Reduction in Mutual Coupling of Separated Tx/Rx ACPA Comprising Trapezoidal Elements

Huiling Jiang [1], Ryo Yamaguchi [1], Keizo Cho [1]

[1] Research Laboratories, NTT DoCoMo, Inc.

3-5, Hikarino-oka, Yokosuka-shi, Kanagawa 239-8536, Japan, jiang@nttdocomo.co.jp

1. Introduction

At the World Radiocommunication Conference 2007 meeting (WRC-07) [1], it was decided that the 3GHz frequency band will be used for IMT. This follows the trend to use the microwave band for mobile communication systems. Broadband transmission and the use of high frequency bands make covering a service area difficult due to propagation loss, feeding loss, etc. To address this, the feeding loss must be decreased and sufficient power must be ensured. An RF integrated antenna configuration is considered to be a useful configuration for base station antennas used in microwave bands [2]. However, a duplexer must be established between the antennas and RF circuit. For this configuration, a trade off between the size of the inner duplexer and the loss is an issue. In this study, we assume that the transmission (Tx) antennas are separately arranged from the receiver (Rx) antennas, and a filtering function is added to the antenna elements. The purpose of this configuration is to eliminate or miniaturize duplexers, which represent a large component in the antenna radome.

This study investigates an antenna configuration that integrates a filter function to suppress the coupling signal from the Tx to Rx antenna, which is important in the base station antenna equipment. An aperture coupled patch antenna with multiple rectangular elements has been proposed [7], but the trade off between Rx antenna's wideband resonance and less number of rectangular elements is required. In this paper, we propose an aperture coupled patch antenna with multiple trapezoidal elements installed on the substrate of the Rx antenna between the radiation and feed layers in order to decrease the mutual coupling. The mutual coupling can be reduced greatly by maintaining wideband resonance and retaining the current exterior size of the Rx antenna. This paper is organized as follows. First, we show the structure of an aperture coupled patch antenna (ACPA) that comprises multiple trapezoidal elements. Then the effect of reducing the mutual in the proposed structure is shown. Next, we investigate the far field radiation pattern of the proposed antenna. Finally, the fractional bandwidth of the Rx antenna and the S_{21} characteristics due to the shape and width of the trapezoidal elements are presented.

2. ACPA with Trapezoidal Elements

S Parameter Characteristics

Fig. 1(a) shows two separated ACPAs installed distance d from each other. In this study, we assume a Frequency Division Duplex (FDD) system that employs a lower frequency band for the uplink and a higher frequency band for the downlink. The receiver antenna port is port #1 and the transmitter antenna port is port #2. The central frequency ratios of the Tx and Rx antennas are $f^c_{Tx} : f^c_{Rx} = 1.3 : 1.0$. The distance between the Rx and Tx antennas is $0.5\lambda^c_{Tx}$, and is approximately $0.39\lambda^c_{Rx}$. The array distance (distance between two Tx antennas) is less than $1.0\lambda^c_{Tx}$. Electromagnetic coupling through the bow tie slot [3], which is installed between the feeding layer and radiation layer, causes each antenna to resonate. Fixed parameters for the Rx and Tx antennas are given in Table 1.

Fig. 1(b) and 1(c) show the top view of the ACPA structure with conventional rectangular elements and that with the proposed trapezoidal elements, respectively. Fig. 1(c) shows the enlarged view of the trapezoidal elements. Above the bow tie slot of the Rx antenna, two trapezoidal elements are installed instead of two rectangular elements as shown in Fig. 1(b) for the conventional model. The trapezoidal element with length L_0 is installed centered above the electromagnetic coupling bow tie slot. The second trapezoidal element with length L_1 ($L_1 = 1.1 \times L_0$) is installed at distance d_{sub} from the first element. The trapezoidal elements are installed in opposing directions. The width of the trapezoidal elements are W_1 and W_2, the ratio of these two parameters is defined as $T_{ratio} = W_2/W_1$. In the same way as the conventional model, the upper patch (*Patch*#2) is installed on the underside of Substrate #3. Other parameters and the dielectric constant are the same as those for the conventional model (Table 1). The 3D electromagnetic field analysis simulator, CST MW-Studio 2006B [4], is used in this study. The Berenger′s PML (6 layers) absorbing boundary condition [5] is adopted.

Fig. 2 shows the S parameter characteristics of the conventional and the proposed ACPA structures. The horizontal axis indicates the fractional frequency normalized by the minimum downlink frequency (indicated as f_0 in this paper). The vertical axis indicates the S parameter characteristics. Mutual coupling (S_{21}) in the downlink frequency band (Tx band) is observed. The target of this study is to decrease the mutual coupling of the S_{21} characteristics to approximately -30 dB. At the same time, the fractional bandwidth @ VSWR $\leqq$ 1.5 of the Rx and Tx antennas should be kept at higher than 20% and higher than 10%, respectively. Furthermore, the external size of the antennas should be maintained.

Fig. 2 shows that precipitous S_{11} characteristics in the higher Rx band and S_{21} characteristics in the lower Tx band are achieved. The S_{11} characteristics in the Tx band are suppressed to less than -1.2 dB. The worst mutual coupling of the S_{21} characteristics is suppressed from -29.8 dB to -33.0 dB. Furthermore, the minimum S_{21} value in the Tx band reaches -41 dB. On the other hand, the fractional bandwidth of the Rx antenna can be improved from 15.9% to 20.2%. If we use the conventional ACPA with rectangular elements, three rectangular elements are required to achieve a 20% bandwidth. The proposed structure can obtain broadband resonance and a decrease in the number of elements. In addition, the locus of the S_{21} characteristics is similar to that for a low pass filter (LPF). A trap frequency ($0.99 f_0$ in Fig. 2(b)) is observed. The length of the second rectangular element, L_1, is approximately $0.58\lambda_r$. Term λ_r indicates the guide wavelength ($\epsilon_r = 3.3$). The trapezoidal elements resonate at approximately half a wavelength.

Far Field Radiation Patterns

Fig. 3 shows a comparison between the Z-X plane radiation patterns of the ACPA with and without the trapezoidal element structure. The observation frequencies are $0.87 f_0$ and $0.92 f_0$, respectively. The figure shows that the far field radiation patterns are in good agreement between the two antenna structures. Table 2 shows a comparison of the gain, radiation efficiency, half power beamwidth (HPBW), and cross polarization value in the Z-X plane between the two antennas. The far field radiation pattern does not change greatly due to the proposed trapezoidal elements.

Fractional Bandwidth and Maximum S_{21} Characteristics Due to T_{ratio} and W_1

Fig. 2 shows that the proposed trapezoidal elements improve the fractional bandwidth of the Rx antenna and the maximum mutual coupling between the Tx and Rx antennas. This section investigates these two characteristics as functions of T_{ratio} *and* W_1. Fig. 4 shows the fractional bandwidth and the maximum S_{21} value when T_{ratio} and W_1 are changed. $T_{ratio} = 1.0$ represents an ACPA with two rectangular elements. From the distribution shown in Fig. 4, we find that the structures with trapezoidal elements improve the fractional bandwidth of the Rx antenna compared to when rectangular elements are employed. At the same time, the mutual coupling between the Tx antenna and Rx antenna is reduced.

3. Conclusion

In this paper, we proposed a broadband ACPA that integrates a filter function. By installing two trapezoidal elements in the Rx antenna, the mutual coupling between the Tx and Rx antennas is reduced from -29.8 dB to -33.0 dB (min. -41 dB). At the same time, the fractional bandwidth of the Rx antenna is improved from 15.9% to 20.2%. The external size and far field radiation characteristics are maintained after adding the filter function. By investigating the fractional bandwidth of the Rx antenna and maximum S_{21} value in the Tx frequency band due to T_{ratio}, we found that the broadband resonance can be obtained by using the trapezoidal elements.

References

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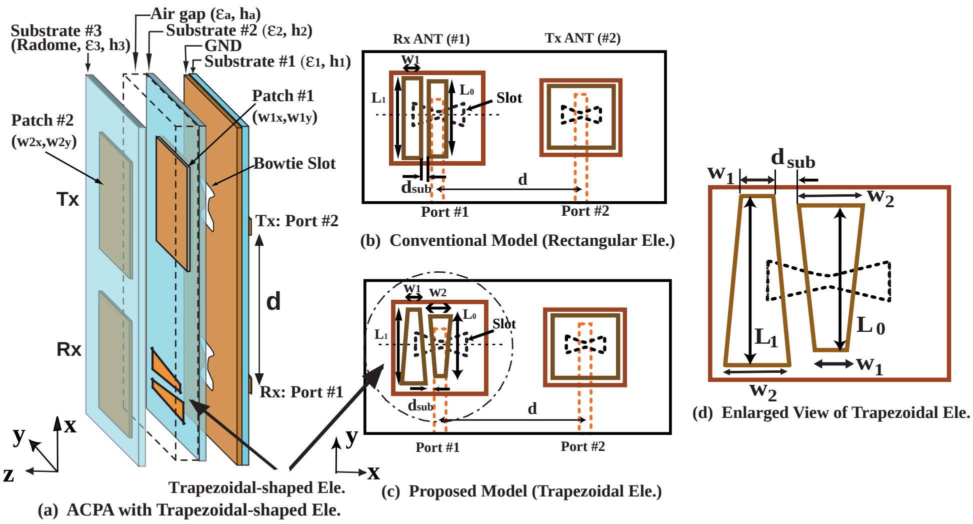
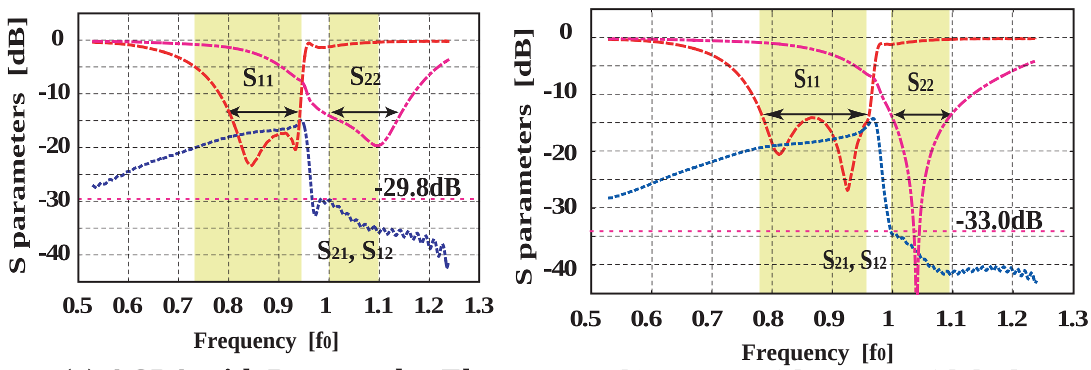


Figure 1: Aperture Coupled Planner Antenna with Trapezoidal Patches

Table 1: Fixed Parameters of Rx and Tx Antennas in Simulation (Unit of Length: $[\lambda_0]$)

	Rx Antenna	Tx Antenna
Feed line	$W_f = 0.04$	$W_f = 0.04$
Substrate #1	$\epsilon_1 = 3.3, h_1 = 0.01$	
Substrate #2	$\epsilon_2 = 3.3, h_2 = 0.03$	
Trapezoidal elements/Patch #1	$W_1 = 0.056, L_0 = 0.29$	$W_{1x} = W_{1y} = 0.19$
Air gap	$\epsilon_a = 1.0, h_a = 0.10$	
Patch #2	$W_{2x} = W_{2y} = 0.33$	$W_{2x} = W_{2y} = 0.20$
Substrate #3	$\epsilon_3 = 3.3, h_3 = 0.03$	
Bowtie slot	$W_a = 0.15, L_a = 0.02,$ $L_h = 0.05, L_s = 0.13$	$W_a = 0.15, L_a = 0.02,$ $L_h = 0.05, L_s = 0.13$



(a) ACPA with Rectangular Ele. (b) ACPA with Trapezoidal Ele.

Figure 2: S Parameter Characteristics of ACPA with Rectangular and Trapezoidal Elements(d_{sub} = $0.047\lambda_0, w_1 = 0.056\lambda_0$)

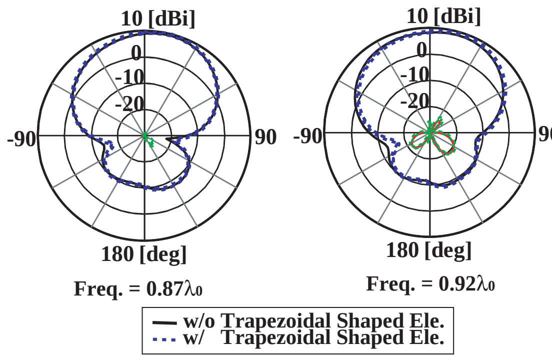
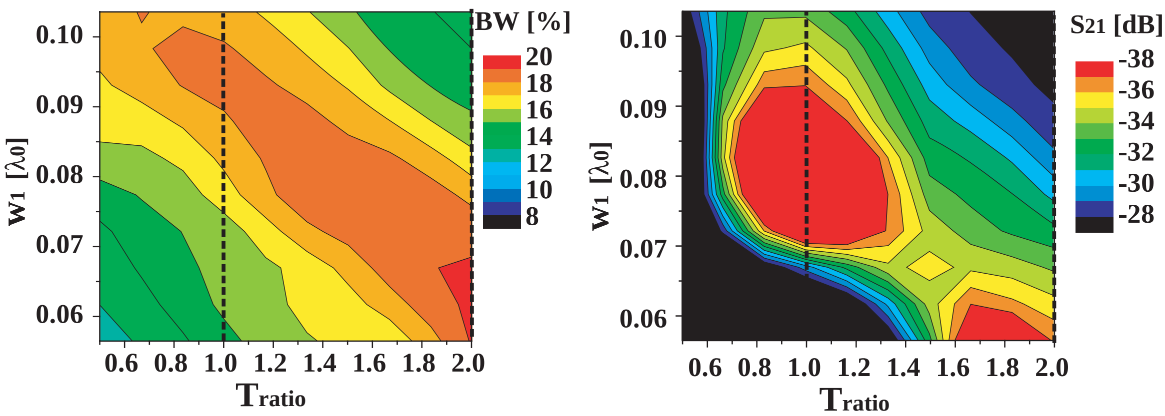


Figure 3: Far Field Radiation Patterns of ACPA With and Without 2 Trapezoidal Elements(d_{sub} = $0.047\lambda_0, w_1$ = $0.056\lambda_0, T_{ratio} = 2$)

Table 2: Comparison of Far Field Radiation Pattern Between ACPA With and Without 2 Trapezoidal Elements (Freq.=$0.87 f_0$)

	Without Trapezoidal Ele.	With Trapezoidal Ele.
Gain $[dBi]$	9.2	9.3
Rad. Effic. $[\%]$	93.3	95.5
HPBW $[deg]$	70.1	72
FB Ratio $[dB]$	-16.8	-17.4
Cross Pol. $[dB]$	-38.4	-34.3



(a) Fractional bandwidth characteristics (b) Maximum S21 value in Tx frequency band

Figure 4: Fractional Bandwidth and Maximum S_{21} Value at Tx Frequency Band Due to T_{ratio} and W_1 ($d_{sub} = 0.028\lambda_0$)