Broadband Dielectric Resonator Antenna With an Offset Well

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***Abstract*—A broadband dielectric resonator (DR) antenna with an offset well is proposed. The well perturbs the original field distribution in the DR block to increase the impedance bandwidth associated with the TE_{111}^{y} mode. The feeding aperture generates a similar radiation pattern at adjacent band. The overall bandwidth covers the 5–6 GHz band of WLAN 802.11a.**

***Index Terms*—Dielectric resonators (DR), slot antennas.**

I. INTRODUCTION

THE loss of DR antennas at high frequency is lower than conventional patch antennas. Different approaches have been proposed to increase the impedance bandwidth of the former, for example, stacking multiple dielectric resonators with different resonant frequencies [1], inserting an air gap or a low-permittivity substrate between DR and the ground plane [2], [3].

Alternative approaches based on reducing the Q factor of DRs have been proposed to incur a wider impedance bandwidth, for example, carving a notch [4], drilling a cavity off DR and fill it with lower-permittivity material [5], perforating holes in DR [6]. The impedance bandwidth can be increased by exciting different modes with close resonant bands [7]. DR antennas can also be combined with other types of antennas like patch or ring slot to extend their bandwidth [8], [9].

In this letter, a broadband DR antenna is proposed. A well is drilled off the DR to perturb the original electric field distribution of the TE_{111}^{y} mode, thus reducing its Q factor. The effect of the well dimensions on the resonant frequency is studied. The coupling aperture also serves as a slot antenna, and its band is merged with that of the TE_{111}^{y} mode to achieve a wider bandwidth.

II. DIELECTRIC RESONATOR WITH A WELL

Fig. 1(a) shows a DR antenna with a well, fed by a microstrip line through aperture coupling. A rectilinear DR of dimensions $a \times b \times d$ is adhered to the ground plane, and a well of size $s_1 \times s_2 \times d$ is drilled off the DR with an offset p between the well center and the DR center. The dimension of the coupling aperture is $L_a \times w_a$, and the microstrip line extends over the aperture by length L_s.

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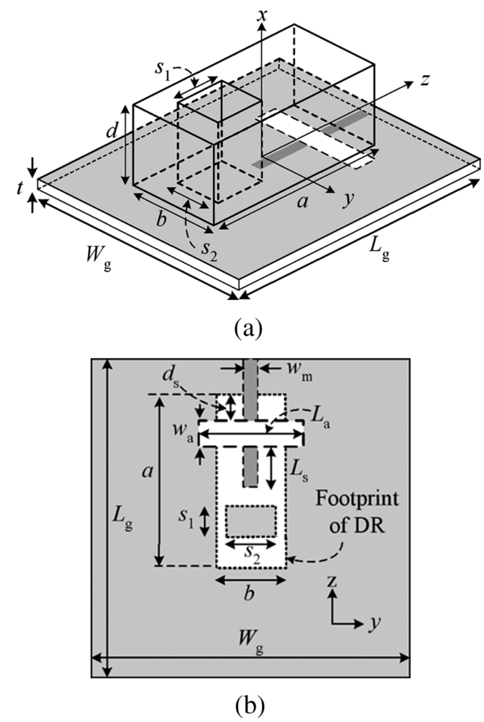

Fig. 1. Configuration of DR with an offset well: (a) schematic; (b) layout of feeding structure.

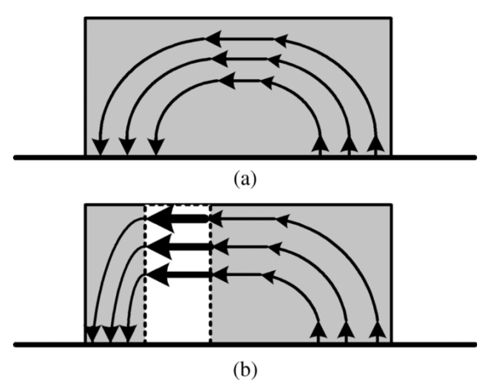

Fig. 2. Electric field distribution of TE_{111}^{y} mode in DR: (a) without well; (b) with a well.

Fig. 2 shows the electric field distribution of the TE_{111}^{y} mode within the rectilinear DR with or without the well. When a well is drilled off the DR, the electric field distribution is perturbed. Since the permittivity of the DR ($\epsilon_r \epsilon_0$) is much larger than that of the air (ϵ_0), the electric field within the well is significantly enhanced, as depicted in Fig. 2(b), enabling more effective radiation. Hence, the Q factor is decreased, and a wider bandwidth is obtained.

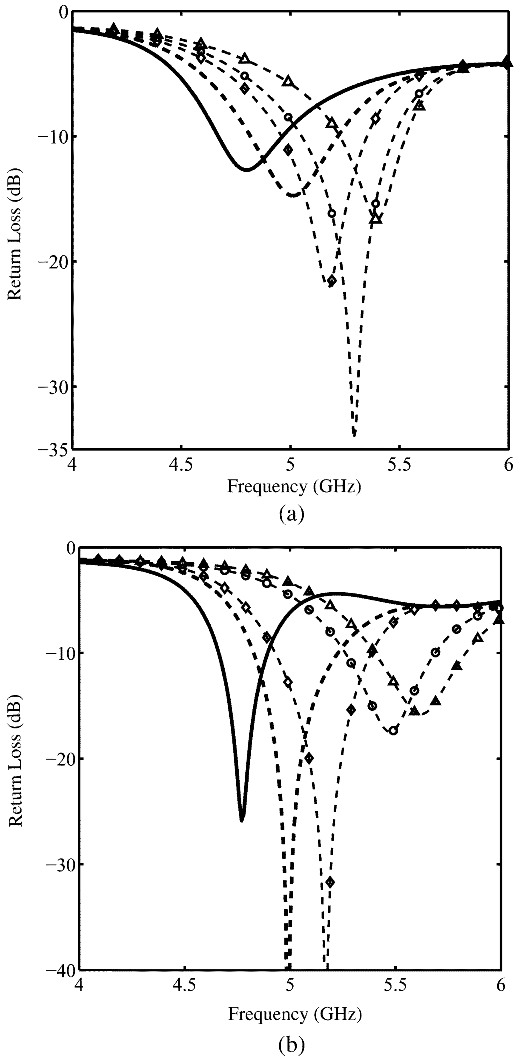

Fig. 3. Effects of well dimensions on the resonant frequency of TE^y_{111} mode, $a = 15$ mm, $b = 8$ mm, $d = 6$ mm, $\epsilon_r = 20$, $p = 0$ mm, $w_a = 1$ mm, $W_g = L_g = 50$ mm. (a) Effect of s_2, $s_1 = 1$ mm, $d_s = 4$ mm, $L_s = 7$ mm, $L_a = 8$ mm, —: without well, - - -: $s_2 = 2$ mm, -◇-: $s_2 = 3$ mm, -○-: $s_2 = 4$ mm, -△-: $s_2 = 5$ mm. (b) Effect of s_1, $s_2 = 5$ mm, $d_s = 3$ mm, $L_s = 6$ mm, $L_a = 6.5$ mm, —: $s_1 = 0.2$ mm, - - -: $s_1 = 0.5$ mm, -◇-: $s_1 = 1$ mm, -○-: $s_1 = 2$ mm, -△-: $s_1 = 3$ mm.

Fig. 3 shows the effect of well dimension on the resonant frequency. The 10-dB impedance bandwidth of the DR with a well is wider than that without well, and is increased as either s_1 or s_2 is increased. Note that the well dimensions do not affect the radiation patterns significantly.

Let $(\bar{E}_0, \bar{H}_0)$ and $(\bar{E}, \bar{H})$ be the field distributions of the TE^y_{111} mode without and with the well, respectively, ω_0 and ω be the resonant frequencies of the TE^y_{111} mode without and with the well, respectively. The resonant frequency of the DR with well can be approximated as

$$\omega = \frac{\tilde{W}_m + \tilde{W}_{eb}}{\tilde{W}_m + \tilde{W}_{ea}}\omega_0 - \frac{j \iint_S \left(\bar{H} \times \bar{E}_0^* + \bar{H}_0^* \times \bar{E}\right) \cdot d\bar{s}}{\tilde{W}_m + \tilde{W}_{ea}} \qquad (1)$$

TABLE I
EFFECT OF WELL DIMENSIONS ON THE RESONANT FREQUENCY f_r (GHz) AND THE BANDWIDTH BW (%)

s_2 (mm)	1	2	3	4	5
Δf_r (Eq. (1))	0.14	0.28	0.41	0.53	0.64
Δf_r/BW (HFSS)	0.13/6.7	0.21/8	0.37/7.5	0.49/8	0.6/5.5

Parameters (mm): $s_1 = 1$, $d_s = 4$, $L_a = 8$, $L_s = 7$.

s_1 (mm)	0.2	0.5	1	2	3
Δf_r (Eq. (1))	0.22	0.39	0.64	0.82	1.01
Δf_r/BW (HFSS)	0.23/8	0.4/8.8	0.53/8.3	0.7/7.8	0.85/7.4

Parameters (mm): $s_2 = 6$, $d_s = 3$, $L_a = 6.5$, $L_s = 6$.
Default (mm): $a = 15$, $b = 8$, $d = 6$, $p = 0$, $w_a = 1$.

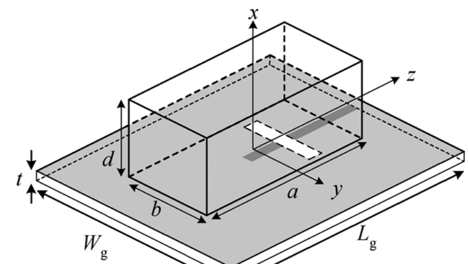

Fig. 4. Slot antenna with dielectric superstrate.

with

$$\tilde{W}_m = \iiint_V \mu \bar{H}_0^* \cdot \bar{H} dv$$

$$\tilde{W}_{ea} = \iiint_V \epsilon(\bar{r}) \bar{E} \cdot \bar{E}_0^* dv, \quad \tilde{W}_{eb} = \iiint_V \epsilon \bar{E}_0^* \cdot \bar{E} dv$$

where V is the volume of the DR without well, and S is its surface. For example, an intact DR with dimensions $18 \text{ mm} \times 8 \text{ mm} \times 5 \text{ mm}$ has the resonant frequency of 4.8 GHz and the impedance bandwidth of about 5–6%. The bandwidth can be increased to 6%–8.8% if a well is drilled off the DR.

Table I summarizes the effect of the well dimensions on the frequency shift caused by the well, where $\Delta f_r = (\omega - \omega_0)/2\pi$. Simulation results using HFSS are also compared.

III. Slot Antenna With Dielectric Superstrate

Fig. 4 shows a slot antenna covered with a finite-extent high-permittivity superstrate. The electric field gets stronger near the slot, and the width of superstrate b has stronger effect on the resonant frequency than the length a. Fig. 5 shows the effect of superstrate thickness d on the resonant frequency of the slot antenna. Larger value of d implies higher effective permittivity or shorter wavelength as viewed by the slot, hence incurring a lower resonant frequency.

IV. Results and Discussions

The input impedance can be matched by tuning the length of the extending microstrip line L_s, the aperture size $L_a \times w_a$, and the relative position between the DR and the aperture d_s. The well position p is used to fine tune the resonant frequency and the input impedance. Fig. 6 shows the measured and simulated return loss of the DR with an offset well. The 10-dB impedance

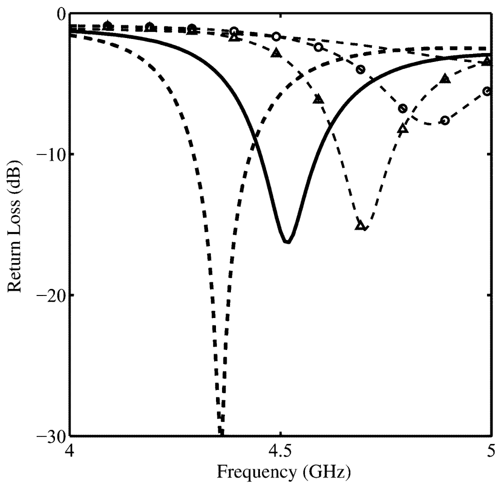

Fig. 5. Effect of superstrate thickness on the resonant frequency of slot antenna, $a = 16$ mm, $b = 8$ mm, $\epsilon_r = 20$, $d_s = 6$ mm, $w_a = 1$ mm, $L_a = 6$ mm, $L_s = 3$ mm, $W_g = L_g = 50$ mm, - - -: $d = 5.5$ mm, —: $d = 5$ mm, -△-: $d = 4.5$ mm, -○-: $d = 4$ mm.

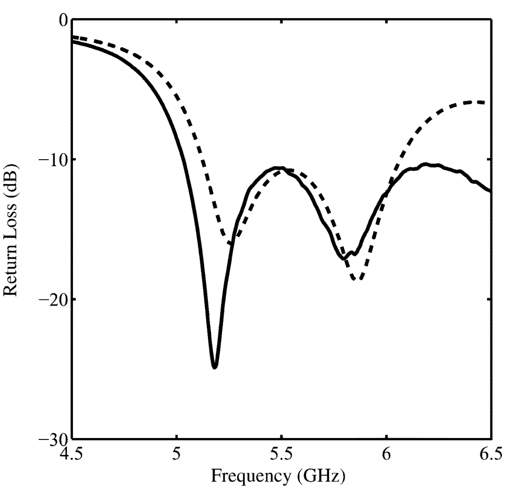

Fig. 6. Return loss of DRA with an offset well, —: measurement, - - -: simulation, $a = 18.5$ mm, $b = 8.1$ mm, $d = 5$ mm, $s_1 = 5.6$ mm, $s_2 = 4.6$ mm, $p = 2.45$ mm, $w_a = 1$ mm, $d_s = 1.7$ mm, $L_a = 7$ mm, $L_s = 2$ mm, $W_g = L_g = 60$ mm, $t = 0.6$ mm, $\epsilon_r = 20$.

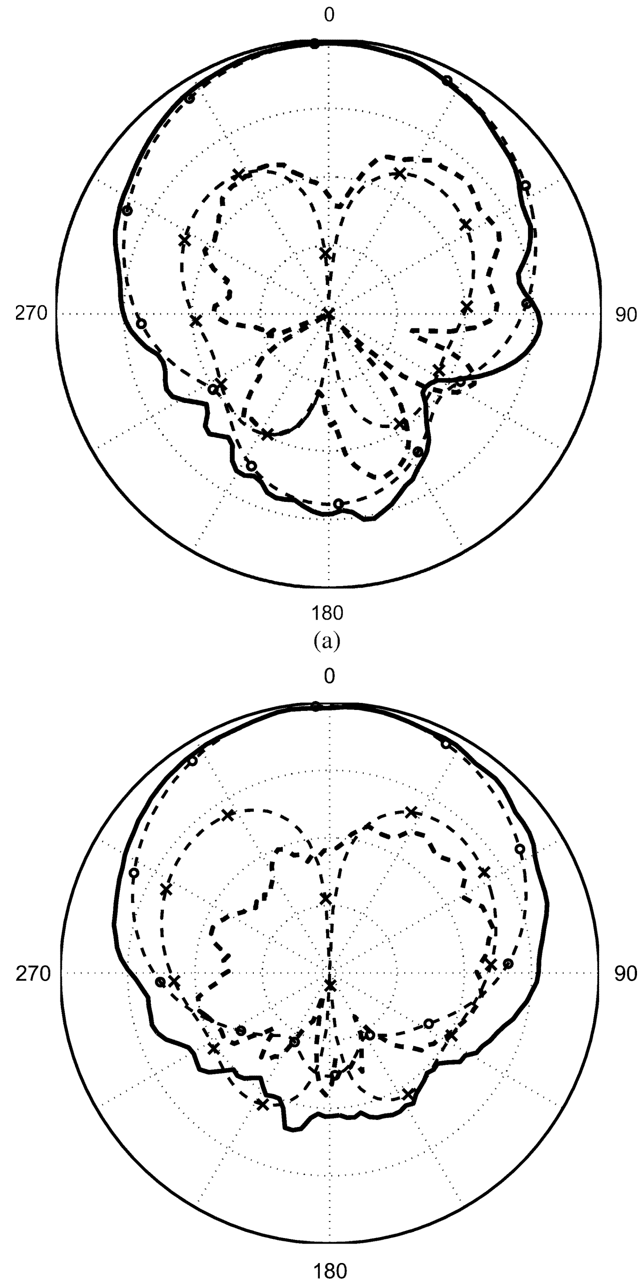

Fig. 7. Radiation patterns on the xy-plane at: (a) $f = 5.2$ GHz; (b) $f = 5.76$ GHz, —: measured E_θ, - - -: measured E_ϕ, -○-: simulated E_θ, -×-: simulated E_ϕ, 10-dB per division on radials, all parameters are the same as in Fig. 6.

bandwidth is about 18% (5–6 GHz), which covers the WLAN 802.11a bands. The two nulls are associated with the slot antenna mode and the TE^y_{111} mode of the DR, respectively.

Fig. 7(a) shows the radiation pattern associated with the slot mode. The half-power beamwidth of the E_θ pattern is about 84° $(-42^\circ \leq \phi \leq 42^\circ)$, and the cross-polarization (E_ϕ) over the half-power beamwidth is 10 dB lower than the vertical polarization. The gain is 5.6 dBi at $\phi = 0^\circ$. Fig. 7(b) shows the radiation pattern associated with the TE^y_{111} mode of the DR. The half-power beamwidth of the E_θ pattern is about 94° $(-48^\circ \leq \phi \leq 46^\circ)$, and the cross-polarization over the half-power beamwidth is 12 dB lower than the vertical polarization. The gain is 4 dBi at $\phi = 0^\circ$. Note that the back radiation associated with the slot mode is stronger than that associated with the TE^y_{111} mode. For WLAN applications, for example, this DR antenna can be mounted on the wall with the z axis pointing to ceiling, providing a broadside radiation pattern with vertical polarization on the xy-plane in front of the wall.

V. Conclusion

In this letter, the bandwidth of the TE^y_{111} mode of DR is increased by drilling a well, and is further extended by merging with the band of the slot mode, achieving a wider bandwidth of 18%(5–6 GHz). The E_θ pattern on the xy-plane has a half-power beamwidth of about 90° over the impedance bandwidth. Its gain is higher than 4 dBi. This antenna can be used in WLAN 802.11a applications.

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