Scheme of the interlaboratory comparison of radiated power measurements in reverberation chamber in the 100 MHz to 6000 MHz frequency range Interlaboratory comparison ILC(RP-100-6000)

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Rev. 0 – January 7, 2025
Rev. 1 – May 5, 2025: improved the description of the RESET function and procedure.

1. Scope

1.a) This document describes the participation scheme to an interlaboratory comparison of radiated power measurement in reverberation chamber in the 100 MHz to 6000 MHz frequency range. The scheme includes:

- The description of the interlaboratory comparison;
- The selection criteria of the participants and the terms of admission to the interlaboratory comparison;
- The description of the technique adopted for the statistical analysis of the results of the interlaboratory comparison;
- The instructions to the participating laboratory (briefly, Laboratory) on how to perform measurements;
- The description of the method by which the results of the interlaboratory comparison are registered by the Laboratory and by the Coordinator of the interlaboratory comparison;
- The test report forms to be filled by the Laboratory and by the Coordinator;
- The registration forms (for selecting the week for measurements and providing shipment information).

1.b) Although the scope of this interlaboratory comparison is mainly to quantify the reproducibility of radiated power measurements in reverberation chamber, the Coordinator will provide each participating laboratory with a feedback about its performance through an individual report.

1.c) In addition to an individual report, a document will be issued containing general information about the outcome of the interlaboratory comparison and permitting to each participating Laboratory to compare its performance with the performance of all the other participating Laboratories.

1.d) The last revision of the present document can be downloaded from the following URL:
https://www.dinfo.unifi.it/vp-436-schemes-of-the-proficiency-tests.html

2. Coordinator

2.a) The Coordinator of the interlaboratory comparison is Carlo Carobbi, from Università degli Studi di Firenze.

2.b) The contact details of the Coordinator are reported below:
Carlo Carobbi

Dipartimento di Ingegneria dell'Informazione
Università degli Studi di Firenze
Via S. Marta, 3 – 50139 Firenze, Italy
Phone: +39 055 2758501
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e-mail: carlo.carobbi@unifi.it

3. Type of interlaboratory comparison

3.a) The interlaboratory comparison consists in the comparison of the measurements of a travelling standard (Sample) provided by the Coordinator. Each Laboratory makes a quantitative examination (Measurement) of the Sample thus providing the Coordinator with a measurement result.

3.b) The Coordinator designed and assembled the Sample.

3.c) The Coordinator assigns to the Sample a reference value and the corresponding uncertainty. The reference value, x^*, and its standard uncertainty, s^*, are obtained by the Coordinator through the statistical analysis of the measurement results provided by the Laboratories during the interlaboratory comparison. The reference value x^* and the standard uncertainty s^* will be known at the end of the interlaboratory comparison, after that the last participating Laboratory has submitted its measurement results.

3.d) The scheme of participation in the interlaboratory comparison is sequential and it is illustrated in Fig. 1. The Coordinator passes the Sample to the 1st participating Laboratory. The 1st Laboratory performs the measurement thus obtaining the 1st measurement result. Then, the 1st Laboratory passes the Sample to the 2nd Laboratory which, in turns, performs the measurement and determines the 2nd measurement result. The 2nd Laboratory passes the Sample to the 3rd Laboratory which obtains the 3rd measurement result, and so on. The last Laboratory passes back the Sample to the Coordinator. The interlaboratory comparison is completed when the last participating Laboratory has submitted its measurement result to the Coordinator.

3.e) The measurement result provided by each Laboratory consists of a measured value x and its expanded uncertainty U_{lab}. The measurement result provided by each Laboratory will be compared against the reference value assigned by the Coordinator.

3.f) The transmission of the test report from the Coordinator to the Laboratory will take place only after that the interlaboratory comparison is concluded. No communication of the results of the interlaboratory comparison shall be done by the Coordinator to the Laboratory in the period comprised between the beginning and the conclusion of the interlaboratory comparison.

3.g) Participation is free (no charge).

3.h) The Laboratory has one (1) week available to perform the measurement and two (2) weeks to communicate the measurement result to the Coordinator. Late results will not be accepted nor processed by the Coordinator.

3.i) In case that a Laboratory is willing to submit more than one set of measurement results (e.g., because the Laboratory wants to assess the performance of different facilities and instrumentations) then the Laboratory shall contact the Coordinator in order to determine the

appropriate scheduling. In such case more than one test report shall be issued by the Laboratory, one for each submitted set of measurement results. Any request for more than one test report must be individually evaluated by the Coordinator (the Laboratory shall contact the Coordinator to this purpose.

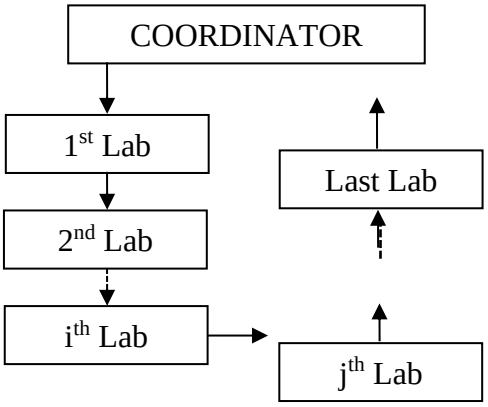

Fig. 1: Sequence by which the Sample is passed from the Coordinator to the Laboratories and from the Laboratories to the Coordinator.

4. Admission requirements

4.a) The present scheme applies to Laboratories that:

- Can make radiated power measurements in a reverberation chamber accordance with the methods described in clause 6.2 and Annex E (normative) of the standard EN 61000-4-21:2011
- Have evaluated the measurement uncertainty U_{lab} of the measurement method mentioned in the previous clause.

4.b) Accreditation to ISO/IEC 17025 is not required for admission to the interlaboratory comparison. The Coordinator designed the present scheme assuming participation of both accredited and non-accredited Laboratories.

4.c) Participation in the interlaboratory comparison is admitted also to laboratories that cannot cover the full frequency range from 100 MHz to 6000 MHz. E.g., measurement of the thirteen harmonics listed in Table 2 from 400 MHz to 4 GHz is acceptable.

4.d) The Coordinator starts the interlaboratory comparison if there are at least five participating Laboratories. The maximum number of participating laboratories is twenty-five (30) which corresponds to a total duration of the interlaboratory comparison of about one year.

4.e) The Coordinator assigns a code to the Laboratory for anonymous identification. The same code will be used to identify the Laboratory in e-mail correspondence and in the test reports. The code is as follows:

ILC(RP-100-6000)LAB(#)

The code is the combination of a general part – ILC(RP-100-6000) – that identifies the measurement method, and therefore a homogenous set of measurement results, and a specific part – LAB(#) – that identifies a particular Laboratory.

4.f) The Laboratory that is willing to participate in the interlaboratory comparison shall:

- Designate a Technical Responsible. The Technical Responsible shall sign the test report submitted by the Laboratory to the Coordinator (Annex C), in addition he/she will be the reference person for correspondence with the Coordinator.

- Select the week in which measurements will be performed as follows:
  - Find the available weeks at this spreadsheet
  - https://docs.google.com/spreadsheets/d/1UrBT4bmJesd2t5kqErIY9qnXBS1JdisSrm1xr-fh4rM/edit?usp=drive_link
  - Send, by e-mail, to the Coordinator (carlo.carobbi@unifi.it) the name of the Laboratory, the shipping address, the name of the Technical Responsible, his/her e-mail and phone number and the selected week for measurements;
  - The Coordinator will fill the spreadsheet with the Laboratory information.

4.g) The Laboratory shall observe the following shipping rules:
- Shipping of the Sample from the Coordinator to the Laboratory is in charge of the Coordinator;
- Shipping of the Sample from Laboratory X to the next Laboratory Y or to the Coordinator is in charge of Laboratory X;
- Shipments shall be done by means of an express courier;
- The same packaging used by the Coordinator shall be used by the Laboratory.

Handle with care the travelling Sample. A damage to the Sample will cause a delay and eventually the interruption of the interlaboratory comparison. Each Laboratory shall verify by inspection the mechanical integrity of the Sample. Possible defect or damage, proven or suspected, shall be immediately notified to the Coordinator. A verification of the electrical performance of the Sample is also envisaged (see §7).

5. Statistical analysis of the measurement results

5.a) The statistical analysis is based on the zeta-scores (symbol ζ) performance statistics (see §9.6 of ISO 13528:2022). The measurement result x_i, in dBm, provided by the i-th Laboratory ($i = 1, 2, ..., p$, where p is the number of participating Laboratories) is compared with the value X, in dBm, assigned by the Coordinator. The standard uncertainty of x_i is $u_{xi} = (U_{lab})_i / 2$ where $(U_{lab})_i$, in dB, is the expanded uncertainty stated by the i-th Laboratory (see §3). The standard uncertainty of X is $u_X = U/2$, where U, in dB, is the expanded uncertainty obtained multiplying the standard uncertainty by a coverage factor $k = 2$ (which corresponds to a coverage probability of about 95 %, assuming a normal distribution) that the Coordinator assigned to the reference value X. The Coordinator calculates the following measure ζ_i of relative deviation between x_i and X:

$$\zeta_i = \frac{x_i - X}{\sqrt{u_{xi}^2 + u_X^2}} . \qquad (1)$$

The value of ζ_i is calculated for each Laboratory and for each investigated frequency. Therefore, as many values of ζ_i will be calculated as the number of investigated frequencies (ten frequencies investigated, ten values of ζ_i for the i-th Laboratory). The measurement result provided by the i-th Laboratory will produce a warning signal if, at least at one frequency, we have ζ_i less than −2 or greater than +2. The measurement result provided by the i-th Laboratory will produce an action signal if, at least at one frequency, we have ζ_i less than −3 or greater than +3. If at all frequencies, we have ζ_i greater than −2 and less than +2 then the measurement result provided by the i-th Laboratory will not give evidence of any anomaly.

5.b) The reference values *X* and *U* that the Coordinator uses to evaluate the performance of a Laboratory are the robust mean x^* and the robust expanded uncertainty U^*, respectively. The standard uncertainty of the reference value $X = x^*$ is $u_X = U^*/2 = 1,25 \cdot s^*/\sqrt{p}$.

5.c) The values of the robust mean x^* and the robust standard deviation s^* are obtained by the Coordinator by using the robust analysis (Algorithm A) described in Annex C of ISO 13528:2022. The robust analysis is based on an iterative calculation. At the first step of iteration

$$x^* = \text{median of } x_i \quad (i = 1,2,..., p) \tag{2}$$

and

$$s^* = 1,483 \cdot \{\text{median of } |x_i - x^*|\} \quad (i = 1,2,..., p) . \tag{3}$$

NOTE : The factor 1,483 which appears in (3) represents the ratio between the standard deviation σ and the median of the absolute deviations from the median, *MAD*, assuming normal distribution. It is indeed possible to show that in the case of symmetric distribution, $MAD/\sigma = \Phi^{-1}(3/4)$, where Φ is the cumulative distribution function. In the case of normal distribution $\Phi^{-1}(3/4) = 0,6745$ and therefore $\sigma = 1,4826 \cdot MAD$.

NOTE 2: The factor 1,25 that appears in the formula $U^*/2 = 1,25 \cdot s^*/\sqrt{p}$ represents the ratio between the standard deviation of the median and the standard deviation of the mean (see §7.7.7 of ISO 13528:2022). Therefore x^* and $1,25 \cdot s^*/\sqrt{p}$ are interpreted as the mean and the standard deviation of the mean of the measurement results, respectively.

6. Characteristics of the Sample

6.a) The Sample is an electromagnetic field source made of the combination of a battery-operated comb generator and an antenna, see Fig. 2. The comb generator and the battery are embedded in the antenna. The shape of the Sample is cylindrical with approximate sizes 10 cm (base diameter) x 12 cm (height).

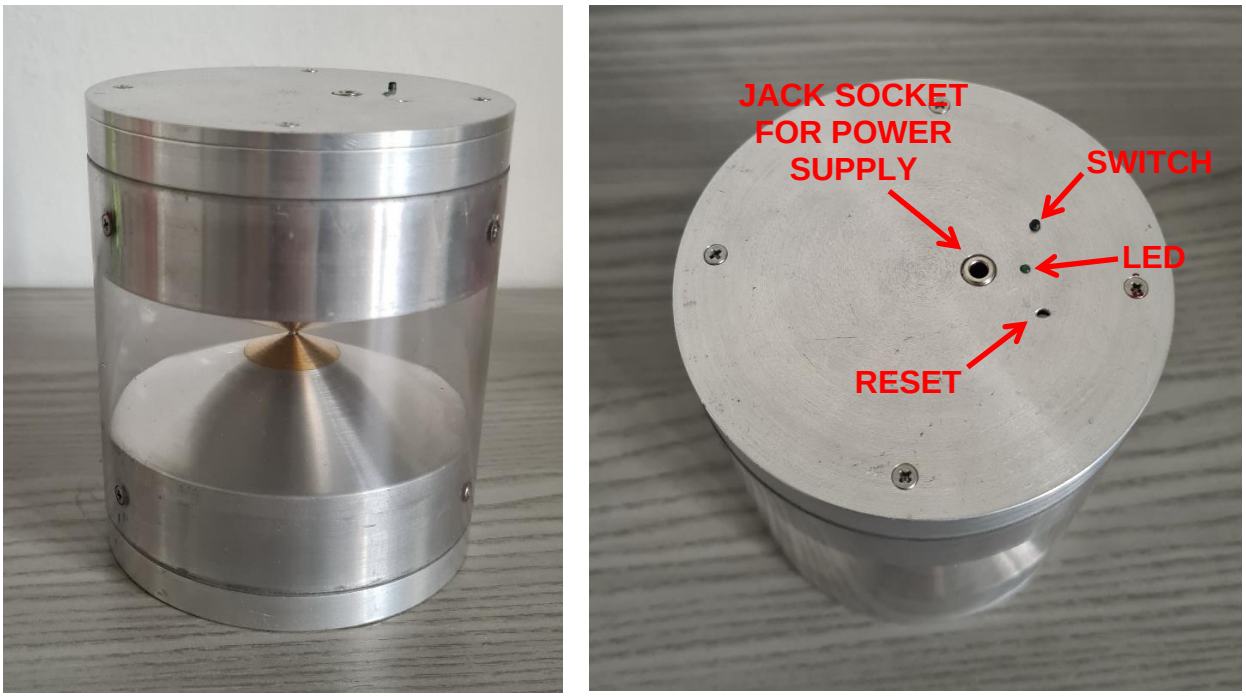

Fig. 2: Picture of the Sample.

6.b) The Sample is equipped with a SWITCH (Fig. 2, right) through which the comb generator can be turned on and off. To turn on/off the comb generator press the SWITCH for at least five seconds. The (green) LED flashes when the comb generator is on. The comb generator generates a narrow impulse at a repetition frequency of 50 MHz. If the SWITCH is then pushed for at least five seconds, then the comb generator is turned off.

6.c) <u>The repetition frequency and the harmonics' spacing is 50 MHz.</u>

6.d) Three hours of continuous and reliable operation of the comb generator are permitted by the fully charged battery. The comb generator automatically turns off when the charge level drops below the limit for reliable operation.

6.e) The Sample is equipped with a jack connector for battery recharge. The power supply is provided by the Coordinator. Three hours are needed to fully recharge the battery. During battery recharge the led intermittently flashes. If the LED is continuously on, then the battery is fully charged.

6.f) A RESET button is provided to disconnect the battery from the comb generator. It can rarely happen that the comb generator goes into an idle state in which the generator appears turned on but no signal is generated. When in this idle state, the LED flashes fast (about two flashes per second) and the generator cannot be switched off. In such case, a RESET is needed then gently push the RESET button until it clicks. The LED stops flashing. Then push the RESET button again to reconnect the battery to the comb generator. If not done before, it is recommended to recharge the battery.

6.g) The comb generator does not require warm up prior to measurement.

6.h) The harmonics' spacing is 50 MHz and the first available harmonic in the frequency range from 100 MHz to 6000 MHz is at 100 MHz.

6.i) The Coordinator identifies the harmonics to be measured through their ordinal number and the approximate frequency value. For example: the 20th harmonic is at approximately 1000 MHz.

6.j) <u>What identifies the harmonic is its order not its frequency. Frequencies are given only for guidance. The peak of the closest harmonic to the indicated frequency is the level to be measured, not the level at the indicated frequency.</u>

6.k) The combination of the lock is 183. Input the combination from top to bottom (see Fig. 3).

Fig. 3: Picture of the lock.

7. Measurement procedure

7.a) Radiated power measurement must be preceded by a <u>preliminary verification</u> of the correct operation of the Sample by using the magnetic field loop probe provided by the Coordinator, a short section of coaxial cable (length less than 1 m, not provided by the coordinator) and a receiver (spectrum analyzer or EMI receiver). The verification shall be as follows:

- Connect the probe to the input of the receiver through the short section of coaxial cable.
- Put the Sample on the same table used for radiated emission testing of table-top equipment.
- Turn on the Sample. The Sample shall be fed by its internal battery (the Sample shall not be connected to the power supply).
- Place the probe in the position sketched in Fig. 4. The probe shall be positioned so that its cable is perpendicular to the axis of the Sample and at half height of the Sample. The plane of the loop shall be the one containing the probe cable and the axis of the Sample. The probe shall touch the cones of the Sample.
- Use your hand to support the probe. No special care is required.
- Measure the power P_m that the probe delivers to the input of the receiver at the frequency of the 4th harmonic (about 200 MHz). Register the values of P_m (in dBm, rounded to the integer) in Table 1. Calculate and annotate the deviation $\Delta = P_m - P_{ref}$ (in dB, rounded to the integer).

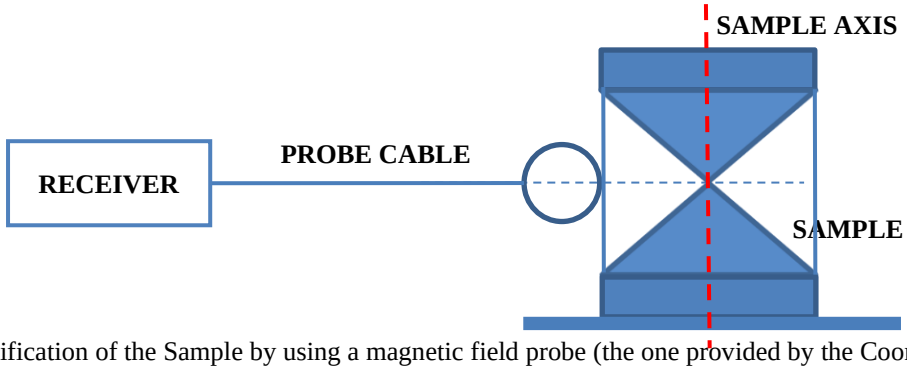

Fig. 4: Verification of the Sample by using a magnetic field probe (the one provided by the Coordinator).

- Verify that:
  - The measured power P_m decreases by at least 20 dB rotating the probe by 90°;
  - $-3\text{dB} \le \Delta \le 3\text{dB}$.

Table 1: Verification of the power that the probe delivers to the receiver.

Harmonic #	**Frequency MHz**	P_{ref} **dBm**	P_m **dBm**	**Δ dB**
4	200	−48		

7.b) If the preliminary Sample verification is successful then the Laboratory can pass to the next step, i.e., the radiated emission measurement, otherwise the Coordinator is informed and the radiated emission measurement is temporarily delayed.

7.c) The scope of the measurement is to obtain the best estimate of the power radiated by the Sample, expressed in dBm, and measurement uncertainty, expressed in dB. Measurement frequencies are reported in Table 2.

7.d) The source is narrow-band then the measurement result does not depend on the choice of the resolution bandwidth of the receiver. The selected resolution bandwidth can be the one permitting the most convenient compromise between sensitivity and measurement speed.

7.e) Any stirring method is admissible, including, but not limited to, mode-tuning, mode-stirring, source stirring, use of a vibrating intrinsic reverberation chamber, or a combination thereof.

7.f) The power radiated by the Sample is in the range between – 50 dBm to – 10 dBm.

7.g) Use of a low-noise preamplifier can be necessary in some frequency ranges.

7.h) Use of log-periodic and horn antennas in their nominal frequency range is recommended, but not mandatory.

7.i) It is up to the Laboratory to charge the battery before preliminary verification and measurement. Handle the Sample with care.

7.j) The measurement result provided by the Laboratory shall be:

- The estimate x, expressed in dBm, of the amplitude of the selected harmonics;

- The expanded uncertainty of the estimate x, U_{lab}, expressed in dB and obtained multiplying the combined standard uncertainty by the coverage factor $k = 2$ (which corresponds to a coverage probability of about 95 % assuming normal distribution).

7.k) The Laboratory may assign a different value of U_{lab} to each measured frequency.

8. Recording radiated power measurement results

8.a) The measured radiated power x, in dBm, shall be rounded to 3 significant digits (e.g., -35,6 dBm). Measurement uncertainty U_{lab}, in dB, shall be rounded to 2 significant digits (e.g., 2,6 dB).

8.b) The values of x and U_{lab} shall be recorded in the sixth and seventh column of Table 2, respectively. The Coordinator will complete the rest of Table 2.

Table 2: Table to be used for recording the radiated power measurement result x and its expanded uncertainty U_{lab}. Columns six and seven shall be filled up by the Laboratory, the other columns will be filled up by the Coordinator.

1	2	3	4	5	6	7	8
Band	**Harmonic** #	**Frequency** MHz	***x**** dBm	***s**** dB	***x*** dBm	U_{lab} dB	ζ
D	2	100	-	-			-
D	4	200	-	-			-
D	6	300	-	-			-
D	8	400	-	-			-
D	10	500	-	-			-
D	12	600	-	-			-
D	14	700	-	-			-
D	16	800	-	-			-
D	18	900	-	-			-
E	20	1000	-	-			-
E	30	1500	-	-			-
E	40	2000	-	-			-
E	50	2500	-	-			-
E	60	3000	-	-			-
E	70	3500	-	-			-
E	80	4000	-	-			-
E	90	4500	-	-			-
E	100	5000	-	-			-
E	110	5500	-	-			-
E	120	6000	-	-			-

8.c) The Laboratory fills columns six and seven and sends a copy of Table 2 to the Coordinator. The Coordinator completes the rest of Table 2 and sends a copy to the Laboratory. The interlaboratory comparison result does not give evidence of any anomaly if, at all frequencies, $-2 \le \zeta \le 2$. Otherwise anomalies shall be described in terms of warning and action signals as discussed in §5.

NOTE: Warning signals do not add up to give an action signal.

9. Test reports

9.a) The test report issued by the Laboratory to the Coordinator shall conform to Annex A and it shall be signed by the Technical Responsible. The test report issued by the Coordinator to the Laboratory will conform to Annex B. Annexes A and B, once completed by the Laboratory and by the Coordinator, will be integral part of the present document and they will provide evidence to any interested part (e.g. the Accreditation Body) of the participation of the Laboratory to the interlaboratory comparison.

9.b) The following information shall be reported in the test report along with measurement results:

- Shape, size and material of the reverberation chamber
- Stirring method (mode tuning, mode stirring or other method)
- Number of stirrer positions (mode tuning) or number of acquisitions (mode stirring)
- Antennas and relevant frequency range
- Brief description of the measurement setup used over the different frequency ranges (e.g., the one used in band D and the one used in band E)
- Procedure followed to evaluate measurement uncertainty (short description or reference to a public document)
- Pictures of the measurement setup used over the different frequency ranges
- Any additional comment having technical relevance

10. Remarks and complaints

10.a) The Coordinator issued and made freely available this document in order to prevent remarks and complaints from the Laboratories during the progress of the interlaboratory comparison.

10.b) Remarks and complaints will be considered by the Coordinator only if they are related to management or technical aspects actually relevant to the interlaboratory comparison but not considered in the present document. Registration to the interlaboratory comparison implies formal acceptance of the terms and conditions of participation in the interlaboratory comparison as described in this document.

10.c) Any Laboratory is allowed to verbally contact (e.g. by phone) the Coordinator to represent possible remarks and complaints about management and technical problems related to the interlaboratory comparison that appear during the progress of the activity. If possible, and depending on the importance of the problem originating the remark or complaint, the Coordinator will give advice to the Laboratory in order to resolve the problem.

10.d) Possible technical problems related to the management of the Sample (including shipment), such as a delay caused by a Laboratory or by the Coordinator, shall be dealt with by the Coordinator through appropriate action intended to minimize delays and successfully conclude the activity.

11. Confidentiality and impartiality

11.a) The Coordinator and his technical and scientific collaborators shall keep confidential any information pertaining the performance of the Laboratories involved in the interlaboratory comparison during its progress and after its completion. The Coordinator warrants that the results originated from the participation of the Laboratories in the interlaboratory comparison shall be kept confidential through:

- Keeping anonymous the result associated with each Laboratory. The individual result produced by each Laboratory may be released only in such a way that the anonymity of the Laboratory is preserved.

- Keeping anonymous aggregate results (i.e., statistical average, dispersion, …). The aggregate interlaboratory comparison results may be released only in such a way that the anonymity of the Laboratories that generated the results is preserved.

- Informing accredited Laboratories about a possible request of the Accreditation Body to reveal their interlaboratory comparison result. The interlaboratory comparison result shall be revealed to the Accreditation Body under written permission of the accredited test Laboratory.

11.b) The Coordinator will avoid any conduct that could cause some Laboratories to take advantage with respect to the others in the successful participation in the interlaboratory comparison.

11.c) Laboratories shall avoid raising issues that could generate a situation of disparity in the successful completion in the interlaboratory comparison.

Annex A

Test report issued by the participating Laboratory

Laboratory: Name of the Laboratory
Laboratory Code: ILC(RP-100-6000)LAB(#)
Address: Address of the Laboratory
Technical Responsible: First name and last name of the Technical Responsible
E-mail: E-mail address of the Technical Responsible
Phone: Phone number of the Technical Responsible
Date of issue: Date of issue of this test report

Date of Sample receipt: .....
Date of measurements: .....
Data of Sample shipment: .....

Test result

Fill in the empty cells of columns six and seven with the measured value x and the measurement uncertainty U_{lab}.

1	2	3	4	5	6	7	8
Band	**Harmonic** #	**Frequency** MHz	***x**** dBm	***s**** dB	***x*** dBm	U_{lab} dB	ζ
D	2	100	-	-			-
D	4	200	-	-			-
D	6	300	-	-			-
D	8	400	-	-			-
D	10	500	-	-			-
D	12	600	-	-			-
D	14	700	-	-			-
D	16	800	-	-			-
D	18	900	-	-			-
E	20	1000	-	-			-
E	30	1500	-	-			-
E	40	2000	-	-			-
E	50	2500	-	-			-
E	60	3000	-	-			-
E	70	3500	-	-			-
E	80	4000	-	-			-
E	90	4500	-	-			-
E	100	5000	-	-			-
E	110	5500	-	-			-
E	120	6000	-	-			-

Information, comments and pictures: see 9.b).

Signature of the Technical Responsible

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Annex B

Test report no. XYZ
Issued by the Coordinator of the interlaboratory comparison code ILC(RP-100-6000)

Carlo Carobbi
Dipartimento di Ingegneria dell'Informazione
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Phone: +39 055 2758501
Mob. phone: +39 329 6509116
e-mail: carlo.carobbi@unifi.it

to the participating Laboratory

Laboratory: Name of the Laboratory
Laboratory Code: ILC(RP-100-6000)LAB(#)
Address: Address of the Laboratory

Start and stop dates of the interlaboratory comparison:
Number of participants:
Date of measurements of the participating Laboratory:
Data of issue of this report:

Test result

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Band	**Harmonic** #	**Frequency** MHz	x^* dBm	s^* dB	x dBm	U_{lab} dB	ζ
D	2	100	-	-			-
D	4	200	-	-			-
D	6	300	-	-			-
D	8	400	-	-			-
D	10	500	-	-			-
D	12	600	-	-			-
D	14	700	-	-			-
D	16	800	-	-			-
D	18	900	-	-			-
E	20	1000	-	-			-
E	30	1500	-	-			-
E	40	2000	-	-			-
E	50	2500	-	-			-
E	60	3000	-	-			-
E	70	3500	-	-			-
E	80	4000	-	-			-
E	90	4500	-	-			-
E	100	5000	-	-			-
E	110	5500	-	-			-
E	120	6000	-	-			-

Outcome

Here the Coordinator inserts the applicable outcomes:

- No anomaly is detected
- Warning signal(s) is (are) detected
- Action signal(s) is (are) detected

Signature of the Coordinator

….....