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# Misleading Issues that Came Up when Calibrating the Alenia Aeronautica Reverberation Chamber

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*Abstract* — **In this paper we present two misleading issues that masked the correct consideration of the lowest useable frequency when applying the IEC 61000-4-21 international standard to the Alenia Aeronautica reverberation chamber. Analysis of results showed some contradictions between theory and practical experience of RCs. Particularly, these issues were found to be the number of frequency points and the harmonic distortion produced by the amplifiers.**

## 1 Introduction

When a RC is thought to be used for testing, it needs to undergo a calibration procedure. The calibration (or, better said: validation, in up-dated lexicon) is mainly focused on determining the lowest useable frequency (LUF) and other characterization parameters. Important criteria to do so is given by statistical models [1, 2, 3]. Nevertheless, from the operational point of view, using theoretical distribution functions to determine whether a RC is useable as a test facility is not viable when homogeneous test conditions and standardization must be assured. As known, standards like [4] establish a performance-based decision criteria, without any reference to statistical distributions. Applying the requirements and using the procedures introduced in [4] a performance-based description of RCs can be realized by means of a field uniformity measurement. However, some precautions need to be taken when performing such measurements.

Alenia Aeronautica SpA has recently put into operation an experimental reverberation chamber (RC) prototype as part of its High Intensity Radiated Fields Ground Test Center located at Torino-Caselle, Italy. A feasibility research program has been conducted into the use of this technology to perform testing in small platforms for aircrafts. An intensive characterization of the chamber was undertaken. We will address in the present paper some issues that came up when characterizing the Alenia Aeronautica Reverberation Chamber (AARC). Even though all the requirements in [4] were met, the first results were not consistent with other evaluations performed and with what is reported in other RC measurements. These issues are specifically reported to be the number of frequency points and the harmonic distortion produced by the amplifiers.

## 2 The Alenia Aeronautica Reverberation Chamber Prototype

The prototype RC shown in Fig. 1 has inner dimensions of 3.83 × 3.83 × 3.04 m (height), giving a total internal volume of approximately 44.6 $m^3$. It features several geometrical details such as one access door of 1.48 × 2.10 m; two access panels of 0.35 × 0.35 m; two honeycomb ducts for ventilation of 0.25 × 0.25 m. One access panel is used as a feed-through panel, and the other one for mounting the stirrer motor drive unit. The chamber walls are made of zinc-galvanized steel, welded.

Figure 1: AARC prototype. Inside: the "Z-fold" stirrer, a logperiodic excitation antenna, a conical dipole receiving antenna, the field probe and a dummy EUT.

The vertical "Z-fold" stirrer measures 2.5 × 1.1 × 1.2 m. The distance from the lowest paddle edge to the RC floor is 0.2 m, and from the topmost paddle edge to the ceiling, 0.35 m. The stirrer was built according to the generally accepted design principles available at the time of the prototype construction's start, i.e.: the stirrer should be electrically large at the LUF and the overall stirrer structure must not be rotationally symmetric [4]. Measurements described in this paper were performed using mode-tuning techniques, thus under static conditions.

## 3 Lowest Useable Frequency

Reverberation chambers are band-limited test equipments. The lowest useable frequency (LUF, $f_{LUF}$) is commonly understood to be the frequency from which on a RC meets basic operational requirements. Such a value, however, depends on the chosen criterion and field-related quantity of practical interest and generally does not show a clear threshold characteristic (see [7, §2.3.7]).

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Some empirical definitions can be found for the LUF, coming from practical experience. It is generally accepted that the LUF in a chamber is close to one or both of the following definitions [4]: 1) the LUF is approximately 3. . .6 times the cutoff frequency $f_c$ of the fundamental mode of a cavity with the same dimensions as the RC under investigation; 2) the LUF is the frequency at which $60 \ldots 100$ modes within an ideal cavity of the same size as the RC are excited and at least 1.5 modes/MHz are present. The AARC has its first ($TM_{110}$) resonance at 55.4 MHz. The LUF as defined in [4] results in $f_{LUF} = 166 \ldots 332$ MHz when the first criteria is used and in $f_{LUF} = 160 \ldots 200$ MHz, when the second one is used. The frequency at which at least 1.5 modes per MHz is present results in 192.3 MHz.

Some theoretical models attempt to predict the LUF analytically. In [5], for example, an expression for the LUF is derived based on the chamber mode density. In [6] instead, a thermodynamic approach has been used and an approximation for the LUF was deduced by matching the coherence volume of a quasimonochromatic blackbody radiator with the working volume of a RC. Theoretical approximations as defined in [5] and [6] are $f_{LUF} = 459.4$ MHz and $f_{LUF} = 590.0$ MHz, respectively.

Considering both the empirical and theoretical approaches, the predicted LUF for the AARC ranges from 166 to 590 MHz. It is true that these values are only intended to provide an estimate for the order of magnitude of $f_{LUF}$, rather than a sharp value. But such a broad frequency span witnesses some still unclear issues regarding the use of the LUF as a functional threshold. Anyway, consensus in defining the LUF was somehow reached by measuring field uniformity. Even though this kind of measurement resembles pretty much to anechoic chamber calibration, and thus are originally thought to a completely different test method, is the winning indicator and is the main criteria used in the standards such as [4].

In this sense, the LUF becomes finally defined as the lowest frequency at which a specified field uniformity can be achieved over a defined volume. This definition is much more stringent than the previous ones, since it involves measurements within the chamber and forces the user to think about the desired measurement uncertainties and confidence intervals to be obtained for a given number of stirrer steps. It is therefore of a great utility to have a unified consensus on how to define the LUF. Nevertheless, there are still some unclear issues in its practical definition that can lead to deceptive or confusing conclusions.

## 4 Field Uniformity

The lowest useable frequency from which a RC can be used is mainly determined by the size and shape of the chamber and the effectiveness of the stirrer. A procedure for knowing a RC's LUF is described in [4].

For the calibration, the fields must be recorded at eight positions within the working volume (its corner points). Field uniformity must be tested at 45 logarithmically spaced frequencies over the first decade, after only 20 frequencies per decade are required. Subsequently, the standard deviation (deviation between the eight positions in space) is calculated for the field components. For acceptable mode-stirring, the standard deviations should lay below a tolerance level defined in [4], knowing also that three frequencies per octave may exceed the limits by no more than 1 dB.

The field uniformity measurement as described above was performed in the AARC. The "volume of uniform field" has dimensions of 2.8 × 1.5 × 1.4 m. Figure 2 shows the field uniformity in terms of the standard deviations $\sigma_\xi$ ($\xi = x, y, z$ and *total*) and the IEC limit. It can be seen that a LUF of about $f_{LUF} \approx 258$ MHz was found, which agrees with the general estimations of section 3.

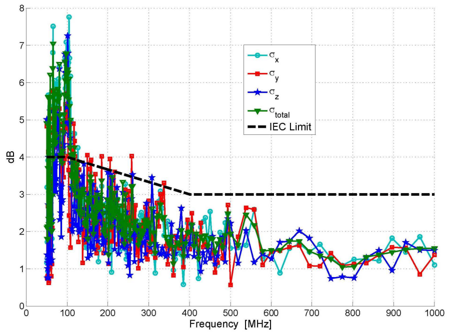

Figure 2: Field uniformity $\sigma_\xi$ measurements at AARC.

Nevertheless, it is to be noticed that the number of frequency points in Fig. 2 is not the one required in [4]. In fact, more than 230 logarithmically spaced frequencies were considered in the first decade. The reason for this decision will be explained in the next section, where some caveats for the calibration process as described in [4] will be addressed and explained.

## 5 Caveats for Calibration

Some precautions need to be taken when performing field uniformity measurements. We will address in the present section some misleading issues that came up when characterizing the AARC, specifically about the number of frequency points and the harmonic distortion produced by the amplifiers.

Even though all the requirements were met, the first results were not satisfactory.

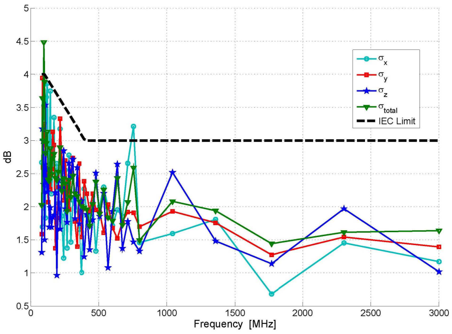

Figure 3: Field uniformity $\sigma_\xi$ measurements with few frequency points.

Figure 3 shows the field uniformity that was measured the first time that the calibration process was applied. The LUF was not found since the only two points exceeding the IEC limit are not in the same octave and do not overpass the limit by more than 1 dB.

Further measurements were performed starting from 30 MHz and for the first decade. In this way, the required 45 frequency points would be concentrated in the first decade, and the probability of knowing the actual LUF would increase. Figure 4 shows this measurement.

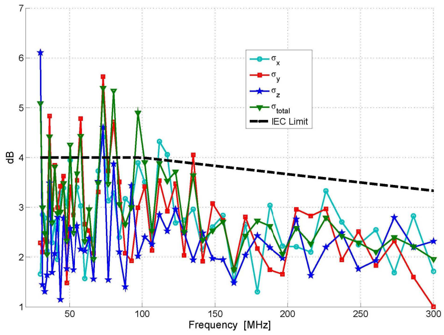

Figure 4: Field uniformity $\sigma_\xi$ measurements obtained at 45 frequency points in the first decade by considering a starting frequency $f_s = 30$ MHz.

As it can be seen from Fig. 4, the measured LUF is approximately $f_{LUF} \approx 100$ MHz. It means that field uniformity was reached with only 11 modes present. Even though this fact could be theoretically probable, it is obviously practically impossible, considering the widely-accepted criteria that at least 60 modes should be present. It is true that some works report on the fact that special chambers like the VIRC can achieve acceptable reverberation conditions with approximately 40 modes [8], but this is still far from the 11 modes found for the AARC. However, as discussed in [7, §2.2.7], 11 ideally well-stirred modes (i.e. statistically independent, identically distributed with no one dominating) could be enough to be able to apply the central limit theorem and thus, obtaining the desired statistical behavior.

Theory and practice seem to disagree when looking at these measurements. It is then crucial to highlight that several statistical indicators (i.e. field uniformity, stirring ratio, power deviation to the mean, autocorrelation coefficient, etc.) can guide us to different conclusions and the only criteria to be used in order to understand that "something is going wrong" is just based on practical experience.

### 5.1 Frequency points

The standard deviation curves as defined by [4] have a "noise-like" shape. It is clear then, that between two consecutive measurement points it would be quite difficult to predict whether that measurement would have exceeded or not the IEC limit. In order to investigate this fact, a new measurement was defined. The idea is to choose three frequency bands: $f_{low} = 70 \dots 110$ MHz, $f_{mid} = 160 \dots 200$ MHz and $f_{high} = 490 \dots 510$ MHz. The frequency points were uniformly spaced in each band every 1 MHz. Figure 5 shows the field uniformity measured for this experiment. It can be seen how the aspect of the field uniformity graph significantly changes when choosing more frequency points. At $f_{low}$, *many or most* of the points exceed the limit, at $f_{high}$ *none* of the points does it, while at $f_{mid}$ *some* of them overpass the limit. The idea of determining the *exact* LUF is not completely straightforward, and thus other ways of characterizing a RC should be applied if it is necessary to more thoroughly understand these facts.

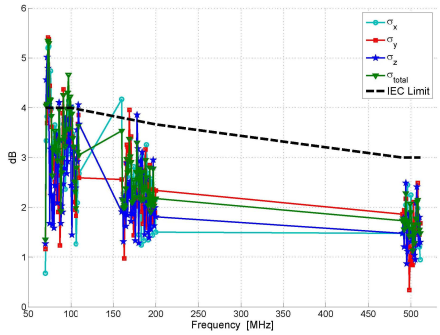

Figure 5: Field uniformity $\sigma_\xi$ measurements for three different frequency bands.

If we assume that $\sigma_\xi$ would immediately exceed the limit before $f_{mid}$, the LUF would be $f_{LUF} \approx 160$ MHz. A more coherent result with respect to the general accepted estimations. Nevertheless, it still results in a somehow too optimistic LUF (less than three times the cut-off frequency).

## 5.2 Harmonics

The IEC 61000-4-21 international standard has a requirement over the amplifiers to be used in RC calibration and measurements, that is [4, §7]: *"The harmonics and distortion produced by the power amplifier shall be at a level less than or equal to 15 dB below carrier level."*.

Before initiating with the calibration in the AARC, this requirement was checked and found out that the level of the harmonics were never more than 22 dB below the fundamental, thus largely compliant with the IEC requirement. Nevertheless, it is known that due to the filtering property of cavities, even when the distortion can be relatively low when measuring it directly from the amplifier to the spectrum analyzer, the situation drastically changes inside the chamber. It would amplify the frequencies close to the natural resonances and reduce those that are not. Figure 6 shows the harmonic contribution inside the chamber, for four frequencies and for different output power levels of the signal generator. It can be seen that for an output power of 0 dBm (the level used in the previous measurements, and the level at which the validation of the IEC requirement was done), the harmonic contribution is larger than the accepted in [4].

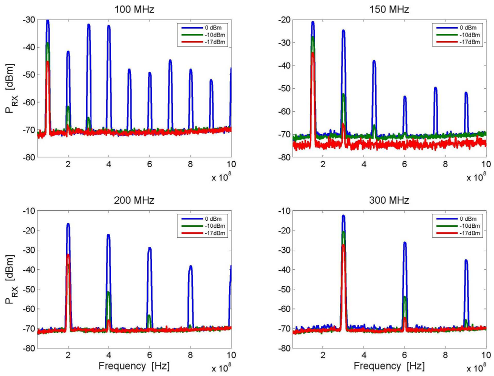

Figure 6: Harmonic contribution inside the chamber for four different frequencies and three output power levels of the signal generator.

The presence of important harmonic contribution will affect especially the electric field probe, due to its inherent wide-band nature. All frequencies present in the cavity will be measured by the probe, providing potentially misleading results. Furthermore, this effect is more influent at low frequencies (where the characterization is focussed), since a larger number of frequencies lay inside the wideband probe.

Having learned the effect of the number of frequency points and the presence of harmonic distortion on the research of the LUF, a measurement was defined with the signal generator at an output level where the contribution of the harmonics was below 30 dB the level of the fundamental *inside* the chamber, cf. Fig. 6, and with more points to be taken. The result was already shown in Fig. 2.

## 6 Conclusions

Misleading issues that came up during the AARC calibration process such as the influence of the number of frequency points and the presence of harmonics (even within the standard limits) on the determination of the LUF according to [4] were addressed.

Table 1 sums up the different LUFs that were found performing different calibration processes, with and without caring about these factors, i.e. the number of frequency points and the harmonic distortion.

| | Few points | Many points |
|---|---|---|
| Harmonics IEC | 100 MHz | 160 MHz |
| Harmonics reduced | 110 MHz | 258 MHz |

Table 1: The field uniformity test is highly sensitive to the number of frequency points and the presence of harmonics (even if compliant to the standard).

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