Approximate surface-current distributions of rectangular dipole antennas

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Abstract

An approximate surface-current distribution of the rectangular dipole antennas, composed of two linear-currents along the antenna edges and a uniform surface-current within the antenna bodies, is proposed. It presents some new insights to planar dipole antennas, and could also be used for fast, explicit and Ultra-wideband predictions of their radiation patterns. The averaged errors between the calculated results based on the proposed distributions and the full-wave results are respectively 0.075 dB on the H-plane and 2.95º on the E-plane. From the explicit results, some design considerations for stable radiation patterns are presented.

1. Introduction

With the fast development of Ultra-wideband (UWB) technology for future wireless communications, various radars and airborne applications, high-performance UWB antennas were found to be a key component in these systems and lots of efforts were devoted on this topic [1-4]. Among the possible candidates reported in the literatures, planar dipole antennas were considered to be highly prospective for their attractive merits as wide impedance bandwidth and symmetric E-plane radiation patterns [5-6].

Stable radiation patterns within the desired operating bandwidth are important considerations for many UWB applications. However, the radiation patterns of planar dipole antennas could not be readily obtained from some simple and explicit equations, thus a half-empirical optimization process usually needs to be performed at the assistance of full-wave simulators, which make the design of planar dipole antennas much more complicated and laborious. More importantly, the results obtained by the full-wave simulations usually obscure the physical fundamentals and present few insights to many novel dipole antennas. Thus the presented explanations in the literatures are mostly based on the personal understandings as well as qualitative.

In this paper, an approximate surface-current distribution of rectangular dipole antennas is proposed. It presents some new insights to planar dipole antennas, and could be also for fast, explicit and Ultra-wideband calculations of the radiation patterns. The calculated results based on the proposed distributions are verified by comparison with the full-wave results. From the explicit results, some design considerations for stable radiation patterns are presented.

2. Approximate surface-current distribution

The surface-currents of planar dipole antennas usually gather at their geometrical edges and are remarkably weakened within their bodies. Therefore, for rectangular dipole antennas with single- and trident- feedings in Fig. 1 [7-8], the surface-current distributions could be approximated as

$$\begin{aligned}
&\vec{J}(\vec{r}') = \vec{J}_1(\vec{r}') + \vec{J}_2(\vec{r}') \\
&\vec{J}_1(\vec{r}') = \hat{z}\frac{a}{2}\sin\left[k\left(l-|z'|\right)\right]\delta(y') \\
&\qquad\left[\delta(x'-w)+\delta(x'+w)\right] \\
&\vec{J}_2(\vec{r}') = \hat{z}\frac{1-a}{2w}\sin\left[k\left(l-|z'|\right)\right]\delta(y') \\
&\quad -w \le x \le w, -l \le z \le l
\end{aligned} \tag{1}$$

Where $\vec{J}_1$ depicts summations of two linear-currents along the antenna edges, $\vec{J}_2$ is the uniform surface-current within antenna bodies, and constant a is the normalized amplitude of $\vec{J}_1$. With the approximate surface-current distributions in Equation 1, the corresponding radiation patterns of rectangular monopole antennas could be easily obtained as [9]

$$\vec{E}(\vec{r}) = i\omega\mu\left(II + \frac{1}{k^2}\nabla\nabla\right)\bullet\iiint dV'\frac{e^{ik|\vec{r}-\vec{r}'|}}{4\pi|\vec{r}-\vec{r}'|}\vec{J}(\vec{r}') \tag{2}$$

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After using the far-field approximations, the H-plane and E-plane radiation patterns could be explicitly calculated as

$$\vec{E} = -\hat{\theta}\frac{i\omega\mu e^{ikr}}{2\pi r}\frac{\left[\cos\left(kl\cos\theta\right)-\cos\left(kl\right)\right]}{k\sin\theta}\left[a\cos\left(kw\sin\theta\cos\varphi\right)+\frac{1-a}{w}\frac{\sin\left(kw\sin\theta\cos\varphi\right)}{k\sin\theta\cos\varphi}\right] \quad (3)$$

3. Calculated and simulated results

To verify the predictions above, two rectangular dipole antennas with single- and trident- feedings were selected as the example antennas as shown in Fig.1, and the structural parameters are illustrated in Table 1. Radiation patterns of the two antennas were simulated by the full-wave simulator CST MWS and also calculated by using the proposed surface-current distributions in Equations (1) and (3). The simulated and calculated results are summarized in Table 2 and Table 3. Calculated and simulated radiation patterns of the single-fed dipole antenna are also presented in Fig. 2. Close agreements between the full-wave and approximate results could be observed for both H-plane and E-plane patterns: The averaged error between them is 0.075 dB on the H-plane; and the calculated beamwidths are 2.95º larger than the simulated ones on the E-plane on average. The differences on the E-plane patterns are mainly caused by the neglect of the contributions of the x-axially linear-currents and surface-currents along the antenna edges, which also limit the highest frequency applicable by the proposed distributions in Equation (1)

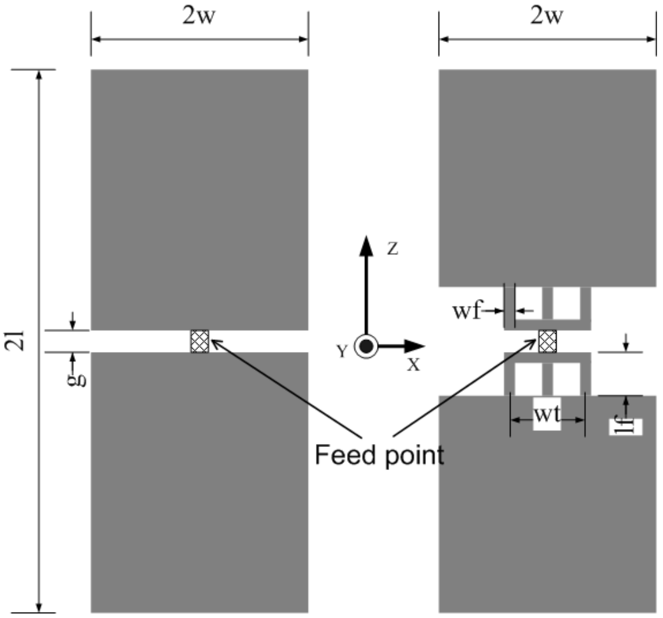

Fig. 1. Structures of the planar dipole antennas with single- and trident- feedings.

TABLE I
PARAMETERS OF THE RECTANGULAR DIPOLE ANTENNAS WITH SINGLE- AND TRIDENT- FEEDINGS

Parameters	Value	Parameters	Value
w	8.3 mm	l	24.5 mm
g	1.0 mm	wf	1.0 mm
wt	6.0 mm	lf	2.5 mm

TABLE II
CALCULATED AND SIMULATED NON-UNIFORMITY OF THE H-PLANE (X-Y PLANE) RADIATION PATTERNS OF THE PLANAR DIPOLE ANTENNAS

	Freq./GHz	2.0	3.0	4.0	5.0	6.0
Single Feeding	Cal./dB (a=0.32)	0.29	0.66	1.19	1.89	2.80
	Sim./dB	0.23	0.56	1.08	1.87	2.82
Trident Feeding	Cal./dB (a=0.27)	0.27	0.62	1.11	1.77	2.61
	Sim./dB	0.21	0.50	0.97	1.66	2.62

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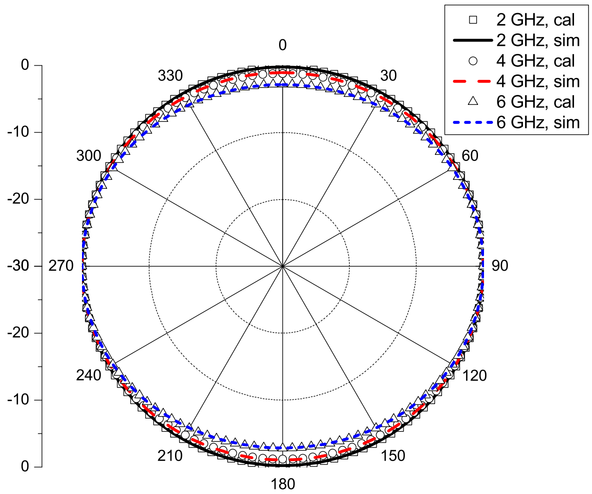
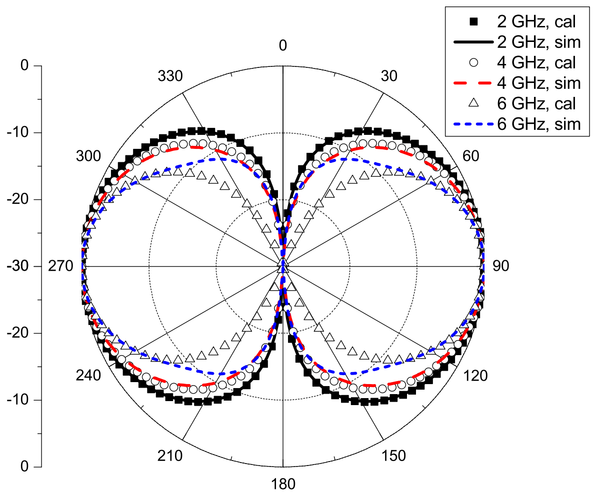
TABLE III

CALCULATED AND SIMULATED 3-dB BEAMWIDTH OF THE E-PLANE (Y-Z PLANE) RADIATION PATTERNS OF THE PLANAR DIPOLE ANTENNAS

	2 GHz	3 GHz	4 GHz	5 GHz	6 GHz
Calculated Both of feedings	84.8°	78.6°	69.8°	59.8°	49.0°
Simulated Single feeding	83.3°	75.7°	65.3°	55.7°	47.1°
Simulated Trident feeding	83.6°	75.4°	65.5°	55.7°	47.2°



(a)



(b)

Fig. 2. Simulated and calculated radiation patterns of the planar dipole antenna with single-feeding: (a) H-plane, (b) E-plane.

Equation 3 could be further divided into E-plane and H-plane cases. The normalized E-plane radiation patterns with the condition $2l \le 1.25\lambda_H$ could be calculated as

$$\tilde{E}_{\max}\left(\theta = 90°, \varphi = 90°\right) = 1$$
$$\tilde{E}\left(\theta = others, \varphi = 90°\right) = \frac{\cos\left(kl\cos\theta\right) - \cos\left(kl\right)}{\left[1 - \cos\left(kl\right)\right]\sin\theta} \quad (4)$$

Obviously, the E-plane radiation patterns are mainly determined by the height of rectangular dipole antennas and the operating frequency regardless of the feeding structures, which could be verified by the results in Table 3.

While the normalized H-plane radiation patterns with the condition could be calculated as

$$\tilde{E}_{\max}\left(\theta=90°,\varphi=90°\right)=1$$

$$\tilde{E}_{\min}\left(\theta=90°,\varphi=0°\right)=a\cos\left(kw\right)+\frac{\left(1-a\right)\sin\left(kw\right)}{kw} \tag{5}$$

The H-plane radiation patterns are determined by the width of rectangular dipole antennas, the operating frequency and the constant a. It is interesting to notice that the feeding structures have noticeable influences on the surface-current distributions as the constant a increases a little with the trident-feeding, and the uniformity of H-plane patterns is also improved by ~0.2 dB in the frequency band above 5 GHz.

4. Conclusion

An approximate surface-current distribution of the rectangular dipole antennas, composed of the linear currents along the two edges and the uniform surface currents within antenna bodies, is presented. The errors between the calculated results based on the proposed distribution and the full-wave results are respectively 0.075 dB on the H-plane and 2.95º on the E-plane. In order to obtain stable radiation patterns, the height and width of planar dipole antennas should comply with the restrictions associated with the wavelength of the highest operating frequency. The feeding structures could noticeably influence the uniformity of the H-plane patterns while have little influence on the E-plane patterns.

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