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Dual-Feed Ultra-Compact Reconfigurable Handset Antenna for Penta-Band Operation

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Introduction

In the past two decades, antenna engineers have achieved impressive reductions in the size of mobile phone antennas, although physical constraints have essentially limited such reductions [1]. The design challenge posed by handset antennas is becoming more critical as networks evolve to offer a wider range of services, such as video telephony, web browsing, navigation services, entertainment etc. The increasing number of different functionalities in the mobile terminal puts great pressure on the available space for antennas, while handset designers expect that antennas can be operated successfully in close proximity to components such as cameras, flash units, loudspeakers, batteries and other hardware.

The operation of electrically small antennas is dictated by a fundamental relationship, which relate the Q-factor to the volume of the smallest sphere in which the antenna can be enclosed. A small antenna intrinsically has a very reactive input impedance with an associated very narrow bandwidth [2]. Therefore, in order to be able to cover both low bands (GSM850 and GSM900) by a passive antenna in a mobile phone, the antenna needs a large volume. The monopole antenna requires large ground clearance in order to cover both low bands, which increases the total antenna volume and lowers the Q-factor. An attractive antenna miniaturization method, by which the varying input impedance could be overcome, is the use of switchable matching circuits. Using this switchable matching circuit, a reconfigurable antenna can reuse its entire volume at different operating bands so the physical size of the antenna can be reduced [3]. In [3]-[5], different types of reconfigurable antenna concepts has been presented, but the switching techniques proposed there provides the antenna to reconfigure the operating frequency over Low Band (LB) and High Band (HB) simultaneously. This could pose a problem, especially in the cases where HB realized efficiency requirements are high since the switch adds loss to the matching network.

This paper proposes a very small (1cc) dual-feed reconfigurable antenna concept. The circuit layout of the dual-feed antenna system is shown in Figure 1(d). Since the low bands are more challenging to cover with a passive antenna, the frequency reconfigurability is more important there. Therefore, at the low band the antenna consists of a radiator element, a RF switch together with matching network to obtain a frequency-reconfigurable antenna system. The trade off is the complexity and loss which is introduced by the switch and matching network. At the high bands (DCS1800, PCS1900, WCDMAI) the antenna is electrically larger and will operate more independently of the phone chassis. Furthermore, the efficiency requirements are usually higher for

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the high bands. Therefore, the high bands are covered using a radiator element with matching network in order to reduce complexity and loss.

Antenna concept

Figure 1 shows the geometry of the proposed combined antenna mounted in extension of a double-sided Printed Wire Board (PWB) with a full ground plane. The PWB and antenna has the total dimensions of 110mm x 50mm x 1mm, which is a preferable size for the modern candy-bar mobile phones with a long touch display. In extension of the PWB (FR-4; $\epsilon_r = 4.4$, tan $\delta = 0.02$) a ground clearance area of 5mm x 50mm is reserved for the antenna carrier (see Figure 1(b)). The antenna carrier is made of PC/ABS material and has the dimensions 5mm x 50mm x 4mm (LxWxH). The antenna off-ground volume is 1cc, but the area for the contact points (3mm x 3mm x 3mm) is also regarded as part of the antenna volume, giving a total antenna volume of 1.05cc. The antenna system consists of two Inverted L Antenna elements for LB and HB operation, respectively. The feeding point of the two elements are placed at opposite corners (see figure 1(c)). The LB radiator is designed to keep the 2^{nd} resonance far away in frequency from the HB in order to keep a high isolation to the HB. For HB operation a G-shaped pattern is designed with a good distance (6mm) to the LB radiator, which is also to ensure a high isolation between the two antennas.

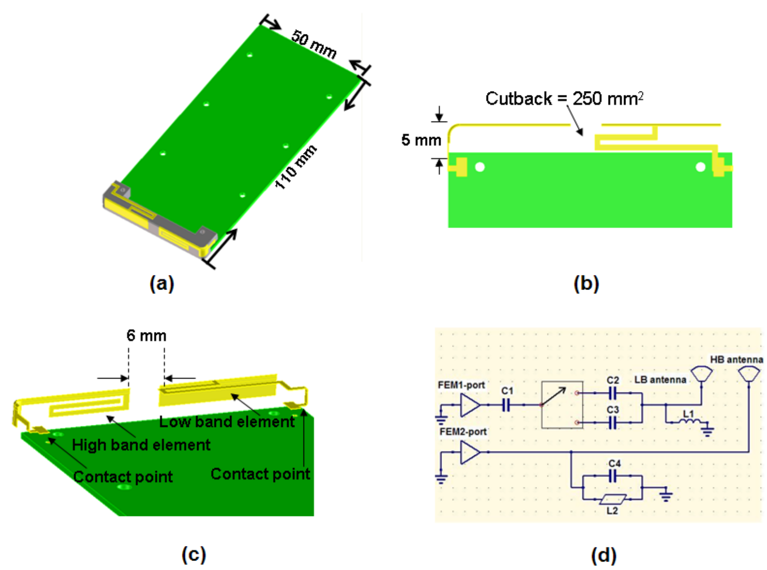

Figure 1: Geometry of the antenna: (a) PWB with the antenna element, (b) Antenna ground clearance area, (c) Antenna elements and contact points, (d) Circuit diagram of the proposed antenna and matching network.

The LB switching circuit is placed on a PWB close to the LB feed port. A GaAS SPDT switch from M/A-COM [6], together with discrete components from Murata are mounted on the PWB, which together with the LB element provides the antenna to work in the GSM850 and the GSM900 band (see Figure

1(d)). A 2.7V DC control voltage is used to control the switch. Three DC-blocking capacitors (C1, C2 and C3) are used as part of the matching network. These capacitors are necessary to block the DC at RF-lines. An inductor (L1) to ground is used to provide zero at DC, which helps ESD protection. This shunt inductor also adjusts the antenna impedance. GSM900 is covered in switch state 1, where the RF signal is routed through the switch and capacitor C2. The GSM850 band is fulfilled by switching to state 2, where the RF signal is routed through capacitor C3. At GSM900, the C2 capacitor (39pF) acts only as a DC-block, and the small shunt inductor L1(5.1nH) turns the impedance curve in the Smith Chart and provides the necessary impedance match. At GSM850 the impedance curve will have increased negative series reactance due to the decreased capacitance value of C3 (1.8pF), while the shunt inductor L1 again provide the required impedance match. The HB matching circuit is located on the PWB close to the feed point. The HB impedance match is obtained through the HB radiator and a tank circuit. The tank circuit consists of a capacitor C4 (4.3pF) and a short transmission line L2 (2mm), which is designed to resonate at higher frequency area of the HB. This in order to keep the component loss from the tank circuit as far away as possible. The switching technique at the LB and tank circuit at the HB provides the small 1cc antenna to achieve penta-band operation.

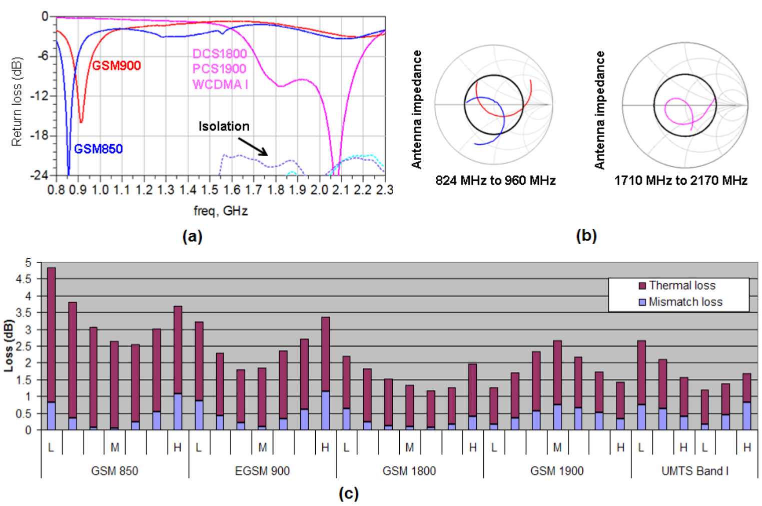

Figure 2: Measured antenna performance: (a) Log magnitude impedance plot, (b) Complex impedance plot, (c) Antenna efficiency divided into thermal and mismatch loss.

Measurement results

The measured performance of the antenna is presented in Figure 2. As shown in Figure 2(a), the antenna is capable of covering the frequency ranges of GSM900 and GSM850 with a -6dB relative bandwidth of 10% and 9.1%, respectively. 24.8% relative bandwidth is achieved at the high bands. An isolation of better than -20dB is achieved with a 6mm distance between the LB and HB antenna elements. Figure 2(b) shows the complex impedance plots of LB (824-960 MHz) and HB (1710-2170 MHz) together with the SWR=3 circle.

The antenna efficiency, shown in Figure 2(c), is divided into thermal and mismatch loss, where the term thermal loss (radiation efficiency) takes into account conduction and dielectric losses of the phone and the components (matching components and the switch). Mismatch loss takes into account impedance mismatch of the antenna. The conduction and dielectric losses are very difficult to measure separately so they are lumped together to form thermal loss. A mismatch loss of lower than 1dB is achieved in general over all five frequency bands. Thermal loss is higher at the LB due to the switch circuitry, but it is highest at GSM850, specially at the lower band edge. This is due to the higher Q of the antenna at GSM850. Another probable reason is that at GSM850 the PWB length is further away from its resonance length. Taking the PWB length and width into account 160mm total length is achieved, which means the PWB is at resonance (lambda/2) for GSM900, but not for GSM850. At the HB, lower thermal loss is achieved because the switch is not part of the feed line.

Conclusions

This paper presents a very small (1cc) dual feed frequency reconfigurable monopole antenna concept capable of fulfilling penta-band operation. The antenna is switching the lower operating frequency between the two lower GSM bands using one feed port and covering the higher frequency bands through a separate radiator and a tank circuit using the second feed port. Five frequency bands are covered through the two feed ports. The isolation between the two ports is lower than -20dB. With this technique a practical reconfigurable antenna, with low HB thermal loss, is introduced.

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