

Validation of Compact-Standard Antenna Method for Antenna Calibration above 1 GHz

Min-Joo Jeong¹ · Jong-Hyuk Lim² · Ji-Woong Park¹ · Sung-Won Park² · Nam Kim^{1,*}

Abstract

In this paper, we propose a compact-standard antenna method (C-SAM) for antenna calibration above 1 GHz. The test-site evaluation of the fully-anechoic room (FAR) condition satisfied the free-space conditions. When the C-SAM was compared with conventional antenna calibration methods, the maximum deviation was within ± 0.18 dB for the 1–18 GHz frequency range. Unlike the conventional antenna calibration methods, the proposed method is a simple standard antenna method that calculates the antenna factor of the antenna under calibration (AUC) with only one site insertion loss (SIL) measurement of an antenna calibration site that meets free-space conditions. Therefore, the C-SAM is the best candidate for antenna calibration owing to the method's simplicity and cost-reduction potential.

Key Words: Antenna Calibration, Antenna Factor, C-SAM, Standard Antenna Method, Three-Antenna Method.

I. INTRODUCTION

The recent rapid development of information and communication technology (ICT) has increased the development and utilization of ICT equipment. This increase has created a complex propagation environment, which has expanded the electromagnetic interference (EMI) problem. Internationally, to distribute electric and electronic equipment on the market, companies must obtain electromagnetic compatibility (EMC) certification [1, 2].

The core equipment for EMC certification is an antenna that measures EMI. If this antenna is damaged, the inherent propagation characteristics of the antenna are also changed. Therefore, it is not possible to provide accurate EMC certification results.

For this reason, the importance of the calibration method for

an EMI antenna to measure its inherent propagation characteristics is increasing. Calibrating an antenna for EMI measurements involves measuring the antenna factor (AF), which means the conversion coefficient of the measured voltage and the electric field strength.

As shown in Table 1, the typical antenna calibration methods above 1 GHz specified in the international standard CISPR 16-1-6 [3] include the three-antenna method (TAM) [4, 5] and the standard antenna method (SAM) [6]. The TAM is based on the Friis equation. This method calculates the AF of the antenna under calibration (AUC) using three antennas with no previous knowledge of the AF. The SAM does not consider the ground reflected wave. In this condition, the AF of the AUC is calculated with two measurements through the difference between the site insertion loss (SIL) of the AUC and the SIL of the standard antenna (STA) from the transmitting antennas for

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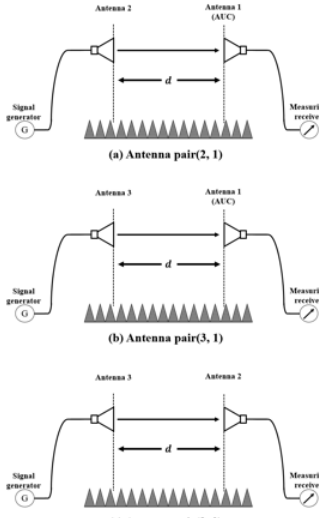
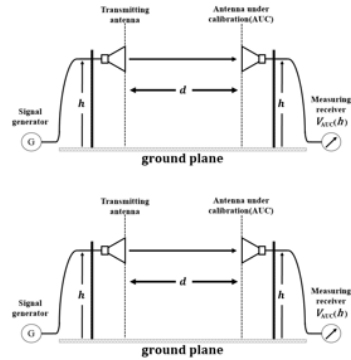
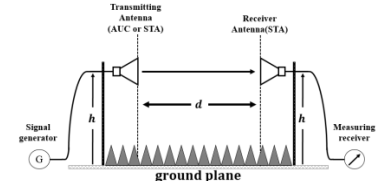
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Table 1. Comparison of conventional antenna calibration methods and the C-SAM

	TAM	SAM	C-SAM
Frequency range	1–18 GHz	1–18 GHz	1–18 GHz
Site condition	Free space	Free space	Free space
Standard antenna	No	1	1
Antenna factor (calculation equation)	$A_i(2,1) = F_a(1) + F_a(2) + K(2,1)$ $A_i(3,1) = F_a(1) + F_a(3) + K(3,1)$ $A_i(3,2) = F_a(2) + F_a(3) + K(3,2)$	$F_{AUC} = F_{STA}(h) + \{V_{STA}(h) - V_{AUC}(h)\}$	$AF_{TX} + AF_{RX} = SIL + 20 \log(f_{MHz}) - 20 \log(d) - 32$ The equation for the antenna being calibrated: $AF_{AUC}(dB/m) = AF_{STA} + (SIL_{STA} - SIL_{AUC})$
Strengths	The TAM is a method that does not require AF previous knowledge of the three antennas, including the AUC.	The SAM calculates the antenna factor by measuring twice.	Unlike the TAM and the SAM, if the AF of the STA calibrated by the TAM is known, the AF of the AUC can be calculated by measuring the SIL only once.
Weaknesses	The TAM should be measured 3 times with 3 antennas for the AF calculation, including the AUC.	No STA above 1 GHz; therefore, the antenna is calibrated with the TAM.	If the SIL measurement configuration of the STA is changed, the AF of the AUC cannot be accurately calculated.
Measurement setup	 <p>(a) Antenna pair(2, 1)</p> <p>(b) Antenna pair(3, 1)</p> <p>(c) Antenna pair(3, 2)</p> <p>$d = 1 \text{ m or } 3 \text{ m}$</p> <p>Number of measurements = 3</p>	 <p>ground plane</p> <p>ground plane</p> <p>$d = 1 \text{ m or } 3 \text{ m}$</p> <p>Number of measurements = 2</p>	 <p>ground plane</p> <p>$d = 3 \text{ m, } h = 2 \text{ m}$</p> <p>Number of measurements = 1</p>

which previous knowledge is not known. These methods must perform SIL measurements two or three times by using the three antennas to calculate the AF. Setting up these measurements involves high cost and a long measurement time to calibrate the antenna.

Many studies have been carried out to deal with the limitations of conventional calibration methods [7–10]. These studies showed that the AF of the AUC can be calculated with a single measurement if the AF is already known using antennas with the same characteristics. However, the antenna calibration

method is only for low frequencies (30 MHz to 1 GHz) using a diode loaded standard dipole antenna [7, 8].

The antenna calibration methods presented by Lim et al. [9, 10] are restricted to frequency bands ranging from 3.95–5.85 GHz and 26.5–40 GHz, respectively. Moreover, there is no test-site evaluation method in which the antenna calibration test site can be proven to be free space [10].

In this paper, we propose a compact-standard antenna method (C-SAM) for a broad frequency range from 1 GHz to 18 GHz which is different from conventional antenna methods.

Unlike the TAM, the C-SAM has the advantage of knowing the AF of the AUC with one measurement. In addition, the C-SAM differs from the SAM, because the ground reflected wave is considered. In other words, if the AF is known for one antenna, this method can calculate the AF of the AUC with only one SIL measurement.

To use this method above 1 GHz, the antenna calibration test site must meet free-space conditions. For this reason, the test site was verified using the test site evaluation of the fully-anechoic room (FAR) condition. In addition, the C-SAM was verified by comparing it with conventional antenna calibration methods (the SAM and the TAM).

II. COMPACT-STANDARD ANTENNA METHOD

As shown in Fig. 1, the C-SAM is an antenna calibration method that fixes the distance (d) and height (h) between the STA and the AUC. Then, the AF of the AUC can be calculated with the SIL measurement between two antennas, where the STA is an antenna whose AF is already known. The pyramidal horn antenna is used for antenna calibration above 1 GHz.

The C-SAM is based on the Friis equation [11]. As shown in Fig. 1, if information about the electric field strength (E_R) is given at the receiving location, then the distance d_1 between the transmitting antenna and the receiving antenna is as follows:

$$E_R = \frac{\sqrt{30G_T P_T}}{d_1}, \quad (1)$$

where G_T is the gain of the transmitting antenna, and P_T is the output power of the transmitting antenna.

AF is the parameter that determines the unique performance of the antenna. AF is defined as the ratio of the field strength (E) to the voltage (V) induced at the receiving antenna as follows:

$$AF \left(\frac{dB}{m} \right) = 20 \log \left(\frac{E}{V} \right). \quad (2)$$

When the transmitting antenna (T_X) AF is AF_{TX} , and the receiving antenna (R_X) AF is AF_{RX} , AF can be calculated as follows:

$$AF_{TX} + AF_{RX} = SIL + 20 \log(f_{MHz}) - 20 \log(d) - 32. \quad (3)$$

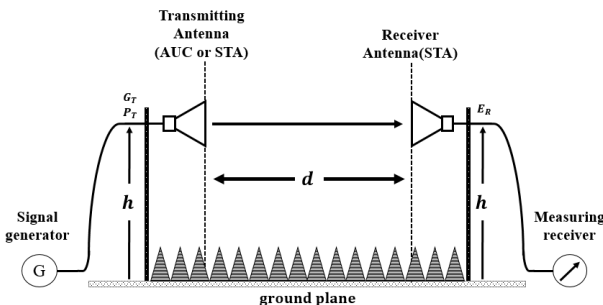


Fig. 1. Measurement setup of the C-SAM.

SIL is a site insertion loss between the two antennas, f_{MHz} is the frequency in MHz, and d is the separation distance in meters.

If the STA that knows the values either AF_{RX} or AF_{TX} is used in Eq. (3), then the AF of the AUC can be calculated as only one measurement with the following equation:

$$AF_{AUC} \left(\frac{dB}{m} \right) = AF_{STA} + (SIL_{STA} - SIL_{AUC}). \quad (4)$$

AF_{STA} is the AF of the STA, AF_{AUC} is the AF of the AUC, SIL_{STA} is the site insertion loss of the STA, and SIL_{AUC} is the site insertion loss of the AUC. Now, AF_{AUC} and AF_{STA} must be calculated at the same position (the antenna height (h) and the separation distance (d) from R_X antenna). In other words, if there is an STA whose AF is known, then the C-SAM can easily calculate the AF of the AUC with only one measurement.

III. TEST-SITE EVALUATION OF THE FAR CONDITION

Eq. (3) is based on the Friis equation. Thus, the C-SAM should be applied in the FAR condition test site. The aim is to create a free-space environment for calibrating antennas. This method is applied to calibrate antennas with directivity above 1 GHz.

In other words, the C-SAM is an antenna calibration method above 1 GHz and is based on the Friis equation.

Therefore, before verifying this method, the antenna calibration test site must prove that it is free space. The verification method for the FAR condition is defined in detail in CISPR 16-1-5.

As shown in Fig. 2, the measurement configuration of the test-site evaluation method of the FAR condition is that the broadband horn antennas (T_X and R_X) are placed at a height of 2 m from the ground plane. The antennas used for the measurement are the Schwarzbeck BBHA 9120 D model. The direction of the two antennas is vertical polarization, and an absorber is placed on the ground plane. The measurement method calculates the SIL between the antennas by moving the distance of the T_X antenna from the fixed R_X antenna to 2.8 m, 2.9 m,

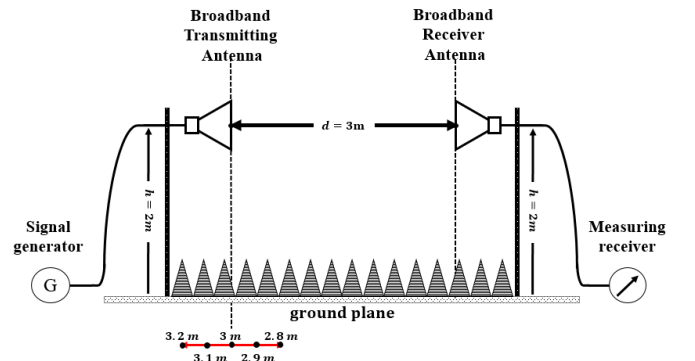


Fig. 2. Test-site evaluation setup of the FAR condition.

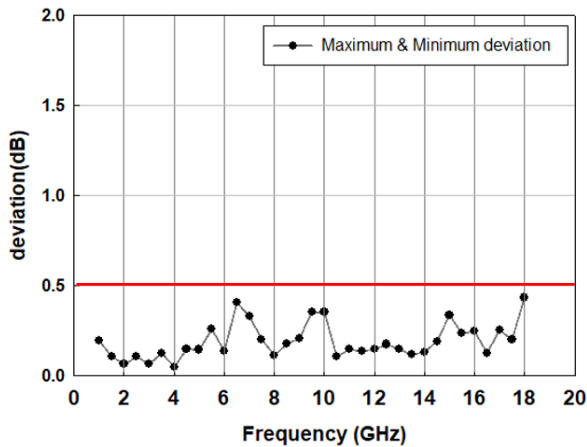


Fig. 3. Test-site evaluation results for the FAR condition.

3.0 m, 3.1 m, and 3.2 m. The measurement frequency range is 1–18 GHz (500 MHz steps).

The calculated distance relative to the SIL for FAR validation via the measurement results is as follows:

$$A_{im}(d) = S_{21\ cable} - S_{21\ antennas} + 20\log(d), \quad (5)$$

where $S_{21\ cable}$ is the transmission cable loss ratio, and $S_{21\ antennas}$ is the transmission loss ratio of the antennas. $A_{im}(d)$ for each varied distance by the movement T_X antenna is normalized for 3 m, which is the central position of the T_X antenna, can be defined as the following equation:

$$A_{im}(d)_{Normalized\ 3m} = A_{im}(d) - A_{im}(d_{3m}). \quad (6)$$

If the maximum and minimum deviations of the $A_{im}(d)_{Normalized\ 3m}$ for each distance are within ± 0.5 dB (peak to peak $A_{im}(d) \leq \pm 0.5$ dB), the test site is said to satisfy the FAR condition [12].

The result for the test-site evaluation was within ± 0.5 dB (peak to peak $A_{im}(d) \leq \pm 0.5$ dB), in the range of 1–18 GHz (Fig. 3). Therefore, the antenna calibration test site may be defined as free-space conditions for the frequency range 1–18 GHz.

IV. EXPERIMENTAL VALIDATION

The measurement configuration of the C-SAM is shown in Fig. 4, where the distance between the two antennas ($d = 3$ m), the antenna height ($h = 2$ m), and the absorbers are installed on the ground plane.

The validation method for the C-SAM is as follows. The AUC (1–18 GHz broadband horn antenna C) measures the SIL using the C-SAM, TAM, and SAM, and the AF. The two antennas except the AUC are pyramidal horn antennas. For this reason, each measurement frequency band is divided into 7 sub-bands (1.12–1.70 GHz, 1.7–2.6 GHz, 2.60–3.95 GHz,

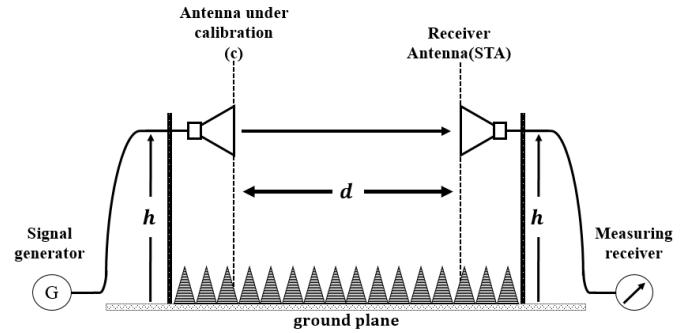


Fig. 4. Setup for the C-SAM validation.

3.95–5.85 GHz, 5.85–8.20 GHz, 8.20–12.4 GHz, and 12.4–18.0 GHz). Then the AFs calculated by the C-SAM and the conventional methods were compared. The measurement configuration and the AF calculation method of the TAM and the SAM are shown in Table 1.

The AFs of the wideband antenna (C) obtained with the three methods are compared in Fig. 5. The maximum deviation was found to be within ± 0.18 dB, which was recorded at 15.8 GHz. There are small deviations from the conventional methods and compared results. The C-SAM uses the AF calculated using Eq. (3). In addition, the C-SAM is a calibration method that measures the AF of the AUC at one time with the measurement configuration shown in Table 1. Therefore, the measurement configuration such as the distance between the antennas and the height is very important. A deviation may occur due to errors in the measurement setup. Thus, the experimental results verify that C-SAM can be used for antenna calibration for the wide frequency range of 1–18 GHz.

V. CONCLUSION

In this study, we proposed a C-SAM antenna calibration method above 1 GHz. To apply this method, we performed a test-site evaluation of the FAR condition to determine whether it was free space. The maximum and minimum deviations of the $A_{im}(d)_{Normalized\ 3m}$ for each distance were within ± 0.5 dB, and the test site was validated as the free-space condition. The C-SAM was compared with conventional antenna calibration methods at the test site satisfying the FAR condition, and the proposed method was verified by confirming that the maximum deviation for 1–18 GHz was ± 0.18 dB. Contrary to conventional antenna calibration schemes, and if one AF is known on the calibration test site that satisfies the free-space condition, the number of SIL measurements can be reduced using the C-SAM. In addition, this method can be a suitable candidate for the revision of the measure CISPR 16-1-6 and a reduction in the measurement cost.

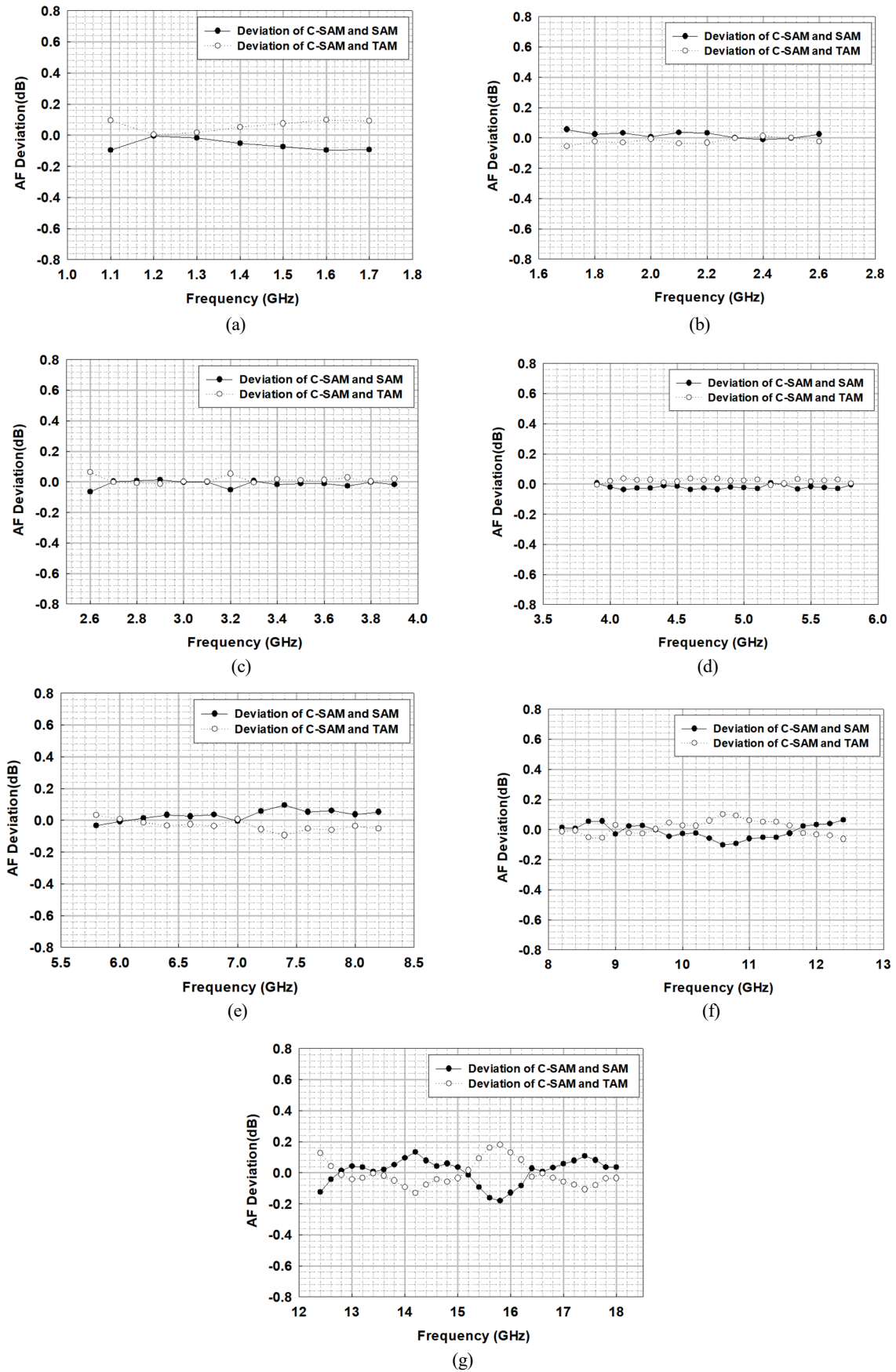


Fig. 5. The AF for the C-SAM, TAM, and SAM: (a) 1.12–1.70 GHz, (b) 1.7–2.6 GHz, (c) 2.60–3.95 GHz, (d) 3.95–5.85 GHz, (e) 5.85–8.20 GHz, (f) 8.20–12.4 GHz, and (g) 12.4–18.0 GHz.

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