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WIDEBAND OMNIDIRECTIONAL PRINTED DIPOLE ANTENNA WITH COUPLING FEED FOR WIRELESS COMMUNICATION APPLICATIONS

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Abstract—The wideband and omnidirectional performance of a printed dipole antenna with a novel coupling feed structure is presented. Besides using printed dipole for omnidirectional radiation patterns, the coupling feed structure, which includes the transmission line coupling to a slot line to effectively improve the impedance matching, can be used for bandwidth enhancement. A wideband impedance characteristic of about 45.6% for VSWR ≤ 2 ranging from 1.54 to 2.45 GHz is obtained. The omnidirectional radiation patterns in the whole operation bands are achieved which the un-roundness in H-plane is less than 1.6 dB. It is sufficient for accommodating recent wireless communication services such as DCS1800, PCS1900, UMTS, IMT2000, Wibro, etc. Furthermore, the proposed antenna should be a good candidate as a unit of the omnidirectional array. A prototype has been fabricated and tested, and the experimental results validate the design procedure.

1. INTRODUCTION

Rapid development in modern wireless communications raises the demand for antennas operating at wide frequency bands to facilitate the application for various needs. Printed architectures have been widely investigated in previous literatures [1, 2] and are attractive for their conformability, small size, easy implementation and cost effectiveness. The antennas with omnidirectional characteristic have

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been widely used in the applications of mobile communication, indoor radio and wireless communication system. Printed dipole antennas which have the omnidirectional pattern in the horizontal plane have become widely investigated and are attractive for their configuration advantages, such as low cost, conformity, and ease of manufacture [3–8]. However, a common drawback of the printed dipole antennas is that the bandwidth of those antennas is generally narrow and insufficient for many applications. Many attempts have been made to widen the bandwidth of the printed dipole antennas, including usage of double-sided printed dipoles [9], printed dipoles with PBG structure [10] and integrated with balun [11, 12]. By using the V-shaped ground, a miniaturized wideband printed dipole antenna in [13] achieve an enhanced bandwidth of 36%. For wideband applications, some rectangle apertures etching onto the antenna surface is adopted [14], and a 47.8% and a 15.1% bandwidth are obtained at L-band and S-band, respectively. A printed dipole antenna with a parasitic strip is proposed in [15], which an enhanced bandwidth of 41.3% is achieved. Some of the omnidirectional printed dipole antennas with bandwidth about 58% [16] and 93% [17] are proposed; however, the omnidirectional radiation characteristics in H-plane would not be so good owing to the effects of the feeding line and the coaxial cable. Due to the asymmetry of the antenna unit structure in H-plane, the un-roundness of the array composed of the units will become worse. That is to say, the antennas proposed in [16, 17] would not be good candidates as the unit of the omnidirectional array.

In this paper, we propose a design of printed dipole antenna with a novel coupling feed structure for bandwidth enhancement. Using the coupling feed structure which includes the transmission line coupling to the slot line to effectively improve the impedance matching, the proposed antenna can achieve an operating bandwidth of about 45.6% ranging from 1.54 GHz to 2.45 GHz (VSWR $\leq$ 2). In particular, good omnidirectional radiation characteristic in the whole operation bands is also obtained by using the symmetry of the antenna structure including the feeding line in x-y plane, which the un-roundness in H-plane is less than 1.6 dB. With this omnidirectional radiation and the wideband characteristics, it is an excellent candidate for the recent wireless communication services such as DCS1800, PCS1900, UMTS, IMT2000, and Wibro, etc.. Furthermore, the proposed antenna should be a good candidate as the unit of the omnidirectional array. Design considerations of the proposed antenna are described in the article. Results of the constructed prototype are presented and discussed.

2. ANTENNA DESIGN AND DISCUSSION

The configuration of the proposed antenna and coordinate system is shown in Figure 1. The antenna mainly comprises a dipole with C-shaped arms and the coupling feed structure which both printed on a PTFE substrate with the relative permittivity (ε_r) of 2.65, the thickness of $H = 1$ mm and the loss tangent of 0.002. The two C-shaped arms of the dipole are printed on the same side of the substrate (front side) with the width of Wd and length of Ld which is about a quarter of the medium wavelength referred to the lower frequency of the antenna.

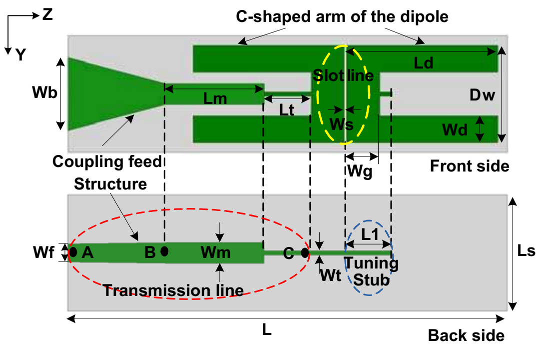


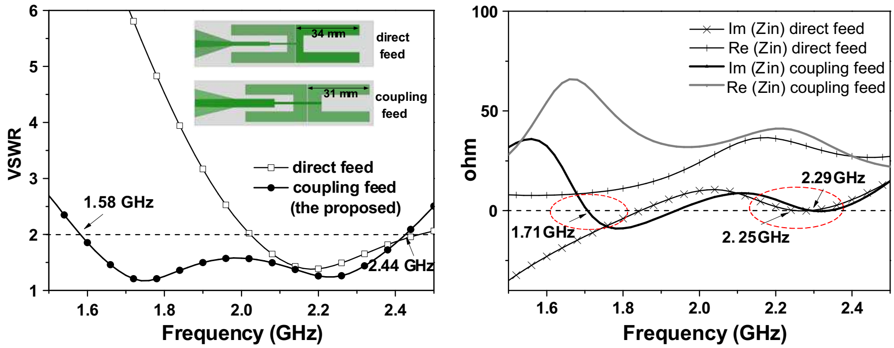
Figure 1. Geometry of the proposed design.

The coupling feed structure as shown in Figure 1 is designed into three parts: the transmission line, a slot line and the tuning stub. The transmission line is composed of two parts as designated in the figure as point A, point B and point C. From point B to point C are two balanced parallel transmission lines with length of Lm and Lt which feed to an arm of the dipole directly. The transition line with linear change from point A to point B is employed to provide an unbalance-balance transition between the SMA connector and the balanced parallel transmission line. One end (point A) of the transmission line is connected to the SMA connector and the other end (point C) is joined to the edge of the coupling strip which couple to the slot line. The electrical energy transmits from the SMA connector to the transmission line and then the slot line. Once the electric energy passes through the slot line, coupling effect upon the two printed C-shaped arms of the dipole occurs. In addition, the width of the two parallel transmission lines are Wm and Wt, respectively, which corresponding to the characteristic impedance of 42 Ω matching to the impedance of the transition line with linear change at point B and 122 Ω matching to the characteristic impedance of the slot line that can be calculated using the empirical formula presented in [18]. The slot line also acts like an inductive reactance. In order to compensate of the inductive reactance, the tuning stub acted like a capacitive reactance is joined to form an open transmission line. Wide impedance bandwidth can be achieved, when the capacitive reactance can balance off the inductive reactance by adjusting the width of the slot line (Ws) and the length of the tuning stub ($L1$). The detailed dimensions of the antenna are given in Figure 1, and the final optimal antenna parameters are shown in Table 1.

Table 1. Dimensions of proposed antenna.

Parameters	Wd	Ld	Wg	Ws	Ls	Wt	Lt
Values/mm	5.5	31	6.8	0.5	20	0.8	9.5
Parameters	Wm	Lm	Wb	Wf	L	$L1$	H
Values/mm	4.3	20	15	2.8	89.5	7	1

In the following, details of the operating principle of the proposed antenna are discussed. The simulated results are obtained by using the Ansoft High-Frequency Structure Simulator (HFSS.13) simulation software. Figure 2(a) shows the simulated VSWR against frequency for the designed antenna. It can be observed that for VSWR ≤ 2, the impedance bandwidths are from 1.58 to 2.44 GHz, which clearly cover the required bandwidths of the DCS1800, PCS1900, UMTS, IMT2000, and Wibro applications. Meanwhile, to examine the effects of the coupling feed structure to the antenna's matching condition, the simulated results of VSWR for the case with direct feed are also studied and plotted in Figure 2(a). Obviously, for the case with direct feed, it is clearly seen that the impedance bandwidths are from 2.0 to 2.45 GHz for VSWR ≤ 2, which is far from covering the lower band. The input resistance and reactance for the two cases are also analyzed and shown in Figure 2(b). In the figure, it can be observed that for the case with direct feed, there is only one resonance at 2.25 GHz (zero reactance) seen, which correspond to the dipole mode. For the case of the proposed design, one more resonance at 1.71 GHz which corresponds to the coupling feed mode occurs besides the resonance at 2.29 GHz which correspond to the dipole mode. It is noted that the dipole and the coupling-feed modes are coupled together and form a wideband bandwidth as shown in Figure 2(a). Furthermore, the length of the arm of the dipole in the case for direct feed is 34 mm, which is longer than that in the case for coupling feed (31 mm), as shown in the figure. These results clearly indicate that existence of



(a) (b)

Figure 2. Comparison between simulated (a) VSWR and (b) input impedance with the direct feed and the proposed antenna.

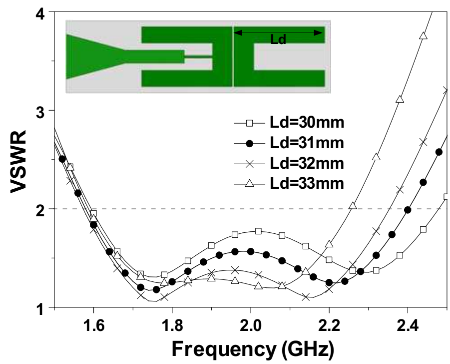


Figure 3. Simulated VSWR for the proposed antenna as a function of the length of the dipole arm.

the coupling feed can not only significantly improve the impedance matching and enhance the impedance bandwidth through achieving one more resonance, but also decrease the dimension of the antenna.

The effects of the antenna parameters on the antenna's impedance characteristics are also studied. Figure 3 shows the simulated VSWR for the length of the dipole arm (Ld) varied from 30 to 33 mm. In the figure, it can be seen that the parameter (Ld) has very small effects on the antenna's lower band; on the other hand, there are significant effects on the upper band, which the impedance matching is to deteriorate with decreases of the parameters and the excited resonant mode is shifted to lower frequencies with increases of the parameters. With $Ld = 31\,\mathrm{mm}$, the optimal results are obtained for the proposed antenna.

Figure 4 shows the simulated VSWR for the width of the slot line (Ws) varied from 0.3 to 0.9 mm. In the figure, it can be observed that with a decrease in Ws, the upper band resonant point is shifted to the lower frequency whereas that of the lower band is almost unchanged. The case of 0.5 mm is the proposed optimal design. The results for the length of the open-stub ($L1$) varied from 6 to 9 mm are presented in Figure 5. It is also noted that the low resonant point shifts to the lower frequency when $L1$ increases. Meanwhile, the impedance matching of the operation band is deteriorating. The case of 7 mm is the proposed optimal design. These results clearly indicate that these parameters all have great effects on the impedance matching of the antenna; however, the upper resonance and the lower resonance are mainly affected by the dipole and the coupling feed structure, respectively, which corresponds to the results obtained in Figure 2.

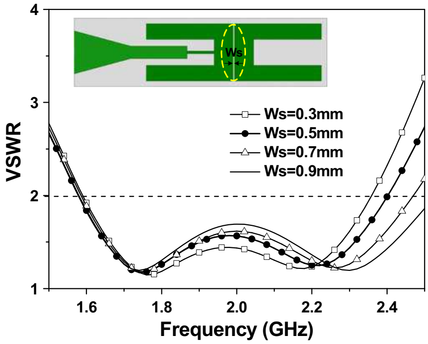


Figure 4. Simulated VSWR for the proposed antenna as a function of the width of the slot line.

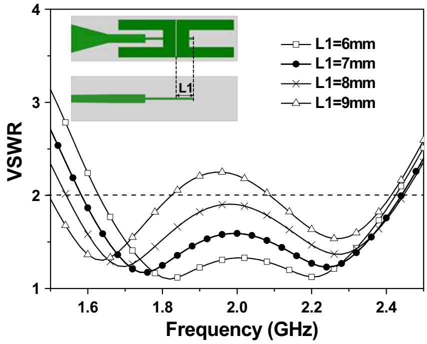


Figure 5. Simulated VSWR for the proposed antenna as a function of the length of the tuning stub.

3. EXPERIMENTAL RESULTS

A prototype of the proposed antenna was fabricated according to these design parameters, as shown in Figure 6. The measured results are obtained with Agilent E8363B network analyzer and an anechoic chamber. Figure 7 presents the measured and simulated VSWR against the frequency for this antenna. Obviously, wideband operations are obtained. The measured result matches well with the simulated

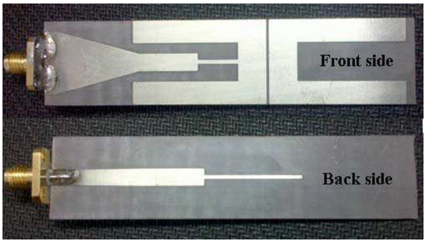


Figure 6. Photograph of the proposed antenna.

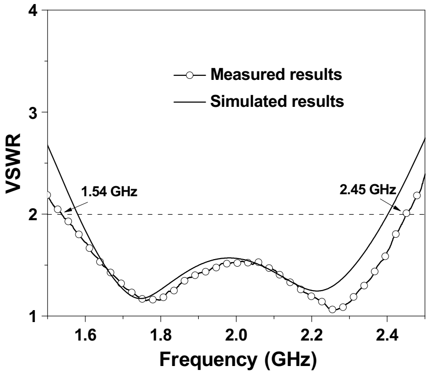


Figure 7. Simulated and measured VSWR against frequency.

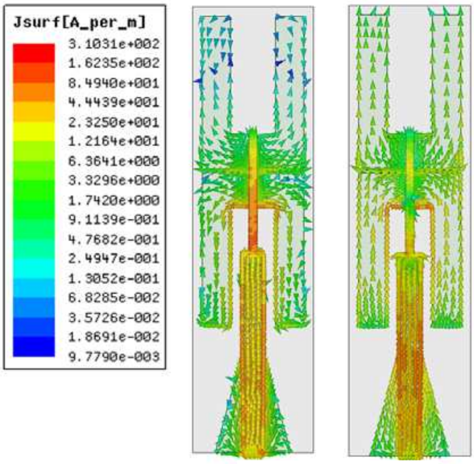


Figure 8. Current distribution on the proposed antenna at the (a) 1.74 GHz, (b) 2.22 GHz.

one. A slight disagreement is due to the imperfect constructed prototype. For VSWR ≤ 2, the measured impedance bandwidth is about 45.6% from 1.54 to 2.45 GHz centered at 1.995 GHz.

In order to further study the wideband operation property of the proposed antenna, surface current distributions at the frequencies of 1.74 and 2.22 GHz are given in Figure 8. It can be clearly seen from the figure that the current distributions are different in the two bands.

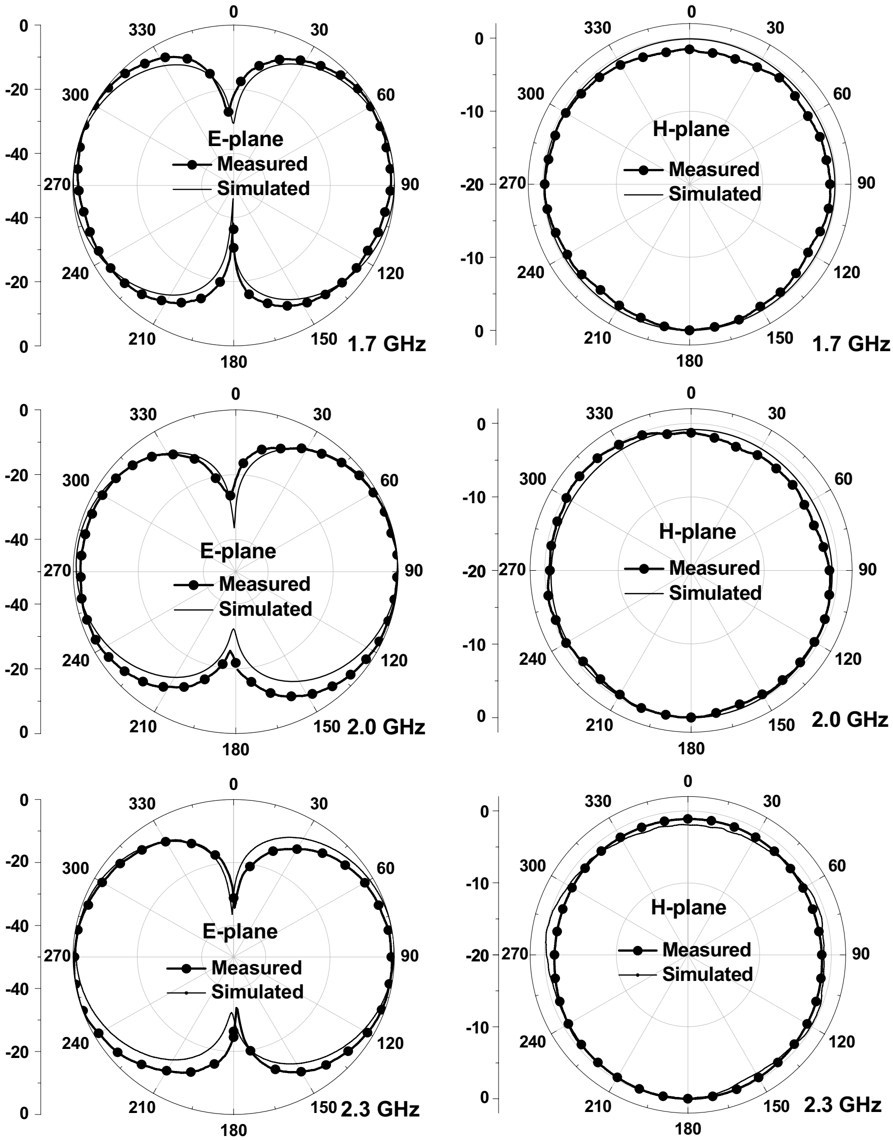


Figure 9. Measured and simulated radiation patterns at 1.7, 2.0 and 2.3 GHz.

When the antenna operates at 1.74 GHz, most of the surface currents are concentrated along the feed line and the slot line as shown in Figure 8(a). Figure 8(b) shows the simulated current distributions at 2.22 GHz. As expected, the currents distributions are mainly around the dipole arms. The current distribution also indicate that the upper resonance and the lower resonance are mainly affected by the dipole and the coupling feed structure, respectively.

The simulated and measured radiation patterns for the designed antenna in the E- and H-planes are shown in Figure 9 at 1.7, 2.0, and 2.3 GHz, respectively. The proposed antenna has a stable monopole-like conical radiation pattern in the elevation planes (E-plane) and a nearly omnidirectional pattern in the azimuth plane (H-plane). By using the symmetry of the antenna structure including the feeding line in x-y plane, it can be seen that the measured un-roundness of the antenna is less than 1.6 dB in H-plane, which should be a good candidate as the unit of the omnidirectional array. In addition, it is noted that the width of the proposed antenna (Dw) is significant to the un-roundness in H-plane. However, the compression of the width of the antenna means that the width of the arm of the printed dipole must be compressed, which will cause a worse impedance bandwidth performance. By choosing a proper width ($Dw = 20$ mm), the antenna can achieve a wide impedance bandwidth while performing a good omnidirectional characteristic. A slight disagreement between the simulated and measured results is due to the imperfect constructed prototype and the measured errors. Over the operating band of 1.54–2.45 GHz, the gain of the antenna is simulated and measured as shown in Figure 10.

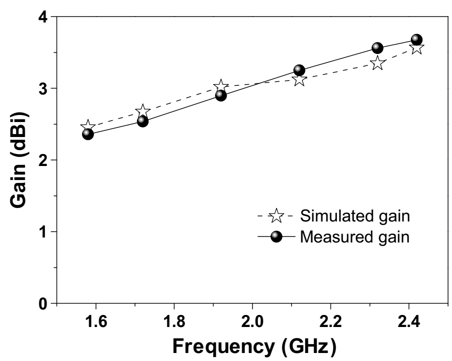


Figure 10. Simulated and measured peak gain against frequency for the proposed antenna.

4. CONCLUSION

The wideband and omnidirectional performance of a printed dipole antenna with a novel coupling feed structure is presented and investigated. Using the coupling feed structure which includes the transmission line coupling to a slot line to effectively improve the impedance matching, the proposed antenna can achieve an enhanced operating bandwidth of about 45.6% for VSWR ≤ 2. In particular, the omnidirectional radiation patterns in the whole operation bands are also achieved, and the un-roundness in H-plane is less than 1.6 dB. The proposed antenna should be a good candidate as a unit of the omnidirectional array. Due to these performances, the antenna has wide and potential applications in recent wireless communication services.

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