network Analysers (VNA)”, but with some modification.

Basically, reflection measurement uncertainty U_{VRC} of Type B have been calculated using the formula:

$$U_{VRC}=\sqrt{(D+M\Gamma^2)^2+(T\Gamma)^2+(S_{21}^2\Gamma_L)^2+(2\Gamma M S_{21}^2\Gamma_L)^2}$$

where Γ is the Measured Voltage Reflection Coefficient, while D is the Measured Effective Directivity (of VNA), T the Estimated Overall Effect of Tracking and Non-Linearity (of VNA), M the Measured Effective Test Port Match (of VNA), Γ_L the Effective Load Match (of VNA) and S_{21} the Measured Transmission Coefficient of the device under test, all of them expressed in modulus and linear scale.

Directivity and test port mismatch terms combine linearly before entering in the square sum because are considered highly correlated terms.

For transmission measurement uncertainty U_{TM} the following formula have been used:

$$U_{TM}=L+M_{TM}+I$$

where L is the Measured System Deviation from linearity, M_{TM} the Calculated Mismatch term and I the Estimated/Measured Cross-Talk.

M_{TM} is given by:

$$M_{TM}=20\log_{10}\frac{1+MS_{11}+\Gamma_L S_{22}+M\Gamma_L S_{11}S_{22}+M\Gamma_L S_{21}S_{12}}{1-M\Gamma_L}$$

where $S_{11},S_{22},S_{21},S_{12}$ are the scattering parameters (in modulus) of the device under test.

In U_{TM} all terms are expressed in logarithmic scale.

The terminology here used has correspondence to that of the EA-10/12 document.

Anyway, the INRIM does not support the suggestion of the EA-10/12 in adding random components (R_{VRC} & R_{dB}) to the Type B uncertainty, because all random effects should appear in the dispersion of the measurements and accounted in the Type A uncertainty term.

B.19 VNIIFTRI Measurements (V. Bekkerov, S. Bezdenezhnykh, S. Kucherenko, V. Turyansky)

The measurement equipment applied during measurements at 60 MHz and 5.0 GHz is different, therefore they will be described separately.

Equipment applied during comparisons at 60 MHz.

The attenuation measurement of NPL's travelling standards is carried out by means of the system from the National Standard of Attenuation of Russia. This system is a measuring system with frequency conversion with further substitution of attenuation of measured RF-attenuator by attenuation of standard attenuator, operating at low IF 230 Hz.

As a standard, the system uses precision resistive attenuator, calibrated by means of a standard LF inductive voltage divider.

The process of attenuation measurement, introduction of corrections, excluding main sources of systematic errors, as well as measurement results processing is automated.

The magnitudes of reflection coefficients of travelling standards ($|S_{11}|$, $|S_{22}|$), "source" and "load" are measured by means of three devices:

- RF Network analyser HP8714ET (300 kHz – 3000 MHz);
- two Russian single-type devices for measurement of complex coefficients of transmission and reflection P4-11 (1 – 1250 MHz).

Measurements are made by comparison of close values of measured reflection coefficients and reflection coefficient, reproduced by the standard. The weighted values, calculated as described in [1], are considered to be the results of the reflection coefficients measurement.

Equipment applied during comparisons at 5.0 GHz.

The attenuation measurement of standards K19.CL/1 and K19.CL/2 at 5.0 GHz is carried out by means of the standard system DK1-16, manufactured in Russia and researched by our metrological special rules. This system is intended for the measurement of attenuation and phase shift angle.

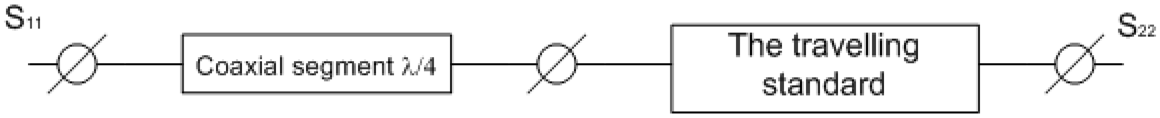
The system is two-channel superheterodyne measuring device with parallel substitution of attenuation of measured RF attenuator at operating frequency for attenuation of standard resistive attenuator at IF frequency 55.5 kHz.

The standard resistive attenuator was researched and calibrated on the National Standard of HF Attenuation of Russia. The measurement system DK1-16 is a Russian analogue of the famous attenuation measurement system VM-4B of Weinschel Engineering, USA.

The process of attenuation measurement, introduction of corrections, excluding main sources of systematic errors, as well as measurement results processing is automated.

During the attenuation measurement of standards K19.CL/1 and K19.CL/2, sign compensation of the main component of mismatch error was carried out by means of precision quarter-wave-length coaxial segment with air filling. Phase of the segment’s transmission coefficient at 5.0 GHz was (90 ± 0.5)°. Besides, the accuracy of the realisation of inner and outer conductors of the coaxial waveguide segment enabled only the phase relationship to change during insertion (removal) of the segment in transmission line, almost without changing reflection coefficients.

Attenuation measurements consisted of two stages:



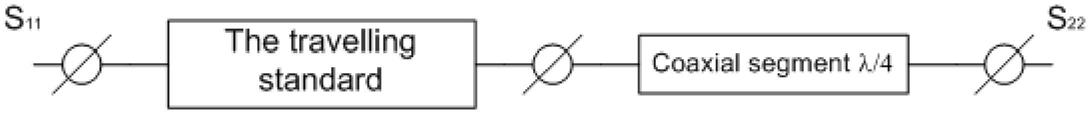


Fig B.19.1 – Two-stage measurement

- the segment is inserted in front of port 1 of attenuator;
- the segment is inserted behind of port 2 of attenuator.

The arithmetic mean of attenuation values, obtained in the two above mentioned cases, is considered to be the result of attenuation measurement.

Reflection coefficients of the measured standards ($|S_{11}|$, $|S_{22}|$), "source" and "load" are measured by means of tuned reflectometer system.

The reflectometer is tuned according to a generally used procedure [2] up to around 54-56 dB and $|\Gamma_{2i}| < 0.005$ ($|\Gamma_{2i}|$ - magnitude of reflection coefficient in output section of reflectometer). The indicator of the reflectometer is the aforementioned superheterodyne attenuation measurement system. The precision shorting unit is used as a standard of reflection coefficient. Both reflectometer calibration (during connection of shorting unit to its output) and reflection coefficient measurement are carried out with inserted quarter-wavelength segment and without it with further averaging of obtained results.

During attenuation measurement of standards K19.CL/1 and K19.CL/2 at 5.0 GHz it was worthwhile to use three variants of "source" and "load" match.

Variant 1. Ferrite isolator and matching transformer (standard K19.CL/1, in attenuation range 0-70 dB, and standard K19.CL/2, in attenuation range 0-40 dB). The match of this device with reflection coefficient ≤ 0.01 is carried out by means of matching tuning transformer; the tuned reflectometer is used as a match indicator.

Variant 2. Ferrite isolator and matching attenuator of "Agilent Tech." with attenuation 6 dB (standard K19.CL/1, in attenuation range 0-70 dB, and standard K19.CL/2, in attenuation range 60-80 dB).

Variant 3. Ferrite isolator (standard K19.CL/2, in attenuation range 100-110 dB). Attenuation of standard K19.CL/1 is determined for Variant 1 and Variant 2 of "source" and "load" match.

Weighted measurement results for variants 1 and 2 of "source" and "load" match, obtained as accepted in [1], are final results for standard K19.CL/1 at 5.0 GHz.

In the tables containing attenuation measurements results of researched standards, SU_{tot} is total standard uncertainty, calculated by the equation [3]:

$$SU_{tot} = \sqrt{U_A{}^2 + U_B{}^2},$$

where U_A – standard uncertainty, evaluated by A-type;

U_B – standard uncertainty, evaluated by B-type.

Uncertainty evaluation U_A and U_B is carried out, as recommended in [3].
Effective number of degrees of freedom V_{eff} is calculated according to equation:

$$V_{eff} = (n-1)[1+(\frac{U_B}{U_A})^2]^2,$$

which follows from (G.2b) [3], supposing that $V_{eff\,A} = n - 1$; $V_{eff\,B} = \infty$, where $V_{eff\,A}$ and $V_{eff\,B}$ – effective number of degrees of freedom for uncertainty, evaluated by Type A and Type B respectively.

References

[1] J. RANDA, "Proposal for KCRV and Degree of Equivalence for GTRF Key Comparisons", NIST, 8/18/00, GT-RF/2000-12

[2] G.F. ENGEN & R.W. BEATTY, "Microwave reflectometer techniques", *IRE Trans. on Microwave Theory and Techniques*, vol. MMT-7, pp. 351 – 355, July 1959

[3] “Guide to the Expression of Uncertainty in Measurement. First Edition” – ISO, Switzerland, 1993

B.20 NMIA Measurements (S. P. Grady, J. E. Peters, T. Zhang, M. Daly)

NMI Australia has two 30 MHz Wave Guide below Cut-off (WBCO) Standard Attenuators. The Mark I Standard Attenuator [1] [2] is primarily used for heterodyne measurements and the Mark II Standard Attenuator [3] is only used for 30 MHz measurements.

Each attenuator is operated as a parallel IF substitution system with the WBCO Piston travel measured by a moiré fringe plate system in the case of the Mark I attenuator and a laser interferometer in the case of the Mark II attenuator.

Traceability is established by ratio techniques using a 30 MHz Voltage Doubler Calculable Attenuation Step [4].

Attenuator reflection coefficient measurements were carried out with a Hewlett Packard (Agilent) 8510 Vector Network Analyser.

60 MHz Measurements

The 60 MHz measurements were carried out with the NMI Australia Mark I Standard Attenuator. The moiré fringe plate system locks the WBCO Piston at intervals of 0.02 dB, to an accuracy of 0.0001 dB, the DC output of the Phase Sensitive Detector is used to interpolate between the 0.02 dB points.

The source (60 MHz) and local oscillator signals (90 MHz) were provided by Hewlett Packard 83640A 40 GHz signal generators with their time bases locked to the 10 MHz standard provided by the NMI Australia Time and Frequency Section. The outputs of the generators were connected to a mixer where the output product is 30 MHz and this is connected via a band pass filter to the input of the Mark I Standard Attenuator. The RF generator and mixer generator had filters on their outputs to reduce harmonic and spurious products from the mixer.

In order to maximise source and load matching to the attenuator under test the source was padded with a 20 dB attenuator and the load was padded with a tuner and a 10 dB attenuator. The reflection coefficient of the source (looking into the RF source) and load (looking into the mixer) were measured to be better than 0.01 and this figure was used in the uncertainty calculations as a worst case even if the actual figures were better.

Control of the attenuator under test was done manually, while the Standard Attenuator measured the step change in the attenuator under test under the control of a software computer program. The uncertainty budget for the measurements is attached in the supplied Excel Spreadsheet.

Measurements on the mixer showed it was linear within 2 mdB over the range of 30 to 100 dB of the Standard Attenuator and from 20 to 30 dBm the linearity degrades by a few mdB due to compression. The receiver of the Standard Attenuator is limited to around 100 dB due to increasing noise, so the dynamic range of our measurements was limited to 70 dB. This was fine for the K19-CL/1 attenuator although we were able to measure the 80 dB step of the K19-CL/2 attenuator by increasing the input level by 10 dBm and measuring the 40 to 80 dB step and adding this step value to the value of the 40 dB step. So measurements greater than 80 dB were not reported.

5 GHz Measurements

The 5 GHz measurements were similar to the 60 MHz measurements except for the attenuators used for the source and load match. In this case stub tuners and 38 dB isolators were tuned on our HP 8510 VNA at 5 GHz for best reflection coefficient measurements while being terminated into 50 Ω. The match was checked by removing the 50 Ω terminations and checking that the reflection coefficient was not worst than 0.01 when been terminated in an open circuit. Then like the 60 MHz measurements 0.01 was used as a worst case reflection coefficient for source and load match in the uncertainty calculations.

Again measurements on the mixer showed it was linear within 2 mdB over the range of 30 to 100 dB of the Standard Attenuator and from 20 to 30 dBm the linearity degrades by a few mdB due to compression. Accepting this slightly worst mixer performance the attenuator was operated over 20 to 100 dB of its range so the 80 dB measurements were able to be achieved without cascading attenuation steps.

References

[1] Hollway D.L. and Kelly F.P. "A Standard Attenuator and the Precise measurement of Attenuation", *IEEE Trans.*, 1964, IM-13, pp. 33-44.

[2] Hollway, D.L. and Somlo, P.I., "The reduction of errors in a precise microwave attenuation calibration system", *IEEE Trans*., 1973, IM-22, pp. 268-270.

[3] Cousins T.E. and Kobler H. "A 30 MHz Standard Attenuator", *Journal of Electrical and Electronic Engineering, Australia – IE Aust. and IREE Aust.,* 1984, Vol 4 No. 1, pp. 1-5, March 1984 and Erratum June 1984 p. 117.

[4] Somlo, P.I., "A voltage doubling circuit for the absolute calibration of 30 MHz attenuation measurement systems", *IEEE Trans*, 1978, IM-27, pp. 76-79.

Appendix C – Uncertainty budgets

C.1 – NPL uncertainty budget

Table C.1.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	Type	u_T(i) (dB)
Random	A	0.0001
Inductive Voltage Divider	B	0.0002
DVM	B	0.0001
Non-linearity	B	0.0002
Leakage	B	0.0006
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.1.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	Type	u_T(i) (dB)
Random	A	0.0002
Inductive Voltage Divider	B	0.0002
DVM	B	0.0000
Non-linearity	B	0.0002
Leakage	B	0.0000
Mismatch	B	0.0013
Combined uncertainty (k = 1):		0.001

Table C.1.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	Type	u_T(i) (dB)
Random	A	0.0002
Inductive Voltage Divider	B	0.0005
DVM	B	0.0004
Non-linearity	B	0.0007
Leakage	B	0.0020
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.002

Table C.1.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0009
Inductive Voltage Divider	B	0.0005
DVM	B	0.0002
Non-linearity	B	0.0007
Leakage	B	0.0001
Mismatch	B	0.0013
Combined uncertainty (k = 1):		0.002

Table C.1.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0001
Inductive Voltage Divider	B	0.0002
DVM	B	0.0001
Non-linearity	B	0.0002
Leakage	B	0.0002
Mismatch	B	0.0004
Combined uncertainty (k = 1):		0.001

Table C.1.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0001
Inductive Voltage Divider	B	0.0002
DVM	B	0.0000
Non-linearity	B	0.0002
Leakage	B	0.0000
Mismatch	B	0.0031
Combined uncertainty (k = 1):		0.003

Table C.1.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Inductive Voltage Divider	B	0.0005
DVM	B	0.0002
Non-linearity	B	0.0007
Leakage	B	0.0006
Mismatch	B	0.0004
Combined uncertainty (*k* = 1):		0.001

Table C.1.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Inductive Voltage Divider	B	0.0005
DVM	B	0.0001
Non-linearity	B	0.0007
Leakage	B	0.0001
Mismatch	B	0.0033
Combined uncertainty (*k* = 1):		0.004

Table C.1.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
Inductive Voltage Divider	B	0.0009
DVM	B	0.0005
Non-linearity	B	0.0012
Leakage	B	0.0012
Mismatch	B	0.0006
Combined uncertainty (*k* = 1):		0.002

Table C.1.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
Inductive Voltage Divider	B	0.0009
Non-linearity	B	0.0012
Leakage	B	0.0014
Mismatch	B	0.0050
Resolution	B	0.0033
Combined uncertainty (k = 1):		0.006

C.2 – NIST uncertainty budget

Table C.2.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.007
Standard deviation (u_d)	A	0.001
Airline and test port imperfections (u_b)	B	0.001
Combined uncertainty (k = 1):		0.007

Table C.2.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.009
Standard deviation (u_d)	A	0.002
Airline and test port imperfections (u_b)	B	0.003
Combined uncertainty (k = 1):		0.010

Table C.2.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.080
Standard deviation (u_d)	A	0.073
Airline and test port imperfections (u_b)	B	0.001
Combined uncertainty (k = 1):		0.086

Table C.2.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.080
Standard deviation (u_d)	A	0.013
Airline and test port imperfections (u_b)	B	0.003
Combined uncertainty (k = 1):		0.081

Table C.2.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.007
Standard deviation (u_d)	A	0.000
Airline and test port imperfections (u_b)	B	0.001
Combined uncertainty (k = 1):		0.007

Table C.2.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.009
Standard deviation (u_d)	A	0.001
Airline and test port imperfections (u_b)	B	0.003
Combined uncertainty (k = 1):		0.010

Table C.2.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.081
Standard deviation (u_d)	A	0.044
Airline and test port imperfections (u_b)	B	0.001
Combined uncertainty (k = 1):		0.083

Table C.2.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Calibration (u_a)	A	0.081
Standard deviation (u_d)	A	0.002
Airline and test port imperfections (u_b)	B	0.003
Combined uncertainty (k = 1):		0.081

C.3 – LNE uncertainty budget

Table C.3.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00046
Standard calibration	B	0.00119
Resolution	B	0.00067
Noise	B	0.00015
Non-linearity	B	0.00071
Mismatch	B	0.00143
Source stability	B	0.00031
Combined uncertainty (k = 1):		0.010

Table C.3.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00046
Standard calibration	B	0.00119
Resolution	B	0.00067
Noise	B	0.00015
Non-linearity	B	0.00071
Mismatch	B	0.00212
Source stability	B	0.00031
Combined uncertainty (k = 1):		0.012

Table C.3.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00126
Standard calibration	B	0.00323
Resolution	B	0.00067
Noise	B	0.00043
Non-linearity	B	0.00200
Mismatch	B	0.00143
Source stability	B	0.00031
50 dB attenuator	B	0.00339
Combined uncertainty (k = 1):		0.024

Table C.3.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00126
Standard calibration	B	0.00323
Resolution	B	0.00067
Noise	B	0.00043
Non-linearity	B	0.00200
Mismatch	B	0.00212
Source stability	B	0.00031
50 dB attenuator	B	0.00401
Combined uncertainty (k = 1):		0.027

Table C.3.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00046
Standard calibration	B	0.00119
Resolution	B	0.00067
Noise	B	0.00015
Non-linearity	B	0.00071
Mismatch	B	0.00143
Source stability	B	0.00031
Combined uncertainty (k = 1):		0.010

Table C.3.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00046
Standard calibration	B	0.00119
Resolution	B	0.00067
Noise	B	0.00015
Non-linearity	B	0.00071
Mismatch	B	0.00329
Source stability	B	0.00031
Combined uncertainty (k = 1):		0.016

Table C.3.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.00126
Standard calibration	B	0.00323
Resolution	B	0.00067
Noise	B	0.00043
Non-linearity	B	0.00200
Mismatch	B	0.00143
Source stability	B	0.00031
50 dB attenuator	B	0.00378
Combined uncertainty (k = 1):		0.025

Table C.3.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.00126
Standard calibration	B	0.00323
Resolution	B	0.00067
Noise	B	0.00043
Non-linearity	B	0.00200
Mismatch	B	0.00370
Source stability	B	0.00031
50 dB attenuator	B	0.00586
Combined uncertainty (k = 1):		0.035

Table C.3.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.00163
Standard calibration	B	0.00647
Resolution	B	0.00067
Noise	B	0.00113
Non-linearity	B	0.00200
Mismatch	B	0.00143
Source stability	B	0.00037
50 dB attenuator	B	0.00541
Combined uncertainty (k = 1):		0.040

Table C.3.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00163
Standard calibration	B	0.00647
Resolution	B	0.00067
Noise	B	0.00113
Non-linearity	B	0.00200
Mismatch	B	0.00452
Source stability	B	0.00037
50 dB attenuator	B	0.00824
Combined uncertainty (k = 1):		0.052

C.4 – PTB uncertainty budgets

Table C.4.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00006
Bolometer bridge voltage	B	0.00002
Difference voltage, DUT out	B	0.00004
Difference voltage DUT in	B	-0.00010
Linearity	B	0.00065
Mismatch	B	0.00044
Combined uncertainty (k = 1):		0.001

Table C.4.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00006
Bolometer bridge voltage	B	0.00002
Difference voltage, DUT out	B	0.00004
Difference voltage DUT in	B	-0.00010
Linearity	B	0.00065
Mismatch	B	0.00104
Combined uncertainty (k = 1):		0.001

Table C.4.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00063
Linearity	B	0.00087
Mismatch	B	0.00088
Reference attenuators	B	0.00149
Cable flexure	B	0.00082
Crosstalk and noise	B	0.00003
Combined uncertainty (k = 1):		0.002

Table C.4.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00095
Linearity	B	0.00087
Mismatch	B	0.00354
Reference attenuators	B	0.00230
Cable flexure	B	0.00163
Crosstalk and noise	B	0.00029
Combined uncertainty (k = 1):		0.005

Table C.4.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00006
Bolometer bridge voltage	B	0.00002
Difference voltage, DUT out	B	0.00004
Difference voltage DUT in	B	-0.00010
Linearity	B	0.00065
Mismatch	B	0.00033
Combined uncertainty (k = 1):		0.001

Table C.4.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00006
Bolometer bridge voltage	B	0.00002
Difference voltage, DUT out	B	0.00004
Difference voltage DUT in	B	-0.0001
Linearity	B	0.00065
Mismatch	B	0.00248
Combined uncertainty (k = 1):		0.003

Table C.4.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00063
Linearity	B	0.00087
Mismatch	B	0.00065
Reference attenuators	B	0.00146
Cable flexure	B	0.00082
Crosstalk and noise	B	0.00003
Combined uncertainty (k = 1):		0.002

Table C.4.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00063
Linearity	B	0.00087
Mismatch	B	0.00627
Reference attenuators	B	0.00230
Cable flexure	B	0.00163
Crosstalk and noise	B	0.00029
Combined uncertainty (k = 1):		0.007

Table C.4.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00095
Linearity	B	0.00087
Mismatch	B	0.00072
Reference attenuators	B	0.00209
Cable flexure	B	0.00082
Crosstalk and noise	B	0.00285
Combined uncertainty (k = 1):		0.004

Table C.4.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.00095
Linearity	B	0.00087
Mismatch	B	0.00691
Reference attenuators	B	0.00346
Cable flexure	B	0.00163
Crosstalk and noise	B	0.02953
Combined uncertainty (k = 1):		0.032

C.5 – NMIJ uncertainty budget

Table C.5.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0007
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0002
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0007
Combined uncertainty (k = 1):		0.001

Table C.5.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0005
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0003
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.5.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0010
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0008
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0008
Combined uncertainty (k = 1):		0.002

Table C.5.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0012
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0009
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.002

Table C.5.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0003
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0005
Combined uncertainty (k = 1):		0.001

Table C.5.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0003
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0014
Combined uncertainty (k = 1):		0.002

Table C.5.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0014
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0005
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0005
Gauge block calibration	B	
Combined uncertainty (*k* = 1):		0.002

Table C.5.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0029
Reference standard (IVD)	B	0.0005
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0006
Leakage	B	0.0000
Stability	B	0.0001
Mismatch	B	0.0016
Gauge block calibration	B	
Combined uncertainty (*k* = 1):		0.003

Table C.5.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0047
Reference standard (IVD)	B	0.0052
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0030
Leakage	B	0.0029
Stability	B	0.0001
Mismatch	B	0.0006
Gauge block calibration	B	0.0015
Combined uncertainty (*k* = 1):		0.008

Table C.5.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0036
Reference standard (IVD)	B	0.0052
Source and load impedance to IVD	B	0.0001
Amplitude change of phase shifter	B	0.0003
Non-linearity	B	0.0006
Leakage	B	0.0029
Stability	B	0.0001
Mismatch	B	0.0016
Gauge block calibration	B	0.0015
Combined uncertainty (k = 1):		0.007

C.6 – CMI uncertainty budget

Table C.6.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0005
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0115
Resolution	B	0.0006
Mismatch	B	0.0019
Combined uncertainty (*k* = 1):		0.012

Table C.6.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0004
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0115
Resolution	B	0.0006
Mismatch	B	0.0066
Combined uncertainty (*k* = 1):		0.013

Table C.6.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0008
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0231
Resolution	B	0.0006
Mismatch	B	0.0019
Combined uncertainty (*k* = 1):		0.023

Table C.6.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0231
Resolution	B	0.0006
Mismatch	B	0.0062
Combined uncertainty (*k* = 1):		0.024

Table C.6.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0004
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0115
Resolution	B	0.0006
Mismatch	B	0.0015
Combined uncertainty (*k* = 1):		0.012

Table C.6.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0095
Resolution	B	0.0006
Mismatch	B	0.0106
Combined uncertainty (*k* = 1):		0.014

Table C.6.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0086
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0231
Resolution	B	0.0006
Mismatch	B	0.0015
Combined uncertainty (*k* = 1):		0.025

Table C.6.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0007
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.0231
Resolution	B	0.0006
Mismatch	B	0.0118
Combined uncertainty (*k* = 1):		0.026

Table C.6.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0027
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.2211
Resolution	B	0.0058
Mismatch	B	0.0016
Combined uncertainty (k = 1):		0.221

Table C.6.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0027
VM7 calibration	B	0.0006
Vm7 linearity and range switching	B	0.1443
Resolution	B	0.0058
Mismatch	B	0.0121
Combined uncertainty (k = 1):		0.145

C.7 – CSIR uncertainty budget

Table C.7.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0089
Receiver calibration	B	0.0027
Isolation	B	0.0000
Repeatability	A	0.0010
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.009

Table C.7.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0196
Receiver calibration	B	0.0027
Isolation	B	0.0000
Repeatability	A	0.0010
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.020

Table C.7.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0089
Receiver calibration	B	0.0096
Isolation	B	0.0003
Repeatability	A	0.0010
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.013

Table C.7.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0197
Receiver calibration	B	0.0096
Isolation	B	0.0003
Repeatability	A	0.0020
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.022

Table C.7.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0070
Receiver calibration	B	0.0027
Isolation	B	0.0000
Repeatability	A	0.0010
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.008

Table C.7.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0421
Receiver calibration	B	0.0027
Isolation	B	0.0000
Repeatability	A	0.0010
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.042

Table C.7.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0070
Receiver calibration	B	0.0096
Isolation	B	0.0003
Repeatability	A	0.0010
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.012

Table C.7.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0466
Receiver calibration	B	0.0096
Isolation	B	0.0003
Repeatability	A	0.0020
Resolution	B	0.0003
Combined uncertainty (*k* = 1):		0.048

Table C.7.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0078
Receiver calibration	B	0.0186
Isolation	B	0.0283
Repeatability	A	0.0100
Resolution	B	0.0003
Combined uncertainty (k = 1):		0.036

Table C.7.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Mismatch	B	0.0497
Receiver calibration	B	0.0186
Isolation	B	0.0281
Repeatability	A	0.0100
Resolution	B	0.0003
Combined uncertainty (k = 1):		0.061

C.8 – NRC uncertainty budget

Table C.8.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0006
Linearity	B	0.0029
Leakage	B	0.0030
Resolution	B	0.0006
Readings	A	0.0010
Repeatability	A	0.0100
Combined uncertainty (k = 1):		0.011

Table C.8.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0006
Linearity	B	0.0029
Leakage	B	0.0030
Resolution	B	0.0006
Readings	A	0.0010
Repeatability	A	0.0100
Combined uncertainty (k = 1):		0.011

Table C.8.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0012
Linearity	B	0.0058
Leakage	B	0.0058
Resolution	B	0.0023
Readings	A	0.0100
Repeatability	A	0.0200
Combined uncertainty (k = 1):		0.024

Table C.8.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0012
Linearity	B	0.0058
Leakage	B	0.0058
Resolution	B	0.0023
Readings	A	0.0100
Repeatability	A	0.0200
Combined uncertainty (k = 1):		0.024

Table C.8.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0006
Linearity	B	0.0029
Leakage	B	0.0030
Resolution	B	0.0006
Readings	A	0.0010
Repeatability	A	0.0100
Combined uncertainty (k = 1):		0.011

Table C.8.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0006
Linearity	B	0.0029
Leakage	B	0.0030
Resolution	B	0.0006
Readings	A	0.0010
Repeatability	A	0.0100
Combined uncertainty (k = 1):		0.011

Table C.8.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0012
Linearity	B	0.0058
Leakage	B	0.0058
Resolution	B	0.0023
Readings	A	0.0100
Repeatability	A	0.0200
Combined uncertainty (k = 1):		0.024

Table C.8.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive Voltage Divider	B	0.0006
Mismatch	B	0.0012
Linearity	B	0.0058
Leakage	B	0.0058
Resolution	B	0.0023
Readings	A	0.0100
Repeatability	A	0.0200
Combined uncertainty (k = 1):		0.024

C.9 – NMi-VSL uncertainty budget

Table C.9.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.00002
Linearity	B	0.00026
Drift in linearity	B	0.00012
Mismatch uncertainty of 0 dB setting	B	0.00003
Mismatch uncertainty for 20 dB setting	B	0.00002
Combined uncertainty (k = 1) – linear units:		0.00029
Combined uncertainty (k = 1) – dB:		0.025

Table C.9.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.00003
Linearity	B	0.00026
Drift in linearity	B	0.00000
Mismatch uncertainty of 0 dB setting	B	0.00007
Mismatch uncertainty for 20 dB setting	B	0.00004
Combined uncertainty (k = 1) – linear units:		0.00027
Combined uncertainty (k = 1) – dB:		0.024

Table C.9.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.000002
Linearity	B	0.000007
Drift in linearity	B	0.000001
Mismatch uncertainty of 0 dB setting	B	0.000000
Mismatch uncertainty for 60 dB setting	B	0.000000
Combined uncertainty (k = 1) – linear units:		0.000008
Combined uncertainty (k = 1) – dB:		0.066

Table C.9.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.000003
Linearity	B	0.000007
Drift in linearity	B	0.000000
Mismatch uncertainty of 0 dB setting	B	0.000001
Mismatch uncertainty for 60 dB setting	B	0.000000
Combined uncertainty (k = 1) – linear units:		0.000008
Combined uncertainty (k = 1) – dB:		0.071

Table C.9.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.00003
Linearity	B	0.00026
Drift in linearity	B	0.00012
Mismatch uncertainty of 0 dB setting	B	0.00002
Mismatch uncertainty for 20 dB setting	B	0.00001
Combined uncertainty (k = 1) – linear units:		0.00029
Combined uncertainty (k = 1) – dB:		0.025

Table C.9.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.00065
Linearity	B	0.00026
Drift in linearity	B	0.00011
Mismatch uncertainty of 0 dB setting	B	0.00016
Mismatch uncertainty for 20 dB setting	B	0.00006
Combined uncertainty (k = 1) – linear units:		0.00073
Combined uncertainty (k = 1) – dB:		0.064

Table C.9.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.000002
Linearity	B	0.000007
Drift in linearity	B	0.000001
Mismatch uncertainty of 0 dB setting	B	0.000000
Mismatch uncertainty for 60 dB setting	B	0.000000
Combined uncertainty (k = 1) – linear units:		0.000007
Combined uncertainty (k = 1) – dB:		0.066

Table C.9.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.000002
Linearity	B	0.000007
Drift in linearity	B	0.000001
Mismatch uncertainty of 0 dB setting	B	0.000002
Mismatch uncertainty for 60 dB setting	B	0.000001
Combined uncertainty (k = 1) – linear units:		0.000008
Combined uncertainty (k = 1) – dB:		0.072

Table C.9.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.0000003
Linearity	B	0.0000001
Drift in linearity	B	0.0000000
Mismatch uncertainty of 0 dB setting	B	0.0000000
Mismatch uncertainty for 100 dB setting	B	0.0000000
Combined uncertainty (k = 1) – linear units:		0.0000011
Combined uncertainty (k = 1) – dB:		0.907

Table C.9.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Type A	A	0.0000018
Linearity	B	0.0000001
Drift in linearity	B	0.0000000
Mismatch uncertainty of 0 dB setting	B	0.0000000
Mismatch uncertainty for 100 dB setting	B	0.0000000
Combined uncertainty (k = 1) – linear units:		0.0000036
Combined uncertainty (k = 1) – dB:		2.824

C.10 – METAS uncertainty budget

Table C.10.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Attenuation standard	B	0.0010
Environment	B	0.0003
Mismatch	B	0.0007
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.003

Table C.10.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0011
Attenuation standard	B	0.0010
Environment	B	0.0003
Mismatch	B	0.0023
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.004

Table C.10.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Attenuation standard	B	0.0030
Environment	B	0.0010
Mismatch	B	0.0007
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.004

Table C.10.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0031
Attenuation standard	B	0.0030
Environment	B	0.0010
Mismatch	B	0.0022
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.006

Table C.10.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0005
Attenuation standard	B	0.0010
Environment	B	0.0003
Mismatch	B	0.0003
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.003

Table C.10.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Attenuation standard	B	0.0010
Environment	B	0.0003
Mismatch	B	0.0048
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.006

Table C.10.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Attenuation standard	B	0.0030
Environment	B	0.0010
Mismatch	B	0.0003
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
Combined uncertainty (k = 1):		0.004

Table C.10.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
Attenuation standard	B	0.0030
Environment	B	0.0010
Mismatch	B	0.0048
Non-linearity (mixer and WBCO)	B	0.0001
WBCO source stability	B	0.0030
High attenuation	B	
Combined uncertainty (k = 1):		0.007

Table C.10.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0012
Attenuation standard	B	0.0050
Environment	B	0.0016
Mismatch	B	0.0004
Non-linearity (mixer and WBCO)	B	0.0004
WBCO source stability	B	0.0030
High attenuation	B	0.0040
Combined uncertainty (k = 1):		0.007

Table C.10.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0019
Attenuation standard	B	0.0050
Environment	B	0.0016
Mismatch	B	0.0053
Non-linearity (mixer and WBCO)	B	0.0004
WBCO source stability	B	0.0030
High attenuation	B	0.0330
Combined uncertainty (k = 1):		0.034

C.11 – SP uncertainty budget

Table C.11.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0001
Measurement drift	B	0.0001
Cable flexure	B	0.0000
Frequency error	B	0.0000
Isolation	B	0.0000
Linearity	B	0.0007
Residual port match on port 1	B	0.0000
Residual port match on port 2	B	0.0001
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0000
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0003
Combined uncertainty (k = 1) – linear units:		0.0008
Combined uncertainty (k = 1) – dB:		0.007

Table C.11.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0000
Measurement drift	B	0.0003
Cable flexure	B	0.0001
Frequency error	B	0.0000
Isolation	B	0.0001
Linearity	B	0.0028
Residual port match on port 1	B	0.0001
Residual port match on port 2	B	0.0001
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0002
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0003
Combined uncertainty (k = 1) – linear units:		0.0028
Combined uncertainty (k = 1) – dB:		0.025

Table C.11.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0003
Measurement drift	B	0.0001
Cable flexure	B	0.0000
Frequency error	B	0.0000
Isolation	B	0.0016
Linearity	B	0.0007
Residual port match on port 1	B	0.0000
Residual port match on port 2	B	0.0001
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0000
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0010
Combined uncertainty (k = 1) – linear units:		0.0020
Combined uncertainty (k = 1) – dB:		0.018

Table C.11.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0005
Measurement drift	B	0.0003
Cable flexure	B	0.0001
Frequency error	B	0.0000
Isolation	B	0.0093
Linearity	B	0.0028
Residual port match on port 1	B	0.0001
Residual port match on port 2	B	0.0001
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0002
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0010
Combined uncertainty (k = 1) – linear units:		0.0098
Combined uncertainty (k = 1) – dB:		0.085

Table C.11.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0000
Measurement drift	B	0.0001
Cable flexure	B	0.0000
Frequency error	B	0.0000
Isolation	B	0.0000
Linearity	B	0.0007
Residual port match on port 1	B	0.0000
Residual port match on port 2	B	0.0000
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0000
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0003
Combined uncertainty (k = 1) – linear units:		0.0008
Combined uncertainty (k = 1) – dB:		0.007

Table C.11.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0000
Measurement drift	B	0.0003
Cable flexure	B	0.0001
Frequency error	B	0.0000
Isolation	B	0.0001
Linearity	B	0.0028
Residual port match on port 1	B	0.0003
Residual port match on port 2	B	0.0003
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0005
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0003
Combined uncertainty (k = 1) – linear units:		0.0029
Combined uncertainty (k = 1) – dB:		0.025

Table C.11.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0002
Measurement drift	B	0.0001
Cable flexure	B	0.0000
Frequency error	B	0.0000
Isolation	B	0.0016
Linearity	B	0.0007
Residual port match on port 1	B	0.0000
Residual port match on port 2	B	0.0000
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0000
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0010
Combined uncertainty (k = 1) – linear units:		0.0020
Combined uncertainty (k = 1) – dB:		0.018

Table C.11.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (linear)**
Random	A	0.0006
Measurement drift	B	0.0003
Cable flexure	B	0.0001
Frequency error	B	0.0000
Isolation	B	0.0097
Linearity	B	0.0028
Residual port match on port 1	B	0.0003
Residual port match on port 2	B	0.0002
Residual port match interaction	B	0.0000
Uncertainty due to S_{22} of adaptor	B	0.0005
Uncertainty due to S_{12} and S_{22} of adaptor	B	0.0000
Uncertainty due to S_{21} and S_{22} of adaptor	B	0.0000
Temperature coefficient of DUT	B	0.0010
Combined uncertainty (k = 1) – linear units:		0.0102
Combined uncertainty (k = 1) – dB:		0.088

C.12 – UME uncertainty budget

Table C.12.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0299
Mismatch	B	0.0003
Crosstalk (Isolation)	B	0.0023
System Repeatability	A	0.0003
Noise	B	0.0008
Connector Repeatability	A	0.0006
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (*k* = 1):		0.032

Table C.12.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0299
Mismatch	B	0.0009
Crosstalk (Isolation)	B	0.0023
System Repeatability	A	0.0002
Noise	B	0.0008
Connector Repeatability	A	0.0004
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (*k* = 1):		0.032

Table C.12.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0901
Mismatch	B	0.0003
Crosstalk (Isolation)	B	0.2395
System Repeatability	A	0.0035
Noise	B	0.0284
Connector Repeatability	A	0.0070
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (*k* = 1):		0.258

Table C.12.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0901
Mismatch	B	0.0006
Crosstalk (Isolation)	B	0.2395
System Repeatability	A	0.0076
Noise	B	0.0284
Connector Repeatability	A	0.0153
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (k = 1):		0.258

Table C.12.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0299
Mismatch	B	0.0002
Crosstalk (Isolation)	B	0.0023
System Repeatability	A	0.0003
Noise	B	0.0008
Connector Repeatability	A	0.0006
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (k = 1):		0.032

Table C.12.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0299
Mismatch	B	0.0010
Crosstalk (Isolation)	B	0.0023
System Repeatability	A	0.0003
Noise	B	0.0008
Connector Repeatability	A	0.0006
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (k = 1):		0.032

Table C.12.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0902
Mismatch	B	0.0002
Crosstalk (Isolation)	B	0.2395
System Repeatability	A	0.0062
Noise	B	0.0284
Connector Repeatability	A	0.0125
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (k = 1):		0.258

Table C.12.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Linearity	B	-0.0902
Mismatch	B	0.0017
Crosstalk (Isolation)	B	0.2395
System Repeatability	A	0.0075
Noise	B	0.0284
Connector Repeatability	A	0.0151
Cable Flexure	B	0.0100
Ambient conditions	B	0.0020
Combined uncertainty (k = 1):		0.258

C.13 – SPRING uncertainty budget

Table C.13.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0003
System uncertainty including leakage	B	0.0003
Non-linearity	B	0.0017
Repeatability	A	0.0001
Combined uncertainty (*k* = 1):		0.002

Table C.13.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0005
System uncertainty including leakage	B	0.0023
Non-linearity	B	0.0012
Repeatability	A	0.0003
Combined uncertainty (*k* = 1):		0.003

Table C.13.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0002
System uncertainty including leakage	B	0.0044
Non-linearity	B	0.0052
Repeatability	A	0.0001
Combined uncertainty (*k* = 1):		0.007

Table C.13.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0005
System uncertainty including leakage	B	0.0054
Non-linearity	B	0.0035
Repeatability	A	0.0008
Combined uncertainty (*k* = 1):		0.006

Table C.13.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0002
System uncertainty including leakage	B	0.0003
Non-linearity	B	0.0017
Repeatability	A	0.0001
Combined uncertainty (*k* = 1):		0.002

Table C.13.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0012
System uncertainty including leakage	B	0.0023
Non-linearity	B	0.0012
Repeatability	A	0.0003
Combined uncertainty (*k* = 1):		0.003

Table C.13.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0002
System uncertainty including leakage	B	0.0042
Non-linearity	B	0.0052
Repeatability	A	0.0002
Combined uncertainty (*k* = 1):		0.007

Table C.13.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0013
System uncertainty including leakage	B	0.0055
Non-linearity	B	0.0035
Repeatability	A	0.0002
Combined uncertainty (*k* = 1):		0.007

Table C.13.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0011
Mismatch	B	0.0002
System uncertainty including leakage	B	0.0102
Non-linearity	B	0.0150
Repeatability	A	0.0017
Combined uncertainty (k = 1):		0.018

Table C.13.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Inductive voltage divider	B	0.0004
Mismatch	B	0.0014
System uncertainty including leakage	B	0.0096
Non-linearity	B	0.0058
Repeatability	A	0.0021
Combined uncertainty (k = 1):		0.011

C.14 – NIM uncertainty budget

Table C.14.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0003
Mismatch	B	0.0008
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0002
Combined uncertainty (k = 1):		0.002

Table C.14.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0003
Mismatch	B	0.0028
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0002
Combined uncertainty (k = 1):		0.003

Table C.14.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0020
Mismatch	B	0.0008
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0002
Combined uncertainty (k = 1):		0.003

Table C.14.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0020
Mismatch	B	0.0027
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0003
Combined uncertainty (k = 1):		0.004

Table C.14.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0003
Mismatch	B	0.0006
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0002
Combined uncertainty (k = 1):		0.001

Table C.14.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0003
Mismatch	B	0.0061
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0001
Combined uncertainty (k = 1):		0.006

Table C.14.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0015
Mismatch	B	0.0006
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0002
Combined uncertainty (k = 1):		0.002

Table C.14.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0020
Mismatch	B	0.0065
System Linearity	B	0.0006
Leakage	B	0.0000
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0002
Combined uncertainty (k = 1):		0.007

Table C.14.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0030
Mismatch	B	0.0006
System Linearity	B	0.0032
Leakage	B	0.0060
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0004
Combined uncertainty (k = 1):		0.008

Table C.14.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference Standard	B	0.0030
Mismatch	B	0.0069
System Linearity	B	0.0032
Leakage	B	0.0060
Resolution	B	0.0003
Connector Repeatability	B	0.0010
Random	A	0.0005
Combined uncertainty (k = 1):		0.010

C.15 – SIQ uncertainty budget

Table C.15.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Measuring receiver ratio measurement	B	0.0150
Mismatch	B	0.0066
Leakage	B	0.0000
Random	A	0.0005
Combined uncertainty (k = 1):		0.016

Table C.15.2 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Measuring receiver ratio measurement	B	0.0266
Mismatch	B	0.0066
Leakage	B	0.0006
Random	A	0.0008
Combined uncertainty (k = 1):		0.027

Table C.15.3 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Measuring receiver ratio measurement	B	0.0150
Mismatch	B	0.0066
Leakage	B	0.0000
Random	A	0.0008
Combined uncertainty (k = 1):		0.016

Table C.15.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Measuring receiver ratio measurement	B	0.0266
Mismatch	B	0.0066
Leakage	B	0.0006
Random	A	0.0004
Combined uncertainty (k = 1):		0.027

Table C.15.5 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Measuring receiver ratio measurement	B	0.0670
Mismatch	B	0.0066
Leakage	B	0.0614
Random	A	0.0007
Combined uncertainty (k = 1):		0.091

C.16 – MIKES uncertainty budget

Table C.16.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0015
Reference mismatch	B	0.0044
Reference drift	B	0.0004
DUT mismatch	B	0.0007
Leakage	B	0.0001
Drift during measurement	B	0.0011
Linearity	B	0.0120
Random	A	0.0003
Combined uncertainty (k = 1):		0.013

Table C.16.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0015
Reference mismatch	B	0.0149
Reference drift	B	0.0014
DUT mismatch	B	0.0038
Leakage	B	0.0001
Drift during measurement	B	0.0036
Linearity	B	0.0122
Random	A	0.0012
Combined uncertainty (k = 1):		0.020

Table C.16.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0025
Reference mismatch	B	0.0044
Reference drift	B	0.0004
DUT mismatch	B	0.0007
Leakage	B	0.0062
Drift during measurement	B	0.0011
Linearity	B	0.0361
Random	A	0.0059
Combined uncertainty (k = 1):		0.037

Table C.16.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0025
Reference mismatch	B	0.0149
Reference drift	B	0.0018
DUT mismatch	B	0.0037
Leakage	B	0.0065
Drift during measurement	B	0.0036
Linearity	B	0.0363
Random	A	0.0011
Combined uncertainty (k = 1):		0.040

Table C.16.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0015
Reference mismatch	B	0.0044
Reference drift	B	0.0004
DUT mismatch	B	0.0004
Leakage	B	0.0001
Drift during measurement	B	0.0007
Linearity	B	0.0120
Random	A	0.0003
Combined uncertainty (k = 1):		0.013

Table C.16.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0015
Reference mismatch	B	0.0149
Reference drift	B	0.0014
DUT mismatch	B	0.0082
Leakage	B	0.0001
Drift during measurement	B	0.0036
Linearity	B	0.0123
Random	A	0.0006
Combined uncertainty (k = 1):		0.021

Table C.16.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0025
Reference mismatch	B	0.0044
Reference drift	B	0.0004
DUT mismatch	B	0.0004
Leakage	B	0.0063
Drift during measurement	B	0.0007
Linearity	B	0.0361
Random	A	0.0058
Combined uncertainty (k = 1):		0.037

Table C.16.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Reference uncertainty	B	0.0025
Reference mismatch	B	0.0149
Reference drift	B	0.0018
DUT mismatch	B	0.0086
Leakage	B	0.0066
Drift during measurement	B	0.0038
Linearity	B	0.0364
Random	A	0.0013
Combined uncertainty (k = 1):		0.041

C.17 – KRISS uncertainty budget

Table C.17.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0004
Standard attenuator	B	0.0021
Mismatch	B	0.0009
Resolution	B	0.0004
Leakage	B	0.0000
Stability	B	0.0006
Combined uncertainty (k = 1):		0.002

Table C.17.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Standard attenuator	B	0.0021
Mismatch	B	0.0040
Resolution	B	0.0004
Leakage	B	0.0000
Stability	B	0.0006
Combined uncertainty (k = 1):		0.005

Table C.17.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0009
Standard attenuator	B	0.0032
Mismatch	B	0.0010
Resolution	B	0.0004
Leakage	B	0.0003
Stability	B	0.0006
Combined uncertainty (k = 1):		0.004

Table C.17.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0005
Standard attenuator	B	0.0032
Mismatch	B	0.0040
Resolution	B	0.0004
Leakage	B	0.0003
Stability	B	0.0006
Combined uncertainty (*k* = 1):		0.005

Table C.17.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0004
Standard attenuator	B	0.0021
Mismatch	B	0.0009
Resolution	B	0.0004
Leakage	B	0.0000
Stability	B	0.0006
Combined uncertainty (*k* = 1):		0.002

Table C.17.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0004
Standard attenuator	B	0.0021
Mismatch	B	0.0046
Resolution	B	0.0004
Leakage	B	0.0000
Stability	B	0.0006
Combined uncertainty (*k* = 1):		0.005

Table C.17.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0008
Standard attenuator	B	0.0032
Mismatch	B	0.0010
Resolution	B	0.0004
Leakage	B	0.0003
Stability	B	0.0006
Combined uncertainty (k = 1):		0.004

Table C.17.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0007
Standard attenuator	B	0.0032
Mismatch	B	0.0047
Resolution	B	0.0004
Leakage	B	0.0003
Stability	B	0.0006
Combined uncertainty (k = 1):		0.006

C.18 – INRIM uncertainty budget

First measurement

Table C.18.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.0099
Type B	B	0.0013
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0005
Combined uncertainty (k = 1):		0.0113

Table C.18.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.0002
Type B	B	0.0015
Linearity	B	0.0006
Mismatch	B	0.0004
Crosstalk	B	0.0005
Combined uncertainty (k = 1):		0.0017

Table C.18.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.0342
Type B	B	0.0519
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0511
Combined uncertainty (k = 1):		0.0861

Table C.18.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_{T}(i) (dB)**
Random	A	0.0043
Type B	B	0.0537
Linearity	B	0.0006
Mismatch	B	0.0003
Crosstalk	B	0.0528
Combined uncertainty (k = 1):		0.0580

Table C.18.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0100
Type B	B	0.0013
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0005
Combined uncertainty (*k* = 1):		0.0113

Table C.18.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Type B	B	0.0015
Linearity	B	0.0006
Mismatch	B	0.0004
Crosstalk	B	0.0005
Combined uncertainty (*k* = 1):		0.0017

Table C.18.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0358
Type B	B	0.0522
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0516
Combined uncertainty (*k* = 1):		0.0880

Table C.18.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0030
Type B	B	0.0071
Linearity	B	0.0006
Mismatch	B	0.0011
Crosstalk	B	0.0054
Combined uncertainty (*k* = 1):		0.0101

Repeat Measurement

Table C.18.9 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0099
Type B	B	0.0013
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0005
Total uncertainty on insertion loss	A+B	0.0108
Combined uncertainty (k = 1):		0.0221

Table C.18.10 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0038
Type B	B	0.0015
Linearity	B	0.0006
Mismatch	B	0.0004
Crosstalk	B	0.0005
Total uncertainty on insertion loss	A+B	0.0032
Combined uncertainty (k = 1):		0.0084

Table C.18.11 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0342
Type B	B	0.0519
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0511
Total uncertainty on insertion loss	A+B	0.0108
Combined uncertainty (k = 1):		0.0861

Table C.18.12 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0043
Type B	B	0.0537
Linearity	B	0.0006
Mismatch	B	0.0003
Crosstalk	B	0.0528
Total uncertainty on insertion loss	A+B	0.0032
Combined uncertainty (k = 1):		0.0584

Table C.18.13 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0100
Type B	B	0.0013
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0005
Total uncertainty on insertion loss	A+B	0.0102
Combined uncertainty (k = 1):		0.0215

Table C.18.14 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Type B	B	0.0015
Linearity	B	0.0006
Mismatch	B	0.0004
Crosstalk	B	0.0005
Total uncertainty on insertion loss	A+B	0.0051
Combined uncertainty (k = 1):		0.0067

Table C.18.15 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0358
Type B	B	0.0522
Linearity	B	0.0006
Mismatch	B	0.0002
Crosstalk	B	0.0516
Total uncertainty on insertion loss	A+B	0.0102
Combined uncertainty (k = 1):		0.0979

Table C.18.16 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0030
Type B	B	0.0071
Linearity	B	0.0006
Mismatch	B	0.0011
Crosstalk	B	0.0054
Total uncertainty on insertion loss	A+B	0.0051
Combined uncertainty (k = 1):		0.0148

C.19 – VNIIFTRI uncertainty budget

Table C.19.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Reference attenuator	B	0.0003
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.19.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Reference attenuator	B	0.0012
Non-linearity	B	0.0006
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.19.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Reference attenuator	B	0.0003
Non-linearity	B	0.0001
Leakage	B	0.0003
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.19.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Reference attenuator	B	0.0012
Non-linearity	B	0.0006
Leakage	B	0.0012
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.002

Table C.19.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Reference attenuator	B	0.0003
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.19.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Reference attenuator	B	0.0012
Non-linearity	B	0.0006
Leakage	B	0.0005
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.002

Table C.19.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Reference attenuator	B	0.0003
Non-linearity	B	0.0001
Mismatch	B	0.0006
Combined uncertainty (k = 1):		0.001

Table C.19.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0005
Reference attenuator	B	0.0012
Non-linearity	B	0.0006
Leakage	B	0.0001
Mismatch	B	0.005
Combined uncertainty (k = 1):		0.005

Table C.19.9 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0010
Reference attenuator	B	0.0003
Non-linearity	B	0.0012
Leakage	B	0.0004
Mismatch	B	0.0009
Combined uncertainty (k = 1):		0.002

Table C.19.10 – Uncertainty budget for measurement of 100 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.003
Reference attenuator	B	0.012
Non-linearity	B	0.006
Leakage	B	0.014
Mismatch	B	0.023
Combined uncertainty (k = 1):		0.030

C.20 – NMIA uncertainty budget

Table C.20.1 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0008
Mismatch	B	0.0011
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0020
Environmental Influences on Standard	B	0.0000
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.003

Table C.20.2 – Uncertainty budget for measurement of 20 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0010
Mismatch	B	0.0028
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0020
Environmental Influences on Standard	B	0.0000
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.004

Table C.20.3 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0006
Mismatch	B	0.0011
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0060
Environmental Influences on Standard	B	0.0000
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.006

Table C.20.4 – Uncertainty budget for measurement of 60 dB step of K19.CL/1 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0008
Mismatch	B	0.0025
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0060
Environmental Influences on Standard	B	0.0001
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.007

Table C.20.5 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0002
Mismatch	B	0.0008
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0020
Environmental Influences on Standard	B	0.0000
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.002

Table C.20.6 – Uncertainty budget for measurement of 20 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0005
Mismatch	B	0.0058
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0020
Environmental Influences on Standard	B	0.0000
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.006

Table C.20.7 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 60 MHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0003
Mismatch	B	0.0008
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0060
Environmental Influences on Standard	B	0.0001
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.006

Table C.20.8 – Uncertainty budget for measurement of 60 dB step of K19.CL/2 at 5 GHz

Source (i)	**Type**	**u_T(i) (dB)**
Random	A	0.0010
Mismatch	B	0.0062
Mixer Linearity	B	0.0012
Attenuation Resolution	B	0.0001
Leakage	B	0.0000
Standard Attenuation Scaling Factor	B	0.0060
Environmental Influences on Standard	B	0.0001
Reference Attenuator	B	0.0000
Combined uncertainty (k = 1):		0.009

Appendix D – Other reported results

Please note: the average values given here are the unweighted means of *ALL* measurements supplied and the uncertainties are the root sum squares of all uncertainties divided by the number of participants (excluding INRIM first measurement). There are provided for guidance only and do not form part of the main body of this comparison; hence they should not be treated as KCRVs.

Lab *i*	Measurement and Combined Uncertainty of 40 dB attenuation step of K19.CL/1 at 60 MHz	
	A_{40_i} (dB)	$u(A_{40\_i})$ (dB)
NPL	40.117	0.002
NIST	40.113	0.020
LNE	40.120	0.020
PTB	40.117	0.002
NMIJ	40.119	0.001
CMI	40.105	0.017
CSIR	40.112	0.010
NRC	40.120	0.015
NMi-VSL	40.117	0.043
METAS	40.112	0.004
SP	40.112	0.009
UME	40.119	0.066
SPRING	40.121	0.007
NIM	40.116	0.002
SIQ	40.110	0.022
MIKES	40.112	0.025
KRISS	40.113	0.003
INRIM	40.137	0.016
INRIM repeat	40.120	0.027
VNIIFTRI	40.117	0.001
NMIA	40.114	0.004
	A_{40_ave} (dB)	$u(A_{40\_ave})$ (dB)
Average value	40.115	0.005

Table D.1

All uncertainties are given for coverage factor *k* = 1.

Lab i	Measurement and Combined Uncertainty of 40 dB attenuation step of K19.CL/1 at 5 GHz	
	A_{40_i} (dB)	$u(A_{40\_i})$ (dB)
NPL	40.116	0.002
NIST	40.101	0.021
LNE	40.120	0.020
PTB	40.113	0.005
NMIJ	40.112	0.001
CMI	40.094	0.019
CSIR	40.105	0.030
NRC	40.110	0.015
NMi-VSL	40.093	0.042
METAS	40.117	0.005
SP	40.105	0.027
UME	40.113	0.066
SPRING	40.113	0.004
NIM	40.114	0.004
SIQ		
MIKES	40.104	0.029
KRISS	40.117	0.006
INRIM	40.068	0.007
INRIM repeat	40.112	0.010
VNIIFTRI	40.119	0.002
NMIA	40.111	0.005
	A_{40_ave} (dB)	$u(A_{40\_ave})$ (dB)
Average value	40.110	0.005

Table D.2

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 70 dB attenuation step of K19.CL/1 at 60 MHz	
	A_{70_i} (dB)	$u(A_{70\_i})$ (dB)
NPL	70.022	0.003
NIST	70.018	0.165
LNE	70.020	0.033
PTB	70.024	0.003
NMIJ	70.014	0.003
CMI	70.011	0.079
CSIR	70.004	0.020
NRC	70.030	0.029
NMi-VSL	70.033	0.081
METAS	70.024	0.005
SP	70.023	0.046
UME	70.011	0.754
SPRING	70.023	0.008
NIM	70.015	0.004
SIQ	70.015	0.031
MIKES	70.023	0.049
KRISS	70.020	0.004
INRIM	70.650	0.270
INRIM repeat	70.012	0.280
VNIIFTRI	70.021	0.002
NMIA	70.003	0.008
	A_{70_ave} (dB)	$u(A_{70\_ave})$ (dB)
Average value	70.018	0.042

Table D.3

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 70 dB attenuation step of K19.CL/1 at 5 GHz	
	A_{70_i} (dB)	$u(A_{70\_i})$ (dB)
NPL	70.045	0.002
NIST	69.973	0.156
LNE	70.070	0.040
PTB	70.032	0.006
NMIJ	70.027	0.003
CMI	70.007	0.027
CSIR	70.024	0.030
NRC	70.033	0.029
NMi-VSL	69.996	0.119
METAS	70.034	0.006
SP	69.881	0.259
UME	70.033	0.755
SPRING	70.035	0.007
NIM	70.027	0.004
SIQ		
MIKES	70.035	0.050
KRISS	70.044	0.007
INRIM	69.979	0.175
INRIM repeat	70.063	0.170
VNIIFTRI	70.034	0.004
NMIA	70.013	0.009
	A_{70_ave} (dB)	$u(A_{70\_ave})$ (dB)
Average value	70.021	0.044

Table D.4

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 40 dB attenuation step of K19.CL/2 at 60 MHz	
	A_{40_i} (dB)	$u(A_{40\_i})$ (dB)
NPL	40.195	0.001
NIST	40.195	0.020
LNE	40.190	0.020
PTB	40.191	0.002
NMIJ	40.193	0.001
CMI	40.180	0.017
CSIR	40.186	0.010
NRC	40.189	0.015
NMi-VSL	40.204	0.041
METAS	40.195	0.004
SP	40.191	0.009
UME	40.195	0.066
SPRING	40.195	0.007
NIM	40.192	0.002
SIQ	40.183	0.022
MIKES	40.184	0.025
KRISS	40.187	0.003
INRIM	40.206	0.014
INRIM repeat	40.200	0.024
VNIIFTRI	40.193	0.001
NMIA	40.183	0.004
	A_{40_ave} (dB)	$u(A_{40\_ave})$ (dB)
Average value	40.191	0.005

Table D.5

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 40 dB attenuation step of K19.CL/2 at 5 GHz	
	A_{40_i} (dB)	$u(A_{40\_i})$ (dB)
NPL	40.151	0.003
NIST	40.135	0.021
LNE	40.160	0.020
PTB	40.165	0.007
NMIJ	40.153	0.002
CMI	40.125	0.021
CSIR	40.137	0.050
NRC	40.152	0.010
NMi-VSL	40.244	0.045
METAS	40.160	0.006
SP	40.162	0.027
UME	40.152	0.066
SPRING	40.151	0.004
NIM	40.157	0.007
SIQ		
MIKES	40.142	0.030
KRISS	40.154	0.006
INRIM	40.150	0.003
INRIM repeat	40.159	0.008
VNIIFTRI	40.173	0.002
NMIA	40.138	0.008
	A_{40_ave} (dB)	$u(A_{40\_ave})$ (dB)
Average value	40.156	0.006

Table D.6

All uncertainties are given for coverage factor $k = 1$.

Lab i	Measurement and Combined Uncertainty of 80 dB attenuation step of K19.CL/2 at 60 MHz	
	A_{80_i} (dB)	$u(A_{80\_i})$ (dB)
NPL	80.335	0.002
NIST	80.341	0.372
LNE	80.300	0.030
PTB	80.332	0.003
NMIJ	80.330	0.002
CMI	80.290	0.106
CSIR	80.318	0.014
NRC	80.340	0.062
NMi-VSL	80.369	0.126
METAS	80.330	0.006
SP	80.389	0.151
UME		
SPRING	80.336	0.011
NIM	80.328	0.003
SIQ	80.326	0.034
MIKES	80.357	0.082
KRISS	80.319	0.004
INRIM	82.164	1.095
INRIM repeat	80.531	0.369
VNIIFTRI	80.331	0.002
NMIA	80.316	0.006
	A_{80_ave} (dB)	$u(A_{80\_ave})$ (dB)
Average value	80.343	0.031

Table D.7

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 80 dB attenuation step of K19.CL/2 at 5 GHz	
	A_{80_i} (dB)	$u(A_{80\_i})$ (dB)
NPL	80.295	0.005
NIST	80.251	0.263
LNE	80.280	0.043
PTB	80.302	0.008
NMIJ	80.293	0.003
CMI	80.237	0.061
CSIR	80.303	0.050
NRC	80.292	0.062
NMi-VSL	80.477	0.339
METAS	80.301	0.008
SP	81.044	0.987
UME		
SPRING	80.290	0.007
NIM	80.296	0.007
SIQ		
MIKES	80.286	0.085
KRISS	80.302	0.007
INRIM	80.342	0.089
INRIM repeat	80.200	0.107
VNIIFTRI	80.312	0.006
NMIA	80.270	0.012
	A_{80_ave} (dB)	$u(A_{80\_ave})$ (dB)
Average value	80.335	0.061

Table D.8

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 110 dB attenuation step of K19.CL/2 at 60 MHz	
	A_{110_i} (dB)	$u(A_{110\_i})$ (dB)
NPL	110.212	0.006
NIST		
LNE		
PTB	110.210	0.010
NMIJ	110.214	0.024
CMI	110.180	0.279
CSIR	110.230	0.100
NRC		
NMi-VSL		
METAS	110.211	0.008
SP		
UME		
SPRING		
NIM	110.195	0.021
SIQ	110.204	0.218
MIKES		
KRISS		
INRIM		
VNIIFTRI	110.191	0.004
NMIA		
	A_{110_ave} (dB)	$u(A_{110\_ave})$ (dB)
Average value	110.205	0.041

Table D.9

All uncertainties are given for coverage factor $k = 1$.

Lab *i*	Measurement and Combined Uncertainty of 110 dB attenuation step of K19.CL/2 at 5 GHz	
	A_{110_i} (dB)	$u(A_{110\_i})$ (dB)
NPL	110.187	0.013
NIST		
LNE		
PTB	110.210	0.095
NMIJ	110.181	0.020
CMI	110.070	0.203
CSIR	110.230	0.110
NRC		
NMi-VSL		
METAS	110.169	0.034
SP		
UME		
SPRING		
NIM	110.180	0.022
SIQ		
MIKES		
KRISS		
INRIM		
VNIIFTRI	110.253	0.060
NMIA		
	A_{110_ave} (dB)	$u(A_{110\_ave})$ (dB)
Average value	110.185	0.033

Table D.10

All uncertainties are given for coverage factor $k = 1$.

Appendix E – Stability of Intercomparison Attenuators

E.1 - Background

One of the duties of the Pilot Laboratory is to confirm the suitability and stability of the travelling comparison devices. To this end the attenuators have been measured five times at NPL. Once on delivery from the supplier, and at the start, middle and end of the main comparison, then again following the return of the artefacts from NMIA. The initial measurements were performed to both verify the correct operation of the attenuators and also to clean and condition the RF switch contacts. These measurements are reported to demonstrate the stability of the attenuators over the duration of the comparison.

As stated elsewhere only one set (the 'middle') results are used as the NPL contribution to the KCRV.

Following the nominal completion of the comparison, and after the circulation of the 'draft' Draft A report, INRIM requested and was given permission to re-measure the travelling attenuators in October 2006. Also NMIA requested to join the intercomparison and measured the attenuators after INRIM in late 2006 to early 2007. During the course of these measurements NMIA reported that attenuator K19.CL/1 exhibited some instability in measured attenuation but this stabilized with repeated switch operation. However on return to NPL, measurements at 60 MHz suggested that the attenuation value had indeed altered and that the NPL measurements agreed with the values reported by NMIA. This would explain the slight discrepancies in the NMIA results. Repeat measurements on the second attenuator would suggest that its value is unchanged.

E.2 - Mechanical Condition

On delivery from the supplier the attenuators were cleaned and checked for mechanical tolerances, and in the case of K19.CL/2 the connectors adjusted to optimise the relative position of the inner and outer connector mating faces.

At each subsequent NPL measurement the connectors were cleaned and re-gauged. Additionally each participant was requested to inspect, mechanically measure and report on the condition of the connectors. No significant deterioration in the connectors was observed during the comparison, a testament to the careful handling of the attenuators by the participants.

E.3 - Pilot Lab Held Check Standards

The pilot laboratory keeps, for its own internal use, similar attenuators to those circulated in the comparison. These are used to monitor the performance of the attenuation measurement systems and are regularly measured. These attenuators were also available for use in the event of loss or failure of the travelling attenuators. It is estimated that these attenuators received a similar level of usage to the travelling devices, but were kept in temperature controlled measurement laboratory.

These devices showed a very similar level of agreement between each set of measurements to that shown by the travelling attenuators, indicating that the transport of the devices has not adversely affected their stability.

E.4 - Pilot Laboratory Measurements

The measurements, performed in October 2001, November – December 2002 and December 2005 to February 2006 are presented below.

K19.CL/1 60 MHz

Nominal Attenuation	Mean 2001	U 2001	Mean 2002	U 2002	Mean 2005	U 2005
20	19.9538	0.0010	19.9525	0.0009	19.9543	0.0011
40	40.1183	0.0017	40.1173	0.0016	40.1191	0.0020
60	60.0713	0.0025	60.0698	0.0024	60.0735	0.0029
70	70.0221	0.0031	70.0215	0.0029	70.0275	0.0035

K19.CL/1 5000 MHz

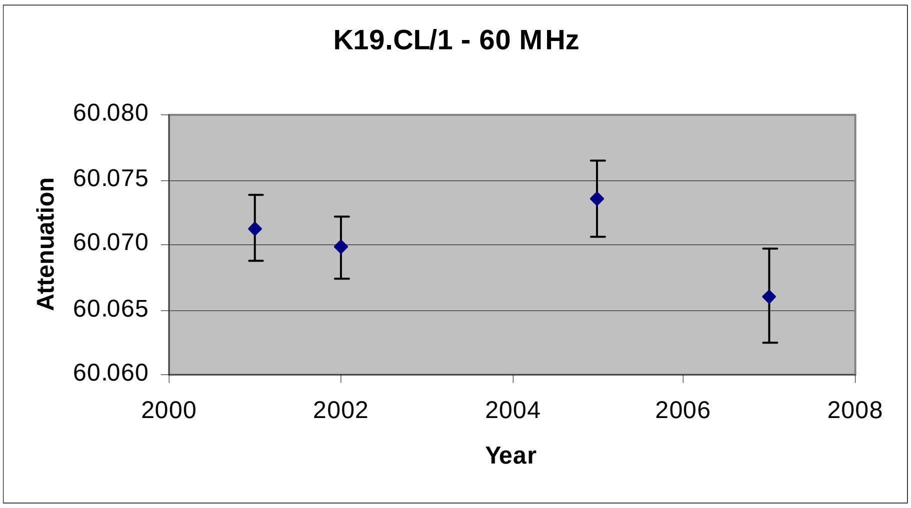
Nominal Attenuation	Mean 2001	U 2001	Mean 2002	U 2002	Mean 2005	U 2005
20	19.9607	0.0062	19.9564	0.0014	19.9558	0.0026
40	40.1125	0.0020	40.1158	0.0017	40.1165	0.0035
60	60.0689	0.0022	60.0691	0.0018	60.0714	0.0042
70	70.0259	0.0029	70.0450	0.0023	70.0484	0.0052

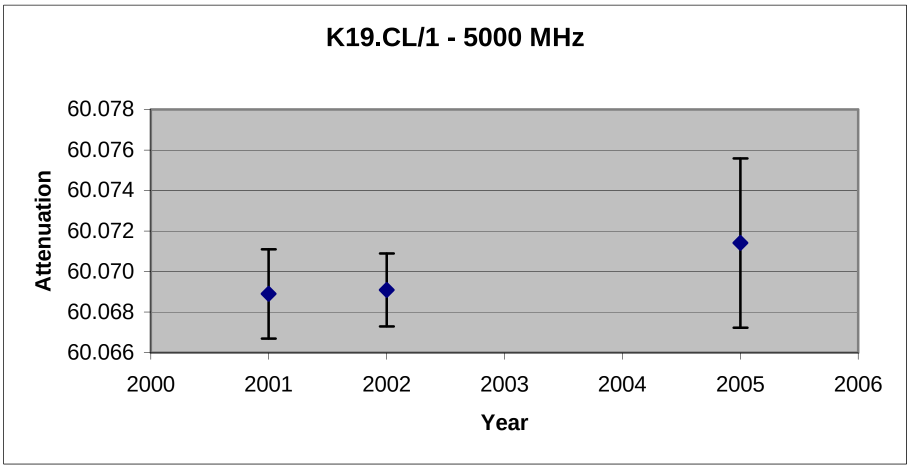
K19.CL/2 60 MHz

Nominal Attenuation	Mean 2001	U 2001	Mean 2002	U 2002	Mean 2005	U 2005
20	19.9430	0.0008	19.9452	0.0006	19.9468	0.0009
40	40.1935	0.0017	40.1952	0.0009	40.1960	0.0016
60	60.1377	0.0025	60.1404	0.0012	60.1426	0.0023
80	80.3317	0.0033	80.3349	0.0016	80.3328	0.0031
100	100.2753	0.0060	100.2767	0.0021	100.2788	0.0039
110	110.1952	0.0103	110.2118	0.0058	110.2187	0.0073

K19.CL/2 5000 MHz

Nominal Attenuation	Mean 2001	U 2001	Mean 2002	U 2002	Mean 2005	U 2005
20	19.9275	0.0006	19.9313	0.0031	19.9320	0.0049
40	40.1582	0.0014	40.1513	0.0034	40.1502	0.0057
60	60.1061	0.0040	60.0980	0.0035	60.0978	0.0063
80	80.3011	0.0045	80.2951	0.0046	80.2900	0.0072
100	100.2493	0.0063	100.2457	0.0064	100.2361	0.0078
110	110.1550	0.0103	110.1866	0.0127	110.1731	0.0133


K19.CL/1 - 60 MHz
Attenuation
60.080
60.075
60.070
60.065
60.060
2000
2002
2004
2006
2008
Year


K19.CL/1 - 5000 MHz
Attenuation
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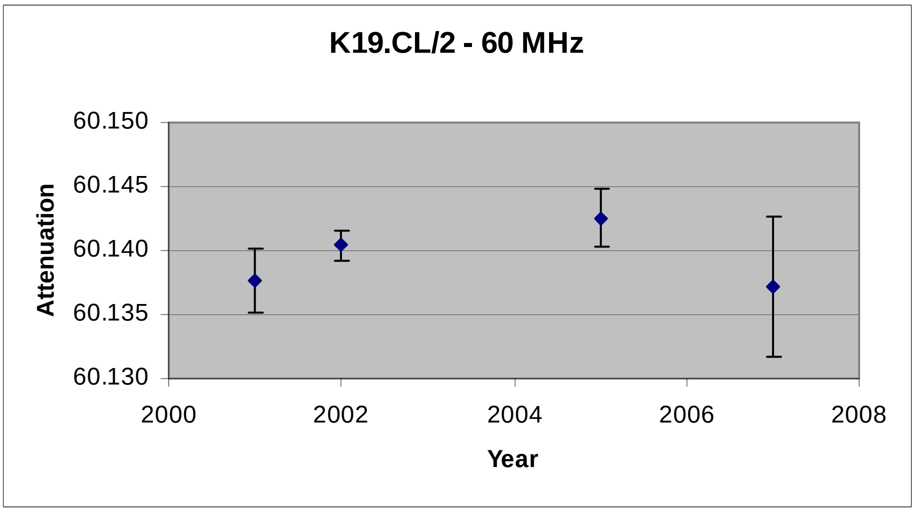
60.076
60.074
60.072
60.070
60.068
60.066
2000
2001
2002
2003
2004
2005
2006
Year


K19.CL/2 - 60 MHz
Attenuation
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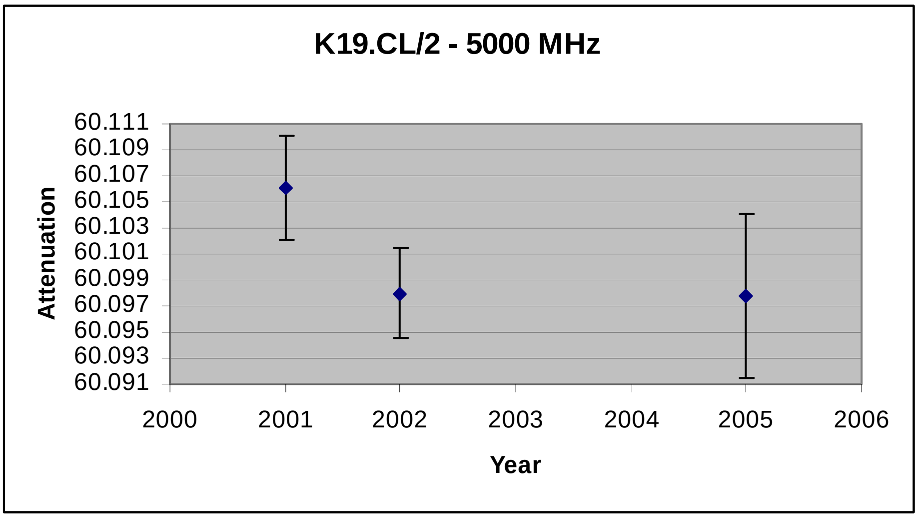
60.145
60.140
60.135
60.130
2000
2002
2004
2006
2008
Year



E.5 Observations

As can be seen from the above data and graphs the attenuators have remained stable within the measurement uncertainties (expressed at the one standard uncertainty level) during the main portion of the comparison. No allowance or adjustment to the comparison participant's reported attenuation values is required.

E.6 INRIM, NMIA and final NPL Measurements

As reported above, attenuator K19.Cl/1 appears to have changed its attenuation prior to the measurements being performed at NMIA. While the following information is available in the main report, for convenience the 60 MHz results for both attenuators are summarised below for the NPL 2005 and 2007, INRIM and NMIA measurements:

K19.CL/1 60 MHz

Nominal Attenuation	NPL Mean (2005)	NPL U (2005)	INRIM Mean (2006)	INRIM U (2006)	NMI-A Mean (2007)	NMI-A U (2007)	NPL Mean (2007)	NPL U (2007)
20	19.9543	0.0011	19.9520	0.0221	19.9438	0.0027	19.9449	0.0014
40	40.1191	0.0020	40.1200	0.0268	40.1136	0.0043	40.1226	0.0024
60	60.0735	0.0029	60.0590	0.0964	60.0595	0.0062	60.0661	0.0036
70	70.0275	0.0035	70.0120	0.2795	70.0031	0.0075	70.0163	0.0042

K19.CL/2 60 MHz

Nominal Attenuation	NPL Mean (2005)	NPL U (2005)	INRIM Mean (2006)	INRIM U (2006)	NMI-A Mean (2007)	NMI-A U (2007)	NPL Mean (2007)	NPL U (2007)
20	19.9468	0.0009	19.9440	0.0215	19.9379	0.0024	19.9476	0.0018
40	40.1960	0.0016	40.2000	0.0241	40.1834	0.0043	40.1949	0.0036
60	60.1426	0.0023	60.1410	0.0979	60.1253	0.0062	60.1372	0.0055
80	80.3328	0.0031	80.5310	0.3685	80.3157	0.0060	80.3300	0.0073
100	100.2788	0.0039	-	-	-	-	100.3223	0.0109