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Citation for published version:
Ding, Y, Du, Z, Gong, K & Feng, Z 2007, 'A Four-Element Antenna System for Mobile Phones', *IEEE Antennas and Wireless Propagation Letters*, vol. 6, pp. 655-658.
https://doi.org/10.1109/LAWP.2007.913276

Digital Object Identifier (DOI):
10.1109/LAWP.2007.913276

Published In:
IEEE Antennas and Wireless Propagation Letters

A Four-element Antenna System for Mobile Phones

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***Abstract*—A multi-antenna system with four printed monopoles is presented. The monopoles that occupy relatively small area are positioned at the four corners of a printed circuit board, so that the four-element antenna system can be equipped on the lid of a folder-type mobile phone, leaving enough space for the circuits and reducing the effect of human hands. Based on simulation, a prototype for UMTS operation has been constructed and tested. The measured -10 dB impedance bandwidths of the four elements are larger than 320 MHz with higher than 11.5 dB isolation. Moreover, the proposed antenna can provide spatial and pattern diversity in a diversity/MIMO system.**

***Index Terms*—diversity, mobile phone, multi-antenna**

I. Introduction

Digital communication using multiple-input multiple-output (MIMO) has recently emerged as one of the most significant technical breakthroughs in modern communications [1]. In a MIMO wireless communication system, the transmitting end as well as the receiving end has to be equipped with multiple antenna elements. Nowadays, in a cellular communication system, it is easy to be implemented at the base station where antenna separations of many wavelengths are readily available. However, it is still a great challenge for designing multiple antenna elements in a mobile phone with low coupling and high efficiency.

The most designs of multi-antenna system in mobile terminals are for WLAN operation [2] and applied in the PCMCIA card of a laptop. In [3], a dual-band diversity antenna in 2.4/5.2-GHz WLAN bands is proposed. The antenna consists of two orthogonal C-shaped monopoles. A protruding T-shaped stub at the ground plane is used to increase the isolation. Another design with dual-helical antenna on mobile handsets was provided in [4]. However, the relatively large antenna volume and the strong coupling between two elements restrict its application. At present, few of diversity antennas operate in the UMTS band (1920-2170 MHz). However, the demand for diversity antenna in the UMTS band is more and more great. The design faces the problems of working at lower frequency, wider bandwidth and more limited volume than one in the WLAN band does.

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In this letter, a four-element antenna system in the UMTS band is proposed. In Section II, the geometry of the antenna with some detailed dimensions is provided. In Section III, after presenting the measured S parameters, the effects of some important parameters are discussed and concluded. The measured far-field radiation patterns are presented afterwards. Based on the measured results, the envelope correlation coefficients and the mean effective gains (MEGs) are calculated. Results show that the proposed antenna is capable of providing uncorrelated signals with the same power level, and is a good candidate for mobile phones in a diversity/MIMO system. Finally, a conclusion is given in Section IV.

II. Antenna configuration

The specific geometry with some detailed dimensions of the proposed antenna is illustrated in Fig. 1, and some important dimensions are marked with parameters (l_1, l_2, l_3, l_4, l_5, l_6, l_7, d_1, d_2), which will be discussed in Section III. The four monopoles and the 50 Ω microstrip feed lines are printed on the front side of an FR4 substrate board with dimensions $95\times60\times0.8$ mm^3 and relative permittivity 4.4. The four elements of the multi-antenna system can be further separated into two pairs. Each pair has two monopoles, which have the symmetric configuration with the same dimensions. The monopoles 1 and 2 (pair 1), which are located at the corners 1 and 2, are two back-to-back elements. While the monopoles 3 and 4 (pair 2), which are positioned at the corners 3 and 4, are simple inverted-L antenna elements with capacitive load. On the back side of the substrate, the main rectangular ground plane of 60 mm in width and 80 mm in length with a hole at corner 3 and corner 4 respectively is printed and treated as the circuit part on the lid of a folder-type mobile phone.

It should be pointed out that the monopoles 1 and 2, as well as the T-shaped and dual inverted-L-shaped ground branches, have the similar configuration with the two-element antenna system provided in [5]. So in section III, the effects of the related parameters (l_1, l_2, l_3, l_5, l_6, d_1) are presented directly without any repeated analysis.

III. Results and discussions

Based on plenty of simulation and analysis, we choose a group of optimal dimension parameters to make the proposed antenna operate at UMTS band, and Fig. 2 shows both sides of

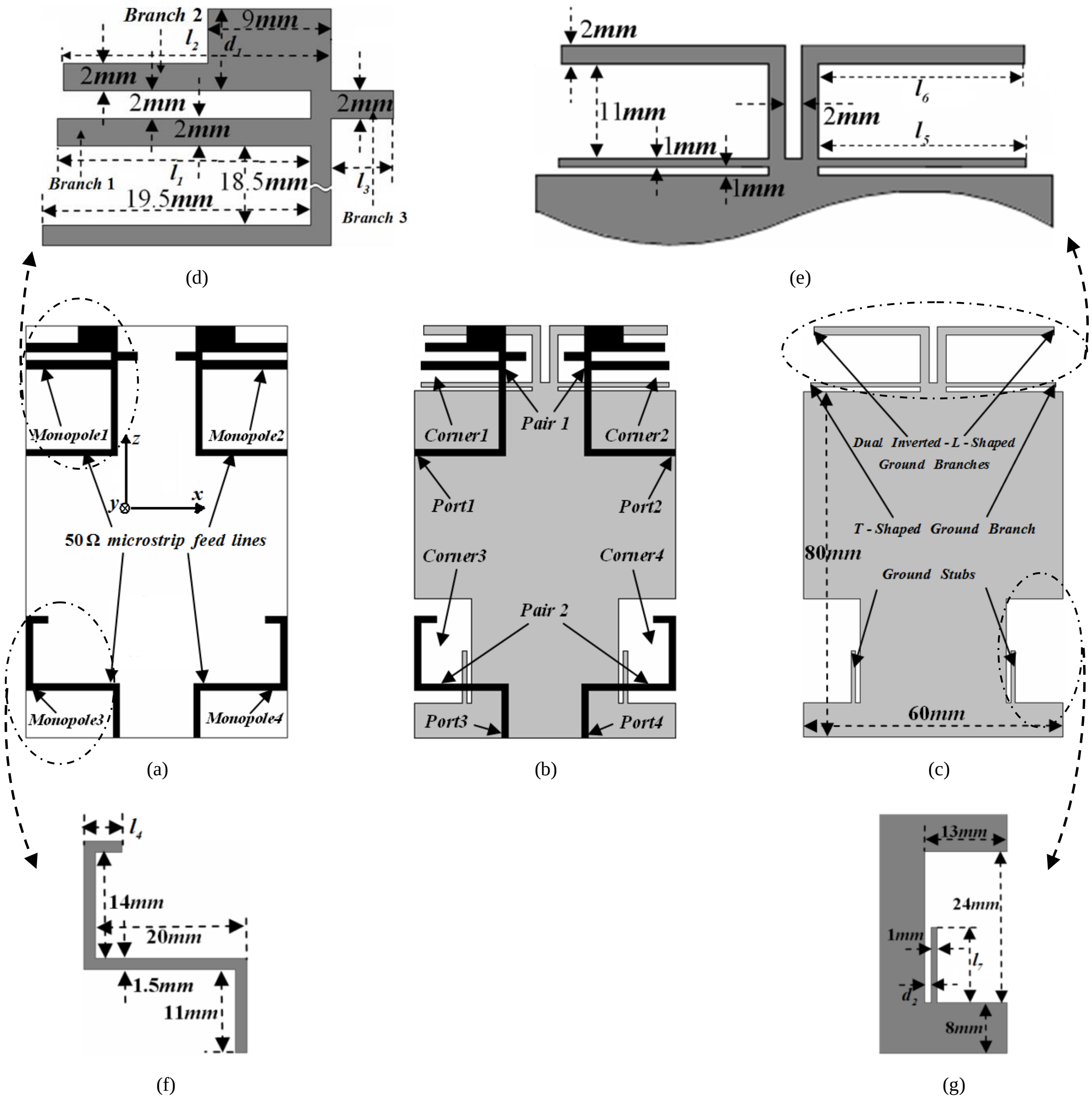
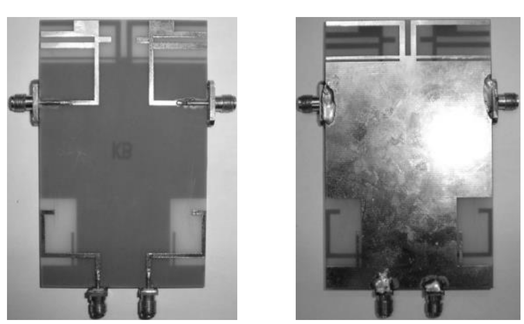


Fig. 1. Configuration of the proposed four-element antenna system: (a) Front view; (b) General view; (c) Back view; (d)Dimensions of the monopole 1; (e) Dimensions of the T-shaped and dual inverted-L-shaped ground branches; (f) Dimensions of the monopole 3; (g)Dimensions of the ground stub



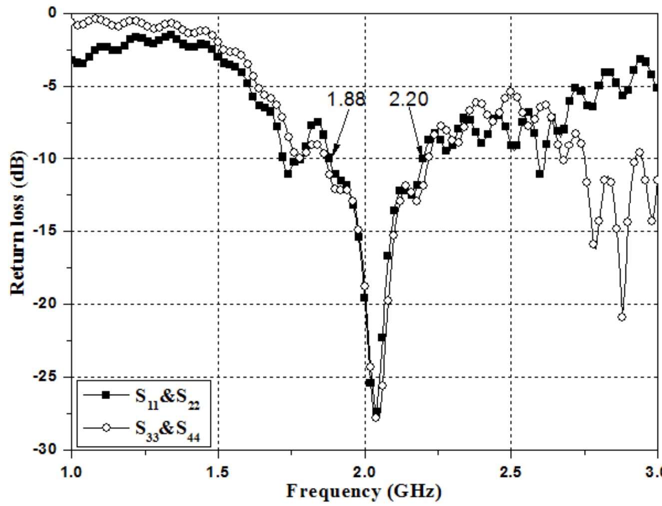
(a) (b)

Fig. 2 Photograph of the proposed four-element antenna system
(a) Front view (four printed monopoles); (b) Back view (ground plane)

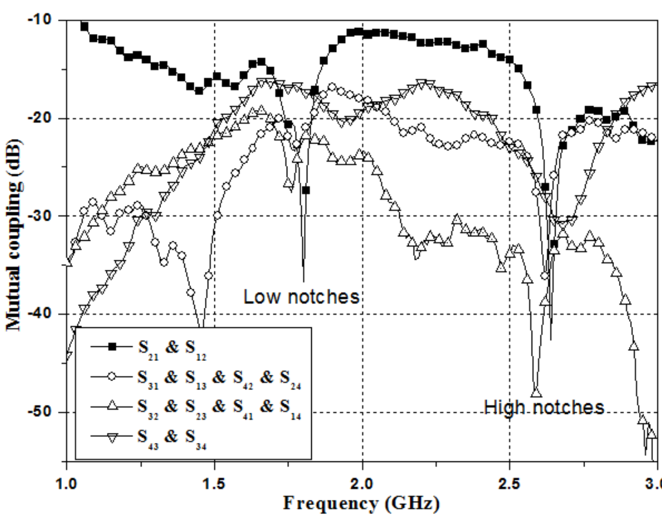
the constructed prototype. The dimensions of the prototype are (l_1, l_2, l_3, l_4, l_5, l_6, l_7, d_1, d_2) = (19.5 mm, 19.5 mm,4.5mm, 5 mm, 27 mm, 27 mm, 12 mm, 6 mm, 1 mm).

Under a selected combining scheme (that is to say, when a certain element is fed, the others are terminated to 50 Ω impedances), S parameters of the prototype were measured using a vector network analyzer (E5071B) and the results are shown in Fig. 3. It can be observed that the measured bandwidths (defined by $S_{ii} < -10$ dB, i=1, 2, 3, 4) of pair 1 are 1.88 ~ 2.20 GHz, while 1.87 ~ 2.21 GHz for pair 2. Moreover, the configuration was found to exhibit good isolation characteristic, since the mutual coupling among the antenna elements, in terms of S_{ij} (i, j=1, 2, 3, 4; i≠j) curves presented in Fig. 3(b), does not exceed -17 dB except for S_{21} (S_{12}), which is less than -11.5 dB across the expected band. Thus, the antenna efficiency values can be maintained at a high level since they are less affected by the mutual coupling.

In Fig. 3(b), two notches on S_{mn} (S_{nm}) (m=1, 2, 3, 4; n=1, 2; m≠n) curve can be seen. According to the characteristic of the frequency, we call them the high notch and the low notch respectively. In this figure, the frequencies of the high notches on different S_{mn} (S_{nm}) (m=1, 2, 3, 4; n=1, 2; m≠n) curves are almost the same, and so are the frequencies of the low notches. These are not coincidence. The details can be found in [6].



(a)



(b)

Fig. 3 Measured return loss and mutual coupling for the prototype
(a) Return loss; (b) Mutual coupling

As mentioned in Section II, the effects of some dimension parameters (l_1, l_2, l_3, l_5, l_6, d_1) have already been fully analyzed in [6], so they are concluded and listed as follows.

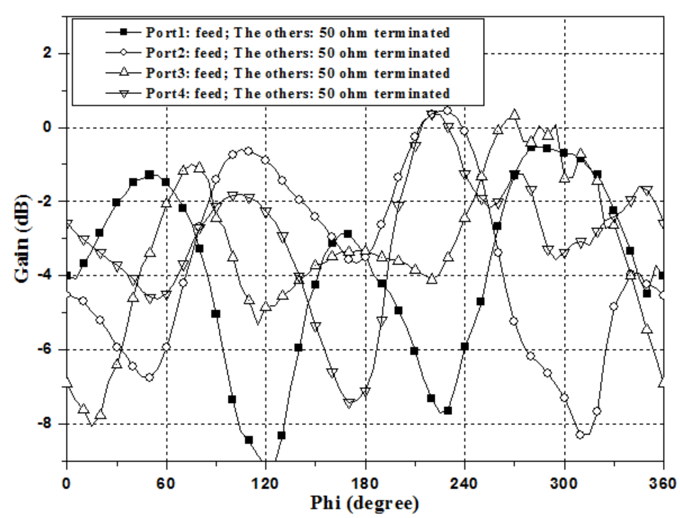
- l_1: the length of branch 1 on monopole 1 (2). When l_1 increases, the frequency of the high notch on S_{mn} (S_{nm}) (m=1, 2, 3, 4; n=1, 2; m≠n) curve will reduce gradually.
- l_2: the length of branch 2 on monopole 1 (2). When l_2 increases, the frequency of the high notch on S_{mn} (S_{nm}) (m=1, 2, 3, 4; n=1, 2; m≠n) curve will reduce gradually. When l_2 and l_6 increase simultaneously, the resonant frequency on S_{ii} (i=1, 2) curve will reduce obviously.
- l_3 and d_1: the length and the position of branch 3 on monopole 1 (2). They can adjust the matching characteristic of monopole 1 (2) a little in the resonant frequency bands.
- l_5: the length of one arm of the T-shaped ground branch. When l_5 increases, the frequency of the low notch on S_{mn} (S_{nm}) (m=1, 2, 3, 4; n=1, 2; m≠n) curve will reduce gradually.
- l_6: the length of the inverted-L-shaped ground branch. When l_6 and l_2 increase simultaneously, the resonant frequency on S_{ii} (i=1, 2) curve will reduce obviously.

Besides the parameters listed above, there are three parameters (l_4, l_7, d_2) that need to be analyzed. Based on plenty of results obtained from both simulations and the experiments, it is concluded that they only affect the return loss of monopoles 3 and 4 obviously.

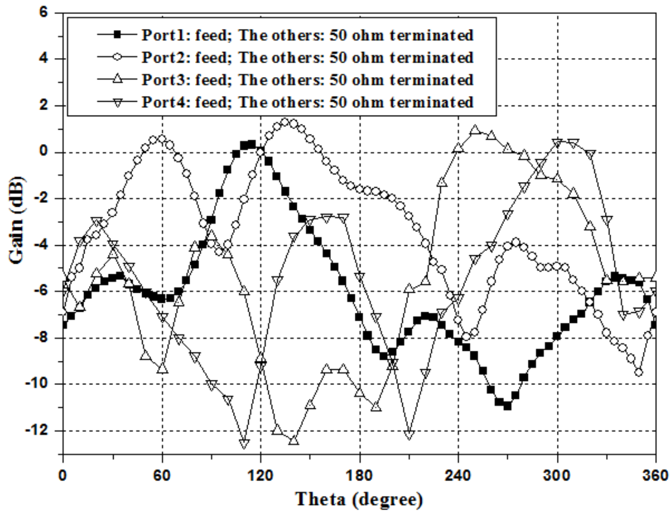
Clearly, l_4 determines the length of the surface current path on monopole 3 (4), as well as the value of the capacitive load formed by the last segment on monopole 3 (4) and the nearest parallel ground edge. The increment of l_4 can extend the length of the current path and enlarge the capacitance. Consequently, the resonant frequency of pair 2 moves downwards.

Base on much research work, we found out that when ground stubs exist, the monopole 3 (4) will exhibit dual-band characteristic, which has already been shown in Fig. 3(a). In that figure, besides the resonance appeared at UMTS band, another one can be seen on S_{33} (S_{44}) curve at around 2.8 GHz. And we call them the high and the low resonance on S_{33} (S_{44}) curve respectively. The length (l_7) and the position (d_2) of the ground stubs are the key parameters to determine the high resonant frequency. As the l_7 or d_2 increases within a certain extent, the high resonant frequency reduces, while a better matching characteristic can be obtained within the low resonant frequency band.

Besides the S parameters, the far-field radiation patterns at 2.05 GHz (the center frequency of the UMTS band) were measured in an anechoic chamber. Fig. 4 depicts the measured gain patterns of the four elements under a selected combining scheme. It should be noted that, the measured radiation patterns of these four elements tend to cover complementary space regions, which can provide pattern diversity for the prototype. The fact that patterns are not symmetric enough is mainly because the tolerances of fabrication have more effect on patterns and the feeding cable can also affect them.



(a)



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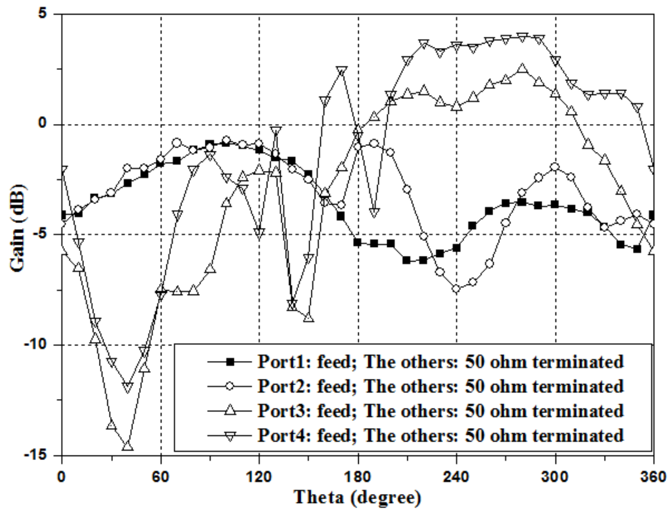

(c)

Fig. 4 Measured gain patterns of four elements under a selected combining scheme at 2.05 GHz
(a) x-y plane; (b) x-z plane; (c) y-z plane

Table 1 The mean effective gains and the envelope correlation coefficients for the prototype at 2.05 GHz.

MEG_1 (Γ=0dB) (dBi)	MEG_2 (Γ=0dB) (dBi)	MEG_3 (Γ=0dB) (dBi)	MEG_4 (Γ=0dB) (dBi)
-6.2672	-5.9312	-5.8236	-5.6703
MEG_1 (Γ=6dB) (dBi)	MEG_2 (Γ=6dB) (dBi)	MEG_3 (Γ=6dB) (dBi)	MEG_4 (Γ=6dB) (dBi)
-5.9981	-5.6928	-6.3545	-5.5972
ρ_{e12}, ρ_{e21}	ρ_{e13}, ρ_{e31}, ρ_{e24}, ρ_{e42}	ρ_{e14}, ρ_{e41}, ρ_{e23}, ρ_{e32}	ρ_{e34}, ρ_{e43}
0.0081	0.0079	0.0034	0.263

In the mobile wireless environment defined in [6], according to the method presented in [7], the envelope correlation coefficients and the MEGs of the prototype are calculated, which are listed in Table 1. The parameter Γ is the cross-polarization discrimination (XPD) (ratio of vertical to horizontal power density) of the incident field. In this letter, Γ of 0 dB and 6 dB, which are the average values in an indoor and an urban fading environment respectively [8], are assumed. From the table, it can be noticed that the received signals satisfy the conditions $\rho_{eij} < 0.5$ and $P_i \approx P_j$ ($|MEG_i - MEG_j| < 3$dB; i, j=1,2,3,4; i≠j) [8]. And these results indicate that the proposed four-element antenna system for a mobile phone can achieve good diversity performance.

IV. Conclusion

In this letter, a novel four-element antenna for diversity/MIMO system is presented. A prototype for UMTS operation was constructed and measured. The measured -10 dB impedance bandwidth of the prototype is 320 MHz (defined by S_{11}&S_{22}&S_{33}&S_{44}<-10 dB) with more than 11.5 dB isolation over the required band. Several important dimension parameters' effects on antenna performance are discussed. The envelope correlation coefficients and the MEGs are also calculated from the measured far-field radiation patterns and the typical multi-path environment to prove that the proposed antenna can achieve high performance for diversity and is very suitable for mobile phones.

Acknowledgment

This work was supported in part by the National Basic Research Program of China under Grant 2007CB310605, in part by the National High Technology Research and Development Plan of China under Grant 863-2006AA01Z265, in part by the Specialized Research Fund for the Doctoral Program of Higher Education under Grant 20060003100, and in part by the Tsinghua-QUALCOMM Associated Research Plan. We appreciate some revisions from Zhengyi Li.

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