INTERLABORATORY COMPARISON OF RADIATED EMISSION MEASUREMENTS USING A TUBULAR DIPOLE

by

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This paper presents an interlaboratory comparison of radiated emission measurements in the frequency range of 30-1000 MHz. A tubular dipole was specifically designed and employed as a reference emitting source. The most important for a tubular dipole is stability in the testing process. The stability is not the performance of the sample, but the emission signal of the sample is stable. In addition, two ways of determining the reference value of the electromagnetic field strength are considered. The first reference value is obtained by using robust analysis. It is a robust average value that is calculated by averaging the measurement results provided by the participating testing laboratories. The other reference value is obtained through the simulation-experimental results of the tubular dipole in the semi-anechoic chamber or full anechoic chamber, for horizontal and vertical polarizations and 3 m distance measurement, respectively. In addition, this value is assigned by the coordinator. Measurement results are compared using the robust z-scores and ς-scores, respectively.

Key words: interlaboratory comparison, testing laboratory, radiated emission, tubular dipole, robust analysis, simulation-experimental result

INTRODUCTION

The participation of accredited testing laboratories in interlaboratory comparisons (ILC) or proficiency testing (PT) schemes is an obligation arising from the requirements of the standard ISO/IEC 17025: 2017 [1]. Consequently, participation in ILC other than PT enables a laboratory to prove its technical competence to its clients, Accreditation Body, and other interested parties. Four testing laboratories in Serbia (Technical Test Center Ministry of Defense, Idvorsky Laboratories Belgrade, Laboratory for measurement of radio frequency interference Security-Information Agency, SIQ Belgrade), all accredited by the Accreditation Body of Serbia according to the standard ISO/IEC 17025:2017 in the field of radiated emission measurements, conducted an ILC in the second half of 2019. In addition, the Protocol for the preparation and conduct of an ILC is prepared following the guidelines [2]. Because there was no reference laboratory, one of the participating testing laboratories conducted the co-ordination of this ILC. Namely, this laboratory (Technical Test Center) expressed to the Accreditation Body of Serbia in writing that it is interested in being a PT provider in the field of electromagnetic compatibility testing.

An ILC is performed for radiated emission measurements in the frequency range of 30-1000 MHz according to standards such as SRPS EN 55016-2-3 (Identical with EN 55016-2-3) [3] and SRPS EN 55032 (Identical with EN 55032) [4]. In addition, a tubular dipole (sample) was specifically designed (homemade) and employed as a reference emitting source. The most important for a tubular dipole is stability in the testing process [5, 6]. Namely, the stability is not the performance of the sample, but the emission signal of the sample is stable [7]. An ILC item to be measured circulates successively from one participating testing laboratory to the next (sequential participation schemes) [2]. An ILC is completed when the last participating testing laboratory has submitted its measurement result to the co-ordinator. Measurements are made at three semi-anechoic chambers (SAC) and a full anechoic chamber (FAC), for horizontal and vertical polarizations and 3 m distance measurement, respectively.

The coordinator of an ILC decided to assign two distinct reference values to the electromagnetic field strength E in dB [$\mathrm{Vm^{-1}}$], generated by the tubular dipole (sample). In addition, dB [$\mathrm{Vm^{-1}}$] is a unit that is

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a numerical transformation to get values that are easier to calculate in real-world applications, because the values are usually very small (*e. g*. 10^{-6} Vm^{-1} corresponds to 0 dB [Vm^{-1}]). The first reference value, X_{rob}, is obtained by using the robust analysis described in [8]. Namely, it is a robust average value that is calculated by averaging the measurement results provided by the participating testing laboratories [7, 8]. The other reference value, X_{ser}, is obtained through the simulation-experimental results (SER) of the tubular dipole in the SAC or FAC, for horizontal and vertical polarizations and 3 m distance, respectively [9, 10]. In addition, the value X_{ser} is assigned by the co-ordinator.

To evaluate an ILC of each testing laboratory, the robust *z*-scores and *ς*-scores are used [2]. In addition, these statistical methods are used for the quantitative description of the performance of each laboratory through the comparison between the measurement result produced by the laboratory and the reference value (X_{rob} and X_{ser}, respectively) [8]. The measurement uncertainty of each testing laboratory is evaluated in accordance with the Guide to the expression of uncertainty in measurement (GUM) [11]. So, all participating testing laboratories declare that the measurement uncertainty is less than U_{cispr} [12].

CONDITIONS OF THE INTERLABORATORY COMPARISON

Reference sample

An ILC is performed by testing a known sample that gives a signal of stable frequency and stable amplitude (level), which ensures repeatability of measurements in all laboratories and the possibility of exact comparison of measurement results in all laboratories. Namely, the stability of the reference sample should be less than the measurement uncertainty of participant testing laboratories. Consequently, a tubular dipole was specifically designed (homemade) and employed as a reference emitting source. It is an electrically short dipole made of aluminum tubes, fig. 1(a) [9].

The tubular dipole consists of a quartz oscillator and a 9 V battery with a 5 V voltage stabilizer, fig. 1(b). In addition, the fundamental frequency of the oscillator was 50 MHz. So, the harmonics' spacing is 50 MHz and the first available harmonic in the frequency range of 30-1000 MHz is at 50 MHz. More details on the tubular dipole can be found in [9, 10].

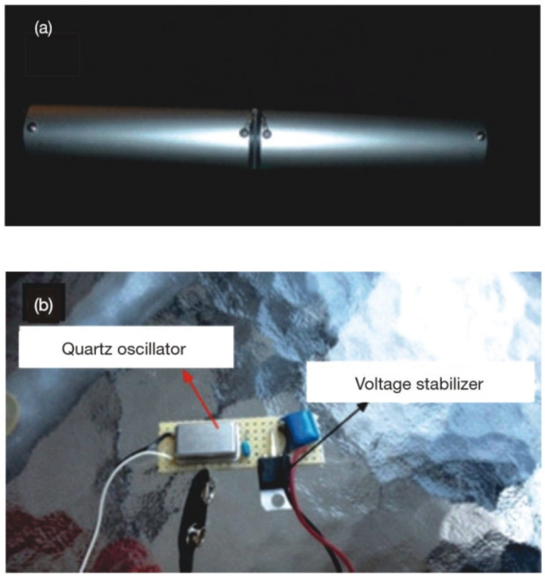

Figure 1. Tubular dipole; (a) outside and (b) inside

Measurement methods

At each testing laboratory, the radiated emission measurements have been made according to standards SRPS EN 55016-2-3 and SRPS EN 55032 [3, 4], respectively. Measurements have been made at six discrete frequencies (the selected harmonics): 50 MHz, 150 MHz, 250 MHz, 350 MHz, 550 MHz, and 750 MHz in the frequency range of 30-1000 MHz. In compliance with the previous standards, measurements are made at a distance of 3 m for horizontal and vertical polarizations, respectively. In addition, bilog or ultralog antennas are used as the receiving antenna.

Within each measurement, the frequency subband of the measurement receiver (EMI receiver or EMI spectrum analyzer) is scanned three times, with the highest value taken as a result of the measurement. In addition, all three detectors of the measurement receiver (peak Pk, quasi-peak QP, and average detector AVG or CA) are used for measurements.

The measurements are performed in four cases:
– When the tubular dipole is placed in a horizontal position at a height of 1.29 m (mounted on a plastic bracket) above the horizontal reference ground plane (RGP), and the receiving antenna is also placed at a height of 1.29 m, horizontal polarization.
– When the tubular dipole is placed in a vertical position at a height of 1.29 m, and the receiving antenna is also placed at a height of 1.29 m, vertical polarization.
– When the tubular dipole is placed in a horizontal position at a height of 1.29 m, and the receiving antenna is placed at a height of 1.80 m, horizontal polarization.
– When the tubular dipole is placed in a vertical position at a height of 1.29 m, and the receiving antenna is placed at a height of 1.80 m, vertical polarization.

Four test facilities are included in the testing: three chambers SAC and a chamber FAC. The measurements set-up in the SAC (for case 1) and in the FAC (for case 2) are illustrated in fig. 2(a) and fig. 2(b), respectively.

The radiated emission testing system includes RF cables, an RF limiter, and all kinds of measurement receivers (EMI receiver or EMI spectrum analyzer).

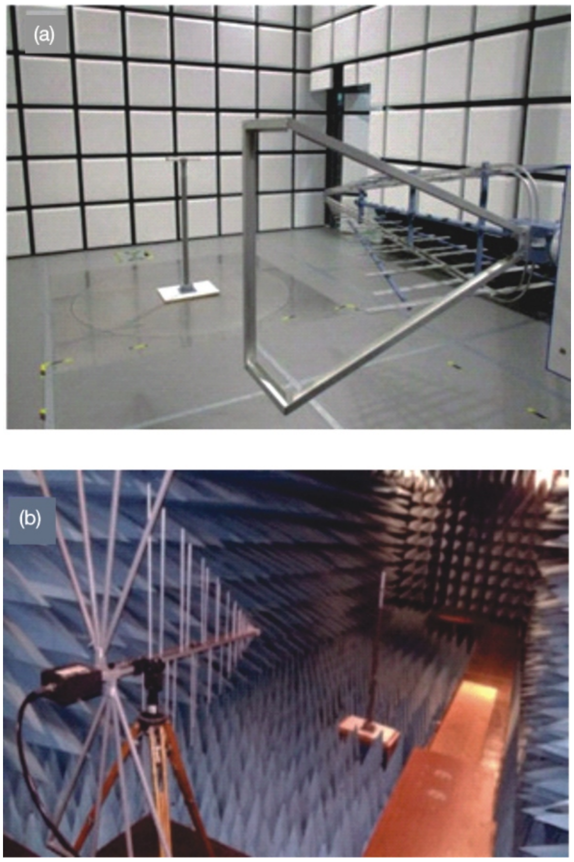

Figure 2. Set-up of radiation emission measurement; (a) In the SAC (for case 1) and (b) In the FAC (for case 2)

Measurement results

Measurements are performed at six discrete frequencies (the selected harmonics): 50 MHz, 150 MHz, 250 MHz, 350 MHz, 550 MHz, and 750 MHz in the frequency range of 30-1000 MHz.

The measurement results in the SAC (for case 1) and in the FAC (for case 2) are illustrated in fig. 3(a) and fig. 3(b), respectively. Namely, these figures show graphs of measured radiation emission levels. In addition, the broken lines, for both cases, represent the limits of measured radiation emission levels according to standard SRPS EN 55032, class B, for the quasi-peak detector (QP).

Since the values of measured radiation emission levels differed slightly for all three detectors, the co-ordinator decided to perform the ILC on the results obtained by the quasi-peak detector.

Statistical methods for interlaboratory comparison

In data analysis, it is often necessary to choose a statistical model, as well as appropriate statistical methods [13, 14]. As each test is random a certain distribution function is attached to the obtained results [15, 16].

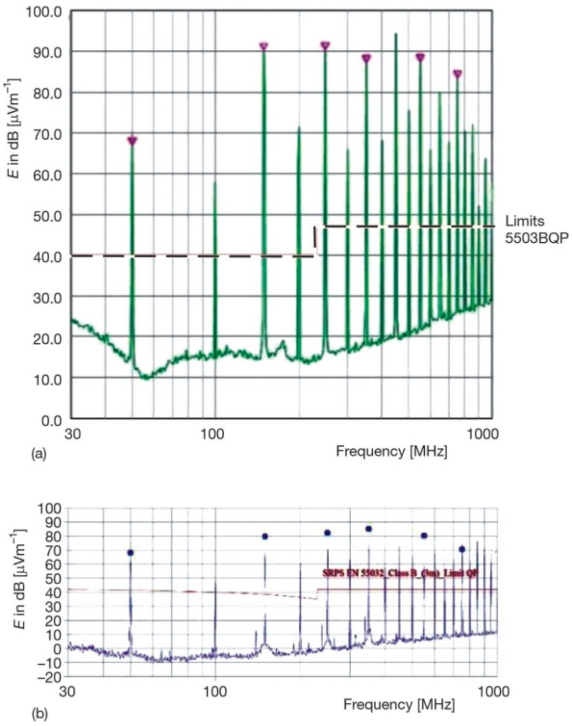

Figure 3. Graph of measured radiation emission levels; (a) In the SAC (for case 1) and (b) In the FAC (for case 2)

In this case, statistical methods are used in the ILC to convert participants' raw results into a standard form that provides information on assessing their performance. The z-scores and the E_n numbers are the most commonly used methods. In addition, the robust z-scores and ς-scores are used in some situations [17]. In this paper, the robust z-scores are used to compare the measurement result x_i with the robust average value X_{rob} [18]. In addition, the value X_{rob} is calculated by averaging the measurement results provided by the participating testing laboratories. Also, the ς-scores are used because it provides a rigorous assessment of the complete result submitted by the participating testing laboratories. Namely, using ς-scores allow direct assessment of whether laboratories can deliver measurement results that agree with the other reference value, X_{ser}, within their measurement uncertainties [8]. In addition, the value X_{ser} is assigned by the co-ordinator.

The robust z-scores, z_{rob_i}, are calculated

$$z_{\mathrm{rob}_i} = \frac{x_{\mathrm{lab}_i} - X_{\mathrm{rob}}}{\sigma_{\mathrm{rob}}}, \quad i = 1,2,\ldots,4 \tag{1}$$

where x_{lab_i}, X_{rob}, and σ_{rob} are the i^{th} testing laboratory result (participant's result), assigned value, and target standard deviation, respectively.

In addition, X_{rob} and σ_{rob} have the greatest influence on the calculation of z-scores. They must be selected with care if they are to provide a realistic assessment of testing laboratory performance [8].

There are five procedures for establishing the assigned value in ILC. These procedures involve the use of known values, certified reference values, reference values,and consensus values from expert participants, and consensus values from participants [2]. In this paper, two special reference values are used for the assigned values. In addition, the first assigned value, X_{rob}, is obtained by using the robust analysis described in [8]. Namely, it is a robust average value that is calculated as follows

$$X_{\mathrm{rob}} = \text{median of } x_{\mathrm{lab}_i}, i = 1,2,\ldots,4 \tag{2}$$

In addition, σ_{rob} is the robust standard deviation of $x_{\mathrm{lab}i}$ about X_{rob} which is calculated as follows

$$\sigma_{\mathrm{rob}} = 1.483 \, \{\text{median of } |x_{\mathrm{lab}_i} - X_{\mathrm{rob}}|\}, i = 1,2,\ldots,4 \tag{3}$$

Since the robust analysis is based on an iterative calculation, the convergence is assumed when there is no change from one iteration to the next in the 3rd significant figure of the robust average value, X_{rob}, and the robust standard deviation rob [8]. In this paper, the second step of iteration was sufficient for convergence (at most frequencies).

The interpretation of robust z-scores is as follows:

- $|z| \leq 2.0$ – the result indicates satisfactory performance (generates no signal),
- $2.0 < z < 3.0$ – the result indicates questionable performance (generates a warning signal), and
- $z \geq 3.0$ – the result indicates unsatisfactory performance (generates an action signal).

The ς-scores are calculated as

$$\varsigma_i = \frac{x_{\mathrm{lab}_i} - X_{\mathrm{ser}}}{\sqrt{u_{lab_i}^2 + u_{ser}^2}}, i = 1,2,\ldots,4 \tag{4}$$

where $x_{\mathrm{lab}i}$ and X_{ser} are the i^{th} testing laboratory result (participant's result) and assigned value, respectively. In addition, the value X_{ser} is obtained through the SER of the tubular dipole in the SAC or FAC, for horizontal and vertical polarizations and 3 m distance measurement, respectively [9, 10]. The value X_{ser} is assigned by the co-ordinator. In eq. (4), $u_{\mathrm{lab}i}$ and u_{ser} are the combined standard uncertainty of a participant's result (i^{th} testing laboratory) and the combined standard uncertainty of the assigned value X_{ser}, respectively. In addition, the measurement result provided by the i^{th} testing laboratory produces a warning, action, or no signal according to the same rules previously described for robust z-scores.

RESULTS OF THE INTERLABORATORY COMPARISON

The robust z-score and ς-score methods are used to evaluate the measurement results of the ILC of all participating testing laboratories.

Using the robust z-score method

The robust z-score method consists of several steps. First, one calculates initial values for X_{rob} and rob using eqs. (2) and (3), respectively. In addition, the final values for X_{rob} and σ_{rob} are obtained through an iterative calculation using Algorithm A in [8, section C.3.1]. In this paper, the second step of iteration was sufficient for convergence (at most frequencies).

The values of the electric field strength measured by each laboratory are shown in fig. 4 [19] (marked with different labels) together with the robust average value X_{rob} (marked with the broken line) as a function of frequency, for four cases (see the previous section), respectively. In addition, one label represents the value of one laboratory at a selected frequency.

When the robust average value and the robust standard deviation, X_{rob} and σ_{rob}, are determined, then one calculates the value $z_{\mathrm{rob}i}$ for each participant and each selected frequency using eq. (1).

The values of the robust z-score calculated by each laboratory and each selected frequency are shown in fig. 5 [19] (marked with different labels), for four cases, respectively. In addition, the broken and solid lines represent the limits for warning and action signals, respectively.

It is observed in fig. 5(a) three values exceed the limit for warning signal (the broken line), two due to Lab. 4 (2.22 at 150 MHz and 2.05 at 250 MHz) and one due to Lab. 3 (2.54 at 750 MHz), respectively. As only 3 out of 96 values fell out of the acceptance interval ($|z| \leq 2$), the overall performance of the participant laboratories seems to be adequate.

As the number of participants is not enough, the ς-score method is also used.

Using the ς-score method

The ς-score method, as in the previous case, consists of several steps. First, the assigned value X_{ser} by the co-ordinator is obtained through the SER of the tubular dipole in the SAC and FAC (simulated in the program WIPL D Pro [20]), for horizontal and vertical polarizations and 3 m distance measurement, respectively. Figure 6(a) shows the WIPL-D model of the tubular dipole at a height of 1.29 m above the perfect electric conductor plane – PEC plane (simulated SAC). For this case, the simulated near electric field distribution of tubular dipole is shown in fig. 6(b).

The assigned values X_{ser1} (in the SAC) and X_{ser2} (in the FAC) are reported in tab. 1, respectively. In addition, these values are given for Case 1). The combined standard uncertainty of the assigned value X_{ser} is obtained $u_{\mathrm{ser}} = 0.83$ dB [10]. Namely, $u_{\mathrm{ser}} = U/2$, where U, in dB, is the expanded uncertainty obtained by multiplying the standard uncertainty by a coverage factor $k = 2$ (which corresponds to a coverage probability of about 95 %, assuming a normal distribution) [11].

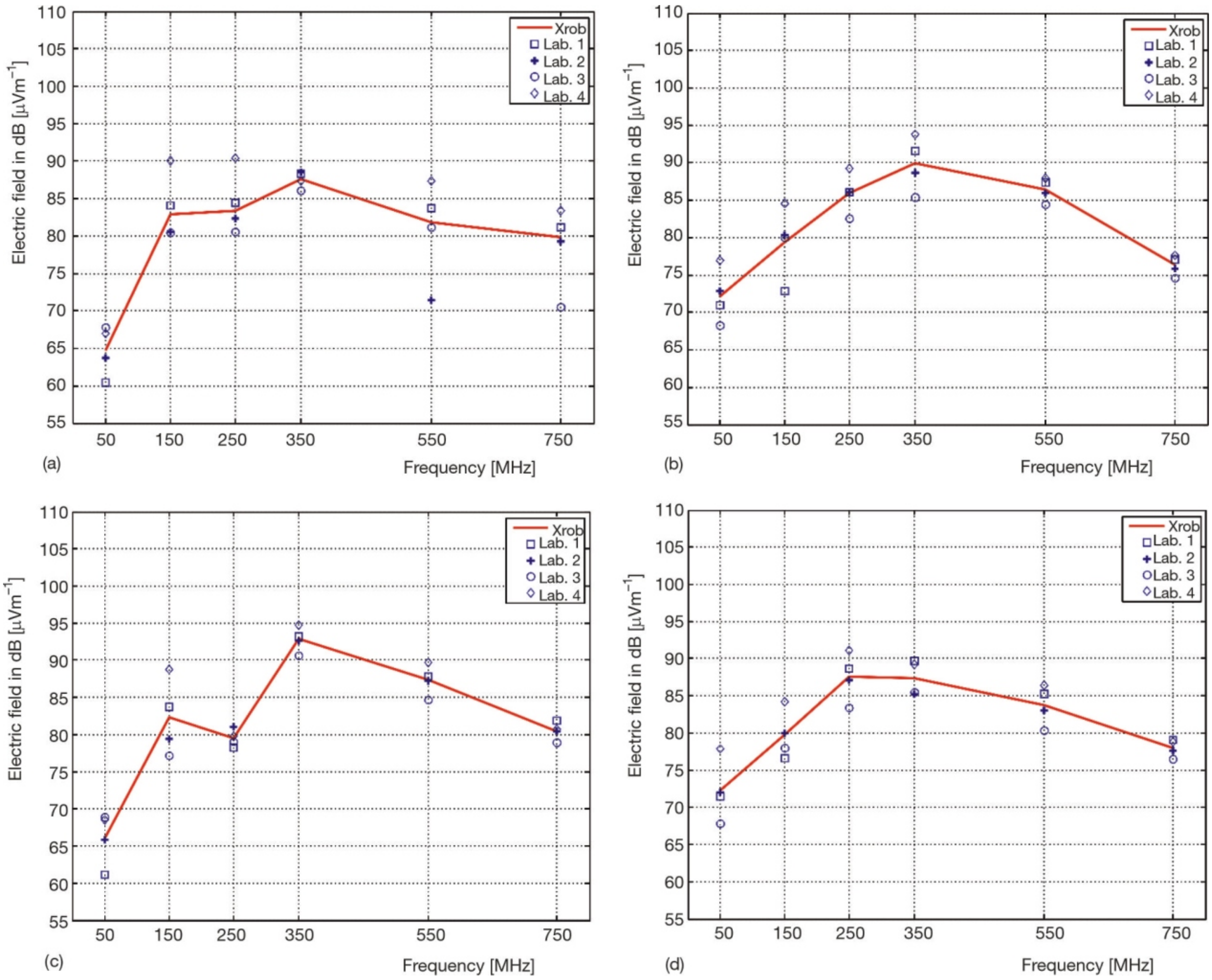

Figure 4 (a)-(d). Values of the electric field strength measured by each laboratory for four cases

The laboratory uncertainties were estimated and reported by each participant. In addition, the combined standard uncertainty of x_i is $u_{\mathrm{lab}i} = U_{\mathrm{lab}i}/2$, where $U_{\mathrm{lab}i}$ in dB, is the expanded uncertainty stated by the i-th Laboratory, tab. 2. In addition, the expanded uncertainty, $U_{\mathrm{lab}i}$, is obtained by multiplying the standard uncertainty by a coverage factor $k = 2$ (which corresponds to a coverage probability of about 95 %, assuming a normal distribution) [11].

When the assigned values (X_{ser1} and X_{ser2}) and the combined standard uncertainties ($u_{\mathrm{lab}i}$ and u_{ser}) are determined, then one calculates the value of ς_i for each participant and each selected frequency using eq. (4).

The values of the ς-score calculated by each laboratory (participant) and each selected frequency are shown in fig. 7 [19] (marked with different labels), for four cases, respectively. In addition, the broken and solid lines represent the limits for warning and action signals, respectively.

Considering the results of fig. 7, testing laboratories can be categorized into three groups as follows:
– Group 1: Lab. 4. It has no warning or action signals.
– Group 2: Lab. 1. It has 1 warning and 2 action signals.
– Group 3: Lab. 2 and Lab. 3. These laboratories have 7 and 8 warning signals, respectively, and 5 action signals for both laboratories.

The total number of measurement results was 96. Those giving warning or action signals were 28. This means that 29.17% of measurement results were not within the range of acceptable relative deviation from the corresponding reference values X_{ser}. In addition, in the case of Group 3, Lab. 2 and Lab. 3 will require special attention in the next ILC round, to have their performances improved. Namely, some of the possible sources of error are the inexperience of the operator in radiated emission measurements, possibly impacting on poor cable connections and adjustment of direction and height between transmitting and receiving antenna, the use of an external preamplifier for some types of receiving antennas, age of the absorbing material, *etc*.

RESULTS DISCUSSION

The ς-score appears to be stricter if compared with the z-score. Comparing fig. 5 and fig. 7 a larger number of warning and action signals are associated with the ς-score than with the z-score. The discrepancy in the z statistic and ς statistic determined by the two methods stems mainly from the fact that the median in the z-score method and the assigned value, obtained

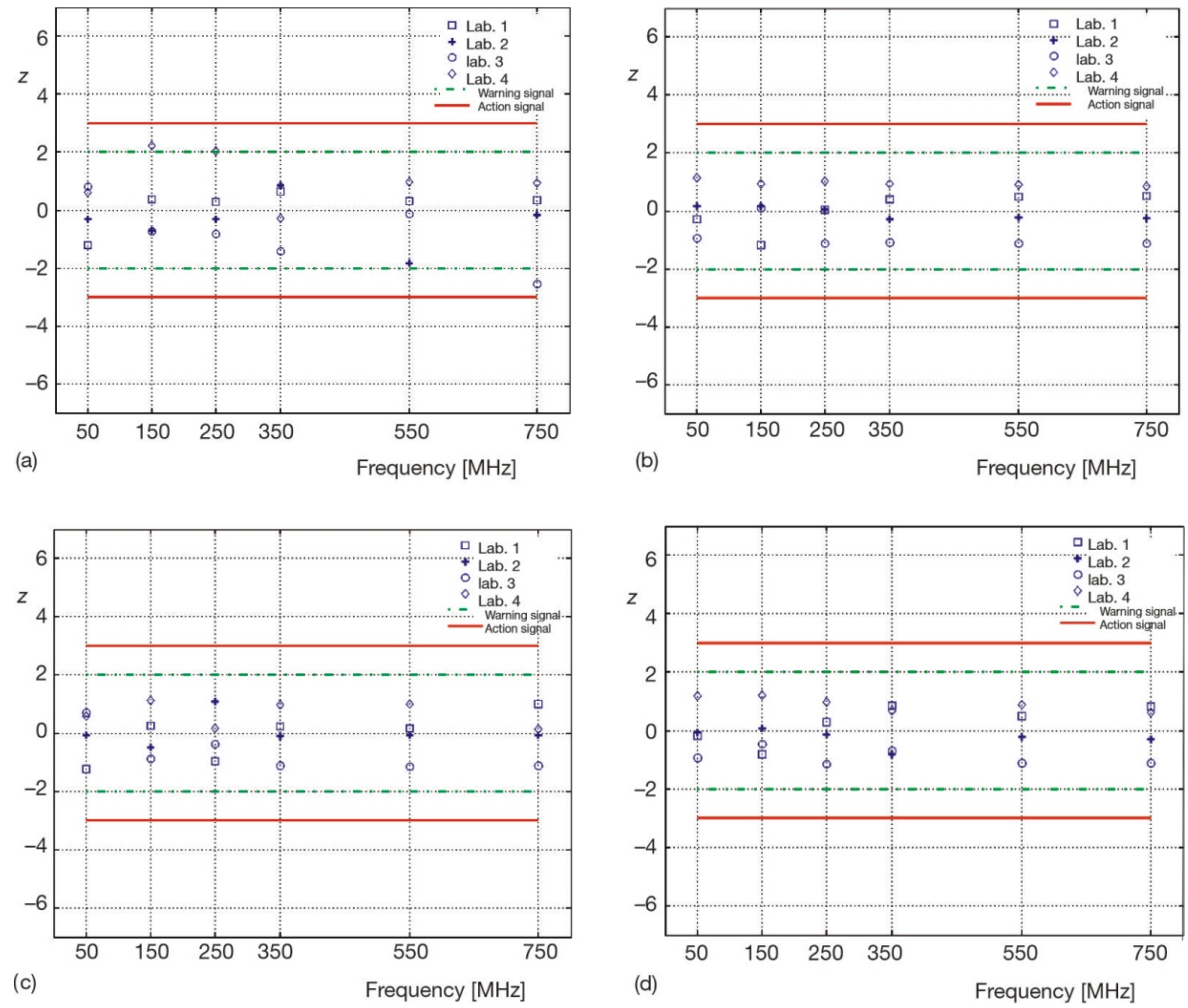

Figure 5 (a)-(d). Values of the robust *z*-score calculated by each laboratory for four cases

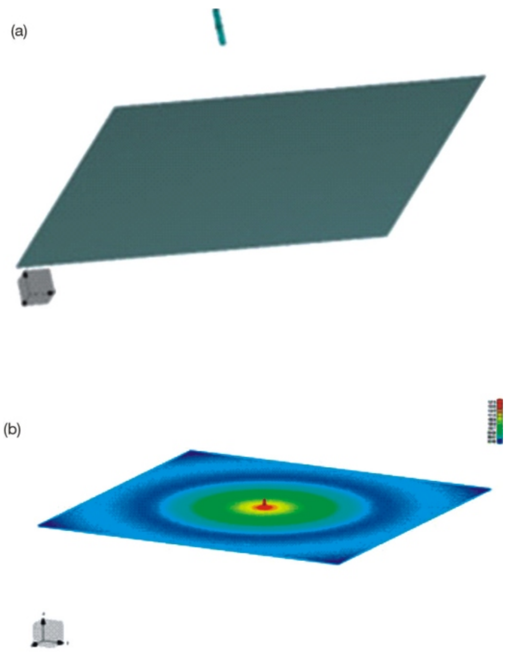

Figure 6. (a) WIPL-D model of the tubular dipole at a height of 1.29 m above PEC plane (simulated SAC) and (b) simulated near electric field distribution of tubular dipole

Table 1. The assigned values X_{ser1} and X_{ser2}

f [MHz]	X_{ser1} in dB Vm^{-1}]	X_{ser2} in dB [Vm^{-1}]]
50	69.57	71.44
150	88.85	83.95
250	90.10	89.51
350	89.95	93.29
550	85.23	86.19
750	86.41	83.26

Table 2. Expanded uncertainties reported by the participant laboratories

Laboratory	1	2	3	4
U_{lab} [dB]	5.69	5.20	5.04	4.40

through the SER, in the ς-score are different in principle. In addition, this is due to generally larger robust standard deviation σ_{rob}, that appears in the denominator of eq. (1) if compared with the combined standard uncertainty of a participant's result u_{labi}, in the denominator of eq. (4).

For future ILC, perhaps a solution should be suggested to abandon *z*-score statistics because it is impossible to regulate participants' behavior.

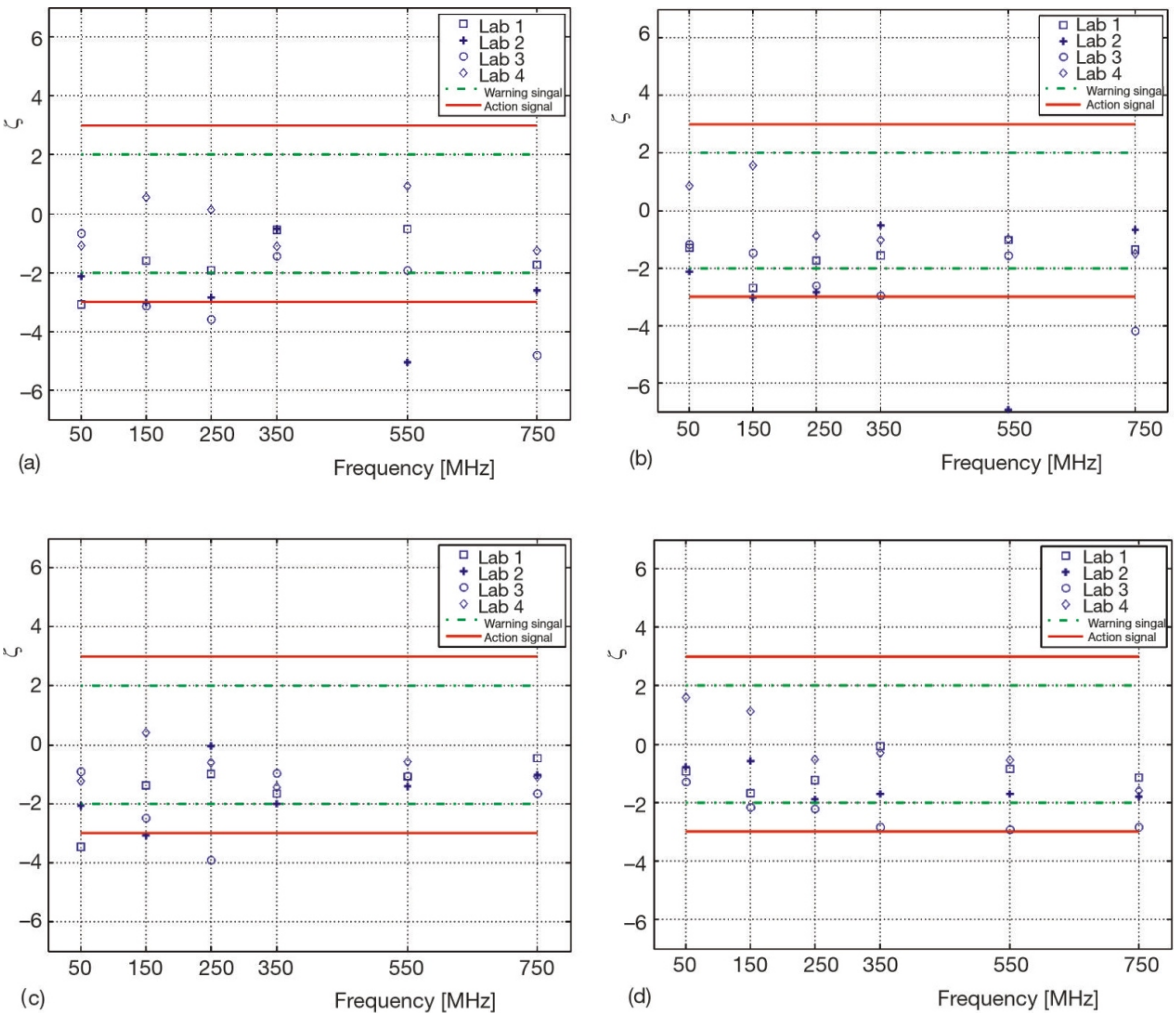

Figure 7 (a)-(d). Values of the ς-score calculated by each laboratory for four cases

CONCLUSIONS

To evaluate the interlaboratory comparison of each testing laboratory, the robust *z*-scores and ς-scores are used. As only three out of 96 values fell out of the acceptance interval (|*z*| 2), the overall performance of the participant laboratories seems to be adequate. As the number of participants is not enough, the ς-score method is also used. The total number of measurement results was 96. Those giving warning or action signals were 28. This means that 29.17 % of measurement results were not within the range of acceptable relative deviation from the corresponding reference values X_{ser}. In addition, Lab. 2 and Lab. 3 will require special attention in the next ILC round, to have their performances improved. The ς-score appears to be stricter if compared with the *z*-score. The discrepancy in the *z* statistic and ς statistic determined by the two methods stems mainly from the fact that the median in the *z*-score method and the assigned value, obtained through the simulation-experimental results, in the ς-score are different in principle. For future ILC, perhaps a solution should be suggested to abandon the *z*-score statistic since it is impossible to regulate the conduct of the participants.

Results show that the decision on technical competence for the measurement of a laboratory depends on the evaluation method used. The results presented in this paper should be useful to the Accreditation Body of Serbia tasked with assessing the competence of testing laboratories. In addition, a tubular dipole adopted in the ILC may be proposed as an alternative type of signal source for measurement comparisons.

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AUTHORS' CONTRIBUTIONS

Conceptualization, methodology, writing the original draft, and editing was carried out by A. M.

Kovačević. Formal analysis, reviewing, and approving were carried out by all authors. Software simulation was performed by N. V. Munić.

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МЕЂУЛАБОРАТОРИЈСКО ПОРЕЂЕЊЕ МЕРЕЊА ЕМИСИЈЕ ЗРАЧЕЊА КОРИШЋЕЊЕМ ЦЕВАСТОГ ДИПОЛА

Рад представља међулабораторијско поређење мерења емисије зрачења у фреквенцијском опсегу од 30-1000 MHz. Цевасти дипол посебно је дизајниран и коришћен као референтни извор емитовања. Најважније за цевасти дипол је његова стабилност у процесу испитивања. Иако стабилност није карактеристика узорка, сигнал емисије узорка јесте стабилан. Поред тога, разматрају се два начина одређивања референтне вредности јачине електромагнетског поља. Прва референтна вредност добија се коришћењем робусне анализе. Ради се о робусној просечној вредности која се израчунава усредњавањем резултата мерења које су дале испитне лабораторије учеснице. Друга референтна вредност добија се кроз симулационо-експерименталне резултате цевастог дипола у полуанехоичној соби или анехоичној соби, за хоризонталну и вертикалну поларизацију, и мерење на удаљености од 3 m, респективно. При томе, ову вредност додељује координатор. Резултати мерења упоређују се коришћењем робусног z-скора и ς-скора.

Кључне речи: међулабораторијско поређење, лабораторија за испитивање, емисија зрачења, цевасти дипол, робусна анализа, симулационо-експериментални резултат