(values under "Original" are calculated by Su and Wu's model with improved parameters from (1)).

The applicable frequency range of the proposed method is dependent on the geometry of the antenna. For the geometry listed in Table I the calculation is valid up to 10 GHz for gap width from 0.5 to 10 mm. Gross testing also shows that this method is robust for other geometries, e.g., with increased external Teflon thickness at $c = 3.5\ \mathrm{mm}$ the calculation error is at the order of 1 dB up to frequency of 6 GHz. These results indicate that this proposed extension of Su and Wu's theory provides an excellent approximation of reflection coefficients for coaxial dipole and slot antenna.

IV. Conclusion

This communication proposes a new model for the prediction of the input impedance of insulated coaxial dipole antenna. Along with the improved parameter calculation excellent accuracy is achieved. Agreements between theoretical calculated and simulated S_{11} confirm this model. The model performance is much superior when compared to Su and Wu's model when the width of the feed gap is $\geq 1.0\ \mathrm{mm}$. This method provides a tool for design and optimization of a microwave applicator's impedance matching performance in tissue.

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Sectorial-Beam Dielectric Resonator Antenna for WiMAX With Bent Ground Plane

Tze-Hsuan Chang and Jean-Fu Kiang

***Abstract*—A dielectric resonator (DR) antenna with a well is proposed, of which the beamwidth is increased to more than 120 ° by bending the ground plane. This DR antenna has its 10-dB return-loss band in 3.4–3.8 GHz, thus can be used as a sectorial antenna in WiMAX (3.4–3.7 GHz) base station.**

***Index Terms*—Dielectric resonator (DR).**

I. Introduction

Dielectric resonator (DR) antennas are made of low-loss ceramics, which have lower ohmic loss than metallic antennas at higher frequencies. Various types of radiation pattern can be obtained by choosing proper DR shapes and exciting proper resonant modes. For example, a rectangular DR with TE_{111} mode excited can render a broadside radiation pattern with antenna gain of about 5 dBi.

Typical bandwidth of a DR antenna is about 6%–10%, and several approaches have been proposed to increase the DR return-loss bandwidth. For example, creating discontinuity in a DR will reduce its Q factor and increase its bandwidth [1], [2]. Merging multiple resonant modes can also achieve a wider return-loss bandwidth [3].

It has been shown that the gain of a patch antenna is affected by its ground plane size [4]. The edge effect of patch antenna on radiation pattern has also been estimated using geometrical theory of diffraction (GTD) [5]. Different shapes of ground plane have been proposed to increase the antenna gain or reduce the cross polarization [6]–[9]. In [9], a short horn is mounted on the ground plane of a DR antenna to focus its radiation power and incur a narrower beamwidth in the E-plane and H-plane, thus achieving a high antenna gain of 8.5 dBi.

In this paper, two metal plates are attached to the edge of the ground plane with an angle to broaden the half-power beamwidth (HPBW) of E_θ component in the H-plane at the cost of gain reduction. Another two metal plates are adhered to steer the beam direction in the E-plane to the broadside direction so that its gain can be increased. In addition, the bandwidth of DR antenna is further increased by carving a well. This DR antenna can be used as a sectorial antenna in WiMAX base station.

II. Dielectric Resonator With a Well

Fig. 1(a) shows a DR with a well of dimensions $s_1 \times s_2 \times d$, which is fed by a microstrip line through an aperture. The microstrip line of width w_m is printed on the substrate of thickness t. The offset between DR and the aperture is d_s, the size of coupling aperture is $L_a \times w_a$, and the length of microstrip line extending over the aperture is L_s, which can be adjusted to match the input impedance of DR antenna. When the gap of the well s_1 is small, the E_z component within the well normal to the air-dielectric interface is enhanced by a factor of approximately

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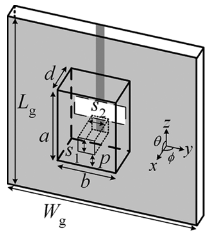
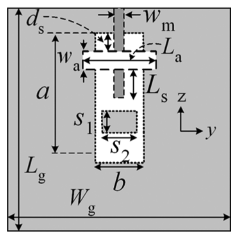
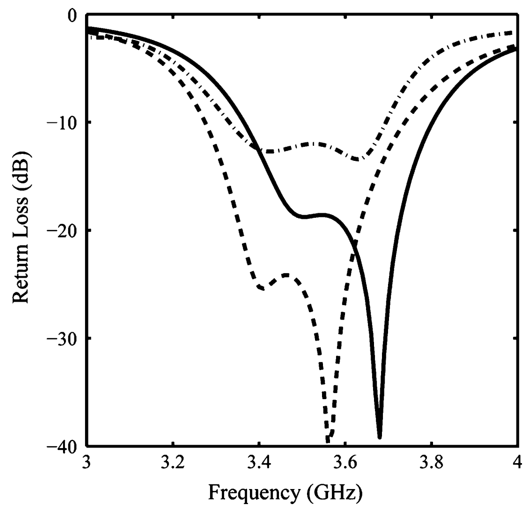


(a)

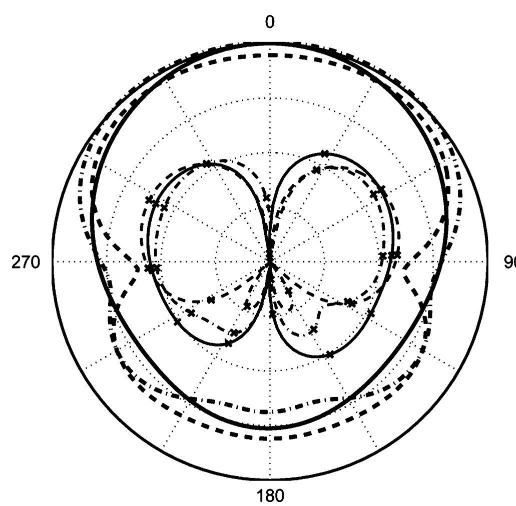


(b)

Fig. 1. (a) Configuration of DR antenna with a well. (b) Top view.

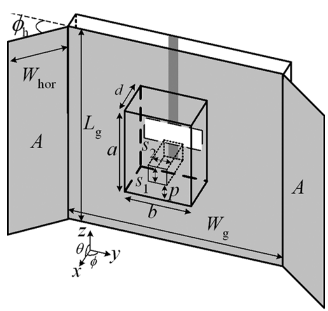


(a)

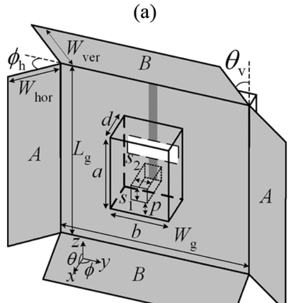


(b)

Fig. 3. (a) Return loss and (b) radiation patterns in the xy-plane of DR antennas, –: with flat ground plane, $- - -$: attaching metal plates A, $- \bullet -$: attaching metal plates A and B, $a = 20.5$ mm, $b = 13.5$ mm, $d = 10$ mm, $s_1 = 5.5$ mm, $s_2 = 9$ mm, $p = 8.5$ mm, $t = 0.6$ mm, $w_a = 1$ mm, $L_a = 12$ mm, $d_s = 2.5$ mm, $l_s = 3$ mm, $W_g = 55$ mm, $L_g = 80$ mm, $\epsilon_r = 20$, cross marks in (b) indicate cross polarization.



(a)



(b)

Fig. 2. DR antenna with a well on a finite ground plane. (a) Two plates with mark A are attached to vertical edges of ground plane. (b) Two plates with mark B are attached to horizontal edges of ground plane.

ϵ_r. The resonant frequency of the DR with a well can be calculated as in [11], which increases as s_1 or s_2 is increased.

III. Beam Broadening by Bending Ground Plane

To design a sectorial antenna for WiMAX base station, radiation pattern with wide beam in the H-plane is desired. In [6]–[9], the size and shape of ground planes are modified to increase the antenna gain, and the radiation pattern is also changed. As shown in Fig. 2(a), two metal plates (marked A) are attached to the two vertical edges of the ground plane with an inclined angle $\phi_{\rm h}$, which are used to broaden the beam in the xy-plane at the cost of gain reduction. As shown in Fig. 2(b), another two metal plates (marked B) are attached to the two horizontal edges of the ground plane with an inclined angle $\theta_{\rm v}$, which are used to steer the beam direction in the xz-plane toward the x-direction.

Fig. 3(a) shows the return loss of DR antennas with flat and bent ground planes, respectively, with all other dimensions the same. Although the input impedance is significantly affected by the bent ground plane, the 10 dB return-loss bands of all these three designs cover 3.4–3.7 GHz, which is achieved by merging the bands of TE^y_{111} mode of DR and the slot resonant mode of coupling aperture.

Fig. 3(b) shows the radiation pattern in the xy-plane. The HPBW of E_θ pattern is about 90°, and the gain is 5.3 dBi at $\phi = 0°$. When metal plates A are attached, the HPBW is increased from 90 ° to 132 °, and

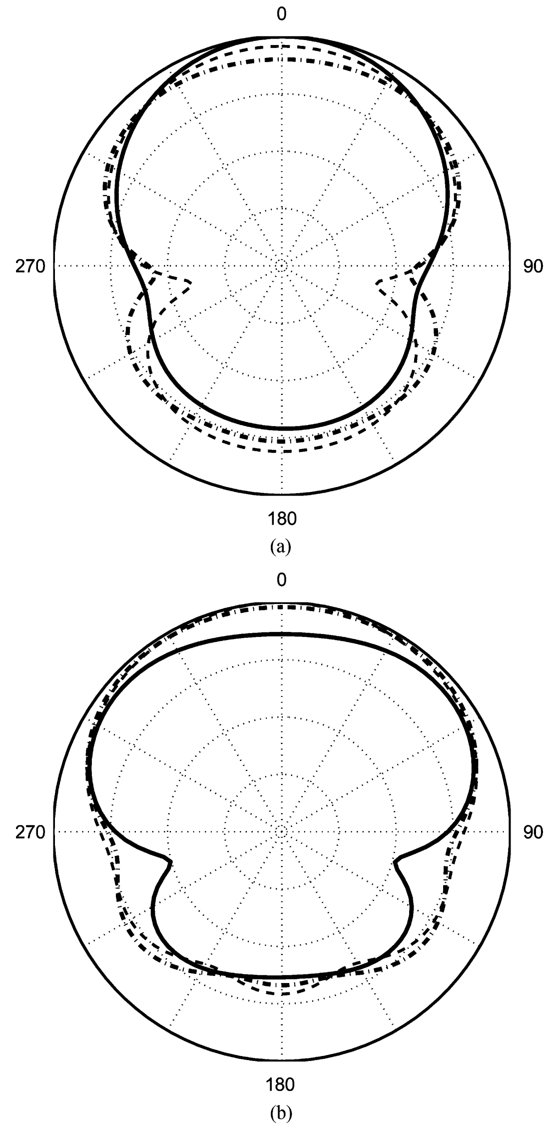


Fig. 4. Effects of bent ground plane sizes $W_{\rm hor}$ and $W_{\rm ver}$ on the E_θ pattern in xy-plane at $f = 3.4$ GHz. (a) Structure of Fig. 2(a), –: $W_{\rm hor} = 20$ mm, $- - -$: $W_{\rm hor} = 40$ mm, $- \bullet -$: $W_{\rm hor} = 60$ mm. (b) Structure of Fig. 2(b) with $W_{\rm hor} = 60$ mm, –: $W_{\rm ver} = 20$ mm, $- - -$: $W_{\rm ver} = 50$ mm, $- \bullet -$: $W_{\rm ver} = 60$ mm, 10 dB per division on radial, all parameters are the same as in Fig. 3.

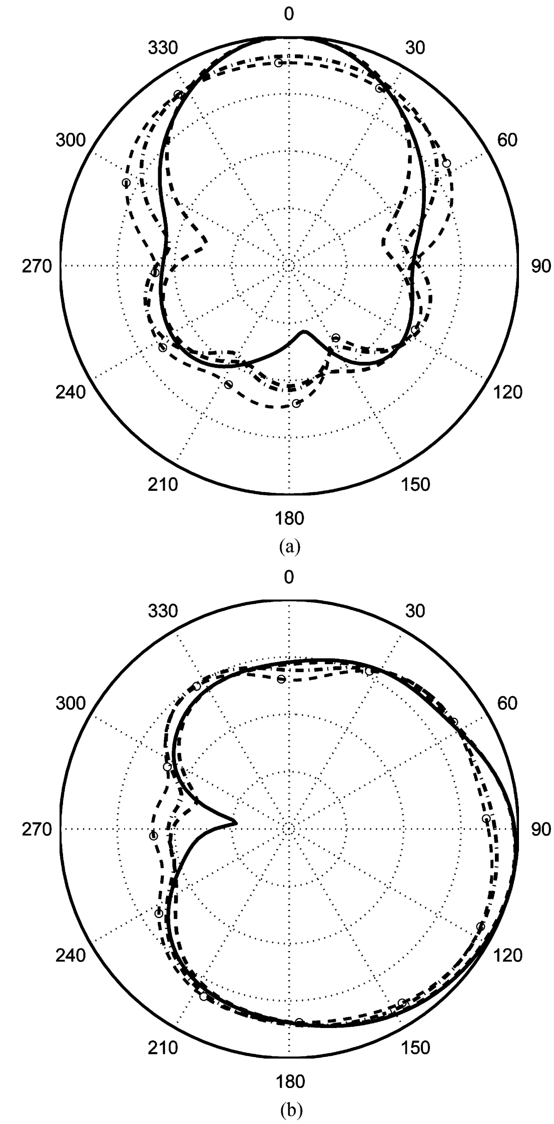


Fig. 5. Effects of bent angle $\phi_{\rm h}$ on the radiation patterns at $f = 3.7$ GHz. (a) In xy-plane. (b) In xz-plane, $a = 20$ mm, $b = 14$ mm, $d = 10$ mm, $s_1 = 5$ mm, $s_2 = 9$ mm, $p = 9$ mm, $w_a = 1$ mm, $L_a = 12.5$ mm, $d_s = 3.5$ mm, $l_s = 3$ mm, $W_{\rm hor} = 60$ mm, $W_x = 80$ mm, $W_y = 55$ mm, $\epsilon_r = 20$, –: $\phi_{\rm h} = 30°$, $- - -$: $\phi_{\rm h} = 50°$, $- \bullet -$: $\phi_{\rm h} = 70°$, $\cdots$: $\phi_{\rm h} = 85°$.

the gain decreases from 4.5 to 2.3 dBi. Note that the cross polarization levels with the bent ground plane is similar to that with a flat one.

Fig. 4 shows the effects of ground plane size $W_{\rm hor}$ and $W_{\rm ver}$ on the E_θ pattern. When using the structure shown in Fig. 2(a), the 3-dB beamwidth of E_θ pattern in the xy-plane is increased from 80° to 130° when $W_{\rm hor}$ is increased from 20 to 60 mm, and the gain is reduced by 4 dB, as shown in Fig. 4(a). The E_θ pattern in the xz-plane is broadened and tilted. When using the structure shown in Fig. 2(b), the antenna gain in the x-direction is increased from 0 to 5.5 dBi when $W_{\rm ver}$ is increased from 20 to 50 mm, and the HPBW of E_θ pattern is about 130°. Note that the beamwidth of a typical sectorial antenna is about 120 °.

Fig. 5 shows the effects of $\phi_{\rm h}$ on radiation patterns. The 3-dB beamwidth changes slightly when $30° \leq \phi_{\rm h} \leq 50°$, and significantly increases from 45 ° to 144 ° when $50° \leq \phi_{\rm h} \leq 85°$. However, the gain at $\phi = 0°$ is reduced to less than 3 dBi because the radiated power is distributed over a wider angular range and the main beam of E_θ pattern in the xz-plane is steered away from $\theta = 90°$.

One way to increase the gain of E_θ pattern in the xy-plane is to steer the main beam in the xz-plane toward $\theta = 90°$, which can be achieved by attaching two metal plates marked B as shown in Fig. 2(b). As shown in Fig. 6, the E_θ pattern is significantly disturbed in the xy-plane, and the antenna gain at $\phi = 0°$ is reduced. A broadside radiation pattern is achieved again when $\theta_{\rm v}$ is increased to 60 °. A larger HPBW with reasonably high gain near $\phi = \pm 60°$ is obtained with $60° \leq \theta_{\rm v} \leq 70°$.

As for the E_θ pattern in the xz-plane, the pattern exhibits two lobes when $30° \leq \theta_{\rm v} \leq 50°$, and exhibits one beam pointing at $\theta = 90°$ when $\theta_{\rm v} \geq 60°$.

IV. Final Design

Fig. 7 shows the return loss of the DR antenna on a bent ground plane. The measured 10-dB return-loss band covers 3.38–3.85 GHz,

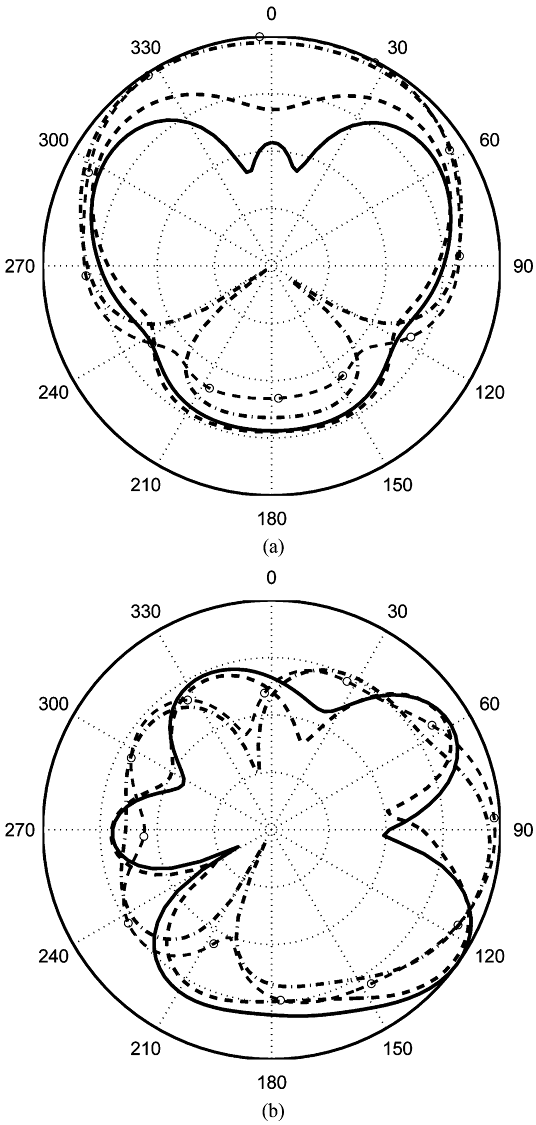


Fig. 6. Effects of bent angle $\theta_{\rm v}$ on the radiation patterns at $f = 3.7$ GHz (a) In xy-plane. (b) In xz-plane, $a = 20.5$ mm, $b = 13.5$ mm, $d = 10$ mm, $s_1 = 5$ mm, $s_2 = 9$ mm, $w_a = 1$ mm, $L_a = 12.5$ mm, $d_s = 2.5$ mm, $l_s = 3$ mm, $W_{\rm hor} = W_{\rm ver} = 60$ mm, $\phi_{\rm h} = 85°$, $W_g = 80$ mm, $W_y = 55$ mm, $\epsilon_r = 20$, –: $\theta_{\rm v} = 30°$, — — —: $\theta_{\rm v} = 40°$, — • —: $\theta_{\rm v} = 70°$, ···: $\theta_{\rm v} = 85°$.

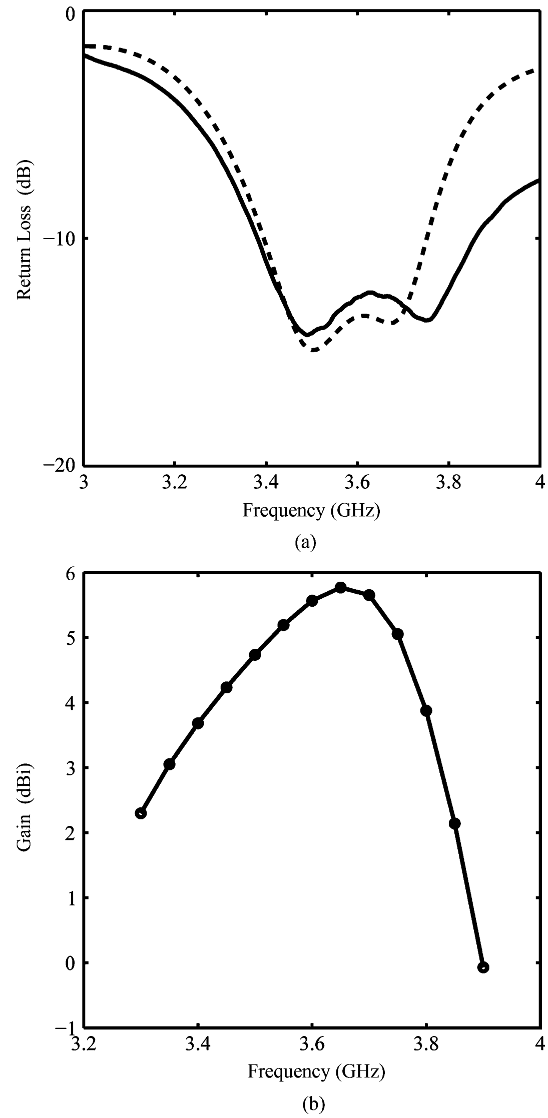


Fig. 7. Return loss of DR antenna with broadside radiation pattern, $a = 21$ mm, $b = 13.5$ mm, $d = 9.7$ mm, $s_1 = 5.4$ mm, $s_2 = 9.1$ mm, $p = 8.5$ mm, $w_a = 1$ mm, $L_a = 12.5$ mm, $d_s = 2.6$ mm, $l_s = 3$ mm, $W_{\rm ver} = W_{\rm hor} = 60$ mm, $\phi_{\rm h} = 85°$, $\theta_{\rm v} = 75°$, $\epsilon_r = 20$, $W_x = 80$ mm, $W_y = 55$ mm, –: measurement, — — —: simulation. (b) Antenna gain at ($\theta = 90°$, $\phi = 0°$).

wider than the simulation result. The wide return-loss band is accomplished by merging bands associated with the slot mode of aperture and the TE^y_{111} mode of DR. Fig. 8 shows the radiation patterns in the xy-plane and xz-plane, respectively. The HPBW of vertical polarization in the xy-plane is about 120 ° with $\phi_{\rm h} = 85°$. The antenna gain is more than 5 dBi, and the front-to-back ratio is 10 dB. Over the HPBW, the cross-polarization (E_ϕ) is 5 dB less than the vertical polarization. In the xz-plane, the beam is steered to point at $\theta = 90°$ due to the attached plates B with $\theta_{\rm v} = 75$ °. It is observed that the measured cross-polarization level is higher than that of simulation, possibly due to imperfect alignment when adhering metal plates to edges of the flat ground plane.

Fig. 7(b) shows the antenna gain, which varies from 3.6 to 5.6 dBi over 3.4–3.7 GHz, and drops rapidly as the frequency is higher than 3.75 GHz. The radiation efficiency is more than 80% over the 10 dB return-loss band. The microstrip line on the substrate with $\tan\delta = 0.02$ contributes about 0.4 dB of insertion loss at 3.6 GHz. When the DR operates near the higher band edge, the operating frequency is quite different from the resonant frequency of TE^y_{111} mode, hence the radiation pattern is distorted and the gain in the x-direction is reduced.

V. Conclusion

A wideband DR antenna embedding a well and with bent ground plane is proposed. The HPBW of E_θ pattern is increased by bending the ground plane by 85° horizontally. The main beam of E_θ pattern in the xz-plane is steered toward $\theta = 90°$ by bending the ground plane vertically. The 10-dB return-loss band covers 3.4–3.8 GHz, and the HPBW of E_θ pattern is more than 120 °, rendering this DR antenna suitable as a sectorial antenna in WiMAX (3.4–3.7 GHz) base station.

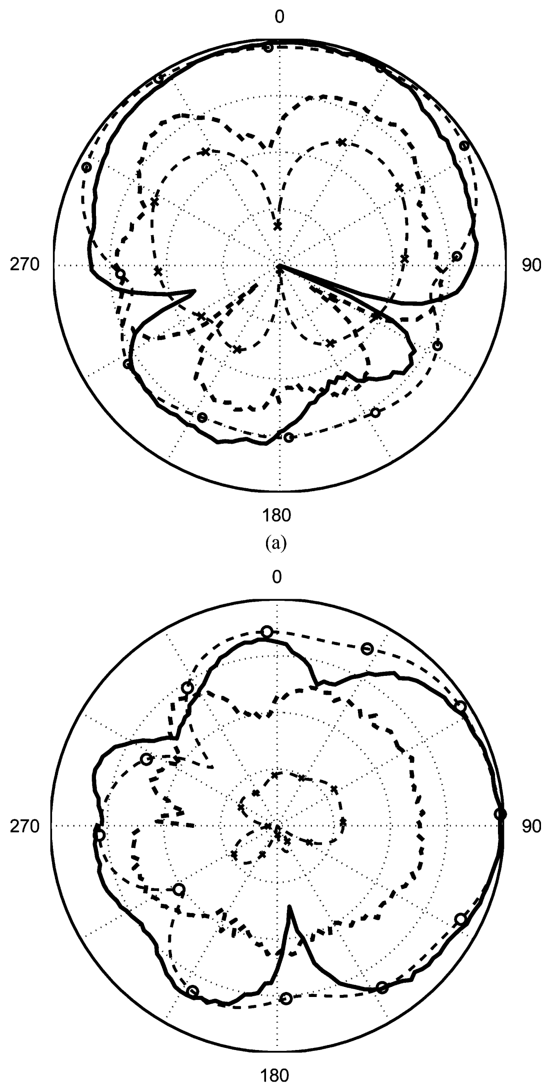


Fig. 8. Measured radiation patterns of the DR antenna in (a) xy-plane. (b) xz-plane, all parameters are the same as in Fig. 7, 10 dB per division on the radial, –: measured E_θ, — — —: measured E_ϕ, $- \circ -$: simulated E_θ, $- \times -$: simulated E_ϕ.

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Lateral Waves Over Planar Earth: A Validity Check of a Proposed Solution

Vassilios A. Houdzoumis

***Abstract*—A newly proposed approximate solution to the problem of lateral waves over planar Earth is checked in its asymptotic range for large distances from the source. Upon analyzing the integral expression of the exact solution, it is shown that the proposed solution introduces an error factor. This factor becomes negligible for large values of Earth's complex relative permittivity.**

***Index Terms*—Dipole radiation, surface waves, Earth.**

I. INTRODUCTION

In a recent paper, Collin [1] presented a detailed review of the problem of radiation of a vertical infinitesimal dipole over a lossy planar Earth, with special reference to the original work of Sommerfeld. In the same paper, the author elaborated a new approximate solution to this old problem, starting from standard integral expressions for the exact solution.

Having engaged the continuous interest of physicists and engineers since Sommerfeld's time, the radiation of a vertical infinitesimal dipole over planar Earth constitutes undoubtedly one of the most important and extensively studied problems of electromagnetic wave theory. Consequently, now that a new approximate solution for this problem is being proposed, the examination of its validity appears fully warranted, if not imperative.

The interest in this problem lies mostly in the special case where both the source dipole and the point of observation are on or close to the interface of the two media. This is because, in this case, neither the application of the reflection coefficient nor the method of images

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