A Back-to-Back Rectangular-Patch Antenna Fed by a CPW

Hisao Iwasaki, *Member, IEEE*

***Abstract*— The configuration of a back-to-back rectangular-patch antenna fed by a coplanar waveguide (CPW) is proposed. The characteristics of the proposed antenna element were clarified by experiments. The radiation patterns and input impedances were measured as parameters of the widths of the rectangular patch and the substrate. The experimental results for an array antenna using the proposed back-to-back rectangular-patch antenna element are described. Good omnidirectional radiation patterns and input impedance characteristics were obtained. The proposed array antenna is suitable for microcellular, wireless LAN, and indoor radio systems.**

***Index Terms*—Microstrip antennas.**

I. Introduction

An antenna having an omnidirectional pattern in a horizontal plane and a beam-tilt directivity in a vertical plane is required in mobile communication, indoor radio, and wireless LAN systems. Many types of antennas have been proposed and developed for such systems. For example, a collinear array antenna constructed from coaxial elements such as sleeve dipoles [1] or patch-array antenna using parasitic cylinders [2] and dipole arrays [3] are employed as antennas with omnidirectional and beam-tilt radiation patterns. However, these antennas are large-sized arrays with complex structures and high production costs. In addition, the direction of the main beam is squinted with frequency and unwanted radiation may occur from the feed line, both of which reduce the antenna gain.

Another method for obtaining an omnidirectional radiation pattern is to decrease the width of ground plane of a microstrip antenna [4]. This type of antenna is very simple, but cannot produce an omnidirectional pattern in the horizontal plane. In addition, the relationship between the width of the ground plane and the radiation pattern and the input impedance is not clear.

Therefore, it is necessary to develop an antenna technology, which permits the construction of a simple, small-size, and low-cost antenna element or an array antenna that provides an omnidirectional radiation pattern in the horizontal plane and a beam-tilt directivity pattern in the vertical plane.

The purpose of this paper is to propose a novel back-to-back rectangular-patch antenna configuration with an omnidirectional radiation pattern in the horizontal plane and to develop an array antenna that satisfies the previously mentioned requirements using the proposed antenna as a base station.

Manuscript received September 17, 1996; revised March 6, 1997.

The author is with the Communication and Information Systems Research Laboratories, Toshiba Research and Development Center, 1, Komukai, Toshiba-cho, Saiwai-ku, 210, Japan.

Publisher Item Identifier S 0018-926X(98)07501-2.

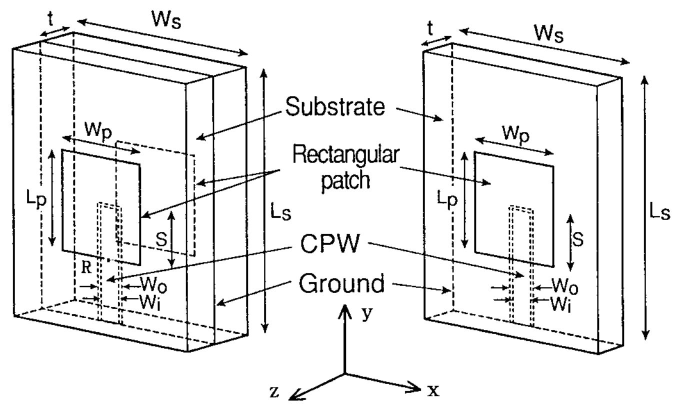


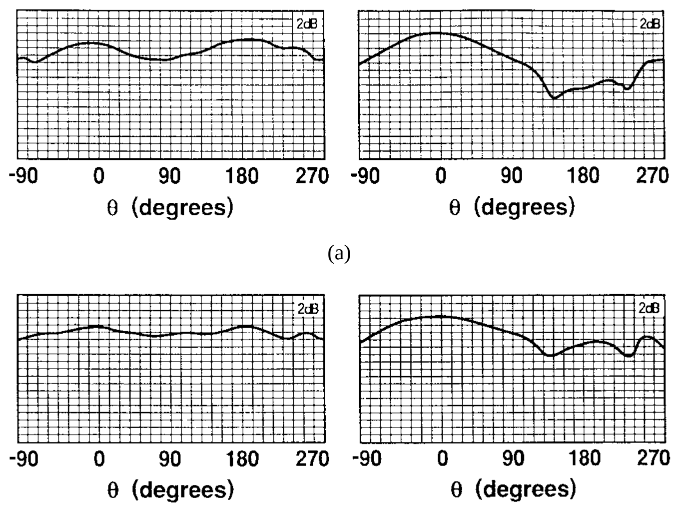
Fig. 1. Configurations of the back-to-back rectangular patch and the conventional single rectangular patch.

First, the configuration of a single back-to-back rectangular-patch antenna element fed by a coplanar waveguide (CPW) is proposed. The characteristics of the proposed antenna element, which were clarified by experiments, are described. The radiation patterns and input impedances were measured as parameters of the widths of the rectangular-patch antenna and the substrate. In addition, the experimental results for an array antenna using the proposed antenna element are also described. Good omnidirectional radiation patterns and input impedance characteristics were obtained.

II. Antenna Element

A. Configuration

Fig. 1 shows the proposed back-to-back rectangular-patch antenna fed by the CPW and the conventional single-patch antenna [5]. In the proposed antenna, two rectangular patches are used and each rectangular patch is arranged back-to-back relative to the CPW on the ground plane. This is feature of the proposed antenna compared with a conventional single-patch antenna. It is expected that the proposed antenna can easily obtain an omnidirectional pattern in the horizontal plane because the two rectangular patches radiate in opposite directions along to the z axis and the radiated power from the two rectangular patches is added in perpendicular direction along to the x axis.



(b)

Fig. 2. The measured radiation patterns of the back-to-back and the single rectangular-patch antennas. (a) $W_s = 70$ mm, $W_p = 47.3$ mm, $f = 1.89$ GHz and (b) $W_s = 50$ mm, $W_p = 47.3$ mm, $f = 1.87$ GHz.

The rectangular patches are fabricated on a substrate with a dielectric constant ϵr and thickness t. The length and width of the substrate are L's and W's, respectively. The length of the rectangular-patch antenna is L_p and the width is W_p. The rectangular patches are arranged back-to-back, sandwiching the CPW on the ground plane. The characteristic impedance of the CPW is 50 Ω, the outer and inner widths of the CPW are W_o and W_i, respectively. S is the distance between the lower edge of the rectangular patch and the end edge of the CPW.

B. Experimental Results

To clarify the characteristics of the proposed back-to-back rectangular-patch antenna, radiation patterns, and input impedances were measured as parameters of the width of the rectangular patch and the width of the substrate, because the radiation pattern depends heavily on the widths of the rectangular patch and substrate.

Experimental models were fabricated on a substrate with $\epsilon r = 2.6$ and $t = 1.6$ mm. The length L_p and width W_p of the rectangular patch were determined at a resonance frequency of 1.9 GHz by using the simple cavity method [6]. Therefore, L_p is 47.3 mm and the length of the substrate L_p is 150 mm. The widths of the CPW are $W_o = 4.9$ mm and $W_i = 4.5$ mm, which corresponds to the characteristics impedance of 50 Ω.

Fig. 2 shows the measured radiation patterns of the proposed back-to-back rectangular-patch antenna and the conventional single-patch antenna in the H-plane. Fig. 2(a) shows the radiation patterns for $W_s = 70$ mm and $W_p = 47.3$ mm. A radiation pattern with 6-dB gain variation was obtained in the proposed antenna. On the other hand, the radiation pattern with the 21-dB difference between the maximum and minimum levels was obtained in the conventional single-patch antenna. Fig. 2(b) shows the radiation patterns for $W_s = 50$ mm and $W_p = 47.3$ mm. W_s is almost the same as W_p. The gain variation of the proposed antenna was deduced within 3 dB in the horizontal plane at the resonance frequency of 1.9 GHz. Compared with the conventional single-patch antenna, it is clear that the proposed rectangular-patch antenna has a more omnidirectional pattern in the horizontal plane.

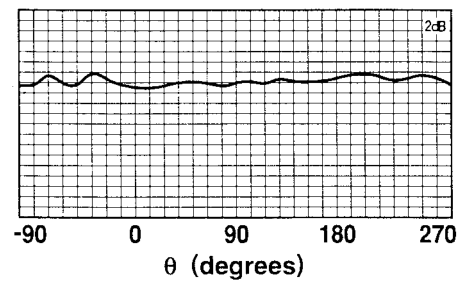


Fig. 3. The measured radiation pattern of the back-to-back narrow-width rectangular-patch antenna with $W_s = W_p = 20$ mm, $f = 1.91$ GHz.

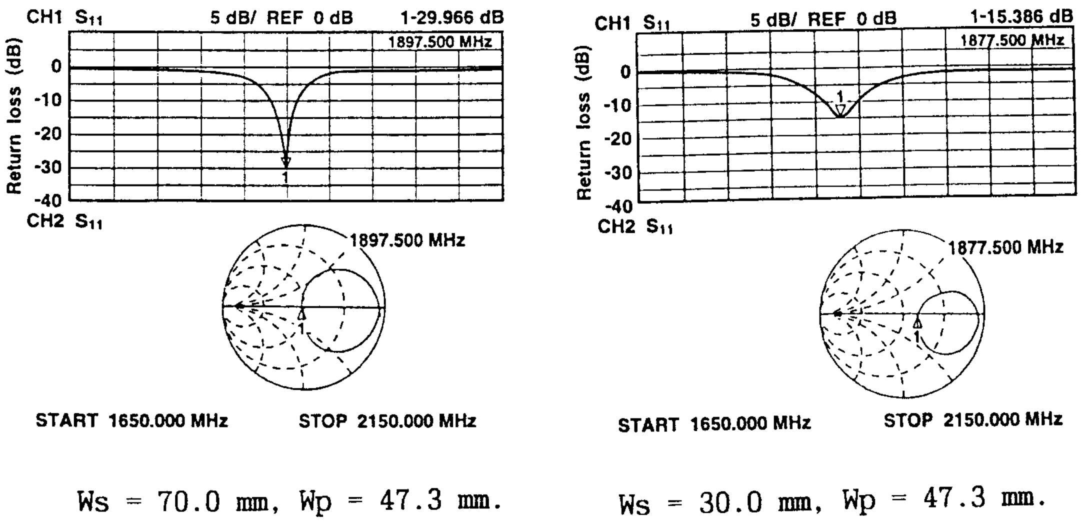
TABLE I
SUMMARIZED EXPERIMENTAL RESULTS

Wp \ Ws	20	25	50	70 (mm)
47	(Resonant	Freq.)	1.87G	1.89G
	(Input R	esistance)	36.0Ω	56.7Ω
30			1.89G	1.91G
			58.9Ω	90.5Ω
25		1.89G	1.90G	1.92G
		63.6Ω	78.8Ω	112.1Ω
20 (mm)	1.91G	1.92G	1.94G	1.95G
	73.9Ω	97.8Ω	148.8Ω	182.5Ω

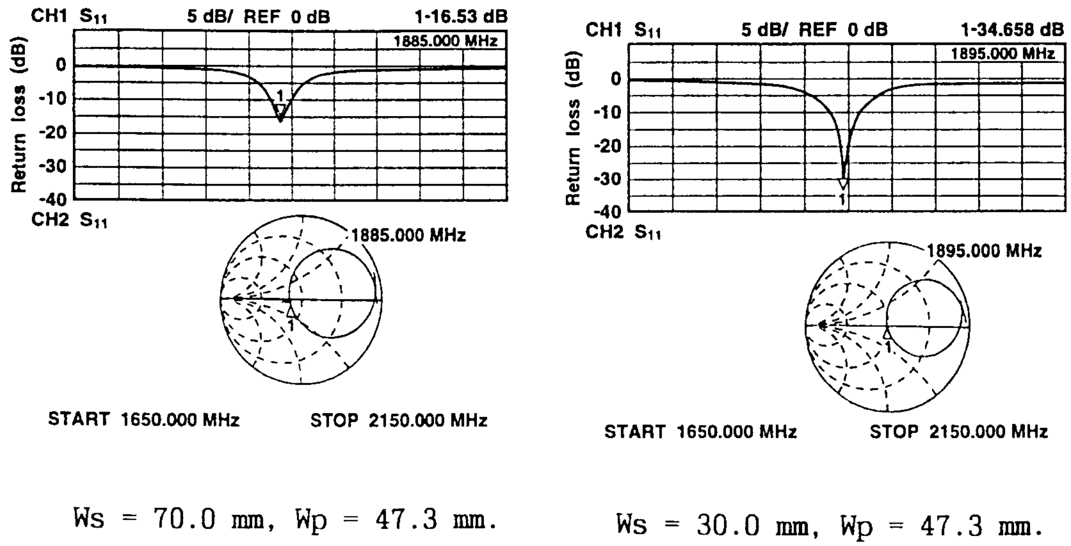
Fig. 3 shows the H-plane radiation pattern of the proposed back-to-back narrow-width rectangular-patch antenna with $W_s = 20$ mm, $W_p = 20$ mm, and $L_p = 47.3$ mm. The gain variation was reduced to within 1.5 dB at a frequency of 1.91 GHz.

These experimental results indicate that an omnidirectional pattern can be obtained by using the proposed antenna element configuration and decreasing the widths of the substrate and the rectangular patch.

Table I summarizes the measured input impedances and resonance frequencies as parameters of the width W_s of the substrate and the width W_p of the rectangular patch. The upper figure is the resonance frequency and the lower figure is the input resistance. The input impedance reference point is the lower end edge of the rectangular patch and is marked as "R" in Fig. 1. From this table, the following results are clear: By decreasing the W_p/W_s ratio, the resonance frequency and the input resistance increased, respectively. In general, the equivalent length of the rectangular patch is greater than L_p due to the fringing effects [6], but it can be decreased by decreasing the width W_p. The resonance frequency thus increases when the width of the rectangular patch W_p decreases, and the input resistance of the rectangular patch varies inversely with W_p [6]. Therefore, the experimental results were agreed very well with the theoretical considerations outlined above.



(a)



(b)

Fig. 4. The measured input impedance of the back-to-back and the single-rectangular-patch antennas. (a) Back-to-back rectangular-patch antenna and (b) single-rectangular-patch antenna.

Fig. 4 shows the measured input impedances of the proposed back-to-back rectangular-patch antenna and the conventional single rectangular-patch antenna as shown in Fig. 1. From these results, it is clear that the 2 : 1 VSWR bandwidth is about 1.7% in both patch antennas and these bandwidths are almost the same as that of a conventional patch antenna fed by coaxial pins. Furthermore, the input resistance of the proposed back-to back rectangular-patch antenna is lower than that of a conventional single rectangular-patch antenna.

III. Array Antenna

A. Configuration

Fig. 5 shows the four-element linear array antenna that uses the proposed back-to-back narrow-width rectangular-patch antenna. Each back-to-back rectangular patch is series-fed by a CPW with a characteristic impedance of 50 Ω. This array antenna has a two-layered configuration, making it easy to fabricate an array antenna due to its simple structure. Here d is the element spacing and g is the distance between the CPW lines.

The experimental model was fabricated on a substrate with $\epsilon r = 2.6$ and $t = 1.6$ mm. The width of the back-to-back rectangular patch W_p and the width of the substrate W_s were both 20 mm, and the length of the patch L_p was 47.3 mm. The length of the substrate was $L_s = 400$ mm. The element spacing d was 100 mm, which corresponded to 1 λg by using the CPW line. Each element was thus fed by almost same phase. Power division between the back-to-back rectangular patch and the CPW line was mainly determined by the distance g between the CPW lines [7]. The value of g was 5 mm in this experiment. The amplitude distributions of each element shown in Fig. 5 were #1 = 0.3, #2 = 0.2, #3 = 0.15, and #4 = 0.35.

B. Experimental Results

Fig. 6 shows the measured radiation pattern at 1.91 GHz in the H-plane ($\phi = 0°$ plane). The gain variation is within 1 dB.

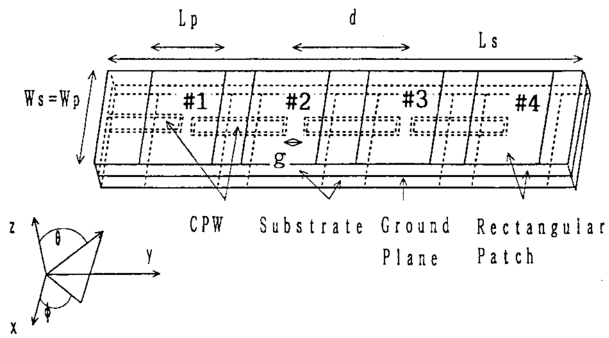


Fig. 5. The four element linear array antenna using the back-to-back rectangular-patch antenna.

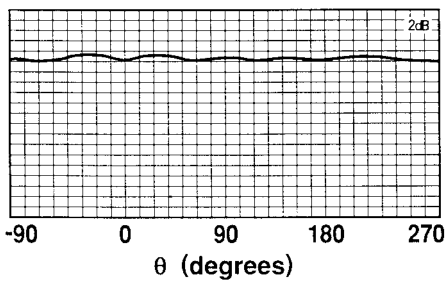


Fig. 6. The measured radiation pattern of the array antenna in a H-plane. $f = 1.91$ GHz.

A good omnidirectional pattern was thus obtained in the array antenna as well as in each antenna element. Fig. 7 shows the E-plane ($\phi = 90°$ plane) pattern. In Fig. 7(a), the maximum direction is the $\theta = 0°$ plane, which is the horizontal plane. The 3-dB beamwidth is 18°.

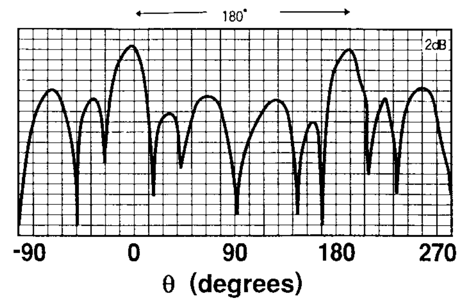
The second sidelobe is -8 dB. This level is relatively high and reduction of the sidelobe level is necessary for microcellular or wireless LAN applications.

In addition, a beam tilt in the vertical plane is necessary for the reduction of interference between cells. In order to achieve this, nonuniform phase illumination is required. Fig. 7(b) shows the measured radiation pattern with the element spacing $d = 110$ mm. A beam tilt of 6° was realized by increasing the length of the CPW line relative to the case of Fig. 7(a). The calculated beam tilt angle was 8°. The experimental result was almost agreed the calculated result.

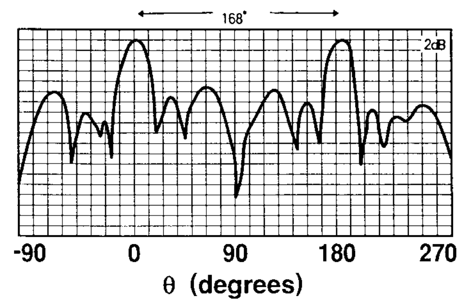
The measured gain was about 6 dBi at 1.91 GHz for both cases.

IV. Conclusion

This paper has described the experimental results for the proposed back-to-back rectangular narrow-width patch antenna element fed by the CPW and for the array antenna consisting of the proposed back-to-back rectangular-patch antenna element fed by CPW lines to obtain an omnidirectional pattern in the horizontal plane. Using this array antenna configuration, a gain variation of less than 1 dB in the horizontal plane and a beam tilt of 6° were achieved. Also, a gain of 6 dBi was obtained. This array antenna meets the requirements for a simple, small-size, and low-cost antenna for base stations. The proposed antenna is suitable for microcelluar, wireless LAN, and indoor radio systems.



(a)



(b)

Fig. 7. The measured radiation pattern of the array antenna in a E-plane. $f = 1.91$ GHz: (a) $d = 100$ mm and (b) $d = 110$ mm.

References

[1] T. J. Judasz and B. B. Balaley, “Improved theoretical and experimental models for the coaxial collinear antenna,” *IEEE Trans. Antennas Propagat.*, vol. 37, pp. 289–296, Mar. 1989.

[2] M. Karikomo, T. Matsuoka, and L. W. Chen, “An omnidirectional broad band microstrip antenna using a parasitic cylinder,” *IEICE Trans. Communicat.*, vol. E76-B, no. 12, pp. 1514–1517, Dec. 1993.

[3] K. Ogawa and T. Uwano, “A variable tilted fan beam antenna for indoor base stations,” in *IEEE Int. Symp. Dig. Antennas Propagat.*, June 1994, pp. 332–335.

[4] M. Sand, “Microstrip antennas on very small ground planes for portable communication systems,” in *IEEE Int. Symp. Dig. Antennas Propagat.*, June 1994, pp. 810–813.

[5] S. Deng, M. Wu, and P. Hau, “Analysis of coplanar waveguide-fed microstrip antenna,” *IEEE Trans. Antennas Propagat.*, vol. 43, pp. 734–737, July 1995.

[6] J. Bahl and P. Bhartia, *Microstrip Antennas*. Norwood, MA: Artech House, 1980, pp. 86–90.

[7] H. Iwasaki, “A microstrip array antenna with omnidirectional pattern fed by CPW,” in *IEEE Int. Symp. Dig. Antennas Propagat.*, July 1996, pp. 1912–1915.

Hisao Iwasaki (M’86) received the B.S. and D.E. degrees in electrical engineering from Tohoku University, Sendai, Japan, in 1975 and 1994, respectively.

In 1975, he joined the Toshiba Research and Development Center, Kawasaki, Japan, where he did research on antennas for communications. In 1986, he joined ATR Optical and Radio Communications Research Laboratories, Kyoto, Japan, where he was engaged in research on active array antennas. From 1989 to 1997, he worked at the Communication and Information Systems Research Labs, Toshiba Research and Development Center, Kawasaki, Japan, where he was a Senior Research Scientist and has been engaged in the development of the microstrip antennas for communications. He is currently a Senior Research Scientist at Wireless Communication Technology Center Toshiba Information and Communication Technology Systems Laboratories, Hino, Japan, where he has been engaged in the development of the microstrip antennas for communications and the antennas for handsets.

Dr. Iwasaki received the Young Engineers Award from IEICE Japan in 1985.