Circularly Polarized Log-Periodic Dipole Antenna for EMI Measurements

Ryoji Wakabayashi, Kazuo Shimada, *Member, IEEE,* Haruo Kawakami, *Senior Member, IEEE,*
and Gentei Sato, *Life Fellow, IEEE*

***Abstract*—Two types of broad-band antennas are widely used for electromagnetic interference (EMI) measurements in the frequency range from 30 to 1000 MHz. Log-periodic dipole antennas (LPDA) are mainly used for the range above 300 MHz and biconical antennas for the range less than 300 MHz. These two antennas have linear polarization. However, EMI measurements can sometimes be more conveniently made with an antenna having circular polarization and so we propose an improved LPDA, which has circular polarization. This LPDA has a second array of dipoles so arranged that each dipole of the second array has a quarter-wavelength phase difference from that of the corresponding dipole of the standard LPDA array for the given radiation field. For this reason, we named it a cross-element LPDA. The cross-element LPDA does not need a broad-band 90° hybrid junction to produce circular polarization. We calculated the height pattern and the frequency characteristics of the classical site attenuation (CSA) for the cross-element LPDA when used for both transmitting and receiving, as well as the antenna factor. Moreover, we calculated the normalized site attenuation (NSA) when the cross-element LPDA is used for receiving or for both transmitting and receiving.**

***Index Terms*— Antenna factor, broad-band antenna, circular polarization, LPDA, moment method, near field, site attenuation.**

I. INTRODUCTION

DIFFERENT types of broad-band antennas are used for electromagnetic interference (EMI) measurements in each frequency range according to ANSI-C 63.2 [1]. For example, a biconical antenna or a log-periodic dipole antenna (LPDA) [2] is used as the broad-band linear antenna in the frequency range from 30 MHz to 1 GHz. A biconical antenna is often used in the frequency range from 30 to 300 MHz and an LPDA in the range of 300–1000 MHz.

Theoretical values have been calculated for the site attenuation or the antenna factor when broad-band biconical or LPDA antennas are used for receiving in the frequency range from 30 to 1000 MHz [3], [4].

The site attenuation or electromagnetic noise from an equipment under test (EUT) are usually measured to give separately the horizontal and vertical components of the received electric wave. So a linearly polarized antenna such as a tuned dipole, an LPDA, or a biconical antenna is often used for EMI measurements.

However, when the horizontal and the vertical components of the received electric field are required simultaneously, for example, when measuring EMI for high-speed vehicle communication, a circularly polarized antenna will be needed.

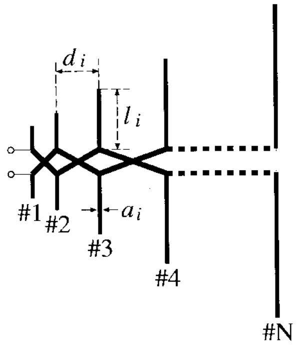

Fig. 1. Standard LPDA with associated parameters.

Therefore, in this paper, we propose an LPDA [5]. This LPDA, called a “cross-element LPDA,” has a second dipole array which is orthogonal to that of the standard LPDA. Though a cross-element LPDA for electromagnetic compatibility (EMC) measurement has been manufactured by EMCO, this version of the antenna requires a discrete broad-band 90° hybrid junction to produce the circular polarization. However, our version of an LPDA antenna does not require such a hybrid junction.

First, we show the radiation patterns of the cross-element LPDA; then, the calculated height pattern and frequency characteristics of the classic site attenuation (CSA) when the cross-element LPDA is used for both transmitting and receiving.

The cross-element LPDA antenna can radiate the horizontal and vertical components of the electric field with a polarization ratio of about only 1 dB for the vertical plane and so the cross-element LPDA gives good circular polarization.

In addition, the antenna factors of the cross-element LPDA are shown. Moreover, the calculated normalized site attenuation (NSA) in the case of the cross-element LPDA used for receiving or for both transmitting and receiving are shown.

II. CROSS-ELEMENT LPDA

The geometry of a standard N-element LPDA with associated parameters is shown in Fig. 1. Table I shows the length of the ith element, the distance between element $i-1$ and i, and the wire radius of the ith element of a standard 16-element LPDA. These parameters are referred to the model

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The authors are with the Department of Electronics Engineering, Tokyo Metropolitan College of Aeronautical Engineering, Tokyo, 116 Japan.

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TABLE I
DIMENSIONS OF 16-ELEMENT STANDARD LPDA

Element no. i	Element length l_i (mm)	Distance d_i (mm)	Wire radius a_i (mm)
1	78.0	—	4.00
2	91.2	11.3	4.00
3	105.4	13.5	4.00
4	123.4	15.5	4.00
5	142.2	18.6	4.25
6	166.0	21.4	4.25
7	191.8	25.7	6.40
8	225.0	29.7	6.40
9	261.4	34.5	6.40
10	303.0	39.8	6.40
11	352.6	46.6	6.40
12	410.0	54.7	6.40
13	476.4	62.8	6.40
14	553.4	73.8	6.40
15	645.4	84.2	6.40
16	749.4	98.2	6.40

TABLE II
THE PARAMETERS OF THE 16-ELEMENT STANDARD LPDA

Element no.	d_i/l_i	d_i/d_{i-1} $(=\tau)$	Half wave Resonance (MHz)	σ	α
1			1921.8		
2	0.124	0.837	1643.6	0.0620	33.33
3	0.128	0.871	1422.2	0.0640	26.73
4	0.126	0.833	1214.7	0.0628	33.56
5	0.131	0.869	1054.1	0.0654	26.57
6	0.129	0.833	903.0	0.0645	32.98
7	0.134	0.865	781.5	0.0670	26.68
8	0.132	0.861	666.2	0.0660	27.79
9	0.132	0.867	573.4	0.0660	26.77
10	0.131	0.854	494.7	0.0657	29.05
11	0.132	0.852	425.1	0.0661	29.26
12	0.133	0.871	365.6	0.0667	25.80
13	0.132	0.851	314.6	0.0659	29.48
14	0.133	0.876	270.9	0.0667	24.85
15	0.130	0.857	232.3	0.0652	28.65
16	0.131		200.0	0.0655	

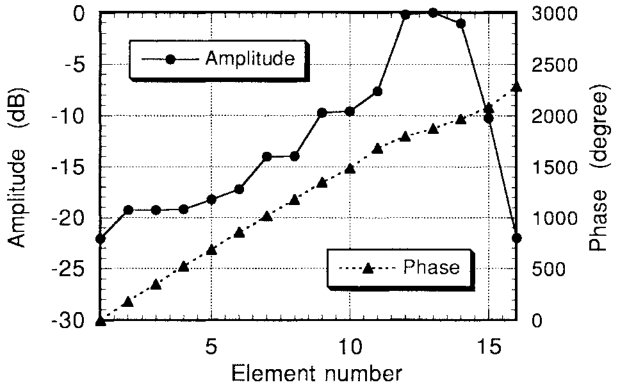


Fig. 2. The base current on each element of the LPDA (f = 300 MHz).

TABLE III
THE SIZE OF 16 CROSS ELEMENTS OF THE CROSS-ELEMENT LPDA

Element no. i	Element length l_i (mm)	Distance d_i (mm)	Wire radius a_i (mm)
17	85.2	6.0	4.00
18	99.6	12.3	4.00
19	115.1	14.6	4.00
20	134.8	16.9	4.00
21	155.3	20.5	4.25
22	181.3	23.2	4.25
23	209.5	27.7	6.40
24	245.8	32.3	6.40
25	285.5	37.3	6.40
26	331.0	43.0	6.40
27	385.2	50.4	6.40
28	447.9	59.1	6.40
29	520.4	67.9	6.40
30	604.5	79.2	6.40
31	705.0	91.3	6.40
32	818.6	106.2	6.40

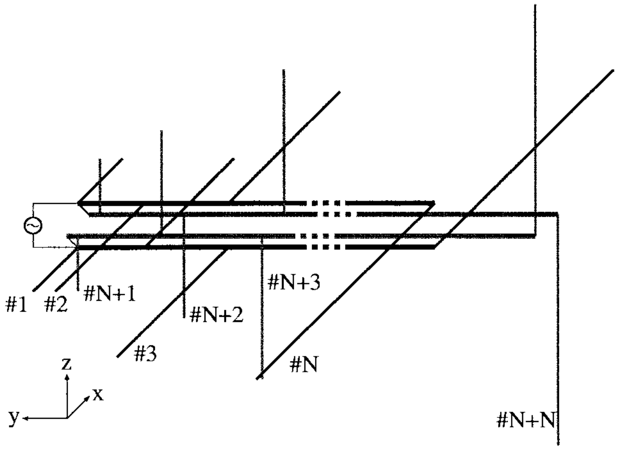


Fig. 3. Suggested cross-element LPDA with associated parameters.

3146 (a product of EMCO), the standard LPDA for EMI measurements.

The parameters of the LPDA d_i/l_i scale factor ($\tau = d_i/d_{i-1}$), the frequency of the half-wave resonance spacing factor ($\sigma = d_i/l_i$), and α are shown in Table II.

Fig. 2 shows the base current of each element of the LPDA calculated by the method in [2]. The maximum current distribution occurs on the element closest to half-wave length of the feeding source. The phase shift of the base current at the feeding point of this LPDA is about 20π per wavelength at 300 MHz.

Then we reasoned that the LPDA would have circular polarization if the LPDA had a set of cross elements perpendicular to the original elements and if each cross element was shifted from the original elements a distance equivalent to a phase shift of $\pi/4$ for the given radiation field.

The geometry of the cross-element LPDA with $2N$ elements is shown in Figs. 3 and 4. Each $N+i$th cross element is lengthened to be $14.2/13 \simeq 1.09$ times longer than the corresponding ith element (see Table III) so that α of the cross elements of the LPDA comes to the values of the original LPDA in Table II.

Fig. 5 shows the front view of the feed lines of the cross-element LPDA for the #i and #$i+N$ elements. The charac-

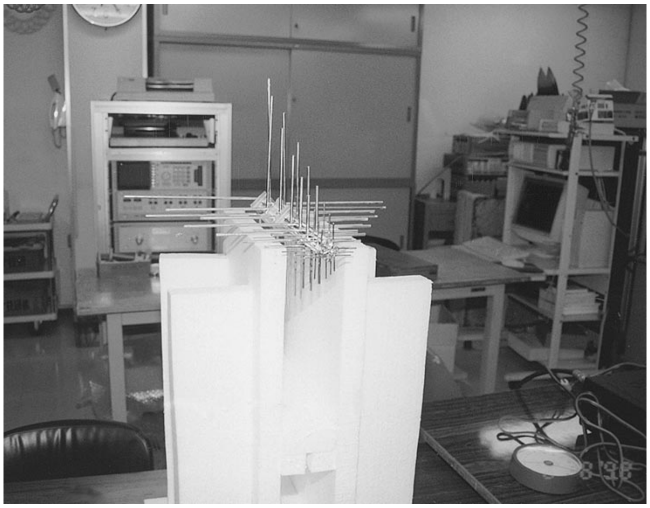


Fig. 4. An exterior view of the suggested cross-element LPDA.

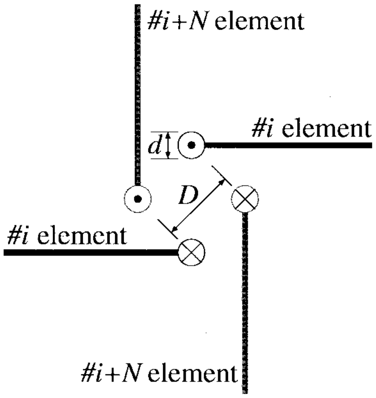


Fig. 5. A pair of feed lines with #ith and #$i+N$th elements of the cross-element LPDA.

teristic impedance Z_0 of the feed line in Fig. 5 can be given as

$$Z_0 = 138 \log_{10} \frac{2\sqrt{2}D}{d}. \tag{1}$$

It is found that $Z_0 \geq 62.3\,\Omega$, because $D \geq d$. In this paper, Z_0 is 75.0 Ω, for example, if $d = 10.0$ mm, then $D = 12.4$ mm.

Fig. 6 shows values calculated by the moment method [6], [7] and the typical measured radiation pattern of the cross-element LPDA for a frequency of 1 GHz. The calculated patterns seem to be in close agreement to the measured patterns.

Fig. 7 shows the measured polarization ratio of the cross-element LPDA for a frequency of 750 MHz. The polarization ratio of the cross-element LPDA is within 3 dB for the horizontal and 1 dB for the vertical plane in the forward direction. This shows that this type of antenna has circular polarization. Similar patterns are obtained for other frequencies from 300 to 1000 MHz.

We consider that the two orthogonal components of the electric field (the E_ϕ component radiated from the original element and the E_θ component radiated from the cross element of the LPDA), where maximum current is obtained, have a phase difference of $\pi/4$.

III. ANALYZED MODEL FOR SITE ATTENUATION AND ANTENNA FACTOR

Fig. 8 shows the model for a measuring system for site attenuation when the cross-element LPDA is used for both transmitting and receiving.

The CSA: A_C is defined [8] as follows:

$$A_C = V_{\mathrm{DIRECT}} - V_{\mathrm{SITE}} - a_1 - a_2 \tag{2}$$

where

V_{DIRECT}	signal source voltage;
V_{SITE}	voltage received;
a_1	transmitting antenna circuit loss;
a_2	receiving antenna circuit loss.

By the method which we have described in [4] we have calculated the CSA when the cross-element LPDA is used for both transmitting and receiving. In this paper, the load connected to the receiving antenna terminal is assumed to be 50 Ω.

The NSA: A_N is defined [9] as

$$A_N = V_{\mathrm{DIRECT}} - V_{\mathrm{SITE}} - AF_T - AF_R - \Delta AF_{\mathrm{TOT}} \tag{3}$$

where

V_{DIRECT}	signal source voltage;
V_{SITE}	voltage received;
AF_T	transmitting antenna factor;
AF_R	receiving antenna factor;
ΔAF_{TOT}	mutual impedance correction factor.

However ΔAF_{TOT} is used only for the specific geometry of horizontal polarization using tunable dipoles separated by 3 m. The ΔAF_{TOT} is assumed to be zero for all other geometries. For the cross-element LPDA used, $\Delta AF_{\mathrm{TOT}} = 0$. In order to apply (3) to EMI measurements, we have to calculate the antenna factor correctly. So we calculated the antenna factor AF of the cross-element LPDA shown in Fig. 9 as

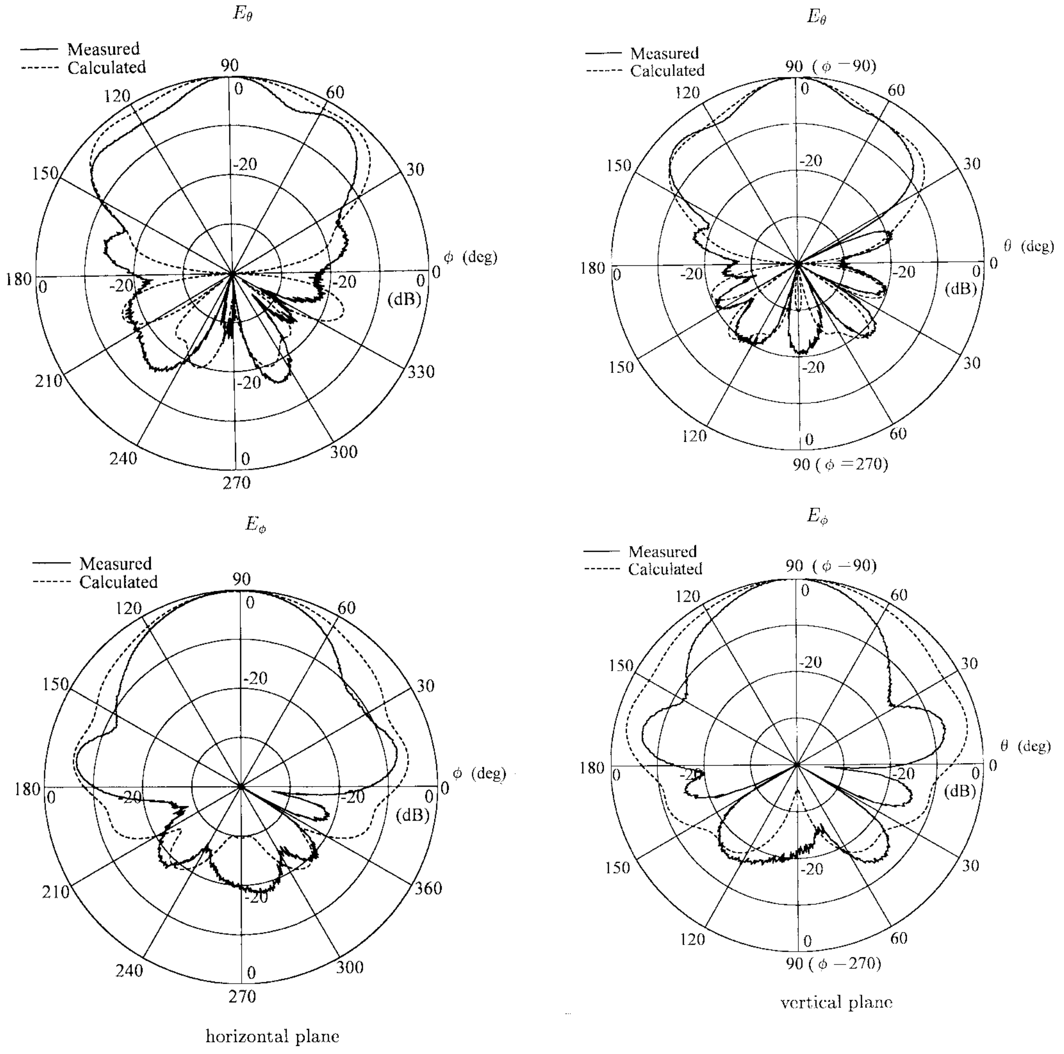
$$AF = 20 \log \frac{E}{V_r} \qquad \text{(dB/m)} \tag{4}$$

where

E	electric field strength at the phase center of receiving antenna;
V_r	voltage received.

For our calculation, we assumed that the ground plane is infinite and that it is a perfect conductor. The electric field strength E at the phase center of the receiving antenna is calculated by using a matrix method [10].

V_r is calculated by using the moment method [6], [7]. The triangle function is used as both the expansion and the testing function in this calculation.



(a) (b)

Fig. 6. Radiation pattern of the cross-element LPDA for horizontal and vertical planes at 1000 MHz. (a) Horizontal plane. (b) Vertical plane.

IV. CALCULATED RESULTS OF SITE ATTENUATION AND ANTENNA FACTOR

A. The CSA Above a Perfectly Conducting Plane

Fig. 10 shows the calculated and measured height pattern of the CSA in Fig. 8 for the cross-element LPDA used for both transmitting and receiving, under the following conditions:

R 3 m;
h_1 2 m;
h_2 1–4 m scanned.

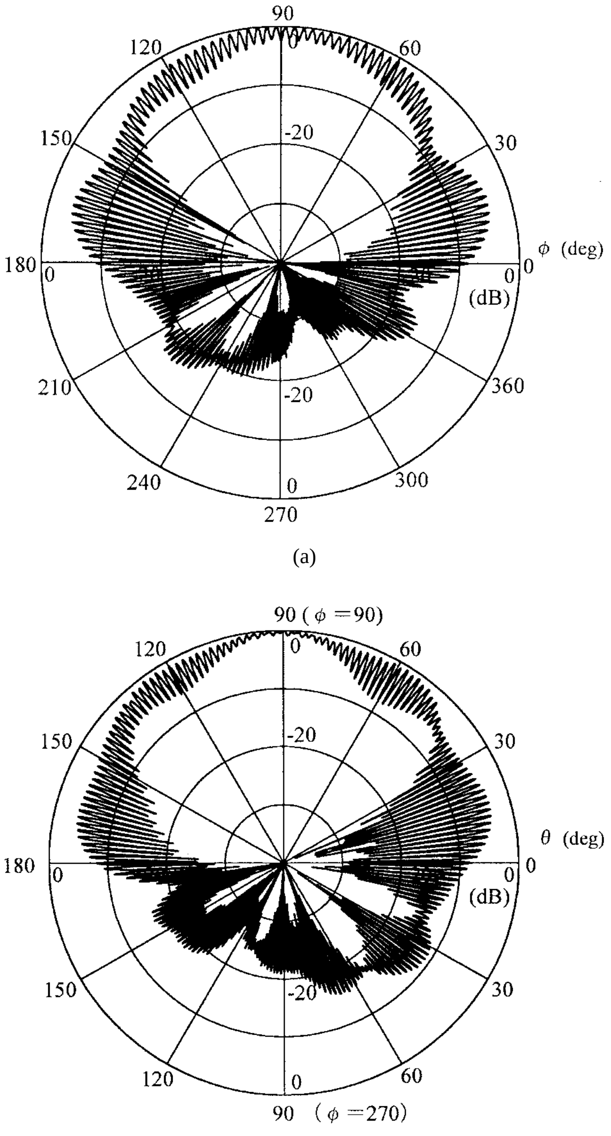
The agreement between the measured and calculated height pattern is satisfactory. The height pattern for 300 MHz is similar to that of horizontal polarization when dipole antennas are used [11]. The height pattern at a frequency of 1000 MHz is the superposition of the horizontal polarization and the vertical polarization for the dipole antennas used [12]. Similar results have also been found in a calculated CSA for circular polarization when a short dipole is used for transmitting [13]. It seems that the higher the frequency the lower the mutual coupling between the real and the image antenna. Therefore, the height pattern is seen to be influenced by the image antenna, especially in the lower frequency range.

Fig. 11 shows the calculated frequency characteristics of the CSA. The relation between frequency versus CSA is almost linear for the frequency range less than 600 Mhz.

B. The AF in Free-Space and the NSA Above a Perfectly Conducting Plane

The NSA was also automatically measured by the swept frequency method in an anechoic chamber. Therefore, in this section, as one of the applications of the cross-element LPDA, we present the NSA calculated by (3) when a cross-element LPDA is used for receiving or for both transmitting and receiving.

Table IV shows the calculated antenna factors of the cross-element LPDA for horizontal, vertical, and circular polarization, and that for the half-wave dipole antenna in free-space. For the system of Fig. 9, the AF was calculated for circular polarization when each cross-dipole was fed by a voltage shifted $\pi/2$ from the corresponding original dipole.



(a)

(b)

Fig. 7. Measured polarization ratio of the cross-element LPDA for horizontal and vertical planes at 750 MHz. (a) Horizontal plane. (b) Vertical plane.

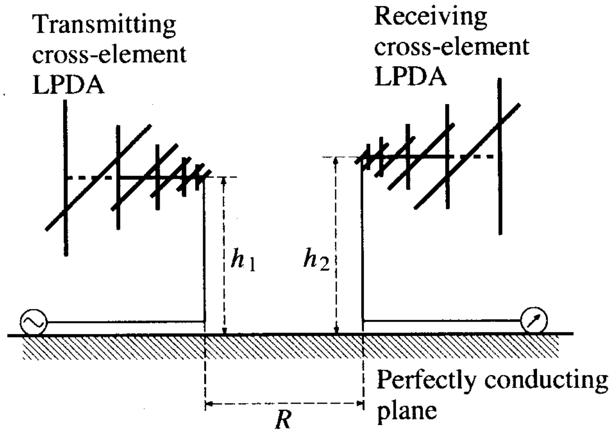


Fig. 8. The model of the measuring system for site attenuation when the cross-element LPDA is used for transmitting and receiving.

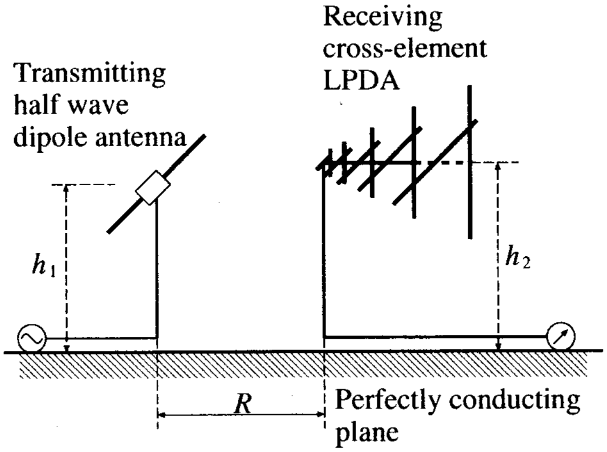


Fig. 9. Model system for measuring the antenna factor when a cross-element LPDA is used for receiving.

The calculated antenna factor of the half-wave dipole antenna AF_k is nearly equal to the value from the approximate equation given in [9] as

$$AF_k = 20\log\left(\frac{2\pi}{\lambda}\right) + 10\log\left(\frac{73}{50}\right) \qquad (\text{dB}) \qquad (5)$$

where λ is the wavelength in meters.

Fig. 12 shows the NSA calculated above a perfectly conducting plane. The cross-element LPDA was used for both transmitting and receiving and the parameters in Fig. 8 are:

R 3 m;
h_1 2 m;
h_2 1–4 m scanned.

From Fig. 12, the NSA when the cross-element LPDA is used for receiving has an approximately linear relation to frequency for the frequency range less than 700 MHz. On the other hand, the NSA for the cross-element LPDA used for both transmitting and receiving fluctuated with frequency. We consider that this variation is due to the radiant gain of the transmitting antenna. We plan to investigate further the ΔAF_{TOT} for the cross-element LPDA.

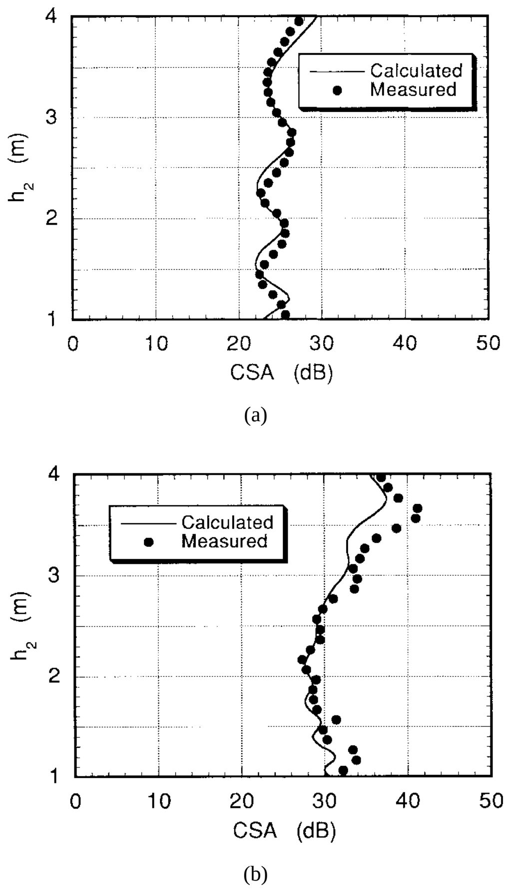
V. CONCLUSION

We have proposed a cross-element LPDA for EMI measurements. We have calculated the gain for the cross-element LPDA and have shown the characteristics of the cross-element LPDA clearly.

The cross-element LPDA has a polarization ratio of about 1 dB for the vertical plane. The cross-element LPDA has almost circular polarization.

Therefore, the cross-element LPDA can be used for EMI measurements when it is necessary to get horizontal and vertical polarization information simultaneously. Consequently the cross-element LPDA can be used more widely than the standard LPDA.

Moreover, we have shown the CSA, the AF of the cross-element LPDA, and the SA when the cross-element LPDA is used for receiving or for transmitting and receiving.



(a)

(b)

Fig. 10. Height pattern of the CSA above the perfectly conducting plane with the cross-element LPDA. (a) $f = 500$ MHz. (b) $f = 1000$ MHz.

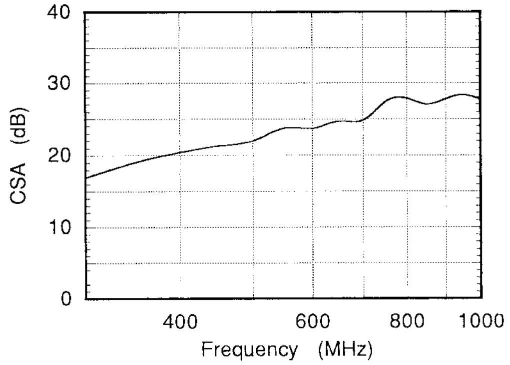


Fig. 11. The CSA above the perfectly conducting plane in the case of the cross-element LPDA used for both transmitting and receiving.

Our calculated results can be useful for establishing the specifications for an LPDA for EMI measurements, especially for high-speed mobile communication equipment.

Further investigation should take up the ΔAF_{TOT} of a cross-element LPDA in the NSA and the ΔAF_{TOT} of the cross-element LPDA. In the near future, we intend to make actual measurements of the antenna factor and the NSA for a cross-element LPDA used for both transmitting and receiving.

TABLE IV
THE AF OF THE HALF-WAVE DIPOLE ANTENNA AND THE CROSS-ELEMENT LPDA IN FREE-SPACE

f (MHz)	AF (dB/m)			
	The cross-element LPDA			Half-wave dipole antenna
	Horizontal pol.	Vertical pol.	Circular pol.	
300	13.2	14.5	7.8	18.0
350	14.4	14.1	8.1	19.3
400	15.5	15.8	9.6	20.5
450	16.5	17.1	10.7	21.5
500	18.1	18.4	12.3	22.4
550	19.1	18.9	12.8	23.3
600	19.5	19.5	13.3	24.0
650	20.2	20.3	14.0	24.7
700	21.1	21.8	15.2	25.4
750	22.4	23.0	16.7	26.0
800	23.4	23.3	17.6	26.5
850	24.0	23.3	17.5	27.1
900	23.5	24.2	17.5	27.6
950	25.0	23.8	17.8	28.0
1000	24.7	23.3	17.2	28.5

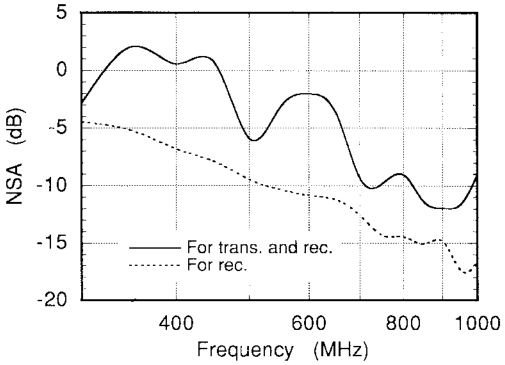


Fig. 12. The NSA above the perfectly conducting plane in the case of the cross-element LPDA used for receiving or for both transmitting and receiving.

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Ryoji Wakabayashi was born in Osaka, Japan, on April 1, 1962. He received the B.E. and M.E. degrees from the Department of Electrical and Electronics Engineering, Sophia University, Tokyo, Japan, in 1987 and 1989, respectively, and the Ph.D. degree from Tsukuba University, Ibaragi, Japan, in 1999.

He became a Research Associate of Tokyo Metropolitan College of Aeronautical Engineering, Japan, where he was promoted to Lecturer and Associate Professor in 1992 and 1995, respectively. He has been engaged in research on linear antennas, electromagnetic compatibility, and satellite communication.

Dr. Wakabayashi received a URSI YS Award in 1993.

Kazuo Shimada (M’72) was born in Tokyo, Japan, on January 11, 1940. He received the B.E. degree in communication engineering from the University of Electro-Communications, Tokyo, Japan, in 1966, and the Ph.D. degree in electrical engineering from the University of Tokyo, in 1986.

From 1966 to 1974, he was with the Department of Electronics Engineering, Sophia University, Tokyo, Japan. In 1971 he joined the Institute of Space and Aeronautical Science, University of Tokyo, as a Research Associate. In 1981, after the Institute’s reorganization, he was transferred to the Institute of Interdisciplinary Research, Faculty of Engineering, University of Tokyo. Since 1988, he has been a Professor at Tokyo Metropolitan College of Aeronautical Engineering. He has been engaged in research on propagation of millimeter waves.

Haruo Kawakami (M’70–SM’89) was born in Okayama, Japan, on January 24, 1939. He received the B.E. degree from the Department of Electrical Engineering, Meiji University, Tokyo, Japan, in 1962, and the Ph.D. degree from Tohoku University, Sendai, Japan, in 1983.

In 1962, he joined YAGI Antenna Co., Ltd., Saitama, Japan. In 1964 he became a Research Associate of the Department of Electric and Electronic Engineering, Sophia University, Tokyo, Japan, and was promoted to Lecturer and Associate Professor there in 1985 and 1992, respectively. He is currently a Director at Antenna Giken Co., Ltd., Saitama, Japan. In 1989 he was a part-time Lecturer at the Department of Electronics Engineering, Tokyo Metropolitan College of Aeronautical Engineering. In 1998 he was a Visiting Professor at Utsunomiya University, Tochigi, Japan. He is the author of *Antenna Theory and Application* (Tokyo, Japan: Mimatsu Data, 1991), *New Electrical Circuit Practice* (Tokyo, Japan: Kogaku-Tosho, 1990), and *New Alternate Current Circuit Practice* (Tokyo, Japan: Kogaku-Tosho, 1992). He has been engaged in the research and development of mobile systems, automobile-borne antennas, and electromagnetic compatibility.

Dr. Kawakami received a Best Defense Technology Paper Award in 1987. He is a member of the Applied Computational Electromagnetics Society, the Institute of Electronics, Information, and Communication Engineers of Japan, and the Institute of Image Information and Television Engineers of Japan. His name has been listed in Marquis *Who’s Who in the World*.

Gentei Sato (M’63–SM’77–F’84–LF’95) was born in Miyagi, Japan, on March 15, 1926. He received the B.E. and Ph.D. degrees from the Department of Communication Engineering, Tohoku University, Sendai, Japan, in 1947 and 1961, respectively.

He became a Research Associate of the Department of Communication, Tohoku University, in 1947, and was promoted to Associate Professor there in 1956. He became the Head of the Research Laboratory, Yagi Antenna Co., Ltd., Saitama, Japan, in 1957. He was promoted to Professor at the Department of Electric and Electronic Engineering, Sophia University, Tokyo, Japan, in 1964. He is now a Professor Emeritus at the same university, since 1992. He is currently a Representative Director at Antenna Giken Co., Ltd., Omiya, Japan, and has been engaged in research on microwave antennas, transmission equipment, and electromagnetic compatibility. He is the author of *Antenna Engineering* (Tokyo, Japan: Sogo Denshi, 1969), *Antenna Theory and Applications* (Tokyo, Japan: Mimatsu Data System, 1991), and *Dates on Ultra High Speed Variable Transmission Devices and its Application*, (Tokyo, Japan: Sogo Denshi, 1995).

Dr. Sato received a Best Defense Technology Paper Award in 1987. He is a member of the Institute of Electronics, Information, and Communication Engineers of Japan, the Institute of Image Information and Television Engineers of Japan, and the Institute of Electronic Engineers of Japan.