Rectangular Microstrip Antenna Excited by Monopole Antenna Mounted on Finite Dielectric Substrate

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1. Introduction

The Bluetooth wireless technology enables links between mobile computers, mobile phones, portable handheld devices, and connectivity to the Internet [1]. The Bluetooth system is operating in the frequency from2400 MHz to 2483.5 MHz.

In this paper, the rectangular patch microstrip antenna printed on the parallelepiped dielectric chip for the Bluetooth system is numerically and experimentally analyzed. This antenna is excited by the monopole antenna printed on the sidewall of substrate. In order to locate this antenna close to the transceiver circuit, this antenna is mounted on the printed circuit board.

In the numerical analysis, the electromagnetic simulator “Fidelity” based on FDTD method is used [2].

2. Structure of antenna

Figure 1(a) and (b) show the structure of rectangular patch microstrip antenna with a cross slot on the rectangular parallelepiped dielectric chip. The dielectric chip is located on the upper conducting plate of Wx = 16mm by Wy = 16mm on the surface of lower dielectric substrate. The size of lower dielectric substrate is Gx = 40mm by Gy = 40mm and its height is 0.5 mm. The printed monopole antenna on the sidewall of dielectric substrate is fed by a coaxial probe. The relative permittivity of upper dielectric is $\varepsilon_{r1} = 37$ and that of lower one is $\varepsilon_{r2} = 4.6$. The transceiver circuit is located close to the antenna on the lower dielectric substrate.

In the numerical analysis with FDTD method, the perfectly matched layer of six-layer and fourth-order is used as the absorbing boundary condition. The space steps are from 0.2 mm to 2 mm (non-uniform mesh). The time step is 3.659×10^{-13} sec. The calculation region is 180 mm by 180 mm by 120 mm in dimensions. In the numerical analysis, the existence of the transceiver circuit is not considered.

3. Numerical and measured results and Discussion

Figure 2 shows the return loss characteristics. The measured resonant frequencies are higher than the calculated frequencies. This may be due to that the relative permittivity of dielectric material for test antenna becomes small. Figure 3 show the calculated electric field radiation patterns at the resonant frequencies 2.295 GHz and 2.405 GHz. Figure 4 show the electric field distributions on the surface of patch conductor at two resonant frequencies. Figure 5 show the electric field distributions in yz-plane at these two frequencies. From figure 4 and 5, at the lower resonant frequency 2.295 GHz, the resonant mode of dielectric resonator antenna seems to be excited. On the other hand, at frequency of 2.405 GHz, the resonant mode of microstrip antenna seems to be appeared.

Here, the resonant frequency of rectangular dielectric resonator is calculated. From the continuity condition of electromagnetic field at the boundary between free space and dielectric substrate, the following eigenvalue equations for the E^{z}_{pq} mode are derived [3].

$$k_x \tan\left(k_x D_x/2\right) - \gamma = 0 \quad \text{for even mode} \qquad (1)$$

$$k_x \tan\left(k_x D_x/2\right) + \gamma = 0 \quad \text{for odd mode} \tag{2}$$

According to Marcatili [4], k_y and k_z are approximated as;

$$k_y = \frac{p\pi}{D_y}\left\{1 + \frac{1}{\pi D_y}\frac{\lambda}{\left(\varepsilon_{r1}-1\right)^{1/2}}\right\}^{-1}, \quad k_z = \frac{q\pi}{D_z}\left\{1 + \frac{1}{\pi \varepsilon_{r1} D_z}\frac{\lambda}{\left(\varepsilon_{r1}-1\right)^{1/2}}\right\}^{-1} \tag{3}$$

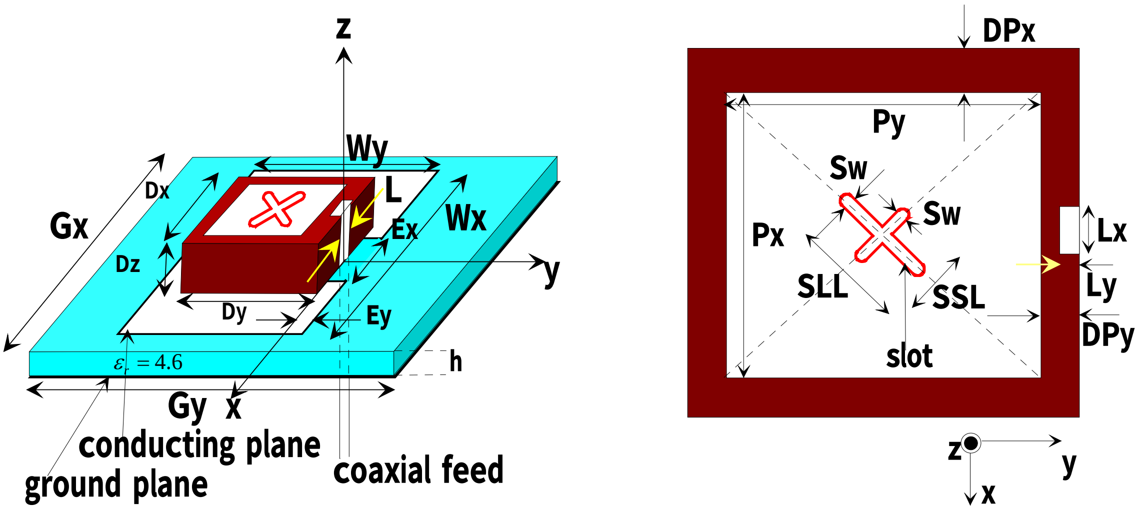
$$k_x = \sqrt{\varepsilon_{r1}k_0^2 - k_y^2 - k_z^2}\,. \tag{4}$$

$$\gamma^2 = k_y^2 + k_z^2 - k_0^2 \quad (k_0: \text{ propagation constant in free space}) \tag{5}$$

From the equation (1) or (2), the resonant frequency of E_{pq}^z mode is obtained. The resonant frequency of E_{11}^z mode becomes to be 2.203 GHz for $\varepsilon_{r1} = 37$ and 2.291 GHz for $\varepsilon_{r1} = 34$.

4. Conclusion

The rectangular patch microstrip antenna printed on the parallelepiped dielectric chip for the Bluetooth system is numerically and experimentally analyzed. The approximated resonant frequency of dielectric resonator is calculated and compared with the calculated frequency by FDTD method. This antenna seems to operate as the microstrip antenna and the dielectric resonator antenna.



(a) Analytical model (b) Top view of model antenna

Figure 1 Microstrip antenna excited by monopole antenna.

Gx=Gy=40mm, h=0.5mm, Dx=Dy=12mm, Dz=4mm, Wx=Wy=16mm, L=1.2mm, Ex=4mm, Ey=2mm, Px=9.4mm, Py=9mm, Lx=2mm, Ly=0.8mm, DPx=1.3mm, DPy=1.5mm, SSL=3mm, SLL=6.1mm, Sw=1mm

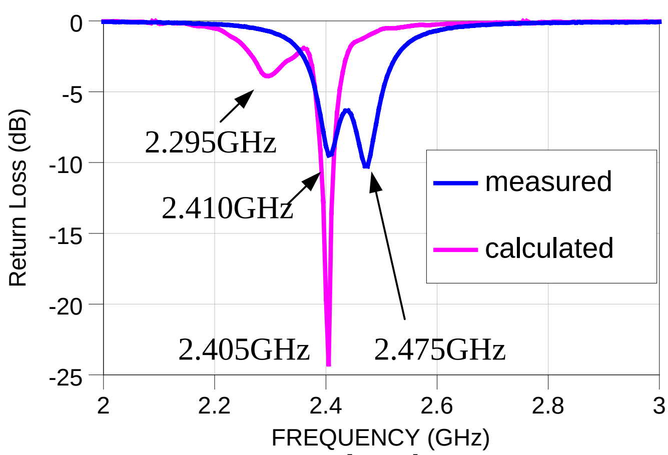
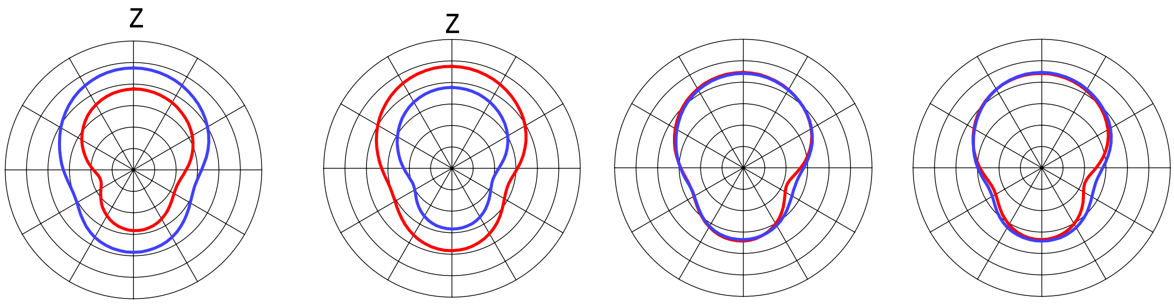


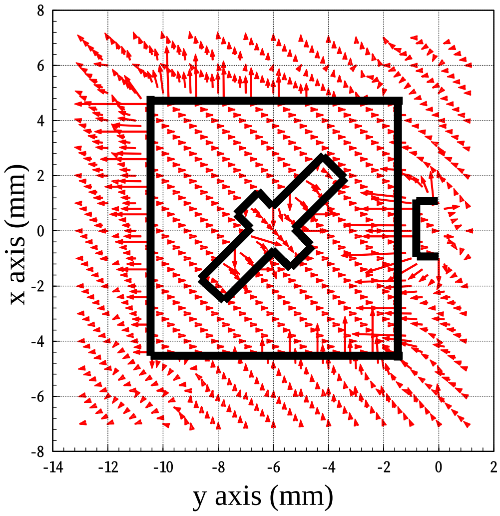
Figure 2 Return loss characteristics

References
[1] http://www.bluetooth.com/: "Specification of the Bluetooth System", Ver. 1.1, Feb. 2001.
[2] "Fidelity User's Manual", Zeland Software, Inc., April 2000.
[3] C. Chang and T. Itoh: "Resonant characteristics of dielectric resonators for millimeter wave integrated circuits", Arch. Elektron. Ubertag, Tech., AEU-33, pp.141-144, 1979.
[4] E. A. J. Marcatili: "Dielectric rectangular waveguide and directional couplers for integrated optics", Bell Syst. Tech. J., 48, pp.2071-2102, 1969.

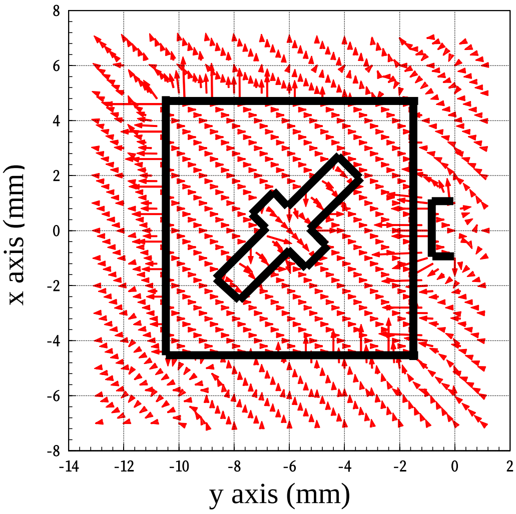


(a) 2.295 GHz (b) 2.405 GHz

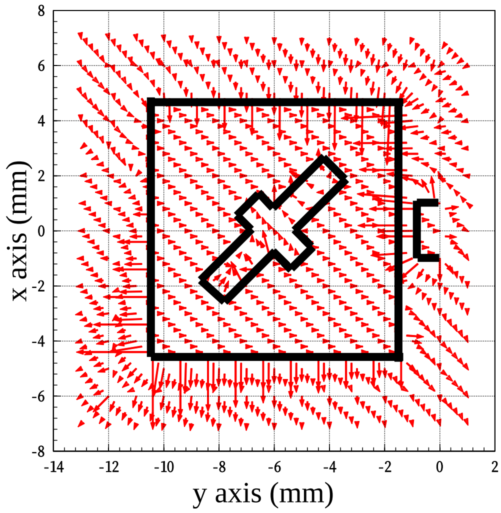
Figure 3 Calculated radiation patterns — E_θ — E_ϕ



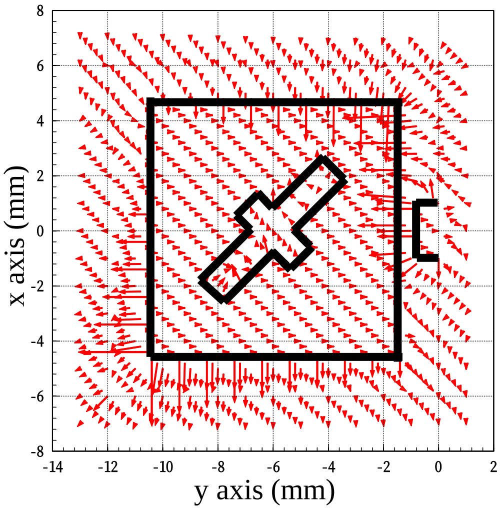
(a) 2.295GHz, ωt = 0



(b) 2.295GHz, ωt = π/8

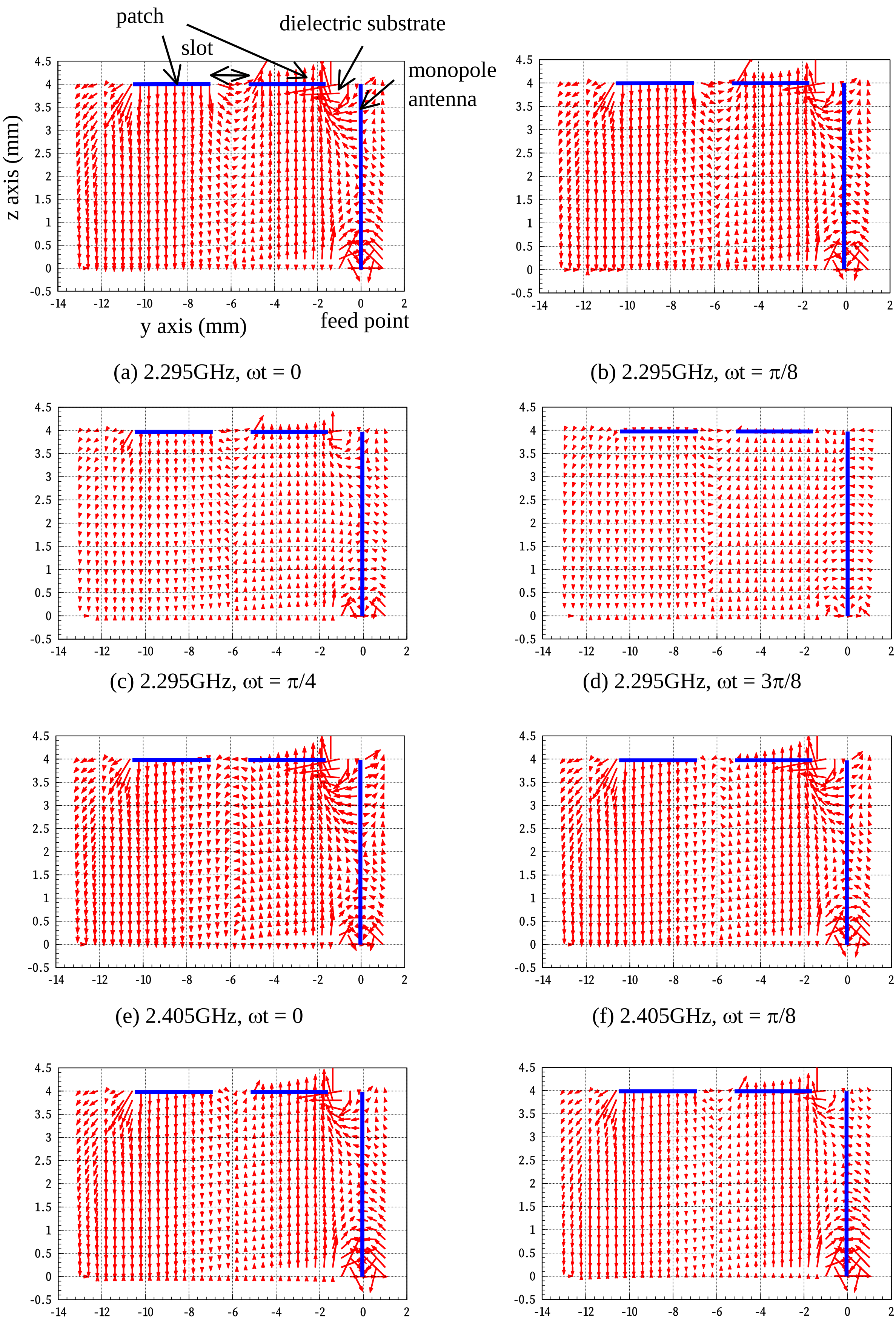


(c) 2.405GHz, ωt = 0



(d) 2.405GHz, ωt = π/8

Figure 4 Electric field distributions on the surface of patch conductor at resonant frequencies.



(a) 2.295GHz, ωt = 0　　(b) 2.295GHz, ωt = π/8

(c) 2.295GHz, ωt = π/4　　(d) 2.295GHz, ωt = 3π/8

(e) 2.405GHz, ωt = 0　　(f) 2.405GHz, ωt = π/8

(g) 2.405GHz, ωt = π/4　　(h) 2.405GHz, ωt = 3π/8

Figure 5　Electric field distributions in yz-plane at resonant frequencies.