A Closed-Loop Calibration Method for the Vibrating Intrinsic Reverberation Chamber

Abstract—The Vibrating Intrinsic Reverberation Chamber (VIRC) is a special resonant cavity with flexible conductive walls. It can be used to check the susceptibility of electronic equipment to external radiated electromagnetic fields. This work suggests a closed-loop calibration method to adjust the expected level of the field strength in the working volume of the cavity. The regulation of the field level is based on its average value and is particularly useful whenever the VIRC is used as a temporary installation to transform a semi-anechoic chamber in a reverberation environment. In this case, a closed-loop calibration method appears to be more suitable as it permits fast regulation of the test field after new installation of the test environment.

Keywords—Radiated immunity, VIRC, reverberation chamber, calibration.

I. INTRODUCTION

A Reverberation Chamber (RC) is a special testing environment where it is possible to create a statistically uniform and isotropic electromagnetic field (EM-field) and study the radiated electromagnetic susceptibility of a device under test (DUT) [1]. The field distribution can be changed, within the cavity, by rotating structures equipped with metallic paddles called “stirrer” or “tuner”. The rotating stirrer changes the boundary conditions imposed on the electromagnetic field in the cavity and consequently, the position of the field maxima, the polarization and the angles of incidence of the field. This electromagnetic test environment is of particular interest when one wants to test the susceptibility of large DUTs made of several subsystems and thus reducing the total test time. The Vibrating Intrinsic Reverberation Chamber (VIRC) [2] is a special RC made of conductive fabric, the stirring of the field inside the cavity is simply performed by shaking its flexible walls. It can be used as temporary installation to transform a semi-anechoic chamber in a reverberation environment in a few hours.

Extensive literature has been devoted to the validation of a reverberation chamber and, in particular, to the study of the field strength homogeneity and isotropy. Less information can be found about the calibration procedure of the target field, e.g., how to level the power transmitted to the antenna when a large DUT (as a bus or truck) loads the tent changing its quality factor and the modal structure of the field.

The calibration scheme presented in this paper uses the empirical average electric field strength and the maximum-to-average ratio as feedback parameters to adjust the level of the power transmitted to the VIRC (Fig. 1). The quality factor of the chamber \( Q \) determines the value of the maximum field strength \( E_{\text{max}} \) and its average \( E_{\text{avg}} \) in the cavity. It depends, among other factors, on the loading condition of the chamber.

![Fig. 1. Closed-loop feedback method for the control of the maximum field strength in the VIRC.](image)

A clear advantage of a calibration method based on the average value of the field is that, in a VIRC, this has smaller fluctuations than the maxima of the field and is therefore easier to control.

In the following sections, the closed-loop method is discussed and the maximum-to-average value compared with the experimental data. The measurement set-up, used for this work, is described in the Section II and an overview on the tent characteristics and theory is given in Section III. Sections IV to V provide the validation of the field homogeneity, test results and comparisons between predicted and measured field. The conclusions are summarized in Section VI.

II. THE MEASUREMENT SET-UP

The measurement set-up is the same described in [3]. The VIRC is a large tent of dimensions 26 m (L) x 8 m (W) x 6 m (H) with a working volume of dimensions 15 m (L) x 4.5 m (W) x 4.5 m (H). The EM-field was generated by a linearly polarized antenna and sampled simultaneously along the three directions \( x, y, \) and \( z \) by fast 3-axis EM-field probes positioned at the 8 corners of the working volume. The stirring of the field was achieved by shaking the VIRC with linear actuators anchored at two corners of the VIRC. A third linear actuator...
was positioned at one sidewall of the tent. There was no
synchronization between the angular positions of the three
linear motors. [3].

Two loading conditions of the VIRC has been considered,
the empty and the loaded configurations. The electric field in
the test environment was loaded by positioning a truck in the
working volume as showed in Fig. 2. The measurement was
controlled by a testing software used to save information from
the field probes, signal generators and the power amplifiers.

At the time of performing the test, the testing software could
not implement the active levelling of the transmitted power.
Thus, the forwarded power to the VIRC was 150 W for all the
test frequencies and chamber conditions but this does not
affect the scope of the work as showed in the next sections.

Finally, it was not possible, during the test, controlling the net
power transmitted to the antenna by measuring its reflected
fraction.

Fig. 2. A truck is positioned inside the VIRC to measure the statistics of the
electromagnetic field in the cavity under the effects of a load.

III. THEORY OVERVIEW

A. The coherence time of the VIRC

Before introducing the results and the main conclusions of
the experiments, this section is to give the reader a short
outline of the theory about the coherence time of the VIRC
and how evaluating the number of uncorrelated samples
present in a dataset. In accordance to the terminology used in
the reverberation chambers context, the term “independent
samples”, instead of the more appropriate definition
of “uncorrelated samples”, will be used in this work to describe
the number of independent volume (or stirring) realizations of
the VIRC. The autocorrelation function is traditionally
adopted to find uncorrelated field samples produced at
different angular positions of the mechanic stirrer(s). The
VIRC has typically not such a stirrer inside the working
volume and the independent stirring realizations, which
produce new boundary conditions imposed on the EM-field,
shall be referred to the flexible structure of the tent.

When the field is sampled with a rate faster than its
coherence time [4] by the EM-field probes, the samples have
a statistical correlation. Thus, with the term coherence time
\(\theta_C\) it is here intended the interval of time between
uncorrelated samples and independent stirring configurations
of the VIRC at the same time. From the coherence time of the
VIRC, one can calculate \(N_{\text{ind}}\) according to the expression:

\[
N_{\text{ind}} = \frac{\text{time window [s]}}{\theta_C [s]} \quad (1)
\]

However, it must be observed that the value of \(N_{\text{ind}}\) could
be not remain constant during the stirring process. It is a
random variable, whose confidence interval depends on the
number of independent stirring configurations generated in
the temporal window. This concept is fundamental and will be
better explained in Section III-B.

\(\theta_C\) can be found through the autocorrelation function (2)

\[
\rho(\tau) = \frac{\sum_{i=1}^{N_{\text{tot}}-\tau} (e(i) - \bar{e})(e(i+\tau) - \bar{e})}{\sum_{i=1}^{N_{\text{tot}}} (e(i) - \bar{e})^2} \quad (2)
\]

The correlation (2) between two samples of the field is a
function of the time lag \(\tau\) between them and can be thought as
a decreasing exponential function:

\[
\rho(\tau) \approx \exp\left(-\frac{\tau}{\theta_C}\right) \quad (3)
\]

When the lag \(\tau\) between two observations of the field strength
is equal or greater than the coherence time of the VIRC, it
follows from (3) that:

\[
\rho(\theta_C) \leq 0.37 \quad (4)
\]

and the samples are defined “independent”. Finally, the
threshold must be corrected according to the effective number
of samples \((N_{\text{tot}})\) obtained with the sampling rate of the field
probe according to [5].

Fig. 3. The autocorrelation function of a test signal in the VIRC has an
exponential decay.

B. Changes in the coherence time of the VIRC

As mentioned in the previous section, \(N_{\text{ind}}\), hence \(\theta_C\), is a
random variable and its spread is determined by the chaoticity
of the vibrations imposed on the flexible walls of the VIRC.
The fluctuation of \(N_{\text{ind}}\) through series of time windows has
been empirically found and reported in the Fig. 4 for the
electromagnetic field at 400 MHz.

Fig. 4. Number of independent samples measured into an empty VIRC, 50
tests with temporal window 3 s at 400 MHz.
It would be almost impossible to control the geometry of the cavity surface during the test, therefore the variations of $\theta_C$ through the time are expected.

C. The ratio between maxima and average values of the electromagnetic field in the VIRC

The prediction of the extreme values of the electric field and the maximum-to-average behavior of the field in a resonant cavity was already discussed in [6], [7], [8] and here reported for convenience of the reader. For each polarization, $R$, one is interested in the maximum value of the $N$-dimensional array $(\varepsilon_{R1}, \varepsilon_{R2}, ..., \varepsilon_{RN})$ formed by the samples of the electric field strength sampled by the field probes at a given position. Let us assume that the sampling rate produces only independent samples and that, under well-stirring conditions, they are identically distributed (iid) with a Rayleigh CDF, $\text{cdf}_{\varepsilon_R}(\varepsilon)$ [9]. We are interested into the Cumulative Distribution Function (CDF) of the maximum field strength, $\varepsilon_{R\text{max}}$ defined in (5):

$$\varepsilon_{R\text{max}} = \max(\varepsilon_{R1}, \varepsilon_{R2}, ..., \varepsilon_{RN}) \quad (5)$$

The CDF of this random variable is:

$$\Phi_{\varepsilon_{R\text{max}}}(\varepsilon_{R\text{max}}) = P(\varepsilon_{R1} \leq \varepsilon_{R\text{max}}, \ldots, \varepsilon_{RN} \leq \varepsilon_{R\text{max}}) \quad (6)$$

From the iid assumption of the sample $\varepsilon_{Ri}$, it follows:

$$\Phi_{\varepsilon_{R\text{max}}}(\varepsilon_{R\text{max}}) = [\text{cdf}_{\varepsilon_R}(\varepsilon_R)]^N \quad (7)$$

Deriving (7), one obtains the Probability Distribution Function (PDF) of the field maxima:

$$\varphi_{\varepsilon_{R\text{max}}}(\varepsilon_{R\text{max}}) = N[\text{cdf}_{\varepsilon_R}(\varepsilon_R)]^{N-1} \ast \text{pdf}_{\varepsilon_R}(\varepsilon_R) \quad (8)$$

From the assumption that rectangular components of the field are Rayleigh distributed, (8) can be written as:

$$\varphi_{\varepsilon_{R\text{max}}}(x) = \frac{N \ast x}{\sigma^2} [1 - \exp\left(-\frac{x}{2\sigma^2}\right)]^{N-1} \ast \exp\left(-\frac{x}{2\sigma^2}\right) \quad (9)$$

where $x = \varepsilon_{R\text{max}}$. Finally, the expression of the expected field maxima is given in (10):

$$\langle E_{\text{max}} \rangle = \int_0^{\infty} N \frac{x^2}{\sigma^2} [1 - \exp\left(-\frac{x}{2\sigma^2}\right)]^{N-1} \ast \exp\left(-\frac{x}{2\sigma^2}\right) dx \quad (10)$$

As suggested in [7], the integral (10) can be solved numerically. Its value, normalized to the expected average value of the field ($\langle E_{\text{avg}} \rangle$), is represented in the Fig. 5.

A comparison with experimental data set showed that $N_{\text{ind}}$, estimated through the autocorrelation method described in the Section III-A, was always lower than the $N_{\text{ind}}$ derived from the empirical ratio ($\langle E_{\text{max}} \rangle / \langle E_{\text{avg}} \rangle$) (Fig. 5). The cause of this difference between the results is under investigation, and future studies will concern this argument. However, the expression (10) does not take into account the non-idealities of the stirring process and a difference between empirical and predicted values was expected.

Therefore, a correction factor has been searched to match the value of $N_{\text{ind}}$ coming from the empirical maximum-to-average and the theoretical one. This adjustment is given in (11):

$$\frac{\langle E_{\text{max}} \rangle}{\langle E_{\text{avg}} \rangle} = 1.06 \ast \frac{\langle E_{\text{max}} \rangle}{\langle E_{\text{avg}} \rangle} \quad (11)$$

The value 1.06 is the correction factor calculated for the field samples at 1 GHz and it is used for the entire frequency range. This value was empirically found for the VIRC described in Section II, other reverberation environments could have different values.

IV. VIRC VALIDATION

A. Number of independent samples and field uniformity

The spatial-averaged number of independent samples present in the test signal has been calculated through the autocorrelation function (2) in a temporal window of 3 s for 5 test frequencies, the results are reported in the Table I for the cases of empty and loaded VIRC. The temporal window is large enough to find, in each case, more than 12 independent samples. The values in the Table I suggest that, under the loaded conditions, the coherence time of the VIRC increases reducing the number of independent samples.

<table>
<thead>
<tr>
<th>Frequency [MHz]</th>
<th>Coherence time / Nr. of ind. samples (Empty VIRC)</th>
<th>Coherence time / Nr. of ind. samples (Loaded VIRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>121.1 / 24</td>
<td>232.3 / 12</td>
</tr>
<tr>
<td>500</td>
<td>86.5 / 34</td>
<td>234.6 / 12</td>
</tr>
<tr>
<td>700</td>
<td>73.6 / 40</td>
<td>109.8 / 27</td>
</tr>
<tr>
<td>1000</td>
<td>50.0 / 60</td>
<td>107.9 / 27</td>
</tr>
<tr>
<td>5000</td>
<td>13.8 / 218</td>
<td>26.1 / 114</td>
</tr>
</tbody>
</table>

The homogeneity of the field is validated through the field uniformity calculation reported in the Table II. The field uniformity is determined by the estimation of the spatial standard deviation of the expected maxima, i.e. it measures the uniformity of the maxima field strength distributed in the working volume. The table shows that, for the VIRC analyzed, the maximum field has good homogeneity with a standard deviation below the standardized limit of 3 dB. It must be noted that, despite the very large and elongated working volume of the VIRC used for the test, the standard deviation of the maximum field strength is below a threshold that is normally given for smaller and regular volumes. For simplicity, the table reports only the largest value of the 4 standard deviations analyzed according to [5].
TABLE II. FIELD UNIFORMITY

<table>
<thead>
<tr>
<th>Frequency [MHz]</th>
<th>Field uniformity Empty VIRC [dB]</th>
<th>Field uniformity Loaded VIRC [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>500</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>700</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>1000</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>5000</td>
<td>1.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

B. The coherence of the maximum field strength

The maxima of the electric field strength for the 8 measurement positions at the corners of the working volume were simultaneously measured by 3-axis field probes. The expected maximum field \( \langle E_{\text{max}} \rangle \), which is the target of the calibration procedure, is the space-averaged value of all the 24 maxima observed in an interval of time. A closed loop calibration algorithm based on \( \langle E_{\text{max}} \rangle \) is, in the praxis, complicated because of the stochastic nature of this variable. In Fig. 6, the value of \( E_{\text{max}} \) has been measured in series of 90 independent time windows of 3 s.

The decreasing trend, at least for the first 20 time windows, showed in Fig. 6 cannot be attributed to the forwarded power, which remained constant during the test. The possible causes are under research. The fluctuations of \( E_{\text{max}} \) follow the instability of \( N_{\text{ind}} \) and the non-idealities of the reverberation environment. Thus, the adjustment of the transmitted power could result complicated and time-consuming: how large shall be the levelling to correct a random variable with a certain standard deviation?

It was already observed in the Section III-B that the number of independent stirring configurations is not a constant during a test performed in a VIRC and this determines a spread for the values of the ratio \( E_{\text{max}} / E_{\text{avg}} \). It then follows an instability of the adjustments of the transmitted power and many step could be necessary before reaching the target field. On the other hand, \( E_{\text{avg}} \) shows lower spread than \( E_{\text{max}} \). The Fig. 7 gives the distribution of both the expected values of the maximum and average fields at 400 MHz in the empty configuration of the VIRC. The figure depicts series of the expected field values in 75 independent time windows with the 95% confidence interval represented as shaded area.

![Fig. 6](image6.png)

![Fig. 7](image7.png)

As described in Table II, the standard error of the expected field maximum and average decreases as the frequency increases. This can be observed in the Fig. 8, where the values of \( E_{\text{max}} \) and \( E_{\text{avg}} \) with the 95% confidence interval represented as shaded area have been measured at 5 GHz.

![Fig. 8](image8.png)

The stability of the average field strength is confirmed, under the hypothesis of a well-stirred energy, by the analysis of the average received power (proportional to the field strength) described in [1]:

\[
\langle P_{\text{rx}} \rangle = \langle P_{\text{tx}} \rangle \cdot \frac{Q}{\eta \cdot 4\pi \cdot \omega \cdot eV} \cdot \frac{\lambda^2}{2} = \langle P_{\text{tx}} \rangle \cdot \alpha
\]

It follows from (12) that the average field strength is constant if the chamber characteristics (the quality factor \( Q \), the volume \( V \), the free-space impedance \( \eta \) and the dielectric constant \( \varepsilon \)) do not change. From (12) it is equally easy to recognize the linear dependence of \( P_{\text{rx}} \) from the average transmitted power \( P_{\text{tx}} \).

V. TEST RESULTS

A. The calculation of the maximum field strength through the number of independent samples

Here, the hypothesis that the number of independent samples gives the maximum-to-average value according to the curve depicted in Fig. 5 is tested and the results reported in the Table III. In this work, the approach described in Section V-B is preferred but the calculation of the maximum field strength through \( N_{\text{ind}} \) is equivalent from a theoretical point of view. At least, this section shows that \( N_{\text{ind}} \) can be extracted from the maximum-to-average ratio during the test without using the autocorrelation function. The measurements show a good
agreement between the value of the expected maximum corrected through (11) and the measured \((E_{max})\) in an empty VIRC. The absolute value \((\Delta J)\) of the deviation between measured and expected field strength maxima have been calculated in dB.

**TABLE III. MAX. FIELD PREDICTED VS. REAL (EMPTY VIRC CASE), TIME WINDOW = 3 s.**

| Frequency [MHz] | \(E_{max}\) Measured [V/m] | \(E_{max}\) Calculated [V/m] | \(\Delta = |E_{max,cal} - E_{max,meas}|\) [dB] |
|-----------------|-----------------------------|-------------------------------|---------------------------------|
| 400             | 136.0                       | 123.3                         | 0.85                            |
| 500             | 126.1                       | 124.3                         | 0.12                            |
| 700             | 135.3                       | 130.2                         | 0.33                            |
| 1000            | 167.0                       | 170.9                         | 0.11                            |
| 5000            | 148.8                       | 148.0                         | 0.05                            |

The Table IV shows the results in a loaded configuration of the VIRC (Fig. 2). In this case, the calculated value approximates very well the real level of the field. Thus, (11) is independent from the loading conditions of the tent, actually its accuracy improves, at lower frequencies, with lower values of the VIRC’s quality factor.

**TABLE IV. MAX. FIELD PREDICTED VS. REAL (LOADED VIRC CASE), TIME WINDOW = 3 s.**

| Frequency [MHz] | \(E_{max}\) Measured [V/m] | \(E_{max}\) Calculated [V/m] | \(\Delta = |E_{max,cal} - E_{max,meas}|\) [dB] |
|-----------------|-----------------------------|-------------------------------|---------------------------------|
| 400             | 68.8                        | 73.3                          | 0.55                            |
| 500             | 65.9                        | 61.9                          | 0.54                            |
| 700             | 70.4                        | 72.3                          | 0.23                            |
| 1000            | 88.4                        | 85.4                          | 0.30                            |
| 5000            | 104.6                       | 103.8                         | 0.07                            |

Finally, the effect of larger time windows (or equivalently larger number of independent samples) on the prediction equation (11) was studied. The results are presented in the following tables for the empty (Tab. V) and loaded (Tab. VI) configurations of the testing environment. As for the previous analysis, the predictions are very close to the real \((E_{max})\).

**TABLE V. MAX. FIELD PREDICTED VS. REAL (EMPTY VIRC CASE), TIME WINDOW = 5 s.**

| Frequency [MHz] | \(E_{max}\) Measured [V/m] | \(E_{max}\) Calculated [V/m] | \(\Delta = |E_{max,cal} - E_{max,meas}|\) [dB] |
|-----------------|-----------------------------|-------------------------------|---------------------------------|
| 400             | 146.5                       | 131.3                         | 0.95                            |
| 500             | 134.3                       | 135.1                         | 0.05                            |
| 700             | 144.6                       | 138.8                         | 0.35                            |
| 1000            | 178.1                       | 178.9                         | 0.04                            |
| 5000            | 153.2                       | 155.5                         | 0.13                            |

**TABLE VI. MAX. FIELD PREDICTED VS. REAL (LOADED VIRC CASE), TIME WINDOW = 5 s.**

| Frequency [MHz] | \(E_{max}\) Measured [V/m] | \(E_{max}\) Calculated [V/m] | \(\Delta = |E_{max,cal} - E_{max,meas}|\) [dB] |
|-----------------|-----------------------------|-------------------------------|---------------------------------|
| 400             | 74.4                        | 75.7                          | 0.15                            |
| 500             | 73.2                        | 70.0                          | 0.39                            |
| 700             | 74.2                        | 76.0                          | 0.23                            |
| 1000            | 91.2                        | 88.8                          | 0.23                            |
| 5000            | 106.5                       | 108.8                         | 0.19                            |

**B. The calculation of the maximum field strength through the maximum-to-average value**

As anticipated in the previous section, the aim of the proposed method is to transform the stochastic behavior of the expected maximum in a straight level (depending only on the small fluctuations of \((E_{avg})\)) easy to control for the calibration. Hence, \((E_{avg})\) and the maximum-to-average ratio of the electromagnetic field in the VIRC are determined at the first iteration of the calibration algorithm, then the value of the field calculated at the step \(i\) is:

\[
(E_{max}(i))_{calculated} = (E_{max}(i)) / (E_{avg}(i))
\]

After a certain amount of steps, where the software increases or decreases the power forwarded to the chamber, the \((E_{max}(i))_{calculated}\) reaches the target level and the software repeats the same analysis at the following testing frequency. Series of 50 independent trials with the values of the measured and calculated \((E_{max})\) at 1 GHz is depicted in Fig. 9. \((E_{max})\) is calculated through \((E_{avg})\) and the ratio maximum-to-average determined at the first iteration loop. Thus, at the first step, measured and calculated fields are the same, but immediately after not.

![Fig. 9. \((E_{max})\) variations in a series of 50 independent trials. Values measured at 1 GHz, input power 150 W (power-levelling not performed).](image-url)
TABLE VII. MAX. DEVIATION BETWEEN EMPIRICAL AND CALCULATED FIELD, TIME WINDOW = 3 s. (EMPTY VIRC)

| Frequency [MHz] | \(<E_{\text{max}}\) Measured [V/m] | \(<E_{\text{max}}\) Calculated [V/m] | \(|\langle E_{\text{max}} \rangle_{\text{dB}} - \langle E_{\text{max}} \rangle_{\text{dB}}\) [dB] |
|----------------|-----------------------------------|------------------------------------|--------------------------------------------------|
| 400            | 130.7                             | 119.6                              | 0.77                                             |
| 500            | 126.9                             | 138.9                              | 0.78                                             |
| 700            | 109.2                             | 136.4                              | 1.93                                             |
| 1000           | 170.1                             | 151.2                              | 1.02                                             |
| 5000           | 148.5                             | 153.9                              | 0.31                                             |

TABLE VIII. MAX. DEVIATION BETWEEN EMPIRICAL AND CALCULATED FIELD, TIME WINDOW = 3 s. (LOADED VIRC)

| Frequency [MHz] | \(<E_{\text{max}}\) Measured [V/m] | \(<E_{\text{max}}\) Calculated [V/m] | \(|\langle E_{\text{max}} \rangle_{\text{dB}} - \langle E_{\text{max}} \rangle_{\text{dB}}\) [dB] |
|----------------|-----------------------------------|------------------------------------|--------------------------------------------------|
| 400            | 72.1                              | 53.9                               | 2.53                                             |
| 500            | 65.5                              | 56.9                               | 1.22                                             |
| 700            | 71.3                              | 63.6                               | 0.99                                             |
| 1000           | 82.6                              | 72.5                               | 1.13                                             |
| 5000           | 100.3                             | 90.4                               | 0.90                                             |

VI. CONCLUSIONS

The work focuses on a fast and repeatable approach for the calibration of the field strength in a VIRC. It is particularly useful in accurately checking the characteristics of the reverberating environment when a large DUT loads the working volume or when the structure is mounted in semi-anechoic chamber prior to perform a test. Indeed, the adjustment of \(<E_{\text{max}}\) could be made difficult by the fact that it has a relative large confidence interval. Thus, a faster method for the test energy calibration has been introduced and discussed in order to reduce the test time and improve its repeatability. This method is based on the regulation of \(<E_{\text{arg}}\), which is in a fixed ratio with the maximum field strength and has a narrow confidence interval.

The basic operating principles of the calibration is depicted in the Fig. 10. At the first step, the software measures \(<E_{\text{arg}}\) and \(<E_{\text{arg}}>/<E_{\text{arg}}\). The second and following steps of the power-levelling algorithm use the maximum-to-average ratio calculated at the first step to adjust the level of the average field strength and obtain \(<E_{\text{arg}}\)calculated. Now \(<E_{\text{arg}}\)calculated is aligned with \(<E_{\text{arg}}\) and an increase (decrease) of the power transferred to the VIRC easily moves the field toward the target level.

![Algorithm steps for the field calibration.](image)

Measurements at several frequencies and loading conditions of the VIRC have been performed and the value of \(<E_{\text{arg}}\)calculated compared with the real levels of the field. It has been shown that the use of a calculated field introduces an error, which decreases as the frequency increases and is lower than the standard deviation of the expected value of the target signal strength.

VII. REFERENCES