CALIBRATION OF VHF EMI ANTENNAS USING VERTICAL POLARIZATION

Suguru Tsushima*, Katsumi Fujii**, Yasushi Matsumoto**
Akira Sugiura*, and Yukio Yamanaka**
*Research Institute of Electrical Communication, Tohoku University Sendai, 980-8577, JAPAN
**National Institute of Information and Communications Technology, Koganei, Tokyo, 184-8795, JAPAN
*Email: stsushi@riec.tohoku.ac.jp

Abstract: *Antennas used in radiated EMI measurements must be calibrated for determining the free-space value of the antenna factor. Hence, the present paper proposes an antenna calibration technique using the Standard Antenna Method where transmit and receive antennas are oriented for vertical polarization. The method of moments is applied to investigate errors introduced in calibration of a biconical antenna for the frequency range from 30 to 250 MHz. As a result, appropriate antenna arrangements are found for the calibration that can provide the free-space antenna factor with an error less than 0.1 dB. Furthermore, insertion loss measurement required in the antenna calibration is theoretically investigated to evaluate errors in actual calibration measurements. It is found that the insertion loss exceeds 60 dB at 30 MHz, which may introduce an additional error of about 0.2 dB in the antenna calibration.*

Keywords: EMI Measurement, EMI Antenna, Antenna Calibration, Antenna Factor

1. INTRODUCTION

The International Special Committee on Radio Interference (CISPR) recently decided to use the free-space value of the antenna factor of a measuring antenna in order to achieve reproducible radiated EMI (electromagnetic noise) measurements at frequencies from 30 to 1000 MHz. Hence, calibration methods of the EMI antennas have been discussed for determining the free-space antenna factor [1].

There are several antenna calibration methods for EMI antennas that are considered to have the potential to yield the free-space antenna factor. Among them, the Standard Antenna Method is believed to yield the most accurate antenna factor specific to the antenna height. But, it requires special antenna arrangements and environments to provide the free-space antenna factor. For example, antennas must be placed in sufficiently high positions or above an absorber-lined ground plane [2].

In contrast to these methods, the present paper proposes application of the Standard Antenna Method where the antennas are placed above a metal ground plane and oriented for vertical polarization to reduce the effects of a ground plane. Hence, numerical investigations are carried out using the method of moments to find appropriate antenna arrangements that can provide accurate free-space antenna factor. Furthermore, theoretical analyses are performed to evaluate an additional error introduced in the practical insertion loss measurements required in the antenna calibration.

2. ANTENNA FACTOR AND CALIBRATION

2.1 Definition and an Equivalent Circuit

The antenna factor of an EMI antenna is usually defined by the ratio of the strength of an incident electrical field E to the voltage V induced across

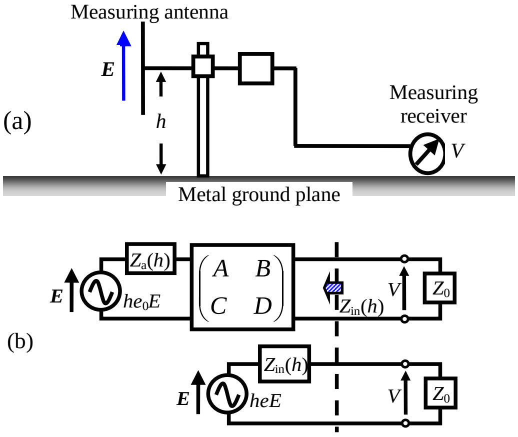

Fig. 1 EMI antenna and its equivalent circuit

ISBN: 89-86522-79-9 94460©KEES

the antenna output terminals, that is,

$$AF \equiv \left| \frac{E}{V} \right| , \tag{1}$$

as shown in Fig.1 (a). An EMI antenna in the VHF band consists of radiating elements and connected circuits, such as a balun and a matching pad. Referring to the equivalent circuit of the EMI antenna shown in Fig.1 (b), the antenna factor can be rewritten as

$$AF = \left| \frac{Z_{in} + Z_0}{h_e Z_0} \right| , \tag{2}$$

where the Z_0 is the load impedance of the antenna (usually 50 Ω). The input impedance Z_{in} and the effective length h_e of the antenna are given by

$$Z_{in} = \frac{Z_a D + B}{Z_a C + A} , \tag{3}$$

and

$$h_e = \frac{h_{e0}}{Z_a C + A} . \tag{4}$$

In the above equations, the Z_a and h_{e0} are the input impedance and the effective length of the radiating elements of the antenna, respectively. The connected circuits are expressed in terms of a transmission matrix (A, B, C, D) [3]. Thus, the antenna factor depends not only on the characteristics of the radiating elements but also on those of the connected circuits.

2.2 Height Dependence

When an antenna is placed above a metal ground plane, as shown in Fig.1 (a), the input impedance of the radiating elements Z_a varies with the antenna height h. It implies that the antenna factor changes in magnitude with the antenna height. For example, height dependence of the antenna factor is shown in Fig.2 for a half-wave tuned dipole antenna oriented for horizontal or vertical polarization. These were calculated with the method of moment (MoM). The solid lines and the dashed lines denote the antenna factor for vertical and horizontal polarizations, respectively. The arrows represent the free-space values of the antenna factor for 30 MHz, 50 MHz, and 70 MHz. From this figure, the antenna factor of an EMI antenna is supposed to converge on the free-space antenna factor as the antenna height increases. The antenna factor for vertical polarization is less sensitive to the ground plane than that for horizontal polarization.

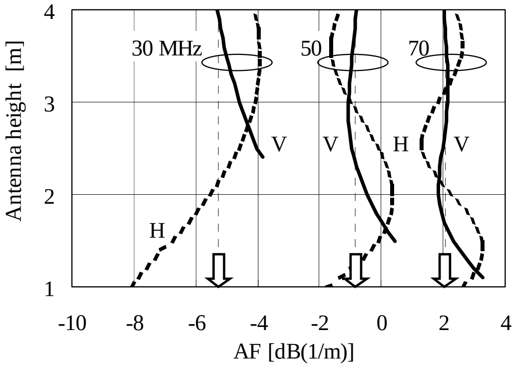

Fig. 2 Variation in the antenna factor with the antenna height (Z_0=100Ω)
(Solid line: vertical polarization, dashed line: horizontal polarization, arrow: free-space value)

2.3 Standard Antenna Method

The Standard Antenna Method is a calibration method of an antenna that requires a specially designed antenna named the standard antenna whose antenna factor, AF_{STD}, is rigorously determined through theoretical and experimental studies. In antenna calibration, a transmit antenna is placed at a height h_t above a metal ground plane as shown in Fig.3. Separated from this antenna by distance D, the standard antenna is placed at a height h_r for the same polarization as the transmit antenna. The strength of the electromagnetic field emitted from the transmit antenna is determined by multiplying the voltage induced at the standard antenna output, V_{std}, by the antenna factor of the standard antenna, AF_{STD}. Alternatively, the standard antenna is replaced with an antenna under calibration (AUC) and the voltage V_{AUC} is measured at the antenna output. Thus, the antenna factor of the AUC is yielded by

$$AF_{AUC}(D, h_r) = \frac{V_{STD}(D, h_r)}{V_{AUC}(D, h_r)} AF_{STD}(D, h_r) . \tag{5}$$

Since this method is implemented above a metal ground plane as illustrated in Fig.3, the derived

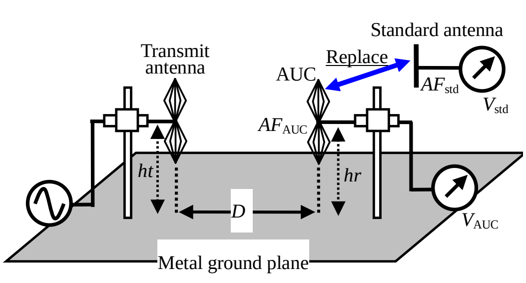

Fig. 3 Standard Antenna Method

antenna factor of the receive antenna may vary with the antenna height h_r. Hence, the Standard Antenna Method may provide accurate free-space antenna factor when the antennas are aligned for vertical polarization because the effects of the ground plane can be reduced.

3. ANTENNA ARRANGEMENTS FOR VERTICAL POLARIZATION

The standard antenna method is usually applied with antenna arrangements for horizontal polarization, but vertical polarization is more suitable for calibration to yield the free-space antenna factor, because the antenna factor is hardly affected by the ground as mentioned in **2.2**. Hence, numerical simulation was made to determine the antenna arrangements for vertical polarization that can yield most accurate free-space antenna factor in the frequency range from 30 to 250 MHz. Considering the dimensions of actual calibration test sites, we confined the allowable range of antenna positions to within D=1 m to 20 m and h_t=h_r=1 m to 4 m. An antenna under calibration was assumed to be a widely used biconical antenna loaded with Z_0=50 Ω. On the other hand, the standard antenna was chosen to be either a half-wave tuned dipole antenna or an 80-MHz tuned dipole antenna according to the frequency range above or below 80 MHz, respectively.

The method of moments (MoM) was applied to various antenna arrangements (D, ht, hr) for evaluating errors associated with the proposed calibration method. For example, Figs. 4-6 show differences in the free-space antenna factor between the calibration result AF_{AUC} and the true value AF_{free} given under the free-space condition. Since a biconical antenna behaves like a shortened dipole antenna at frequencies below about 70 MHz (resonance frequency), the proposed calibration method allows various antenna arrangements for this frequency range as shown in Fig. 4 that can yield accurate free-space antenna factors. On the other hand, at frequencies above 70 MHz, the antenna is placed in a non-uniform field caused by interference of the direct and ground-reflected waves. Accordingly, only limited combinations of D, ht, and hr are allowed for accurate antenna calibration as illustrated in Figs. 5 and 6. These numerical analyses lead to the conclusion that the antenna arrangements shown in Table 1 are most suitable for the calibration measurement to yield accurate free-space antenna factors. Figure 7 indicates the errors introduced in the antenna calibration when the antenna arrangements specified in Table 1 are used. It is

Table 1 Antenna arrangements for calibration of a biconical antenna

Frequency [MHz]	Antenna distance [m]	Antenna height [m]
30 - 80	20	3.5
90 - 250	20	2.0

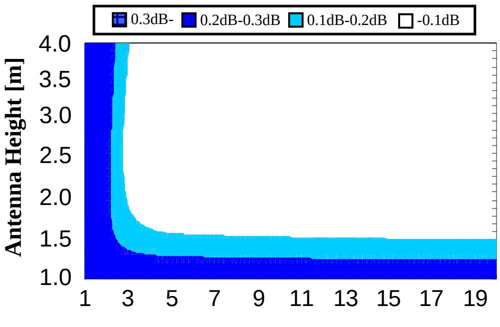

Fig.4 Difference between AF_{AUC} and AF_{free} on 30 MHz (Biconical antenna)

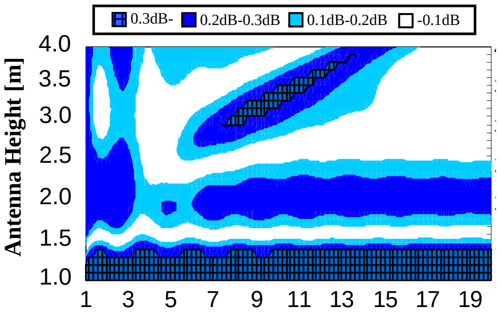

Fig.5 Difference between AF_{AUC} and AF_{free} on 70 MHz (Biconical antenna)

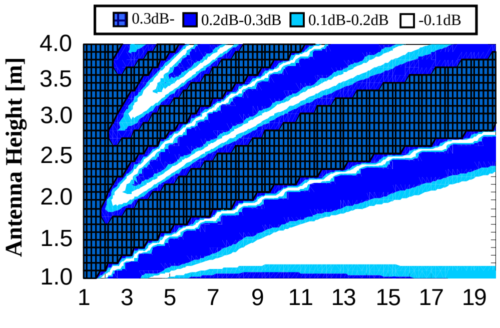

Fig.6 Difference between AF_{AUC} and AF_{free} on 200 MHz (Biconical antenna)

concluded from this figure that the free-space antenna factor can be determined with an error less than 0.1 dB.

4. INSERTION LOSS MEASUREMENT

The Standard Antenna Method requires voltage measurements at the antenna output port on V_{STD} and V_{AUC} as implied by Eq. (5). However, these measurements are usually replaced by insertion loss measurements between the transmit and receive antennas using a network analyzer. Thus, in actual antenna calibration, errors are introduced in this insertion loss measurement. Hence, the maximum insertion loss was computed by the MoM assuming a biconical antenna as the transmit antenna for the whole frequency range from 30 to 250 MHz. The results are shown in Fig. 8 where the insertion loss reaches as much as 60 dB at frequencies around 30 MHz. This is because both transmit antenna (biconical) and receive antenna (standard dipole antenna) have low gains in this frequency range. According to the data sheet of network analyzers [4], insertion loss measurement may introduce an error of about 0.2 dB into the antenna calibration in addition to an error attributed to the antenna arrangement that was discussed in the previous paragraph..

5. CONCLUSION

Radiated EMI measurements require measuring antennas to be accurately characterized in terms of the free-space value of the antenna factor. Hence, the present paper proposed an antenna calibration technique using the Standard Antenna Method where transmit and receive antennas were oriented for vertical polarization. Theoretical investigation was carried out using the method of moments to evaluate errors introduced into calibration of a biconical antenna for the frequency range from 30 to 250 MHz. As a result, appropriate antenna arrangements were found for the calibration that could provide the free-space antenna factor with an error less than 0.1 dB. Furthermore, insertion loss between the transmit and receive antennas was numerically investigated to evaluate errors introduced in actual calibration measurements. It was found that the insertion loss exceeded 60 dB at 30 MHz, resulting in an additional error of about 0.2 dB in the antenna calibration.

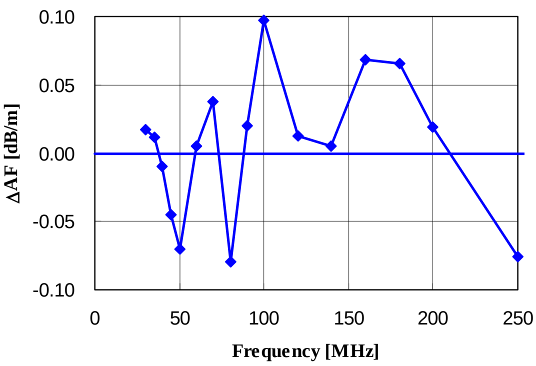

Fig. 7 Difference between AF_{AUC} and AF_{free} in the proposed method

REFERENCES

[1] IEC/CISPR Publication CISPR 16-1, “Specifications for radio disturbance and immunity measuring apparatus and methods-Part 1 Radio disturbance and immunity measuring apparatus.” 1999

[2] Y.Matsumoto, T.Umeda, A.Nishikata, K.Fujii, Y.Yamanaka, and A.Sugiura, “EMI Antenna Calibration on an Absorber-Lined Ground Plane to Determine Free Space Antenna Factor,” *IEEE Trans. Electromagn. Compat.*, vol.45, pp.656-660, Nov.2003

[3] K.Fujii, S.Kaketa, A.Sugiura, Y.Matsumoto, and Y.Yamanaka, “Calibration of EMI Antennas in the VHF Band with Antenna Impedance Measurements,” *International Symposium on Electromagn. Compat.*, pp. 361-364, Jun. 2004

[4] Agilent data sheet 5988-3780EN.pdf, “ENA 2, 3 and 4 port RF network analyzers.”.

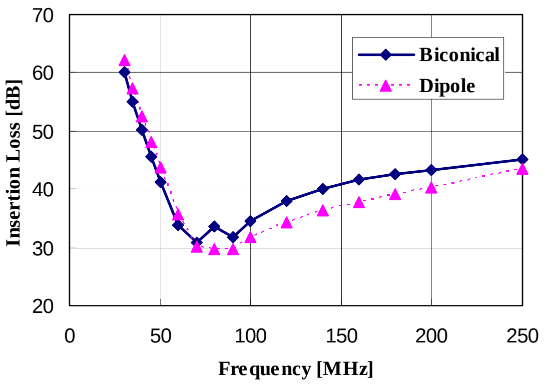

Fig. 8 Maximum insertion loss in calibration of a biconical antenna and a standard dipole