A Novel Reference Antenna Method for EMI Antenna Calibration

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Abstract

The existing calibration methods of EMI antenna have to use three antennas. Even standard antenna method replacing the standard antenna by the calibrated antenna needs a common transmitting antenna. In this paper, a simple calibration method which uses only two antennas is discussed. The method requires a information for electric fields at receiving location. Standard antennas knowing antenna factors can determine such electric fields. Calculable standard dipole antenna has theoretical antenna factors and site insertion losses calculated by Numerical Electromagnetic Code in free space or in open area test site with infinite perfect conducting plane. Formula of new calibration method using the standard antenna are derived. Antenna factors measured by new method in open area test site of National Radio Research Agency (NRRA) are compared to the theoretical values. The results show good agreements within 0.09 dB from 30 MHz to 1 GHz.

1. Introduction

There are several calibration methods for EMI antennas in order to measure antenna factors, AF=E/V, which are defined with the ratio of electric field E at antenna element and voltage V induced at antenna terminal. Three Antenna Method (TAM) is generally referred to one of them. The antenna factors according to the method are calculated by measuring site insertion losses (SIL) between three pairs, (antenna1-antenna2), (antenna2-antenna3) and (antenna3-antenna1) of three antennas as shown in Fig. 1 a). An influential calibration method is also Standard Antenna Method (SAM) which uses standard antennas to know its factors or to be able to know the received electric fields. The former is the calculable standard antenna developed in NPL while the latter is the diode loaded standard antenna developed by NIST. The substitution is used by the existing standard antenna methods. It also needs three antennas - a standard antenna, a transmitting antenna and an antenna under calibration (AUC) shown in Fig. 1 b).

A novel reference antenna method which requires only two antennas, a standard antenna and a AUC shown in Fig. 1 c) is discussed. It was named as R-SAM. It was already applied to the diode loaded standard antenna as receiving only in open area test site (OATS) [1]. In the paper, the antenna factors measured according to R-SAM for biconical antenna showed in good agreement [1] with the results calibrated by Standard Site Method [2] of ANSI C63.5. In this paper, using the NPL type calculable standard dipoles, the height patterns of SILs are measured in OATS of National Radio Research Agency, and are compared with the pattern of theoretical SILs from 30MHz to 1GHz. The R-SAM was also investigated at any height showing signal maximum. Antenna factors given by the new method were verified to good agreement with theoretical values.

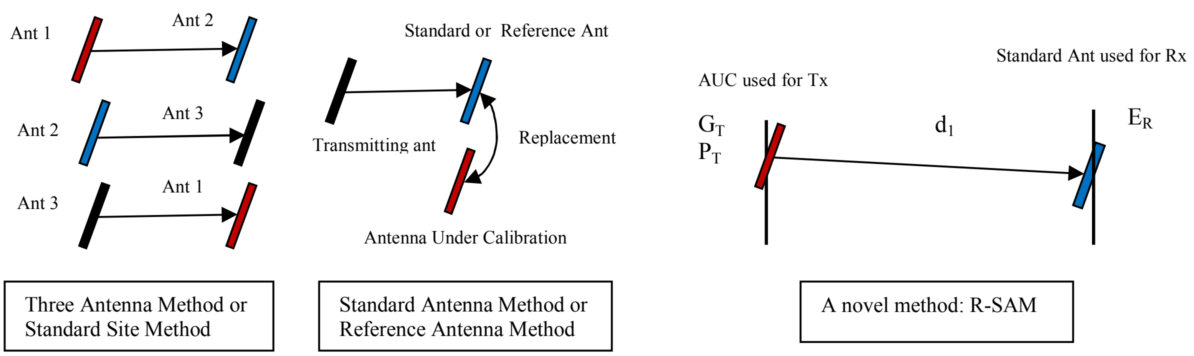

Fig. 1 a) the existing Calibration Methods : TAM or SSM (left)
b) the existing replacement methods : SAM or RAM (center)
c) a proposed new method (right)

2. Basic Equations of Novel Method

For any transmitting antenna, the free-space far-field electric field strength E_R at a separation d_1 from it like the Fig 1 c) is given by

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

where E_R is a electric field intensity at receiving, G_T and P_T are respectively a gain and a output power of transmitting antenna and d_1 is a separation from transmitting to receiving antenna. The equation means that the gain of the transmitting antenna can be calculated if a information for the electric field E_R at receiving is given, and the power P_T and the separation d_1 are measured. There are two type standard antennas determining electric fields at receiving. NPL broadband calculable standard dipole having theoretical antenna factor AF_{RE} calculated by the software CAP2010 using the Numerical Electromagnetic Code (NEC) [3, 4] gives electric field E_R due to the definition of antenna factor:

$$E_R = AF_{RE} V_R, \qquad (2)$$

where V_R is a induced voltage at terminal of the receiving antenna.
NIST diode-loaded standard antenna having RF-DC relationships in its dipole mount also gives electric field E_R [5]:

$$E_R = (aV_{DC} + b) / L_{eff}, \qquad (3)$$

The a and b are coefficients of RF-DC relationships and V_{DC} and L_{eff} are respectively a output DC voltage and a effective length of the antenna. On the other hand, antenna factor AF has connection with gain G as follows:

$$AF^2 = \frac{480\pi^2}{\lambda^2 Z G}, \qquad (4)$$

where λ is wavelength and Z is a input impedance of receiver. Substituting the equations (2), (3), and (4) for (1), the antenna factors of the transmitting antenna connected to a signal generator having input impedance Z_T are respectively given by:

$$AF_T = \frac{120\pi}{\lambda\sqrt{Z_T}} \frac{\sqrt{P_T}}{d_1 V_R} \frac{1}{AF_{RE}}, \qquad (5\text{-}1)$$

$$AF_T = \frac{120\pi}{\lambda\sqrt{Z_T}} \frac{\sqrt{P_T}}{d_1} \frac{L_{eff}}{aV_{DC} + b}. \qquad (5\text{-}2)$$

2.1 Equations in Open Area Test Site

There exists a reflected wave on ground plane of OATS as shown in Fig. 2 a). The geometrical optics 2-ray model gives the following expression for the equation (1) over a perfect metal ground plane:

$$|E_R| = \sqrt{30 G_T P_T} \left| \frac{e^{-j(2\pi/\lambda)d_1}}{d_1} - \frac{e^{-j(2\pi/\lambda)d_2}}{d_2} \right| \equiv \sqrt{30 G_T P_T}\, D, \qquad (6)$$

where $D \equiv \sqrt{d_2^2 + d_1^2 - 2d_1 d_2 \cos\{(2\pi/\lambda)(d_2 - d_1)\}} / (d_1 d_2)$.
Comparing the equation (1) and (6), the equation (5-1) and (5-2) in free space are replaced as the following equation in OATS with perfect metal ground:

$$AF_T = \frac{120\pi}{\lambda\sqrt{Z_T}} \frac{\sqrt{P_T}}{V_R} \frac{D}{AF_{RE}}, \qquad (7\text{-}1)$$

$$AF_T = \frac{120\pi}{\lambda\sqrt{Z_T}} D\sqrt{P_T} \frac{L_{eff}}{aV_{DC} + b}. \qquad (7\text{-}2)$$

How to treat the interference term D of the equations (7-1) and (7-2) varies with whether to scan or fix the antennas with height. When the transmitting antenna in Fig. 2 a) is scanned, the maximum value of D has to be calculated like E_D^{max} [2] of ANSI C63.5. If the heights are fixed, the interference D is calculated according to the fixed heights h_1 and h_2 and the projection R of two antennas onto ground as shown in Fig. 2 a). The former was applied to using NIST type diode loaded standard antenna [1] while the latter is applied to using NPL type calculable standard antenna in this paper.

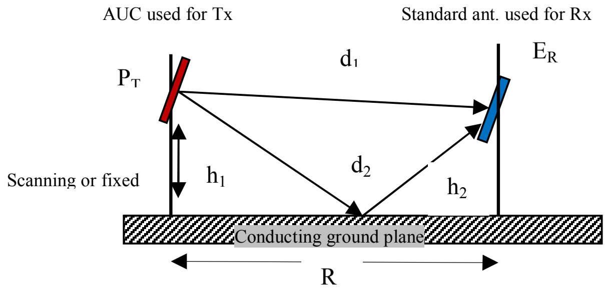

Fig. 2 a) Geometrical 2-ray model for R-SAM over a perfect conducting plane (left)

b) Radio Research Agency 60m×50m ground plane with metal and mesh (right)

3. Measurements and Analysis

3.1 Height Patterns of Site Insertion Loss

The calculable standard dipole antennas were developed by Alexander and Salter [6]. The theory for the SIL using the antennas was also derived by them [6]. NRRA brought in the calculable standard dipoles in order to survey its open area test site with 60m×50m metal and mesh ground plane shown in Fig. 2 b) and also to establish the new calibration method. Availability of the calculable dipoles in OATS of NRRA was checked for by comparing predicted and measured SILs. At the same height of transmitting and receiving antennas, Height patterns of SIL were measured from 1m to 4m heights with 10cm step at 10m separation. The results for four resonant elements of the antenna, 20MHz~100MHz, 100MHz~300MHz, 300MHz~600MHz and 600~1200MHz [5] are given in Fig. 3. There usually exist deep nulls in height patterns of signal strength or SIL over 100 MHz as shown in Fig. 3 and 4. The nulls in SIL are compensated for by the interference 20logD of the equation (6). The Fig. 4 shows the theoretical height patterns of SIL and the interference item expressed as the 20logD. Height patterns of AF calculated due to R-SAM are smooth along the height on account of compensation between the SIL and 20logD as shown in the Fig. 4. However, realistic measurement around the nulls can give big errors owing to a deviation of measured height and a flatness non-uniformity of ground plane. Therefore, R-SAM using NPL type calculable standard antenna have to be tried near the maximum signal height.

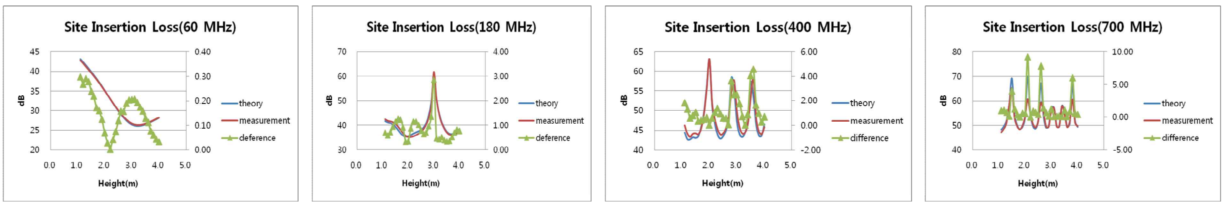

Fig. 3 Height patterns of theoretical and measured SILs between transmitting and receiving antennas at same heights

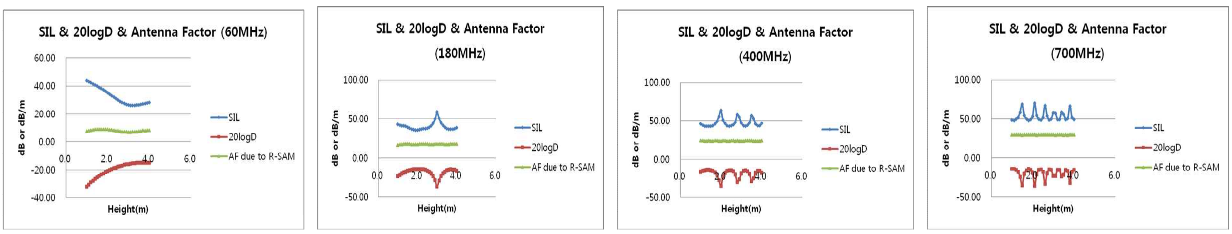

Fig. 4 Height patterns of theoretical SIL(upper in diagram), interference D in equation (6) (lower in diagram) and AF calculated by R-SAM (middle in diagram) between 2m fixed transmitting and 1m~4m scanning antenna

3.2 Antenna Factors

Antenna factors of AUC at transmitting location according to new method were yield to using the equation (6). Theoretical values of receiving and transmitting calculable standard antennas are already calculated by CAP2010. One is used as a AUC and the other is used also as a reference in order to apply to R-SAM. Separation between antennas was 10 m. The two antennas are kept at the same height during measuring. However, measurements were performed at the specific height indicating signal maximum at respective frequencies. Measurement frequencies and heights are given in table 1. The predicted AFs and the measured AFs of the AUC can be looked see in the table too. The results comparing with theoretical and measured AFs are diagrammatized in Fig. 5.

Table 1 Measuring frequencies, heights and comparing with results for theoretical and measured AF of AUC

	element 1(60MHz)				element 2(180MHz)				element 3(400MHz)			element 4(700MHz)			
fre.(MHz)	30	50	70	100	160	200	250	300	400	500	600	700	800	900	1000
height(m)	3	2.7	3.6	1.6	4	1.1	2	1.7	3.3	2.1	2	2.2	4	2.8	1.8
theory AF(dB/m)	19.99	11.65	11.35	16.28	18.17	18.50	22.39	24.76	24.41	28.26	31.29	29.46	31.28	33.61	35.16
measured AF(dB/m)	19.90	11.72	11.34	16.28	18.22	18.49	22.39	24.76	24.43	28.34	31.34	29.41	31.27	33.65	35.21
ΔAF(dB)	0.09	-0.07	0.01	0.00	-0.05	0.01	0.00	0.00	-0.02	-0.08	-0.05	0.05	0.01	-0.04	-0.05

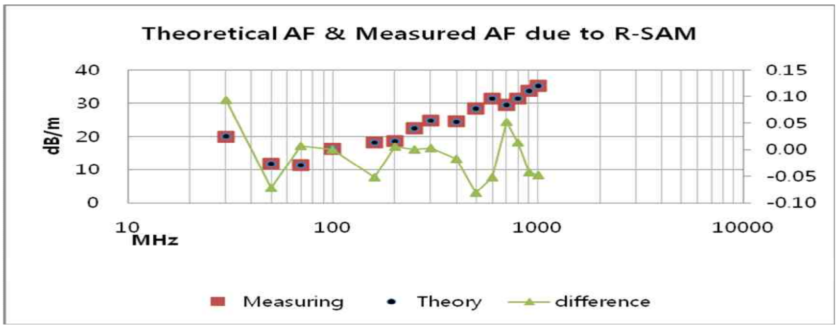

Fig. 5 Comparison between the AFs calculated by NEC of CAP 2010 and the AFs calibrated by new calibration method

4. Discussion and Conclusion

Simple calibration method, R-SAM, using the calculable standard antenna which factors are theoretically calculated by software CAP 2010 was performed in open area test site of NRRA. Maximum difference between theoretical and measured AFs is shown with 0.09 dB at 30 MHz. That is very good agreement. R-SAM using NPL type standard antenna is performed at any specific heights having signal maximum, which two antennas keep same heights. Measurement uncertainty of the method was evaluated within 0.4 dB. A merit of the simple method is to need only two antennas, and to measure one time while the existing TAM, SSM, and SAM for antenna calibrations use three antennas and perform two or three measuring . Therefore, R-SAM brings in convenience of antenna calibration works, and also opens a possibility which measurement uncertainties are reduced

5. References

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