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A Planar Six-Sector Antenna using Loop Antenna with Detour Elements for WLAN Card Terminal

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1. Introduction

In wireless local area network (WLAN) systems, a sector antenna technique is widely used to solve the multi-path fading and shadowing problems. In the case of the small card terminal, it is preferable that the sector antenna is formed in planar structure from the viewpoint of miniaturization. Against the background of demand for the planar sector antenna, various configurations employing the monopole Yagi-Uda array [1], the slot Yagi-Uda array [2] or the patch Yagi-Uda array [3] have recently been proposed.

We have proposed a six-sector antenna employing the Open End Square Antenna (OESA) with a reflector and two detour elements [4]. This antenna has small and planar structure and can be built in the edge of the PCMCIA (Personal Computer Memory Card International Association) card. However, smaller size of the sector antenna is desirable to mount on an ultracompact terminal like the CF (Compact Flash) card.

In this paper, we propose a further small six-sector configuration, which is realized by arrangement of three beam-switched loop antennas. The beam-switched loop antenna is composed of a square loop with a plate reflector, two detour elements and two feed points. The main beam is tilted more than 45 degrees to the direction along the loop plane, and the beam direction can be inverted by selectively exciting at the two feed points. The planar size of the six-sector configuration is smaller by 30 % compared to that of our previous proposal [4]. Moreover, we present the slot structure of the beam-switched loop antenna, which is fed by the microstrip line (MSL) and radiates vertical polarization component.

2. Beam-Switched Loop Antenna

The basic structure of the proposed beam-switched loop antenna is illustrated in Fig. 1. This antenna is based on the square loop antenna of one-third wavelength on a side, and the two detour elements of quarter wavelength are inserted in a set of vertex and the two feed points are inserted in another set of vertex. Moreover, the plate reflector of L on a side is placed at an interval of h from the loop plane. The planar size of this loop antenna is reduced by 30 % compared to that of one element in our previous six-sector antenna [4].

The characteristics of the proposed beam-switched loop antenna are calculated by using the IE3D software package based on the moment method. The current distribution when the Port 1 is excited and the Port 2 is shorted is indicated in Fig. 2. The alphabet marks on the horizontal axis correspond to the antenna element positions indicated in Fig. 1. In Fig. 2, the peak points of the current amplitude are distributed at the positions of the Port 1 and the Port 2, and the current phase difference between the peak points is about 160 degrees. As the current phase difference, the main beam is tilted to the $+X$ direction as shown in the vertical radiation patterns of E_ϕ component in Fig. 3 (a). It is found that the main beam is tilted more than 45 degrees to the $+X$ direction when h is larger than 0.34 λ_0. The conical radiation patterns at the elevation angle of the main beam direction are indicated in Fig. 3 (b). The half-beam power width (HPBW) is about 56 degrees and the directivity is 10.5 dBi when h is 0.42 λ_0. These radiation characteristics are suitable for the six-sector antenna. Similarly, the main beam is also tilted to the $-X$ direction when the Port 2 is excited. Thus, the main beam direction can be inverted by switching the excited port. If three elements of this beam-switched loop are arranged, the six-sector antenna is realized and the planar size is drastically reduced compared to that with six antenna elements.

3. Six-Sector Configuration

This section describes the six-sector configuration using the beam-switched loop antenna explained in Section 2.

The six-sector configuration of the rectangular arrangement is illustrated in Fig. 4. This sector

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configuration is composed of three beam-switched loop antennas arranged in the straight line so that the main beam of each sector is formed at an interval of 60 degrees in the horizontal plane, and is designed on a dielectric board of relative permittivity ε_r = 2.6 and thickness t = 0.027 λ_0. The arrows in Fig. 4 indicate the main beam direction of each antenna element.

In order to reduce the mutual coupling between the antenna elements, the long intervals a and b should be reserved. However, this is trade-off with the planar size of six-sector configuration. Then we adjusted the intervals in an effort to obtain the smallest planar size within the acceptable radiation characteristics.

The calculated radiation patterns when $a = \lambda_0$ and $b = 0.5\ \lambda_0$ are indicated in Fig. 5. Since the symmetrical structure, the Port 5 or 6 is omitted in Fig. 5. The radiation characteristics are suited for the six-sector antenna since the HPBW values of all sectors are about 60 degrees. The planar size of this sector configuration is 0.98 λ_0 × 2.37 λ_0. If the operating frequency is set to be 25 GHz, its size is 11.8 mm × 28.4 mm and is suitable for an antenna built in the edge of the ultracompact terminal like a CF card of 43 mm wide. This planar size is reduced by 30 % compared to that of our previous six-sector antenna [4].

As described above, the six-sector configuration employing the beam-switched loop antenna has small and planar structure suited for card type terminal.

4. Slot Structure

This section describes the slot structure of the beam-switched loop antenna explained in Section 2. The wire structure in Section 2 has the following disadvantages. The balun and the impedance matching circuit are required to excite the antenna from an unbalance circuit. The main polarization is the E_ϕ component. This is not matched to the E_θ component that is assumed in general WLAN systems. Then we have investigated the slot structure shown in Fig.6 in order to solve these problems.

In Fig. 6, the slot elements are formed by cutting the capper foil on +Z side plane of a dielectric board with a relative permittivity of ε_r and a thickness of t, and are fed by an electromagnetic coupling with the MSL, which is formed on –Z side plane of the dielectric board. The impedance matching between the slot elements and the MSL can be realized by adjusting the length L_1 of the MSL.

Moreover, the impedance at the coupling position of the slot element and the unexcited MSL has to be open. That impedance switching mechanism is necessary to invert the main beam. For instance, there are means that the unexcited MSL is shorted at the position where the length from the coupling position becomes odd number multiple of quarter wavelength. In this paper, this means is adopted as the impedance switching mechanism.

The structure of the beam switching circuit is illustrated in Fig. 7. This circuit is composed of three SPDT switches, and is realized by the MSL circuits on the dielectric board. These SPDT switches operate as shown in the case_1 when the loop antenna is excited from the MSL_1. When the loop antenna is excited from the MSL_2, the SPDT switches operate as the case_2. In these cases, the length L_2 from the coupling position to shorted position is set to be n × 0.25 λ_e (λ_e: effective wavelength, n = 1, 3, 5, …).

The measured radiation patterns of the E_θ component are indicated in Fig. 8. The parameters of this antenna are as follows: L_{r1} = 2 λ_0, L_{r2} = 2.33 λ_0, L_{d1} = 1.07 λ_0, L_{d2} = 2.17 λ_0, t =0.027 λ_0, ε_r = 2.26, L_1 = 0.023 λ_e, and h = 0.42 λ_0. The operation frequency is 4.9 GHz.

In the case_1, the tilt angle of the vertical plane is about 40 degrees, the gain is 8.4 dBi, and the HPBW of the conical pattern is 80 degrees. In the case_2, the tilt angle of the vertical plane is about 40 degrees, the gain is 8.5 dBi, and the HPBW of the conical pattern is 74 degrees. The gain includes the switching loss of about 3dB.

Thus, the tilt beam characteristics have been obtained in the slot structure as well as the wire structure, and it is found that the main beam direction can be inverted by switching the excited MSL. The next subjects are the reduction of the switching circuit loss and to optimize the six-sector configuration.

5. Conclusion

In this paper, the small six-sector configuration, which is realized by arrangement of three beam-switched loop antennas has been proposed. The beam-switched loop antenna is based on a square loop structure and the main beam direction can be inverted by selectively exciting at the two feed points.

We have presented the six-sector configuration of the rectangular arrangement of 11.8 mm × 28.4

mm at 25 GHz. The planar size is suitable for a sector antenna for an ultracompact card type terminal. Moreover, we have shown that the impedance matching is achieved and the vertical polarization is obtained by composing the beam-switched loop antenna of the slot element in our experiment. For the future study, we are planning to investigate the reduction of the switching circuit and the six-sector configuration of the slot structure.

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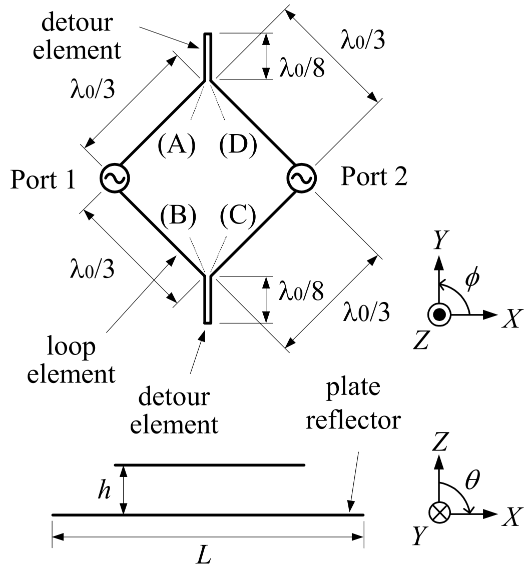

Fig. 1. Beam-switched loop antenna.

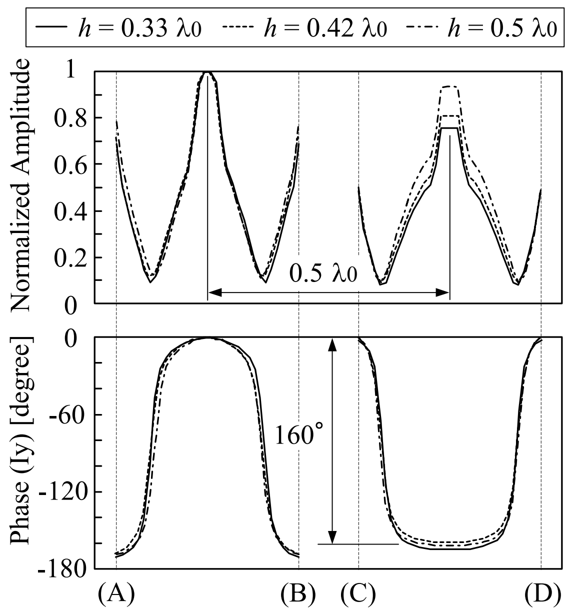

Fig. 2. Current distribution of beam-switched loop antenna.

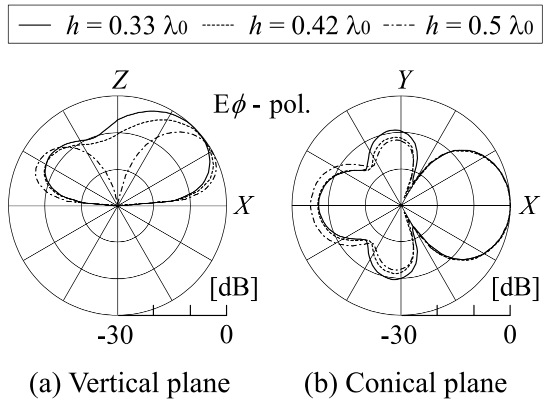

Fig. 3. Radiation patterns of beam-switched loop antenna.

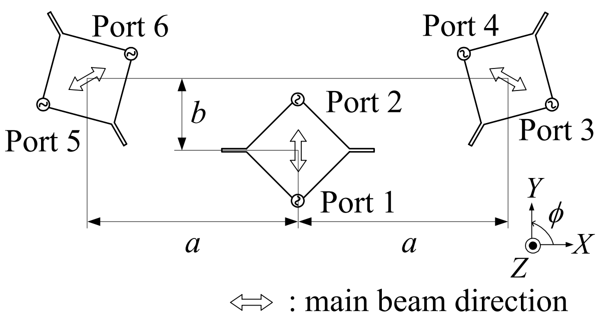

Fig. 4. Rectangular arrangement of six-sector configuration.

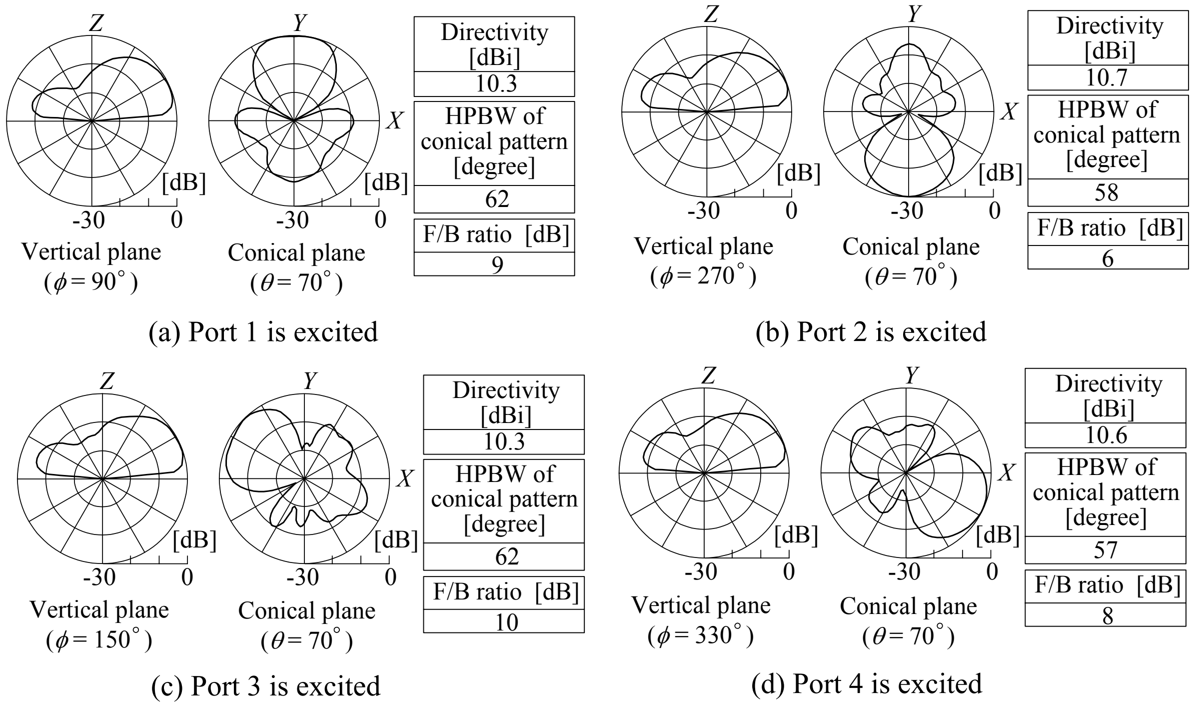

Fig. 5. Radiation patterns of rectangular six-sector configuration (h = 0.42 λ_0).

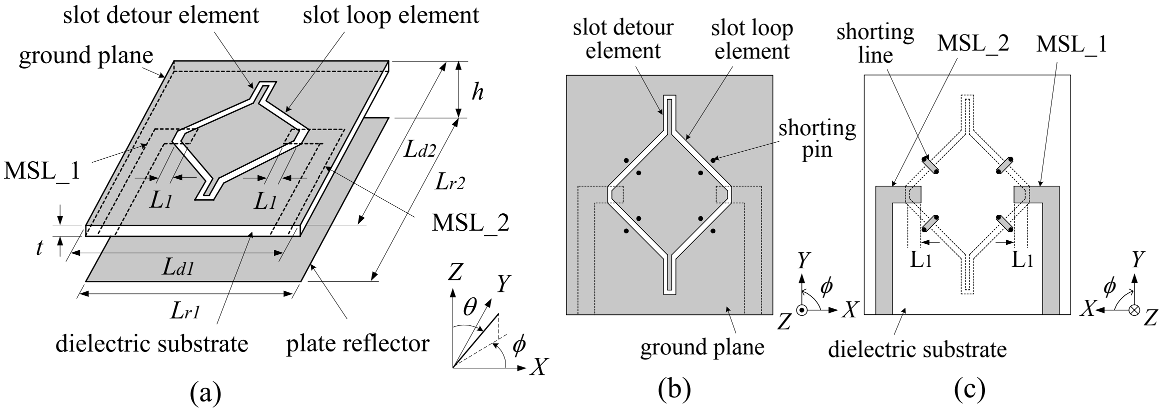

Fig. 6. Slot structure of beam-switched loop antenna.

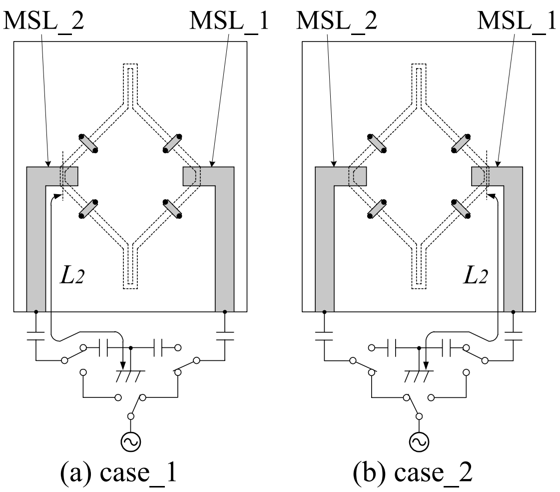

Fig. 7. Structure of beam switching circuit.

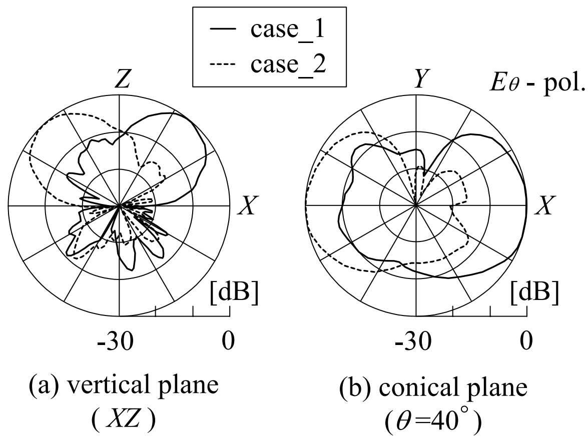

Fig. 8. Radiation patterns of slot beam-switched loop antenna.