# An Intercomparison of the Broadband Electrical Field Meter NARDA NBM 550

Nenad Munić, Aleksandar M. Kovačević, Nenko Brkljač, Ljubiša Tomić

*Abstract*— **This paper presents the intercomparison of five broadband electric field meters from the three laboratories. The Intercomparison was performed in broadband frequency range at different level of the electric field meter. The measurement results were compared using the z-score criteria. The intercomparison was performed with the aim of confirming the accuracy of broadband electric field meters, until the realization of calibration in an accredited metrology laboratory.**

***Index Terms*** **— Intercomparison, Broadband Electric Field Meter, z-score, Calibration.**

## I. Introduction

DIFFERENT measuring equipment can be used during the tests. Their accuracy can significantly affect the reliability of the measurements. Therefore, the measuring equipment must be calibrated before use [1]. In doing so, each laboratory must establish a program and procedure for calibrating its measuring equipment. Due to all the above, the Technical Testing Center (TTC) [2], a specialized military scientific research institution, in accordance with the requirements of the quality management system [3], developed a Procedure [4] for periodic calibration of measuring equipment.

One of the ways to determine and review the deadline for periodic calibration of measuring equipment are intermediate checks [1, 4]. In that case, the method of checking certain metrological characteristics of measuring equipment between two calibrations is used, in one of the following ways: a) using a references instrument; b) using a specially designed test device; c) participation in interlaboratory comparisons; e) participation in intercomparison.

Participation in intercomparison is one of the requirements for laboratories that are entering the accreditation process or have already been accredited [5]. Positive results of intercomparison are confirmation of the accuracy of measurements performed in the laboratory and the competence of that laboratory.

Intercomparison of meters is performed at the request of the user of the meter. In doing so, the intercomparison is performed by the laboratory user of the meter, and if necessary, other laboratories and the competent metrological laboratory can also participate [4]. Measurement intercomparison means the comparison of metrological characteristics of meters of the same type and approximately the same measurement uncertainty under established conditions.

Due to the complicated procedure of calibration in foreign accredited metrological laboratories, and for the needs of measuring in the field of electromagnetic compatibility (EMC), the Department of Electromagnetic Compatibility and Environmental Impacts in TTC initiated and organized intercomparison of broadband EM field meter NBM-550 with other broadband electric field S.A 43, manufactured by CHAUVIN ARNOUX [6].

In the meantime, the number of intercomparison participants increased, at the request of laboratories dealing with risk assessments at workplaces and in the work environment, (non-ionizing radiation), the Institute of Occupational Medicine of the Military Medical Academy (MMA) [7] and the Military Hospital in Nis [8]. A total of five meters from three laboratories were used in this intercomparison.

Intercomparison was performed for two cases: in the first case when setting defining value of electric field from the frequency range of meter and in the second case by measuring several different values of electric field at a certain frequency. Measurement results were compared using the z-score criterion.

The goal of the intercomparison is to extend the use of the broadband EM field meter NBM-550, manufactured by NARDA, until the realization of calibration in an accredited metrological laboratory. Namely, the aim of processing the results of intercomparison of these measures is to analyze the results according to the criteria for measures of the same type and approximately the same measurement uncertainty, under established conditions, then to determine the acceptability of results, and thus confirm their applicability to measure electric field strength.

## II. Intercomparison conditions

The intercomparison was performed in the Faraday cage of the Technical Experimental Center, as shown in Fig. 1.

The subject of intercomparison are broadband EM field meters, as follows:

– Narda NBM-550, s/n: B-0503, with antenna (sensor) EF0391, s/n: A-0610 (Sen 1);
– Narda NBM-550, s/n: B-0594 with antennas (sensors):

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- EF0391, s/n: A-0700 (Sen 2);
- EF6091, s/n: 01084 (Sen 3);
- Narda NBM-550, s/n: H-0386 with antennas (sensors):
  - EF0691, s/n: H-0550 (Sen 4);
  - EF5091, s/n: 01606 (Sen 5);

Fig. 1. Electric field strength measurement with electric field meter, transmitting Ultra log antenna.

Fig. 2. NBM-550, „NARDA“ [6].

Intercomparison was performed by comparing the measured values of the electric field of different antennas (sensors) of EM field meters for the case when changing:

- transmission signal frequency (constant transmission power level),
- transmission signal strength (fixed transmission frequency).

EM field meters NBM-550, with its corresponding antenna (EF0391, EF6091 or EF5091), are mounted on a non-conductive styrofoam bracket mounted on a conductive table in a Faraday cage at a distance of 1.45 m from the transmitting antennas: Ultra log antennas (Fig. 1) or double-crest antennas (Fig. 3). The height of the transmitting antennas of 1.385 m corresponds to the height at which the antenna of the EM field meter is located.

Fig. 3. Electric field strength measurement with electric field meter, double-ridge transmitting antenna.

The NBM-550 meter is controlled by an application installed on a PC, NBM-TS PS Transfer software V 2.1.1. EM field meters are connected via a suitable optical cable and converter to a PC to monitor the value of the electric field.

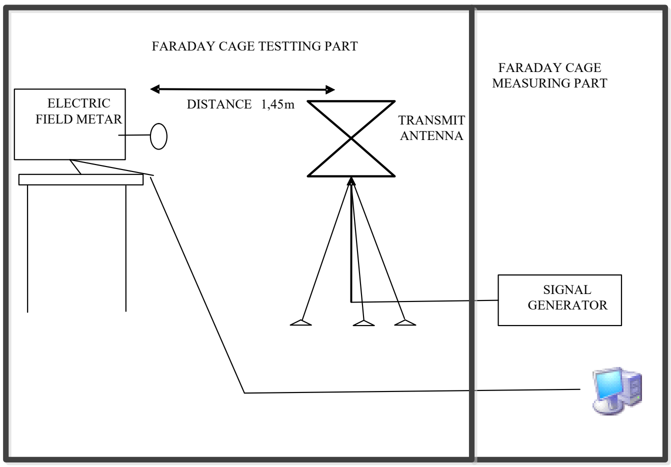


Fig. 4. Block diagram of measuring the strength of electric field, for different frequencies and fixed power level of signal generator.

The measurement is first performed when the excitation frequency is variable, by setting the transmit power level to the maximum value allowed by the signal generator. The block diagram of measuring the value of the electric field strength with the NBM-550 "NARDA" meter, in case when

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the frequency of the excitation signal was being changing is shown in Fig. 4.

For fixed frequency measuring, a signal amplifier was used while the excitation power level changed. The operating frequency is determined in the previous measurement by selecting the frequency from the middle of the measuring range at which the highest values of the electric field were achieved. In this case, the frequency of 600 MHz is selected. The block diagram of this measurement is shown in Fig. 5.

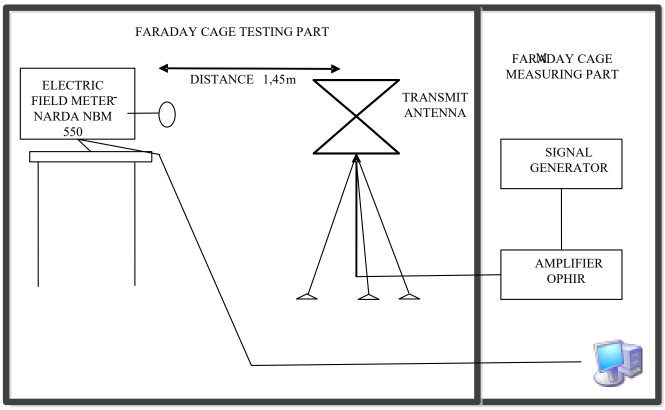


Fig. 5. Block diagram of measuring the strength of electric field, for different values of power levels and at a fixed frequency of signal generator.

The following measuring instruments and equipment were used for testing purposes:

- Broadband EM field meters NBM-550, "NARDA", listed in Chapter II,
- Signal generator SMB100, R&S, s/n. 1406.6000K03-178572-eW,
- RF amplifier 5126, „OPHIR“, from 20 MHz to 1000 MHz, s/n. 1020,
- ULTRALOG antenna HL562, R&S, ser. num. 1000324
- double-ridge antenna 960001, AILTECH, ser. br. 2097,
- Optical cable, 115200 Bd, length of 20 m,
- Cables RG-214/U (N-N), length of 10 m and 1,5 m,
- Wooden stand (tripod).
- Laptop with NBM-TS PS Transfer software V 2.1.1

At the same time, the characteristics of the measuring equipment meet the prescribed standards [9, 10].

Environmental conditions:

- temperature: 24 °C ± 2 °C,
- relative humidity:50 % ± 15 %.

## III. Intercomparison criteria

As a criterion for evaluating the results of intercomparison, taking into account all the specifics of the measurement, the z-score was adopted, in accordance with the standard ISO 13528: 2005 [9, 10]. As five test samples participated in the comparison, the mean value of the test results for all samples was taken as the assigned (reference) value $X_{\text{ref}}$. The z-score should indicate whether the measured value deviates significantly from the assigned value, in our case from the mean value of the test results, taking into account the standard deviation $\sigma$.

The z-score is calculated as follows [10]:

$$z_i = \frac{x_{\text{lab}_i} - X_{\text{ref}}}{\sigma}, i = 1, 2, \dots, 5. \quad (1)$$

where:

$x_{\text{lab}_i}$ test results for each sample (i = 1, 2, ... , 5);

$X_{\text{ref}}$ the assigned (reference) value is the mean value of the test results of all samples,

$$x_{\text{ref}} = \frac{\sum_{i=1}^{n} x_{lab_i}}{n}, \text{ n} = 5\,; \quad (2)$$

$\sigma$ standard deviation for non-repeat testing,

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_{lab_i} - x_{\text{ref}})^2}{n}}, \text{ n} = 5. \quad (3)$$

The z-score coefficient can be positive or negative and determines the number of standard deviations of the data set from the arithmetic mean. A negative result indicates a value less than the mean, and a positive result indicates a value greater than the mean, with the average of each z-score weighing to zero.

The value of z-score is interpreted as follows:

- A result that gives |z| ≤ 2,0 is considered to be acceptable;
- A result that gives 2,0 < |z| < 3,0 is considered to give a warning signal;
- A result that gives |z| ≥ 3, 0 is considered to be unacceptable (or action signal) and the participants should be advised to check their measurement procedures following warning signals in case they indicate an emerging or recurrent problem [10].

## IV. Results of intercomparison

The results of intercomparison at a given maximum signal level of the signal generator and different frequency values are shown in Table I. Based on the results obtained from Table I and the calculation of mean and standard deviation, and using formula (1) obtained values of z-score coefficient, shown in Table II.

TABLE I
RESULTS OF MEASUREMENT THE STRENGTH OF ELECTRIC FIELD, FOR DIFFERENT FREQUENCIES AND FIXED POWER LEVEL OF SIGNAL GENERATOR

| $f$ (MHz) | $E_{\text{sen1}}$ (V/m) | $E_{\text{sen2}}$ (V/m) | $E_{\text{sen3}}$ (V/m) | $E_{\text{sen4}}$ (V/m) | $E_{\text{sen5}}$ (V/m) |
|---|---|---|---|---|---|
| 100 | 5,59 | 5,63 | 4,409 | 5,954 | / |
| 200 | 6,176 | 6,194 | 4,696 | 6,272 | / |
| 300 | 17,89 | 17,68 | 15,26 | 18,36 | 15,52 |
| 400 | 16,93 | 17,14 | 14,93 | 15,77 | 16,15 |

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| $f$ (MHz) | $E_{sen1}$ (V/m) | $E_{sen2}$ (V/m) | $E_{sen3}$ (V/m) | $E_{sen4}$ (V/m) | $E_{sen5}$ (V/m) |
|---|---|---|---|---|---|
| 500 | 10,45 | 11,02 | 8,529 | 9,725 | 7,103 |
| 600 | 22,14 | 21,7 | 21,27 | 21,9 | 21 |
| 700 | 11,92 | 13 | 11,2 | 12,56 | 9,8 |
| 800 | 7,73 | 7,654 | 5,118 | 7,465 | 5,18 |
| 900 | 18,48 | 19,01 | 19,46 | 21,5 | 16,14 |
| 1000 | 20,54 | 20,81 | 18,83 | 21,71 | 19,11 |
| 1200 | 12,89 | 13,05 | 12,84 | 14,84 | 10,52 |
| 1400 | 10,5 | 9,947 | 6,758 | 9,835 | 5,836 |
| 1600 | 10,85 | 10,55 | 8,499 | 10,34 | 5,912 |
| 1800 | 8,366 | 9,512 | 8,485 | 8,831 | 8,154 |
| 2000 | 11,61 | 12,05 | 12,78 | 12,11 | 12,23 |
| 2200 | 11,58 | 10,89 | 4,124 | 10,18 | 4,918 |
| 2400 | 9,145 | 8,299 | 12,26 | 10,23 | 13,45 |
| 2600 | 5,356 | 3,989 | 2,642 | 4,322 | 2,234 |
| 2800 | 11,76 | 9,156 | 7,031 | 10,57 | 5,24 |
| 3000 | 7,669 | 6,529 | 7,422 | 7,858 | 5,421 |
| 3500 | / | / | 6,643 | 10,07 | 4,511 |
| 4000 | / | / | 5,906 | 13,16 | 4,112 |
| 4500 | / | / | 10,41 | 6,313 | 8,919 |
| 5000 | / | / | 5,396 | 6,085 | 4,136 |
| 5500 | / | / | 6,942 | 6,548 | 5,377 |
| 6000 | / | / | 4,875 | 5,005 | 3,158 |
| 7000 | / | / | 2,041 | / | 1,287 |
| 8000 | / | / | 3,957 | / | 2,921 |
| 9000 | / | / | 2,436 | / | 3,427 |
| 10000 | / | / | 1,58 | / | 2,756 |
| 11000 | / | / | 0,6134 | / | 1,72 |
| 12000 | / | / | 0,8626 | / | 2,786 |
| 13000 | / | / | 0,258 | / | 2,819 |

TABLE II
RESULTS OF Z-SCORE, FOR DIFFERENT FREQUENCIES AND FIXED POWER LEVEL OF SIGNAL GENERATOR

| $f$ (MHz) | $z_{sen1}$ | $z_{sen2}$ | $z_{sen3}$ | $z_{sen4}$ | $z_{sen5}$ |
|---|---|---|---|---|---|
| 100 | 0,330 | 0,399 | -1,681 | 0,951 | / |
| 200 | 0,518 | 0,546 | -1,729 | 0,664 | / |
| 300 | 0,735 | 0,572 | -1,305 | 1,100 | -1,103 |
| 400 | 0,930 | 1,192 | -1,563 | -0,516 | -0,042 |
| 500 | 0,772 | 1,178 | -0,595 | 0,256 | -1,610 |
| 600 | 1,296 | 0,236 | -0,800 | 0,718 | -1,451 |
| 700 | 0,198 | 1,158 | -0,440 | 0,767 | -1,684 |
| 800 | 0,908 | 0,845 | -1,247 | 0,689 | -1,195 |
| 900 | -0,253 | 0,053 | 0,3143 | 1,496 | -1,610 |
| 1000 | 0,314 | 0,564 | -1,268 | 1,398 | -1,009 |
| 1200 | 0,045 | 0,161 | 0,008 | 1,465 | -1,680 |
| 1400 | 1,015 | 0,723 | -0,958 | 0,664 | -1,444 |
| 1600 | 0,874 | 0,712 | -0,394 | 0,599 | -1,792 |
| 1800 | -0,639 | 1,773 | -0,388 | 0,339 | -1,085 |
| 2000 | -1,452 | -0,282 | 1,660 | -0,122 | 0,196 |
| 2200 | 1,026 | 0,807 | -1,334 | 0,583 | -1,083 |
| 2400 | -0,798 | -1,239 | 0,825 | -0,232 | 1,445 |
| 2600 | 1,446 | 0,246 | -0,936 | 0,538 | -1,295 |
| 2800 | 1,275 | 0,171 | -0,729 | 0,771 | -1,488 |
| 3000 | 0,763 | -0,499 | 0,489 | 0,972 | -1,726 |
| 3500 | / | / | -0,188 | 1,308 | -1,119 |
| 4000 | / | / | -0,465 | 1,389 | -0,923 |
| 4500 | / | / | 1,100 | -1,319 | 0,219 |
| 5000 | / | / | 0,235 | 1,089 | -1,325 |
| 5500 | / | / | 0,982 | 0,389 | -1,372 |
| 6000 | / | / | 0,62 | 0,78 | -1,41 |

The results of the intercomparison of the measurement of the electric field value with the NARDA NBM-550 meter, for different values of the power level at a fixed frequency of the signal generator, are shown in Table III. Based on the results obtained from Table III and the calculation of the mean and standard deviation, and using formula (1), the values of the z-score coefficient were obtained, which are shown in Table IV.

TABLE III
RESULTS OF MEASUREMENT THE STRENGTH OF ELECTRIC FIELD, FOR DIFFERENT VALUES OF POWER LEVELS AND AT A FIXED FREQUENCY OF SIGNAL GENERATOR

| $P_{gen}$ (dBm) | $E_{sen1}$ (V/m) | $E_{sen2}$ (V/m) | $E_{sen3}$ (V/m) | $E_{sen4}$ (V/m) | $E_{sen5}$ (V/m) |
|---|---|---|---|---|---|
| -20 | 5,016 | 5,212 | 5,215 | 5,947 | / |
| -15 | 8,879 | 9,202 | 9,362 | 10,58 | 2 |
| -10 | 15,62 | 16,29 | 17,02 | 18,69 | 14,66 |
| -5 | 27,88 | 28,66 | 31,99 | 32,99 | 30,15 |
| 0 | 50,4 | 51,33 | 61,92 | 58,16 | 55,56 |
| 5 | 90,37 | 92,69 | 114,6 | 104,1 | 94,89 |
| 10 | 161,1 | 161,1 | 203,5 | 189,7 | 167,2 |
| 15 | 255,1 | 253,3 | 309,7 | 310,9 | 262,1 |

TABLE IV
RESULTS OF *Z-SCORE*, FOR DIFFERENT VALUES OF POWER LEVELS AND AT A FIXED FREQUENCY OF SIGNAL GENERATOR

| $P_{gen}$ (dBm) | $z_{sen1}$ | $z_{sen2}$ | $z_{sen3}$ | $z_{sen4}$ | $z_{sen5}$ |
|---|---|---|---|---|---|
| -20 | 0,341 | 0,431 | 0,433 | 0,771 | / |
| -15 | 0,286 | 0,391 | 0,444 | 0,842 | -1,964 |
| -10 | -0,614 | -0,121 | 0,414 | 1,641 | -1,319 |
| -5 | -1,270 | -0,866 | 0,857 | 1,375 | -0,095 |
| 0 | -1,184 | -0,967 | 1,505 | 0,627 | 0,020 |
| 5 | -1,001 | -0,742 | 1,707 | 0,533 | -0,496 |
| 10 | -0,901 | -0,901 | 1,576 | 0,770 | -0,544 |
| 15 | -0,877 | -0,945 | 1,194 | 1,239 | -0,611 |

Table V gives the budget of measurement uncertainty of electric field strength measurement, measuring instruments NBM-550 "NARDA". For the stated influential quantities (sources of measurement uncertainty), the estimation of measurement uncertainty was performed on the basis of data


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from the manufacturer's specification and calibration certificates.

TABLE V
UNCERTAINTY MEASUREMENT BUDGET FOR THE CASE OF MEASURING THE STRENGTH OF THE ELECTRIC FIELD WITH THE METER NBM-550 „NARDA [6]

| **Uticajna veličina $X_i$** | **Procena $X_i$ ($x_i$)** | | **Standardna nesigurnost $u(x_i)$** | **Koeficijent osetljivosti $c_i$** | **Doprinos standardnoj nesigurnosti $u_i(y)=c_i\,u(x_i)$** |
|---|---|---|---|---|---|
| | **Vrednost (dB)** | **Funkcija raspodele** | | | |
| Merni prijemnik: Tačnost prijema sinusnog signala | ±3,0 | normalna $k = 2$ | 1,5 | 1 | 1,5 |
| Antena – merni prijemnik | +0,9 −1,0 | U-oblika $k = 1{,}414$ | 0,67 | 1 | 0,67 |
| Korekcije mernog prostora | | | | | |
| Nesavršenost mernog prostora | ±4,0 | trougaona $k = 2{,}449$ | 1,63 | 1 | 1,63 |
| Varijacije mernog rastojanja | ±0,2 | pravougaona $k = 1{,}732$ | 0,1 | 1 | 0,1 |
| Visina antenskog postolja na kome se nalazi merni prijemnik | ±0,1 | normalna $k = 2$ | 0,05 | 1 | 0,05 |
| | | | | | |
| Ponovljivost sistema merenja (tip **A**) | ±0.006910 | Standardna devijacija | 0.006910 | 1 | 0.006910 |
| Kombinovana standardna nesigurnost $u_c(y)$ | | normalna | $u_c(y) = \sqrt{\sum_i u_i^2(y)}$ | | 2,3 |
| Proširena merna nesigurnost $U$ | | нормална $k_p = 2$ | $U = k_p u_c(y)$ | | **4,63 dB** |

## V. CONCLUSION

Due to the complicated procedure of calibration in foreign metrological laboratories, and due to the need to confirm the accuracy of five EM field meters NBM-550, the Department of Electromagnetic Compatibility and Environmental Impacts in TTC, initiated and organized intercomparison. The intercomparison was also attended by laboratories that deal with risk assessments at workplaces and in the work environment, from the point of view of non-ionizing radiation, the Institute of Occupational Medicine of the Military Medical Academy and the Military Hospital in Nis.

The result of intercomparison according to frequencies and electric fields strength is represented by the numerical value of the z-score model in Tables 3 and Table 5. Based on the presented results, we conclude that the values of z-score, $|z| \leq 2$ and that the results are satisfactory (acceptable), and no corrective measures are needed. This shows that the deviations in the measurements, the values of the electric field between the five meters are acceptable in the entire frequency range of the meters.

The goal of the intercomparison, which was to extend the use of the broadband EM field meter "NARDA" NBM-550, until the realization of calibration in the accredited metrology laboratory is fulfilled. NBM-550 "NARDA" meters can be used to measure the strength of the electric field, until the realization of calibration in an accredited metrological laboratory.

Based on the above and the analysis of the conducted procedure and the results of the comparison of meters, it can be concluded that the conducted intercomparison procedure is currently sufficient to consider the metrological characteristics of NBM-550 "NARDA", but not metrological confirmation in terms of SRPS ISO / IEC 17025: 2006.

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