Thin dual-resonant stacked shorted patch antenna for mobile communications

J. Ollikainen, M. Fischer and P. Vainikainen

A novel thin stacked shorted patch antenna for the 1800MHz frequency band is presented. The antenna is dual-resonant and small in size. It has a very low profile and a bandwidth of almost 10%, which is sufficient, for example, for GSM1800 or GSM1900 systems. The radiation pattern of the antenna is suitable for directive cellular handset antenna applications.

Introduction: Short-circuited microstrip patch antennas, or PIFAs, can be used as directive internal handset antennas in various communication systems. They provide advantages over traditional external whip and helix antennas in terms of increased total efficiency (when the handset is near the user's head), decreased radiation towards the user, and increased mechanical reliability. The main disadvantage is their narrow impedance bandwidth compared to the volume occupied by the antenna structure. Typical requirements for directive internal antennas designed for cellular handsets (with a thickness $\leq$ 20mm) are antenna thickness $\leq$ 5mm and bandwidth $\geq$ 10%. It is difficult to design such a small, directive, low-profile handset antenna with high radiation efficiency and an impedance bandwidth greater than 10%. Small antenna design is always a compromise between size, bandwidth, and efficiency. Often, the price for improved performance is increased complexity. If the total dimensions of a patch antenna element are fixed, there are two effective ways to enhance its bandwidth: either dissipative loading [1], which reduces the radiation efficiency, or the addition of more resonators into the antenna structure (matching networks or parasitic elements). The latter method may increase the manufacturing complexity of the antenna.

In this Letter, a thin dual-resonant stacked shorted patch antenna is presented. Previously, stacked short-circuited patch antenna elements have been reported in [2, 3]. More recently, similar elements have also been discussed in [4, 5]. The presented antenna is dual-resonant and has a very low profile. The thickness is only one fifth of that of the antenna reported in [5], whereas the surface area reserved for the patches is approximately equal. The small size of the antenna presented in this Letter makes it relatively easy to fit inside a cellular handset. The bandwidth is sufficient for many communication systems. With a common short circuit element which connects both patches to the ground plane, the presented antenna is the simplest example of a stacked shorted microstrip patch antenna. No extra tuning or shorting posts inside the patch area are needed, which makes its manufacturing easier.

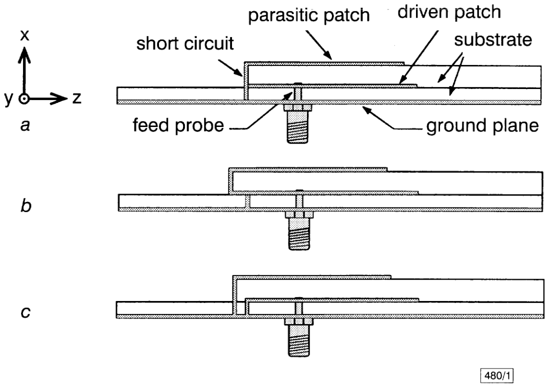

Fig. 1 *Stacked shorted patch antenna configurations*

a Antenna with common shorting element (basic configuration reported in text)
b Antenna with offset parasitic
c Antenna with separately shorted offset parasitic

Antenna structure: The antenna element consists of a driven lower patch, a parasitically coupled upper patch, and a common shorting element which connects both patches to the ground plane (Fig. 1*a*). The substrate material used between the patches and between the lower patch and the ground plane is RT/duroid 5870 ($\varepsilon_R = 2.33$, $\tan\delta = 0.0012$). The lengths of the upper and lower patches are 25 and 26mm, respectively. Both patches as well as the shorting element are 30mm wide. The thickness of the substrate between the lower patch and the ground plane is 1.6mm. The upper patch is positioned 2.4mm above the lower patch. Thus the total thickness of the antenna is only 4mm ($0.024\lambda_0$ at 1800MHz). One of the 30mm-wide edges of the lower patch is short-circuited using 11 evenly spaced copper-plated vias with a diameter of 1 mm. A 30mm-wide short circuit plate is used to connect the upper patch to the 11 vias. In the original design it was also planned to short circuit the lower patch with a 30mm-wide plate; however, that was replaced by a row of vias for prototype manufacturing reasons. The antenna element is positioned in the middle of a ground plane which has dimensions of 65 × 40mm (length × width). The antenna is fed by a probe which is connected to the lower patch (Fig. 1*a*). The distance between the centre of the probe and the shorted edge of the patch is 9.5mm.

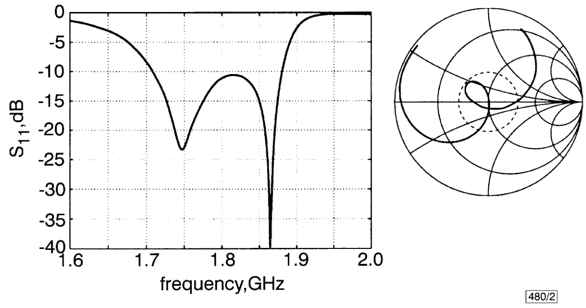

Fig. 2 *Measured reflection coefficient for antenna of Fig. 1a*

– – – – L_{RETN} = 10dB

Design procedure: The design procedure was quite simple. At first, the lower patch, which was overcoupled to the feed, was experimentally tuned to ~1750MHz. After that the second patch was set on top of it. The length of the upper patch was shortened until the small loop (coupling loop) seen on the Smith chart (Fig. 2) had moved close to the centre of the chart. This gave an antenna with a centre frequency (f_C) close to 1800MHz. Before the tuning, the upper and lower patches had equal lengths.

To optimise the impedance behaviour, we must be able to control the coupling (size of the coupling loop) between the driven patch and the parasitic patch. This coupling depends on the distance between the radiating edges of the patches and on the unloaded quality factors (Q_0) of the patches. The smaller the distance between the radiating edges, the stronger the coupling (and the larger the size of the coupling loop). On the other hand, the higher the Q_0s, the stronger the coupling for a given separation of the radiating edges. Attempts to adjust the coupling has led to several other novel stacked shorted patch configurations. Two of them are presented in Fig. 1*b* and *c*.

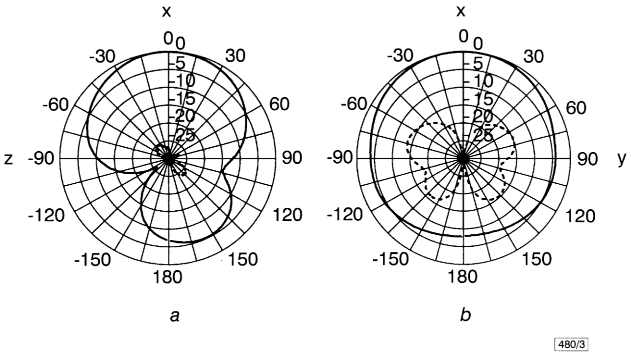

Fig. 3 *Measured cuts of radiation pattern of antenna of Fig. 1a*

a xz-plane
b xy-plane
——— E_θ
– – – – E_φ component (0 dBi corresponds to 3.8 dBi

The bandwidth of a patch antenna is approximately proportional to the volume of the structure measured in wavelengths. To optimise the bandwidth to volume ratio, both patches of the stacked patch antenna should radiate as equally as possible and have as low radiation quality factors as possible. Furthermore, to reach the required matching level (e.g. return loss (L_{RETN}) $\geq$ 10dB), there should be proper coupling between the patches, and between the feed and the driven patch. If the height of the lower patch is significantly lower than that of the upper patch, the lower patch functions mainly as a resonant matching element that feeds the upper patch. Such an element can be used, for example, to make the probe feeding of an electrically thick patch possible.

Measurements and discussion: The measured impedance bandwidth ($L_{RETN} \geq 10$dB) was 9.6% at f_C = 1798MHz (Fig. 2). This meets the requirement for GSM1800. A 4mm thick short-circuited single patch antenna was constructed and measured as a performance reference for the stacked antenna. The impedance bandwidth of the reference antenna was 4.9% at f_C = 1835MHz. Thus, it is concluded that the bandwidth of the antenna almost doubled due to the employment of the stacked parasitic element.

The measured *xz*-plane and *zy*-plane cuts of the radiation pattern are presented in Fig. 3*a* and *b*, respectively. In the *xz*-plane the 3dB beamwidth is 93°, and in the *zy*-plane 135°. The results show that even when the antenna is on a ground plane approximately the size of a handset circuit board, most of the radiation is directed away from the user's head. On the other hand, the *xy*-plane beamwidth is wide, which ensures wide angular coverage. The radiation pattern of the studied antenna seems to be very well suited to directive handset antenna applications. Owing to the low-profile stacked structure there were no significant frequency dependent changes in the radiation pattern. The gain of the antenna was 3.8 ± 1.1dBi over the measured impedance bandwidth.

The presented antenna is the simplest example of a stacked short-circuited microstrip patch antenna. In the measured prototype the short circuit was intentionally left wide. The size of the antenna can of course be decreased by making the short circuit narrower or by replacing it with a single shorting pin. This will, however, decrease its impedance bandwidth.

When a patch antenna is loaded by lossy dielectric material, such as the hand of a cellular telephone user, its resonant frequency shifts downwards and matching deteriorates. The more the antenna is loaded, the larger are the changes. In a cellular handset, the presented antenna is less sensitive to the hand of the user because the lower patch is shielded by the parasitic upper patch. Therefore it is better suited for handset antenna applications than ordinary single patch antennas.

Conclusions: A thin dual-resonant stacked shorted patch antenna has been presented. The antenna has a small size, low profile, and measured impedance bandwidth of 9.6%. The radiation pattern is suitable for directive internal cellular handset antenna applications.

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