

# Novel Broadband Aperture-Coupled Patch Antenna Using Bow-Tie Shaped Slot

# Huiling Jiang <sup>1</sup>, Keizo Cho <sup>1</sup>

<sup>1</sup> Research Laboratories, NTT DoCoMo, Inc.

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

## Abstract

This paper describes the shape of an aperture that yields a significantly improved degree of coupling for aperture-coupled patch antennas. A bow-tie shaped aperture consists of a slot with a narrow center and the width steadily increases toward each end. Simulation data show an increase of up to 44% in the resonant frequency bandwidth of an antenna using the bow-tie shaped aperture, compared to that for the same antenna with a rectangular slot or dog-bone shaped slot. The field distributions of the three slot types are also simulated and compared.

## 1. INTRODUCTION

The next generation mobile communication systems, which will provide high-speed transmission, require base station antennas that have a broad operating frequency bandwidth and a diversity configuration to mitigate multipath fading. A polarization diversity configuration is effective in reducing the number of antennas at the base station establishment sites.

The feeding scheme for aperture-coupled patch antennas (ACPAs), which were first proposed by Pozar [1], eliminates the soldering process required to secure a pin-connected feed circuit to the patch, which is necessary in fabricating the conventional probe-fed patch antenna. The feeding scheme can greatly reduce the complexity in constructing large patch arrays consisting of many elements. The ground plane, sandwiched between the feed circuitry and the radiating patch, can prevent radiation from the feed network interfering with the patch radiation pattern. This type of antenna is attractive due to its low cost, low profile, conformability, and ease of manufacturing. A dual-polarized antenna is achieved by cutting two offset orthogonal slots into the ground plane. In this case, a short aperture is desired to reduce the isolation between the two branches.

The broad bandwidth is achieved by using multiple stacked radiation patches with different lengths [2] or modifying the aperture shape, which yields improved coupling for an ACPA [3][4].

Our goal is to develop a broadband dual-polarized planar antenna. As the first step, we present a technique that extends the operating frequency band of the ACPA while reducing the coupling with the slot length. In this paper, the operating frequency band is defined as having a Voltage Standing Wave Ratio (VSWR) of less than 1.5. To achieve this, we propose a

bow-tie shaped aperture as the coupling slot. By comparing the electric field distributions of the ACPA using the conventional rectangular slot, dog-bone slot, or the proposed bow-tie slot, we shown that the proposed configuration yields the strongest coupling of the three.

## 2. BOW-TIE SHAPED SLOT COUPLED PATCH ANTENNA

Fig. 1 illustrates the geometry of a linearly polarized, multi-layer, aperture-coupled patch radiator with the proposed bow-tie shaped slot. The feed layer of the antenna consists of a microstrip feed line, a thick substrate, and a ground plane with a bow-tie shaped slot. The radiator layer consists of two square patches, in this case, to achieve a broad bandwidth. An air dielectric is used between the patches and there is a dielectric protection layer (radome) over Patch #2.

The microwave signal is coupled from the microstrip feed line through the slot in the ground plane to Patch #1, which in turn is capacitively coupled to all the patches above.

The dimensions below are given with respect to the notation in Fig. 1:  $W_f = 0.04\lambda_0$ ,  $\epsilon_f = 2.2$ ,  $h_f = 0.01\lambda_0$ ,  $W_{gx} = W_{gy} = 1.1\lambda_0$ ,  $\epsilon_1 = 2.2$ ,  $h_1 = 0.03\lambda_0$ ,  $W_{1x} = W_{1y} = 0.55\lambda_0$ ,  $\epsilon_2 = 1.0$ ,  $h_2 = 0.10\lambda_0$ ,  $W_{2x} = W_{2y} = 0.66\lambda_0$ ,  $\epsilon_3 = 2.2$ , and  $h_3 = 0.03\lambda_0$ .

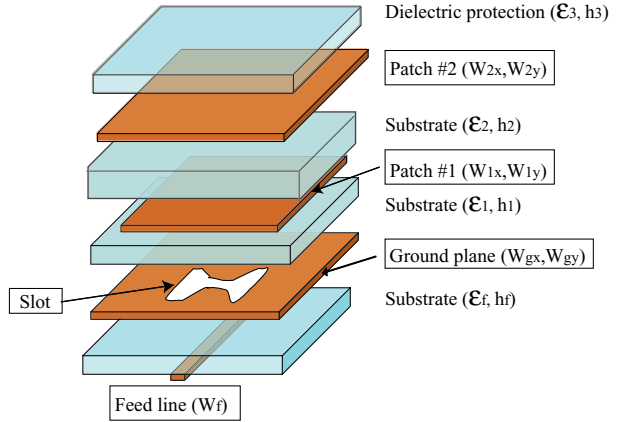


Fig. 1: Antenna Configuration

Fig. 2 shows the top view of the ACPA with conventional rectangular slot and dog-bone slot. Parameter  $W_a$  represents the length of the slot, and  $L_s$  is the stub, which is usually  $\lambda_g/4$ . Tuning  $W_a$  and  $L_s$  can achieve a strong coupling between the

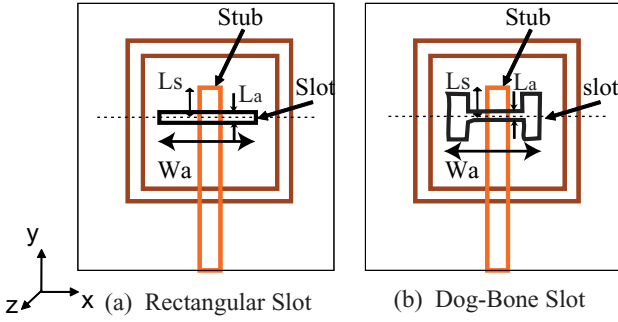


Fig. 2: Top View of Rectangular Slot and Dog-Bone Slot Patch Antenna

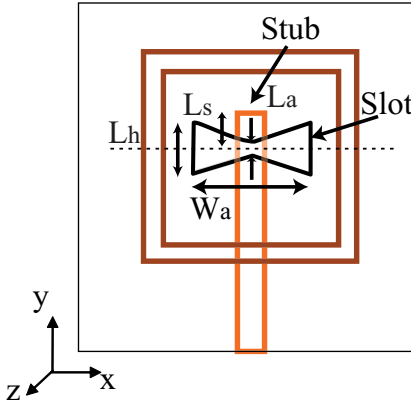


Fig. 3: Top View of Bow-Tie Shaped Slot Patch Antenna

microstrip feed line and Patch #1. Fig. 3 represents the top view of the proposed bow-tie slot coupled patch antenna. The aperture on the ground plane is a bilaterally-symmetric slot, which is narrow at the center, and the width increases steadily toward the edge of the slot. Parameters  $W_a$  and  $L_s$  are defined as the same as that in the conventional models. Parameters  $L_a$  and  $L_h$  are the lengths of the center and the end of the bow-tie shaped slot, respectively.

The 3D electromagnetic field simulator software CST Microwave Studio Suit 2006 [10] is used for the simulation, and 4 layers of Berenger's PML absorbing boundary condition are employed in the simulation.

### 3. INPUT CHARACTERISTICS AND ELECTRICAL FIELD DISTRIBUTION

As mentioned in the previous section, the length of the coupling aperture,  $W_a$ , and the length of the tuning stub on the microstrip feed line,  $L_s$ , affect the coupling to Patch #1 and the input impedance of the antenna. First of all, we adjust these two parameters to find a suitable value set for a broad bandwidth. Then, the proposed patch antenna with a bow-tie slot is compared to the conventional models. Because the investigation focuses on the shape of different apertures, other parameters, such as the width and length of the patches, and

the height of the substrates are fixed in this paper. The total length of the aperture,  $W_a$ , the width of the aperture,  $L_a$ , and length of the tuning stub on the feed line,  $L_s$ , are varied.

As the shape parameters of the aperture,  $W_a$ ,  $L_a$  and  $L_s$ , are changed, we compute each parameter set and evaluate the operating frequency bandwidth for the rectangular slot, dog-bone slot, and bow-tie slot, respectively. Through the investigation of the aperture shape parameters, we found that  $W_a$  and  $L_s$  are dominant factors that influence the input characteristics of the antenna. Thus, the width of the rectangular and dog-bone slots and the smallest width of the bow-tie slot,  $L_a$ , are fixed in this paper.

Using varied  $W_a$  and  $L_s$  values, the operating frequency bandwidth of the rectangular and dog-bone slot patch antennas are simulated.

Figures 4 and 5 show the  $S_{11}$  characteristics of the rectangular and dog-bone slot coupled patch antennas that have the widest operating frequency bandwidth at the  $VSWR \leq 1.5$ , respectively. The operating frequency bandwidths for two models at the  $VSWR \leq 1.5$  are approximately 12.8% and 13.4% for each model. The length of coupling aperture  $W_a$  is  $0.29\lambda_0$  for the rectangular slot and  $0.23\lambda_0$  for the dog-bone slot case. Term  $\lambda_0$  is the wavelength of the central resonant frequency. The optimum length of tuning stub  $L_s$  is approximately  $0.16\lambda_0$ . This value responds appropriately to the well-known rough guide for the tuning stub length of  $\lambda_g/4$ .

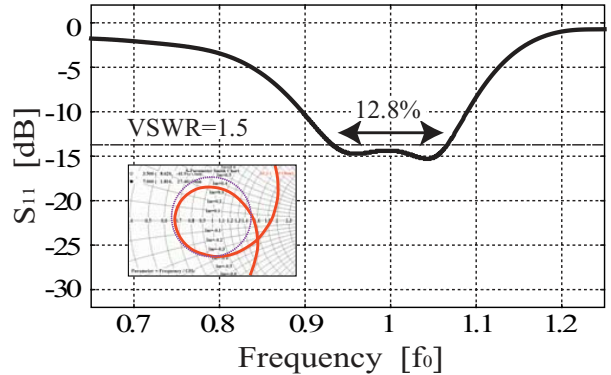


Fig. 4: Input Characteristic of Patch Antenna with Rectangular Slot ( $W_a = 0.29\lambda_0$ ,  $L_s = 0.155\lambda_0$ )

Fig. 6 shows the  $S_{11}$  characteristic of the proposed bow-tie slot coupled patch antenna. The operating frequency bandwidth for the  $VSWR \leq 1.5$  reaches 19.3%, and a shorter slot length  $W_a (\approx 0.20\lambda_0)$  is achieved compared to the conventional rectangular and dog-bone slot. For an ACPA, a smaller aperture area eases the positioning constraints in dual-polarized antenna designs that use two orthogonal coupling apertures. The size reduction in the aperture length is an important advantage to the proposed bow-tie slot.

The input impedance loci shown at Fig. 4 to 6 show that the patch antenna coupled with a bow-tie slot achieves smaller kink loci in the  $VSWR \leq 1.5$  circle, thus a broad operational

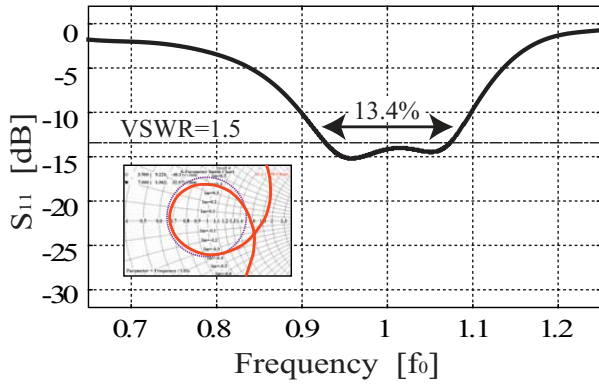


Fig. 5: Input Characteristic of Patch Antenna with Dog-Bone Slot ( $W_a = 0.23\lambda_0, L_s = 0.163\lambda_0$ )

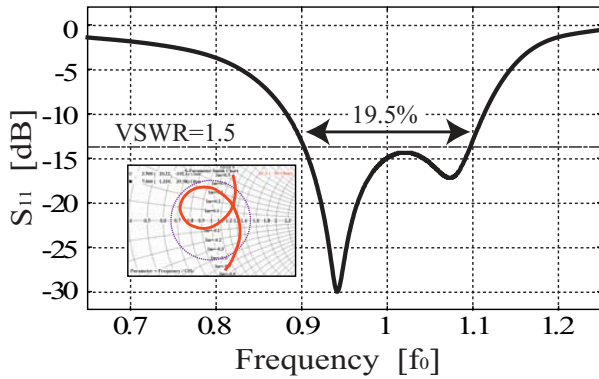


Fig. 6: Input Characteristic of Patch Antenna with Bow-Tie Slot ( $W_a = 0.20\lambda_0, L_s = 0.155\lambda_0$ )

frequency bandwidth is achieved by using the proposed bow-tie slot.

Fig. 7 to 10 show the electrical field near the coupling aperture of the patch coupled with the conventional rectangular slot, dog-bone slot, and proposed bow-tie slot, respectively. The observation plane is set at the center of the patch and in the direction parallel to the z-x plane. The  $E_y$  field magnitude of the major radiation component of the antenna on the observation plane is observed and the maximum values of the  $E_y$  field at a lower frequency ( $f_{low}$ ), central frequency ( $f_0$ ) and higher frequency ( $f_{high}$ ) compared to the operating frequency band are measured. In this paper, the same observation frequency is selected for the three antenna models. And the VSWR of the ACPA with a rectangular slot, dog-bone slot and bow-tie slot both has a value of less than 1.5 at these frequencies. Terms  $f_{low}$  and  $f_{high}$  are  $0.936f_0$  and  $1.064f_0$ , respectively.

Table 1 shows a comparison of the peak value near the coupling aperture at  $f_{low}$ ,  $f_0$  and  $f_{high}$ , respectively. To investigate the effect of the proposed model, each peak value is normalized by the peak value of the rectangular slot case at  $f_0$ . Table 1 shows that the maximum electrical field level at the operating frequency band is 1.32 times to 1.75 times

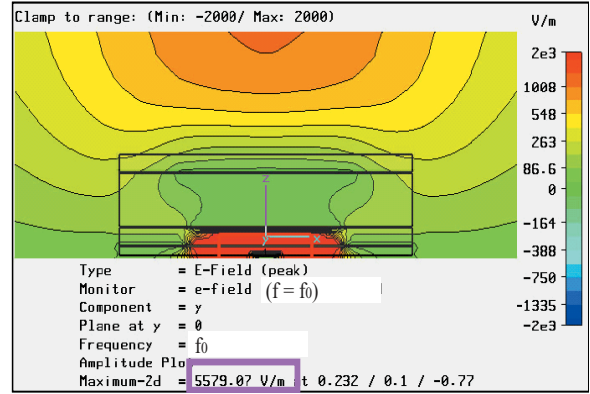


Fig. 7: E-field Distribution( $E_y$  component) of Rectangular Slot Coupled with Patch Antenna ( $Freq. = f_0$ )

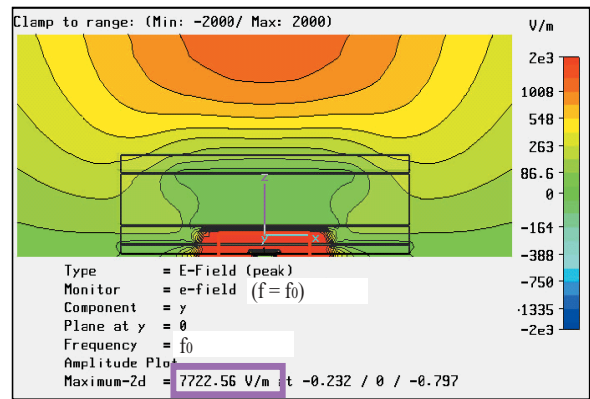


Fig. 8: E-field Distribution( $E_y$  component) of Dog-Bone Slot Coupled with Patch Antenna ( $Freq. = f_0$ )

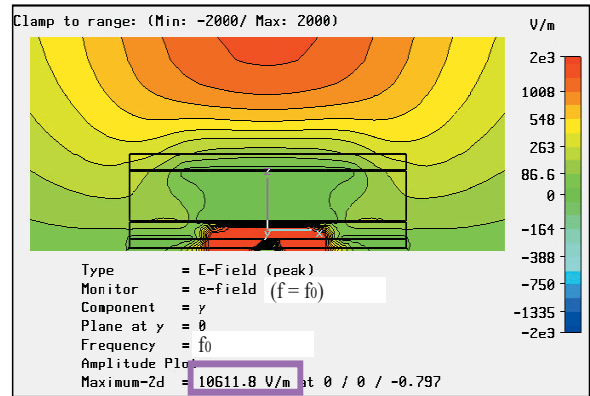


Fig. 9: E-field Distribution( $E_y$  component) of Bow-Tie Slot Coupled with Patch Antenna ( $Freq. = f_0$ )

as strong as those of the rectangular slot case and dog-bone slot case, respectively. The strong coupling between the microstrip feed line and Patch #1 decreases the un-matching at the coupling structure and improves the antenna frequency

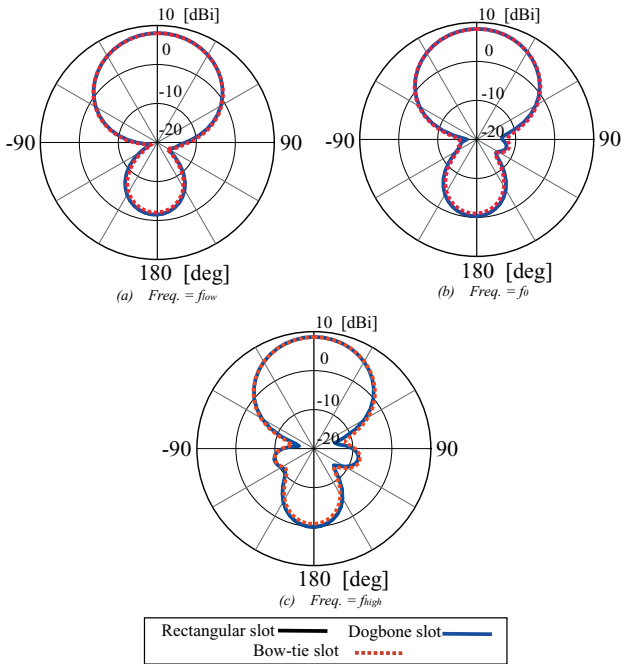
**TABLE 1:** COMPARISON OF  $E_y$  COMPONENT NEAR SLOT (NORMALIZED USING RECTANGULAR CASE)

Shape of Slot	Observation Frequency		
	@ $f_{low}$	@ $f_0$	@ $f_{high}$
Rectangular Slot	0.71	1.0 (Ref.)	1.00
Dog-Bone Slot	1.00	1.38	1.41
Bow-Tie Slot	1.32	1.90	1.75

response characteristics, which leads to a broad operating frequency bandwidth.

#### 4. FAR FIELD RADIATION PATTERN OF BOW-TIE SLOT COUPLED PATCH ANTENNA

In the previous section, we discussed the input characteristics due to the shape of the coupling aperture and proposed a patch antenna with a bow-tie slot feeding structure. In this section, we focus on the far-field radiation pattern of the bow-tie slot coupled patch antenna.



**Fig. 10:** Far Field Radiation Pattern of Bow-Tie Slot Coupled with Patch Antenna

We simulate and compare the far-field radiation pattern of the proposed structure, the conventional rectangular slot, and dog-bone slot. Fig. 10 shows a comparison of the far-field radiation pattern of the rectangular, dog-bone, and bow-tie slot coupled patch antennas at  $f_{low}$ ,  $f_0$ , and  $f_{high}$ . The dotted-line is the radiation pattern of the proposed bow-tie slot coupled patch antenna. The solid black and blue curves indicate the characteristics of the conventional rectangular and dog-bone slot, respectively.

In the comparison shown in Fig. 10, the radiation patterns do not change greatly due to the shape of the coupling slot. The

proposed bow-tie slot can improve the input characteristics and maintain the same radiation pattern at same level as the well-known patch antenna coupled with the rectangular slot or dog-bone slot.

#### 5. CONCLUSION

In this paper, we proposed a broadband ACPA that is better suited to the construction of a broadband dual-polarized planar antenna. Through a comparison of the input characteristics of a patch antenna coupled with the conventional rectangular slot, dog-bone slot, or the proposed bow-tie slot, we find that the proposed structure achieves up to 44% wider operating frequency bandwidth and a  $0.09\lambda_0$  aperture size reduction compared to the other two slot types.

From the results of the electrical field around the coupling aperture, it is clear that using the proposed aperture achieves a strong coupling between the microstrip feed line and Patch #1, which leads to a broadband resonance.

We also described the far-field radiation pattern of the proposed antenna model in this paper. The radiation pattern is the same as the patch antenna coupled with a rectangular slot or a dog-bone slot.

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