Broadband low-profile antennas for wireless applications

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Abstract: Two novel broadband low-profile antennas are developed for the mobile terminals of wireless applications. The first one is a quasiplanar antenna which has a height of $0.06\lambda_0$, where λ_0 is the free-space wavelength at the centre frequency. The second one is a planar antenna which has a height of $0.056\lambda_0$. It is demonstrated that the quasiplanar antenna can achieve a bandwidth for VSWR < 2 of more than 45%, while the planar antenna realises a bandwidth of more than 40%. More importantly, over these bandwidths the broadband low-profile antennas have a quite constant omnidirectional radiation pattern with a peak gain of around 1 dBi. The antennas are designed on a commonly used RT/Duroid substrate; hence it is easy to integrate with RF front-end circuits. The antenna structures are described and the simulation and experimental results are presented.

1 Introduction

The antenna size is one of the main concerns in the design of mobile terminals for wireless applications, such as cellular phones, Bluetooth devices and WLAN (wireless local area network) handsets (e.g. palm handhelds, pocket PCs, laptop computers and PDAs) [1]. Numerous low-profile antennas have been developed over the last decades [2–13]. However, the demand for broadband antennas is becoming strong as nowadays wireless handhelds are required to possess a function of multimode/multiband operations. The second generation and future mobile communication systems, such as the emerging third-generation systems or beyond [14], are allocated the frequency bands around 2 GHz (i.e. PCS 1850–1990 MHz, DCS 1710–1880 MHz, PHS 1895–1918 MHz and UMTS 1920–2170 MHz). In addition to cellular mobile communications, the Bluetooth and WLAN systems may operate in the 2.4 GHz ISM band (2.400–2.485 GHz) [15]. This results in a total bandwidth requirement of near 40% around the 2 GHz band.

Generally, it is difficult for a small low-profile antenna to achieve a broadband performance due to its reduced amount of radiation power [16]. The most popular low-profile antenna is the planar inverted-F antenna (PIFA), whose bandwidth is usually less than 10% [2]. Several other types of small low-profile structures have been presented in [3–7]. The maximum bandwidth of these antennas is around 10%. Of our, a simple way to improve the bandwidth is to load the antenna with resistors [8, 9], but this technique obviously lowers radiation efficiency. In [10, 11], the bandwidth of a planar antenna is increased to 12% by introducing slits in the plates. The bandwidth of some low-profile antennas can be increased to more than 40% (e.g. those in [12, 13]), but these structures have a three-dimensional configuration.

In this paper, we present two simple antenna structures whose bandwidths are broader than 40% while their heights are less than $0.06\lambda_0$ (λ_0 is the free-space wavelength at the centre frequency). The first one has a quasiplanar structure while the second one possesses a fully planar configuration; hence it is easy to integrate on a printed circuit board (PCB). The antenna structures are described and the simulation and experimental results are presented.

2 Quasiplanar antenna

2.1 Antenna structure

The geometry of a low-profile broadband quasiplanar antenna is illustrated in Fig. 1. This antenna has been designed for the 2 GHz band based on an RT/Duroid 5880 substrate, which has a dielectric constant of $\varepsilon_r = 2.2$ and a thickness of 10 mils (0.254 mm). The antenna consists of two perpendicular planar boards (see Fig. 1*a*); therefore it is called a quasiplanar antenna. The vertical part could be part of the PCB substrate of most wireless devices, while the horizontal one could serve as a plug-in chip, maintaining a very low fabrication profile suitable for internal installation of antennas in contemporary wireless handhelds. The width of antenna is 18 mm ($0.12\lambda_0$, λ_0 is the free-space wavelength at 2 GHz) and the height of the horizontal chip is 4 mm ($\sim 0.03\lambda_0$). The vertical board is shared by two components; one is a part of the antenna and the other serves as a ground plane.

The vertical board is two-side patterned. On the back side, there is an open rectangular strip-line loop ABCDEF that is connected at C (the middle of the side BD) to the ground plane G by a short strip line (see Fig. 1*b*). On the front side of the vertical board, there are a folded strip line IKLM and a 50-Ω microstrip line HI which is extended to point J (see Fig. 1*c*). The width of all strip lines on the vertical board is 0.75 mm, which is equal to the width of the 50-Ω microstrip line. The horizontal chip is single-side patterned with a double-T (NOPQR and NOST) feeding structure and a folded strip line UVWX (see Fig. 1*d*). The width of strip lines on the horizontal part is 0.5 mm except for the part NOP, whose width was optimised to be

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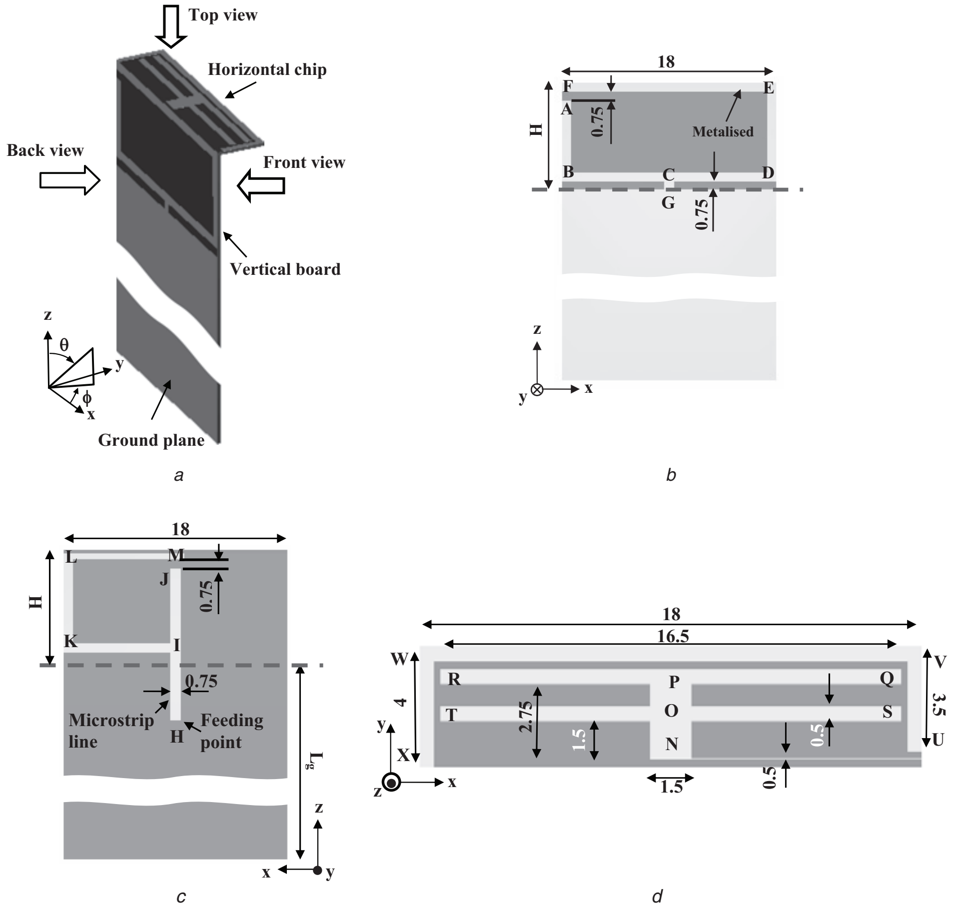


a b

c d

Fig. 1 *Geometry of a broadband quasiplanar antenna (unit: mm)*

a Perspective view
b Back view
c Front view
d Top view

1.5 mm. The vertical board and the horizontal chip are electrically connected at points F–X and M–N, respectively. The feed point is set up at the point H (about 10 mm away from the point G). This setup is completely for the purpose of accurate measurement. As will be shown, the length (L_g) of the ground plane will affect the broadband performance of the antenna. If the feeding point is set up at the end of the ground plane, a coaxial cable connected for the measurement will change the antenna performance because the outer conductor of the coaxial cable (which extends almost infinitely) serves as a part of the ground plane, causing some uncertainty for measurement results. In a real application for wireless handsets, the ground plane can be a part of the PCB and the antenna can be directly connected to the output of an RF front-end (or an RF chip). Therefore, this antenna is integratable with RF circuits.

The quasiplanar antenna can be considered as a folded monopole (formed by GCDEF + XWVU) fed through electromagnetic coupling from a double-T-shaped structure (NOPQR + NOST). The critical parts of the antenna are the folded monopole GCDEF + XWV and the feeding structure IKLM + NOPQR. Note that the strip line GCDEF serves as part of the folded monopole as well as the ground plane for the feeding line IKLM (i.e. a microstrip line). The extension UV further increases the length of the folded monopole (hence lowering the resonant frequency) while the addition (ST) of the feeding structure is to further enhance the electromagnetic coupling between the folded monopole and the feeding structure.

2.2 Simulation and experimental results

The antenna structure was designed by using the TLM (transmission line matrix) based software – *MicroStripes* 7.0. In the simulation, the 50-Ω microstrip line was excited at the feeding point by a wire-port instead of a microstrip-port. (Note that the microstrip-port, which is terminated at an absorbing boundary, is not suitable for the situation where the length of the ground plane affects the simulation results.) We have found by simulation that the antenna height (H) on the vertical board can affect the broadband performance. Fig. 2 shows the simulation results for VSWR (voltage standing wave ratio) when H varies from 8 mm to 10 mm. We can see that as H increases, the level of VSWR increases at a lower frequency in the 2 GHz band. As H decreases, the VSWR level increases at a higher frequency. When $H = 9$ mm ($0.06\lambda_0$), the quasiplanar antenna has an optimal broadband performance; the bandwidth for VSWR < 2 is found to be more than 45%. The reason for the H-dependence of broadband performance is that the antenna part on the vertical board is the major contributor to the radiation fields.

The effect of the length (L_g) of the ground plane on the VSWR of the quasiplanar antenna is demonstrated in Fig. 3. It is observed that there is an optimum value for L_g where the quasiplanar antenna has the best performance. The optimum value for L_g is found to be around 60 mm.

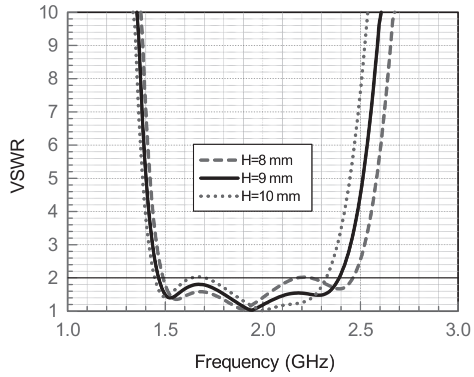


Fig. 2 *Dependence of the broadband performance on the height (H) of the quasiplanar antenna*

Therefore, this quasiplanar antenna is suitable for a compact wireless handset. It is also found by simulation that there is the weakest current distribution around the one-third upper part of the ground plane. This explains why the feeding point is selected at the location ~10 mm away from the point G.

The optimised antennas were fabricated on a 10-mil RT/Duroid 5880 substrate with 0.5 oz copper on both sides by a wet etching process. This process is based on a standard double-side lithography using Karl Suss MA-6 Mask Aligner which is capable of backside alignment. Some alignment markers were printed on both sides to aid the backside alignment. After the photoresist was patterned and developed on both sides, the unwanted copper was removed by the 30% $FeCl_3$ saturated solution. For the purpose of measurement, the antenna is fed by a 0.085″ semirigid coaxial cable. The measured result for VSWR is presented in Fig. 4 (three photographs of the antenna prototype are inset in the figure). To double check the broadband performance of the quasiplanar antenna, we also simulated the structure using an additional simulation tool; the FEM (finite element method) based software – *HFSS* 10.0. Compared to the simulated results, the measurement result shows good agreement. The measured bandwidth is also found to be ~45%. In the experiment, we also found that the measurement results became quite stable after adopting the proposed feeding strategy. The radiation pattern of the quasiplanar antenna is similar to that of a planar antenna, which will be described in the following section.

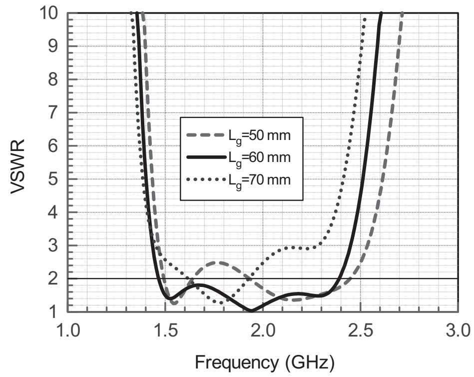


Fig. 3 *Effect of the length (L_g) of the ground plane on the broadband performance of the quasiplanar antenna*

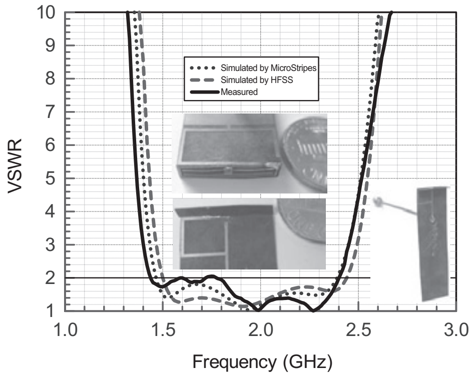


Fig. 4 *Comparison of measured and simulated results for the VSWR of the broadband quasiplanar antenna [$H = 9$ mm ($0.06\lambda_0$) and $L_g = 60$ mm*

Inset are three pictures of the antenna prototype

3 Planar antenna

3.1 Antenna structure

The geometry of a low-profile broadband planar antenna is illustrated in Fig. 5. This antenna is also designed at the 2 GHz band based on the RT/Duroid 5880 planar substrate with a dielectric constant of $\varepsilon_r = 2.2$ and a thickness of $t = 10$ mils. The antenna is printed on both sides (i.e. the front side and the back side) of the substrate. On the front side, there is a T-strip whose lower section is folded and extended to a 50-Ω microstrip line. Again the feed point is set up at the position ~10 mm away from the upper end of the ground plane. On the back side of the substrate, there is an S-strip which is terminated at the ground plane. The upper section of the T-strip is fitted into the area surrounded by the upper section of the S-strip. The height (H_T) and width (W_T) of the T-strip are slightly shorter than those (i.e. H and W) of the S-strip. To alleviate the skin effect, the crossbar of the T-strip is divided into four narrow strips whose width and separation are equal to the width (w_s) of the S-strip. The folded lower section of the T-strip on the front side overlaps with the lower section of the S-strip on the back side, forming a two-strip line. There is no directly electrical connection (e.g. by a shorting via) between the front side and the back side. The total

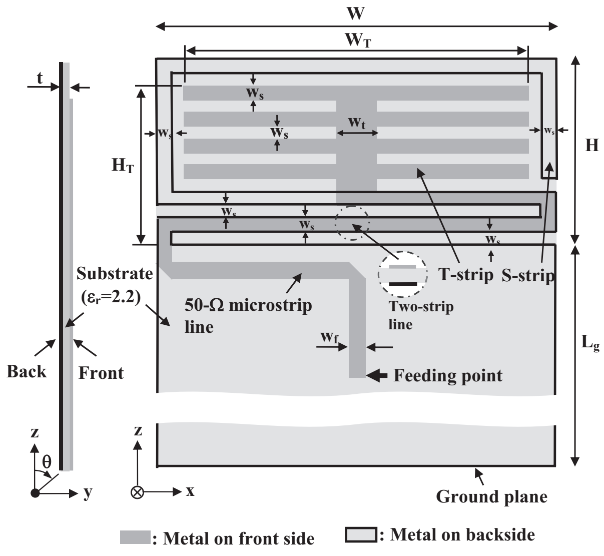


Fig. 5 *Geometry of a broadband planar antenna*

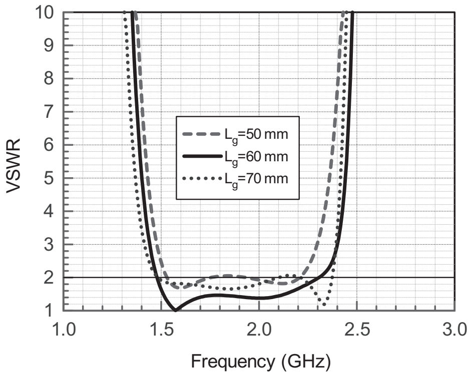


Fig. 6 *Effect of the length (L_g) of the ground plane on the broadband performance of the planar antenna*

height of the antenna is $H = 8.4$ mm ($0.056\lambda_0$) and the width $W = 18$ mm ($0.12\lambda_0$). Other geometrical parameters are attached in the caption of Fig. 5.

3.2 Simulation and experimental results

Like the quasiplanar antenna, the broadband performance of the planar antenna is also affected by the size of the ground plane. Fig. 6 shows the results for VSWR at different lengths of the ground plane. It is found that when $L_g = 60$ mm, the planar antenna has an optimal broadband performance. The bandwidth at this length is found to be slightly wider than 40% for VSWR < 2. The measurement result for VSWR of the planar antenna at $L_g = 60$ mm is

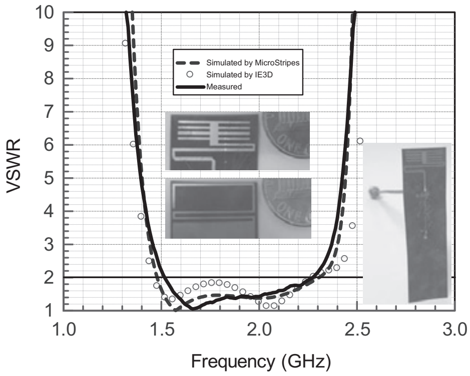
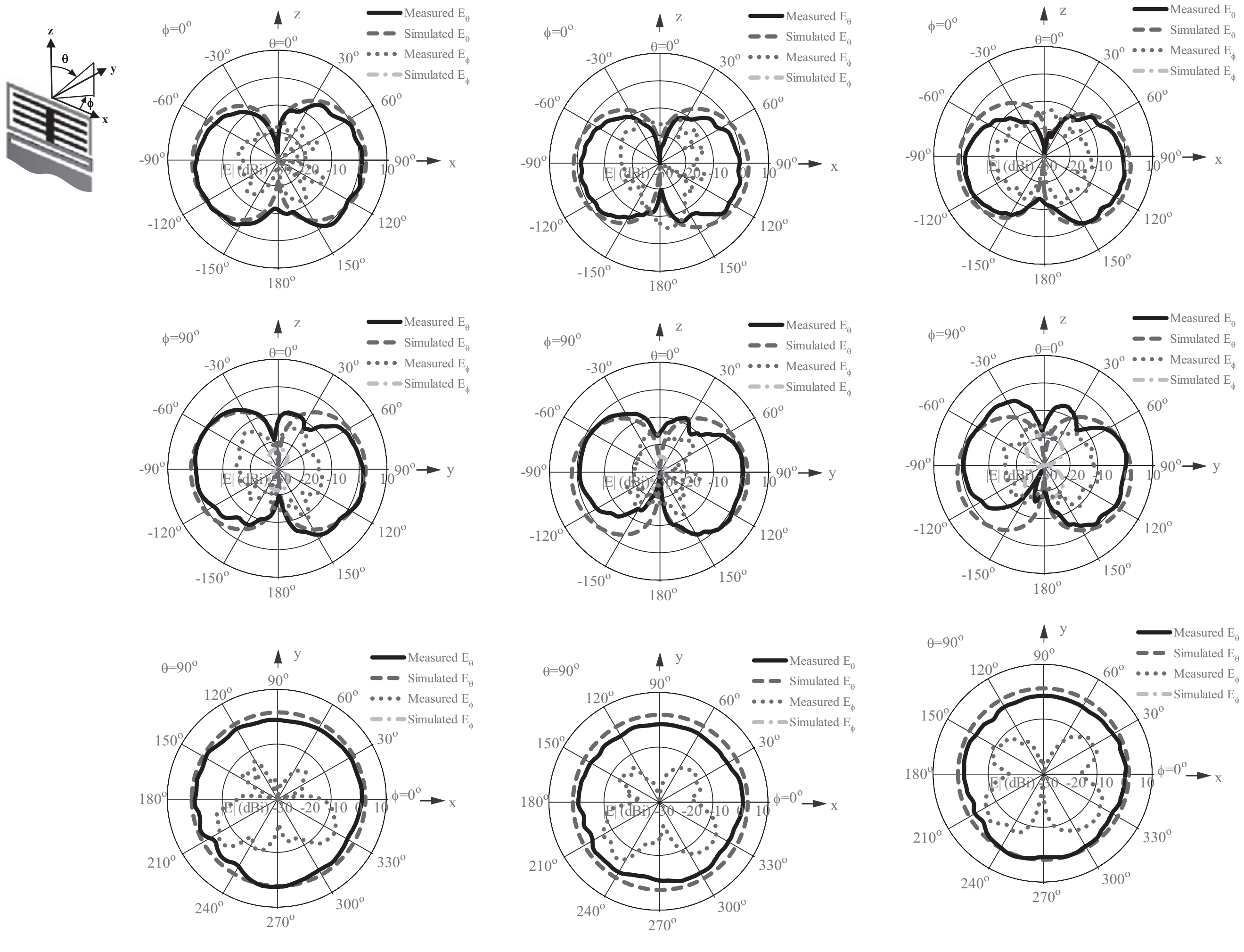


Fig. 7 *Comparison of measured and simulated results for the VSWR of the broadband planar antenna [$H = 8.4$ mm ($0.056\lambda_0$), $W = 18$ mm ($0.12\lambda_0$), $H_T = 7.2$ mm, $W_T = 15.6$ mm, $w_t = 1.8$ mm, $w_s = 0.5$ mm, $w_f = 0.75$ mm, $t = 0.254$ mm and $L_g = 60$ mm*

Inset are three pictures of the antenna prototype



a
b
c

Fig. 8 *Radiation patterns of the broadband planar antenna*

a 1.5 GHz
b 1.9 GHz
c 2.3 GHz

displayed in Fig. 7. The planar antenna was also simulated using *IE3D*. Good agreement is observed between the simulated and measured results.

Fig. 8 shows the measured and simulated radiation patterns of the broadband planar antenna at 1.5, 1.9 and 2.3 GHz. Good agreement is observed for the dominant vertical component (E_θ) [which is more than 10 dB higher than the horizontal component (E_ϕ)]. (The measurement errors mainly come from the spurious radiation created by the feeding coaxial line.) It is seen that the radiation pattern is omnidirectional on the horizontal plane, similar to the pattern for a dipole antenna. Also, it can be observed that there is only a small variation for the radiation pattern over the 2 GHz band. The peak gain of the planar antenna is found to be ~1 dBi on the horizontal plane and the simulated radiation efficiency (using *Microstripes* 7.0, $\sigma = 5.8 \times 10^7$ S/m and $\tan\delta = 0.0009$) keeps above 90% over the frequency range 1.5–2.3 GHz.

4 Conclusions

A quasiplanar antenna and a planar antenna with a low profile have been developed for broadband wireless/mobile applications. The bandwidth of the quasiplanar antenna is more than 45% (VSWR < 2), while its height is only $0.06\lambda_0$. The planar antenna can achieve a bandwidth of ~40% with an antenna height of $0.056\lambda_0$. These antennas have an omnidirectional radiation pattern with a gain of ~1 dBi on the horizontal plane, suitable for the scenario of mobile communication. Another advantage of the antennas is their quasiplanar or planar structures, which make it easy to fabricate with possible integration with RF front-end circuits. These low-profile antennas can find applications in 2G/3G cellular phones and WLAN handsets.

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