

# Numerical Simulation for Accurate Gain Measurement of LPDA

Katsushige Harima

EMC Laboratory, National Institute of Information and Communications Technology  
4-2-1, Nukui-Kitamachi, Koganei, Tokyo, 184-8795, Japan, harima@nict.go.jp

## Abstract

A numerical simulation of gain measurement performed by using the three-antenna method for an LPDA is presented. The effect of measurement distance on gain calibration is estimated by performing a simulation using the finite integration method. The numerical results also demonstrate the efficacy of considering the phase center for calibration.

**Keywords :** Gain measurement LPDA Phase center EMC Finite integration method

## 1. Introduction

The three-antenna method is widely used to determine the far-field gain of antennas. Two antennas are normally separated so as to satisfy the far-field criterion in the gain measurement. However, the gain of aperture antennas varies depending on the separation distance, even if it satisfies well known far-field criteria [1]. Newell et al developed the extrapolation measurement technique, by which accurate gain can be determined at reduced distances [2]. For antenna calibration of aperture antennas such as standard horn and double-ridged guide horn antennas, the efficacy of using the phase center in the three-antenna method has been shown [3, 4].

Log-periodic dipole array antennas (LPDAs) are commonly used as wideband antennas in electromagnetic compatibility (EMC) testing. When the gain is measured on the basis of the distance between the reference points, which is generally chosen to be the midpoint of the LPDA [5], it varies depending on the measurement distance, as with aperture antennas.

In this paper we discuss a numerical simulation of the gain measurements for the LPDA and evaluate the effect of antenna separation on the gain via the finite integration method (FIM).

## 2. Three-antenna Method

The three-antenna method is commonly used to determine the far-field absolute or actual gain of EMC antennas. For two antennas arranged in free space under the far-field condition, as shown in Fig. 1, the Friis transmission formula is expressed as follows:

$$G_t \cdot G_r = \frac{P_r}{P_t} \left( \frac{4\pi r}{\lambda} \right)^2. \quad (1)$$

Here,  $G_t$  is the gain of the transmitting antenna;  $G_r$ , the gain of the receiving antenna;  $P_t$ , the input power to the transmitting antenna;  $P_r$ , the power received by the receiving antenna;  $r$ , the distance between the two antennas;  $\lambda$ , the wavelength; and  $A_{tr}(= P_r/P_t)$ , the antenna insertion loss.

The gain of each antenna can be determined by solving three equations (1) obtained by using all combinations of the three antennas. For example, the gain of one of the three antennas is expressed as follows.

$$G_1 = \frac{4\pi r}{\lambda} \sqrt{\frac{A_{12} \cdot A_{13}}{A_{23}}}. \quad (2)$$

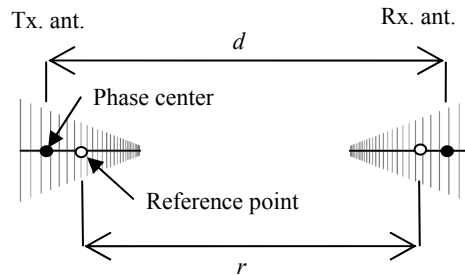


Figure 1: Setup for three-antenna method

If two antennas are identical, the gain is represented by

$$G = \frac{4\pi r}{\lambda} \sqrt{A}. \quad (3)$$

This is referred to as the two-antenna method.

For aperture antennas, e.g., horn antennas, the distance between apertures of two antennas is used as the measurement distance  $r$ . For LPDAs, that between the reference points, which generally chosen as the midpoint of the LPDA [5], on antennas is used. However, it is appropriate to consider the distance  $d (= r+2d_{pc})$  between phase centers when dealing with the antenna separation distance during gain measurement, as shown in Fig. 1. This is because the phase center, defined as the center of curvature of the equiphase front on far-field ranges, is considered an equivalent point source of far-field radiation.

### 3. Numerical Simulation

The effect of measurement distance on gain calibration was simulated by using a full-wave electromagnetic solver, CST MW-Studio, based on the finite integration method (FIM) [6]. The antenna model is shown in Fig. 2(a). The geometry parameters of LPDA [7] were chosen with a scaling factor of  $\tau = (L_{n+1}/L_n) = 0.915$ , spacing factor of  $\sigma = (S_n/2L_n) = 0.052$ , 27 dipole elements ( $= N$ ), and the lengths of the longest and shortest dipole elements ( $L_1$  and  $L_N$ ) corresponding to an operating frequency range of 1 to 10 GHz.

The two-antenna method was applied to the simulation of gain measurement so that identical antennas can be assumed for numerical computation. The simulation model for the two-antenna method is shown in Fig. 2(b). Two identical LPDAs separated by a distance  $r$  were placed facing each other. The analytical region was composed of nonuniform cells, for which the maximum cell size was  $\lambda/20$ . The antenna was assumed to be a perfect conductor and excited by a coaxial feed. The absorbing boundaries were assumed as the boundaries of the analytical region. The perfectly

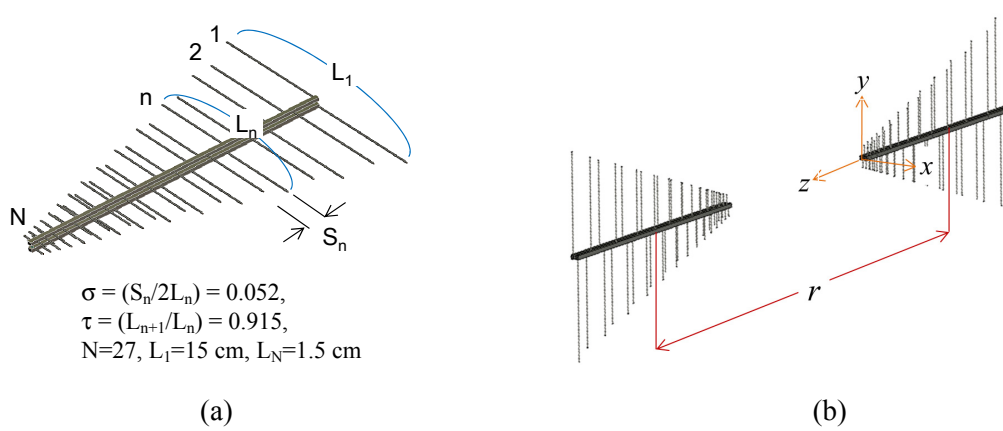


Figure 2: (a) LPDA model and (b) FIM simulation of gain measurement

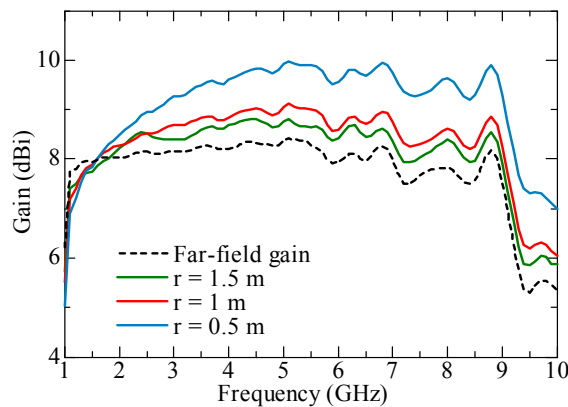


Figure 3: Gain determined by using distance between reference points

matched layer (PML) [8], with eight layers, was used as the absorbing boundary condition. The absolute gain was determined by computing the S21 parameter for the antenna insertion loss,  $A$  in (3), and the S11 parameter for the impedance mismatch loss corresponding to both antenna ports. Figure 3 shows the gains determined using the different distances between the reference points for 0.5, 1, and 1.5 m ( $= r$ ), and the far-field gain. The far field gain was calculated using the near-to-far-field transformation based on the field equivalence theorem. When the gain was determined on the basis of the reference point, it varied depending on the measurement distance.

The location of the phase center can be approximate by exploiting this gain variation [9], i.e., the ratio ( $\Delta G = G_{r1}/G_{r2}$ ) of the gains determined at two different distances ( $r = r1$  and  $r2$ ), as follows [10]:

$$d_{PC} \cong \frac{r1 \cdot r2 \cdot (1 - \Delta G)}{2(\Delta G \cdot r2 - r1)}. \quad (4)$$

Figure 4 shows the location of the phase center estimated using this technique from the gains determined at two distances of 0.5 m ( $= r1$ ) and 1 m ( $= r2$ ). As the frequency increases, the phase center moves from the vicinity of the end of the LPDA toward the tip corresponding to that of the resonant dipoles. However, the location of the phase center differs from the resonant dipoles below 6 GHz. This is similar to Chen's [11] calculation results using the moment method. The phase patterns calculated at 2 GHz at the phase center and their anteroposterior locations are shown in Fig. 5. When the angular region is within approximately  $\pm 25^\circ$  ( $= \theta$ ), which is approximately half the 3-dB beamwidth, the variation in the phase pattern at the phase center is constant.

When the gain,  $G_d$ , is determined on the basis of the distance between the phase centers, it was independent of distance and exhibited good agreement with the far-field gain,  $G_{FAR}$ , as shown in Fig. 6. The changes in the gains determined by considering the phase center,  $d$ , and the reference point,  $r$ ,

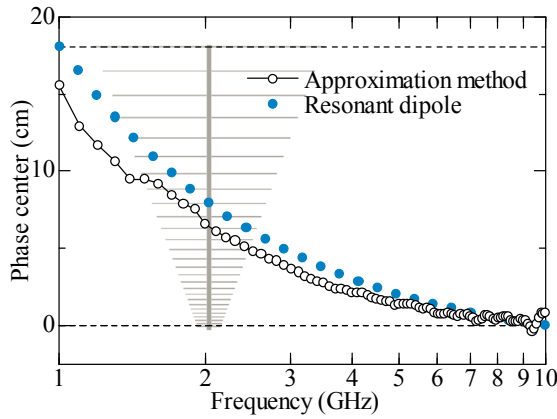


Figure 4: Phase center location relative to the tip of the antenna.

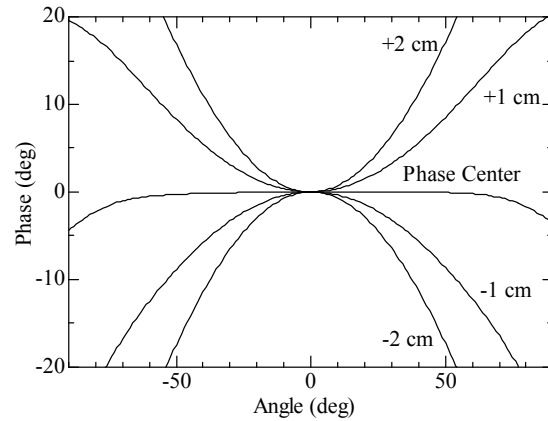


Figure 5: Phase pattern at 2 GHz.

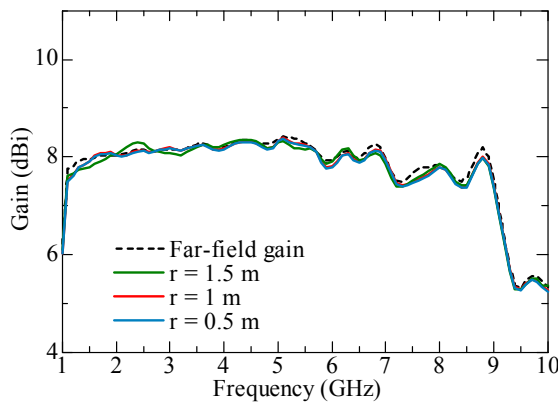


Figure 6: Gain determined by using distance between phase centers.

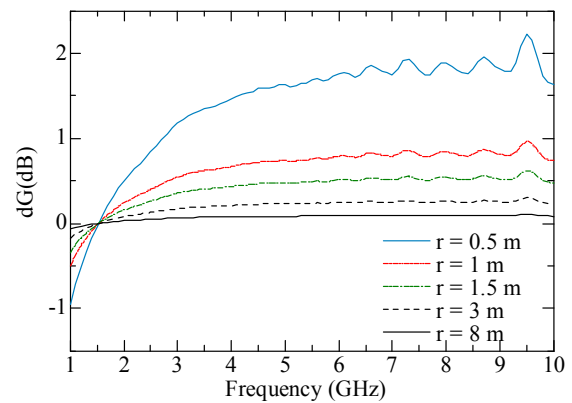


Figure 7: Ratio ( $dG$ ) of gains determined by considering reference point to phase center.

are expressed as the ratio of both distances; this ratio,  $dG$ , is derived from (2) as follows:

$$dG = \frac{G_r}{G_d} = \frac{r}{d} \cong \frac{G_r}{G_{FAR}}. \quad (5)$$

Although this gain variation is negligible if the distance between the antennas is sufficiently large, it is approximately 1 dB for a distance of 1 m, as shown in Fig. 7. The separation needed to obtain a gain variation within 0.1 dB is 8 m or more. When the conventional three-antenna method, in which the location of the reference point is considered, is used, the antenna separation required to determine the far-field gain is considerably large. However, taking the location of the phase center into consideration does not result in gain variation at relatively small antenna separations (e.g.,  $r = 0.5$  m).

## 4. Conclusion

The effect of the separation distance on the gain of a log-periodic dipole array antenna was estimated by conducting numerical simulations based on the finite integration method. The gain was determined by the three-antenna method in which the locations of the phase center and reference point of the antenna were considered. Simulation results indicate the following: (1) the gain determined by the conventional three-antenna method, which involves the use of the distance between the reference points, varies according to the measurement distance. (2) By considering the distance between the phase centers, the far-field gain can be obtained without resulting in a variation in the gain with the measurement distance; thus, at relatively small separations.

## References

- [1] T. S. Chu and R. A. Semplak, "Gain of Electro-magnetic Horns," *Bell Sys. Tech. J.*, vol. 44, no. 3, pp. 527-537, Mar. 1965.
- [2] A. C. Newell, R. C. Baird, and P. F. Wacker, "Accurate Measurement of Antenna Gain and Polarization at Reduced Distances by an Extrapolation Technique," *IEEE Trans, Antennas Propagat.*, vol. AP-21, no. 4, pp. 418-431, Jul. 1973.
- [3] K. Harima, M. Sakasai, and K. Fujii, "Determination of Gain for Pyramidal-Horn Antenna on Basis of Phase Center Location," *Proc. 2008 IEEE EMC Symposium, Detroit, USA, Aug. 2008.*
- [4] K. Harima, "Determination of gain of double-ridged guide horn antenna by considering phase center," *IEICE Electron. Express*, vol. 7, no. 2, pp. 86-91, Jan. 2010.
- [5] IEC CISPR 16-2-3, "Specification for radio disturbance and immunity measuring apparatus and methods. Part 2-3: Methods of measurement of disturbances and immunity - Radiated disturbance measurements," July 2006.
- [6] MW-Studio, Ver.2008, CST, Darmstadt, Germany
- [7] R. Carrel, "The design of log-periodic dipole antennas," *IRE National Conventional Record*, pp. 61-75, 1961.
- [8] J. P. Berekger, "A Perfectly Matched Layer for the Absorption of Electromagnetic Waves," *Journal of Computational Physics*, vol. 114, pp. 185-200, 1994.
- [9] T. W. Hertel, "Phase center measurements based on the three-antenna method," *Proc. 2003 IEEE AP-S Symposium*, pp. 816-819, Columbus, USA, June 2003.
- [10] K. Harima, "Accurate Gain Determination of LPDA by Considering the Phase Center," *IEICE Electron. Express*, vol. 7, no. 23, pp. 1760-1765, Dec. 2010.
- [11] Z. Chen. M. Foegelle, and, T. Harrington, "Analysis of log periodic dipole array antennas for site validation and radiated emissions testing," *Proc. 1999 IEEE EMC Symposium*, pp. 618-623, Seattle, USA, Aug. 1999.

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