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The Measurement and Uncertainty Analysis of Antenna Factor of Microwave Antennas Based on Standard Site Method

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Abstract

A method of Standard Site Method (SSM) in the American National Standards Institute's ANSI C63.5 is de-scribed in the frequency ranges from 30 MHz to 1000 MHz. And a measurement system is set up for determining antenna factors (AF) of antennas on an Open Area Test Sites (OATS). AF of antennas including log-periodic antenna and biconical antenna is measured with SSM method by Shanghai Institute of Measurement and Testing Technology (SIMT), which shows good agreement to data measured by National Institute of Metrology (NIM). In the end, it analyzes the measurement uncertainty of SIMT in the 30 MHz to 1000 MHz frequency band and does comparison to that of NIM.

Keywords

Antenna Factors, Standard Site Method (SSM) Measurement Uncertainty

1. Introduction

High growth in the electromagnetic compatibility (EMC) field makes antennas absolutely important part in EMC test. There are two reasons below:

1) *EMC test need*: Antennas are used in many key EMC tests, antenna factors (AF) determined is a major work in making field strength measurements accurate for EMC compliance. For example, in the electromagnetic radiation disturbance test, we use antennas to receive the interference noise and transfer it to EMI receiver through coaxial cable.

2) *Site validation need*: Antennas are used to validate the performance of test sites such as Open Area Test Sites (OATS) and anechoic chambers, by measuring the parameter of normalized site attenuation (NSA) with ANSI C63.4 standard.

We can find out that the performance of the antennas affects the test results, accurate measurement and traceability of antennas are both important to EMC test. The measurement methods are prescribed in standards such as those published by the ANSI and CISPR [1]-[6]. Three commonly used measurement methods used to calibrate the AF are Reference Antenna Method (RAM), Equivalent Capacitance Substitute Method (ECSM) and Standard Site Method (SSM). These methods' advantages and limitations are illustrated clearly in many papers.

ECSM is used to calibrate AF of monopole antennas frequency ranges from 9 kHz to 30 MHz according to standard ANSI C63.5-2003. RAM provide an AF measurement method based on the use of dipole with well–matched balun in 30 kHz to 1000 MHz. SSM is the most used method to measure AF parameter from 30 MHz to 1000 MHz. This paper provides the setup of SSM test system on OATS in Zhejiang Province of China.

2. AF Measurement Technique OF SSM

2.1. Definition of Antenna Factor (AF)

Antenna factor (AF) is probably is the most important concern of parameter to determine the Antennas used in EMC field. According to ANSI C63.5, AF can be defined as ratio of the electric field in the polarization direction of the antenna to the voltage induced across the load connected to the antenna and expressed in decibel form (20 log (E/Vo)).

2.2. Principles of SSM

Standard Site Method (SSM) is well described for determining antenna performance in some standards [1]-[5].

The SSM requires three site attenuation measurements under identical geometries (h_1, h_2, R) using three different antennas taken in pairs, as shown in **Figure 1**. The three equations associated with the three site attenuation measurements are Equation (1), Equation (2), and Equation (3).

$$AF_1 = 10\log f_M - 24.46 + 1/2\left(E_D^{\max} + A_1 + A_2 - A_3\right) \tag{1}$$

$$AF_2 = 10\log f_M - 24.46 + 1/2\left(E_D^{\max} + A_1 + A_3 - A_2\right) \tag{2}$$

$$AF_3 = 10\log f_M - 24.46 + 1/2\left(E_D^{\max} + A_2 + A_3 - A_1\right) \tag{3}$$

where:

$E_D^{\max}$ is the maximum received field at separation distance R from the transmitting antenna.

AF_1, AF_2, AF_3 are the antenna factors of antennas 1, 2, 3 in dB (1/m).

A_1 is the measured site attenuation in dB using antenna 1 and 2.

A_2 is the measured site attenuation in dB using antenna 1 and 3.

A_3 is the measured site attenuation in dB using antenna 2 and 3.

f_M is the frequency in MHz.

The model assumes a separation of 10 m (R) between the antennas. SSM me-

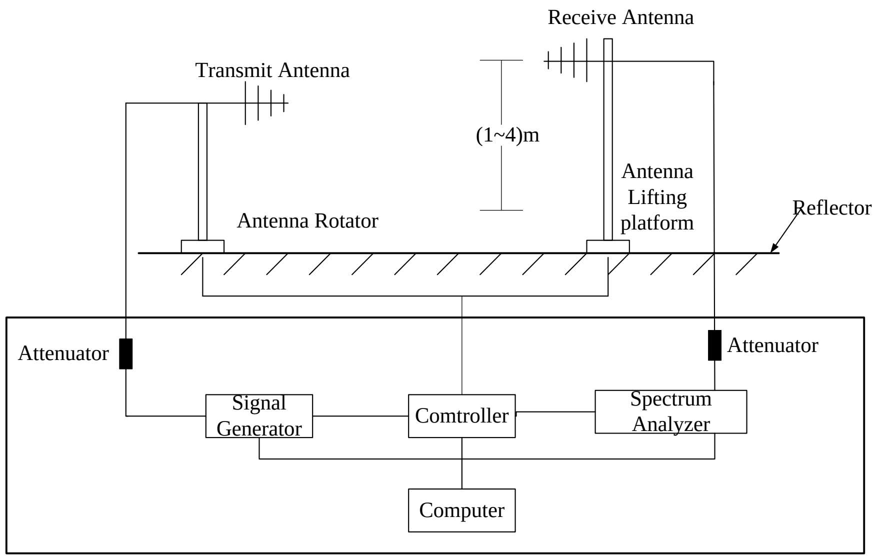

Figure 1. AF measurement system.

thod (based solely on horizontally polarized measurements) provides AF measurements from 30 MHz to 1000 MHz. The measurement method is the same in both cases. The distance between two antennas is 10 m, the height of transmitting antenna is 2 m and the receiving antenna is mounted on bracket, shifting the height from 1 m to 4 m and scanning the maximum power.

These dimensions are annotated in **Table 2**, which provides values for ED_{max} and ideal site attenuation (SA) (**Figure 1** provides the measurement sketch). Antenna factors shall be determined only for horizontal polarization on a standard antenna calibration site, hereafter referred to as a standard site, using the SSM. Horizontal polarization measurements are relatively insensitive to site variations and yield acceptable antenna factors even though the reflecting plane does not create a free-space environment during calibration.

3. AF Measurement of Antennas

In this paper, we adopt SSM method for the calibration of antennas obtained by the C63.5 procedure. To satisfy our own calibration condition, we establish a test system, which was shown in **Figure 2**. It consists of computer, frequency method, signal generator, spectrum analyzer, antenna amounting bracket and its controller. Here we choose discrete frequencies.

For AF measurement experiments, standard biconical antennas and log-periodic antennas of Shanghai Institution of Measurement and Testing Technology (SIMT) are achieved on OATS in Zhejiang province as **Figure 2** shows. Their specifications are shown in **Table 1** and **Table 2**. To ensure the accuracy and reliability of the test, the AF data of standard antennas are also calibrated by the National institute of metrology on OATS.

We get the insertion loss (IL) of different frequency points with spectrum analyzer, and calculate AF data according to Formula (1) to Formula (3). By analyzing the above equations, AF is related to site attenuation and the maxi-

Figure 2. AF measurement system on OATS.

Table 1. Type of biconical antennas.

AF_n	Antennas	Model	Serials	Polarization
AF_1	biconical antenna	HK116	100,183	horizontal
AF_2	biconical antenna	HK116	100,182	horizontal
AF_3	composite log-periodic antenna	3134	9803 - 1092	horizontal

Table 2. Type of log periodic antennas.

AF_n	Antennas	Model	Serials	Polarization
AF_1	composite log-periodic antenna	3134	9803 - 1092	horizontal
AF_2	log-periodic antenna	HL223	100,182	horizontal
AF_3	log-periodic antenna	HL223	100,183	horizontal

mum received field at separation distance. **Figure 3** presents the AF curves of two biconical antennas measured by SIMT and National Institute of Metrology (NIM) and **Figure 4** presents the AF curves of two log periodic antennas measured by SIMT and NIM separately.

Both curves obtained by SIMT and NIM keep in consistent at desired frequency ranges. Now we focus on the comparison between two testing organizations for two different antennas respectively.

Figure 3 indicates that there are certain differences of data measured by SIMT and NIM, especially in the frequency range from 80 MHz to 90 MHz. One of the most important reasons is that as a representative EMC antenna, biconical antenna has lower frequencies (range from 30 MHz to 300 MHz), so it is difficult to eliminate the influence of the OATS' ground, so we should make sure that the floor is well conductive before test.

Figure 4 shows apparently that AF data measured by SIMT is higher than that of NIM. We should consider the mutual coupling between two antennas at 10 m distance. Besides of that, antennas are affected by different measurement system and equipments, OATS is an important influencing factor that cannot be neglected.

4. Estimation of Measurement Uncertainty

In the process of calibrated AF parameter, we should consider the uncertainty caused by measurement instruments and the factors of antenna coupling and OATS.

In metrology, measurement uncertainty is a parameter characterizing the dispersion of the values attributed to a measured quantity [7]. For antenna calibration, the measurement must include the uncertainty components, taking into consideration the environment in which the antenna is to be used for the testing.

The AF measurement process includes a spectrum analyzer, signal generator, amplifier, cables, attenuators, OATS. All these issues should be taken into ac-

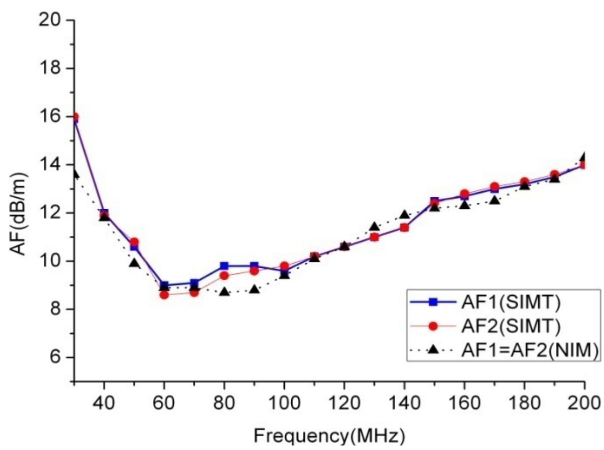

Figure 3. AF of biconical antennas calibrated.

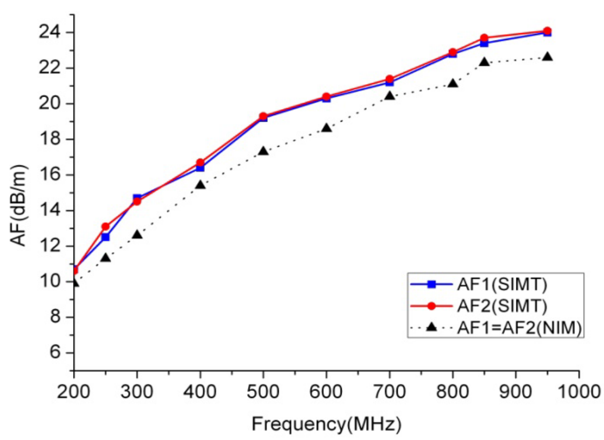

Figure 4. AF of log-periodic antennas calibrated.

count in the uncertainties determination. The contribution to measurement uncertainty from the system can be determined by using type A evaluation and other contribution can be determined by using type B evaluation.

Considering the uncertainty of AF measurement for log periodic antennas, here we discuss standard uncertainty components to each factor respectively.

1) *Spectrum analyzers factor*: Spectrum analyzers have two primary sources of uncertainty that shall be considered with respect to the calibration procedure. These sources are frequency accuracy, and amplitude accuracy. The influence of frequency accuracy can be ignored with respect to amplitude accuracy. So in the frequency range from 200 MHz to 1000 MHz, we get the uncertainty component:

$$U_A^{SA} = 0.3 + 30 * 0.01/10 = 0.6\text{dB} \tag{4}$$

2) *Signal generator factor*: The amplitude uncertainty contribution U_A^{SA} based on the amplitude stability is:

$$U_A^{SA} = 0.1\text{dB} \tag{5}$$

3) *Impedance mismatch of Spectrum analyzer and antenna*: In the frequency band of 200 MHz - 1000 MHz, VSWR of antenna (connected with 6dB attenuator) is 1.2 and that of Spectrum analyzer is 1.07, which are impedance mismatch, so the uncertainty component caused by the receive end is:

$$U_{VSWR}^{T} = 0.027 \tag{6}$$

4) *Impedance mismatch of Signal source and antenna*: In the frequency band of 200 MHz - 1000 MHz, VSWR of antenna (connected with 6 dB attenuator) is 1.2 and that of signal generator is 1.5, which are impedance mismatch, so the uncertainty component caused by the transmitting end is:

$$U_{VSWR}^{T} = 0.157 \tag{7}$$

5) *Site shortage*: Antenna factors can vary within the scope of ±1 dB due to mutual coupling with the ground plane. In every frequency band, we can look up table and get the maximum uncertainty value:

$$U^{SITE} = 0.307\text{dB} \tag{8}$$

6) *Repeatability of system*: Measure NSA (unit: dBμV) for 10 times in the frequency point 100 MHz by using Log Periodic Antenna (Type: HK223, No: 100183). The measured data are: 25.1, 24.3, 24.6, 24.1, 24.2, 25.3, 24.2, 24.1, 25.3, 24.6, 24.1.

$$U^{SYSTEM} = 1 \tag{9}$$

7) *Change of measurement distance*: We can find value from the Uncertainty calculation worksheet (**Table 3**):

$$U^{L} = 0.1\text{m}\left(r = 3\text{m}\right) \tag{10}$$

Now we can get the AF combined uncertainty of Log Periodic Antenna:

$$u = \sqrt{0.173^2 + 0.029^2 + 0.01^2 + 0.055^2 + 0.221^2 + 0.5^2 + 0.084^2} = 1.08\text{dB} \tag{11}$$

In the end, we get AF expanded uncertainty of Log Periodic Antenna:

$$U_{rel} = 2 \times u_{crel}(\delta_P) = 2.16\text{dB} \approx 2.2\text{dB} \quad (12)$$

5. Comparison and Analyzation

To same Log Periodic Antenna measured, we choose two data measured by SIMT and NIM respectively, which have maximum difference in same frequency point. As discussed above, we trace the standard antennas to NIM, which is the highest traceability institutions and has lower uncertainties than SIMT.

Table 4 shows, there exists maximum difference in the 300 MHz frequency point, the AF data is 14.7 (dB/m) measured by SIMT and AF data is 12.6 (dB/m) by NIM. So we get:

$$|y_1 - y_2| = 2.1dB/m \quad (13)$$

$$\sqrt{U_1^2 + U_2^2} = \sqrt{2.2^2 + 1.8^2} = 2.84 \quad (14)$$

Table 3. Uncertainty calculation worksheet of Log Periodic Antenna in the frequency range 200 MHz - 1000 MHz.

Source	Type	Designation	Uncertainty (±)	Contribution	Standard uncertainty	Sensitive factor	Standard uncertainty
Relative amplitude accuracy of Spectrum analyzer	B	U_A^{SA}	0.6 dB	Rectangular	0.173	0.5	0.173
Signal generator amplitude stability	B	U_A^{SG}	0.1 dB	Rectangular	0.058	0.5	0.029
Impedance mismatch of Spectrum analyzer and antenna	B	U_{VSWR}^R	0.027 dB	U-shaped	0.019	0.5	0.01
Impedance mismatch of Signal source and antenna	B	U_{VSWR}^R	0.157	U-shaped	0.111	0.5	0.055
Site shortage	B	U^{SITE}	0.307 dB	T Distribution	0.441	0.5	0.221
Repeatability of system	A	U^{SYSTEM}	1	Sine distribution	1	0.5	0.5
Change of measurement distance	B	U^L	0.1 m (r = 3 m)	Rectangular	0.058 (r = 3)	4.34/r	0.084
AF combined uncertainty of log-periodic antenna							1.08
AF expanded uncertainty of log-periodic antenna (k = 2)							2.16

Table 4. Uncertainty calculation.

Frequency point	SIMT		NIM	
	AF	Uncertainty	AF	Uncertainty
300	14.7	2.2	12.6	1.8

The results above show that:

$$|y_1 - y_2| < \sqrt{U_1^2 + U_2^2} \tag{15}$$

So, the conclusion is that measured results on OATS by SIMT meet the requirements in all frequency points.

6. Conclusion

This paper reviews aspects of the standard site method in the American National Standards Institute's ANSI C63.5 frequency band of 30 MHz to 1000 MHz is which calibrated using the standard method on OATS. Then it analyzes the issues affecting the measurement uncertainty and evaluates the expanded uncertainty of log-periodic antenna. In the end, it compares the data measured by SIMT and NIM, and verifies that our AF calibration method satisfies requirement.

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