Two Rectangular Loops Fed in Series for Broadband Circular Polarization and Impedance Matching

Makoto Sumi, Kazuhiro Hirasawa, *Senior Member, IEEE*, and Song Shi

***Abstract*—Two rectangular wire loops above an infinite ground plane are investigated for broadband circular polarization and impedance matching. Each rectangular loop is connected to each end of a short dipole fed by a coaxial cable through the ground plane. One gap on each loop is introduced to get circular polarization and the gap position controls the sense of circular polarization. The position of the gap, the length of the short dipole, the height of the loop above the ground plane and the shape of the rectangle are very important to get a good axial ratio (AR) and voltage standing-wave ratio (VSWR). The AR bandwidth ($\leq$3 dB) and the VSWR bandwidth ($\leq$2) are 18% and 22%, respectively. The measured and computed results are in good agreement.**

***Index Terms*—Broadband, circular polarization, rectangular loop with a gap, wire antenna.**

I. Introduction

LOW-PROFILE, broadband and circular polarization antennas are currently receiving much attention, and various antennas with those characteristics have been developed [1]–[5]. For a single feed antenna it is not easy to realize circular polarization and impedance matching for a wide frequency range [6] and two feeds with a 90 degree phase difference are often used to get a wider frequency band [7]. Wire antennas consisting of two rhombic loops have been studied for circular polarization and broadband circular polarization is obtained without considering impedance matching [8].

In this paper, two rectangular wire loops fed in series are introduced to get broadband circular polarization and impedance matching at the same time. Each rectangular loop is connected to each end of a short dipole antenna fed by a coaxial cable. Two gap positions on the loops are set symmetrically with respect to the center of the structure to get circular polarization and a symmetrical radiation pattern as shown in [8]. In [8] without considering the impedance matching the widest axial-ratio bandwidth is obtained by a parallel feed. To the contrary, we did not get good axial ratio (AR) and impedance matching with a parallel feed. Therefore in this paper a series feed case is only investigated to get a wide bandwidth for the AR and impedance. The method of moments (MoM) is used to calculate the antenna characteristics and parameters for the low voltage standing-wave ratio (VSWR) and AR are obtained. The relevant experiment is conducted to validate the calculated characteristics of the proposed antenna.

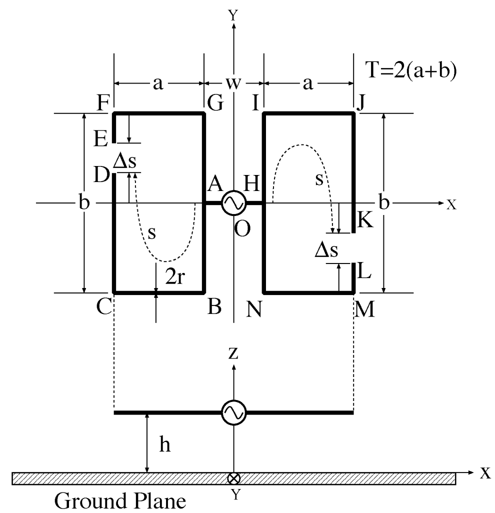

Fig. 1. Two rectangular loops fed in series.

II. Antenna Structure

The antenna model used for calculation and the coordinate system are shown in Fig. 1, where it is assumed that the wire diameter $2r$ is very thin compared with the wavelength λ_0 at center frequency $f_0(= 1.5\text{ GHz})$. The antenna has two rectangular loops with the same size and is at a height of h above an infinite ground plane. The loop surface is parallel to the ground plane. Its side lengths are a and b. The circumference is $T(= 2(a+b))$.

Each rectangle is connected to each end of a short dipole with a length of w. Thus this antenna can be viewed as a rectangle top-loaded short dipole. Each rectangle has a gap with a width of Δs at distance s from the point (A or H) that connects the rectangle to the feed dipole. The two gaps are located symmetrically with respect to the feed point to produce circular polarization. The chosen parameters in this paper are $h = 0.26\lambda_0$ (52 mm), $s = 0.787\lambda_0$ (157.4 mm), $w = 0.05\lambda_0$ (10 mm), $r = 0.005\lambda_0$ (1 mm), $\Delta s = 0.0295\lambda_0$ (5.9 mm), $b = 2a$ and $T = 1.45\lambda_0$ (290 mm). With these parameters the best results for circular polarization and impedance matching are obtained.

Manuscript received June 3, 2002; revised December 23, 2002.

M. Sumi was with the Institute of Information Sciences and Electronics, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan. He is now with NTT DoCoMo, Inc., Tokyo 107-0052, Japan.

K. Hirasawa is with the Institute of Information Sciences and Electronics, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan (e-mail: hirasawa@is.tsukuba.ac.jp).

S. Shi was with the Institute of Information Sciences and Electronics, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan. He is now with KDDI Research & Development Laboratories, Inc., Saitama 356-8502, Japan.

Digital Object Identifier 10.1109/TAP.2004.823876

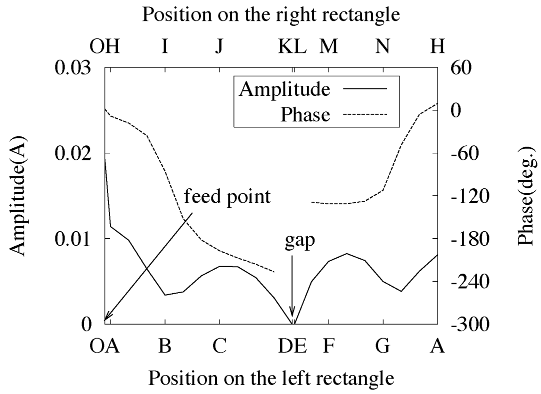

Fig. 2. Current distribution at 1.5 GHz.

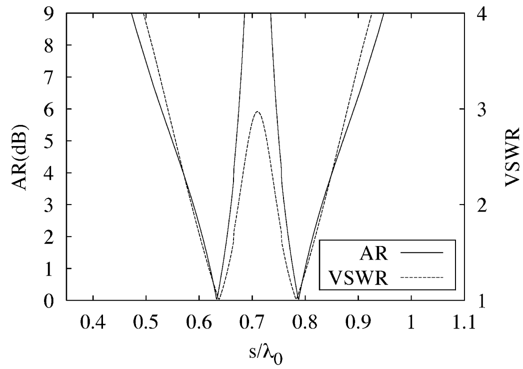

Fig. 3. Effects of the gap position s on AR and VSWR.

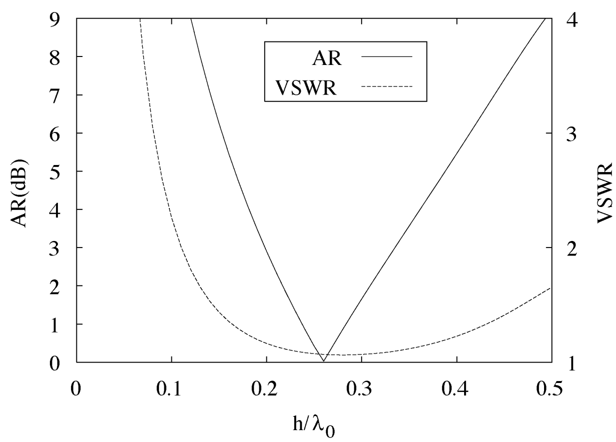

Fig. 4. Effects of the height h on AR and VSWR.

III. Numerical Results

It is assumed that the ground plane is infinite and image theory is used to remove the ground plane. Then characteristics of the real antenna with the image antenna are calculated by using the MoM with piecewise sinusoidal expansion and weighting functions. One of the antenna parameters chosen in Section II is changed at a time and antenna characteristics are calculated to investigate the effects of the particular antenna parameter on the antenna performance.

A. Current Distribution

Fig. 2 shows the current distribution at 1.5 GHz when the parameters in Section II are used. The capital letter above and under the horizontal axis indicates a position on the antenna shown in Fig. 1. The feed voltage at point O is 1 volt and is directed from A–H. The linearly decreasing phase of the current observed on the segments (A-B-C-D and H-I-J-K) shows the existence of a traveling wave and the left-hand elliptically polarized waves are radiated in the z direction from those segments. The AR is 15.0 dB.

The currents on the segments (E-F-G and L-M-N) have almost a constant phase and are standing waves, but the currents on the segments (A-G and H-N) are traveling waves. In total the currents on the segments (A-G-F-E and H-N-M-L) produce right-hand elliptically polarized waves in the z direction $(\mathrm{AR} = 7.3\ \mathrm{dB})$.

The AR in the z direction due to the currents on the loop segments (E-F-G-A-B-C-D and L-M-N-H-I-J-K) is 1.7 dB. In all the AR due to the currents on the loops plus the dipole segment (A-O-H) is 0.03 dB and the antenna produces good left-hand circular polarization in the z direction. Note that the distance between the real and image loop is $2h(= 0.52\lambda_0)$ and the AR in the z direction are the same with or without the image antenna at 1.5 GHz.

B. Parametric Study of AR and VSWR

The antenna characteristics with respect to the antenna parameters are investigated at 1.5 GHz. Fig. 3 shows the AR and VSWR against s/λ_0. The AR and the VSWR strongly depend on the position of the gap. The tendency of the AR is very similar to that of the VSWR. The AR and the VSWR reach their lowest values of 0.03 dB and 1.01, respectively, at $s/\lambda_0 = 0.633$ (right-hand circular polarization) and 0.787 (left-hand circular polarization). Thus, the sense of circular polarization can be controlled easily by choosing one of the two gap positions for good AR in Fig. 3.

Fig. 4 shows the AR and VSWR against h/λ_0. The AR is very sensitive to the height h/λ_0, because the far-fields from the real and image antenna have to be added efficiently in the z direction. The AR reaches the lowest value of 0.03 dB at $h/\lambda_0 = 0.26$. The reason that $2h/\lambda_0$ is slightly different from 0.5 is due to the mutual coupling effects between the real and image antenna. The VSWR reaches the minimum value of 1.06 at $h/\lambda_0 = 0.28$ and does not change with h/λ_0 much compared to the AR, because the mutual coupling effects are not large around $2h/\lambda_0 = 0.5$. The VSWR increases rapidly when h/λ_0 becomes smaller than 0.1 due to the increase of the mutual coupling effects.

Fig. 5 shows the AR and VSWR against w/λ_0. The AR and the VSWR increase as w/λ_0 increases. The AR and the VSWR reach 0.03 dB and 1.06, respectively, at $w/\lambda_0 = 0.05$. The radiation from the dipole segment A-O-H is linearly polarized and smaller radiation from this segment is better for circular polarization. The segments B-G and N-I are close to the feed point O and the mutual coupling between these segments and short dipole (A-H) is large. Therefore the VSWR is sensitive to w.

Fig. 6 shows the AR and the VSWR against a/b. The AR depends on the ratio a/b strongly, because the balance of the radiation from the segments ((A-E and A-D) or (H-L and H-K))

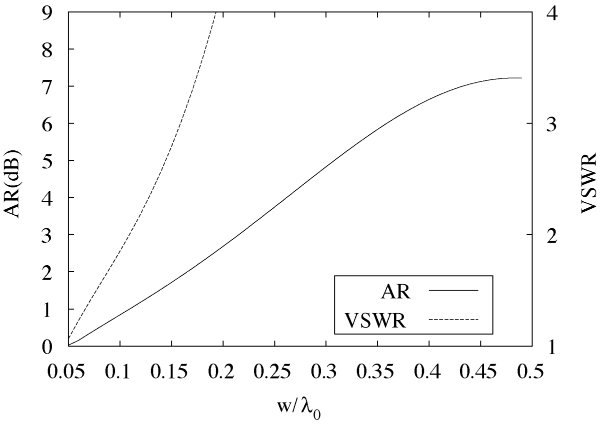

Fig. 5. Effects of the short dipole length w on AR and VSWR.

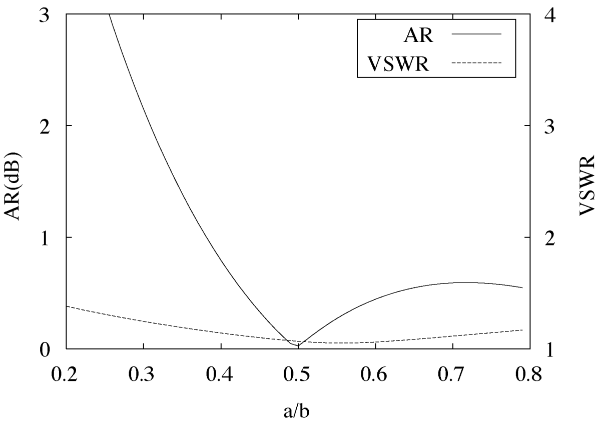

Fig. 6. Effects of the side length ratio a/b on AR and VSWR.

is important for good circular polarization. The VSWR changes slowly as the ratio a/b increases, because the VSWR is usually sensitive to the circumference (T) which is kept constant here. The side length ratio $a/b = 0.5$ is chosen to make a compromise between the AR and VSWR as shown in Section II.

IV. Comparison Between Calculated and Measured Results

To ensure the validity of the numerical results, the input impedance, VSWR, AR and radiation patterns are compared with the experimental results. In the experiment segments AO and HO are connected to the outer and the inner conductor of a semi-rigid cable through the ground plane (0.6 m × 0.6 m). Although in the calculation the effects of the semi-rigid cable are not included, we have found that the effects of the feed cable on the AR and VSWR is not so large from the comparison between the calculated and measured data.

The antenna parameters used for calculation and measurement are as shown in Section II. Fig. 7 shows the frequency characteristics of the input impedance and $R_{\text{in}} = 53.4\Omega$ and $X_{\text{in}} = -0.3\Omega$ are obtained at 1.5 GHz. Also Fig. 7 shows the frequency characteristics of the VSWR that reaches 1.07 at 1.5 GHz. The VSWR bandwidth (≤ 2) is about 22%. Fig. 8 shows the frequency characteristics of the AR that reaches the minimum value, 0.03 dB at 1.5 GHz. The AR bandwidth (≤ 3 dB) is about 18%.

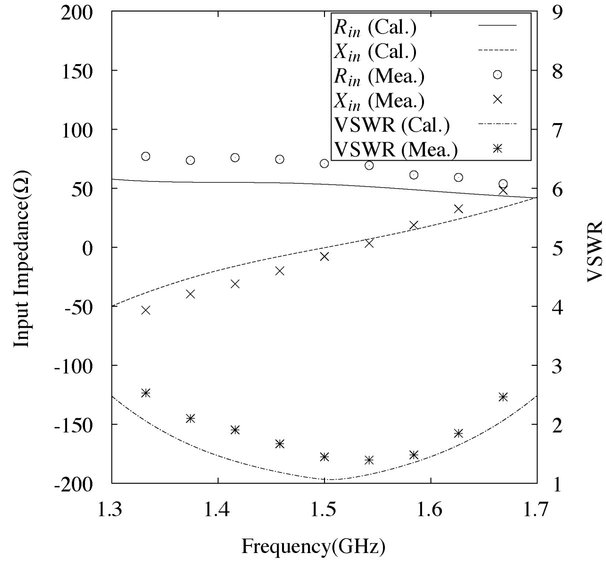

Fig. 7. Frequency characteristics of input impedance and VSWR.

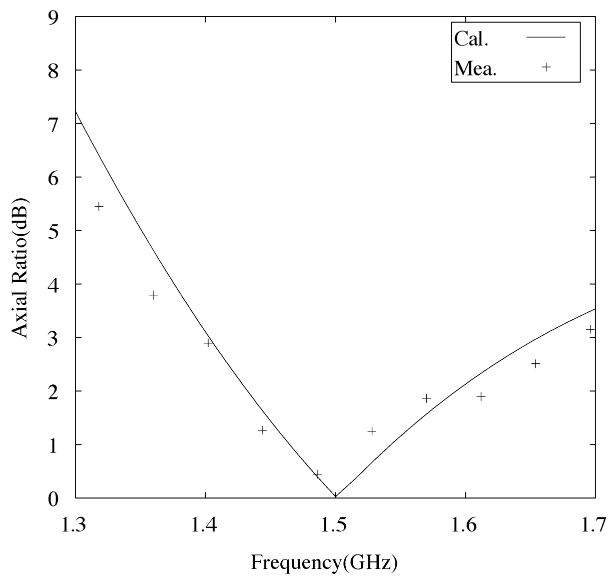

Fig. 8. Frequency characteristics of AR.

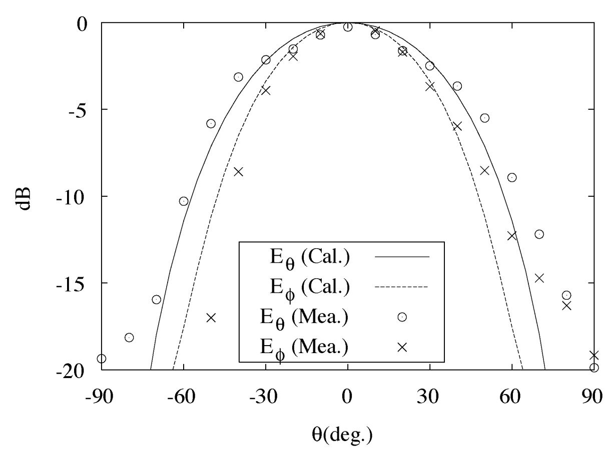

Fig. 9. *YZ* plane radiation patterns at 1.5 GHz.

Fig. 9 shows the YZ plane radiation pattern at 1.5 GHz. The pattern maximum is obtained in the zenith where the calculated gain is 9.75 dBi. The XZ plane radiation patterns are very similar to those in Fig. 9 except the exchange of E_θ and E_ϕ, and are not shown here.

Measured and numerical results are compared in Figs. 7–9. In Fig. 9 there is a little difference between the calculated and measured radiation patterns in the horizontal directions, because the finite-sized ground plane is used for the measurement. Except this, measured and numerical results are in good agreement.

V. Conclusion

Two rectangular wire loops fed in series have been introduced for broadband circular polarization and impedance matching. Their characteristics with the various antenna parameters are investigated numerically and experimentally. An AR bandwidth ($\leq$3 dB) of 18% and a VSWR bandwidth ($\leq$2) of 22% are obtained. From the calculation we have found that the position of the two gaps on the rectangles and the length of the short dipole are sensitive to the AR and VSWR.

References

[1] E. E. Altshuler, "A monopole loaded with a loop antenna," *IEEE Trans. Antennas Propagat.*, vol. 44, pp. 787–791, June 1996.

[2] Y. X. Guo, C. L. Mak, K. M. Luk, and K. F. Lee, "Analysis and design of L-probe proximity fed-patch antennas," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 145–149, Feb. 2001.

[3] Z. N. Chen and M. Y. W. Chia, "Design of broadband probe-fed plate antenna with stub," *Proc. Inst. Elect. Eng.-Microw. Antennas Propag.*, vol. 148, pp. 221–226, Aug. 2001.

[4] D. Roscoe and L. Shafai, "Circularly polarized traveling-wave printed line antennas," *Electron. Lett.*, vol. 25, pp. 1407–1408, Sept. 1989.

[5] A. G. Roederer, "The cross antenna: A new low-profile circularly polarized radiator," *IEEE Trans. Antennas Propagat.*, vol. 38, pp. 704–710, May 1990.

[6] W. S. Chen, C. K. Wu, and K. L. Wong, "Square-ring microstrip antenna with a cross strip for compact circular polarization operation," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1566–1568, Oct. 1999.

[7] X. M. Qing and M. Y. W. Chia, "Broadband circularly polarized slot loop antenna fed by three-step hybrid coupler," *Electron. Lett.*, vol. 35, pp. 1210–1211, July 1999.

[8] H. Morishita, K. Hirasawa, and T. Nagao, "Circularly polarized wire antenna with a dual rhombic loop," *Proc. Inst. Elect. Eng.-Microw. Antennas Propag.*, vol. 145, pp. 219–224, June 1998.

Makoto Sumi received the B.S. degree in electrical engineering from Meiji University, Meiji, Japan, in 1999 and the M.S. degree in electrical engineering from the University of Tsukuba, Tsukuba, Japan, in 2001.

Since 2001, he has been with the Wireless Link Development Department, NTT DoCoMo, Inc.

His research interests are propagation modeling, low-profile antennas and circularly polarized antennas for mobile communications.

Kazuhiro Hirasawa (S'69–M'70–SM'03) received the Ph.D. degree in electrical engineering from Syracuse University, Syracuse, NY, in 1971.

From 1967 to 1975, he was with the Department of Electrical Engineering, Syracuse University. From 1975 to 1977, he was a Consultant on the research and development of various antennas. Since 1978, he has been with the University of Tsukuba, Tsukuba, Japan, where he is currently a Professor in the Institute of Information Sciences and Electronics. He is coauthor of *Small Antennas* (Letchworth, U.K.: Research Studies Press, 1987), *Analysis, Design and Measurement of Small and Low-Profile Antennas* (Norwood, MA: Artech House, 1991), and *Small and Planar Antennas* (Tokyo, Japan: IEICE, 1996). His research interests include mobile antennas, circularly polarized antennas, and smart antennas.

Dr. Hirasawa is a Member of the Institute of Electronics, Information, and Communication Engineers (IEICE), Japan.

Song Shi was born in Mudanjiang, China. He received the B.S. and M.S. degrees in physics from Jilin University, Changchun, China, 1984 and 1987, respectively, and the Ph.D. degree in electrical engineering from the University of Tsukuba, Tsukuba, Japan, in 2000.

From 1987 to 1992, he was with the China Computer Software and Technology Service Corporation (CS&S), where he became a Software Engineer in 1990. From 1993 to 1994, he was a System Engineer at Unix System Technology Corporation (USTC). From 1994 to 1995, he was with The Beijing Representative Office, The Santa Cruz Operation, Inc. From 1995 to 2000, he was with the Institute of Information Sciences and Electronics, University of Tsukuba. From 2000 to 2001, he was a Senior Researcher at the Kyocera DDI Institute of Future Telecommunications, Inc., Japan. Since 2001, he has been with the KDDI Research & Development Laboratories, Inc., Saitama, Japan, as a Research Engineer. His research interests include mobile communications, smart antennas, and circularly polarized antennas.

Dr. Shi is a Member of the Institute of Electrical, Information and Communication Engineers (IEICE), Japan.