Height Scanning Averaging Method for Free-Space Antenna Factors of EMI Antenna

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1. Introduction

The CISPR[1] has been discussing calibration methods of EMI antennas for yielding free-space antenna factors. In general, EMI Antennas are measured at an OATS where AUC is strongly affected by electromagnetic reflected wave on ground plane. Hence, there have been studied several methods to get free space antenna factors. In this paper, Height Scanning Averaging (HSA) Method is described, which has the reflected wave technically eliminated in order to yield free-space antenna factors. The HSA formula having a similar form to Friis equation is derived and it is simulated that the method is hardly affected by mutual impedance between antennas. It is shown that the results of comparison measurements with HSA and Standard Antenna Method used by National Institute of Communication and Technology(NICT : old CRL) in Japan have a good agreement.

2. Theory of HSA

Antenna factor AF is defined as

$$AF = E / V_0 \quad . \tag{1}$$

The antenna factor is determined by one of the following two categories or the mixed:
Category 1 : Attenuation measurement between antennas
Category 2 : Measurements of electric field and received voltage.
Standard Site Method[2] is usually included in the first category and Standard Antenna Method[3] in the second category. It can be said that the HSA is contained in Category 1. The HSA base on the following Friis free-space transmission equation[4] in dB,

$$G_t(dB) + G_r(dB) = 20\log\ 4\pi d/\lambda + 10\log\ P_r/P_t. \tag{2}$$

We begin with the geometrical optics 2-ray model[5] to derive the HSA formula. In general, it gives the following expression for the electric field generated by a simple source situated over a ground plane as shown in Fig. 1:

$$E_r = \sqrt{30 G_t P_t}\ \left(e^{-jkd}/d + |\rho|\, e^{-jkr} e^{j\phi}/r \right) \tag{3}$$

where d is a direct distance between two antennas, $r = \sqrt{d^2 + 4h^2}$ is a path of the reflected wave between the antennas having the same height h.

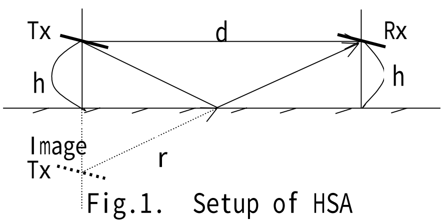

Fig.1. Setup of HSA

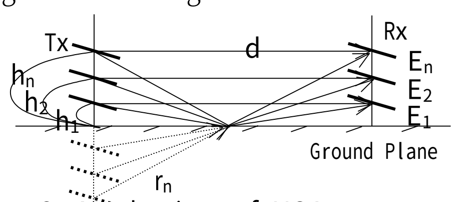

Fig. 2. Mechanism of HSA measurement

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An antenna factor AF_r of received antenna has relation with its gain G_r:

$$AF_r(dB/m) = 10\log\ 480\pi^2 / Z_L\lambda^2 - G_r \qquad \text{(in dB)} \qquad (4)$$

where AF_r is the factor of a received antenna, Z_L is the input impedance of a measuring receiver and G_r is the gain of a received antenna.
The received power is also given by

$$P_r = |V_r|^2 / Z_L = |E_r|^2 / Z_L AF_r^2. \qquad (5)$$

From the equations (4) and (5), The following relationship is given by

$$E_r(dBV/m) \equiv 20\log|E_r| = 10\log P_r + 10\log\ 480\pi^2/\lambda^2 - G_r(dB). \qquad (6)$$

In Fig. 2, if electric field intensity E_n(dBV/m) at nth height from ground according to equations (3) and (6) is averaged from n=1 to N, then HSA formula is expressed as

$$\overline{G_t(dB)} + \overline{G_r(dB)} = 20\log\frac{4\pi d}{\lambda} + \overline{10\log\frac{P_r}{P_t}} + \frac{1}{N}\sum_{n=1}^{N} 20\log|1 + |\rho_n|\frac{d\ e^{-jk(r_n-d)}e^{j\phi}}{r_n}| \qquad (7)$$

where $\overline{G}(dB)$ means a arithmetic average of N functions $10\log G_n$ having height dependency, that is, $\overline{G}(dB) = 1/N\sum_{n=1}^{N} 10\log G_n = 10\log\langle G\rangle$, and $\langle G\rangle$ is a geometrical average given by $\langle G\rangle = (G_1 G_2 \cdots G_N)^{1/N}$ for the values G_n at respective height h_n. The equation (7) has a form that the last term of itself is attached at the Friis equation (2). We call the last term of (7) a interference averaging. If the last term is 0 dB or nearly 0 dB, the HSA is identical to measurement in free-space or quasi free-space.

3. Theoretical and Experimental Investigations

Scanning Ranges

Measurement ranges along height have to let a difference between the maximum and minimum path of the reflected wave be more than at least one wavelength λ in order to have sufficiently an effect of averaging, that is, $r_{max} - r_{min} = \sqrt{d^2 + 4h_{max}^2} - \sqrt{d^2 + 4h_{min}^2} \geq \lambda$.
In the case of 30 MHz, the height is about 8.8 m, when h_1 = 1 m and d = 10 m.

Height Pattern of Attenuations

Attenuations between antennas depend on their height from ground as described in the equation (7). The measurement of attenuations used two BiLog(CBL6111B) was performed with an height increment of 1 cm from 1 m to 5.6 m at frequency 300 MHz, which result is shown in Fig. 3. The height averaging of attenuation is 25.53 dB, which is considered as a value of quasi free space.

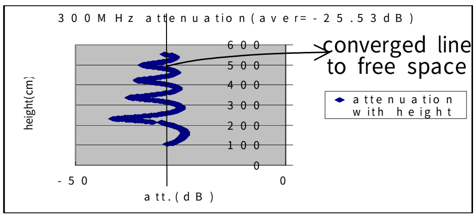


Fig.3 Height Pattern of Attenuations

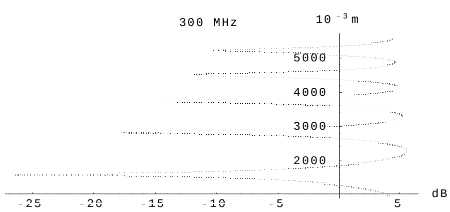


Fig. 4 Height pattern of Averaging at 300MHz

Interference Averaging Term

The last term of the equation (7) is calculated by the software MATHEMATICA. The simulation of height pattern at 300 MHz is shown in Fig. 4, which the averaging is -0.198 dB. Fig. 5 shows how long the interference averaging values in (7) are from free space having 0 dB in ranging 30 MHz to 1GHz, where the simulation is calculated at height ranging 1 m ~ 8.8 m on a perfect conducting ground.

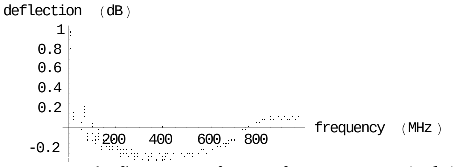


Fig.5 deflection from free space(0dB) 30MHz to 1GHz

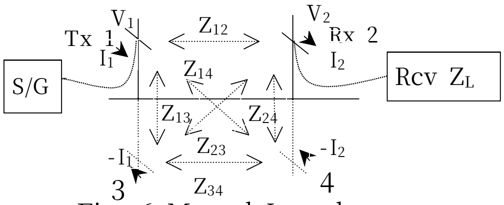


Fig. 6 Mutual Impedance

Mutual Impedance

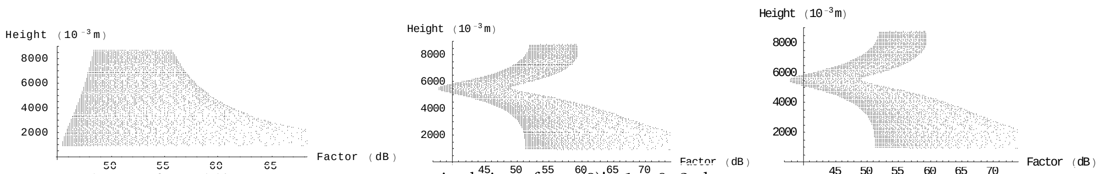
Horizontally polarized antennas exhibit antenna-to-antenna and antenna-to- ground mutual coupling below approximately 100MHz. The antenna terminal impedance change due to close proximity coupling between the transmit and receive antennas as well as the antenna-to-ground coupling can be modeled using a two-port model[6]. In Fig. 6, the relationships are given by

$$V_1 = (Z_{11} - Z_{13})I_1 + (Z_{12} - Z_{14})I_2$$
$$V_2 = -Z_L I_2 = (Z_{12} - Z_{14})I_1 + (Z_{22} - Z_{24})I_2 . \quad (8)$$

In the case of the dipoles which measurement setup is equal to Fig. 6, the self and mutual impedance related to the integrals, $C_i(x)$ and $S_i(x)$[7] are easily simulated by MATHEMATICA. Antenna factor for the dipole at a height h_n from ground by using the two optical ray model and the mutual impedance relations can be expressed as

$$AF_n = \frac{60 I_1}{Z_L I_2 d} e^{-jkd} + \frac{-60 I_1}{Z_L I_2 r_n} e^{-jkr_n} + \frac{-30 I_2}{Z_L I_2 h_n} e^{-jkh_n} . \quad (9)$$

Height pattern of antenna factors at 30MHz is shown in Fig. 7. If h_n is infinite, which is the condition of free space, then, the antenna factor is 51.3247dB. The effect of reflected wave, the 2nd term of (9), is 0.7731dB and the effect due to re-radiating of received antenna, 3th term of (9) is 0.0007dB according to HSA.



simulation of eq. (9)'s 1st term averaging : 51.3371dB
simulation of eq. (9)'s 1st & 2nd averaging : 52.1102dB
simulation of eq. (9)'s all term averaging : 52.1095dB

Fig. 7 Height pattern of factor due to mutual impedance effect at 30MHz

4. Measurements

Height Patterns of attenuations and factors

Some measurement results carried out on OATS having 50 m ×60 m conducting ground are shown in Fig. 8. The distance between antennas is 10m, and, in the case of 30MHz, the increment of height is 10cm from 1m to 5.6m and 300MHz, 7cm increment from 1m to 4m. AUC is Schwarzbeck Dipole 757.

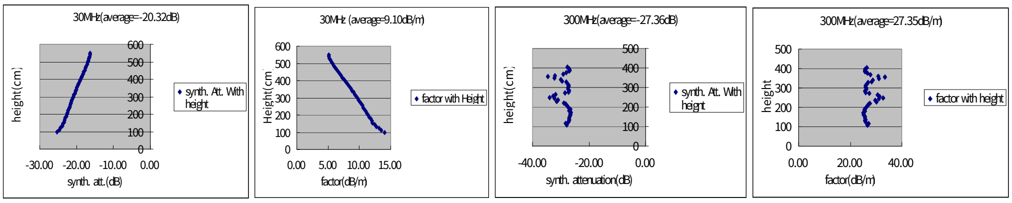


Fig. 8 Height patterns and antenna factors due to averaging at 30MHz and 300MHz

Comparison of HSA with Standard Antenna Method

Antenna factors measured by HSA and SAM are compared in Fig. 11. The Standard

Antenna utilized by the SAM is NICT standard dipole antenna, which antenna factors are accurately calculated. Measurement is carried out at 14 wavelength from 30MHz to 1 GHz. AUC are Anritsu dipole MP652B(30~200MHz) and Schwarzbeck dipole 713(300~1000MHz). The results are productions of co-comparison work of RRL and NICT's antenna measurement in 2004.

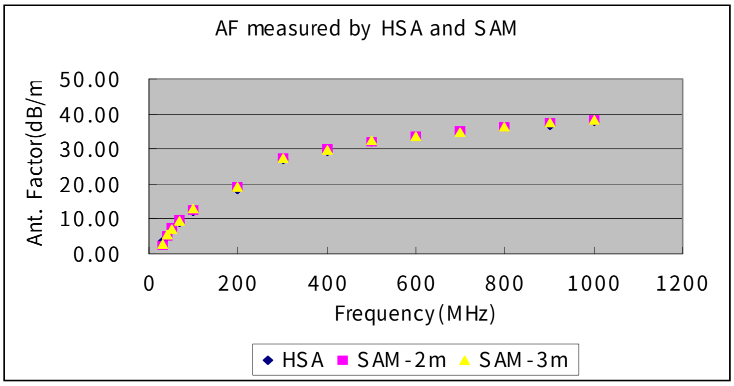


Fig. 11 Comparison with HSA and 2m/3m height SAM

5. Concluding Remarks

The measurement method to determine free space antenna factor on OATS by Height Scanning Averaging Method has been studied theoretically and experimentally. The paper derives the HSA formula similar to Friis equation, surveys the effect of mutual impedance and shows the height pattern measurement of attenuations and factors. The paper also shows the comparison results of measurement between HSA, and SAM made use of by NICT. Most of antenna factors show a good agreement within 1dB except 30MHz. The reason having some deviation at 30MHz is because the scanning height is currently limited to 5.6m and, as mentioned above, the least scanning at 30MHz is 8.8m. Now, a 10m height antenna mast which is possible to scan along the vertical is under construction in RRL. The HSA using standard antenna also requires further study.

Acknowledgement

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