APMP.AUV.V-K1
Regional Key Comparison
of Standard Accelerometer

Final Report

Project Number: APMP-IC-4-95

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January 2001

Abstract

In project APMP-IC-4-95 (BIPM comparison identifier: APMP.AUV.V-K1), an artifact composed of a vibration accelerometer (B&K 8305) with a charge amplifier (B&K 2626) has been circulated in the Asia/Pacific region as part of a regional comparison of the Asia Pacific Metrology Program, APMP. During the period from February 1996 to September 1997, eight laboratories took part in the comparison. Seven laboratories are from the APMP region: CMS/ITRI (Taiwan)--coordinator, NRLM (Japan), KRISS (Korea), CSIRO (Australia), PSB (Singapore), NPL (India) and SIRIM (Malaysia) and one is from the EUROMET region PTB (Germany) which was invited for a peer review and as a final check laboratory. PSB and NPL using the comparison method withdrew their measurement results. The other six laboratories use the laser interferometry primary calibration methods—fringe-counting, minimum-point or sine-approximation. The reported uncertainties (expanded uncertainty for a coverage factor *k*=2, corresponding a confidence level of 95%) of each laboratory are 0.43%~1.06% for CMS/ITRI, 0.31%~1.9% for NRLM, 0.3%~0.4% for KRISS, 0.4%~0.6% for CSIRO, 0.22%~1.84% for SIRIM and 0.1%~0.2% for PTB, respectively. Three versions are proposed to compute the key comparison reference values, version 1 including all the results of the laboratories with different weight, version 2 removing the outliers of the results with different weight and version 3 deleting the outliers of the results with an equal weight. The degree of equivalence of the measurement standards is computed for these three versions. The degree of equivalence between paired laboratories is computed with version 3. There are 98% (121/123) of the calibration points that the relative deviations between the reference values of different versions are within ±0.15%. It indicates that the choice of the version has little effect on the computation of reference values. The estimation of version 3 with greater expanded uncertainty is conservative among these three different versions. There are 90% of the calibration points that the relative deviations between the laboratories and KCRV are within ±0.5% for each version. The worst results of the relative deviations between laboratories and KCRV are 3.4% ~3.6% for different versions. At the reference frequency 160 Hz, the best and the worst results of the relative deviations between the laboratories and KCRV are 0.006% and 0.36% for version 1, 0.008% and 0.36% for version 2, and 0.002% and 0.40% for version 3, respectively.

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1. Introduction

The broad objective of the Asia Pacific Metrology Program is to improve the measurement capabilities in the Asia-Pacific region by sharing facilities and experience in metrology [1]. As part of a major comparison program, the APMP is conducting a comparison on the vibration accelerometer. Eight laboratories participated in this APMP comparison from February 1996 and September 1997. All are members of the APMP except for the PTB that was invited for a peer review and as a final check laboratory. The participants are as follows: Center for Measurement Standards of Industrial Technology Research Institute (CMS/ITRI), Taiwan; National Research Laboratory of Metrology (NRLM), Japan; Korea Research Institute of Standards and Science (KRISS), Korea; Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia; Singapore Productivity and Standards Board (PSB), Singapore; National Physical Laboratory (NPL), India; Standards and Industrial Research Institute of Malaysia (SIRIM), Physikalisch-Technische Bundesanstalt (PTB), Germany.

The following artifact is circulated among the participants for calibration: Brüel&Kjær 8305 accelerometer (S/N 1610202) with Brüel&Kjær 2626 conditioning amplifier (S/N 1242511). Comparison or laser interferometry method depending on the facilities of participating laboratories was used to calibrate the artifact. The frequency range of calibration is 10 Hz to 10 kHz. The measurement points in the range are open to all of the laboratories.

2. Schedule of Program

Participants, the planned schedule, and reporting date for each laboratory are shown in table 1. The proposed time for measuring at each laboratory, for transferring the artifact to the next laboratory, and for reporting to the program coordinator are four weeks, two weeks, and one week, respectively. As for the PTB, the calibrations were performed within 2days in presence of a representative of CMS/ITRI who had hand-carried the artifact to Germany and, after the calibration, back to Taiwan.

The program was started at the laboratory of CMS/ITRI for initial measurement on Feb. 2, 1996. The artifact was circulated for one half year and returned to CMS/ITRI in early July, 1996 for an interim check to make sure of no damage to the artifact. For the same reason, the final check was made by PTB in May 1997. The entire comparison program lasted for about one year and eight months.

Table 1 Participants, the planned schedule and reporting date

Laboratory	Country/Territory	Starting date	Reporting date
CMS/ITRI	Taiwan	2 Feb, 1996 (Initial Measurement)	7 March, 1996
NRLM	Japan	15 March,1996	18 March, 1996
KRISS	Korea	26 April,1996	30 May, 1996
CSIRO	Australia	7 June, 1996	11 July, 1996
CMS/ITRI	Taiwan	19 July, 1996 (Interim Check)	22 August, 1996
PSB	Singapore	5 October, 1996	11 November, 1996
NPL	India	18 November, 1996	4 January, 1997
SIRIM	Malaysia	5 January, 1997	22 May, 1997
PTB	Germany	21 May, 1997 (final check)	19 September, 1997

3. Methods and Measurements

3.1 Condition of Measurements

The measurements of the voltage sensitivity of the artifact at the following frequencies are preferred or at some aforementioned frequencies, depending on the individual laboratory: 30, 50, 100, 160, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10000 Hz. The ambient situations are 23±3 and 50±25% relative humidity. The conditioning amplifier B&K 2626 was operated at the following setting

Sensitivity 1.26 pC/unit

Range 0.01 V/unit

Lower Freq. Limit 0.3 Hz

Upper Freq. Limit Linear

To evaluate the measurement uncertainty, an ISO publication entitled "Guide to the expression of uncertainty in measurement "[2] could be referred to.

3.2 Methodologies of Measurements

In general, there are six participating laboratories, which are CMS/ITRI, NRLM, KRISS, CSIRO, SIRIM and PTB applying laser interferometry primary calibration methods—fringe-counting, minimum-point or sine-approximation-- based upon ISO 5347 or ISO 16063 series standards [3,4,5]. There are two laboratories, which are PSB of Singapore and NPL of India using comparison calibration. A brief of the calibration methods from the individual calibration report is summarized below and outlined in table 2.

NRLM: The Primary calibration system was applied. The fringe-counting method, as shown in figure.1, was used for frequencies from 30 Hz to 300 Hz. As shown in figure 2, J_1 minimum-point method was used for frequencies from 200 Hz to 4 kHz and J_0 minimum-point method was used for frequencies above 4 kHz. There was a reflective mirror, weighted 7 grams, on the top surface of the accelerometer.

KRISS: The primary calibration method was used over a frequency range of 10 Hz to 10 kHz. For frequency range from 10 Hz to 800 Hz, the fringe-counting method was used. For frequency range from 800 Hz to 10 kHz, the method extracting the value of displacement amplitude from the ratio of two harmonic components was used

$$J_1\left(\frac{4\pi}{\lambda}\xi\right) \Big/ J_3\left(\frac{4\pi}{\lambda}\xi\right) = V_1 / V_3 ,$$

where V_1 and V_3 are the measured magnitudes of the first and third harmonics obtained from a spectrum analyzer and □ is the displacement amplitude. There was no load on the top surface of the accelerometer.

CSIRO: The primary calibrations were performed over the frequency range from 30 Hz to 10 kHz. From 30 Hz to 2 kHz, the fringe-counting method was used. The J_1 zero method was used from 2 kHz to 10 kHz. There was no load on the top surface of the accelerometer.

PSB: The accelerometer set was calibrated by using the comparison method over the frequency range from 20 Hz to 5 kHz. For some reasons, Dr. S. Tan withdrew the measurement results on June 10, 1998.

NPL: The accelerometer set was calibrated by using the comparison method over the frequency range from 30 Hz to 10 kHz. For some reasons, Dr. V. Mohana withdrew the measurement results on August 26, 1998.

SIRIM: The primary vibration calibration by laser interferometry based on ISO 5347 was adopted. The fringe-counting method was used up to 300 Hz. The J_1 minimum-point method was used for frequency range from 300 Hz to 4 kHz and J_0. minimum-point method was used for frequency above 4 kHz. The system schematic diagram for the calibration methods is shown in figure 3. There was a reflective mirror, weighted 7 grams, on the top surface of the accelerometer.

PTB: The final check laboratory applied two primary calibration methods: the fringe-counting method was used for frequencies of 10 Hz to 1 kHz and the sine-approximation method [5] was used for higher frequencies. The calibration system diagrams for the medium and high frequency ranges were shown in figures 4 and 5, respectively. There was no load on the top surface of the accelerometer.

CMS/ITRI: Two primary calibration methods were employed in the coordinating laboratory. The fringe-counting method, shown in figure 6, was applied over the frequency range from 50 Hz to 600 Hz. When frequency was greater than 600 Hz, the J_0 minimum method was operated, as shown in figure 7. From 700 Hz to 1 kHz, the measurements were made at the fourth order zero. From 1.5 kHz to 10 kHz, the measurements were made at the first order zero. There is a reflective mirror, weighted 1.33 grams, on the top surface of the accelerometer.

Table 2 Summary of calibration methods of the participating NMIs

NMIs	Date	Primary calibration method		mass attached to the top surface of the accelerometer
		Fringe counting	Bessel minimum Or Sine approximation	
ITRI	1996/2	50-600Hz	J_0: 700-10000 Hz	Mirror:1.33 grams

NRLM	1996/3	30-300Hz	J_1: 200-4000 Hz J_0: 4000-10000Hz	7 grams including the mirror
KRISS	1996/6	10-800 Hz	$J_1/J_3=V_1/V_3$: 800-10000 Hz	None
CSIRO	1996/7	30-2000 Hz	J_1: 2000-10000 Hz	None
PSB	1996/10	Comparison method		-----
NPL	1996/11	Comparison method		-----
SIRIM	1997/1	30-300 Hz	J_1: 300-4000 Hz J_0: 4000-10000 Hz	7 grams including the mirror
PTB	1997/5	10-1000 Hz	Sine approximation: 1000-10000 Hz	None

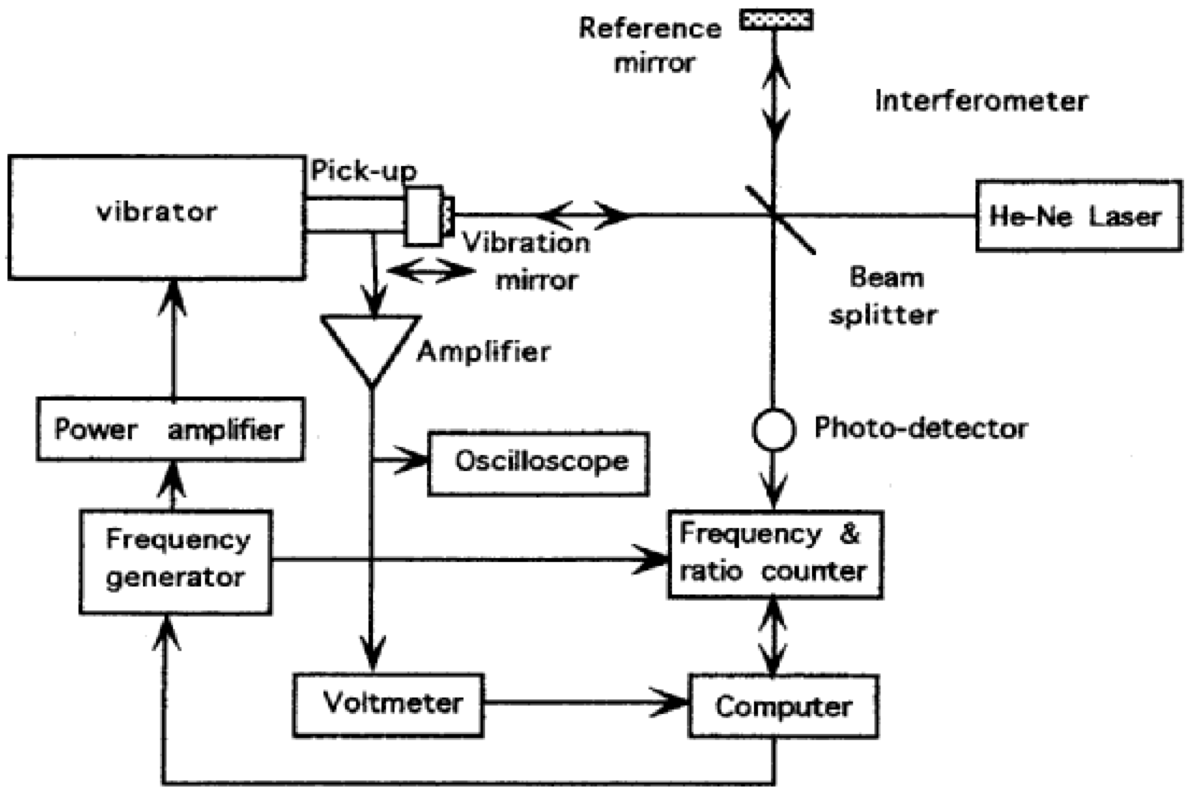

Figure 1 NRLM primary vibration calibration system based on laser interferometry: fringe-counting method

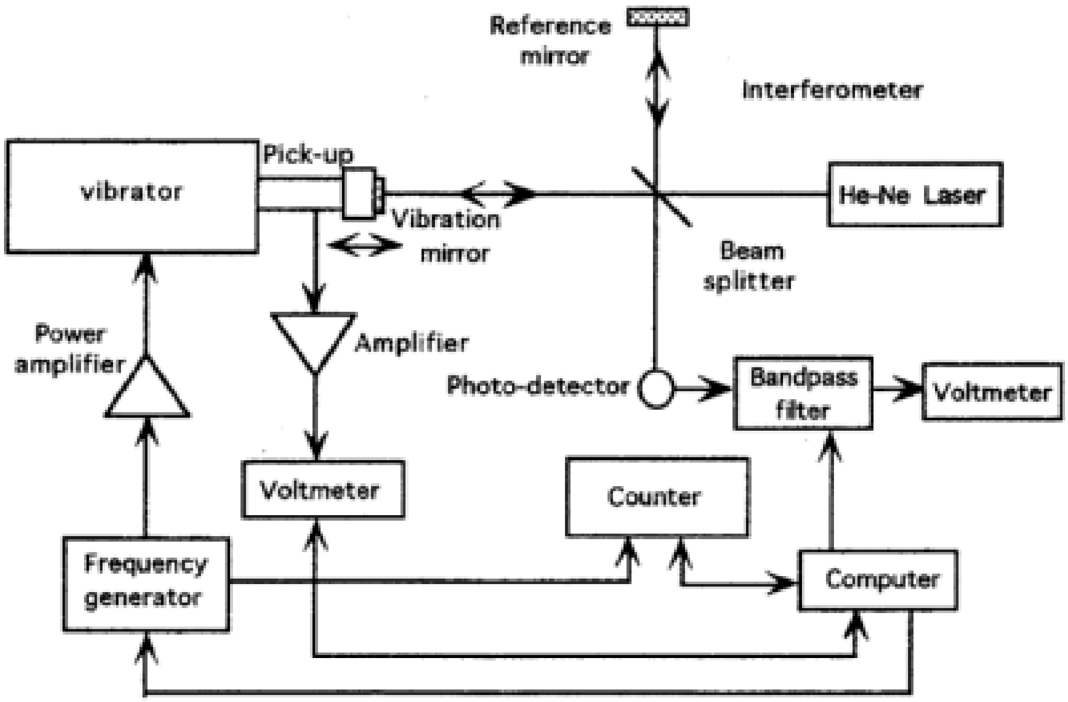

Figure 2 NRLM Primary vibration calibration system based on laser interferometry: minimum-point method

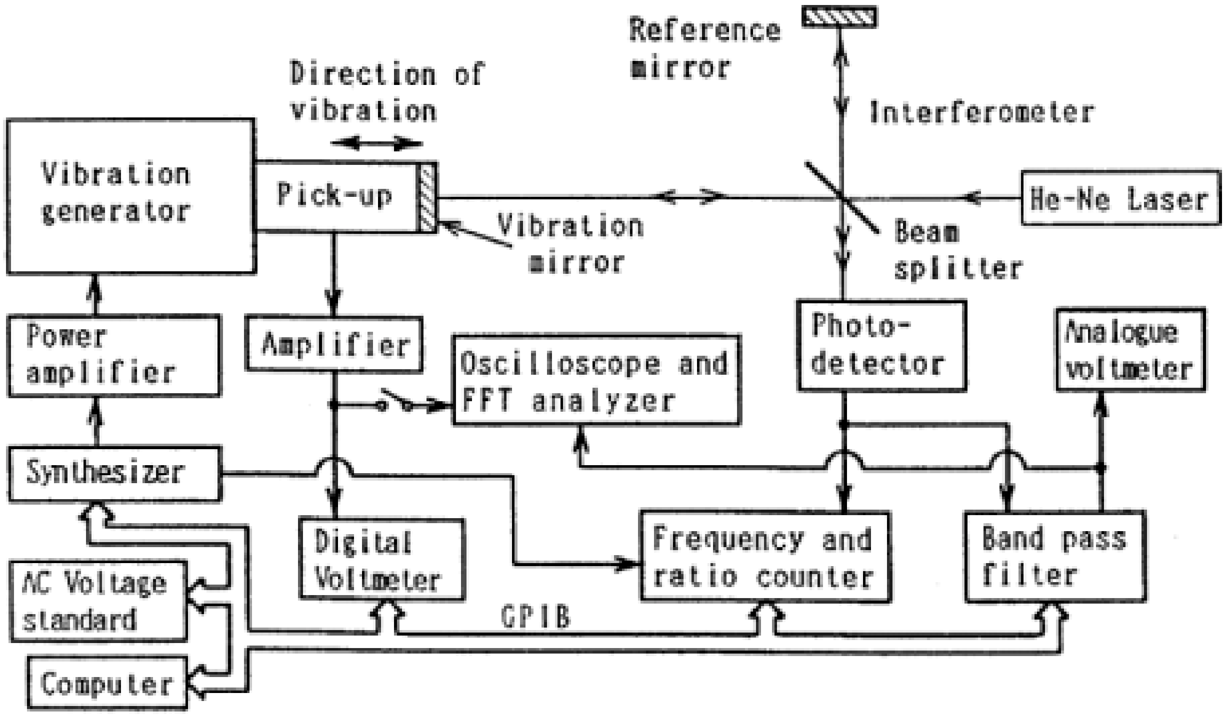

Figure 3 SIRIM primary vibration calibration system based on laser interferometry

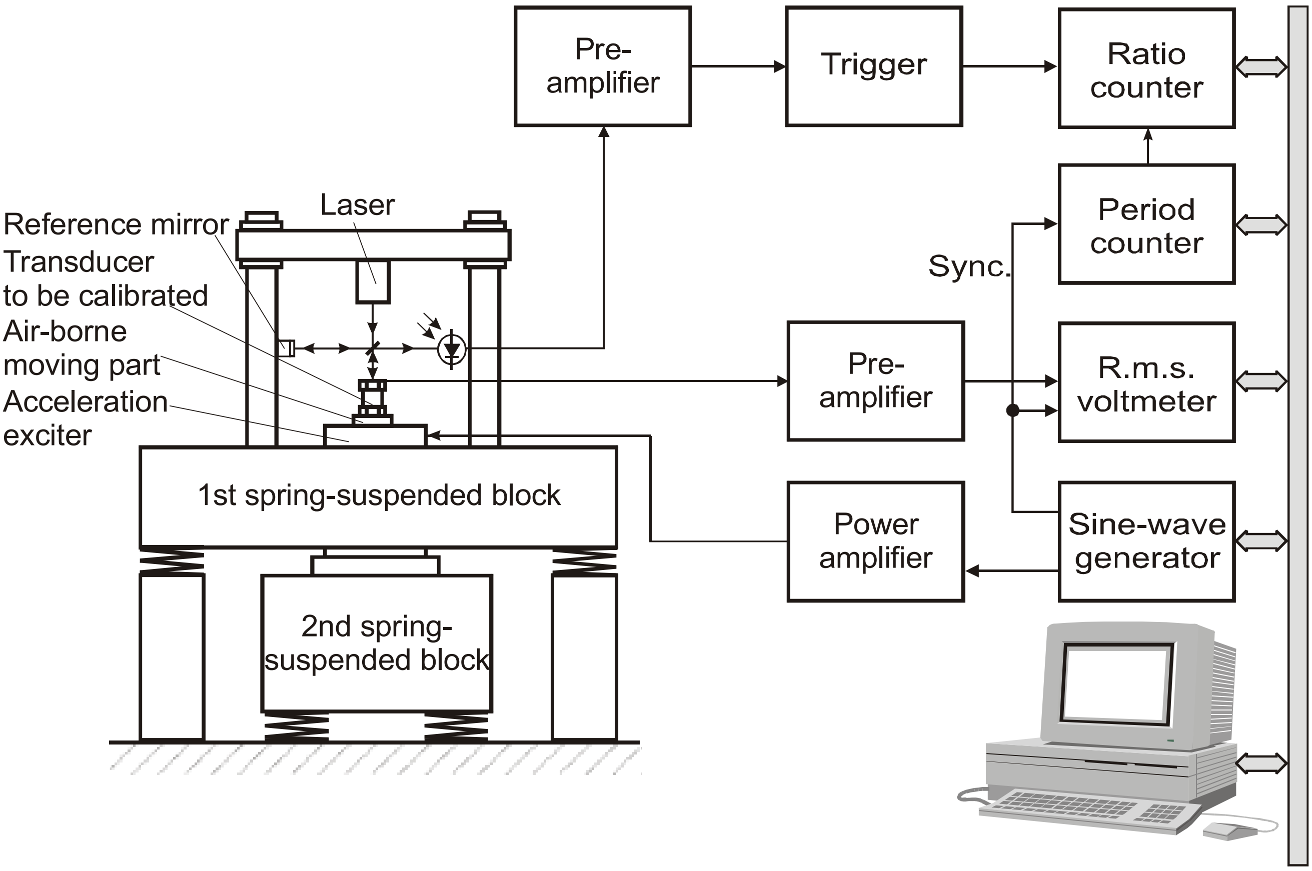

Figure 4 PTB primary vibration calibration system based on laser interferometry: fringe-counting method (medium frequency range)

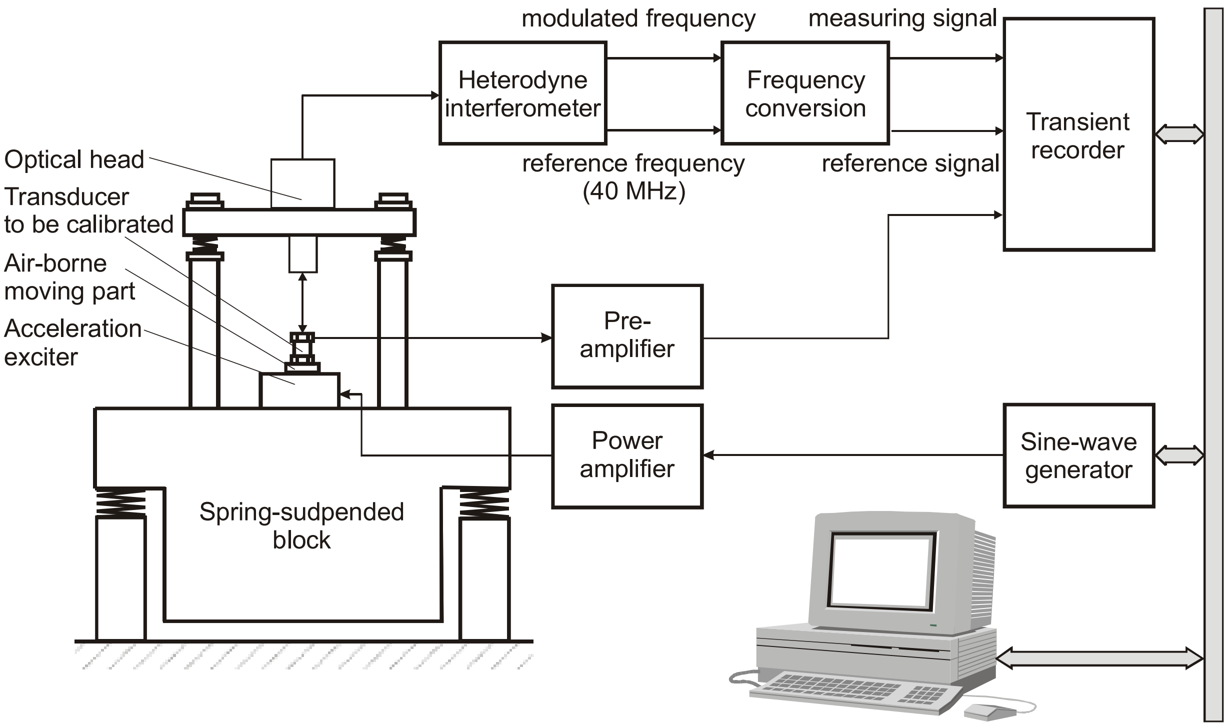

Figure 5 PTB primary vibration calibration system based on laser interferometry: sine approximation method (high frequency range)

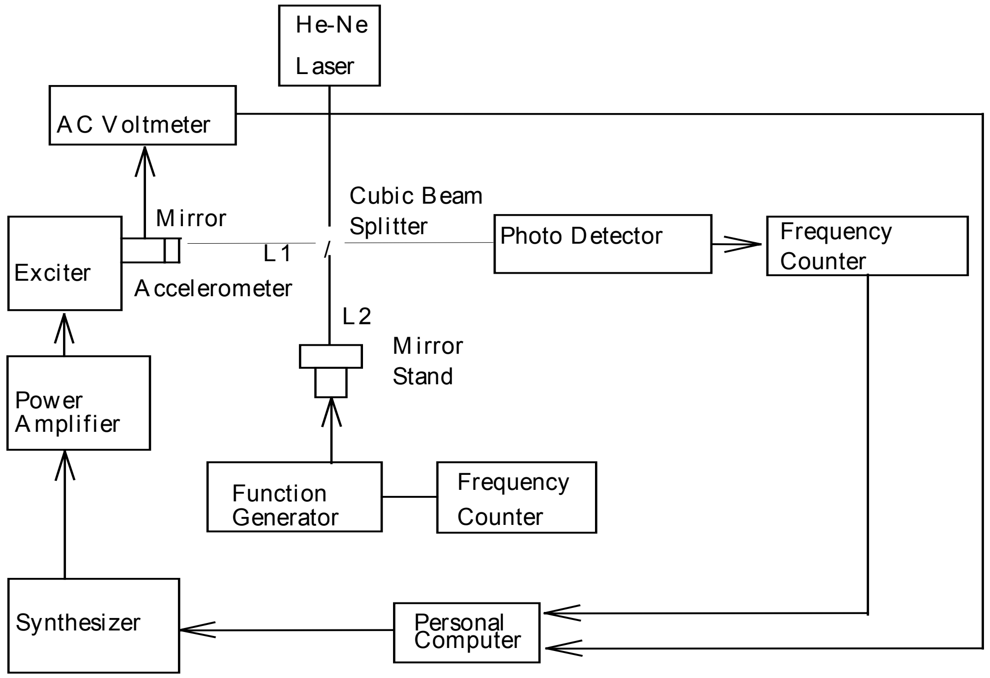

Figure 6 CMS/ITRI primary vibration calibration system：the fringe-counting method

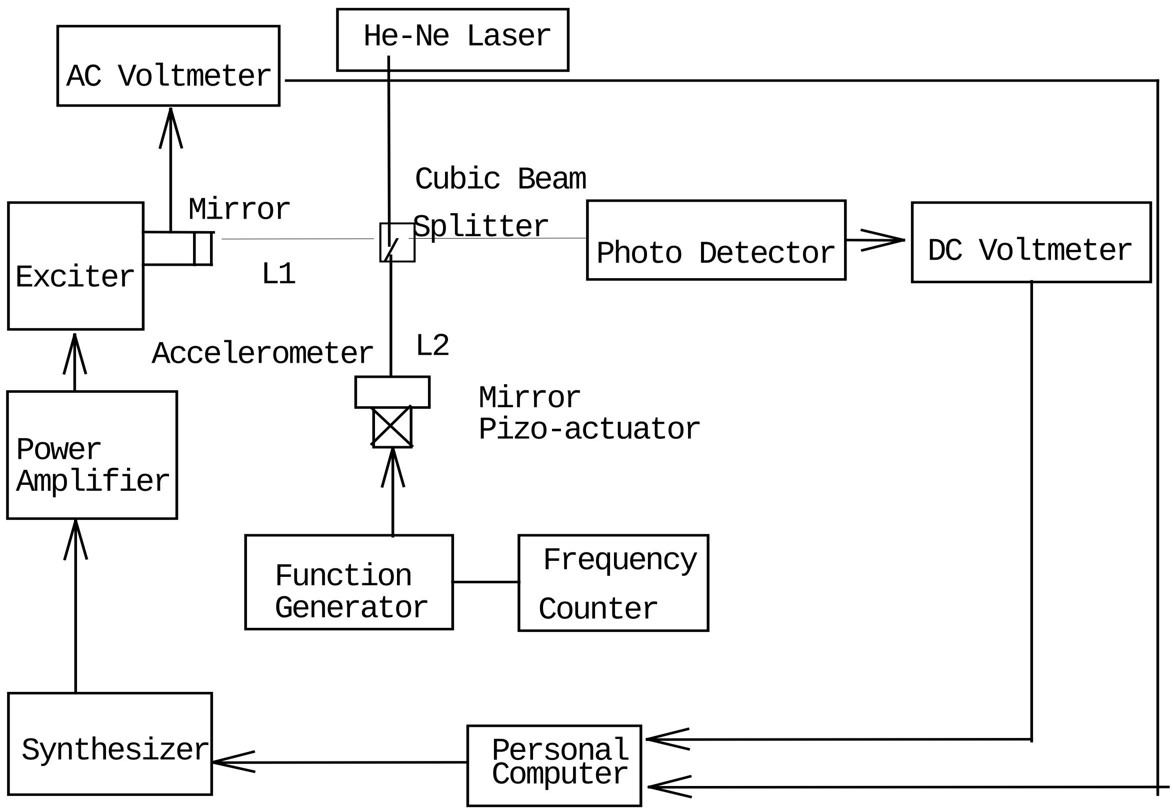

Figure 7 CMS/ITRI primary vibration calibration system：the Bessel minimum method

4. Results of measurement

The results of measurement of each laboratory are shown in the Appendix, through table A1 to table A6. For some reasons, Dr. S. Tan withdrew the results of measurement by PSB, Singapore, on June 10, 1998 and Dr. V. Mohanan withdrew the results of measurement by NPL, India, on August 26, 1998. This withdrawing information was confirmed by the APMP secretariat on August 27, 1998.

The expanded uncertainties with coverage factor *k*=2 at a 95% level of confidence of each laboratory are 0.43%~1.06% for CMS/ITRI, 0.31%~1.9% for NRLM, 0.3%~0.4% for KRISS, 0.4%~0.6% for CSIRO, 0.22%~1.84% for SIRIM and 0.1%~0.2% for PTB, respectively. The expanded uncertainties of KRISS were recomputed from 99% to 95% from the calibration report by KRISS.

The vibration sensitivities, mV/(m/s^2), of the accelerometer with a charge amplifier set by each laboratory were shown in Table A7 and the trend analysis of the vibration sensitivities was plotted in figure A1. In figure A1, an increasing trend with frequency is observed and it complies with the characteristics of the sensitivity of an accelerometer. There are two groups of results in figure A1. The first group contains the laboratories CMS/ ITRI, KRISS, CSIRO and PTB. The second group contains the laboratories NRLM and SIRIM whose results of measurement are close to the first group in the frequency range below 4 kHz, while the results above 4 kHz are down below the first group. To check the quality of the accelerometer during the circulation, the results of the initial measurement (by CMS/ITRI), the interim (by CMS/ITRI) and the final check (by PTB) are shown in figure A2. Preventing the delay of the circulation of the accelerometer, only one measurement number was performed during the interim check at each frequency. Therefore, such quick results of the interim check were not included in the following analysis. During the circulation, the accelerometer actually sustained severe scratching, but this did not apparently affect the vibration sensitivity of the accelerometer based upon the results of final check laboratory (PTB) and the analysis of the next chapter.

Since the measurement frequencies are open to the participating laboratories, each laboratory does not contain all the same measurement frequencies. In order to compare the results among the laboratories, the results with expanded uncertainty (*k*=2) by each laboratory are plotted in figures A3 to A23 respectively for frequencies 100, 160, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000 and 10000Hz. From figures A3 to A23, the following phenomena can be found:

- The overlapping of expanded uncertainty spans (*k*=2) evaluated among the laboratories were clearly observed from 100 Hz to 6000 Hz.
- Above the 6000 Hz, the expanded uncertainty spans (*k*=2) of each group overlaps one another within each group while the uncertainty spans (*k*=2) of the second group (NRLM and SIRIM) do not overlap the expanded uncertainty spans (*k*=2) of the first group (CMS/ITRI, KRISS, CSIRO, PTB). In this

preliminary examination, it shows that the results by the first group are not equivalent to the results by the second group for the frequency above 6000 Hz.

- There is a tendency that the results of the second group (NRLM and SIRIM) deviate from the results of the first group systematically and the uncertainties of the second group are abnormally high when the frequency is beyond 3000 Hz or 4000 Hz.
- A systematic error of the results by CMS/ITRI with uncertainty around 1% is also noticed below the frequency 900 Hz

5. KCRV and Degree of Equivalence

Except the kilogram artifact, the fundamental question of a key comparison is that the key comparison reference value (KCRV) is uncertain. For a purpose of Mutual Recognition Arrangement (MRA), the key comparison reference value is derived from the measurement results of the participating laboratories and is normally a close approximation to the corresponding SI value [6]. The term degree of equivalence of measurement standards is taken to mean the degree to which a standard is consistent with the key comparison reference values. Since the effective degree of freedom is more than 30 for the results of each laboratory in this comparison, the expanded uncertainty for a coverage factor k=2, corresponding a confidence level of 95%.

By considering the uncertainty of each measurement only, the reference value and its uncertainty of a key comparison are often represented by the weighted equations (1) and (2) [7]

$$Y_{\mathrm{KCRV-1}} = \sum_{i=1}^{N} (Y_{\mathrm{lab}-i} / U_{\mathrm{lab}-i}^2) \Big/ \sum_{i=1}^{N} (1/U_{\mathrm{lab}-i}^2) \ , \qquad (1)$$

$$U_{\mathrm{g1,in}}^2 = 1 \Big/ \sum_{i=1}^{N} (1/U_{\mathrm{lab}-i}^2) \ , \qquad (2)$$

where N: the number of chosen laboratory, $Y_{\mathrm{lab}\text{-}i}$: the measurement value of laboratory i, $U_{\mathrm{lab}\text{-}i}$: the expanded uncertainty (k=2) of laboratory i., $Y_{\mathrm{KCRV\text{-}1}}$: reference value, $U_{\mathrm{g1,in}}^2$: the expanded uncertainty (k=2). By considering the diversity of the measurement results of each participating laboratory, an expanded uncertainty of the reference value of equation (1) can also be represented by equation (3)

$$U_{\mathrm{g1,out}}^2 = 4\sum_{i=1}^{N} [(Y_{\mathrm{lab}-i} - Y_{\mathrm{KCRV-1}})^2 / U_{\mathrm{lab}-i}^2] \Big/ [(N-1)\sum_{i=1}^{N} (1/U_{\mathrm{lab}-i}^2)] \ . \qquad (3)$$

If $U_{\mathrm{g1,out}} \le U_{\mathrm{g1,in}}$, then the distribution of the measurement results of the participating laboratories is reasonable, otherwise the uncertainty estimation of the laboratories might be too optimistic [7].

The degree of equivalence of each national measurement standard is expressed quantitatively by two terms: its deviation from the key comparison reference value and the uncertainty of this deviation (at a 95%

level of confidence)[6]. One can treat KCRV as a virtual laboratory (sometime KCRV is treated as the data of the virtual laboratory) when computing the degree of equivalence between paired laboratories. The degree of equivalence of each measurement standard is computed as

Deviation: $D_{\text{lab}-i,\text{KCRV-1}} = (Y_{\text{lab}-i} - Y_{\text{KCRV-1}})$, (4)

As $Y_{\text{lab-}i}$ and $Y_{\text{KCRV-1}}$ are correlated, the expanded uncertainty of equation (4) can be derived as

expanded uncertainty: $U_{\text{lab}-i,\text{KCRV-1}} = (U^2_{\text{lab}-i} - U^2_{\text{g1,in}})^{1/2}$, (5)

or in percentage form

relative deviation: $D_{\text{lab}-i,\text{KCRV-1}}(\%) = 100\% * (Y_{\text{lab}-i} - Y_{\text{KCRV-1}}) / Y_{\text{KCRV-1}}$ (6)

expanded uncertainty of relative deviation:

$$U_{\text{lab}-i,\text{KCRV-1}}(\%) = 100\% * (U^2_{\text{lab}-i} - U^2_{\text{g1,in}})^{1/2} / Y_{\text{KCRV-1}}, \quad (7)$$

An E_n-number, a normalized error, between laboratory *i* and KCRV-1 is [8]

$$E_n = (Y_{\text{lab}-i} - Y_{\text{KCRV-1}}) / (U^2_{\text{lab}-i} - U^2_{\text{g1,in}})^{1/2}. \quad (8)$$

When the condition $-1 \le E_n \le 1$ exists, it indicates that the results of laboratory *i* are consistent with the results of KCRV. Those results declared with greater uncertainty may result in less value of E_n-number even when the deviation is greater.

The key comparison reference values (KCRV-1), named version 1, computed with all the measurement results by the weighted equations (1) and (2) and (3), were shown in table A8. The results of degree of equivalence and the E_n-number between KCRV-1 and other laboratories are shown in table A9 and figures A24 and A25, respectively. These results are summarized in table 3 and as follows:

CMS/ITRI : Results are within ±0.3% of the KCRV-1 at 16 of the 22 calibration points. At frequencies up to 600 Hz, results appear to be systematically low. There are also three apparently abnormal results: at 300 Hz (~0.65% low, E_n= -0.62), at 800 Hz (~0.74% high, E_n =1.31), and at 6 kHz (~0.6% low, E_n =-1.42).

NRLM : Results are within ±0.1% of the KCRV-1 at 13 of the 23 calibration points between 50 Hz and to 2 kHz. At higher frequencies (≥5 kHz), results progressively diverge from the reference value. For frequencies from 5 kHz to 10 kHz, the deviation is ~0.57% (low) to ~2.7% (low). The absolute values of E_n -number are greater than one from frequencies 7 kHz to 10 kHz.

KRISS : Results are within ±0.1% and ±0.2% of the KCRV-1 at 12 and 33 of the 41 calibration points, respectively. Results are low by ~0.3% at 20 Hz and 30 Hz, and the absolute values of E_n -number are –1.06 and –1.10 at 20 Hz and 30 Hz, respectively.

CSIRO : Results are within ±0.2% of the KCRV-1 at 18 of the 25 calibration points. Results appear to be high by ~0.3% at 30 Hz, 200 Hz, 6 kHz and 7 kHz, and by ~0.5% at 8 kHz. All the absolute values of E_n -number are less than one.

SIRIM : Results are within ±0.1% of the KCRV-1 at 13 of the 23 calibration points between 50 Hz and 1.5 kHz. At higher frequencies(▯4 kHz), the results progressively diverge from the reference values. For frequencies from 4 kHz to 10 kHz, the deviation is ~0.7% (low) to ~3.4% (low). The absolute values of E_n -number are greater than one for frequencies beyond 4 kHz.

PTB : Results are within ±0.1% and ±0.15% of the KCRV-1 at 38 and 41 of the 41 of the calibration points, respectively. The greatest difference is ~0.15% high at 3 kHz. All the absolute values of E_n -number are less than one except that E_n=1.04 at 3000 Hz.

E_n -number: There are 160 out of the 175 calibration points (91.4%) that the absolute values of E_n -number are less than one. It means that the measurement results of 91.4% are consistent with the key comparison reference values, KCRV-1. There are 15 out of 175 calibration points (8.6%) that the absolute values of E_n test are greater than one (2 points from CMS/ITRI, 5 points from NRLM, 2 points from KRISS, 5 points from SIRIM and 1 point from PTB).

$U_{g1,out}$, $U_{g1,in}$: The results and the ratios of $U_{g1,out}$ and $U_{g1,in}$ are shown in table A8 and figure A26, respectively. The values of $U_{g1,in}$ are 0.1% below 2000 Hz and 0.2% for the higher frequency. The values of $U_{g1,out}$ are less than 0.2% below 3500 Hz, and getting higher when the frequency increases beyond 4 kHz. The maximum value of $U_{g1,out}$ is 0.46% at 10 kHz. There are 16 of 41 calibration points (39%) that the results of $U_{g1,out}$ /$U_{g1,in}$ are greater than one. It implies that the uncertainty estimation of the laboratories might be too optimistic at these calibration points.

160 Hz : At the reference frequency 160 Hz, the maximum deviation is ~0.36% low and the minimum deviation is 0.006% low of the KCRV-1.

Table 3 Summary of the relative deviation between KCRV-1 and other laboratories

Abs(relative deviation)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
≤0.1%	7	13	12	8	13	38
0.1%~0.2%	4	3	21	10	2	3
0.2%~0.3%	5	1	6	4	0	0
0.3%~0.4%	2	0	2	1	1	0
0.4%~0.5%	1	0	0	1	0	0
>0.5%	3	6	0	1	7	0
Total calibration points	22	23	41	25	23	41
Relative deviation at 160 Hz	-0.36%	+0.044%	-0.026%	+0.18%	+0.024/%	-0.006%
Maximum deviation	+0.7% at 800 Hz	-2.7% at 10 kHz	-0.32% at 30 Hz	+0.51% at 8 kHz	-3.4% at 10 kHz	+0.15% at 3 kHz

number of calibration points/total calibration points

|E_n –number |≤1	
ITRI	20/22
NRLM	18/23
KRISS	39/41
CSIRO	25/25
SIRIM	18/23
PTB	40/41

In the computation of KCRV-1, all the measurement results of the participating laboratories contribute with a different weight in equations (1) and (2). Those results declared with less uncertainty would give more weight when computing the KCRV-1. After the initial computation, some outliers are found, either the absolute values of E_n -number are greater than one or the deviation is high, for example, 0.5%. One may re-compute the key comparison reference values by removing the outliers. However, if there is a theoretical prediction of the measurement results, it may also help identify the outliers of the measurement results in different way. The sensitivity response (S) of an accelerometer, at frequency f, of an unloaded ideal accelerometer with resonance frequency f_0 and damping p can be represented by a fourth-order function, shown in equation (9), and an analysis of the measurement results was studied by Clark [9] with this response equation

$$S = S_0 / \{[1-(f/f_0)^2]^2 + 4p^2(f/f_0)^2\}^{0.5} , \qquad (9)$$

where S_0 is the nominal sensitivity at 0 Hz. It was found that the data set of the NRLM and SIRIM were below the fitted sensitivity response curve in a systematic way in the frequency beyond 3 kHz or 4 kHz. Hence, from the preliminary analysis in section 4, the results of KCRV-1 and the theoretical prediction of the sensitivity response function, the following data set appeared to be mutually consistent:

CMS/ITRI: 900 Hz to 10 kHz
NRLM : 30 Hz to 4 kHz
KRISS : 10 Hz to 10 kHz
CSIRO : 30 Hz to 10 kHz
SIRIM : 30 Hz to 3 kHz
PTB : 10 Hz to 10 kHz.

To obtain different versions of the key comparison reference values, one can compute the above measurement data set (that is by removing the outliers) with a weighted method, such as equations (1) and (2), or with an equal weight. The key comparison reference value ($Y_{\text{KCRV-1}}$, $U^2_{\text{g1,in}}$) that includes all the measurement results of all participating laboratories computed by equations (1) and (2) is named as version 1. The key comparison reference value ($Y_{\text{KCRV-2}}$, $U^2_{\text{g2,in}}$) computed by equations (1) and (2) but without outliers is called as version 2. The key comparison reference value ($Y_{\text{KCRV-3}}$, U_3) averaged with equal weight but without outliers is titled as version 3, and it is computed as follows

$$Y_{\text{KCRV}-3} = \frac{1}{N}\sum_{i=1}^{N} Y_{\text{lab}-i} \qquad (10)$$

$$U_3 = \frac{1}{N}\left[\sum_{i=1}^{N} U^2_{\text{lab}-i}\right]^{1/2} \qquad (11)$$

or in percentage form

$$U_3(\%) = 100\% * \frac{1}{N}\left[\sum_{i=1}^{N} U_{\text{lab}-i}^2\right]^{1/2} / Y_{\text{KCRV}-3}\,. \qquad (12)$$

The key comparison reference values of version 2 and version 3 are shown in table A8. A comparison between key comparison reference values of different versions is studied and shown in table A10 and Figures A26, A27 and A28, respectively.

- Comparison of reference values of different versions, as shown in figure A27
  - The relative deviation of reference values between version 1 and version 2 is within ±0.02% below 3500 Hz, and the maximum deviation is ~0.12% low at 4000 Hz.
  - The relative deviation of reference values between version 1 and version 3 is within ±0.1% for 35 out of 41 calibration points, and the greatest difference is ~0.18% low at 4 kHz and 7 kHz.
  - The relative deviation of reference values between version 2 and version 3 is within ±0.1% for 36 out of 41 calibration points, and the greatest difference is ~0.14% low at 20 Hz.
  - Among these three different comparisons of these different versions of reference values, there are 111 out of 123 calibration points (90%) that the relative deviation is within ±0.1%, and except two points, the relative deviation is within ±0.15% for all other 121 points (98%). A summary of the comparison of reference values of different versions is shown in table 4.

Table 4 Summary of the comparison of reference values of different versions

number of calibration points

Abs(relative deviation)	$(Y_{\text{KCRV-1}} - Y_{\text{KCRV-2}})/Y_{\text{KCRV-2}}$	$(Y_{\text{KCRV-1}} - Y_{\text{KCRV-3}})/Y_{\text{KCRV-3}}$	$(Y_{\text{KCRV-2}} - Y_{\text{KCRV-3}})/Y_{\text{KCRV-3}}$
≤0.05%	36	23	25
0.05%~0.1%	4	11	11
0.1%~0.15%	1	5	5
>0.15%	0	2	0
worst deviation	-0.14% at 4 kHz	-0.18% at 4 kHz and 7 kHz	0.14% at 20 Hz

Total calibration points is 41.

- Comparison of expanded uncertainties of different versions
  - As shown in figure A26, the values of $U_{\text{g1,out}}/U_{\text{g2,out}}$ are greater than or equal to one for the 38 out of 41 calibration points. Because of removing the outliers which have greater value of expanded uncertainty, the values of $U_{\text{g1,out}}/U_{\text{g2,out}}$ are getting higher when the frequency increases beyond

3500 Hz. The results of $U_{g1,in}/U_{g2,in}$ are between 0.9 to 1.0, and there are 37 out of 41 calibration points that the results of $U_{g1,in}/U_{g2,in}$ are equal to one.

- As shown in figure A28, all the values of $U_{g1,in}/U_3$ and $U_{g2,in}/U_3$ are less than one, from 0.2 to 0.8 . The results of $U_{g1,out}/U_3$ are from 0.12 to 1.9. There are 7 out of the 41 calibration points that the values of $U_{g1,out}/U_3$ are greater than one, and at these calibration points the values of $U_{g1,out}/U_{g1,in}$ are greater one too. The results of $U_{g2,out}/U_3$ are from 0.12 to 1.3. There are 2 out of the 41 calibration points that the results of $U_{g2,out}/U_3$ are greater than one, and at these calibration points the results of $U_{g2,out}/U_{g2,in}$ are greater one too.
- There are 10 out of 41 calibration points (25%) that the results of $U_{g2,out}/U_{g2,in}$ are greater than one. It implies that the uncertainty estimation of the laboratories might be too optimistic at these calibration points
- A summary of the comparison of expanded uncertainties of different versions is shown in table 5.

Table 5 Summary of the comparison of expanded uncertainties of different versions

number of calibration points

Ratio range	$U_{g1,out}/U_3$	$U_{g2,out}/U_3$	$U_{g1,in}/U_3$	$U_{g2,in}/U_3$	Ratio range	$U_{g1,out}/U_{g2,out}$	$U_{g1,in}/U_{g2,in}$
≤0.5	22	26	12	12	0.8-0.9	2	0
0.5-1.0	12	13	29	29	0.9-1.0	29	41
1.0-1.5	6	2	0	0	1.0-2.0	6	0
1.5-2.0	1	0	0	0	2.0-3.0	1	0
>2.0	0	0	0	0	3.0-4.0	1	0
					4.0-5.0	0	0
					5.0-6.0	0	0
					6.0-7.0	2	0

Total calibration points is 41.

The degree of equivalence between KCRV-2 and other laboratories is computed as relative deviation: $D_{\text{lab}-i,\text{KCRV-2}}(\%) = 100\% * (Y_{\text{lab}-i} - Y_{\text{KCRV-2}}) / Y_{\text{KCRV-2}}$ (13)

If $Y_{\text{lab-}i}$ is chosen to compute $Y_{\text{KCRV-2}}$, then the expanded uncertainty of equation (13) is

$$U_{\text{lab}-i,\text{KCRV-2}}(\%) = 100\% * (U_{\text{lab}-i}^2 - U_{\text{g2,in}}^2)^{1/2} / Y_{\text{KCRV-2}}, \tag{14}$$

If $Y_{\text{lab-}i}$ is not chosen to compute $Y_{\text{KCRV-2}}$, then the expanded uncertainty of equation (13) is

$$U_{\text{lab}-i,\text{KCRV-2}}(\%) = 100\% * (U_{\text{lab}-i}^2 + U_{\text{g2,in}}^2)^{1/2} / Y_{\text{KCRV-2}}, \tag{15}$$

An E_n-number between laboratory i and KCRV-2 for equations (13) and (14) is [8]

$$E_n = (Y_{\text{lab}-i} - Y_{\text{KCRV-2}}) / (U_{\text{lab}-i}^2 - U_{\text{g2,in}}^2)^{1/2} \tag{16}$$

And an E_n-number between laboratory i and KCRV-2 for equations (13) and (15) is

$$E_n = (Y_{\text{lab}-i} - Y_{\text{KCRV-2}}) / (U_{\text{lab-i}}^2 + U_{\text{g2,in}}^2)^{1/2} \tag{17}$$

The degree of equivalence between KCRV-3 and other laboratories is computed as

relative deviation: $D_{\text{lab}-i,\text{KCRV-3}}(\%) = 100\% * (Y_{\text{lab}-i} - Y_{\text{KCRV-3}}) / Y_{\text{KCRV-3}}$ (18)

If $Y_{\text{lab-}i}$ is chosen to compute $Y_{\text{KCRV-3}}$, then the expanded uncertainty of equation (18) is

$$U_{\text{lab}-i,\text{KCRV-3}}(\%) = 100\% * (\frac{N-2}{N} U_{\text{lab}-i}^2 + U_3^2)^{1/2} / Y_{\text{KCRV-3}}, \quad (19)$$

If $Y_{\text{lab-}i}$ is not chosen to compute $Y_{\text{KCRV-3}}$, then the expanded uncertainty of equation (18) is

$$U_{\text{lab}-i,\text{KCRV-3}}(\%) = 100\% * (U_{\text{lab}-i}^2 + U_3^2)^{1/2} / Y_{\text{KCRV-3}}, \quad (20)$$

An E_{n}-number between laboratory *i* and KCRV-3 for equations (18) and (19) is

$$E_n = (Y_{\text{lab}-i} - Y_{\text{KCRV-3}}) / (\frac{N-2}{N} U_{\text{lab}-i}^2 + U_3^2)^{1/2} \quad (21)$$

And an E_{n}-number between laboratory *i* and KCRV-3 for equations (18) and (20) is

$$E_n = (Y_{\text{lab}-i} - Y_{\text{KCRV-3}}) / (U_{\text{lab}-i}^2 + U_3^2)^{1/2} \quad (22)$$

The results of degree of equivalence and the E_{n} -number between KCRV-2 and other laboratories are shown in table A11 and figures A29 and A30, respectively. The results of degree of equivalence and the E_{n} -number between KCRV-3 and other laboratories are shown in table A12 and figures A31 and A32, respectively. Since the reference values are extremely close for the three different versions, the relative deviations between the reference values and the results of the laboratories are also quite similar for the three different versions. All though the expanded uncertainties are different for the different versions, the values of E_{n} -number are greater than one almost at the same calibration frequencies. Hence, the discussions of the degree of equivalence of versions 2 and 3 would be similar to that of version 1. Tables 6 and 7 summarize the results of the degree of equivalence and E_{n} –number of the versions 2 and 3, respectively.

- Degree of equivalence between pairs of national measurement standards

The degree of equivalence between pairs of national measurement standards is expressed by the difference of their deviations from the reference value and the uncertainty of this difference (at a 95% level of confidence) [6]. The degree of equivalence between paired laboratories *i* and *j* is computed as follows :

Deviation: $D_{\text{lab}-i,\text{lab}-j} = (Y_{\text{lab}-i} - Y_{\text{KCRV}}) - (Y_{\text{lab}-j} - Y_{\text{KCRV}}) = Y_{\text{lab}-i} - Y_{\text{lab}-j}$, (23)

expanded uncertainty: $U_{\text{lab}-i,\text{lab}-j} = (U_{\text{lab}-i}^2 + U_{\text{lab}-j}^2)^{1/2}$, (24)

or in percentage form

relative deviation: $D_{\text{lab}-i,\text{lab}-j}(\%) = 100\% * (Y_{\text{lab}-i} - Y_{\text{lab}-j}) / Y_{\text{KCRV}}$ (25)

expanded uncertainty of relative deviation:

$$U_{\text{lab}-i,\text{lab}-j}(\%) = 100\% * (U_{\text{lab}-i}^2 + U_{\text{lab}-j}^2)^{1/2} / Y_{\text{KCRV}}. \quad (26)$$

An E_{n}-number between laboratory *i* and laboratory *j* is

$$E_{\mathrm{n}} = (Y_{\mathrm{lab}-i} - Y_{\mathrm{lab}-j}) / (U_{\mathrm{lab}-i}^{2} + U_{\mathrm{lab}-j}^{2})^{1/2} . \tag{27}$$

Table 6 Summary of the relative deviation between KCRV-2 and other laboratories

number of calibration points/total calibration points

Abs(Relative deviation)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
≤0.1%	7	13	15	9	13	40
0.1%~0.2%	4	3	16	11	2	1
0.2%~0.3%	4	0	8	2	0	0
0.3%~0.4%	3	0	2	2	1	0
0.4%~0.5%	1	1	0	1	0	0
>0.5%	3	6	0	0	7	0
Total calibration points	22	23	41	25	23	41
Relative deviation at 160 Hz	-0.36%	+0.042%	-0.028%	+0.18%	+0.022%	-0.008%
Worst Deviation	+0.72% at 800 Hz	-2.8% at 10 kHz	-0.32% at 30 Hz	+0.47% at 8 kHz	-3.6% at 10 kHz	+0.15% at 3 kHz

$\lvert E_n$ –number$\rvert \le 1$	
ITRI	20/22
NRLM	18/23
KRISS	39/41
CSIRO	25/25
SIRIM	18/23
PTB	40/41

Table 7 Summary of the relative deviation between KCRV-3 and other laboratories

number of calibration points/total calibration points

Abs(Relative deviation)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
≤0.1%	5	13	19	12	12	29
0.1%~0.2%	5	3	17	8	3	11
0.2%~0.3%	4	0	4	3	1	1
0.3%~0.4%	3	0	1	1	0	0
0.4%~0.5%	1		0	1	0	0
>0.5%	3	6	0	0	7	0
Total calibration points	22	23	41	25	23	41
Relative deviation at 160 Hz	-0.40%	+0.002%	-0.068%	+0.14%	+0.018%	-0.048%
Worst Deviation	+0.75% at 800 Hz	-2.8% at 10 kHz	-0.31% at 30 Hz	+0.48% at 8 kHz	-3.6% at 10 kHz	+0.26% at 3 kHz

$\lvert E_n$ –number$\rvert \le 1$	
ITRI	20/22
NRLM	18/23
KRISS	39/41
CSIRO	25/25
SIRIM	18/23
PTB	40/41

Degree of equivalence between paired laboratories *i* and *j* is shown in tables A13 to A18 and figures A33 to A38. The key comparison reference values of version 3, KCRV-3, are applied in the computation of the degree of equivalence between paired laboratories. In general, except the results by ITRI at frequencies 800 Hz and 6 kHz, the absolute values of E_n -number in the first group (ITRI, KRISS, CSIRO, and PTB) are less than one. The absolute values of E_n -number in the second group (NRLM, SIRIM) are less than one for all frequencies. However, most of the absolute values of E_n -number between the first group and the second group are greater one for frequencies beyond 4000 Hz.

6. Conclusions

Three different versions are proposed to compute the key comparison reference values in this regional comparison. Version 1 includes all the measurement results of the laboratories with the weighting computation. Version 2 without the outliers computes the key comparison reference values with the weighting equations. Version 3 without the outliers computes the key comparison reference values with an equal weight of each laboratory. The degree of equivalence of the laboratories are computed and plotted for these three versions. The degree of equivalence between paired laboratories are computed and plotted with version 3.

There are 90% (111/123) and 98% (121/123) of the calibration points that the relative deviations between the reference values of different versions are within ±0.1% and ±0.15%, respectively. It indicates that the choice of the version has little effect on the computation of reference values. There are 90.3%, 90.9% and 90.9% of the calibration points that the relative deviations between the laboratories and reference values are within ±0.5% for versions 1, 2 and 3, respectively.

The worst results of the relative deviations between laboratories and KCRV are 3.4% (at 10 kHz), 3.6% (at 10 kHz) and 3.6% (at 10 kHz) for version 1, 2 and 3, respectively. At the reference frequency 160 Hz, the best and the worst results of the relative deviations between the laboratories and KCRV are 0.006% and 0.36% for version 1, 0.008% and 0.36% for version 2, and 0.002% and 0.40% for version 3, respectively. There are 80% of version 1 and 95% of version 2 of the calibration points that the expanded uncertainties of reference values are less than that of version 3, respectively. It implies that the estimation of key comparison reference values of version 3 is conservative among these three different versions.

A summary of relative deviation between laboratories and KCRV of different versions is shown in tables 8 and 9, respectively.

Table 8 Summary of relative deviation between laboratories and KCRV in different versions (I)

Number of calibration points

	ITRI			NRLM			KRISS		
Abs(relative Deviation)	KCRV-1	KCRV-2	KCRV-3	KCRV-1	KCRV-2	KCRV-3	KCRV-1	KCRV-2	KCRV-3
≤0.1%	7	7	4	13	13	13	12	15	18
0.1%~0.2%	4	4	6	3	3	3	21	16	18
0.2%~0.3%	5	4	4	1	0	0	6	8	4
0.3%~0.4%	2	3	3	0	0	1	2	2	1
0.4%~0.5%	1	1	1	0	1	0	0	0	0
>0.5%	3	3	3	6	6	6	0	0	0
$\|E_n$-number$\|\leq 1$	20	20	20	18	18	18	39	39	39
Total calibration points	22			23			41		
Relative deviation at 160 Hz	-0.36%	-0.36%	-0.40%	+0.044%	+0.042%	+0.002%	-0.026%	-0.028%	-0.068%
worst Deviation	+0.7% at 800 Hz	+0.72% at 800 Hz	+0.75% at 800 Hz	-2.7% at 10 kHz	-2.8% at 10 kHz	-2.8% at 10 kHz	-0.32% at 30 Hz	-0.32% at 30 Hz	-0.31% at 30 Hz

Table 9 Summary of relative deviation between laboratories and KCRV in different versions (II)

Number of calibration points

	CSIRO			SIRIM			PTB		
Abs(relative Deviation)	KCRV-1	KCRV-2	KCRV-3	KCRV-1	KCRV-2	KCRV-3	KCRV-1	KCRV-2	KCRV-3
≤0.1%	8	9	11	13	13	12	38	40	29
0.1%~0.2%	10	11	9	2	2	3	3	1	11
0.2%~0.3%	4	2	3	0	0	1	0	0	1
0.3%~0.4%	1	2	1	1	1	0	0	0	0
0.4%~0.5%	1	1	1	0	0	0	0	0	0
>0.5%	1	0	0	7	7	7	0	0	0
En-number≤1	25	25	25	18	18	18	40	40	40
Total calibration points	25			23			41		
Relative Deviation at 160 Hz	+0.18%	+0.18%	+0.14%	+0.024/%	+0.022%	+0.018%	-0.006%	-0.008%	-0.048%
worst Deviation	+0.51% at 8 kHz	-0.32% at 30 Hz	+0.48% at 8 kHz	-3.4% at 10 kHz	-3.6% at 10 kHz	-3.6% at 10 kHz	+0.15% at 3 kHz	+0.15% at 3 kHz	+0.26% at 3 kHz

7. Acknowledgement

The authors would like to sincerely express their gratitude to the following persons since without their participation and contribution, this international comparison program can not be done: Dr. T. C. Yang from CMS/ITRI, the original organizer of this comparison, Mr. Kenji Siraishi and Dr. Tomizo Kurosawa from NRLM, Mr. Doo-Hee Lee from KRISS, Mr. Norman Clark from CSIRO, Mr. Yik-Hwee Ho, Dr. Steve Tan and Mr. Aik Peng Tan from PSB, Dr. V. Mohanan from NPL, Mr. Wan Aziz Wan Salleh from SIRIM, Dr. Alfred Link from PTB and Dr. Rohana Ediriweera, the APMP secretariat. Especial thanks are given to Mr. Clark for his truly helpful comments about the measurement results and to Dr. Link for his genuine comments about the computation of uncertainty of the difference between paired laboratories. The project leader would like to take this opportunity to thank his colleagues Dr. B.-T. Lee for measuring the data and preparing the report, Mr. Y.-J. Huang for measuring the data, and Ms. S.-H. Chuang for preparing some of the plots. At last but the most, the project leader would like to express his genuine gratitude to Dr. Hans-Jürgen von Martens, the co-author, for accepting PTB as a pear review and the final check laboratory, and his comments, wide and deep knowledge in preparing this final report.

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Appendix

Results of measurement

and

degrees of equivalence

List of Tables

*Dr. S. Tan withdrew the results of measurement by PSB, Singapore, on June 10, 1998

*Dr. V. Mohanan withdrew the results of measurement by NPL, India, on August 26, 1998
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List of Figures

Table A 1 Results of measurement by CMS/ITRI, Taiwan

Frequency (Hz)	Effective Acceleration (m/s^{-2})	Sensitivity $mV/(m/s^{-2})$	Standard Deviation*	No of Measurement	*k*	Expanded Uncertainty (%)
50	50	0.9928	0.0001	40	2	1.06
100	50	0.9928	0.0001	40	2	1.06
160	50	0.9927	0.0001	40	2	1.06
200	50	0.9947	0.0001	40	2	1.06
300	50	0.9905	0.0003	40	2	1.06
400	50	0.9929	0.0001	40	2	1.06
500	50	0.9964	0.002124	40	2	1.06
600	50	0.9991	0.003622	40	2	1.06
700	11.49	0.9997	0.001656	40	2	0.470
800	15.0	1.0051	0.003177	40	2	0.524
900	18.98	0.9978	0.001402	40	2	0.462
1000	23.44	0.9983	0.000578	40	2	0.432
1500	10.76	1.0019	0.004672	40	2	0.578
2000	19.12	1.0013	0.001491	40	2	0.464
3000	43.03	1.0049	0.002631	40	2	0.504
4000	76.49	1.0126	0.000537	40	2	0.430
5000	119.52	1.0169	0.000897	40	2	0.448
6000	172.11	1.0194	0.001736	40	2	0.472
7000	234.26	1.0403	0.005889	40	2	0.614
8000	305.91	1.0477	0.007710	40	2	0.676
9000	387.18	1.0649	0.002651	40	2	0.50
10000	478.01	1.0801	0.003851	40	2	0.538

*It is the single value of a series of the N repeated measurements.

Table A 2 Results of measurement by NRLM, Japan

Frequency Hz	Effective Acceleration m/s^2 (rms)	Zero Point No.	Approximate Value of Maximum Displacement Amplitude µm	Relative Standard Deviation* %	Number of data	Sensitivity $mV/(m/s^2)$	Expanded Uncertainty % coverage factor *k*=2
30	7-21		835	0.12	11	0.9963	0.31
50	11-25		358	0.28	10	0.9964	0.61
100	11-56		199	0.11	11	0.9965	0.32
160	18-77		107	0.08	11	0.9967	0.31
200	24-81		72.7	0.22	11	0.9969	0.54
300	16,24	60	9.53	0.32	7	0.9973	0.67
400	11,21,28,43	60	9.53	0.10	9	0.9976	0.28
500	17,22,39,44	40	6.37	0.14	8	0.9977	0.35
600	16,24,32,48	30	4.79	0.12	9	0.9981	0.31
700	11,22,33,44	20	3.20	0.09	9	0.9983	0.28
800	15,20,29,43, 57	20	3.20	0.15	9	0.9985	0.37
900	19,37	10	1.62	0.16	9	0.9988	0.40
1000	5,10,14,19,23 45	10	1.62	0.23	15	0.9990	0.52
1500	12,22,32,42	4	0.671	0.07	8	0.9999	0.38
2000	22,39	2	0.353	0.06	18	1.0008	0.59
3000	48	1	0.193	0.28	9	1.0030	1.2
4000	86,158	2	0.353	0.28	10	1.0072	0.81
5000	85,194	2	0.272	0.11	7	1.0130	0.53
6000	122	1	0.121	0.40	9	1.0176	1.3
7000	166	1	0.121	0.17	7	1.0232	1.1
8000	216	1	0.121	0.78	9	1.0298	1.9
9000	274	1	0.121	0.48	8	1.0380	1.4
10000	338	1	0.121	0.42	10	1.0511	1.3

*It is the single value of a series of the N repeated measurements.

Table A 3 Results of measurement by KRISS, Korea

Frequency Hz	Applied acceleration for calibration , m/s^2,(rms)	Sensitivity $mV/m/s^2$	Estimated Uncertainty At CL_{95},%
10	5.0 10.0	0.990 0.995	0.4
20	10.0 20.0	0.992 0.992	0.3
30	30.0	0.992	0.3
40	50.0	0.994	0.3
50	50.0	0.994	0.3
60	50.0	0.995	0.3
70	50.0	0.995	0.3
80	50.0	0.995	0.3
90	50.0	0.995	0.3
100	100.0	0.995	0.3
160	100.0	0.996	0.3
200	100.0	0.995	0.3
300	100.0	0.995	0.4
315	100.0	0.995	0.4
400	100.0	0.997	0.4
500	100.0 150.0	0.997 0.996	0.4
600	200.0	0.996	0.4
630	200.0 300.0	0.997 0.996	0.4
700	300.0	0.996	0.4
800	10.0 300.0	0.997 0.997	0.4
900	10.0	0.996	0.3
1000	10.0	0.997	0.4
1250	10.0 20.0	0.997 0.997	0.4
1500	10.0 20.0	0.998 0.997	0.4
2000	20.0 50.0	1.000 0.999	0.4
2500	50.0	1.000	0.4
3000	50.0	1.002	0.4
3500	50.0	1.009	0.4
4000	50.0	1.012	0.4
4500	100.0	1.014	0.4
5000	100.0	1.020	0.4
5500	100.0	1.024	0.4
6000	100.0	1.027	0.4
6500	200.0	1.032	0.4
7000	200.0	1.037	0.4
7500	200.0	1.043	0.4
8000	200.0	1.049	0.4
8500	200.0	1.058	0.4
9000	200.0	1.065	0.4
9500	200.0	1.070	0.4
10000	200.	1.081	0.4

Table A 4 Results of measurement by CSIRO, Australia

Frequency Hz	Nominal Acceleration m/s^2	Sensitivity $mV/(m/s^2)$	S.D.*	n	U_b % *	*K* *	U % *
30	40	0.998	0.001	36	.2	2	.4
40	50	0.996	0.0002	36	.2	2	.4
60	50	0.997	0.0002	36	.3	2	.6
80	50	0.997	0.0002	36	.3	2	.6
100	100	0.997	0.0008	36	.3	2	.6
160	100	0.998	0.0006	36	.3	2	.6
200	100	1.000	0.01	100	.3	2	.6
300	100	0.999	0.0006	54	.3	2	.6
400	100	0.999	0.0006	100	.3	2	.6
500	100	0.999	0.0045	72	.3	2	.6
600	100	0.998	0.0018	72	.3	2	.6
700	100	1.000	0.0045	36	.3	2	.6
800	200	0.997	0.0005	100	.2	2	.5
900	200	0.997	0.0005	100	.2	2	.5
1.0k	200	0.999	0.0006	100	.2	2	.5
1.5k	200	1.000	0.0005	72	.2	2	.5
2.0k	500	1.001	0.0007	72	.2	2	.5
3.0k	70	1.004	0.0008	36	0.3	2	0.6
4.0k	120	1.012	0.0007	36	0.3	2	0.6
5.0k	190	1.019	0.0005	18	0.3	2	0.6
6.0k	270	1.029	0.0006	18	0.3	2	0.6
7.0k	370	1.042	0.0007	36	0.3	2	0.6
8.0k	490	1.056	0.001	36	0.3	2	0.6
9.0k	620	1.066	0.001	36	0.3	2	0.6
10.0k	760	1.083	0.001	36	0.3	2	0.6

*It is the single value of a series of the N repeated measurements.

Table A 5 Results of measurement by SIRIM, Malaysia

Frequency Hz	Effective acceleration (approxi-mate value) m/s^2(rms)	Maximum number of Zero point	Approximate value of Maximum Displacement Amplitude µm	Relative Standard Deviation* %	Number of data	Sensitivity $mV/(m/s^2)$	Expanded Uncertainty %, coverage factor k=2
30	7~27		1090	0.08	21	0.9934	0.26
48	37~50		784	0.12	11	0.9954	0.31
50	30~81		1150	0.92	16	0.9954	1.84
53	24~52		659	0.09	11	0.9955	0.28
100	25~92		330	0.11	16	0.9961	0.30
160	34~137		192	0.10	21	0.9965	0.30
200	36~147		132	0.17	21	0.9969	0.41
300	24	60	9.53	0.10	26	0.9970	0.28
400	36, 43	60	9.53	0.26	26	0.9970	0.55
500	44, 50, 55, 67	60	9.53	0.10	25	0.9974	0.29
600	48,56, 59, 64,80,96	60	9.53	0.06	26	0.9974	0.24
700	55,65	30	4.79	0.04	26	0.9976	0.22
800	57,85	30	4.79	0.08	26	0.9978	0.25
900	51,55,72, 108	30	4.79	0.09	26	0.9979	0.28
1000	45,67,89	20	3.20	0.11	29	0.9981	0.30
1500	52,62,102, 152	15	2.41	0.05	25	0.9987	0.23
2000	57,75,93, 128,181	10	1.62	0.06	28	0.9993	0.26
3000	48,89,129, 169,208	5	0.829	0.15	29	1.001	0.43
4000	86,158,229, 441	6	0.988	0.13	28	1.003	0.38
5000	85	1	0.121	0.28	16	1.008	1.2
6000	122	1	0.121	0.39	27	1.015	1.3
7000	166	1	0.121	0.31	28	1.020	1.2
8000	216	1	0.121	0.60	26	1.027	1.6
9000	274	1	0.121	0.71	24	1.037	1.8
10000	338	1	0.121	0.64	28	1.043	1.6

*It is the single value of a series of the repeated measurement.

Table A 6 Results of measurement by PTB, Germany

Frequency Hz	Amplitude of Acceleration at m/s^2	Magnitude of Sensitivity S_{ua} $mV/(m/s^2)$	Expanded uncertainty (k=2) %
10	10	0.9957	0.1
20	10	0.9954	0.1
30	10	0.9955	0.1
40	10	0.9958	0.1
50	10	0.9955	0.1
60	20	0.9955	0.1
70	20	0.9956	0.1
80	20	0.9959	0.1
90	20	0.9962	0.1
100	20	0.9966	0.1
160	20	0.9962	0.1
200	20	0.9965	0.1
300	50	0.9971	0.1
315	50	0.9971	0.1
400	50	0.9972	0.1
500	50	0.9978	0.1
600	50	0.9987	0.1
630	70	0.9984	0.1
700	70	0.9988	0.1
800	70	0.9981	0.1
900	70	0.9989	0.1
1000	70	0.9987	0.1
1250	70	0.9993	0.1
1500	80	0.9998	0.1
2000	80	1.0014	0.1
2500	80	1.0024	0.2
3000	80	1.0060	0.2
3500	80	1.0086	0.2
4000	80	1.0111	0.2
4500	80	1.0150	0.2
5000	80	1.0200	0.2
5500	80	1.0227	0.2
6000	80	1.0270	0.2
6500	80	1.0340	0.2
7000	80	1.0376	0.2
7500	80	1.0456	0.2
8000	80	1.0514	0.2
8500	80	1.0600	0.2
9000	80	1.0646	0.2
9500	80	1.0720	0.2
10000	80	1.0810	0.2

Table A 7 Vibration sensitivity of the accelerometer with a charge amplifier set and Data proposed for computing the key comparison reference values (KCRV) of different versions

KCRV-1: averaged with all data, weighted
KCRV-2: averaged without the outliers (the ***italic*** and ***boldfaced*** data), weighted
KCRV-3: averaged without the outliers (the ***italic*** and ***boldfaced*** data), equal weight

Freq	Sensitivity, mV/(m/s^2)						Expanded Uncertainty, k=2, (%)					
(Hz)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
10			0.995			0.9957			0.4			0.1
20			0.992			0.9954			0.3			0.1
30		0.9963	0.992	0.998	0.9934	0.9955		0.31	0.3	0.4	0.26	0.1
40			0.994	0.996		0.9958			0.3	0.4		0.1
50	***0.9928***	0.9964	0.994		0.9954	0.9955	***1.06***	0.61	0.3		1.84	0.1
60			0.995	0.997		0.9955			0.3	0.6		0.1
70			0.995			0.9956			0.3			0.1
80			0.995	0.997		0.9959			0.3	0.6		0.1
90			0.995			0.9962			0.3			0.1
100	***0.9928***	0.9965	0.995	0.997	0.9961	0.9966	***1.06***	0.32	0.3	0.6	0.3	0.1
160	***0.9927***	0.9967	0.996	0.998	0.9965	0.9962	***1.06***	0.31	0.3	0.6	0.3	0.1
200	***0.9947***	0.9969	0.995	1.000	0.9969	0.9965	***1.06***	0.54	0.3	0.6	0.41	0.1
300	***0.9905***	0.9973	0.995	0.999	0.997	0.9971	***1.06***	0.67	0.4	0.6	0.28	0.1
315			0.995			0.9971			0.4			0.1
400	***0.9929***	0.9976	0.997	0.999	0.997	0.9972	***1.06***	0.28	0.4	0.6	0.55	0.1
500	***0.9964***	0.9977	0.997	0.999	0.9974	0.9978	***1.06***	0.35	0.4	0.6	0.29	0.1
600	***0.9991***	0.9981	0.996	0.998	0.9974	0.9987	***1.06***	0.31	0.4	0.6	0.24	0.1
630			0.996			0.9984			0.4			0.1
700	***0.9997***	0.9983	0.996	1.000	0.9976	0.9988	***0.47***	0.28	0.4	0.6	0.22	0.1
800	***1.0051***	0.9985	0.997	0.997	0.9978	0.9981	***0.524***	0.37	0.4	0.5	0.25	0.1
900	0.9978	0.9988	0.996	0.997	0.9979	0.9989	0.46	0.4	0.3	0.5	0.28	0.1
1000	0.9983	0.999	0.997	0.999	0.9981	0.9987	0.43	0.52	0.4	0.5	0.3	0.1
1250			0.997			0.9993			0.4			0.1
1500	1.0019	0.9999	0.998	1	0.9987	0.9998	0.58	0.38	0.4	0.5	0.23	0.1
2000	1.0013	1.0008	1.000	1.001	0.9993	1.0014	0.46	0.59	0.4	0.5	0.26	0.1
2500			1.000			1.0024			0.4			0.2
3000	1.0049	1.003	1.002	1.004	1.001	1.0060	0.50	1.2	0.4	0.6	0.43	0.2
3500			1.009			1.0086			0.4			0.2
4000	1.0126	***1.0072***	1.012	1.012	***1.003***	1.0111	0.43	***0.81***	0.4	0.6	***0.4***	0.2
4500			1.014			1.0150			0.4			0.2
5000	1.0169	***1.0130***	1.02	1.019	***1.008***	1.0200	0.45	***0.53***	0.4	0.6	***1.2***	0.2
5500			1.024			1.0227			0.4			0.2
6000	1.0194	***1.0176***	1.027	1.029	***1.015***	1.0270	0.47	***1.3***	0.4	0.6	***1.3***	0.2
6500			1.032			1.0340			0.4			0.2
7000	1.0403	***1.0232***	1.037	1.042	***1.020***	1.0376	0.61	***1.1***	0.4	0.6	***1.2***	0.2
7500			1.043			1.0456			0.4			0.2
8000	1.0477	***1.0298***	1.049	1.056	***1.027***	1.0514	0.68	***1.9***	0.4	0.6	***1.6***	0.2
8500			1.058			1.0600			0.4			0.2
9000	1.0649	***1.0380***	1.065	1.066	***1.037***	1.0646	0.50	***1.4***	0.4	0.6	***1.8***	0.2
9500			1.07			1.0720			0.4			0.2
10000	1.0801	***1.0511***	1.081	1.083	***1.043***	1.0810	0.54	***1.3***	0.4	0.6	***1.6***	0.2

Table A 8 Key comparison reference values of different versions

Y_{KCRV-1}, $U_{g1,out}$, $U_{g1,in}$: averaged with all data, weighted
Y_{KCRV-2}, $U_{g2,out}$, $U_{g2,in}$: averaged without the outliers, weighted
Y_{KCRV-3}, U_3: averaged without the outliers, equal weight

Freq (Hz)	KCRV-1				KCRV-2				KCRV-3	
	sensitivity mV/(m/s^2)	Expanded Uncertainty, k=2, (%)			sensitivity mV/(m/s^2)	Expanded Uncertainty, k=2, (%)			sensitivity mV/(m/s^2)	Expanded Uncertainty, k=2, (%)
	Y_{KCRV-1}	$U_{g1,out}$	$U_{g1,in}$	$U_{g1,out}/U_{g1,in}$	Y_{KCRV-2}	$U_{g2,out}$	$U_{g2,in}$	$U_{g2,out}/U_{g2,in}$	Y_{KCRV-3}	U_3
10	0.9957	0.04	0.10	0.40	0.9957	0.04	0.10	0.40	0.9954	0.21
20	0.9951	0.21	0.10	2.10	0.9951	0.21	0.10	2.10	0.9937	0.16
30	0.9952	0.13	0.09	1.44	0.9952	0.13	0.09	1.44	0.9950	0.14
40	0.9956	0.08	0.10	0.80	0.9956	0.08	0.10	0.80	0.9953	0.17
50	0.9954	0.06	0.10	0.60	0.9954	0.06	0.10	0.60	0.9953	0.5
60	0.9955	0.04	0.10	0.40	0.9955	0.04	0.10	0.40	0.9958	0.23
70	0.9955	0.04	0.10	0.40	0.9955	0.04	0.10	0.40	0.9953	0.16
80	0.9958	0.05	0.10	0.50	0.9958	0.05	0.10	0.50	0.9960	0.23
90	0.9961	0.08	0.10	0.80	0.9961	0.08	0.10	0.80	0.9956	0.16
100	0.9964	0.05	0.09	0.56	0.9964	0.05	0.09	0.56	0.9962	0.17
160	0.9963	0.04	0.09	0.44	0.9963	0.03	0.09	0.33	0.9967	0.17
200	0.9965	0.07	0.09	0.78	0.9965	0.08	0.10	0.80	0.9971	0.2
300	0.997	0.07	0.09	0.78	0.997	0.06	0.09	0.67	0.9971	0.21
315	0.997	0.1	0.10	1.00	0.997	0.1	0.10	1.00	0.9961	0.21
400	0.9972	0.05	0.09	0.56	0.9973	0.03	0.09	0.33	0.9976	0.2
500	0.9977	0.03	0.09	0.33	0.9977	0.03	0.09	0.33	0.9978	0.18
600	0.9984	0.07	0.09	0.78	0.9984	0.07	0.09	0.78	0.9976	0.17
630	0.9983	0.12	0.10	1.20	0.9983	0.12	0.10	1.20	0.9972	0.21
700	0.9985	0.07	0.09	0.78	0.9985	0.08	0.09	0.89	0.9981	0.17
800	0.9982	0.11	0.09	1.22	0.998	0.04	0.09	0.44	0.9977	0.16
900	0.9985	0.08	0.09	0.89	0.9985	0.08	0.09	0.89	0.9977	0.15
1000	0.9986	0.04	0.09	0.44	0.9986	0.04	0.09	0.44	0.9984	0.17
1250	0.9992	0.11	0.10	1.10	0.9992	0.11	0.10	1.10	0.9982	0.21
1500	0.9996	0.06	0.09	0.67	0.9996	0.06	0.09	0.67	0.9997	0.17
2000	1.0011	0.07	0.09	0.78	1.0011	0.07	0.09	0.78	1.0006	0.18
2500	1.0019	0.2	0.18	1.11	1.0019	0.2	0.18	1.11	1.0012	0.23
3000	1.0045	0.18	0.16	1.13	1.0045	0.18	0.16	1.13	1.0035	0.27
3500	1.0087	0.04	0.18	0.22	1.0087	0.04	0.18	0.22	1.0088	0.23
4000	1.0101	0.28	0.15	1.87	1.0115	0.07	0.16	0.44	1.0119	0.22
4500	1.0148	0.08	0.18	0.44	1.0148	0.08	0.18	0.44	1.0145	0.23
5000	1.0188	0.22	0.16	1.38	1.0195	0.12	0.17	0.71	1.0190	0.22
5500	1.023	0.11	0.18	0.61	1.023	0.11	0.18	0.61	1.0234	0.23
6000	1.0259	0.27	0.16	1.69	1.0262	0.29	0.17	1.71	1.0256	0.23
6500	1.0336	0.16	0.18	0.89	1.0336	0.16	0.18	0.89	1.0330	0.23
7000	1.0374	0.31	0.17	1.82	1.038	0.16	0.17	0.94	1.0392	0.25
7500	1.0451	0.2	0.18	1.11	1.0451	0.2	0.18	1.11	1.0443	0.23
8000	1.0507	0.31	0.17	1.82	1.0511	0.21	0.17	1.24	1.0510	0.26
8500	1.0596	0.16	0.18	0.89	1.0596	0.16	0.18	0.89	1.0590	0.23
9000	1.0642	0.34	0.17	2.00	1.0648	0.05	0.17	0.29	1.0651	0.23
9500	1.0716	0.15	0.18	0.83	1.0716	0.15	0.18	0.83	1.0710	0.23
10000	1.0802	0.46	0.17	2.71	1.0811	0.07	0.17	0.41	1.0813	0.24

If $U_{g,out} \le U_{g,in}$, then the distribution of the measurement results of NMIs is suitable, otherwise the uncertainty estimations of NMIs might be too optimistic at these calibration points

Table A 9 Degree of equivalence and E_n-number between KCRV-1 and other laboratories

KCRV-1: averaged with all data, weighted

Freq	Relative Deviation(%) $=100\%*(Y_j-Y_{KCRV-1})/Y_{KCRV-1}$						Expanded uncertainty of relative deviation, k=2, (%)						E_n-number					
(Hz)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
10			-0.066			0.004			0.39			0.03			-0.17			0.14
20			-0.307			0.034			0.29			0.04			-1.06			0.86
30		0.113	-0.319	0.284	-0.178	0.033		0.30	0.29	0.40	0.25	0.06		0.38	-1.10	0.71	-0.72	0.55
40			-0.165	0.036		0.016			0.29	0.39		0.04			-0.57	0.10		0.41
50	-0.257	0.105	-0.136		0.005	0.015	1.06	0.61	0.29		1.84	0.04	-0.25	0.18	-0.47		0.01	0.37
60			-0.049	0.152		0.001			0.29	0.60		0.04			-0.17	0.26		0.04
70			-0.054			0.006			0.29			0.04			-0.19			0.16
80			-0.084	0.117		0.006			0.29	0.60		0.04			-0.30	0.20		0.16
90			-0.108			0.012			0.29			0.04			-0.38			0.31
100	-0.362	0.010	-0.141	0.060	-0.030	0.020	1.06	0.31	0.29	0.60	0.29	0.06	-0.35	0.04	-0.49	0.10	-0.11	0.33
160	-0.357	0.044	-0.026	0.175	0.024	-0.006	1.06	0.30	0.29	0.60	0.29	0.06	-0.34	0.15	-0.09	0.30	0.09	-0.11
200	-0.177	0.044	-0.147	0.355	0.044	0.004	1.06	0.54	0.29	0.60	0.41	0.05	-0.17	0.09	-0.51	0.60	0.11	0.08
300	-0.650	0.032	-0.199	0.202	0.002	0.012	1.05	0.67	0.39	0.60	0.27	0.05	-0.62	0.05	-0.51	0.34	0.01	0.24
315			-0.198			0.012			0.39			0.03			-0.51			0.42
400	-0.435	0.037	-0.023	0.177	-0.023	-0.003	1.06	0.27	0.39	0.60	0.55	0.05	-0.42	0.14	-0.07	0.30	-0.05	-0.07
500	-0.134	-0.003	-0.074	0.127	-0.034	0.007	1.06	0.34	0.39	0.60	0.28	0.05	-0.13	-0.02	-0.19	0.22	-0.12	0.14
600	0.075	-0.026	-0.236	-0.036	-0.096	0.034	1.06	0.30	0.39	0.60	0.23	0.06	0.08	-0.09	-0.61	-0.06	-0.42	0.58
630			-0.226			0.014			0.39			0.03			-0.59			0.48
700	0.118	-0.022	-0.252	0.148	-0.092	0.028	0.47	0.27	0.40	0.60	0.21	0.06	0.26	-0.09	-0.64	0.25	-0.44	0.48
800	0.693	0.031	-0.119	-0.119	-0.039	-0.009	0.53	0.37	0.40	0.50	0.24	0.06	1.31	0.09	-0.30	-0.24	-0.17	-0.15
900	-0.068	0.032	-0.248	-0.148	-0.058	0.042	0.46	0.40	0.29	0.50	0.27	0.06	-0.15	0.09	-0.86	-0.30	-0.22	0.71
1000	-0.027	0.043	-0.157	0.043	-0.047	0.013	0.43	0.52	0.39	0.50	0.29	0.05	-0.07	0.09	-0.41	0.09	-0.17	0.27
1250			-0.217			0.014			0.39			0.03			-0.56			0.46
1500	0.228	0.028	-0.163	0.038	-0.093	0.018	0.58	0.38	0.40	0.50	0.22	0.06	0.40	0.08	-0.41	0.08	-0.43	0.30
2000	0.023	-0.027	-0.107	-0.007	-0.177	0.033	0.46	0.59	0.40	0.50	0.25	0.05	0.05	-0.05	-0.27	-0.02	-0.71	0.66
2500			-0.191			0.048			0.36			0.09			-0.54			0.54
3000	0.036	-0.153	-0.253	-0.054	-0.352	0.145	0.49	1.19	0.37	0.59	0.41	0.14	0.08	-0.13	-0.69	-0.10	-0.86	1.04
3500			0.032			-0.008			0.36			0.09			0.09			-0.09
4000	0.245	-0.290	0.186	0.186	-0.705	0.097	0.41	0.80	0.38	0.59	0.35	0.14	0.60	-0.37	0.49	0.32	-2.02	0.69
4500			-0.079			0.020			0.36			0.09			-0.22			0.22
5000	-0.186	-0.569	0.118	0.020	-1.060	0.118	0.43	0.51	0.38	0.59	1.18	0.14	-0.44	-1.12	0.32	0.04	-0.90	0.85
5500			0.102			-0.025			0.36			0.09			0.29			-0.29
6000	-0.638	-0.813	0.103	0.298	-1.067	0.103	0.45	1.28	0.37	0.59	1.28	0.13	-1.42	-0.64	0.28	0.51	-0.84	0.80
6500			-0.155			0.039			0.36			0.09			-0.43			0.44
7000	0.284	-1.364	-0.034	0.448	-1.673	0.024	0.60	1.08	0.37	0.59	1.17	0.12	0.48	-1.27	-0.10	0.76	-1.43	0.20
7500			-0.199			0.050			0.36			0.09			-0.56			0.56
8000	-0.283	-1.987	-0.159	0.507	-2.253	0.069	0.66	1.86	0.37	0.59	1.56	0.12	-0.43	-1.07	-0.44	0.86	-1.45	0.58
8500			-0.151			0.038			0.36			0.09			-0.42			0.43
9000	0.066	-2.462	0.075	0.169	-2.556	0.038	0.48	1.36	0.37	0.58	1.75	0.12	0.14	-1.82	0.21	0.30	-1.47	0.32
9500			-0.149			0.037			0.36			0.09			-0.42			0.42
10000	-0.006	-2.691	0.077	0.263	-3.441	0.077	0.52	1.26	0.37	0.58	1.54	0.12	-0.02	-2.14	0.21	0.46	-2.24	0.65

Table A 10 Comparison of key comparison reference values of different versions

Y_{KCRV-1}, $U_{g1,out}$, $U_{g1,in}$: averaged with all data, weighted
Y_{KCRV-2}, $U_{g2,out}$, $U_{g2,in}$: averaged without the outliers, weighted
Y_{KCRV-3} , U_3: averaged without the outliers, equal weight

Freq (Hz)	(Y_{KCRV-1} - Y_{KCRV-2}) /Y_{KCRV-2} (%)	(Y_{KCRV-1} - Y_{KCRV-3}) /Y_{KCRV-3} (%)	(Y_{KCRV-2} - Y_{KCRV-3}) /Y_{KCRV-3} (%)	$U_{g1,out}/U_3$	$U_{g2,out}/U_3$	$U_{g1,in}/U_3$	$U_{g2,in}/U_3$	$U_{g1,out}/U_{g2,out}$	$U_{g1,in}/U_{g2,in}$
10	0.000	0.031	0.031	0.191	0.191	0.476	0.476	1.000	1.000
20	0.000	0.137	0.137	1.314	1.314	0.626	0.626	1.000	1.000
30	0.000	0.013	0.013	0.929	0.929	0.643	0.643	1.000	1.000
40	0.000	0.037	0.037	0.471	0.471	0.588	0.588	1.000	1.000
50	-0.002	0.003	0.005	0.120	0.120	0.200	0.200	1.000	1.000
60	0.000	-0.035	-0.035	0.174	0.174	0.435	0.435	1.000	1.000
70	0.000	0.024	0.024	0.250	0.250	0.625	0.625	1.000	1.000
80	0.000	-0.013	-0.013	0.217	0.217	0.435	0.435	1.000	1.000
90	0.000	0.048	0.048	0.500	0.500	0.625	0.625	1.000	1.000
100	-0.002	0.016	0.019	0.294	0.294	0.529	0.530	1.000	1.000
160	-0.002	-0.042	-0.040	0.235	0.176	0.529	0.529	1.333	1.000
200	-0.001	-0.060	-0.059	0.350	0.400	0.450	0.500	0.875	0.900
300	-0.005	-0.010	-0.005	0.333	0.286	0.429	0.429	1.167	1.000
315	0.000	0.093	0.093	0.477	0.477	0.477	0.477	1.000	1.000
400	-0.003	-0.033	-0.030	0.250	0.150	0.450	0.450	1.667	1.000
500	-0.001	-0.005	-0.004	0.167	0.167	0.500	0.500	1.000	1.000
600	0.000	0.072	0.071	0.412	0.412	0.530	0.530	1.000	1.000
630	0.000	0.106	0.106	0.572	0.572	0.477	0.477	1.000	1.000
700	0.004	0.038	0.034	0.412	0.471	0.530	0.530	0.875	1.000
800	0.019	0.051	0.032	0.688	0.250	0.563	0.563	2.751	1.000
900	0.000	0.075	0.075	0.534	0.534	0.600	0.600	1.000	1.000
1000	0.000	0.022	0.022	0.235	0.235	0.530	0.530	1.000	1.000
1250	0.000	0.102	0.102	0.524	0.524	0.477	0.477	1.000	1.000
1500	0.000	-0.009	-0.009	0.353	0.353	0.529	0.529	1.000	1.000
2000	0.000	0.044	0.044	0.389	0.389	0.500	0.500	1.000	1.000
2500	0.000	0.072	0.072	0.870	0.870	0.783	0.783	1.000	1.000
3000	0.000	0.105	0.105	0.667	0.667	0.593	0.593	1.000	1.000
3500	0.000	-0.012	-0.012	0.174	0.174	0.783	0.783	1.000	1.000
4000	-0.137	-0.178	-0.041	1.270	0.318	0.681	0.727	3.995	0.936
4500	0.000	0.030	0.030	0.348	0.348	0.783	0.783	1.000	1.000
5000	-0.072	-0.017	0.055	1.000	0.546	0.727	0.773	1.832	0.941
5500	0.000	-0.038	-0.038	0.478	0.478	0.782	0.782	1.000	1.000
6000	-0.029	0.034	0.063	1.174	1.262	0.696	0.740	0.931	0.941
6500	0.000	0.058	0.058	0.696	0.696	0.783	0.783	1.000	1.000
7000	-0.064	-0.180	-0.116	1.238	0.639	0.679	0.679	1.936	0.999
7500	0.000	0.074	0.074	0.870	0.870	0.783	0.783	1.000	1.000
8000	-0.041	-0.033	0.008	1.192	0.808	0.654	0.654	1.476	1.000
8500	0.000	0.057	0.057	0.696	0.696	0.783	0.783	1.000	1.000
9000	-0.057	-0.087	-0.031	1.477	0.217	0.738	0.739	6.796	0.999
9500	0.000	0.056	0.056	0.653	0.653	0.783	0.783	1.000	1.000
10000	-0.083	-0.103	-0.019	1.915	0.292	0.708	0.708	6.566	0.999

Table A 11 Degree of equivalence and E_n-number between KCRV-2 and other laboratories

KCRV-2: averaged without outliers, weighted

Freq	Relative Deviation(%) = 100%*$(Y_j-Y_{KCRV-2})/Y_{KCRV-2}$						Expanded uncertainty of relative deviation, k=2, (%)						E_n-number					
(Hz)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
10			-0.066			0.004			0.39			0.03			-0.17			0.14
20			-0.307			0.034			0.29			0.04			-1.06			0.86
30		0.113	-0.319	0.284	-0.178	0.033		0.30	0.29	0.40	0.25	0.06		0.38	-1.10	0.71	-0.72	0.55
40			-0.165	0.036		0.016			0.29	0.39		0.04			-0.57	0.10		0.41
50	-0.259	0.103	-0.138		0.003	0.013	1.07	0.61	0.29		1.84	0.04	-0.25	0.17	-0.48		0.01	0.32
60			-0.049	0.152		0.001			0.29	0.60		0.04			-0.17	0.26		0.04
70			-0.054			0.006			0.29			0.04			-0.19			0.16
80			-0.084	0.117		0.006			0.29	0.60		0.04			-0.30	0.20		0.16
90			-0.108			0.012			0.29			0.04			-0.38			0.31
100	-0.364	0.007	-0.143	0.057	-0.033	0.017	1.06	0.31	0.29	0.60	0.29	0.06	-0.35	0.03	-0.50	0.10	-0.12	0.29
160	-0.360	0.042	-0.028	0.172	0.022	-0.008	1.06	0.30	0.29	0.60	0.29	0.06	-0.34	0.14	-0.10	0.29	0.08	-0.14
200	-0.178	0.043	-0.148	0.354	0.043	0.003	1.07	0.54	0.29	0.60	0.41	0.05	-0.17	0.08	-0.51	0.59	0.11	0.06
300	-0.655	0.027	-0.204	0.198	-0.003	0.007	1.06	0.67	0.39	0.60	0.27	0.05	-0.62	0.05	-0.53	0.33	-0.02	0.15
315			-0.198			0.012			0.39			0.03			-0.51			0.42
400	-0.438	0.034	-0.027	0.174	-0.027	-0.007	1.06	0.27	0.39	0.60	0.55	0.05	-0.42	0.13	-0.07	0.29	-0.05	-0.14
500	-0.135	-0.004	-0.075	0.126	-0.034	0.006	1.07	0.34	0.39	0.60	0.28	0.05	-0.13	-0.02	-0.20	0.21	-0.13	0.12
600	0.075	-0.025	-0.235	-0.035	-0.095	0.035	1.07	0.30	0.39	0.60	0.23	0.06	0.08	-0.09	-0.61	-0.06	-0.42	0.59
630			-0.226			0.014			0.39			0.03			-0.59			0.48
700	0.122	-0.018	-0.248	0.152	-0.088	0.032	0.48	0.27	0.40	0.60	0.21	0.06	0.26	-0.07	-0.63	0.26	-0.43	0.54
800	0.711	0.050	-0.100	-0.100	-0.020	0.010	0.54	0.36	0.40	0.50	0.24	0.06	1.32	0.14	-0.26	-0.21	-0.09	0.17
900	-0.068	0.032	-0.248	-0.148	-0.058	0.042	0.46	0.40	0.29	0.50	0.27	0.06	-0.15	0.09	-0.86	-0.30	-0.22	0.71
1000	-0.027	0.043	-0.157	0.043	-0.047	0.013	0.43	0.52	0.39	0.50	0.29	0.05	-0.07	0.09	-0.41	0.09	-0.17	0.27
1250			-0.217			0.014			0.39			0.03			-0.56			0.46
1500	0.228	0.028	-0.163	0.038	-0.093	0.018	0.58	0.38	0.40	0.50	0.22	0.06	0.40	0.08	-0.41	0.08	-0.43	0.30
2000	0.023	-0.027	-0.107	-0.007	-0.177	0.033	0.46	0.59	0.40	0.50	0.25	0.05	0.05	-0.05	-0.27	-0.02	-0.71	0.66
2500			-0.191			0.048			0.36			0.09			-0.54			0.54
3000	0.036	-0.153	-0.253	-0.054	-0.352	0.145	0.49	1.19	0.37	0.59	0.41	0.14	0.08	-0.13	-0.69	-0.10	-0.86	1.04
3500			0.032			-0.008			0.36			0.09			0.09			-0.09
4000	0.108	-0.426	0.048	0.048	-0.841	-0.041	0.40	0.83	0.37	0.58	0.41	0.13	0.27	-0.52	0.14	0.09	-2.06	-0.32
4500			-0.079			0.020			0.36			0.09			-0.22			0.22
5000	-0.258	-0.641	0.046	-0.052	-1.131	0.046	0.42	0.56	0.37	0.58	1.20	0.13	-0.62	-1.15	0.13	-0.09	-0.95	0.36
5500			0.102			-0.025			0.36			0.09			0.29			-0.29
6000	-0.667	-0.842	0.073	0.268	-1.096	0.073	0.45	1.30	0.37	0.58	1.30	0.12	-1.49	-0.65	0.20	0.47	-0.85	0.62
6500			-0.155			0.039			0.36			0.09			-0.43			0.44
7000	0.219	-1.428	-0.099	0.383	-1.736	-0.041	0.60	1.10	0.37	0.58	1.20	0.12	0.37	-1.30	-0.27	0.67	-1.45	-0.34
7500			-0.199			0.050			0.36			0.09			-0.56			0.56
8000	-0.324	-2.027	-0.201	0.465	-2.294	0.028	0.66	1.87	0.37	0.58	1.58	0.12	-0.50	-1.09	-0.55	0.81	-1.46	0.24
8500			-0.151			0.038			0.36			0.09			-0.42			0.43
9000	0.009	-2.517	0.019	0.113	-2.611	-0.019	0.48	1.38	0.37	0.58	1.77	0.12	0.02	-1.83	0.06	0.20	-1.48	-0.16
9500			-0.149			0.037			0.36			0.09			-0.42			0.42
10000	-0.089	-2.772	-0.006	0.179	-3.521	-0.006	0.52	1.28	0.37	0.58	1.56	0.12	-0.18	-2.17	-0.02	0.31	-2.26	-0.05

Table A 12 Degree of equivalence and E_n -number between KCRV-3 and other laboratories

KCRV-3: averaged without outliers, equal weight

Freq	Relative Deviation(%) = 100%*(Y_j-Y_{KCRV-3})/Y_{KCRV-3}						Expanded uncertainty of relative deviation, k=2, (%)						E_n -number					
(Hz)	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB	ITRI	NRLM	KRISS	CSIRO	SIRIM	PTB
10			-0.035			0.035			0.21			0.21			-0.17			0.17
20			-0.171			0.171			0.16			0.16			-1.07			1.07
30		0.127	-0.306	0.297	-0.165	0.046		0.28	0.27	0.34	0.24	0.16		0.46	-1.14	0.88	-0.69	0.29
40			-0.127	0.074		0.054			0.25	0.29		0.18			-0.51	0.26		0.30
50	-0.254	0.108	-0.133		0.008	0.018	1.17	0.71	0.54		1.40	0.50	-0.22	0.16	-0.25		0.01	0.04
60			-0.084	0.117		-0.033			0.29	0.42		0.24			-0.29	0.28		-0.14
70			-0.030			0.030			0.16			0.16			-0.19			0.19
80			-0.097	0.104		-0.007			0.29	0.42		0.24			-0.34	0.25		-0.03
90			-0.060			0.060			0.16			0.16			-0.38			0.38
100	-0.345	0.026	-0.124	0.076	-0.014	0.036	1.07	0.30	0.29	0.50	0.29	0.18	-0.33	0.09	-0.43	0.16	-0.05	0.21
160	-0.399	0.002	-0.068	0.132	-0.018	-0.048	1.07	0.29	0.29	0.50	0.29	0.18	-0.38	0.01	-0.24	0.27	-0.07	-0.27
200	-0.237	-0.016	-0.207	0.295	-0.016	-0.056	1.08	0.47	0.31	0.51	0.38	0.21	-0.22	-0.04	-0.67	0.58	-0.05	-0.27
300	-0.660	0.022	-0.209	0.193	-0.008	0.002	1.08	0.56	0.38	0.51	0.30	0.22	-0.62	0.04	-0.55	0.38	-0.03	0.01
315			-0.105			0.105			0.21			0.21			-0.51			0.51
400	-0.467	0.004	-0.056	0.144	-0.056	-0.036	1.08	0.29	0.37	0.51	0.47	0.21	-0.44	0.02	-0.16	0.29	-0.12	-0.18
500	-0.138	-0.008	-0.078	0.122	-0.038	0.002	1.08	0.33	0.36	0.50	0.29	0.19	-0.13	-0.03	-0.22	0.25	-0.14	0.02
600	0.146	0.046	-0.164	0.036	-0.024	0.106	1.08	0.30	0.36	0.50	0.25	0.19	0.14	0.16	-0.46	0.08	-0.10	0.56
630			-0.120			0.120			0.21			0.21			-0.58			0.58
700	0.156	0.016	-0.214	0.186	-0.054	0.066	0.50	0.28	0.35	0.50	0.24	0.18	0.32	0.06	-0.62	0.38	-0.23	0.37
800	0.744	0.082	-0.068	-0.068	0.012	0.042	0.56	0.33	0.35	0.42	0.25	0.18	1.33	0.25	-0.20	-0.17	0.05	0.24
900	0.007	0.107	-0.174	-0.073	0.017	0.117	0.41	0.36	0.29	0.44	0.28	0.18	0.02	0.30	-0.60	-0.17	0.06	0.65
1000	-0.005	0.065	-0.135	0.065	-0.025	0.035	0.39	0.46	0.37	0.45	0.30	0.19	-0.02	0.15	-0.37	0.15	-0.09	0.19
1250			-0.115			0.115			0.21			0.21			-0.55			0.55
1500	0.218	0.018	-0.172	0.028	-0.102	0.008	0.51	0.36	0.37	0.44	0.25	0.19	0.43	0.06	-0.47	0.07	-0.41	0.05
2000	0.067	0.017	-0.063	0.037	-0.133	0.077	0.42	0.52	0.37	0.45	0.28	0.19	0.16	0.04	-0.18	0.09	-0.48	0.41
2500			-0.120			0.120			0.23			0.23			-0.53			0.53
3000	0.141	-0.048	-0.148	0.051	-0.247	0.251	0.49	1.02	0.42	0.56	0.44	0.31	0.29	-0.05	-0.36	0.10	-0.57	0.81
3500			0.020			-0.020			0.23			0.23			0.09			-0.09
4000	0.067	-0.467	0.007	0.007	-0.882	-0.082	0.38	0.84	0.36	0.48	0.44	0.26	0.18	-0.56	0.03	0.02	-2.01	-0.32
4500			-0.049			0.049			0.23			0.23			-0.22			0.22
5000	-0.204	-0.586	0.101	0.002	-1.077	0.101	0.39	0.58	0.36	0.48	1.21	0.26	-0.53	-1.02	0.28	0.01	-0.90	0.39
5500			0.064			-0.064			0.23			0.23			0.28			-0.28
6000	-0.605	-0.780	0.137	0.332	-1.034	0.137	0.40	1.31	0.36	0.48	1.31	0.27	-1.52	-0.60	0.38	0.70	-0.79	0.51
6500			-0.097			0.097			0.23			0.23			-0.43			0.43
7000	0.103	-1.542	-0.214	0.267	-1.850	-0.156	0.50	1.11	0.38	0.49	1.21	0.29	0.21	-1.39	-0.57	0.55	-1.53	-0.54
7500			-0.124			0.124			0.23			0.23			-0.55			0.55
8000	-0.316	-2.019	-0.193	0.473	-2.286	0.036	0.54	1.88	0.38	0.50	1.59	0.29	-0.59	-1.08	-0.51	0.95	-1.44	0.13
8500			-0.094			0.094			0.23			0.23			-0.42			0.42
9000	-0.021	-2.547	-0.012	0.082	-2.641	-0.049	0.42	1.39	0.37	0.49	1.77	0.27	-0.06	-1.84	-0.04	0.17	-1.50	-0.19
9500			-0.093			0.093			0.23			0.23			-0.41			0.41
10000	-0.109	-2.791	-0.025	0.160	-3.540	-0.025	0.45	1.29	0.37	0.49	1.57	0.28	-0.25	-2.17	-0.07	0.33	-2.26	-0.10

Table A 13 Degree of equivalence and E_n -number between ITRI and other laboratories

Freq	Relative Deviation (%) =100%*$(Y_j-Y_{ITRI})/Y_{KCRV-3}$					Expanded uncertainty of relative deviation, k=2, (%)					E_n -number				
(Hz)	NRLM	KRISS	CSIRO	SIRIM	PTB	NRLM	KRISS	CSIRO	SIRIM	PTB	NRLM	KRISS	CSIRO	SIRIM	PTB
10															
20															
30															
40															
50	0.362	0.121	0.254	0.261	0.271	1.23	1.10	1.06	2.13	1.07	0.30	0.11	0.24	0.13	0.26
60															
70															
80															
90															
100	0.371	0.221	0.422	0.331	0.381	1.11	1.10	1.22	1.10	1.07	0.34	0.21	0.35	0.31	0.36
160	0.401	0.331	0.532	0.381	0.351	1.11	1.10	1.22	1.10	1.07	0.37	0.31	0.44	0.35	0.33
200	0.221	0.030	0.532	0.221	0.181	1.19	1.10	1.22	1.14	1.07	0.19	0.03	0.44	0.20	0.17
300	0.682	0.451	0.852	0.652	0.662	1.25	1.13	1.22	1.09	1.06	0.55	0.40	0.70	0.60	0.63
315															
400	0.471	0.411	0.611	0.411	0.431	1.10	1.13	1.22	1.19	1.06	0.43	0.37	0.51	0.35	0.41
500	0.130	0.060	0.261	0.100	0.140	1.12	1.14	1.22	1.10	1.07	0.12	0.06	0.22	0.10	0.14
600	-0.100	-0.311	-0.110	-0.170	-0.040	1.11	1.14	1.22	1.09	1.07	-0.10	-0.28	-0.10	-0.16	-0.04
630															
700	-0.140	-0.371	0.030	-0.210	-0.090	0.55	0.62	0.77	0.52	0.49	-0.26	-0.60	0.04	-0.41	-0.19
800	-0.662	-0.812	-0.812	-0.732	-0.702	0.65	0.67	0.73	0.59	0.54	-1.02	-1.22	-1.12	-1.25	-1.30
900	0.100	-0.180	-0.080	0.010	0.110	0.62	0.56	0.69	0.55	0.48	0.17	-0.33	-0.12	0.02	0.23
1000	0.070	-0.130	0.070	-0.020	0.040	0.68	0.59	0.67	0.53	0.45	0.11	-0.23	0.11	-0.04	0.09
1250															
1500	-0.200	-0.390	-0.190	-0.320	-0.210	0.70	0.71	0.77	0.63	0.59	-0.29	-0.55	-0.25	-0.51	-0.36
2000	-0.050	-0.130	-0.030	-0.200	0.010	0.76	0.62	0.69	0.54	0.48	-0.07	-0.21	-0.05	-0.38	0.03
2500															
3000	-0.189	-0.289	-0.090	-0.389	0.110	1.31	0.65	0.79	0.67	0.55	-0.15	-0.45	-0.12	-0.59	0.20
3500															
4000	-0.534	-0.059	-0.059	-0.949	-0.148	0.92	0.59	0.74	0.58	0.48	-0.59	-0.11	-0.09	-1.64	-0.31
4500															
5000	-0.383	0.304	0.206	-0.873	0.304	0.70	0.61	0.75	1.27	0.49	-0.55	0.50	0.28	-0.69	0.63
5500															
6000	-0.176	0.741	0.936	-0.429	0.741	1.38	0.62	0.77	1.37	0.52	-0.13	1.20	1.22	-0.32	1.43
6500															
7000	-1.645	-0.318	0.164	-1.953	-0.260	1.25	0.74	0.87	1.33	0.65	-1.32	-0.43	0.19	-1.47	-0.40
7500															
8000	-1.703	0.124	0.790	-1.970	0.352	1.98	0.79	0.91	1.71	0.71	-0.87	0.16	0.87	-1.16	0.50
8500															
9000	-2.526	0.009	0.103	-2.619	-0.028	1.46	0.65	0.79	1.83	0.54	-1.73	0.02	0.14	-1.44	-0.06
9500															
10000	-2.682	0.083	0.268	-3.431	0.083	1.38	0.67	0.81	1.64	0.58	-1.95	0.13	0.34	-2.10	0.15

Table A 14 Degree of equivalence and E_n -number between NRLM and other laboratories

Freq	Relative Deviation (%) =100%*$(Y_{NRLM}-Y_j)/Y_{KCRV-3}$					Expanded uncertainty of relative deviation, k=2, (%)					E_n -number				
(Hz)	ITRI	KRISS	CSIRO	SIRIM	PTB	ITRI	KRISS	CSIRO	SIRIM	PTB	ITRI	KRISS	CSIRO	SIRIM	PTB
10															
20															
30		-0.432	0.171	-0.291	-0.080		0.44	0.51	0.41	0.33		-0.99	0.34	-0.72	-0.25
40															
50	-0.362	-0.241	-0.108	-0.100	-0.090	1.23	0.69	0.62	1.94	0.62	-0.30	-0.35	-0.18	-0.06	-0.15
60															
70															
80															
90															
100	-0.371	-0.151	0.050	-0.040	0.010	1.11	0.44	0.69	0.44	0.34	-0.34	-0.35	0.08	-0.10	0.03
160	-0.401	-0.070	0.130	-0.020	-0.050	1.11	0.44	0.68	0.44	0.33	-0.37	-0.16	0.20	-0.05	-0.16
200	-0.221	-0.191	0.311	0.000	-0.040	1.19	0.62	0.81	0.68	0.55	-0.19	-0.31	0.39	0.00	-0.08
300	-0.682	-0.231	0.170	-0.030	-0.020	1.25	0.79	0.91	0.73	0.68	-0.55	-0.30	0.19	-0.05	-0.03
315															
400	-0.471	-0.060	0.140	-0.060	-0.040	1.10	0.49	0.67	0.62	0.30	-0.43	-0.13	0.21	-0.10	-0.14
500	-0.130	-0.070	0.130	-0.030	0.010	1.12	0.54	0.70	0.46	0.37	-0.12	-0.13	0.19	-0.07	0.03
600	0.100	-0.210	-0.010	-0.070	0.060	1.11	0.51	0.68	0.40	0.33	0.10	-0.42	-0.02	-0.18	0.19
630															
700	0.140	-0.230	0.170	-0.070	0.050	0.55	0.49	0.67	0.36	0.30	0.26	-0.48	0.26	-0.20	0.17
800	0.662	-0.150	-0.150	-0.070	-0.040	0.65	0.55	0.63	0.45	0.39	1.02	-0.28	-0.24	-0.16	-0.11
900	-0.100	-0.281	-0.180	-0.090	0.010	0.62	0.51	0.65	0.49	0.42	-0.17	-0.56	-0.28	-0.19	0.03
1000	-0.070	-0.200	0.000	-0.090	-0.030	0.68	0.66	0.73	0.61	0.53	-0.11	-0.31	0.00	-0.15	-0.06
1250															
1500	0.200	-0.190	0.010	-0.120	-0.010	0.70	0.56	0.63	0.45	0.40	0.29	-0.34	0.02	-0.27	-0.03
2000	0.050	-0.080	0.020	-0.150	0.060	0.76	0.72	0.78	0.65	0.60	0.07	-0.12	0.03	-0.24	0.10
2500															
3000	0.189	-0.100	0.100	-0.199	0.299	1.31	1.27	1.35	1.28	1.22	0.15	-0.08	0.08	-0.16	0.25
3500															
4000	0.534	0.474	0.474	-0.415	0.385	0.92	0.91	1.01	0.89	0.84	0.59	0.53	0.47	-0.47	0.46
4500															
5000	0.383	0.687	0.589	-0.491	0.687	0.70	0.67	0.80	1.30	0.57	0.55	1.03	0.74	-0.38	1.21
5500															
6000	0.176	0.917	1.112	-0.254	0.917	1.38	1.36	1.43	1.83	1.31	0.13	0.68	0.78	-0.14	0.70
6500															
7000	1.645	1.328	1.809	-0.308	1.386	1.25	1.16	1.24	1.61	1.11	1.32	1.15	1.46	-0.20	1.25
7500															
8000	1.703	1.827	2.493	-0.266	2.055	1.98	1.91	1.96	2.44	1.88	0.87	0.96	1.28	-0.11	1.10
8500															
9000	2.526	2.535	2.629	-0.094	2.497	1.46	1.43	1.50	2.23	1.38	1.73	1.78	1.76	-0.05	1.81
9500															
10000	2.682	2.765	2.950	-0.749	2.765	1.38	1.33	1.40	2.00	1.28	1.95	2.08	2.11	-0.38	2.17

Table A 15 Degree of equivalence and E_n -number between KRISS and other laboratories

Freq	Relative deviation (%) =100%*$(Y_j-Y_{KRISS})/Y_{KCRV-3}$					Expanded uncertainty of relative deviation, k=2, (%)					E_n -number				
(Hz)	ITRI	NRLM	CSIRO	SIRIM	PTB	ITRI	NRLM	CSIRO	SIRIM	PTB	ITRI	NRLM	CSIRO	SIRIM	PTB
10					0.070					0.42					0.17
20					0.342					0.32					1.07
30		0.432	0.603	0.141	0.352		0.44	0.51	0.40	0.32		0.99	1.19	0.36	1.10
40			0.201		0.181			0.51		0.32			0.40		0.57
50	-0.121	0.241		0.141	0.151	1.10	0.69		1.87	0.32	-0.11	0.35		0.08	0.48
60			0.201		0.050			0.68		0.32			0.30		0.16
70					0.060					0.32					0.19
80			0.201		0.090			0.68		0.32			0.30		0.29
90					0.121					0.32					0.38
100	-0.221	0.151	0.201	0.110	0.161	1.10	0.44	0.68	0.43	0.32	-0.21	0.35	0.30	0.26	0.51
160	-0.331	0.070	0.201	0.050	0.020	1.10	0.44	0.68	0.43	0.32	-0.31	0.16	0.30	0.12	0.07
200	-0.030	0.191	0.501	0.191	0.150	1.10	0.62	0.68	0.51	0.32	-0.03	0.31	0.74	0.38	0.48
300	-0.451	0.231	0.401	0.201	0.211	1.13	0.79	0.73	0.49	0.42	-0.40	0.30	0.55	0.41	0.51
315					0.211					0.42					0.51
400	-0.411	0.060	0.200	0.000	0.020	1.13	0.49	0.73	0.68	0.42	-0.37	0.13	0.28	0.00	0.05
500	-0.060	0.070	0.200	0.040	0.080	1.14	0.54	0.73	0.50	0.42	-0.06	0.13	0.28	0.09	0.20
600	0.311	0.210	0.200	0.140	0.271	1.14	0.51	0.73	0.47	0.42	0.28	0.42	0.28	0.30	0.65
630					0.241					0.42					0.58
700	0.371	0.230	0.401	0.160	0.281	0.62	0.49	0.73	0.46	0.42	0.60	0.48	0.55	0.35	0.67
800	0.812	0.150	0.000	0.080	0.110	0.67	0.55	0.64	0.48	0.42	1.22	0.28	0.00	0.17	0.27
900	0.180	0.281	0.100	0.190	0.291	0.56	0.51	0.59	0.42	0.32	0.33	0.56	0.17	0.46	0.91
1000	0.130	0.200	0.200	0.110	0.170	0.59	0.66	0.65	0.50	0.42	0.23	0.31	0.31	0.23	0.41
1250					0.230					0.42					0.55
1500	0.390	0.190	0.200	0.070	0.180	0.71	0.56	0.64	0.47	0.42	0.55	0.34	0.32	0.15	0.43
2000	0.130	0.080	0.100	-0.070	0.140	0.62	0.72	0.65	0.48	0.42	0.21	0.12	0.16	-0.15	0.34
2500					0.240					0.45					0.54
3000	0.289	0.100	0.199	-0.100	0.399	0.65	1.27	0.73	0.59	0.45	0.45	0.08	0.28	-0.17	0.89
3500					-0.040					0.45					-0.09
4000	0.059	-0.474	0.000	-0.889	-0.089	0.59	0.91	0.73	0.55	0.45	0.11	-0.53	0.00	-1.62	-0.20
4500					0.099					0.45					0.22
5000	-0.304	-0.687	-0.098	-1.178	0.000	0.61	0.67	0.73	1.26	0.45	-0.50	-1.03	-0.14	-0.94	0.00
5500					-0.127					0.45					-0.29
6000	-0.741	-0.917	0.195	-1.170	0.000	0.62	1.36	0.73	1.35	0.45	-1.20	-0.68	0.27	-0.87	0.00
6500					0.194					0.45					0.44
7000	0.318	-1.328	0.481	-1.636	0.058	0.74	1.16	0.73	1.25	0.45	0.43	-1.15	0.66	-1.31	0.13
7500					0.249					0.45					0.56
8000	-0.124	-1.827	0.666	-2.093	0.228	0.79	1.91	0.73	1.62	0.45	-0.16	-0.96	0.92	-1.30	0.51
8500					0.189					0.45					0.42
9000	-0.009	-2.535	0.094	-2.629	-0.038	0.65	1.43	0.73	1.80	0.45	-0.02	-1.78	0.13	-1.47	-0.09
9500					0.187					0.45					0.42
10000	-0.083	-2.765	0.185	-3.514	0.000	0.67	1.33	0.73	1.60	0.45	-0.13	-2.08	0.26	-2.20	0.00

Table A 16 Degree of equivalence and E_n -number between CSIRO and other laboratories

Freq	Relative Deviation (%) =100%*(Y_j-Y_{CSIRO})/Y_{KCRV-3}					Expanded uncertainty of relative deviation, k=2, (%)					E_n -number				
(Hz)	ITRI	NRLM	KRISS	SIRIM	PTB	ITRI	NRLM	KRISS	SIRIM	PTB	ITRI	NRLM	KRISS	SIRIM	PTB
10															
20															
30		-0.171	-0.603	-0.462	-0.251		0.51	0.51	0.48	0.42		-0.34	-1.19	-0.97	-0.60
40			-0.201		-0.020			0.51		0.42			-0.40		-0.05
50															
60			-0.201		-0.151			0.68		0.61			-0.30		-0.25
70															
80			-0.201		-0.110			0.68		0.61			-0.30		-0.19
90															
100	-0.422	-0.050	-0.201	-0.090	-0.040	1.22	0.69	0.68	0.68	0.61	-0.35	-0.08	-0.30	-0.14	-0.07
160	-0.532	-0.130	-0.201	-0.150	-0.181	1.22	0.68	0.68	0.68	0.61	-0.44	-0.20	-0.30	-0.23	-0.30
200	-0.532	-0.311	-0.501	-0.311	-0.351	1.22	0.81	0.68	0.73	0.62	-0.44	-0.39	-0.74	-0.43	-0.57
300	-0.852	-0.170	-0.401	-0.201	-0.191	1.22	0.91	0.73	0.67	0.61	-0.70	-0.19	-0.55	-0.30	-0.32
315															
400	-0.611	-0.140	-0.200	-0.200	-0.180	1.22	0.67	0.73	0.82	0.61	-0.51	-0.21	-0.28	-0.25	-0.30
500	-0.261	-0.130	-0.200	-0.160	-0.120	1.22	0.70	0.73	0.67	0.61	-0.22	-0.19	-0.28	-0.24	-0.20
600	0.110	0.010	-0.200	-0.060	0.070	1.22	0.68	0.73	0.65	0.61	0.10	0.02	-0.28	-0.10	0.12
630															
700	-0.030	-0.170	-0.401	-0.240	-0.120	0.77	0.67	0.73	0.65	0.61	-0.04	-0.26	-0.55	-0.37	-0.20
800	0.812	0.150	0.000	0.080	0.110	0.73	0.63	0.64	0.56	0.51	1.12	0.24	0.00	0.15	0.22
900	0.080	0.180	-0.100	0.090	0.190	0.69	0.65	0.59	0.58	0.51	0.12	0.28	-0.17	0.16	0.38
1000	-0.070	0.000	-0.200	-0.090	-0.030	0.67	0.73	0.65	0.59	0.52	-0.11	0.00	-0.31	-0.16	-0.06
1250															
1500	0.190	-0.010	-0.200	-0.130	-0.020	0.77	0.63	0.64	0.56	0.52	0.25	-0.02	-0.32	-0.24	-0.04
2000	0.030	-0.020	-0.100	-0.170	0.040	0.69	0.78	0.65	0.57	0.52	0.05	-0.03	-0.16	-0.30	0.08
2500															
3000	0.090	-0.100	-0.199	-0.299	0.199	0.79	1.35	0.73	0.74	0.64	0.12	-0.08	-0.28	-0.41	0.32
3500															
4000	0.059	-0.474	0.000	-0.889	-0.089	0.74	1.01	0.73	0.71	0.64	0.09	-0.47	0.00	-1.26	-0.14
4500															
5000	-0.206	-0.589	0.098	-1.080	0.098	0.75	0.80	0.73	1.34	0.64	-0.28	-0.74	0.14	-0.81	0.16
5500															
6000	-0.936	-1.112	-0.195	-1.365	-0.195	0.77	1.43	0.73	1.43	0.64	-1.22	-0.78	-0.27	-0.96	-0.31
6500															
7000	-0.164	-1.809	-0.481	-2.117	-0.423	0.87	1.24	0.73	1.33	0.64	-0.19	-1.46	-0.66	-1.60	-0.67
7500															
8000	-0.790	-2.493	-0.666	-2.759	-0.438	0.91	1.96	0.73	1.68	0.64	-0.87	-1.28	-0.92	-1.65	-0.69
8500															
9000	-0.103	-2.629	-0.094	-2.723	-0.131	0.79	1.50	0.73	1.86	0.64	-0.14	-1.76	-0.13	-1.47	-0.21
9500															
10000	-0.268	-2.950	-0.185	-3.699	-0.185	0.81	1.40	0.73	1.66	0.64	-0.34	-2.11	-0.26	-2.23	-0.29

Table A 17 Degree of equivalence and E_n -number between SIRIM and other laboratories

Freq	Relative Deviation (%) =100%*$(Y_j-Y_{SIRIM})/Y_{KCRV-3}$					Expanded uncertainty of relative deviation, k=2, (%)					E_n -number				
(Hz)	ITRI	NRLM	KRISS	CSIRO	PTB	ITRI	NRLM	KRISS	CSIRO	PTB	ITRI	NRLM	KRISS	CSIRO	PTB
10															
20															
30		0.291	-0.141	0.462	0.211		0.41	0.40	0.48	0.28		0.72	-0.36	0.97	0.76
40															
50	-0.261	0.100	-0.141		0.010	2.13	1.94	1.87		1.85	-0.13	0.06	-0.08		0.01
60															
70															
80															
90															
100	-0.331	0.040	-0.110	0.090	0.050	1.10	0.44	0.43	0.68	0.32	-0.31	0.10	-0.26	0.14	0.16
160	-0.381	0.020	-0.050	0.150	-0.030	1.10	0.44	0.43	0.68	0.32	-0.35	0.05	-0.12	0.23	-0.10
200	-0.221	0.000	-0.191	0.311	-0.040	1.14	0.68	0.51	0.73	0.43	-0.20	0.00	-0.38	0.43	-0.10
300	-0.652	0.030	-0.201	0.201	0.010	1.09	0.73	0.49	0.67	0.30	-0.60	0.05	-0.41	0.30	0.04
315															
400	-0.411	0.060	0.000	0.200	0.020	1.19	0.62	0.68	0.82	0.56	-0.35	0.10	0.00	0.25	0.04
500	-0.100	0.030	-0.040	0.160	0.040	1.10	0.46	0.50	0.67	0.31	-0.10	0.07	-0.09	0.24	0.13
600	0.170	0.070	-0.140	0.060	0.130	1.09	0.40	0.47	0.65	0.26	0.16	0.18	-0.30	0.10	0.51
630															
700	0.210	0.070	-0.160	0.240	0.120	0.52	0.36	0.46	0.65	0.25	0.41	0.20	-0.35	0.37	0.49
800	0.732	0.070	-0.080	-0.080	0.030	0.59	0.45	0.48	0.56	0.27	1.25	0.16	-0.17	-0.15	0.12
900	-0.010	0.090	-0.190	-0.090	0.100	0.55	0.49	0.42	0.58	0.30	-0.02	0.19	-0.46	-0.16	0.34
1000	0.020	0.090	-0.110	0.090	0.060	0.53	0.61	0.50	0.59	0.32	0.04	0.15	-0.23	0.16	0.19
1250															
1500	0.320	0.120	-0.070	0.130	0.110	0.63	0.45	0.47	0.56	0.26	0.51	0.27	-0.15	0.24	0.43
2000	0.200	0.150	0.070	0.170	0.210	0.54	0.65	0.48	0.57	0.28	0.38	0.24	0.15	0.30	0.75
2500															
3000	0.389	0.199	0.100	0.299	0.498	0.67	1.28	0.59	0.74	0.48	0.59	0.16	0.17	0.41	1.04
3500															
4000	0.949	0.415	0.889	0.889	0.800	0.58	0.89	0.55	0.71	0.43	1.64	0.47	1.62	1.26	1.87
4500															
5000	0.873	0.491	1.178	1.080	1.178	1.27	1.30	1.26	1.34	1.21	0.69	0.38	0.94	0.81	0.98
5500															
6000	0.429	0.254	1.170	1.365	1.170	1.37	1.83	1.35	1.43	1.31	0.32	0.14	0.87	0.96	0.90
6500															
7000	1.953	0.308	1.636	2.117	1.694	1.33	1.61	1.25	1.33	1.20	1.47	0.20	1.31	1.60	1.42
7500															
8000	1.970	0.266	2.093	2.759	2.322	1.71	2.44	1.62	1.68	1.58	1.16	0.11	1.30	1.65	1.47
8500															
9000	2.619	0.094	2.629	2.723	2.591	1.83	2.23	1.80	1.86	1.77	1.44	0.05	1.47	1.47	1.47
9500															
10000	3.431	0.749	3.514	3.699	3.514	1.64	2.00	1.60	1.66	1.56	2.10	0.38	2.20	2.23	2.26

Table A 18 Degree of equivalence and E_n -number between PTB and other laboratories

Freq	Relative Deviation (%) =100%*$(Y_j-Y_{PTB})/Y_{KCRV-3}$					Expanded uncertainty of relative deviation, k=2, (%)					E_n -number				
(Hz)	ITRI	NRLM	KRISS	CSIRO	SIRIM	ITRI	NRLM	KRISS	CSIRO	SIRIM	ITRI	NRLM	KRISS	CSIRO	SIRIM
10			-0.070					0.42					-0.17		
20			-0.342					0.32					-1.07		
30		0.080	-0.352	0.251	-0.211		0.33	0.32	0.42	0.28		0.25	-1.10	0.60	-0.76
40			-0.181	0.020				0.32	0.42				-0.57	0.05	
50	-0.271	0.090	-0.151		-0.010	1.07	0.62	0.32		1.85	-0.26	0.15	-0.48		-0.01
60			-0.050	0.151				0.32	0.61				-0.16	0.25	
70			-0.060					0.32					-0.19		
80			-0.090	0.110				0.32	0.61				-0.29	0.19	
90			-0.121					0.32					-0.38		
100	-0.381	-0.010	-0.161	0.040	-0.050	1.07	0.34	0.32	0.61	0.32	-0.36	-0.03	-0.51	0.07	-0.16
160	-0.351	0.050	-0.020	0.181	0.030	1.07	0.33	0.32	0.61	0.32	-0.33	0.16	-0.07	0.30	0.10
200	-0.181	0.040	-0.150	0.351	0.040	1.07	0.55	0.32	0.62	0.43	-0.17	0.08	-0.48	0.57	0.10
300	-0.662	0.020	-0.211	0.191	-0.010	1.06	0.68	0.42	0.61	0.30	-0.63	0.03	-0.51	0.32	-0.04
315			-0.211					0.42					-0.51		
400	-0.431	0.040	-0.020	0.180	-0.020	1.06	0.30	0.42	0.61	0.56	-0.41	0.14	-0.05	0.30	-0.04
500	-0.140	-0.010	-0.080	0.120	-0.040	1.07	0.37	0.42	0.61	0.31	-0.14	-0.03	-0.20	0.20	-0.13
600	0.040	-0.060	-0.271	-0.070	-0.130	1.07	0.33	0.42	0.61	0.26	0.04	-0.19	-0.65	-0.12	-0.51
630			-0.241					0.42					-0.58		
700	0.090	-0.050	-0.281	0.120	-0.120	0.49	0.30	0.42	0.61	0.25	0.19	-0.17	-0.67	0.20	-0.49
800	0.702	0.040	-0.110	-0.110	-0.030	0.54	0.39	0.42	0.51	0.27	1.30	0.11	-0.27	-0.22	-0.12
900	-0.110	-0.010	-0.291	-0.190	-0.100	0.48	0.42	0.32	0.51	0.30	-0.23	-0.03	-0.91	-0.38	-0.34
1000	-0.040	0.030	-0.170	0.030	-0.060	0.45	0.53	0.42	0.52	0.32	-0.09	0.06	-0.41	0.06	-0.19
1250			-0.230					0.42					-0.55		
1500	0.210	0.010	-0.180	0.020	-0.110	0.59	0.40	0.42	0.52	0.26	0.36	0.03	-0.43	0.04	-0.43
2000	-0.010	-0.060	-0.140	-0.040	-0.210	0.48	0.60	0.42	0.52	0.28	-0.03	-0.10	-0.34	-0.08	-0.75
2500			-0.240					0.45					-0.54		
3000	-0.110	-0.299	-0.399	-0.199	-0.498	0.55	1.22	0.45	0.64	0.48	-0.20	-0.25	-0.89	-0.32	-1.04
3500			0.040			0.20	0.20	0.45	0.20	0.20			0.09		
4000	0.148	-0.385	0.089	0.089	-0.800	0.48	0.84	0.45	0.64	0.43	0.31	-0.46	0.20	0.14	-1.87
4500			-0.099					0.45					-0.22		
5000	-0.304	-0.687	0.000	-0.098	-1.178	0.49	0.57	0.45	0.64	1.21	-0.63	-1.21	0.00	-0.16	-0.98
5500			0.127					0.45					0.29		
6000	-0.741	-0.917	0.000	0.195	-1.170	0.52	1.31	0.45	0.64	1.31	-1.43	-0.70	0.00	0.31	-0.90
6500			-0.194					0.45					-0.44		
7000	0.260	-1.386	-0.058	0.423	-1.694	0.65	1.11	0.45	0.64	1.20	0.40	-1.25	-0.13	0.67	-1.42
7500			-0.249					0.45					-0.56		
8000	-0.352	-2.055	-0.228	0.438	-2.322	0.71	1.88	0.45	0.64	1.58	-0.50	-1.10	-0.51	0.69	-1.47
8500			-0.189					0.45					-0.42		
9000	0.028	-2.497	0.038	0.131	-2.591	0.54	1.38	0.45	0.64	1.77	0.06	-1.81	0.09	0.21	-1.47
9500			-0.187					0.45					-0.42		
10000	-0.083	-2.765	0.000	0.185	-3.514	0.58	1.28	0.45	0.64	1.56	-0.15	-2.17	0.00	0.29	-2.26

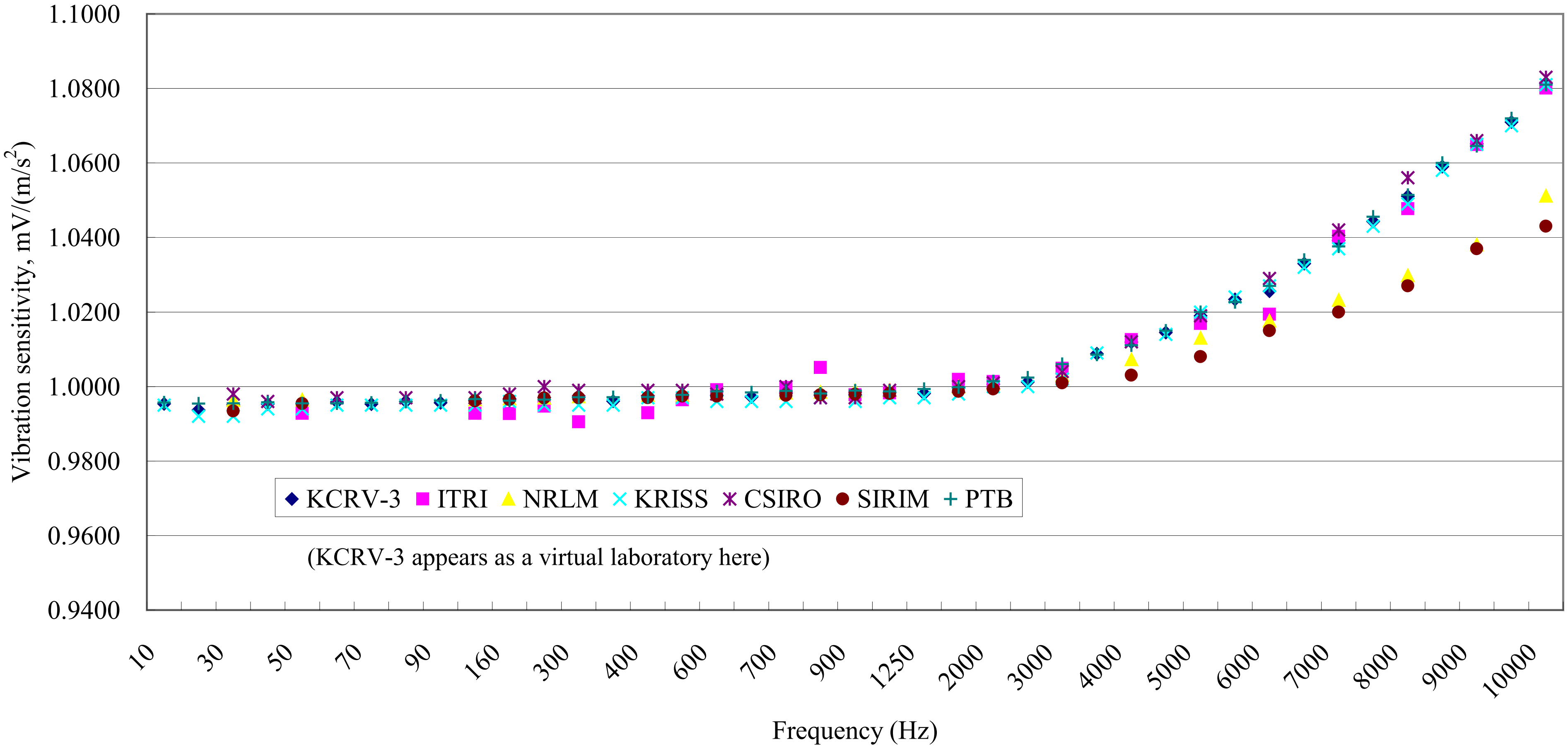

Figure A1 Vibration sensitivity of the accelerometer with a charge amplifier set

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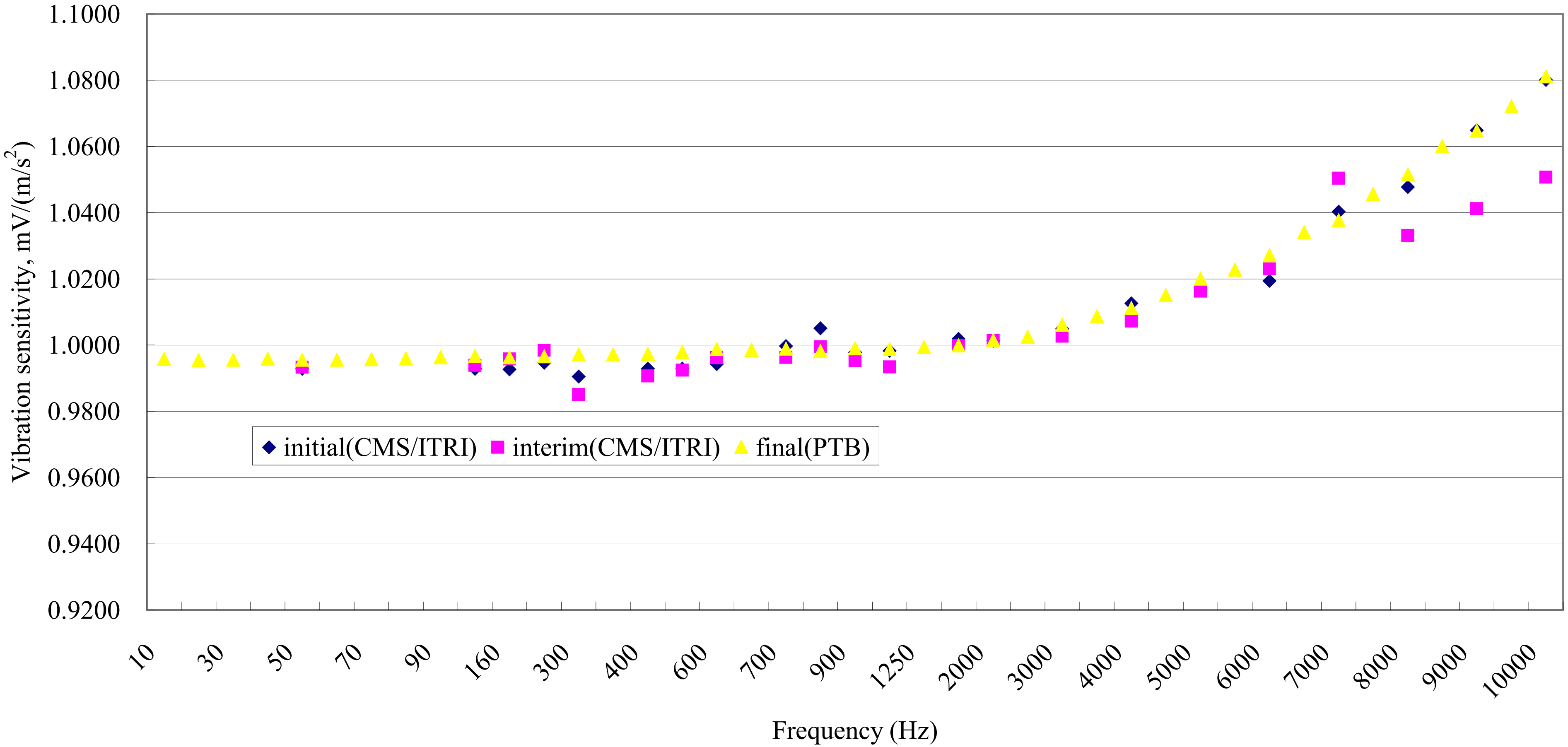

Figure A2 The initial, interim and final sensitivity of the accelerometer in circulation

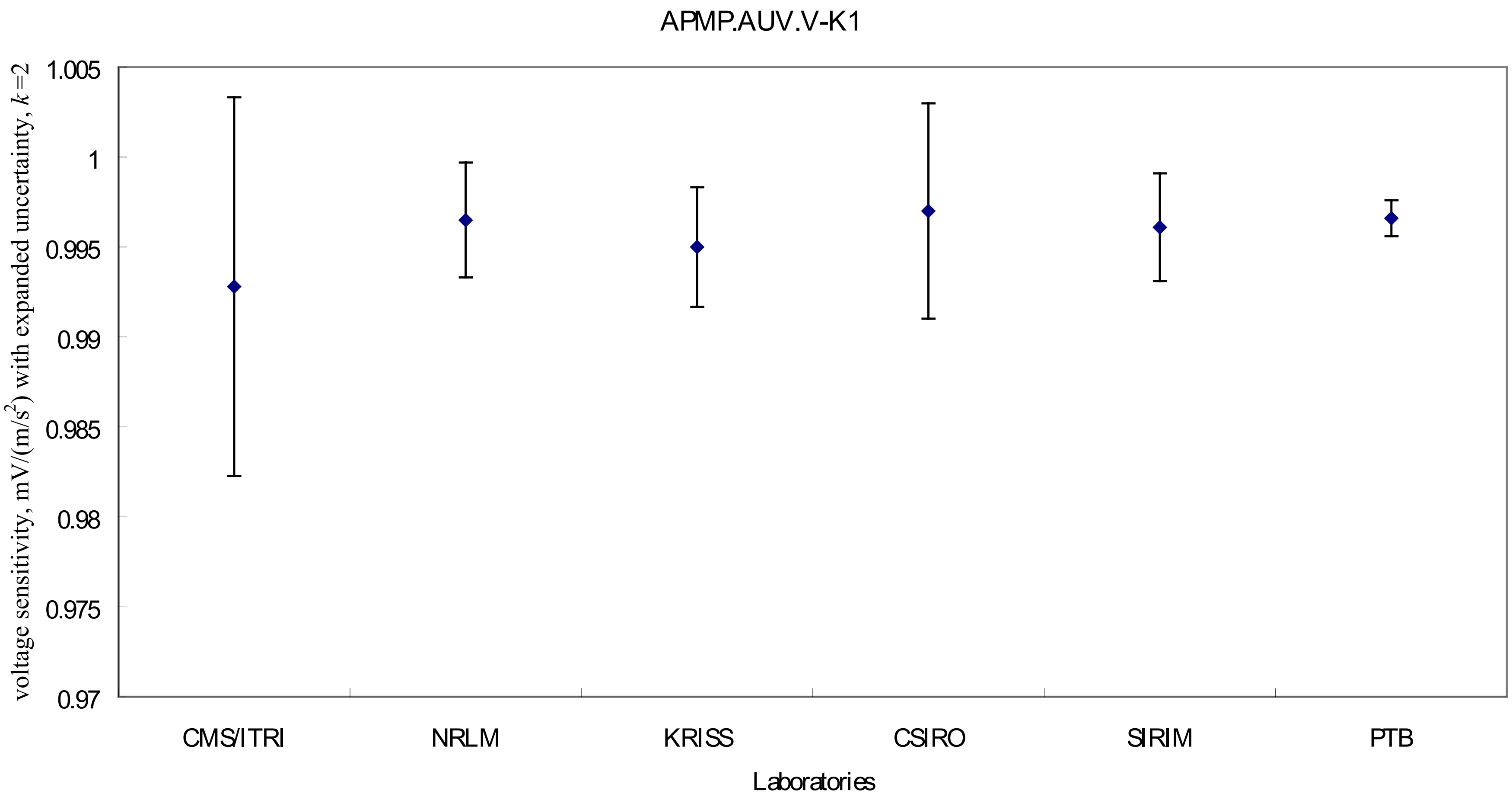

Figure A3 Measurement uncertainty of the accelerometer sensitivity for laboratories at 100 Hz

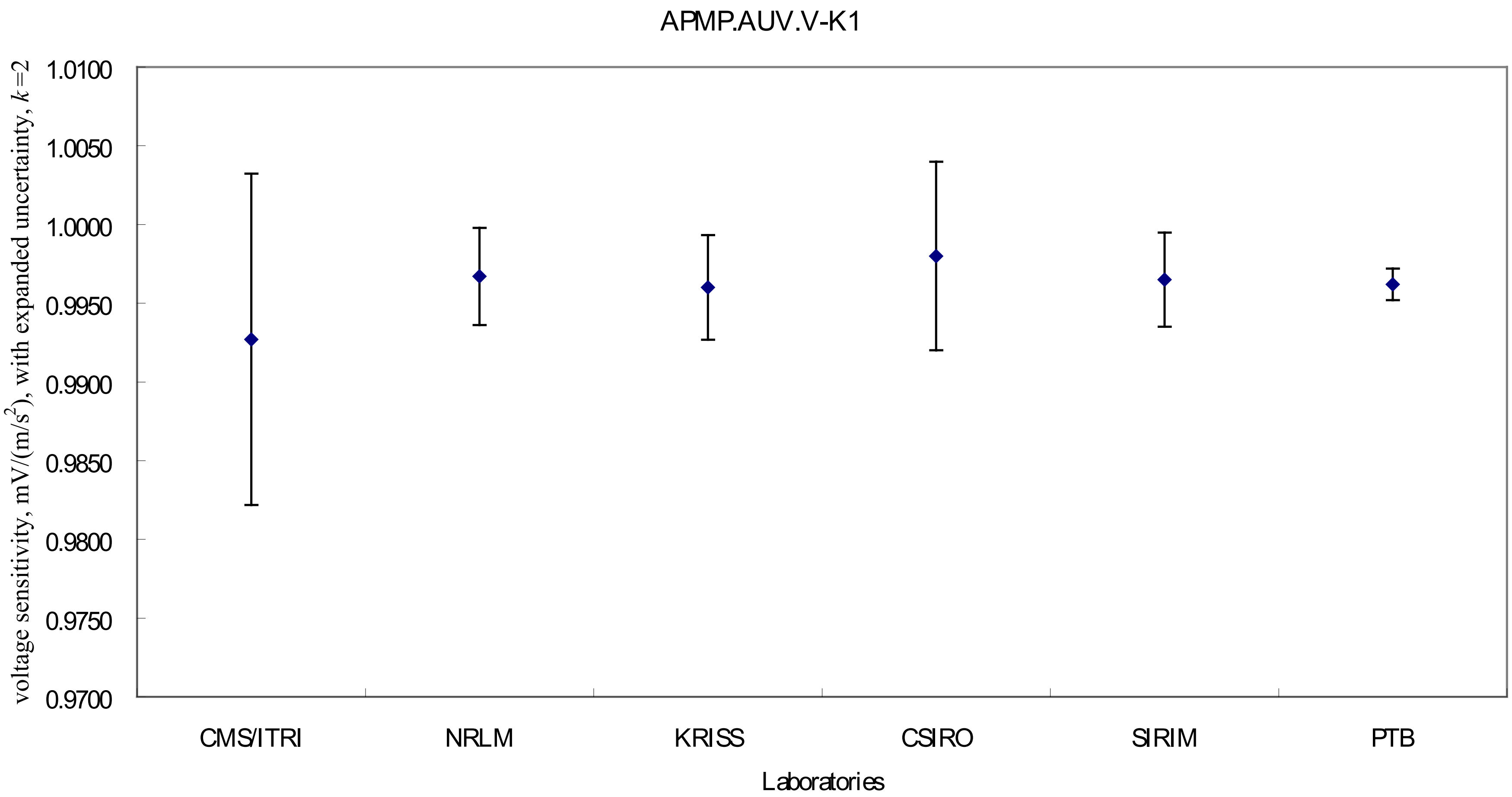

Figure A4 Measurement uncertainty of the accelerometer sensitivity for laboratories at 160 Hz

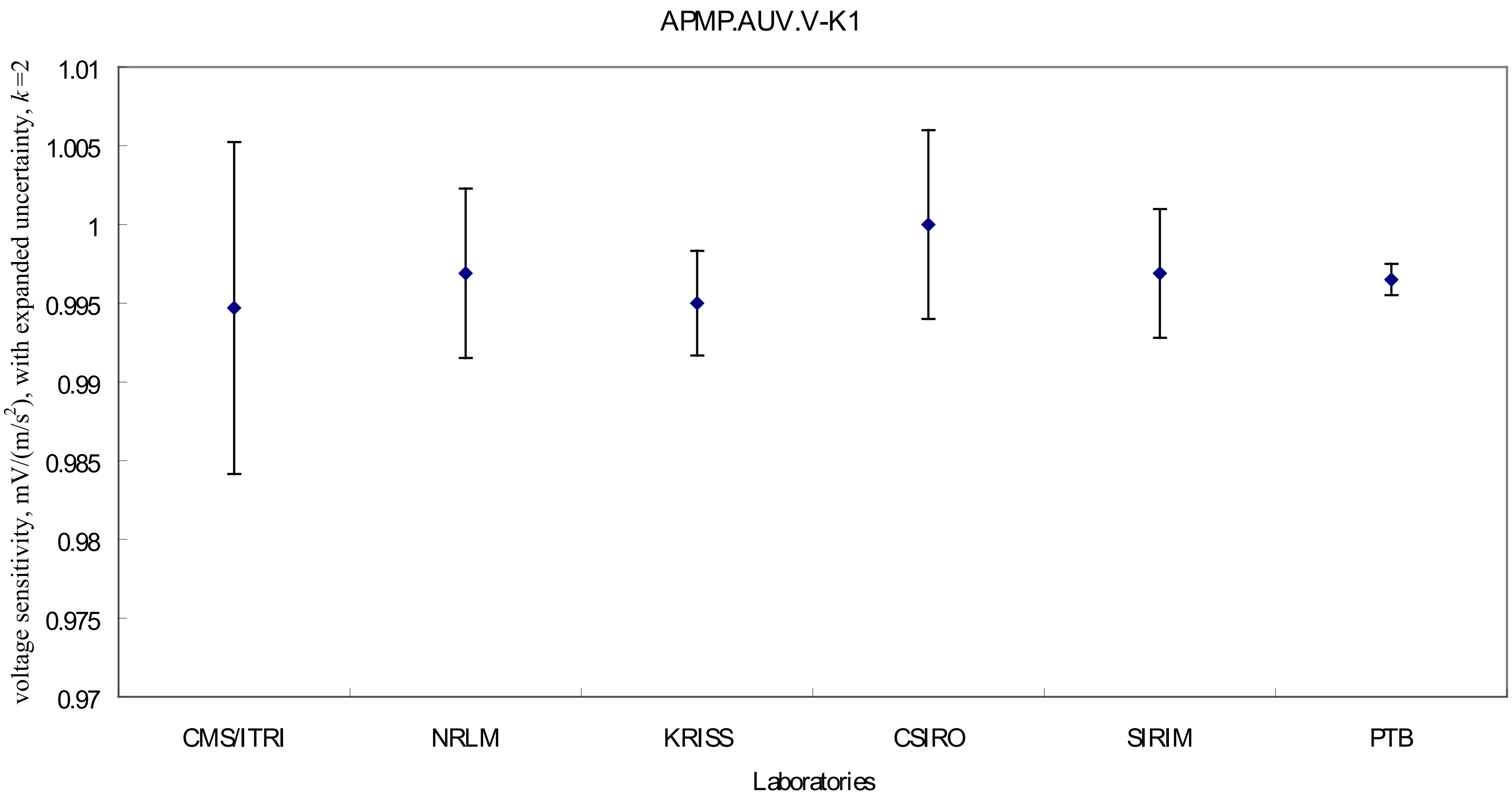

Figure A5 Measurement uncertainty of the accelerometer sensitivity for laboratories at 200 Hz

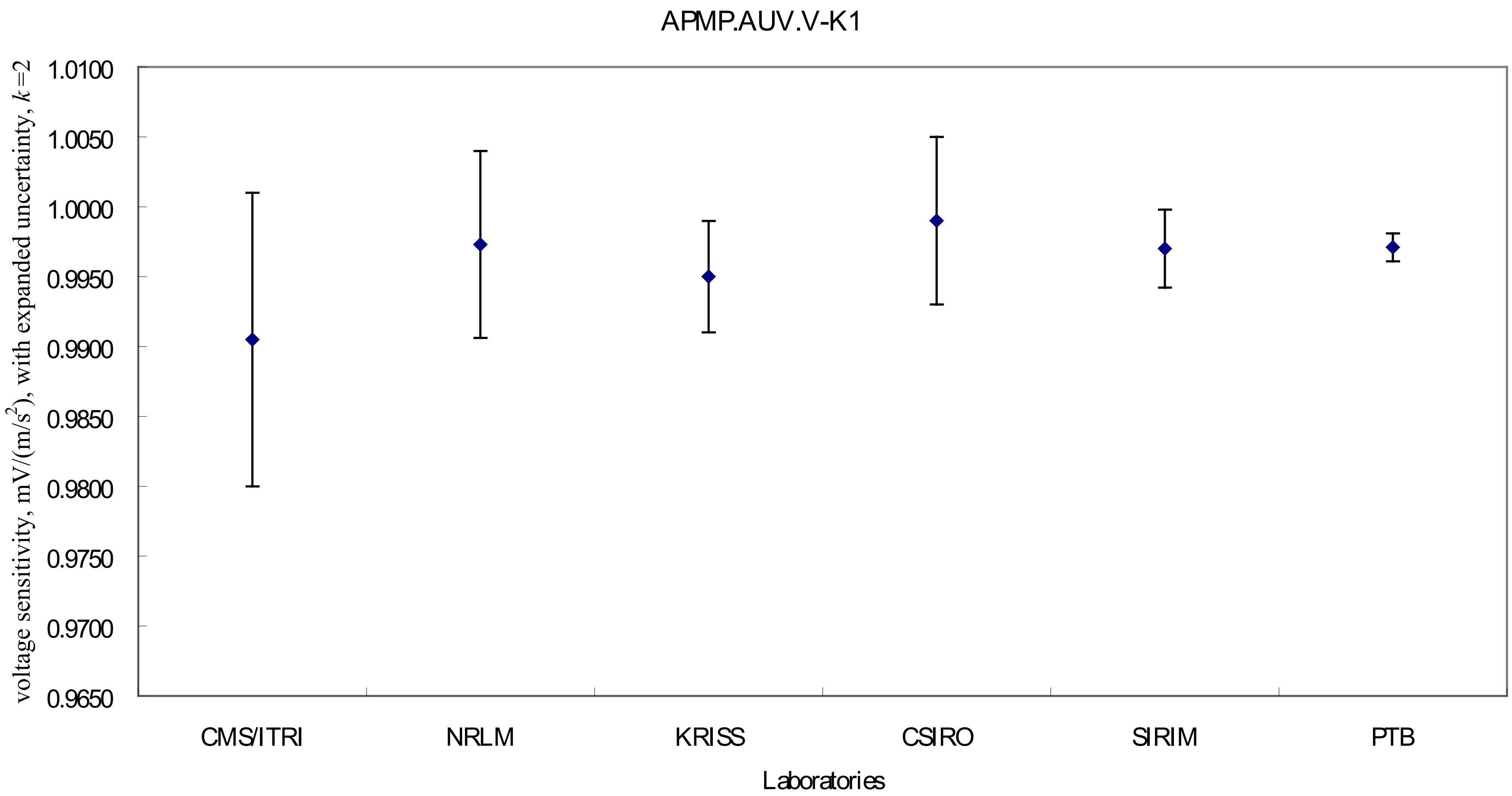

Figure A6 Measurement uncertainty of the accelerometer sensitivity for laboratories at 300 Hz

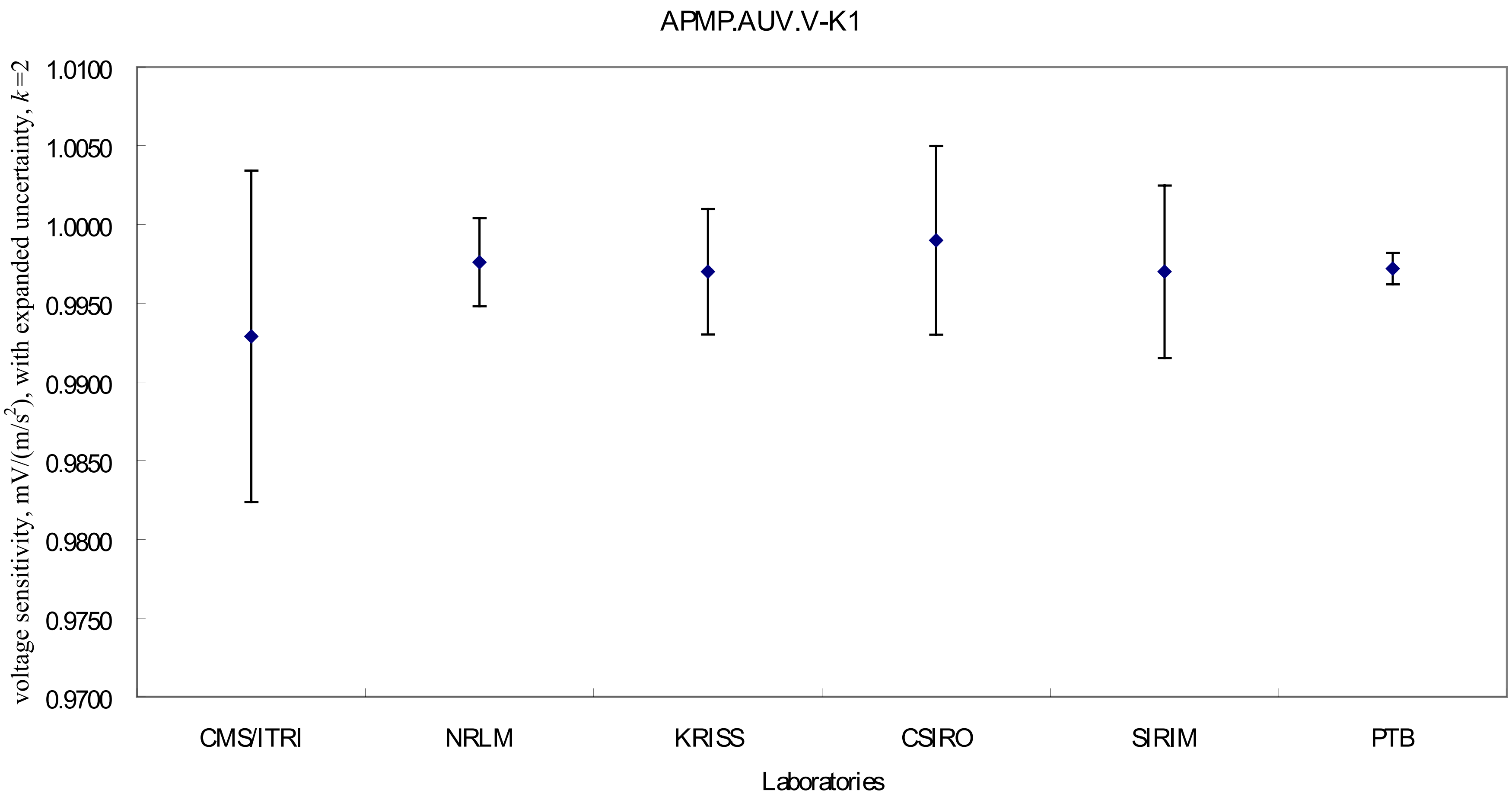

Figure A7 Measurement uncertainty of the accelerometer sensitivity for laboratories at 400 Hz

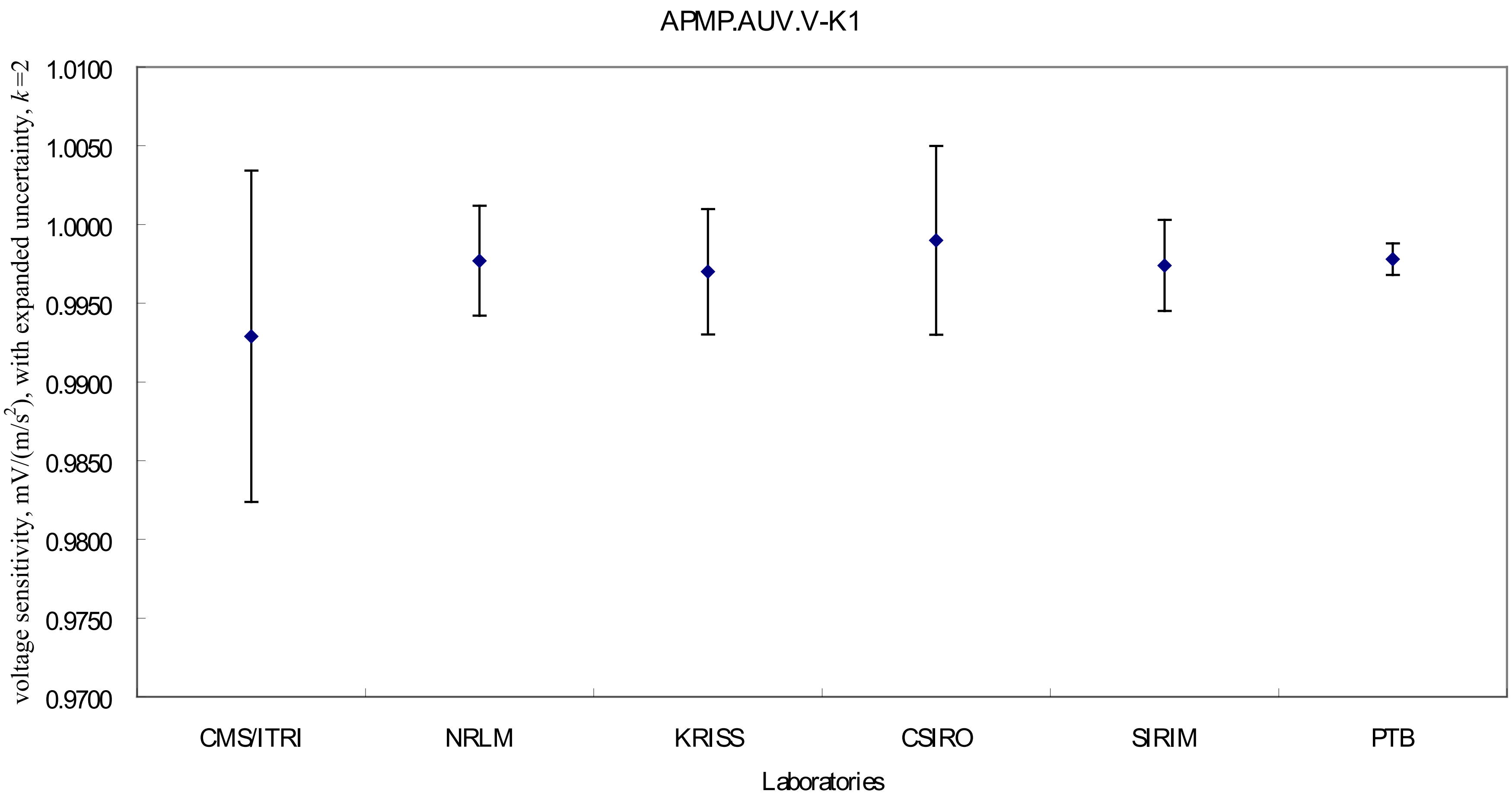

Figure A8 Measurement uncertainty of the accelerometer sensitivity for laboratories at 500 Hz

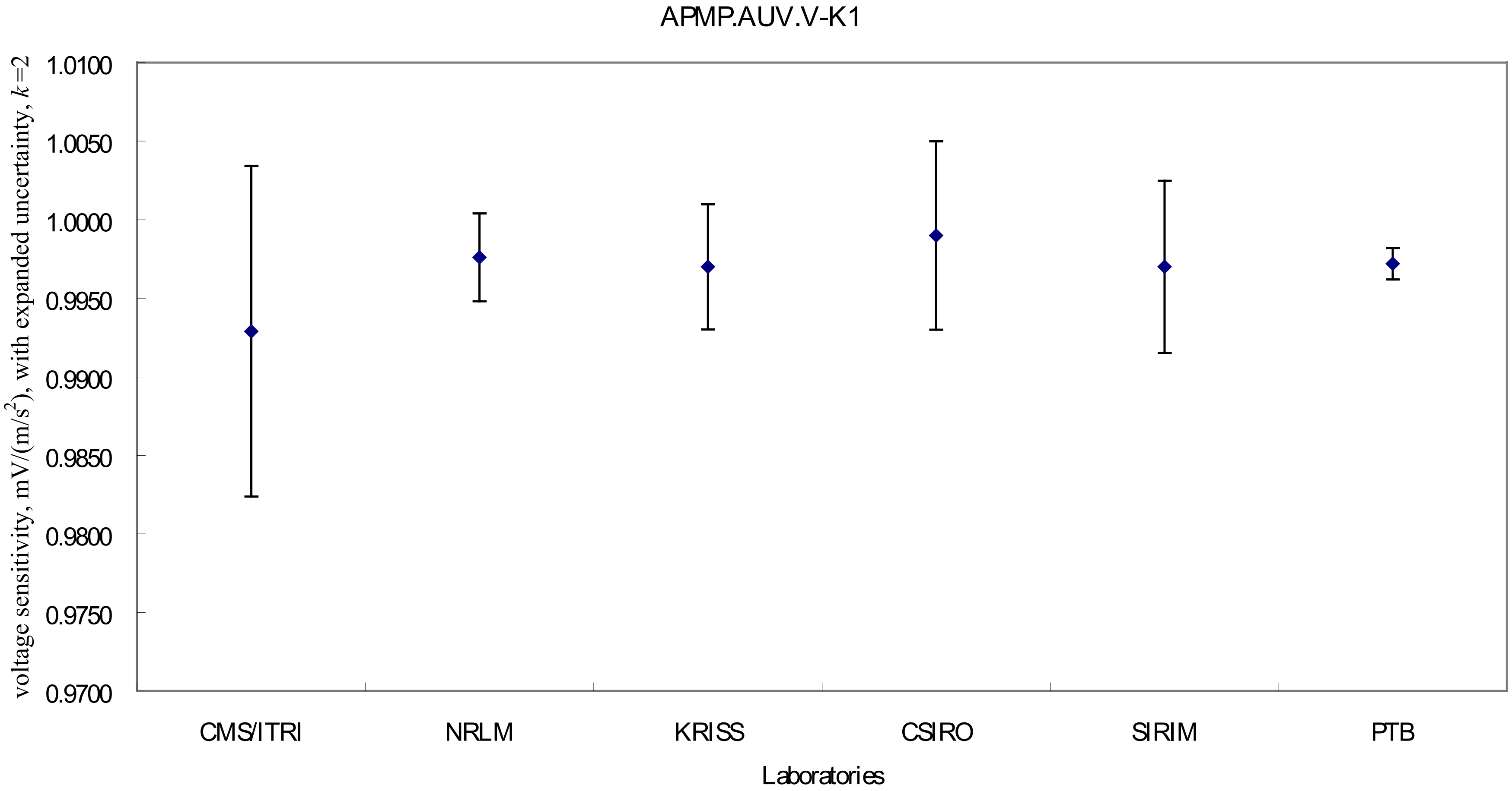

Figure A9 Measurement uncertainty of the accelerometer sensitivity for laboratories at 600 Hz

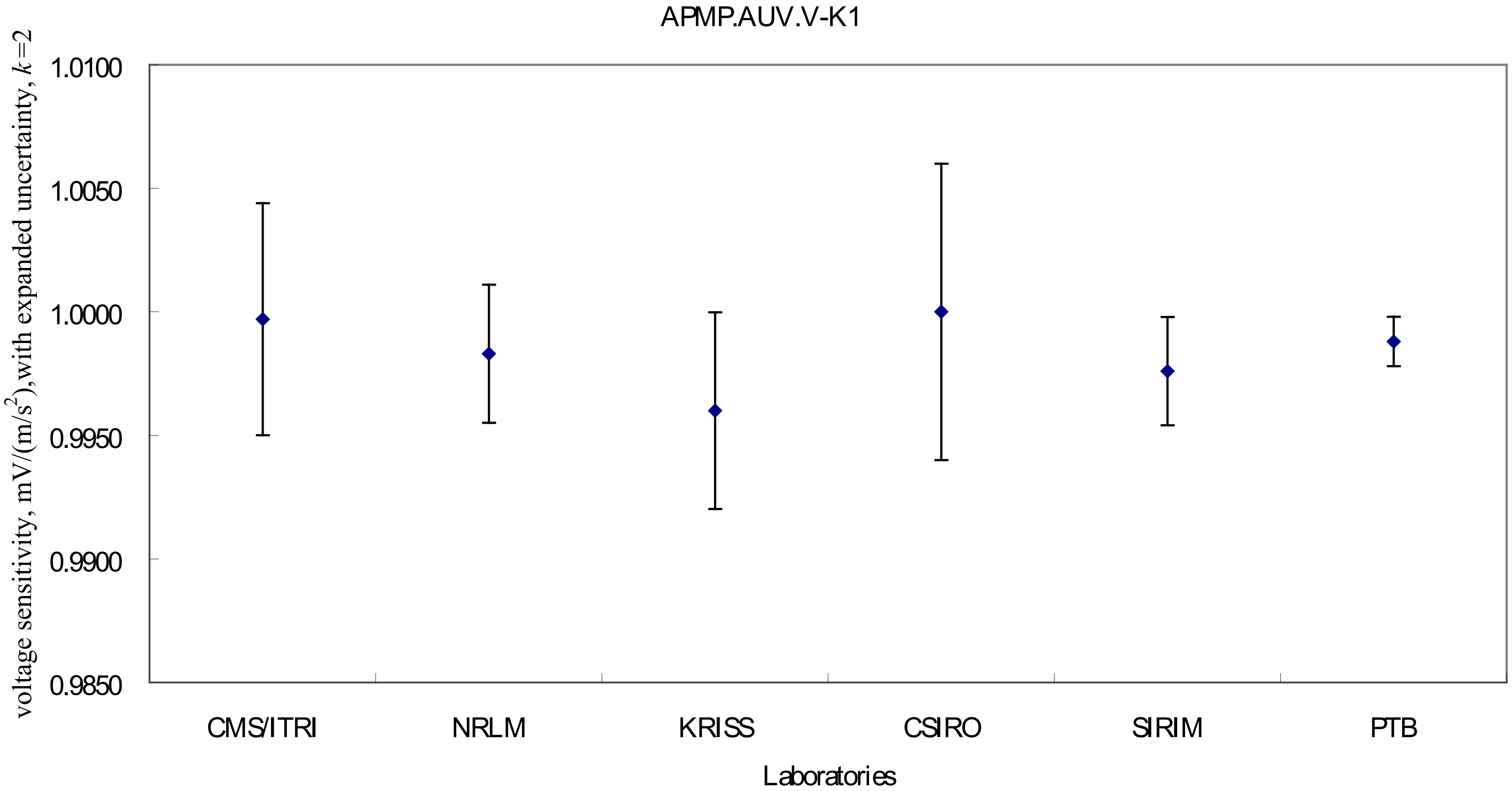

Figure A10 Measurement uncertainty of the accelerometer sensitivity for laboratories at 700 Hz

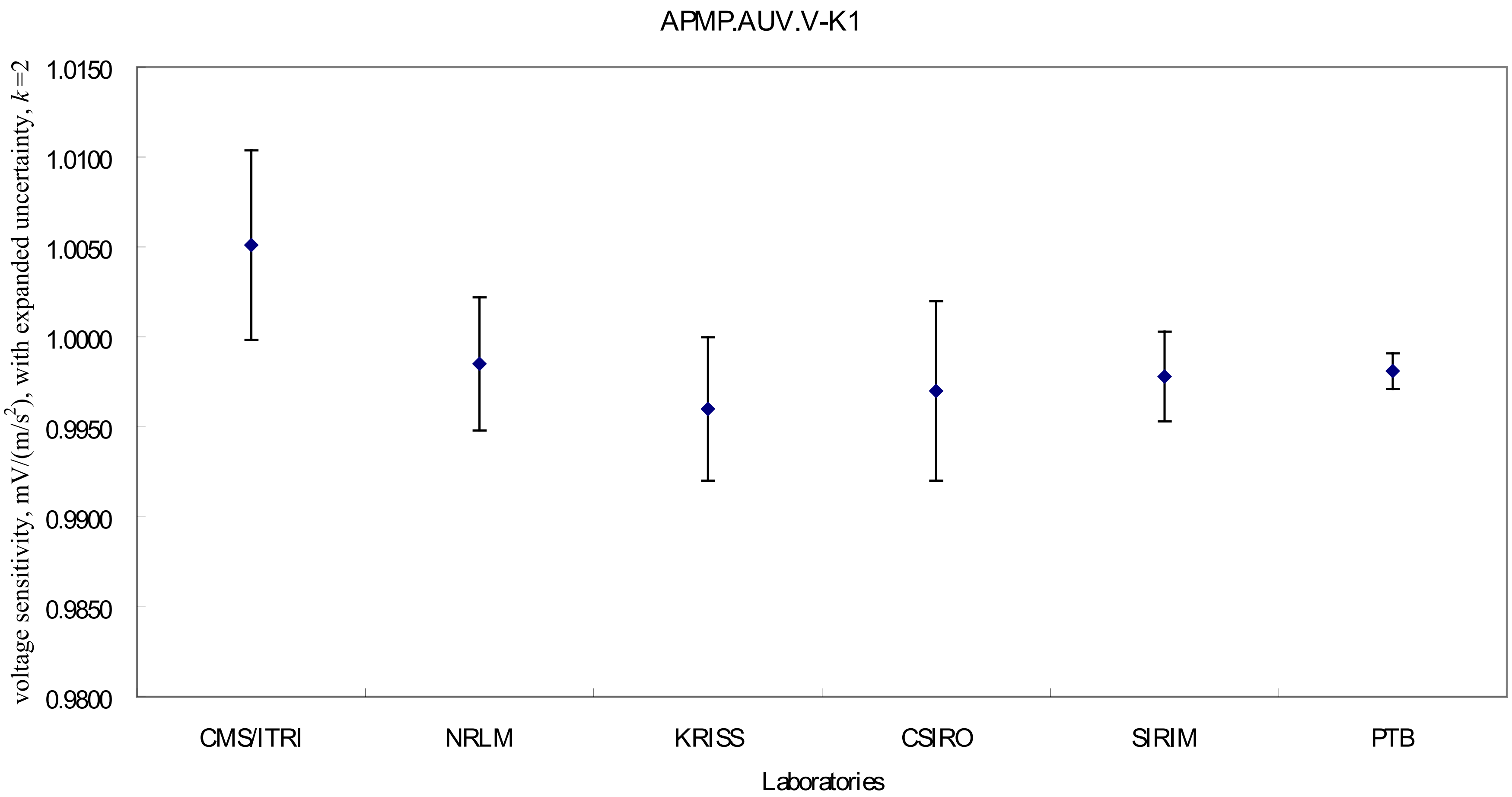

Figure A11 Measurement uncertainty of the accelerometer sensitivity for laboratories at 800 Hz

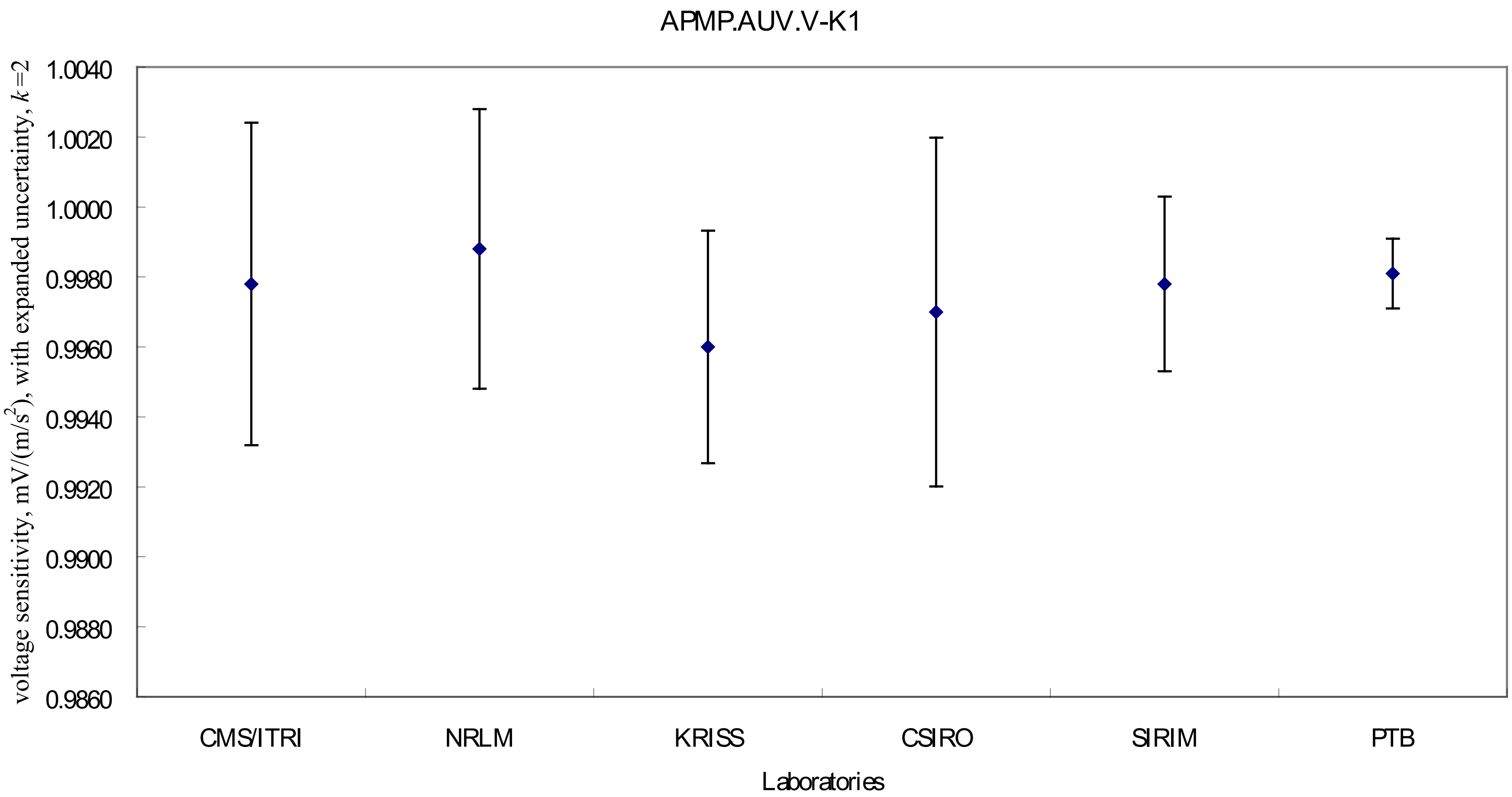

Figure A12 Measurement uncertainty of the accelerometer sensitivity for laboratories at 900 Hz

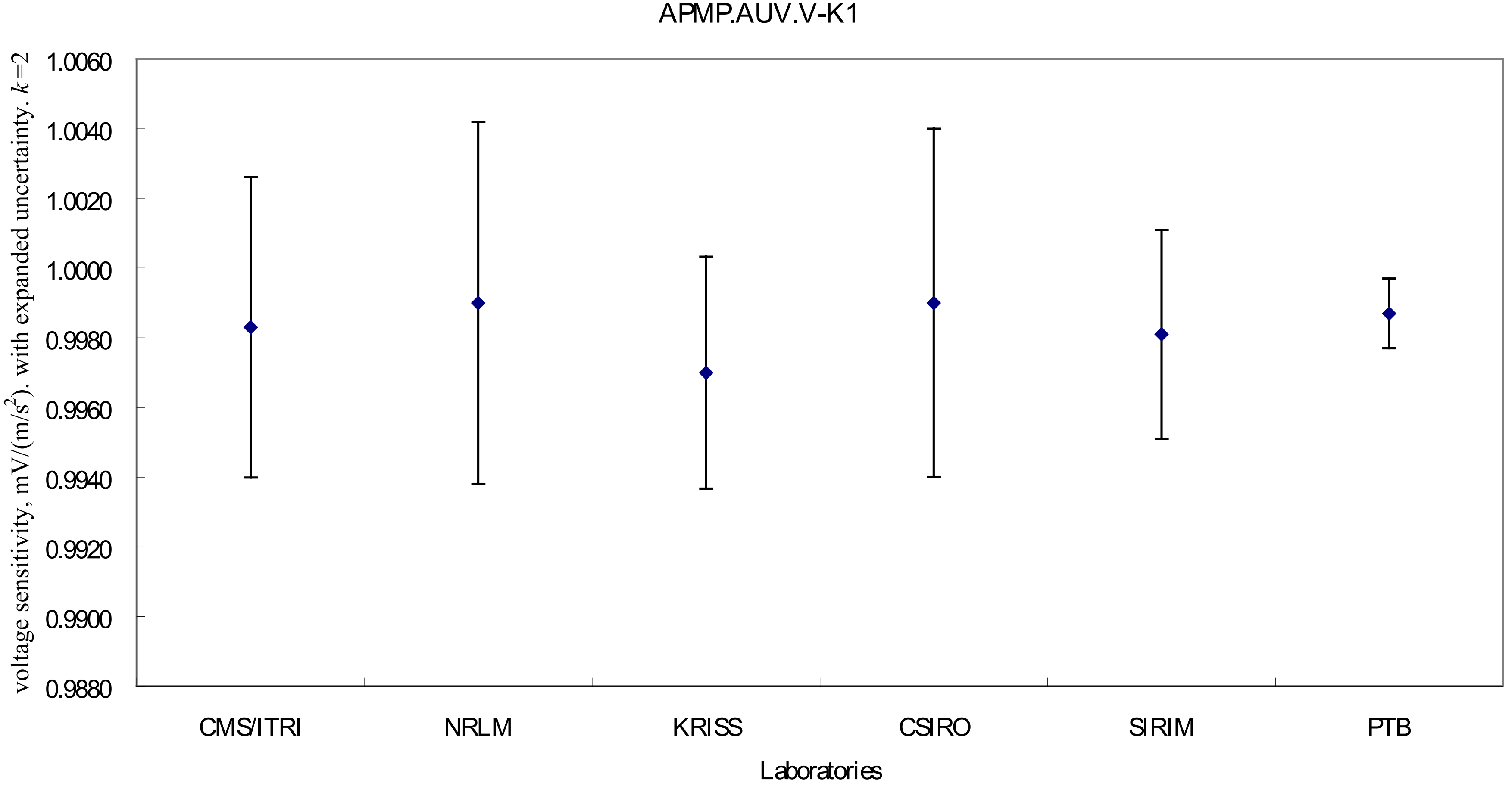

Figure A13 Measurement uncertainty of the accelerometer sensitivity for laboratories at 1000 Hz

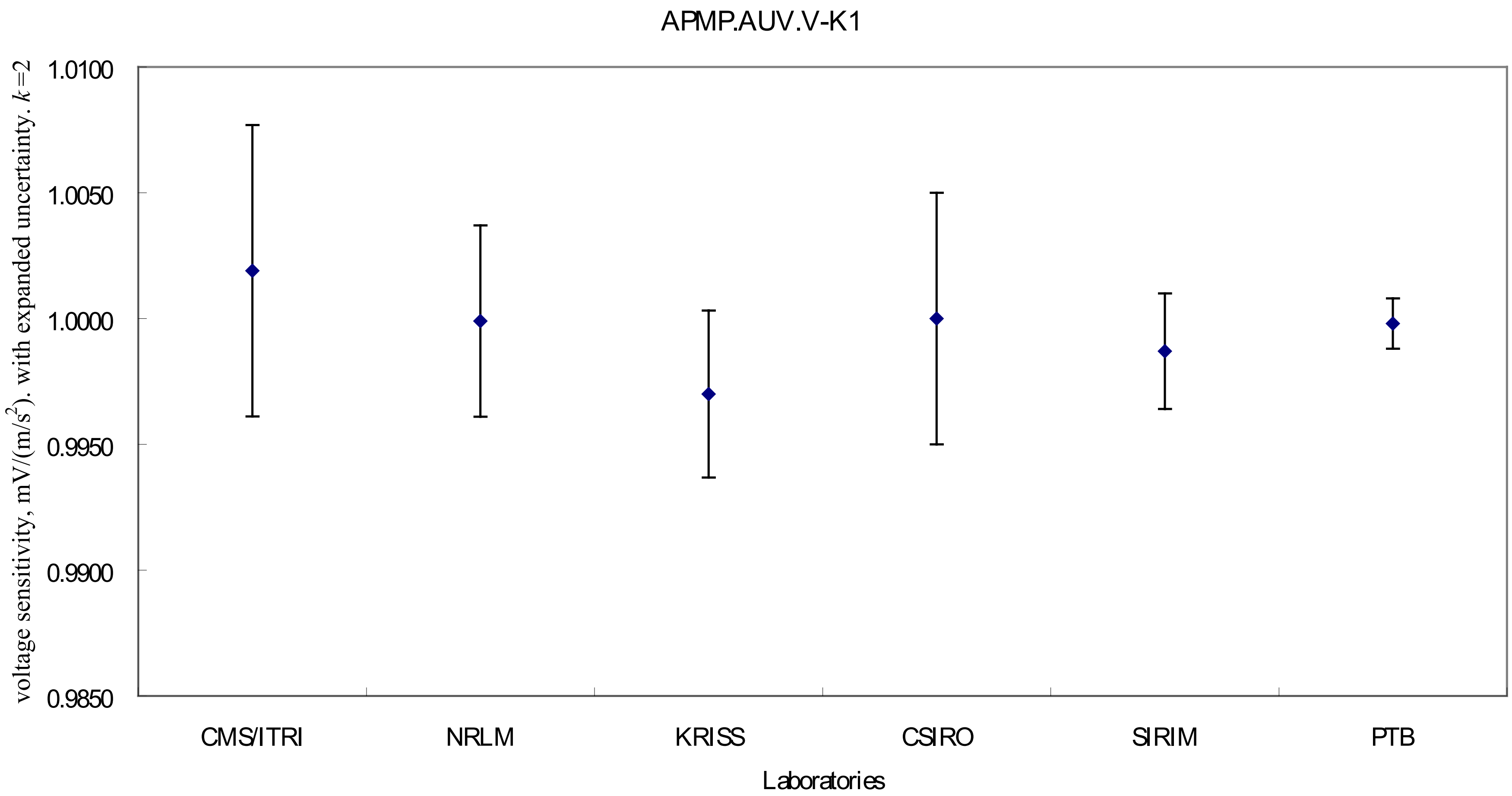

Figure A14 Measurement uncertainty of the accelerometer sensitivity for laboratories at 1500 Hz

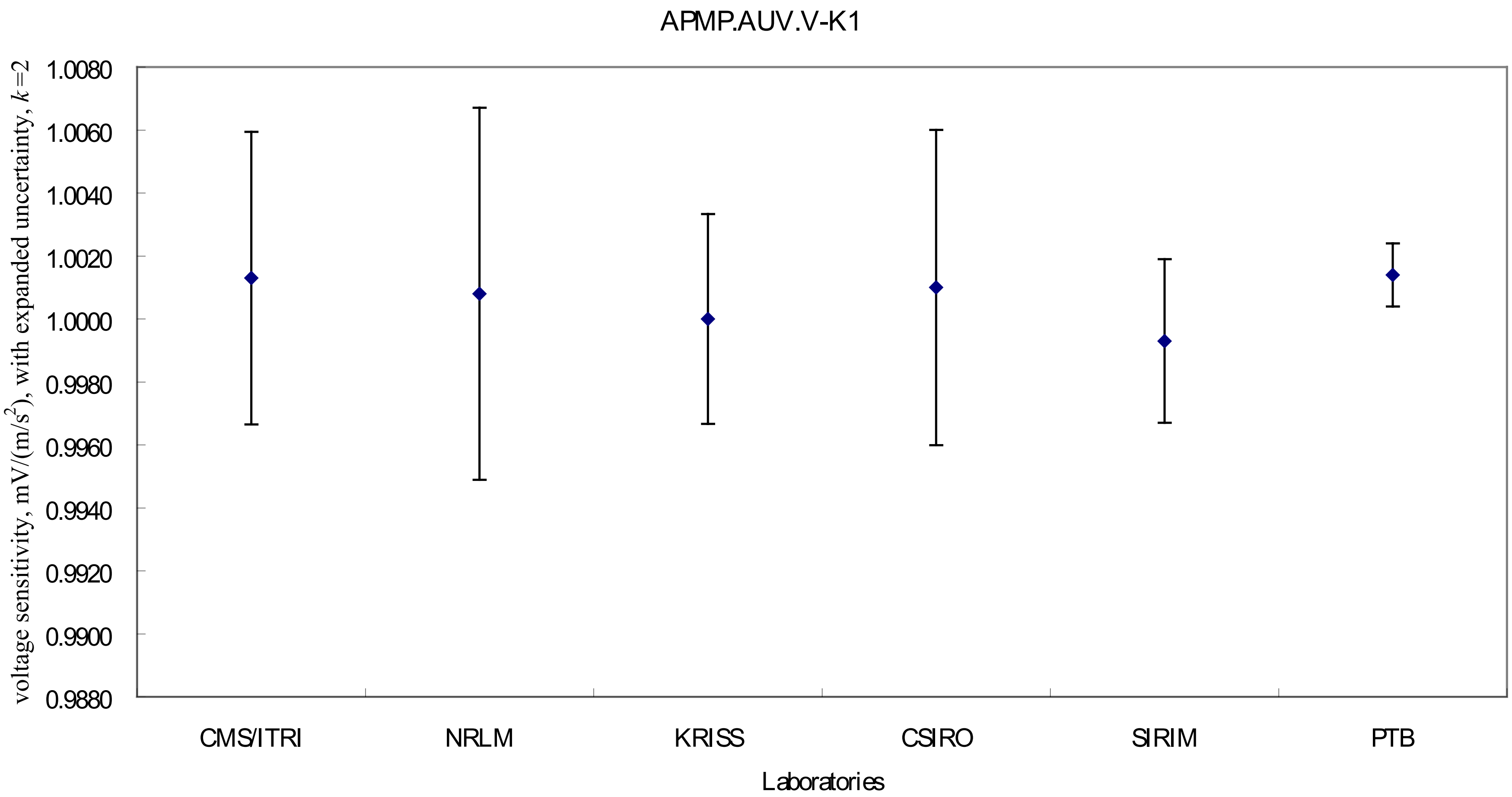

Figure A15 Measurement uncertainty of the accelerometer sensitivity for laboratories at 2000 Hz

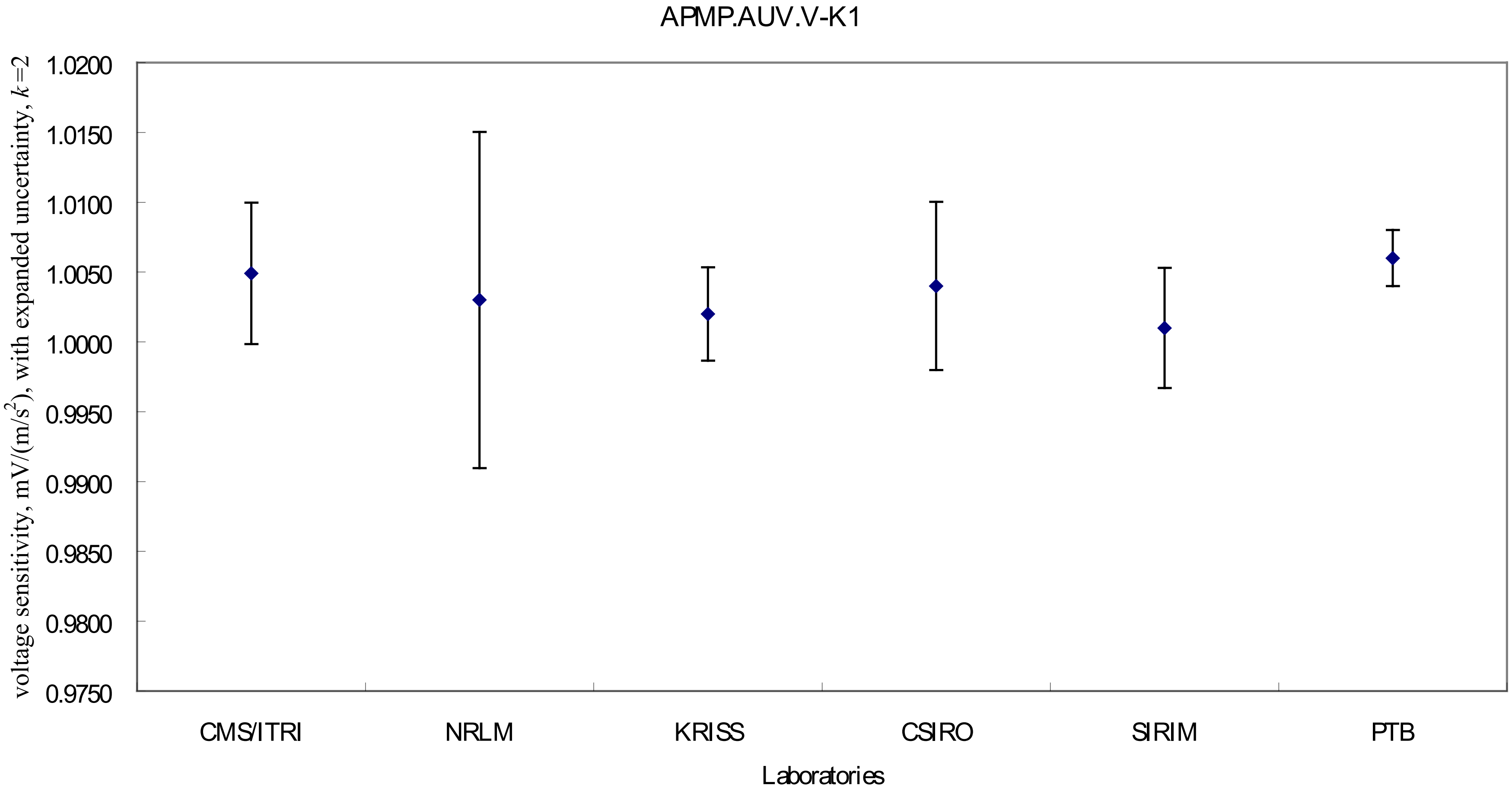

Figure A16 Measurement uncertainty of the accelerometer sensitivity for laboratories at 3000 Hz

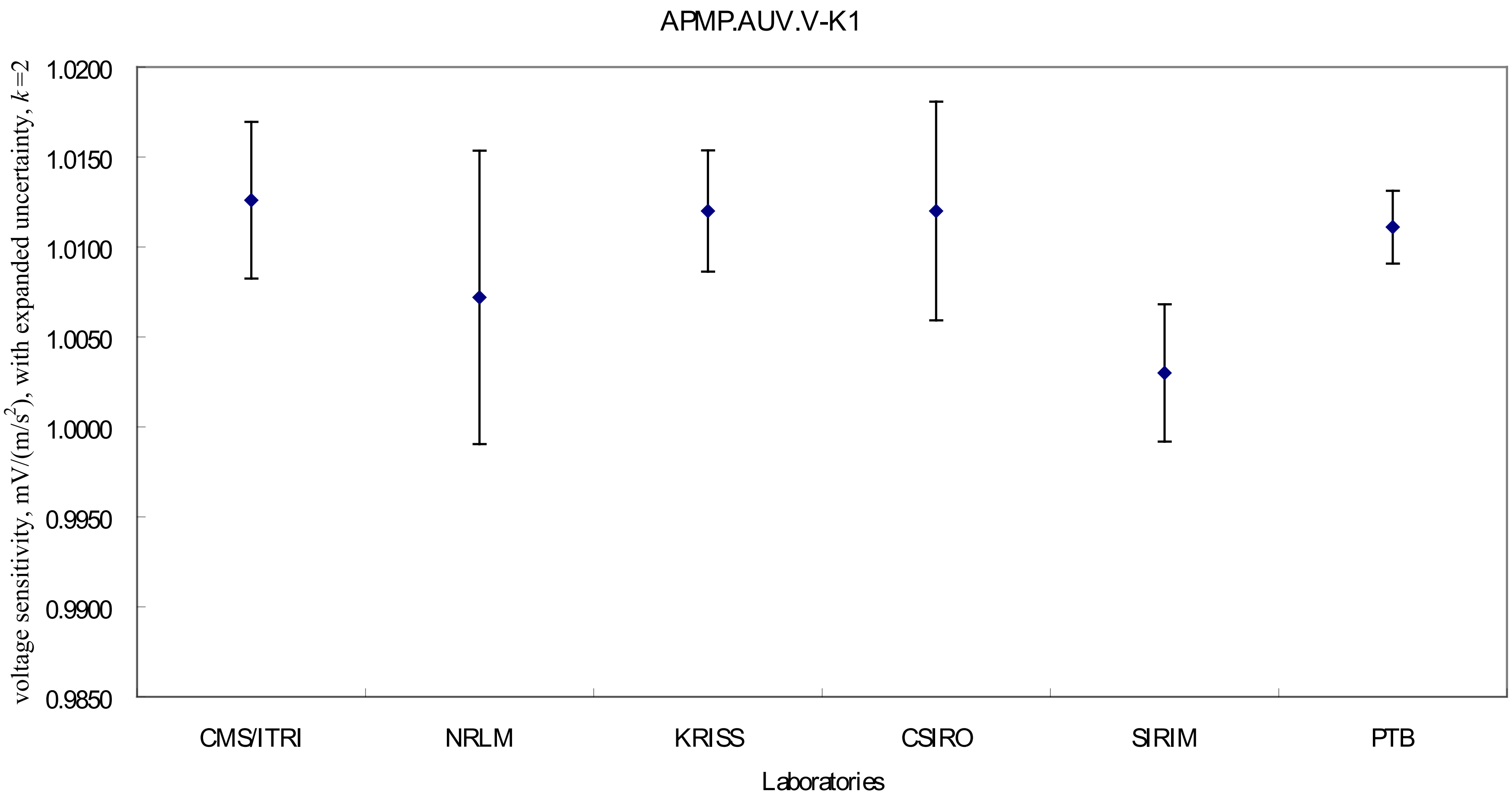

Figure A17 Measurement uncertainty of the accelerometer sensitivity for laboratories at 4000 Hz

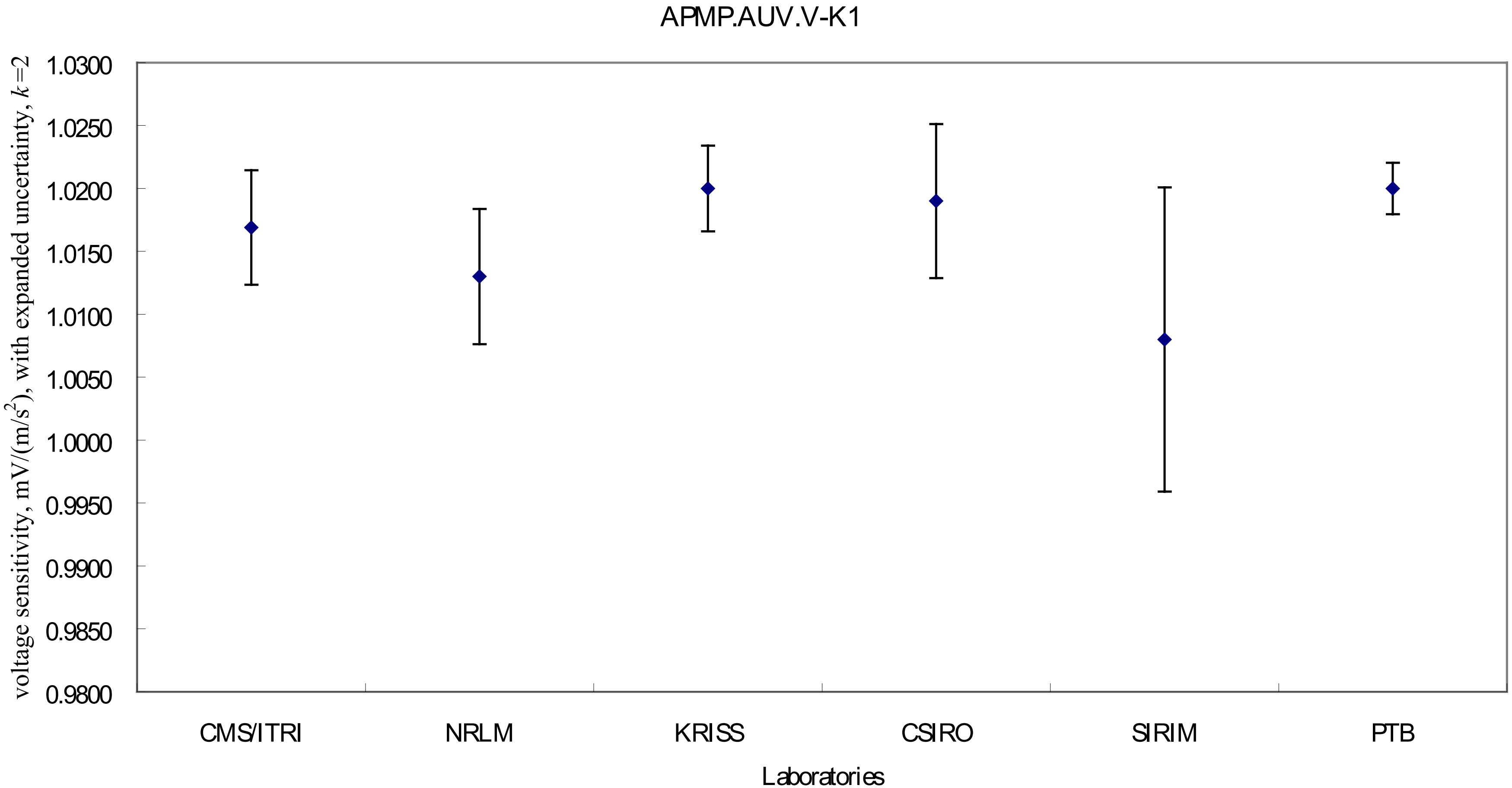

Figure A18 Measurement uncertainty of the accelerometer sensitivity for laboratories at 5000 Hz

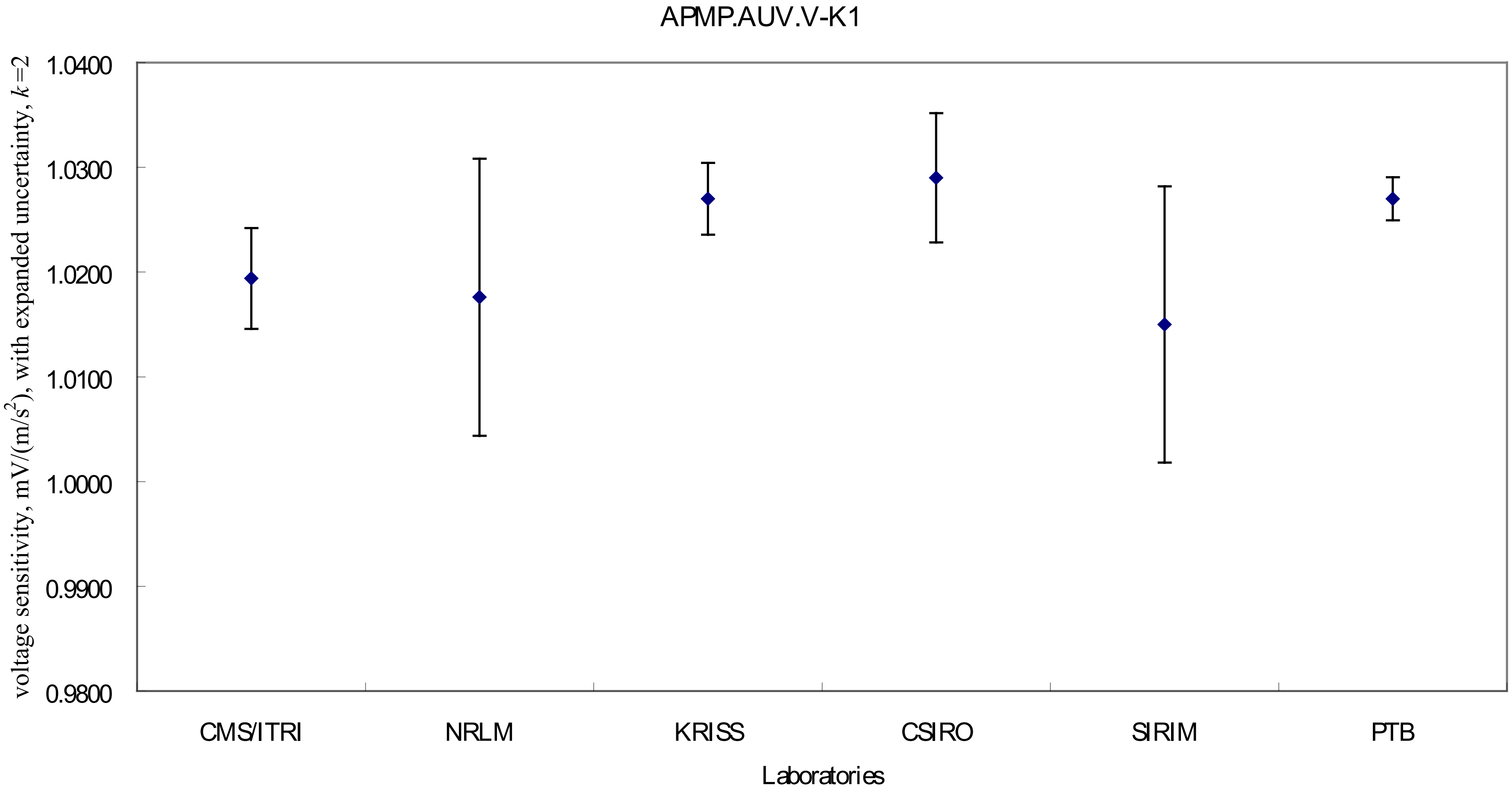

Figure A19 Measurement uncertainty of the accelerometer sensitivity for laboratories at 6000 Hz

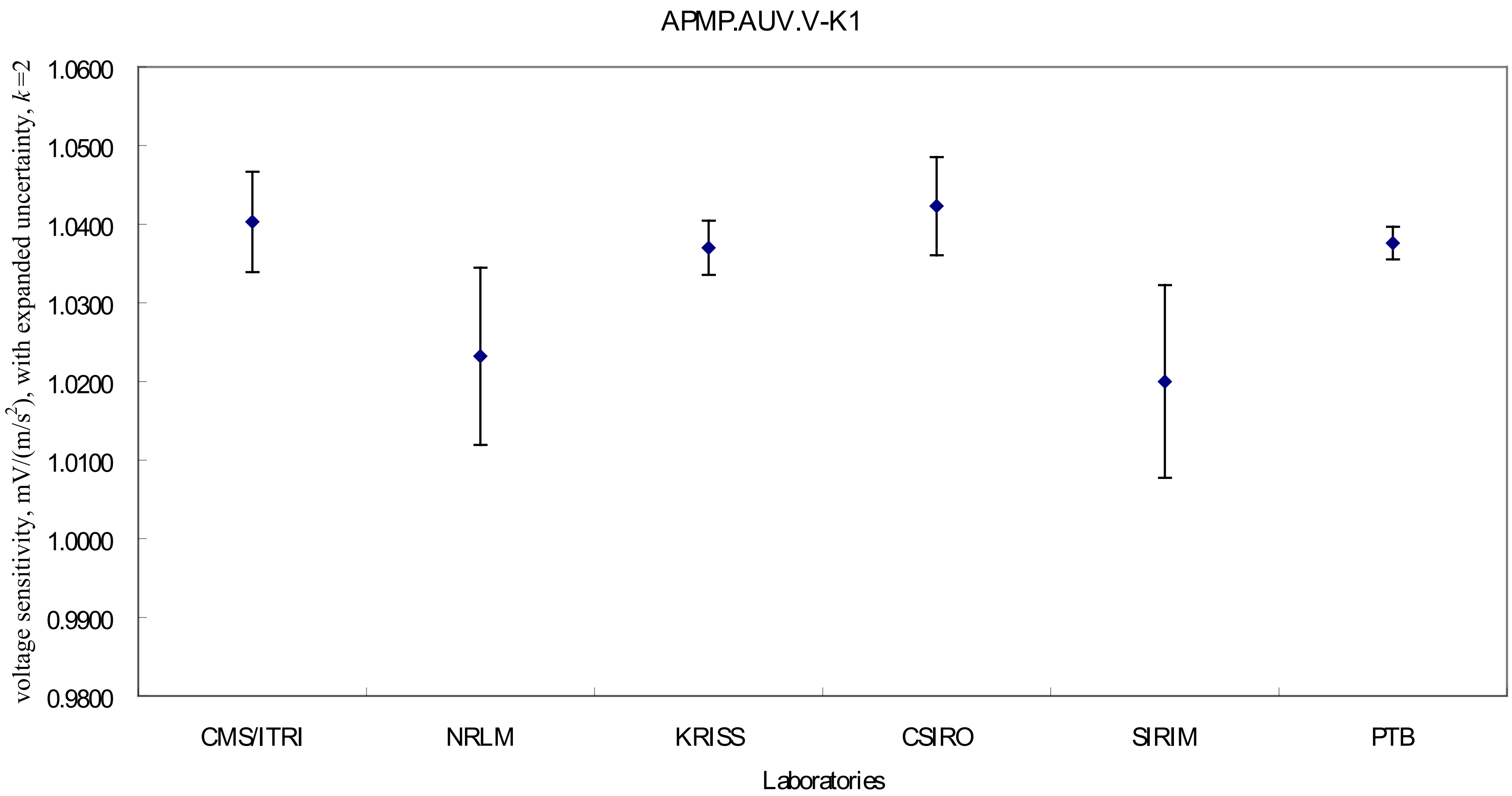

Figure A20 Measurement uncertainty of the accelerometer sensitivity for laboratories at 7000 Hz

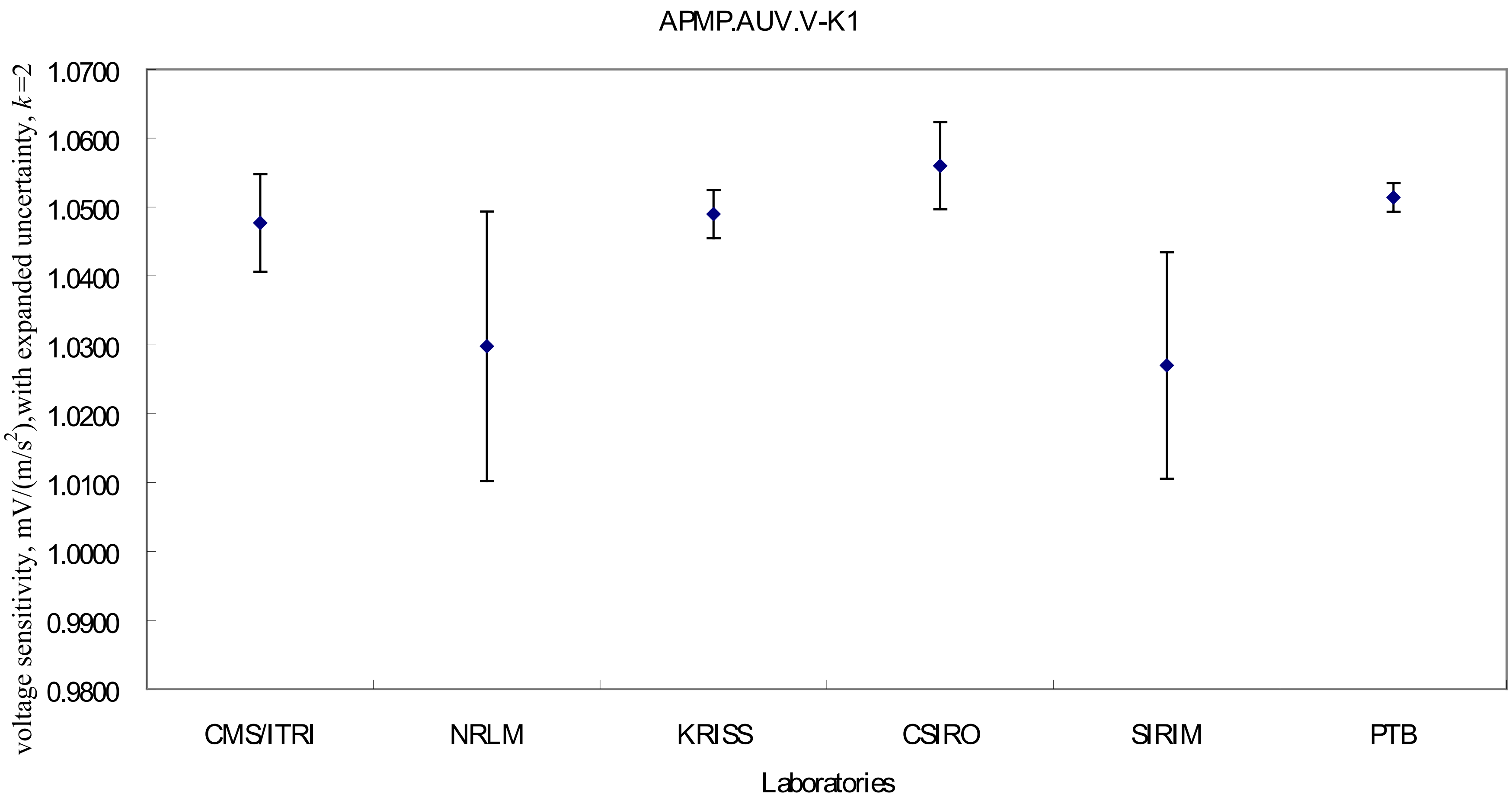

Figure A21 Measurement uncertainty of the accelerometer sensitivity for laboratories at 8000 Hz

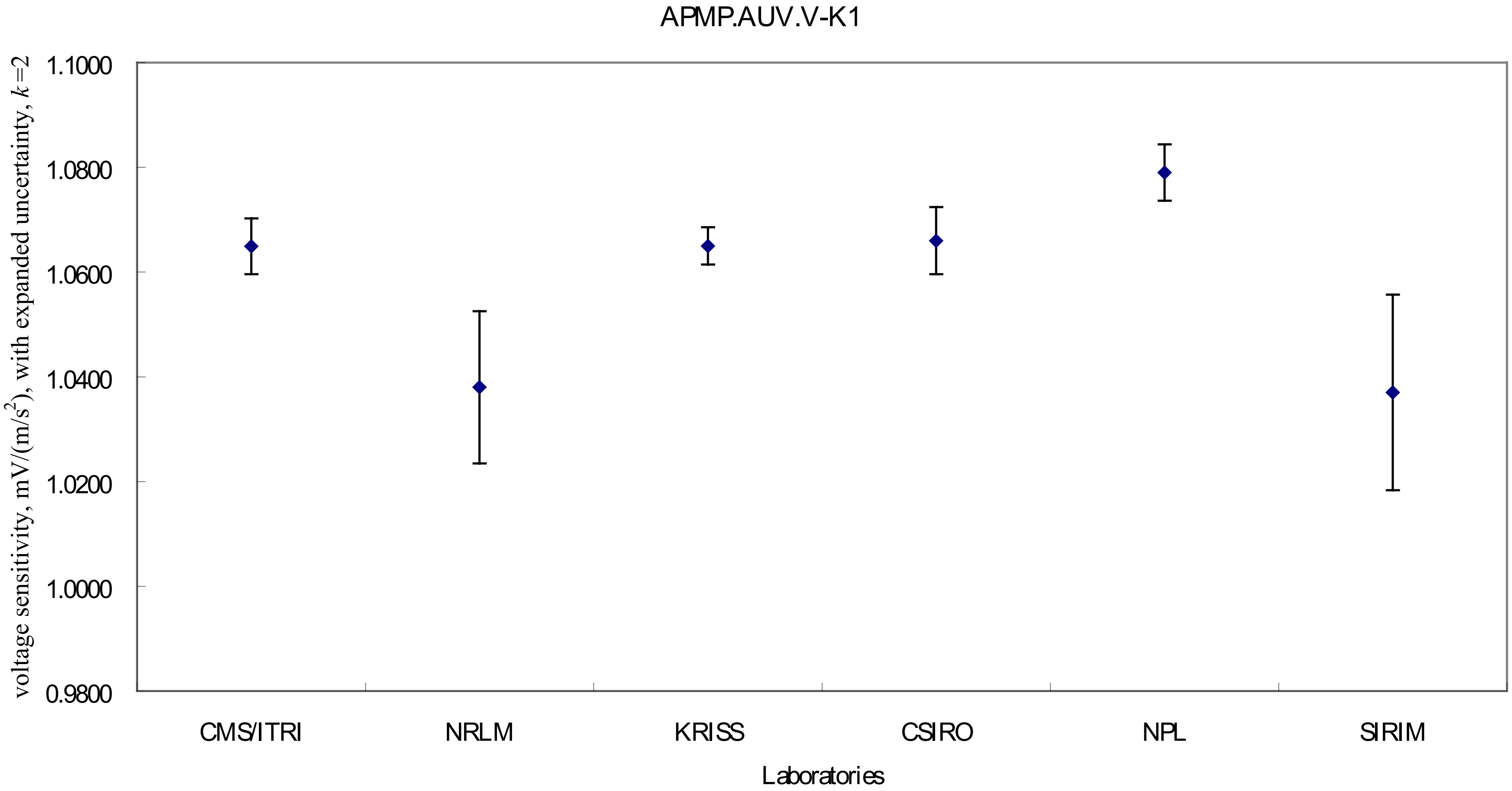

Figure A22 Measurement uncertainty of the accelerometer sensitivity for laboratories at 9000 Hz

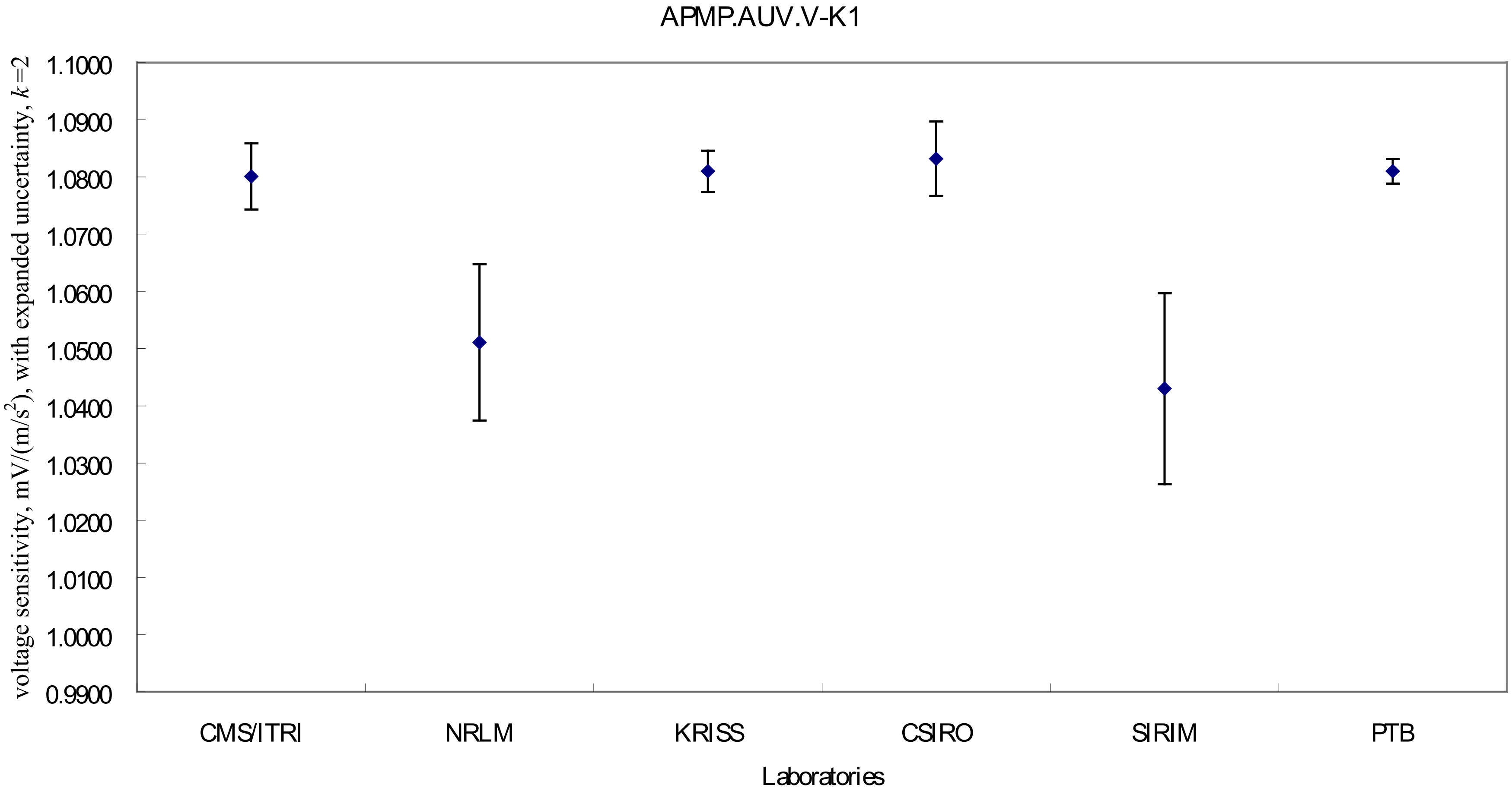

Figure A23 Measurement uncertainty of the accelerometer sensitivity for laboratories at 10000 Hz

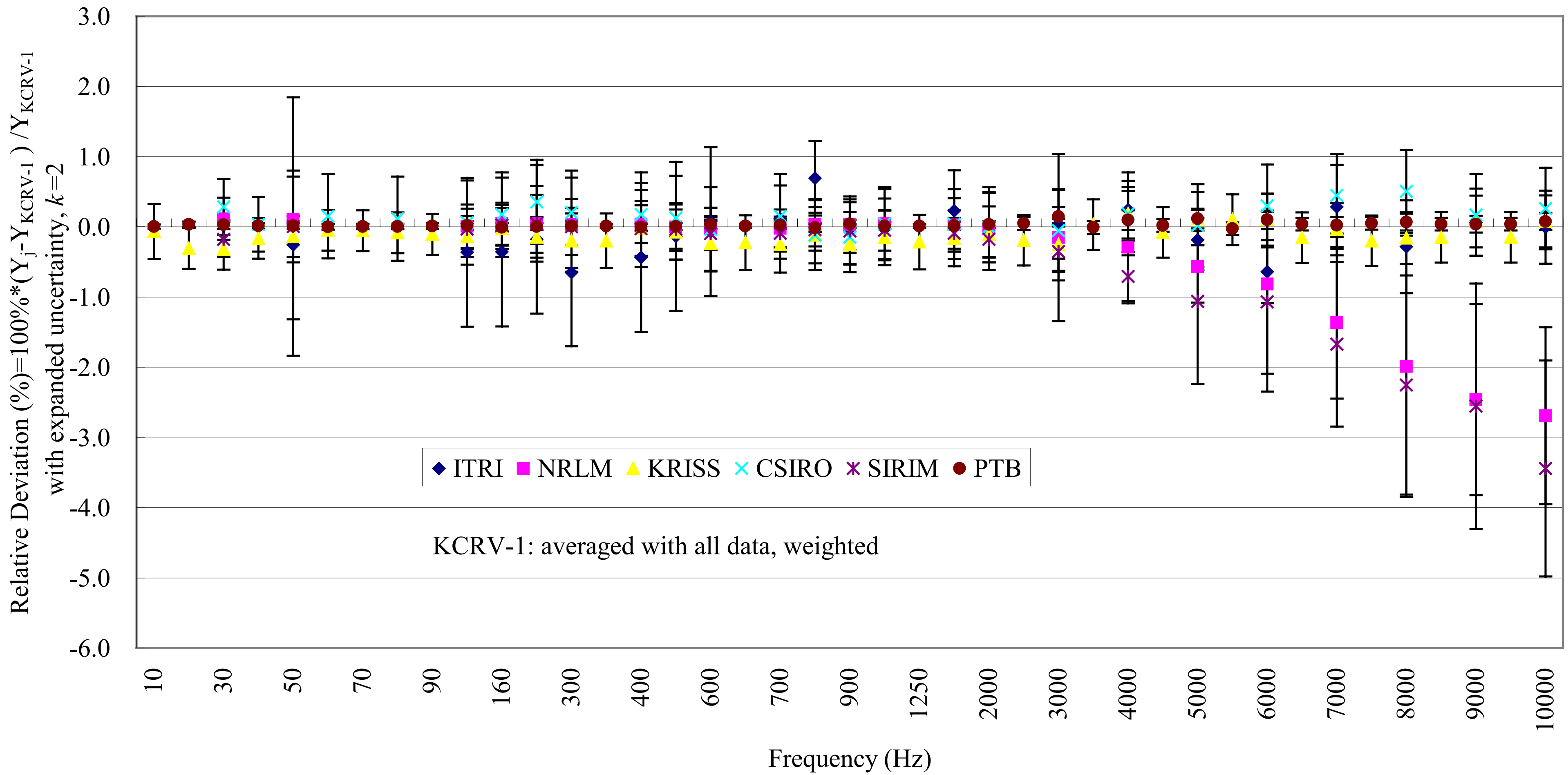

Figure A24 Degree of equivalence between KCRV-1 and other laboratories

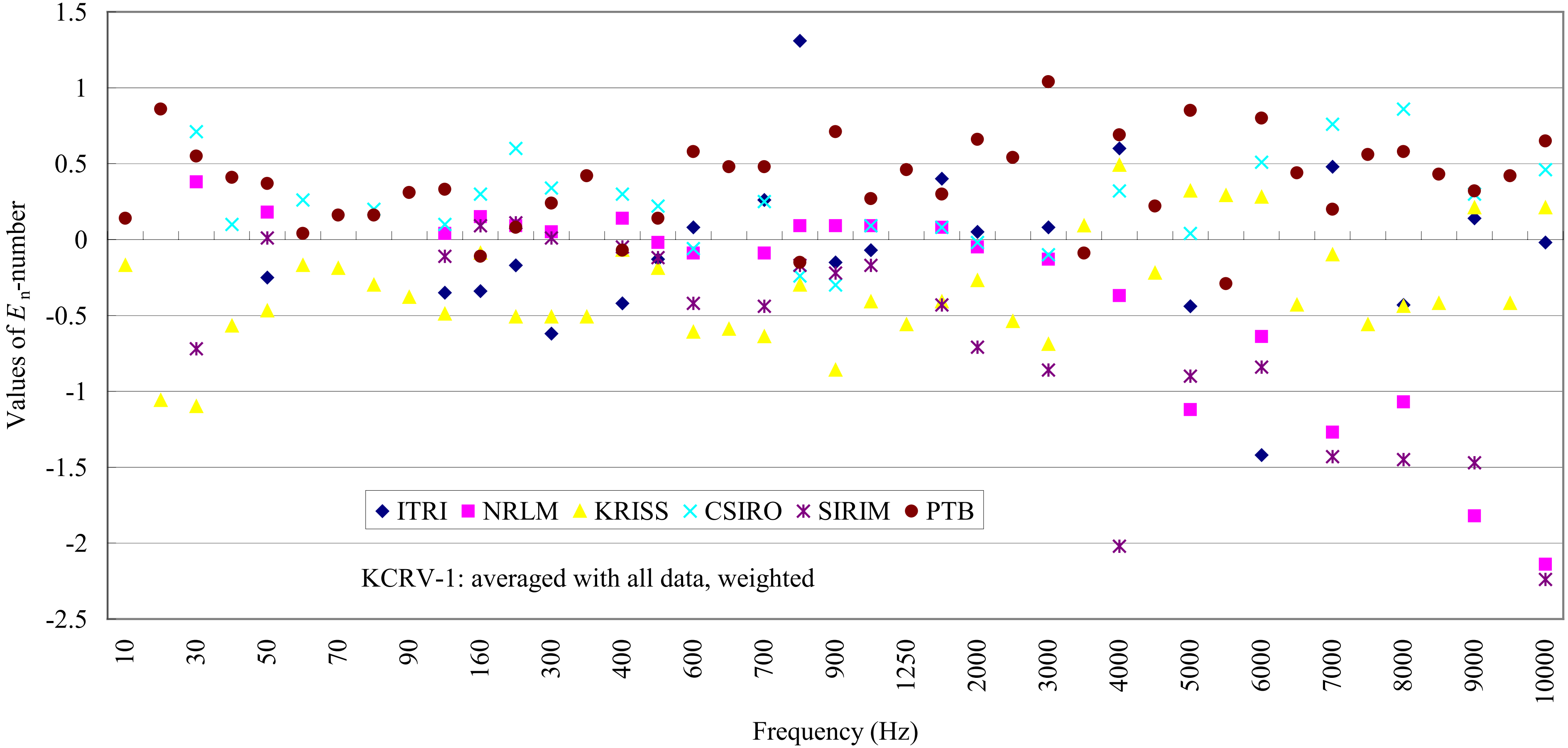

Figure A25 E_n-number between KCRV-1 and other laboratories

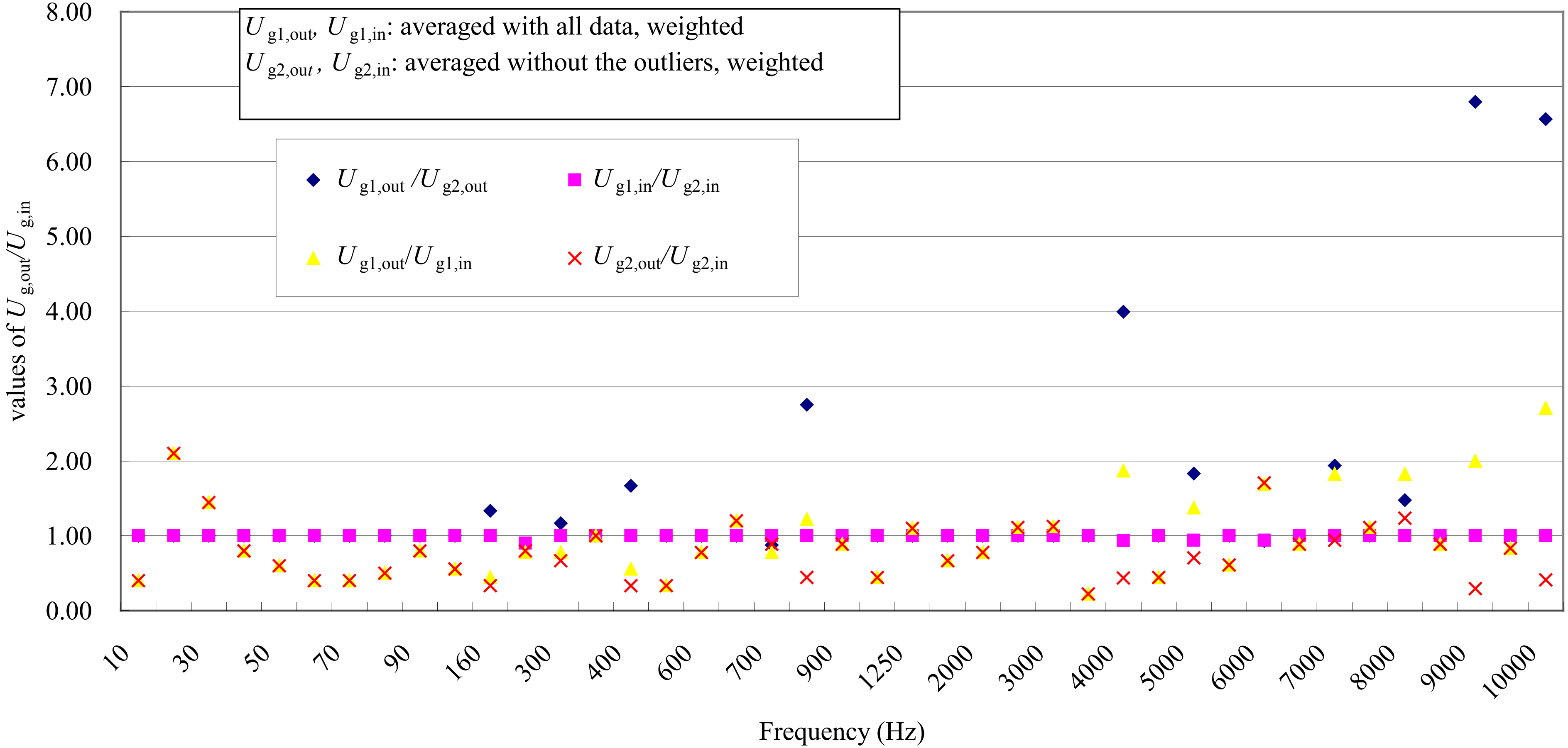

Figure A26 Results of $U_{g1,out}/U_{g1,in}$, $U_{g2,out}/U_{g2,in}$, $U_{g1,out}/U_{g2,out}$, $U_{g1,in}/U_{g2,in}$

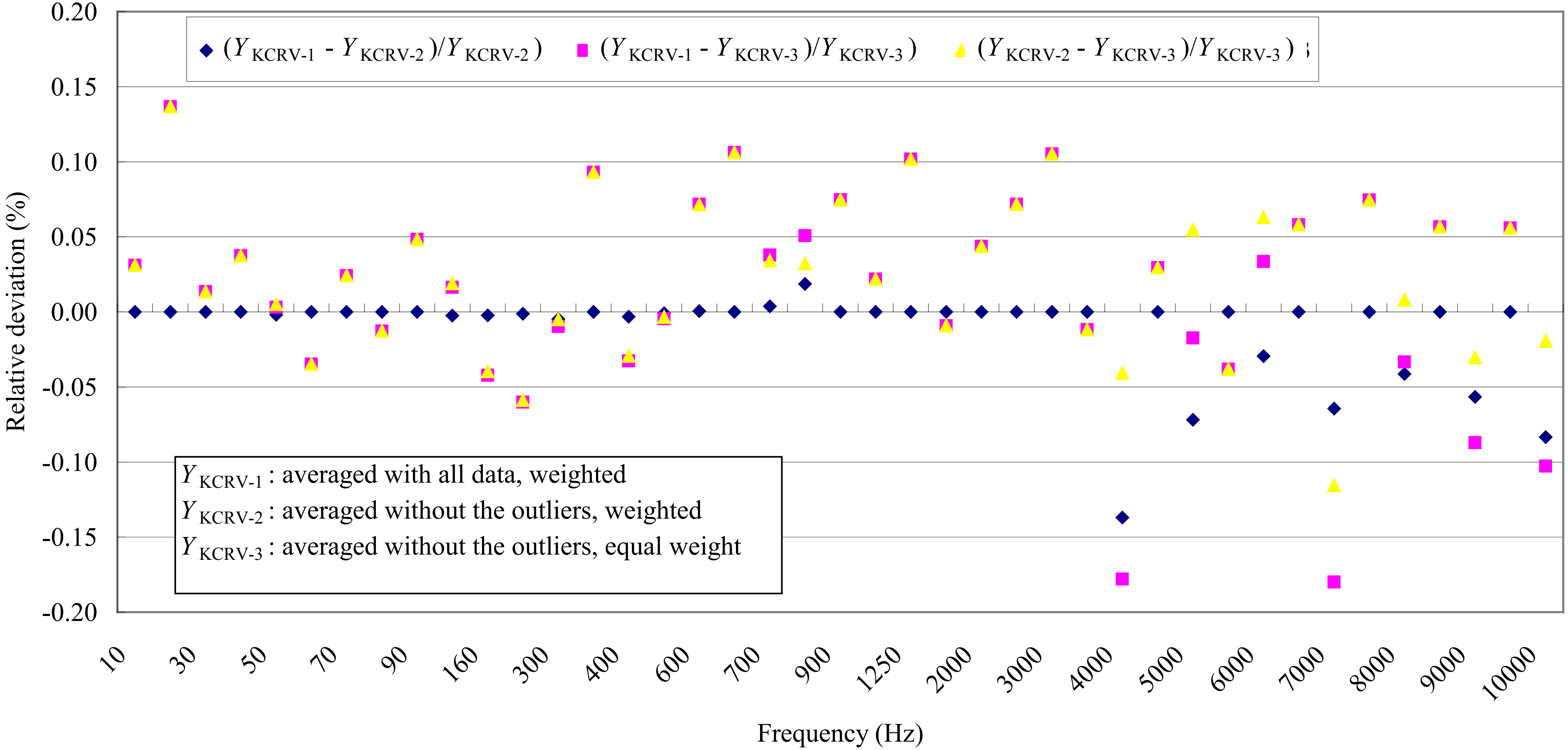

Figure A27 Relative deviation between reference values of different versions (Y_{KCRV-1}, Y_{KCRV-2}, Y_{KCRV-3})

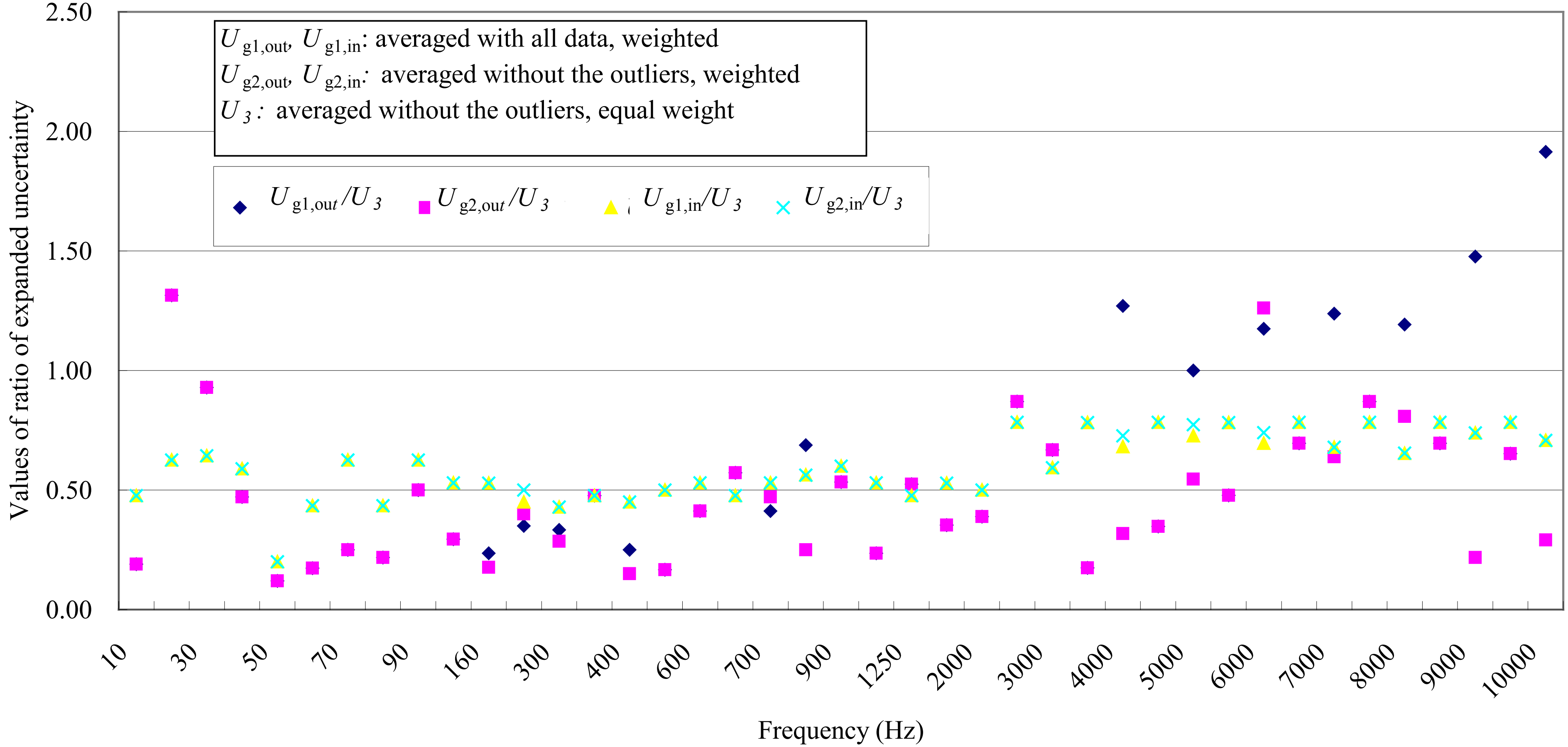

Figure A28 Results of $U_{g1,out}/U_3$, $U_{g1,in}/U_3$, $U_{g2,out}/U_3$ and $U_{g2,in}/U_3$

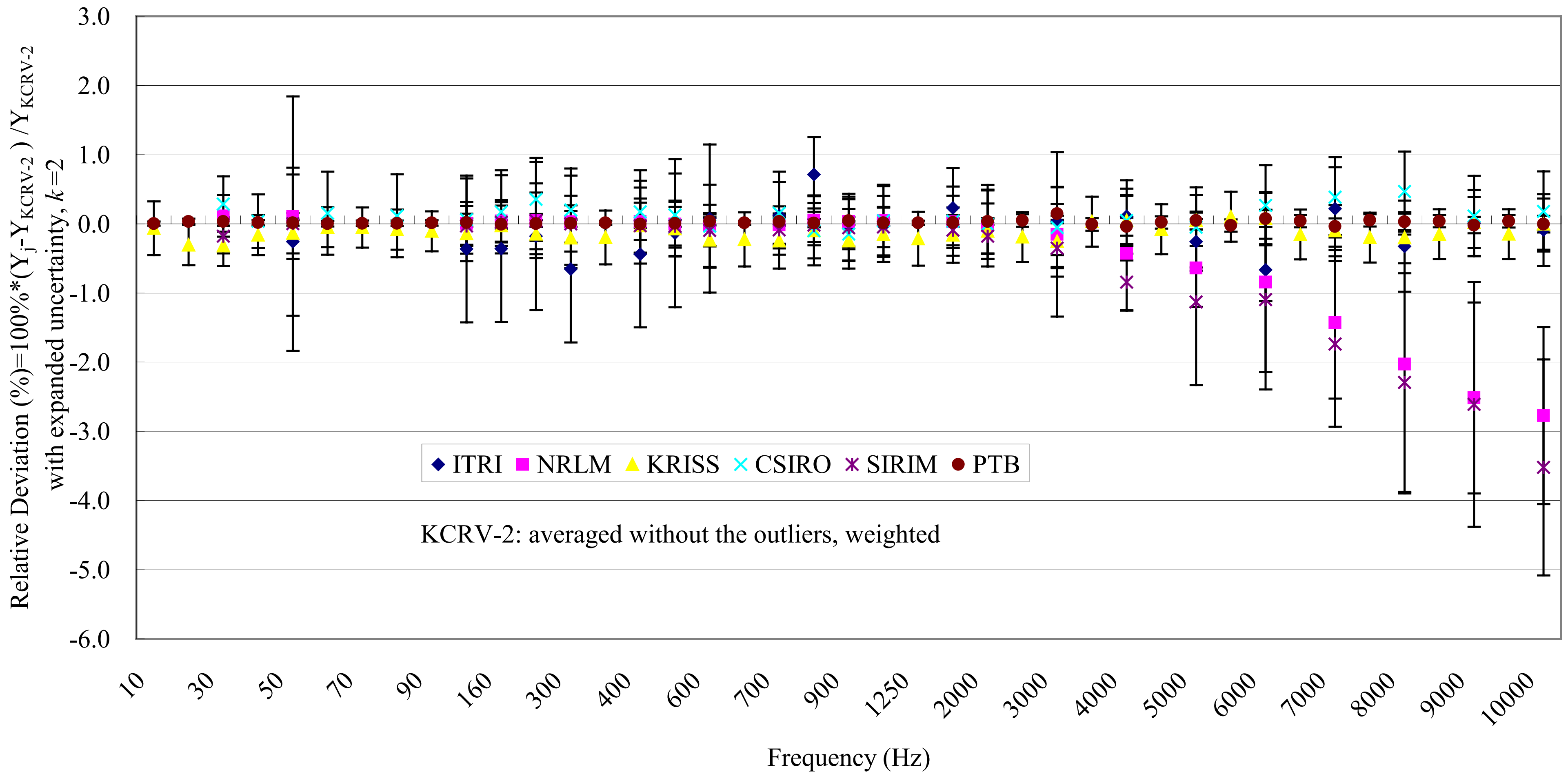

Figure A29 Degree of equivalence between KCRV-2 and other laboratories

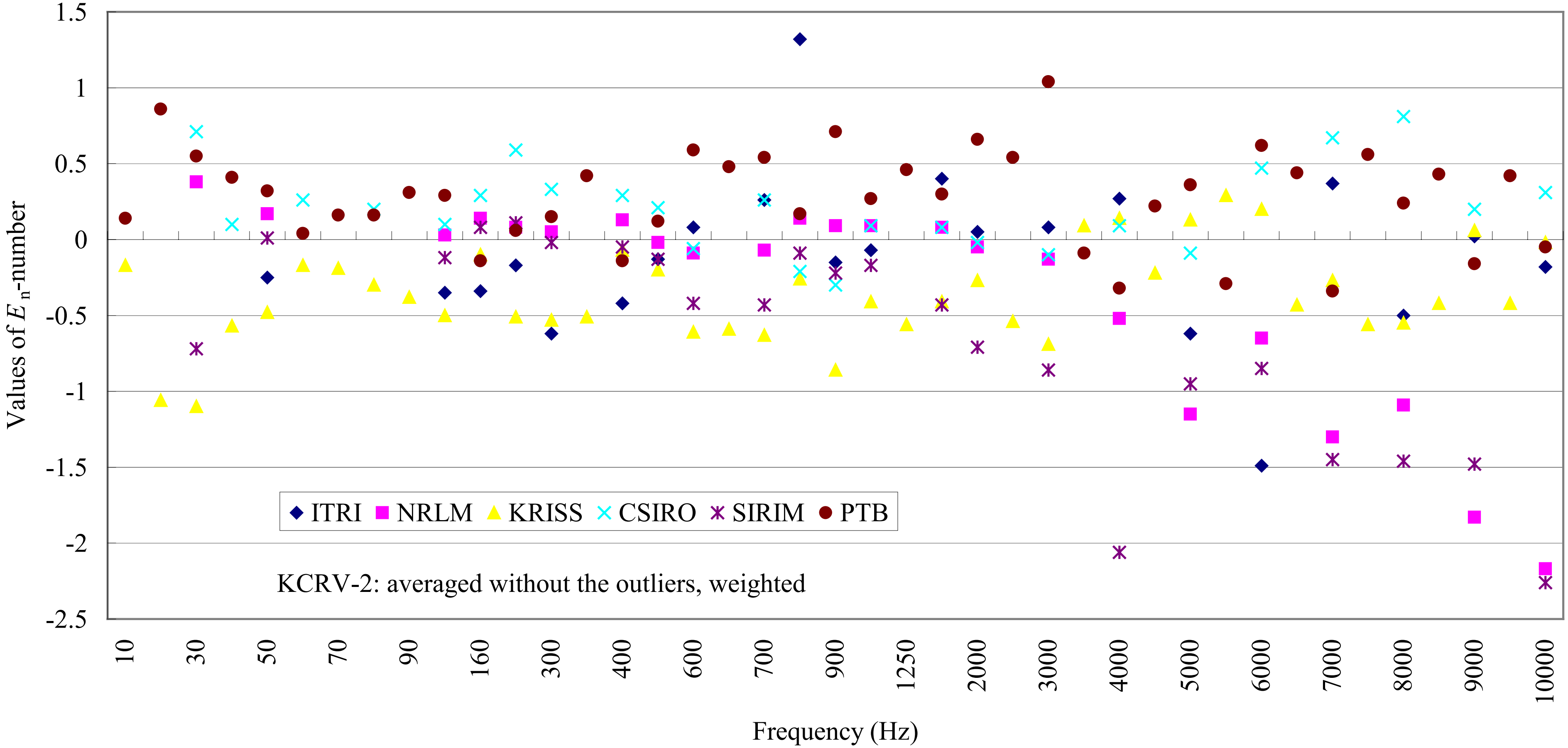

Figure A30 E_n-number between KCRV-2 and other laboratories

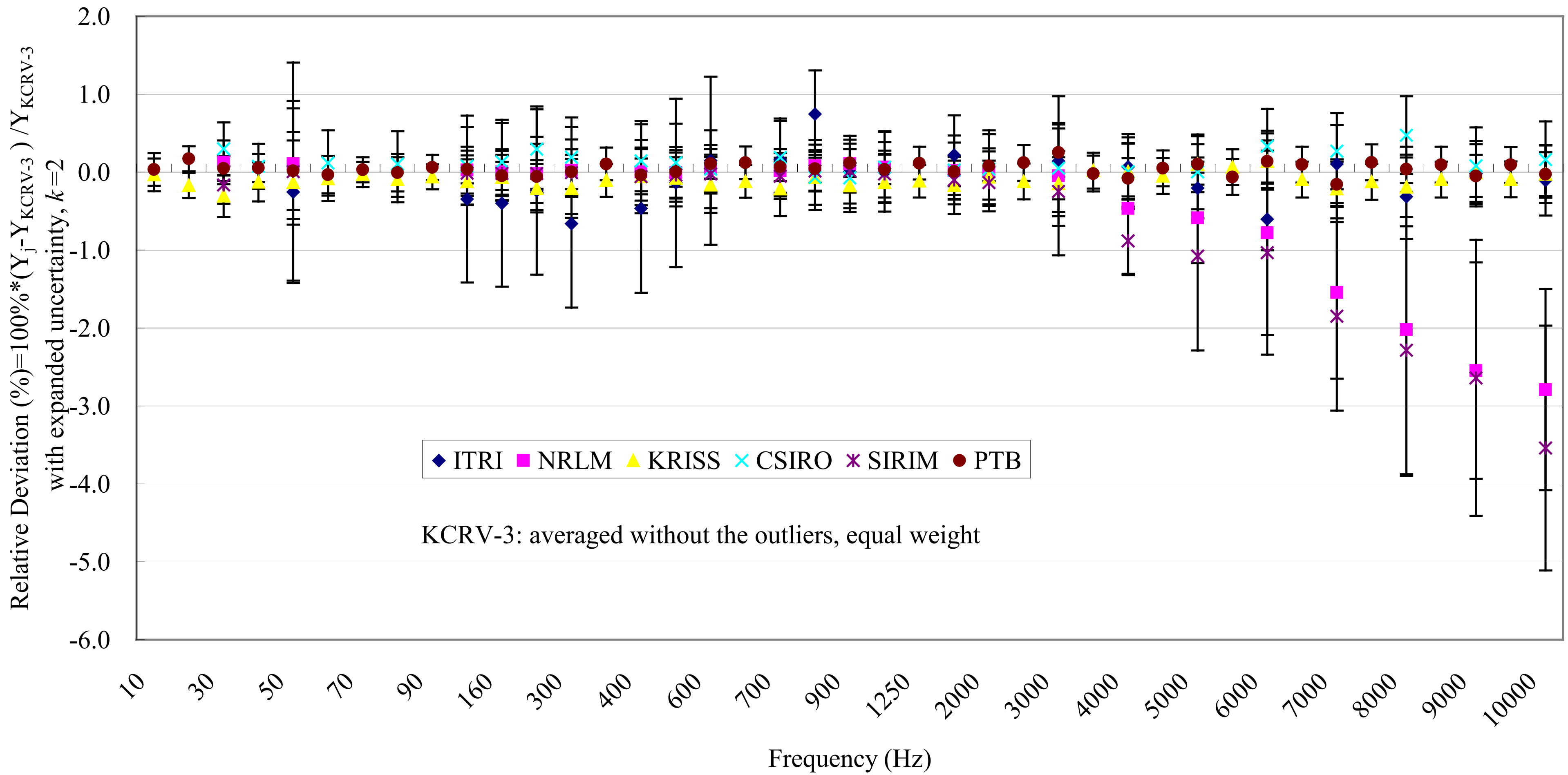

Figure A31 Degree of equivalence between KCRV-3 and other laboratories

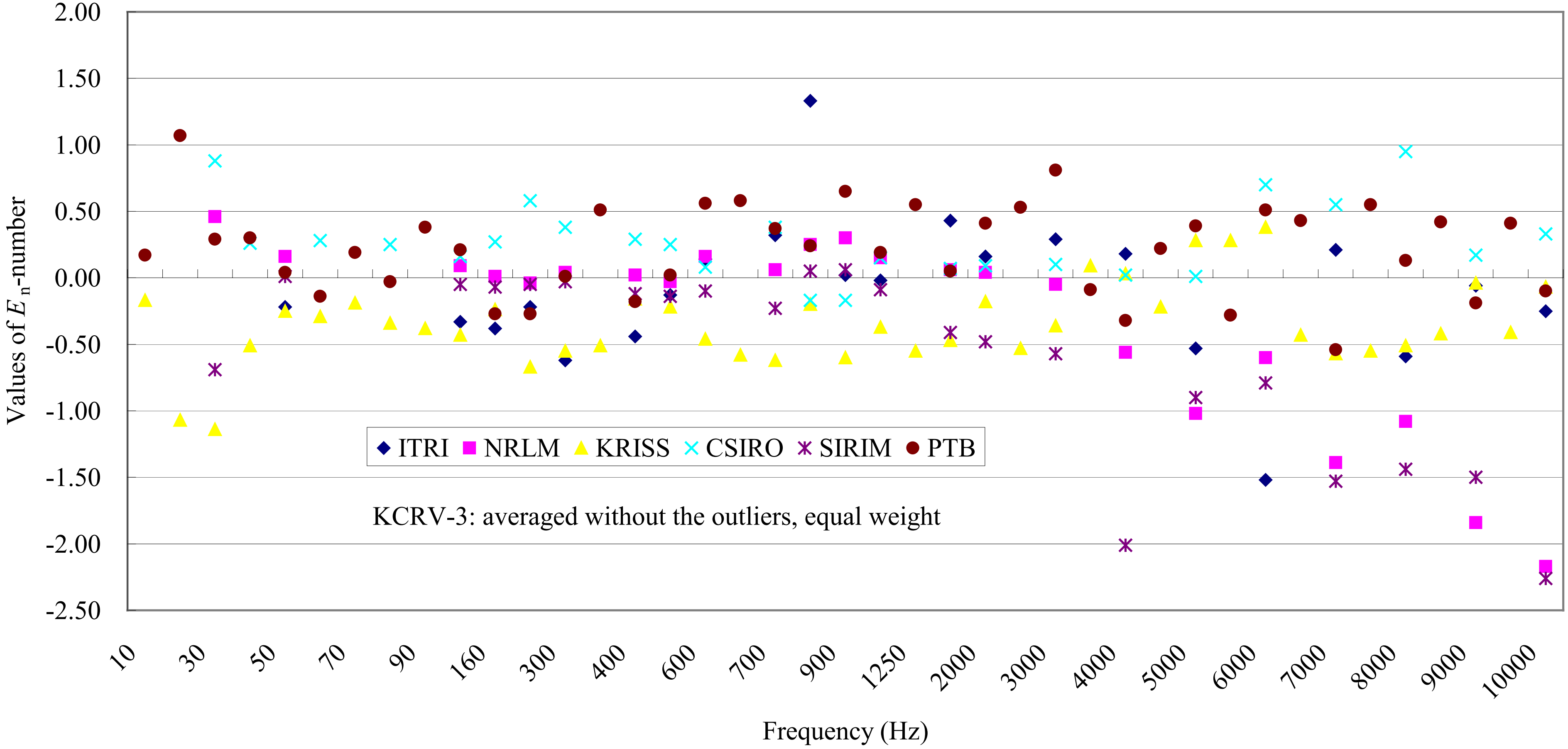

Figure A32 E_n-number between KCRV-3 and other laboratories

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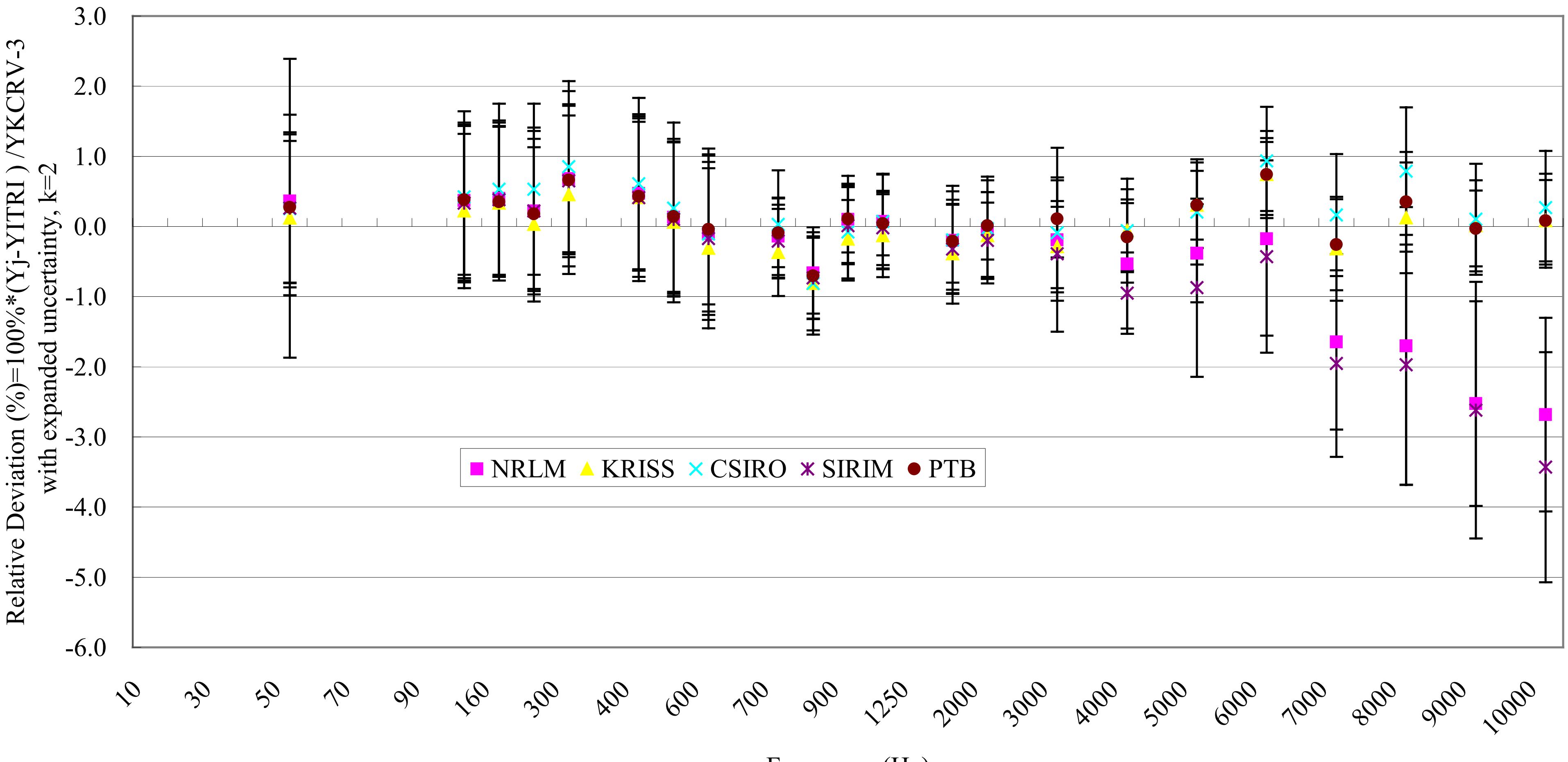

Figure A33　Degree of equivalence between ITRI and other laboratories

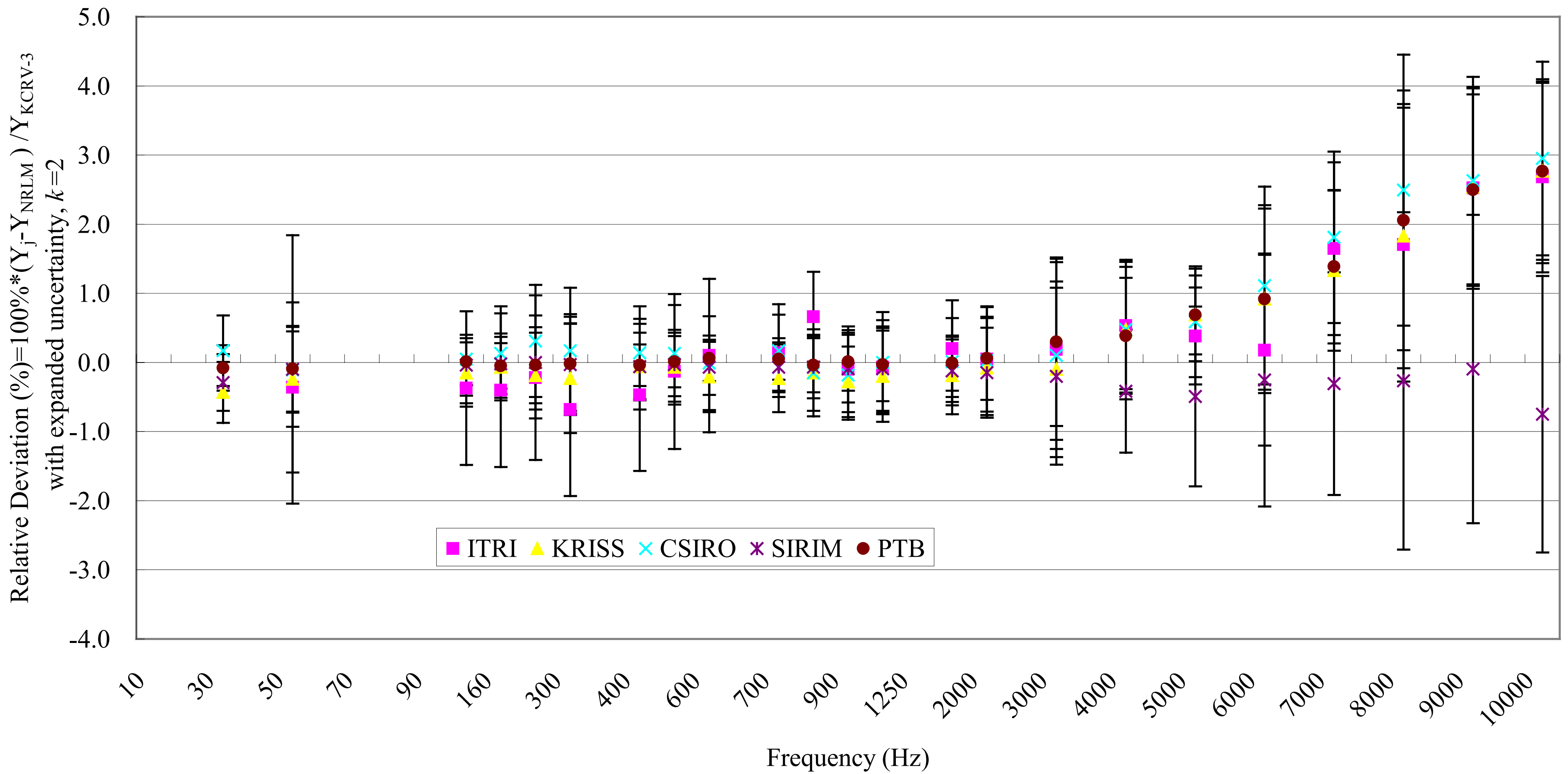

Figure A34 Degree of equivalence between NRLM and other laboratories

APMP.AVU.V-K1

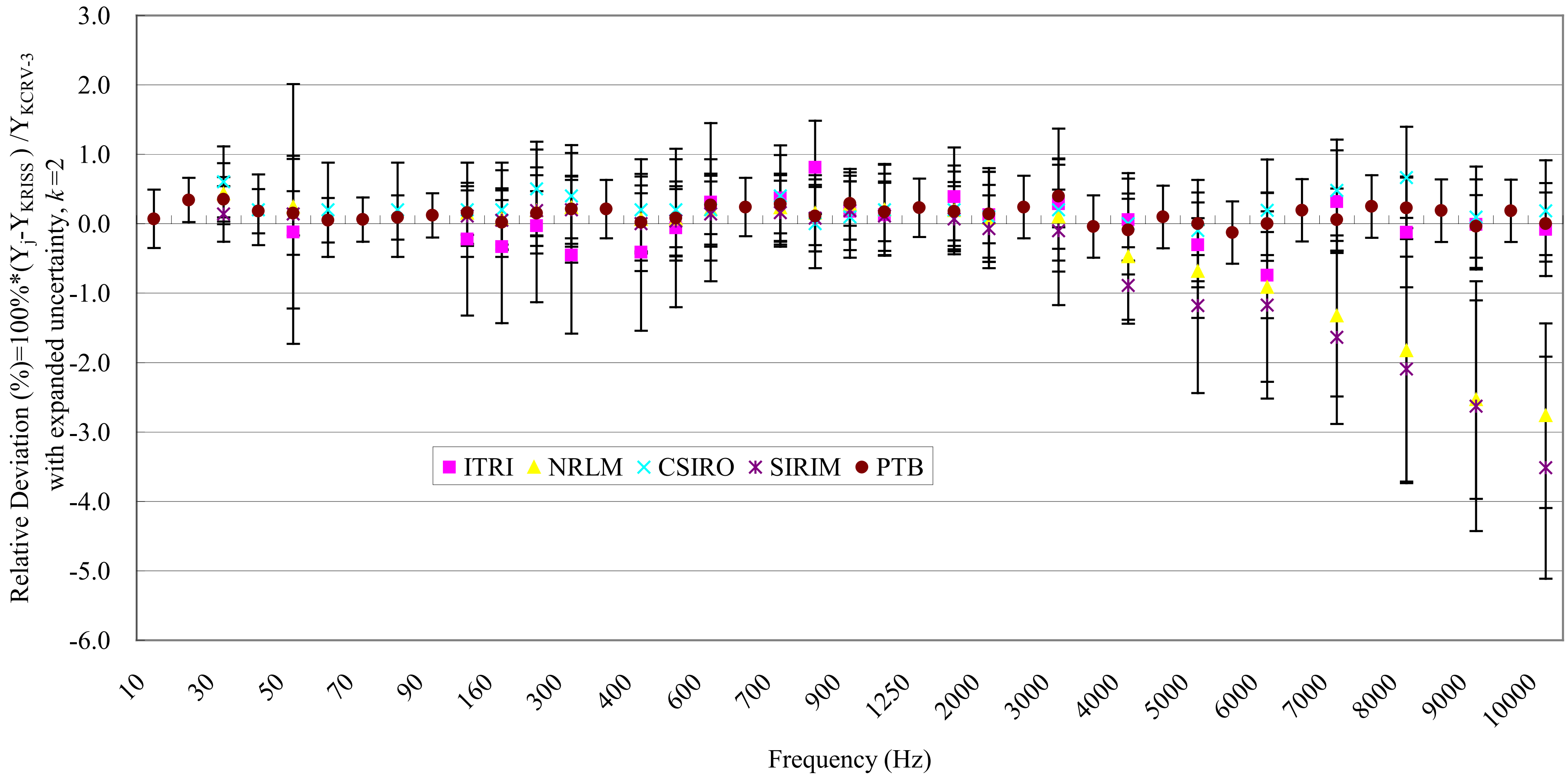

Figure A35 Degree of equivalence between KRISS and other laboratories

APMP.AVU.V-K1

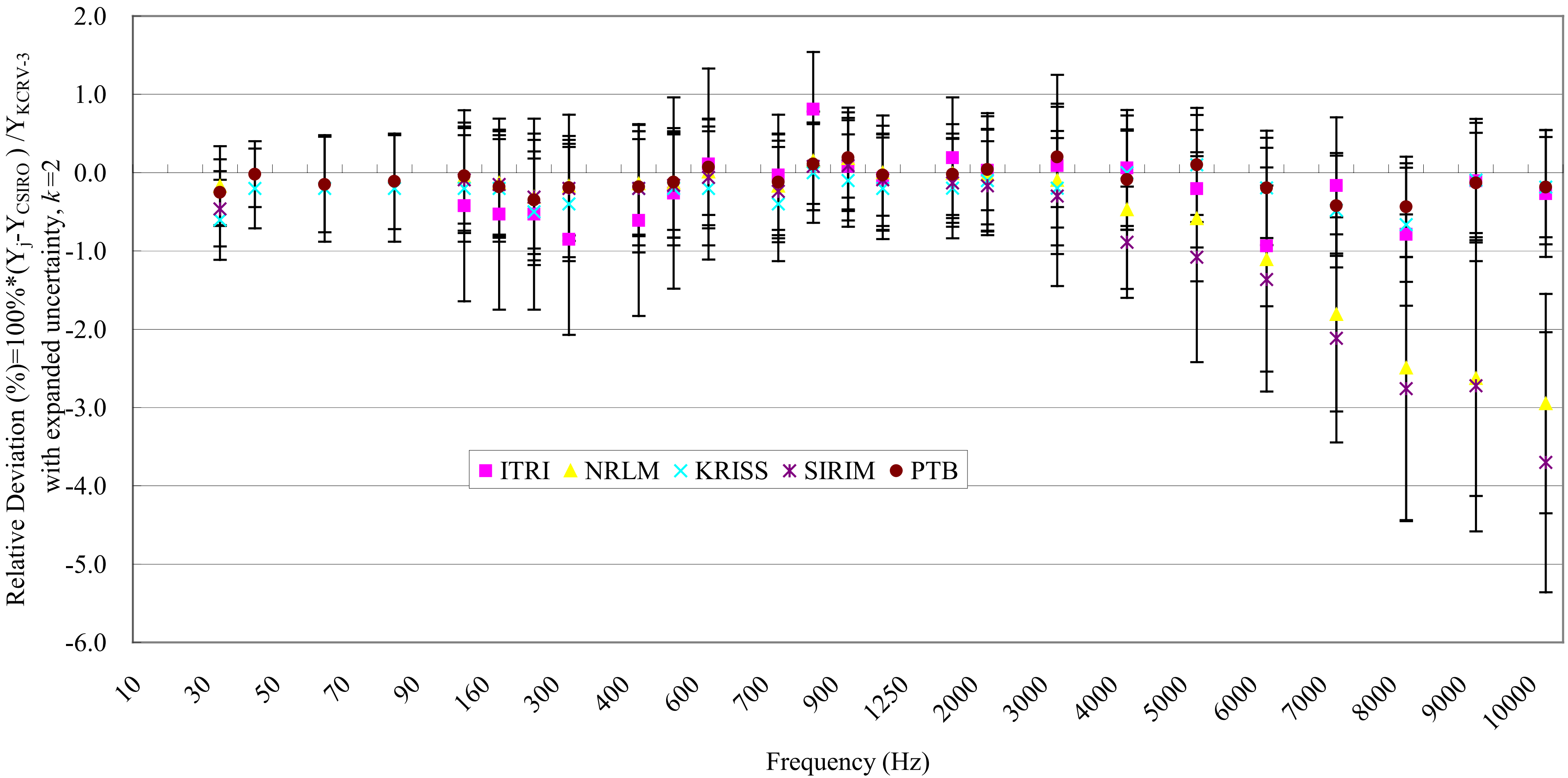

Figure A36 Degree of equivalence between CSIRO and other laboratories

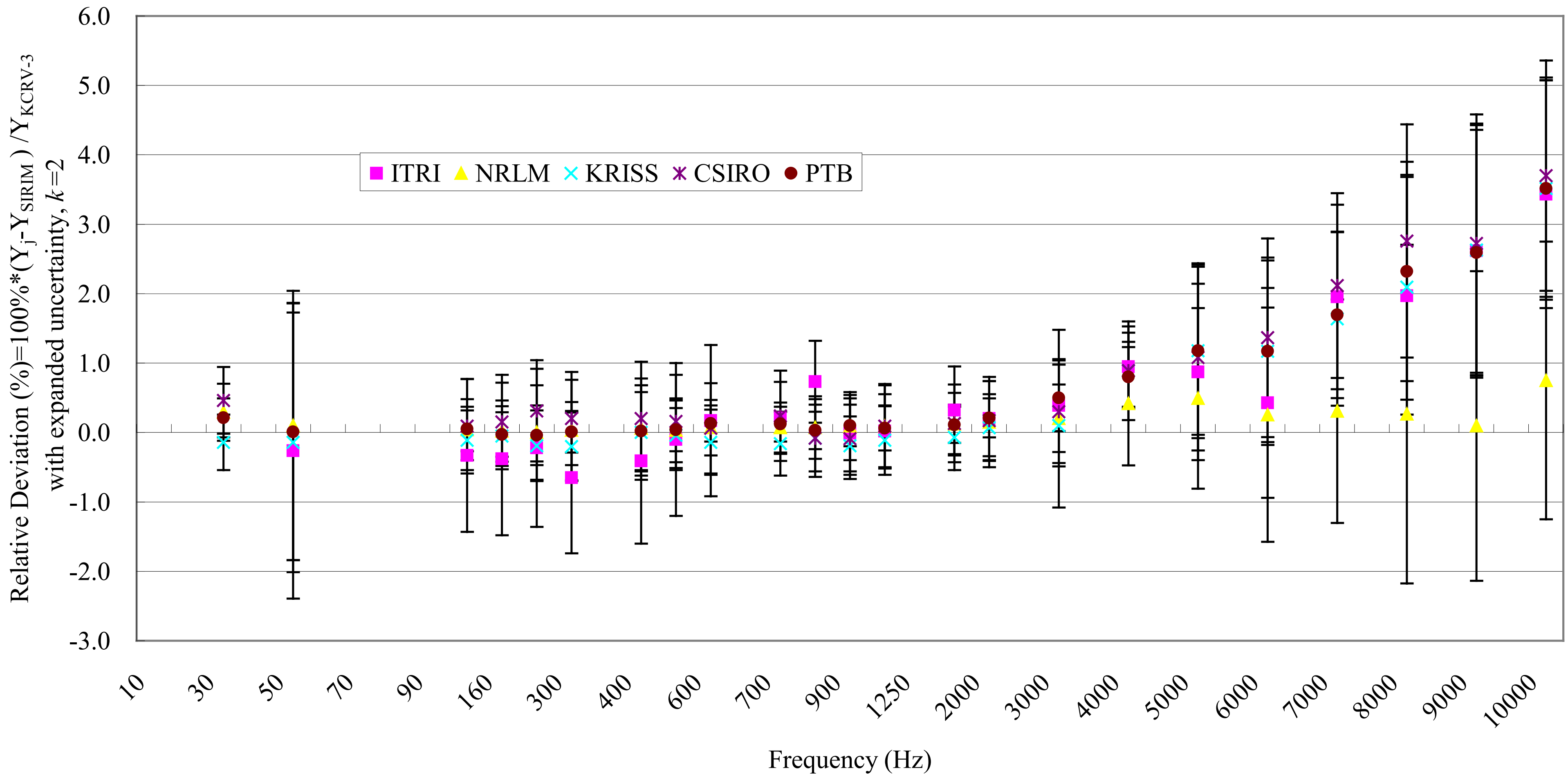

Figure A37 Degree of equivalence between SIRIM and other laboratories

APMP.AVU.V-K1

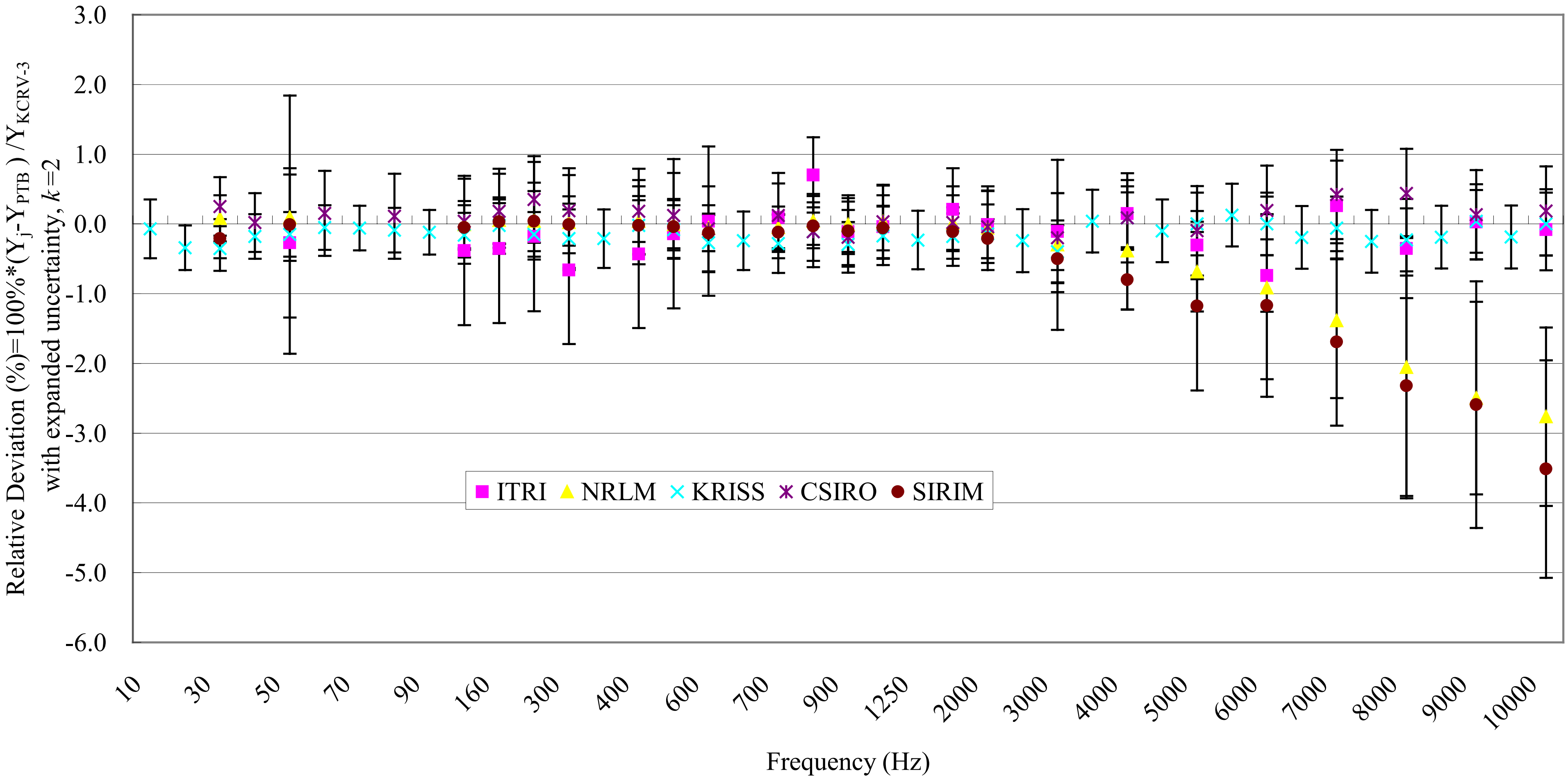

Figure A38 Degree of equivalence between PTB and other laboratories