Proceedings of ISAP'04, Sendai, JAPAN

Cross polarization characteristics in the planes tilted from the boresight of a dual-polarized patch antenna

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1. Introduction

To attain low cross polarization for a dual-polarized patch antenna, some methods have been proposed, for example, shown in [1,2]. These methods are effective for the E-plane and H-plane, because they suppress the cross polarization caused by the mutual coupling between the orthogonal feed points. However, base station antennas for cellular mobile radios require to decrease cross polarization in the planes tilted from the horizontal plane. In the planes tilted from the boresight of a patch antenna, since the dominant TM_{10} mode itself contributes to the cross polarized field, it is impossible to suppress cross polarization only by using the methods shown in [1,2].

In this paper, we analyze the cross polarization characteristics in some tilted planes, and show analytically that there exists the optimum substrate dielectric constant to achieve low cross-polarization. Moreover, we validate these characteristics both by the FDTD simulations and by experiments for a dual-polarized square patch antenna with a parasitic element.

2. Cross-polarization characteristics in some tilted planes

Fig.1 illustrates a general configuration of a dual-polarized square patch antenna. Consider the radiation field in the planes in which θ is constant. We define the θ component of the electric field and the ϕ component of the electric field as E_θ and E_ϕ respectively. E_ϕ is co-polarization and E_θ is cross-polarization when the feed point #1 is excited, and E_θ is co-polarization and E_ϕ is cross-polarization when the feed point #2 is excited. We define co-polarization and cross-polarization as E_{co} and E_x respectively. When the feed point #1 is excited, assuming that only the TM_{10} mode is excited, the ratio of cross-polarization to co-polarization $|E_x/E_{co}|$ is derived from the cavity model analysis [3,4] as follows:

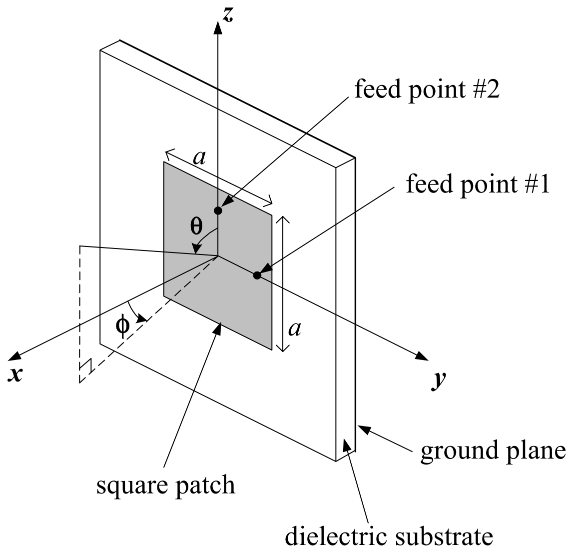


Fig.1 Configuration of a dual-polarized patch antenna

$$\left|\frac{E_x}{E_{co}}\right| = \left|\frac{E_\theta}{E_\phi}\right| = \left|\frac{\sin\phi\cos\theta\cos\phi}{\varepsilon_r - \sin^2\phi}\right| \quad (1)$$

where ε_r is the substrate relative dielectric constant. Similarly, when the feed point #2 is excited, $|E_x/E_{co}|$ is derived as follows:

$$\left|\frac{E_x}{E_{co}}\right| = \left|\frac{E_\phi}{E_\theta}\right| = \left|\frac{\cos\theta\tan\phi}{1+\sin^2\theta/(\varepsilon_r - 1)}\right| \quad (2)$$

Eq.(1) states that $|E_x/E_{co}|$ decreases with an increase of ε_r when the feed point #1 is excited. Conversely,

ISBN: 4-88552-206-4 C3055©IEICE

Eq.(2) states that $|E_x/E_{co}|$ increases with an increase of ε_r when the feed point #2 is excited.

For example, consider some planes tilted by 2, 6, 10[deg.] from the θ=90[deg.] plane. Fig.2 shows ε_r versus the maximum $|E_x/E_{co}|$ within $|\phi|\leq 40$[deg.] in the θ=92, 96, 100[deg.] planes calculated from Eq.(1) and Eq.(2). Note that ε_r = 1.77, 1.76, 1.75 are desirable in order to decrease both of $|E_x/E_{co}|$'s to the same level in the θ=92, 96, 100[deg.] planes respectively. And, the optimized $|E_x/E_{co}|$'s are -38, -28, -24[dB] in the θ=92, 96, 100[deg.] planes respectively. Namely, it is proved that there exists the optimum substrate dielectric constant to decrease both of $|E_x/E_{co}|$'s to the same level in each tilted plane. Fig.3 shows the dependences of the optimized $|E_x/E_{co}|$ and the optimum ε_r on the tilt angle within $|\phi|\leq 40$[deg.]. Note that there is little change in the optimum ε_r even if the tilt angle changes. The optimized $|E_x/E_{co}|$ increases gradually with an increase of the tilt angle.

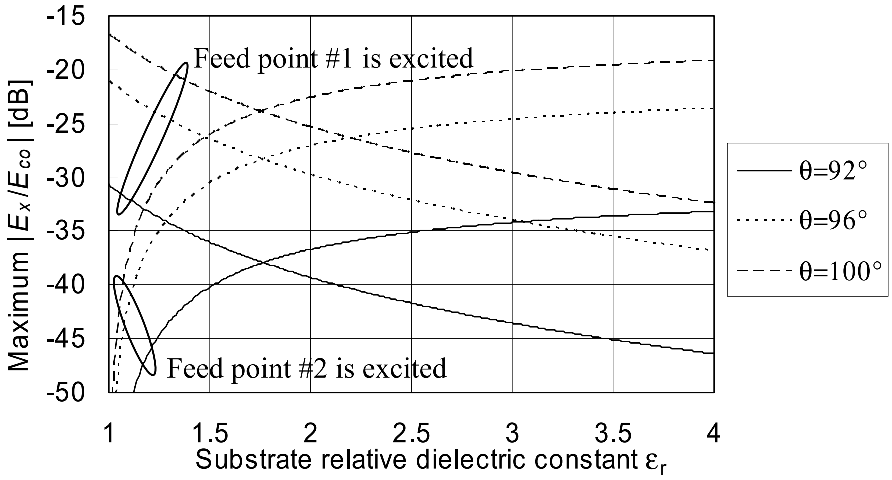


Fig.2 ε_r versus the maximum $|E_x/E_{co}|$ within $|\phi|\leq 40$[deg.] in the θ=92, 96, 100[deg.] planes

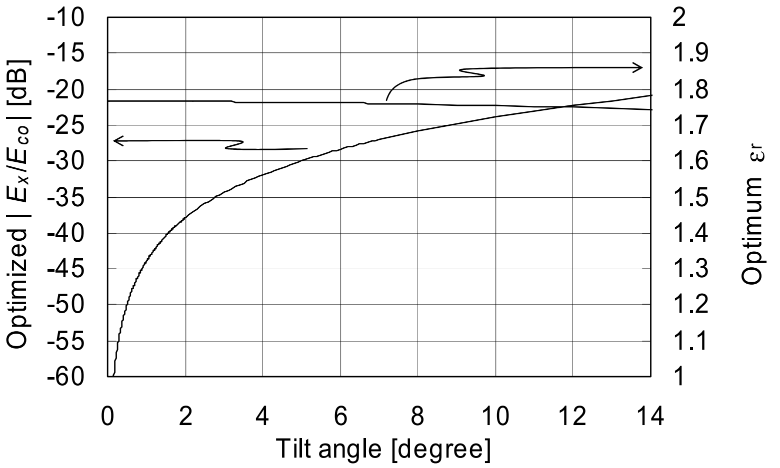


Fig.3 Dependences of the optimized $|E_x/E_{co}|$ and the optimum ε_r on the tilt angle within $|\phi|\leq 40$[deg.]

3. Numerical and experimental results

In this section, the above characteristics derived from the cavity model analysis will be validated both by the FDTD simulations and by experiments. Consider a dual-polarized square patch antenna with a parasitic element shown in Fig.4. The size of a ground plane is $0.68\lambda\times 1.35\lambda$. A fed element is fed by microstrip lines. In case of a patch antenna with a parasitic element, it is a parasitic element that mainly contributes to radiating. Therefore, with varying the effective relative dielectric constant ε_{reff} of the substrates between a parasitic element and a ground plane, we perform FDTD simulations and experiments.

Fig.5 shows the calculated and measured radiation patterns in the θ=99[deg.] plane at ε_{reff} = 1.63. Fig.6 shows ε_{reff} versus the maximum $|E_x/E_{co}|$ within FWHM (Full Width Half Maximum: full width at half power) in the θ=99[deg.] plane. As shown in Fig.5 and Fig.6, the experimental results almost agree with the numerical results. Note that, if the feed point is changed, the slope of the graph of ε_{reff} versus the maximum $|E_x/E_{co}|$ becomes reverse. We validate that there exists the optimum ε_{reff} to decrease both of $|E_x/E_{co}|$'s to the same level (about -18dB) for a dual-polarized square patch antenna with a parasitic element both by the FDTD simulations and by experiments.

Fig.7 shows the dependences of the optimized $|E_x/E_{co}|$ and the optimum ε_{reff} on the tilt angle within FWHM, which are calculated by the FDTD method. Note that there is little change in the optimum ε_{reff} even if the tilt angle changes. The optimized $|E_x/E_{co}|$ increases with an increase of the tilt angle. Comparing Fig.7 with Fig.3, it is found that, at the same tilt angle, the optimized $|E_x/E_{co}|$ of Fig.7 is larger than that of Fig.2 and the optimum dielectric constant of Fig.7 is different from that of Fig.2. The reasons for these differences are considered as follows: (1) Fig.7 includes the field radiated by the feeding pins. (2) The ground plane of Fig.4 is finite, while the ground plane of Fig.1 is infinite. (3) Since a dual-polarized patch antenna shown in Fig.3 has a parasitic element, cross-polarization increases by the stronger mutual coupling between the orthogonal feed points.

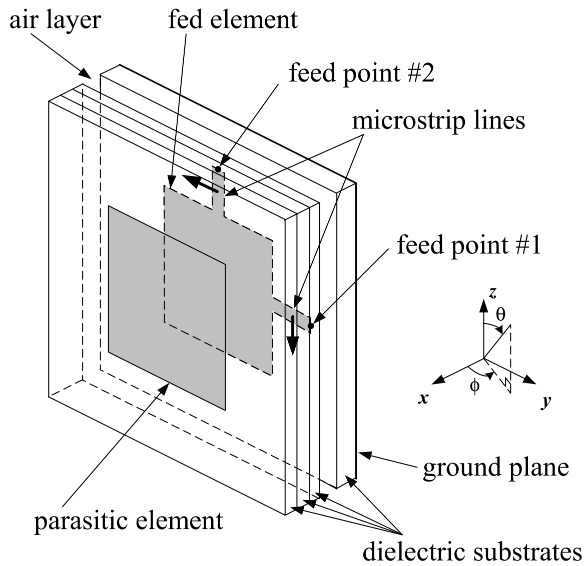
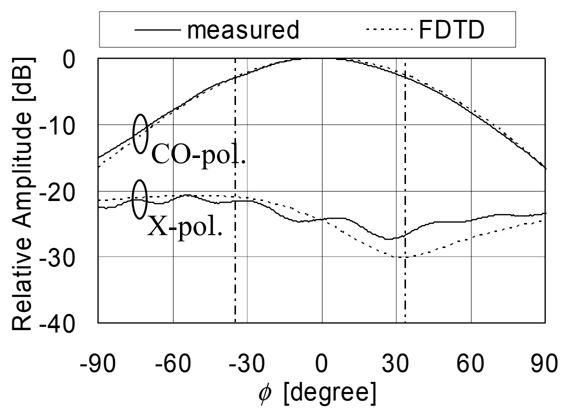
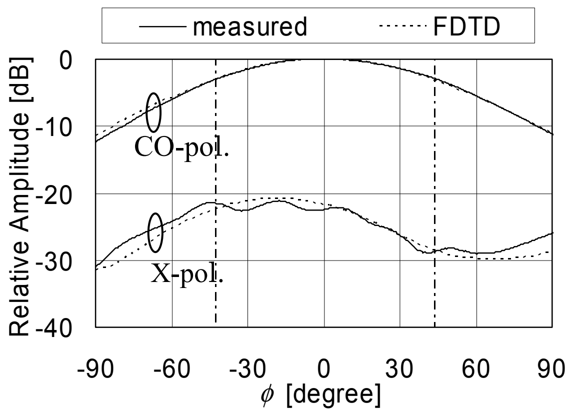


Fig.4 Configuration of a dual-polarized square patch antenna with a parasitic element



(a) Feed point #1 is excited



(b) Feed point #1 is excited

Fig.5 Calculated and measured radiation patterns in the θ=99[deg.] plane at ε_{reff} = 1.63

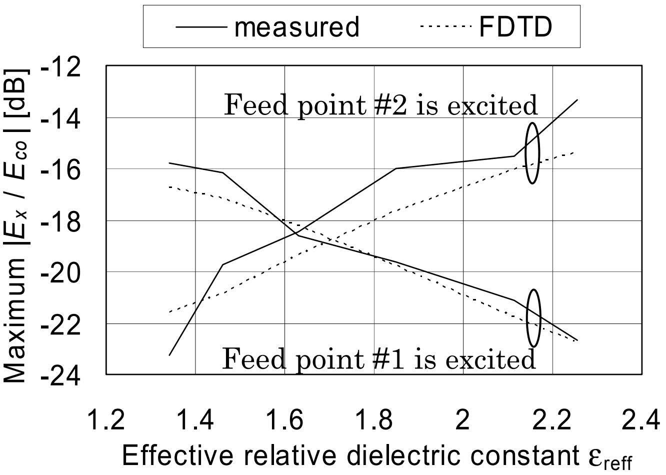


Fig.6 ε_{reff} versus the maximum $|E_x/E_{co}|$ within FWHM in the θ=99[deg.] plane

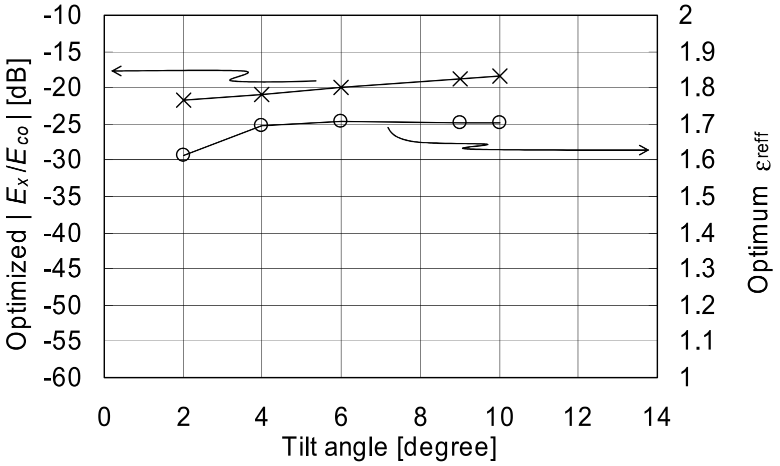


Fig.7 Dependences of the optimized $|E_x/E_{co}|$ and the optimum ε_{reff} on the tilt angle within FWHM

4. Conclusions

We have analyzed the cross polarization characteristics in the planes tilted from the boresight of a dual-polarized patch antenna, and have shown that there exists the optimum dielectric constant to achieve low cross-polarization in each tilted plane. Moreover, we have validated these characteristics both by the FDTD simulations and by experiments for a dual-polarized square patch antenna with a parasitic element. We found that there is little change in the optimum dielectric constant even if the tilt angle changes.

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