

**Specification for radio disturbance and immunity measuring
apparatus and methods**
**Part 1.6: Radio disturbance and immunity measuring apparatus — EMC
antenna calibration**

Amendment No. 2

International adoption identical

Publishing and Approval Dates

Council of Standards Australia Approval: 29 May 2023

New Zealand Standards Approval Board Approval: 7 June 2023

Published: 23 June 2023

Summary

This Amendment applies to the following elements:

- Front Cover
- Preface
- Amendment 2

Amendment Details

AS/NZS CISPR 16.1.6:2015 is amended as follows. The amendment should be inserted in the locations as instructed.

Element	Instruction / New text
Front Cover	After “CISPR 16-1-6:2014/AMD1:2017”, <i>add</i> the following: CISPR 16-1-6:2014/AMD2:2022
Preface	After the first paragraph, <i>add</i> the following: This Standard is identical with, and has been reproduced from, CISPR 16-1-6, Ed. 1.0 (2014), <i>Specification for radio disturbance and immunity measuring apparatus and methods, Part 1-6: Radio disturbance and immunity measuring apparatus — EMC antenna calibration</i> , and its Amendment No.1 (2017) and Amendment No. 2 (2022) which have been added to the source text.
Amd 2 (new)	After Amendment No.1 (2017), <i>add</i> the following Amendment No.2 (2022):

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SPECIFICATION FOR RADIO DISTURBANCE AND
IMMUNITY MEASURING APPARATUS AND METHODS –****Part 1-6: Radio disturbance and immunity measuring apparatus –
EMC antenna calibration****AMENDMENT 2****FOREWORD**

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Amendment 2 to CISPR 16-1-6:2014 has been prepared by subcommittee CISPR A: Radio-interference measurements and statistical methods, of IEC technical committee CISPR: International special committee on radio interference.

The text of this Amendment is based on the following documents:

Draft	Report on voting
CIS/A/1362/FDIS	CIS/A/1365/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Amendment is English.

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The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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2 Normative references

Add to the existing list the following new references:

CISPR 16-1-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Coupling devices for conducted disturbance measurements*

CISPR 16-1-4:2019, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas and test sites for radiated disturbance measurements*

3.1.2.5 magnetic field antenna factor

Replace the existing Note 1 to entry and Note 2 to entry as follows:

Note 1 to entry: The symbol F_{aH} is used only when antenna factor is expressed in dB. The quantity F_{aH} is expressed in dB(S/m) or dB($\Omega^{-1}\text{m}^{-1}$).

Note 2 to entry: The unit dB(pT/ μV) is used in some standards (but not in CISPR 16-1-6), which can be converted to dB(S/m) by subtracting 2 dB.

Add Note 3 to entry:

Note 3 to entry: CISPR 16-1-4 specifies loop antennas for magnetic field strength measurements in the frequency range of 9 kHz to 30 MHz.

3.2 Abbreviations

Add to the existing list the following new abbreviations:

CPM current probe method

SFM standard field method

5.2.1 General

Replace the second and third paragraphs by the following five new paragraphs:

Several techniques have been developed for calibrating loop antennas or measuring magnetic field antenna factors [74]. Reference [18] provides a useful overview. Reference [15] provides a simplified version of the standard field method (SFM) ([32] and [16]), and the TAM is described in [35]. This subclause and Annex H specify acceptable calibration methods for loop antennas.

The TAM and the TEM cell method yield a standard uncertainty of measured antenna factor of approximately $\pm 0,5$ dB, while application of the TEM cell method is restricted to the frequency range below the first resonant frequency of the TEM cell.

The current probe method (CPM) [15] is an improved SFM based on IEEE Std 291 [32]. In the original method, the current flowing in the transmit loop antenna was measured using an RF vacuum thermocouple built into the loop element; however, a thermocouple is typically small and fragile, and therefore is not suitable for use in routine calibration measurements.

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The Helmholtz coil method [34], categorized as a SFM, is accurate to 0,7 % (0,06 dB) up to 150 kHz, and better than $\pm 0,5$ dB up to 10 MHz (see Annex H), but its applicable frequency range depends on the coil size.

A sufficient signal-to-{receiver noise} ratio of at least 34 dB is necessary to obtain low measurement uncertainties, if using a VNA as described in 6.2.4. In addition, it is important to attach attenuators to the transmit loop antenna and the receive loop antenna, to reduce mismatch uncertainties if using a signal generator and a receiver. When calibrating a loop antenna in free-space conditions, the distance between the transmit antenna or the receive antenna and any nearby reflecting objects, including any metallic ground plane, should be greater than 1,3 m; the clearance required also depends on the spacing between the antennas.

Add, at the end of the existing 5.2.2.2, the following new subclauses:

5.2.3 Three antenna method (TAM)

5.2.3.1 General

Antenna calibration using the TAM requires three antennas (numbered as 1, 2, and 3) to form three antenna pairs. Prior knowledge of the AF of any of the three antennas is not needed with the TAM (see also 4.3.3 about the TAM).

SIL for antenna calibration is usually measured with a calibrated network analyzer, to reduce mismatch errors that may occur between the signal output port and the transmit loop antenna, as well as between the signal receiving port and the receive loop antenna. Alternatively, a combination of signal/tracking-generator and measuring receiver can be used; in this case, padding attenuators are required to reduce standing waves on the cables.

Different from TAM calibrations above 30 MHz, which are based on the Friis transmission equation, the TAM method for loop antenna calibrations is based on a modified Neumann mutual inductance formula [75], which is approximately expressed by the so-called Greene's formula [70].

The separation distance between the transmit antenna and the receive antenna shall be small compared to the distance to the surroundings. Therefore, coupling between the antennas is maximized, while coupling to the surroundings is minimized. A specific site validation criterion is not required, but the influences from the site on the magnetic field antenna factor results shall be estimated; see the discussion in 5.2.3.2.

5.2.3.2 Calibration procedure

For antenna pairs coaxially aligned as shown in Figure 21, the site insertion loss, $A_i(i,j)$, between antenna i and antenna j is measured in a free-space environment [35], and is described by Equation (61).

$$A_i(i,j) = F_{aH}(i) + F_{aH}(j) + 45,9 + 20\lg(f_{\text{MHz}}) - 20\lg[K(i,j)] \text{ in dB} \quad (61)$$

From data on the $A_i(i,j)$ for the three antenna pairs, the magnetic field antenna factors F_{aH} of each antenna can be determined using Equations (62).

$$\begin{aligned}
 F_{\text{aH}}(1) &= \frac{1}{2} [-45,9 - 20\lg f_{\text{MHz}} + A_i(1,2) + A_i(1,3) - A_i(2,3) + K(1,2) + K(1,3) - K(2,3)] \\
 F_{\text{aH}}(2) &= \frac{1}{2} [-45,9 - 20\lg f_{\text{MHz}} + A_i(1,2) - A_i(1,3) + A_i(2,3) + K(1,2) - K(1,3) + K(2,3)] \text{ in dB(S/m)} \\
 F_{\text{aH}}(3) &= \frac{1}{2} [-45,9 - 20\lg f_{\text{MHz}} - A_i(1,2) + A_i(1,3) + A_i(2,3) - K(1,2) + K(1,3) + K(2,3)]
 \end{aligned} \quad (62)$$

where

f_{MHz} is the frequency in MHz;

$A_i(i,j)$ is the SIL between antenna i and antenna j ; when it is measured using a network analyzer, the site insertion loss is given by Equation (63).

$$A_i(i,j) = -20\lg |S_{21}(i,j)| \text{ in dB;} \quad (63)$$

$K(i,j)$ is the function shown in Equation (64), based on a modified Neumann equation for antenna pair (i,j)

$$K(i,j) = 20\lg \left(\frac{1}{4\pi S_i S_j} \left| \oint_{C_j} \oint_{C_i} \frac{e^{-j\beta R}}{R} d\mathbf{s}_i \cdot d\mathbf{s}_j \right| \right) \text{ in dB(m}^{-3}\text{)} \quad (64)$$

and

S_i, S_j are the geometric areas ($r^2\pi$) in m^2 of antennas i and j , respectively;

C_i, C_j are the closed curves encircling the loop element of antennas i and j , respectively;

$d\mathbf{s}_i, d\mathbf{s}_j$ are infinitesimal segment vectors of the loop elements of antennas i and j , respectively;

R is the distance in m between the segments $d\mathbf{s}_i$ and $d\mathbf{s}_j$.

If the three loop antennas are true circles and a homogeneous current distribution along each loop is assumed, Equation (64) can be expressed approximately by the following form:

$$K(i,j) = 20\lg \left(\frac{\sqrt{1 + \beta^2 R_0^2(i,j)}}{2\pi R_0^3(i,j)} \left[1 + \frac{15}{8} \left(\frac{r_i r_j}{R_0^2(i,j)} \right)^2 + \frac{315}{64} \left(\frac{r_i r_j}{R_0^2(i,j)} \right)^4 \right] \right) \text{ in dB(m}^{-3}\text{)} \quad (65)$$

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Equation (65) is called Greene's formula [70], where

$$R_0(i, j) = \sqrt{d_{ij}^2 + r_i^2 + r_j^2} \quad \text{in m} \quad (66)$$

r_i, r_j are the radii in m of antennas i and j , respectively;

d_{ij} is the distance, in m, between the loop centres of antennas i and j ;

β is the wave number ($=2\pi/\lambda$) in m^{-1} .

Equation (65) is valid under the conditions that $\beta R_0(i, j) \leq 10$ and $r_i r_j / R_0^2(i, j) \leq 1/16$. Equation (64) and Equation (65) can be fulfilled if the current distribution on both loop antennas is uniform. To calibrate loop antennas accurately, the radius of the loop antenna driven as the transmit loop shall be within derived limits; for example, Table 15 shows suitable combinations for r_i , r_j , and d_{ij} , and indicates the error of Greene's formula at the highest frequency of 30 MHz. The frequency dependency of the error is shown in Figure 22. The loop centre distance between a pair of antennas, d_{ij} , should be selected to fulfil the conditions, and shall be as small as possible to minimize influences from the surroundings. It should be noted that other uncertainty terms, such as the positioning uncertainty increase as the separation reduces.

An estimate for the influence of a ground plane with different loop separation distances d_{ij} ranging from 0,1 m to 1,0 m is given in Figure 23. Figure 23 is obtained by normalizing the SILs between two loop antennas with 60 cm diameter placed 1,3 m and 2,5 m above a ground plane to the SILs in free space. An OATS or a SAC can be used as the calibration test site, and the particular influence of the calibration test site shall be taken into consideration for the calibration measurement uncertainty estimation. The influence of the ground plane also depends on the position of the feed gaps of the two loop antennas.

Alternatively to Equations (62), Equations (67) can be used, which are based on a numerical simulation approach. The advantage of the numerical simulation approach is that the inhomogeneous current distribution is taken into account. The conditions required for the application of Greene's formula do not apply for the numerical simulation approach. It is not necessary to take into account the error given in Table 15.

$$\begin{aligned} F_{\text{aH}}(1) &= \frac{1}{2} [A_i(1,2) + A_i(1,3) - A_i(2,3) - A_N(1,2) - A_N(1,3) + A_N(2,3)] \\ F_{\text{aH}}(2) &= \frac{1}{2} [A_i(1,2) - A_i(1,3) + A_i(2,3) - A_N(1,2) + A_N(1,3) - A_N(2,3)] \quad \text{in dB(S/m)} \\ F_{\text{aH}}(3) &= \frac{1}{2} [-A_i(1,2) + A_i(1,3) + A_i(2,3) + A_N(1,2) - A_N(1,3) - A_N(2,3)] \end{aligned} \quad (67)$$

where

$A_i(i, j)$ is the SIL between antenna i and antenna j ; when it is measured using a network analyzer, the site insertion loss is given by Equation (63).

$A_N(i,j)$ is the normalized site insertion loss (NSIL) calculated by NEC. The same loop geometry shall be used for simulation and calibration. Further information about normalized site attenuation calculation is planned for inclusion in future editions of CISPR 16-1-4.¹

Greene's formula does not apply if the antennas do not have circular shapes. For square shapes, it is feasible to modify Equation (65) by a correction factor for r_i or r_j where

$$r_i = 1,13(s_i/2) \text{ and } r_j = 1,13(s_j/2) \quad (68)$$

r_i, r_j are the radii, in m, of antennas i and j , respectively;

s_i, s_j are the side lengths, in m, of the square loops i and j , respectively.

To obtain $K(i,j)$ for square shapes accurately, or to obtain $K(i,j)$ for other loop antenna shapes, $K(i,j)$ should be calculated per Equation (64) using numerical integration.

The accuracy of Greene's formula is estimated by calculating the difference per Equation (69) of the magnetic field antenna factor found by the application of Greene's formula and the magnetic field antenna factor found by numerical simulation. The accuracy of the integral formula of Equation (64) is estimated by calculating the difference per Equation (71) of the magnetic field antenna factor found by the application of the integral formula and the magnetic field antenna factor found by numerical simulation. The results are shown in Figure 22, where a decreased accuracy at the upper frequency end can be observed.

$$\Delta F_{aH,G} = F_{aH,G} - F_{aH,num} \quad (69)$$

$$\Delta F_{aH,I} = F_{aH,I} - F_{aH,num} \quad (70)$$

$F_{aH,G}$ is the magnetic field antenna factor found by application of Greene's formula,

$F_{aH,I}$ is the magnetic field antenna factor found by application of the integral formula;

$F_{aH,num}$ is the magnetic field antenna factor found by numerical simulation.

¹ As discussed in e.g. 10.6 of CIS/A/1240/RM, a project is ongoing for amending CISPR 16-1-4 to include site validation below 30 MHz; at the time of preparation of this FDIS the most recent documents for that project are CIS/A/1323/CDV and CIS/A/1288/CC.