Wideband Slot Antenna for Low-Profile Hand-held Terminal Applications

Peter Lindberg[1,2], Erik Öjefors[1] and Anders Rydberg[1]

[1]University of Uppsala, Signals and systems, Regementsvägen 1, 752 37 Uppsala, Sweden
+46 18 471 1078, pl@signal.uu.se
[2]Laird Technologies, Box 500, 184 25 Åkersberga, Sweden, +46 8 555 722 00

***Abstract*— A quarter-wave transversal slot in the center of a handheld terminal ground plane is proposed and evaluated as a wideband antenna for low profile mobile phones. By feeding the slot with a microstrip line, a triple-resonance response is obtained from the chassis, slot and microstrip stub interaction, providing sufficient impedance bandwidth and radiation efficiency to cover the 0.9-2.7 GHz frequency range. While the introduction of a slot in the ground plane has many advantages over e.g. PIFA or patch structures, both in terms of performance and cost, the circuit floor planning becomes more complicated. To address this problem, a possible solution in terms of module partitioning and signal line routing is suggested. In addition, simulations of parasitic antenna to signal line coupling and techniques to reduce this effect are presented.**

I. Introduction

As a result of the current trend towards ultra-thin hand-held terminals, the restriction on antenna height above ground plane is now commonly in the 4-6 mm range for typical mobile phone antennas. This implies a substantial reduction of the available impedance bandwidth obtainable by using the standard planar inverted-F antennas (PIFA) that is typically deployed [1]. By instead using a slot in the ground plane as the radiating element the antenna performance becomes independent of available height and PCB area while adding no extra cost. In addition, extremely high bandwidths can be obtained (more than one octave) by careful design, which is beneficial for reducing effects of frequency de-tuning by nearby objects (e.g. user's hand and/or head) and for compatibility with the wide range of frequency bands commonly supported by modern terminals (i.e. GSM850/900/1800/1900, UMTS 2100 MHz, WLAN 2.4 GHz etc). Earlier work on slot antennas for terminal applications has mainly targeted high frequencies, i.e. 1.5 GHz and above. In [2], a large square slot ($\sim$29 cm^2) was fed by a fork-like microstrip line, achieving a bandwidth of 1.8-2.9 GHz (VSWR $<$1:1.5). Besides not supporting the lower frequency bands, the slot size is also too large for typical ground plane dimensions ($\sim$40 x 100 mm^2). A more compact radiator, using a quarter-wave slot (sometimes called "notch" or "monopole slot") measuring 12 x 4 mm^2 and located in the top right corner of the ground plane, has been presented for UWB 3-5 GHz applications [3]. Several similar antenna configurations have been proposed [4][5], all targeting $>$2 GHz applications. In [6], a technique of increasing the bandwidth of slot antennas by using two feed lines connected to a microstrip-Tee for power division was proposed. The presented example achieved a 3-5.5 GHz bandwidth (VSWR $<$1.8:1). Even though the antenna was designed for high frequencies, a large portion of the PCB area was consumed by the microstrip feed lines, impedance transformers and Tee-junction.

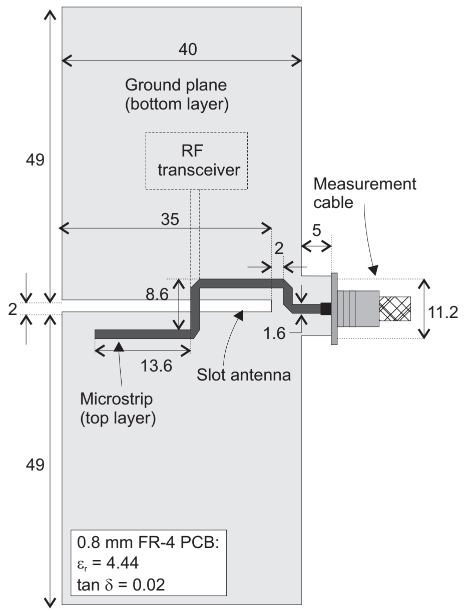

Fig. 1. Layout of slot antenna and microstrip feed. Measurement cable connected to the microstrip at the virtual ground of the antenna, thereby eliminating any currents induced on the outside of the cable shielding. The microstrip line used for real applications is displayed using dashed lines, connecting the antenna to an on-PCB transceiver. All measures in mm.

In this paper, a quarter-wave slot in the ground plane of a wireless terminal is proposed for 0.9-2.7 GHz applications. By placing the slot in the center of the ground plane (i.e. in the current maxima of the dipole type chassis mode), maximum coupling to the low-Q chassis resonator [7] is obtained, thus providing a very broad band response. In addition, by feeding the slot with a microstrip stub, an extra resonance is obtained thereby further increasing the impedance bandwidth.

II. Design and results

The proposed antenna configuration is shown in Fig. 1. A 50 Ohm open ended microstrip line feeds a quarter wave slot (or notch) in the center of a 40 x 100 mm^2 ground plane. The transmission line is bent 90^o after crossing the slot to reduce the PCB area consumption. A standard PCB substrate of 0.8 mm thick FR-4, as typically employed in mobile phones, with permittivity $\varepsilon_r = 4.44$ and loss tangent $\tan\delta = 0.02$ is used. For measurement convenience, the microstrip line is connected to the coaxial cable at the center of the chassis. From the symmetry of the structure, the chassis center point (along the center of the slot) constitutes a virtual ground (i.e. no voltage swing) and is therefore the most suitable place to connect the measurement cable. It was confirmed during measurements that negligible currents were present on the outside of the coaxial shielding, thereby eliminating any need for measurement baluns. The chassis is locally extended 5 mm to facilitate soldering of an SMA edge connector at that point. This has no significant influence on the antenna characteristics, which was verified by simulations. In a real application, the microstrip line would instead be connected to the RF transceiver, see Fig. 1. Since the transmission line has a characteristic impedance Z_0=50 Ω, this rerouting from the measured configuration does not affect the antenna performance.

The antenna was designed and optimized using method of moments based IE3D [8]. By placing the slot at the center of the ground plane, maximum coupling to the low-Q chassis dipole type resonance is obtained, resulting in a very large radiation bandwidth. The open ended microstrip stub, i.e. the section after the slot crossing, adds one extra resonance and so further increases the bandwidth. This section does not have the requirement of Z_0=50 Ω and thus provides an extra design parameter. In this case however, no improvement could be obtained by using a different characteristic impedance.

Return loss measurements, see Fig. 2, were conducted using a calibrated vector network analyzer (Agilent PNA E8364B) and radiation properties were measured in a Satimo STARGATE-64 near field chamber [9]. The return loss is below -6 dB in the frequency band 0.9-2.7 GHz, which is the typical requirement for terminal antennas. The measured antenna efficiency (including missmatch loss), see Fig. 3, is in the 70-95 % range over the entire band, with the smaller values being caused by missmatch losses. Fig. 4 shows the measured gain in the E-plane at frequencies 1, 1.5, 2 and 2.5 GHz. All frequencies displays a ~ 2 dBi gain maxima in the broadside direction, as is typical for both dipole type (chassis radiator) and slot type antennas. The E-plane radiation pattern is slightly irregular in the direction of the cable ($\theta > 90^0$), especially at higher frequencies. The measured H-plane gain is presented in Fig. 5, showing an almost isotropical pattern below 2 GHz and less than 4 dB gain variation at 2.5 GHz. Again, it is clear from Fig. 5 that the coaxial cable is the main contributor to the gain variation. The measured axial ratio, or polarization purity, is higher than 13 dB for all θ-angles (with $\varphi = 90^o$, i.e. H-plane) and frequencies, as shown in Fig. 6, although this is of minor concern in terminal applications. The agreement between simulations and measurements are good.

III. Circuit Floor Planning

The introduction of a ground plane slot complicates the circuit floor planning and signal line routing. Since no metal should be placed above the slot, the available PCB ground is divided into two equal size areas with a 5 mm wide (for a 40 mm wide chassis) ground to ground connection at the rightmost edge. The maximum length of any non-plastic structure is now 49 mm (for a 100 mm long chassis), which puts restrictions on large metal or high-ε_r objects, especially the battery, display and EMC shields. A suitable module distribution that is compatible with the slot antenna is shown in Fig. 7, where the typically most space consuming modules have been indicated with outlined boxes.

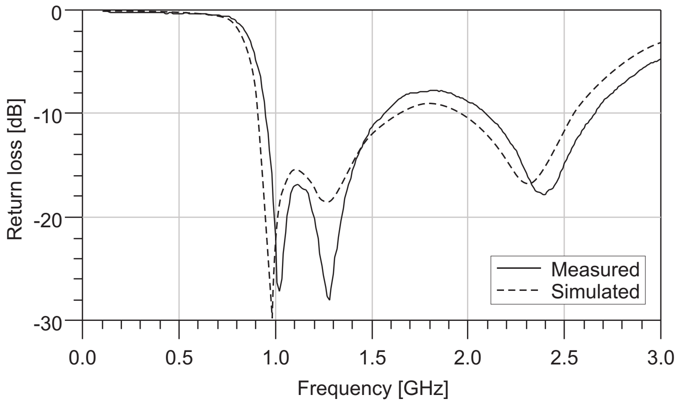

Fig. 2. Measured and simulated return loss of wideband slot antenna.

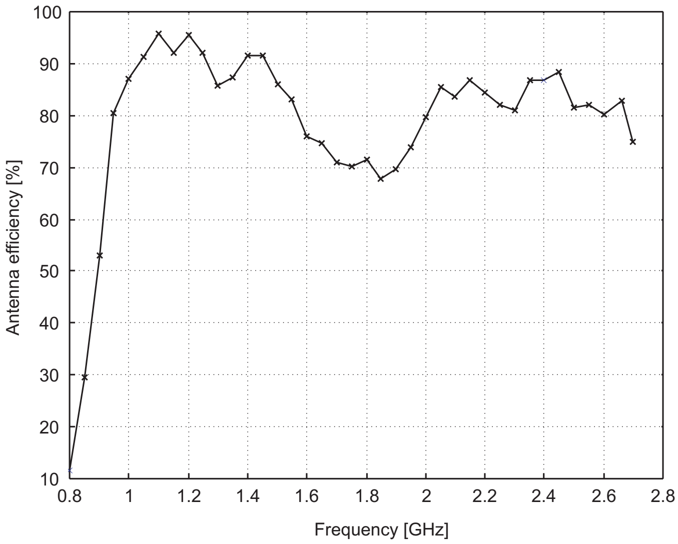

Fig. 3. Measured antenna efficiency (including miss-match loss) of slot antenna.

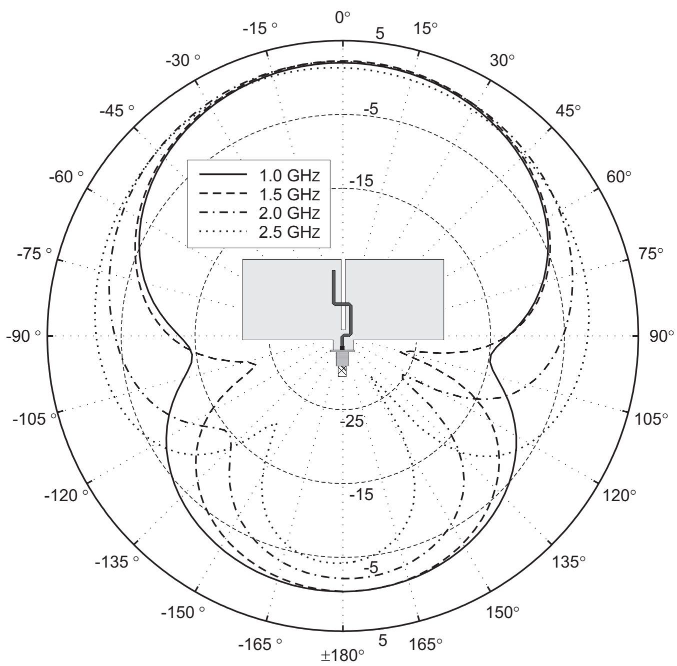

Fig. 4. Measured E-plane ($\theta = -180^0 \rightarrow +180^0$ and $\varphi = 0^o$) radiation pattern for 1-2.5 GHz. Chassis in xz-plane with slot oriented along z-axis.

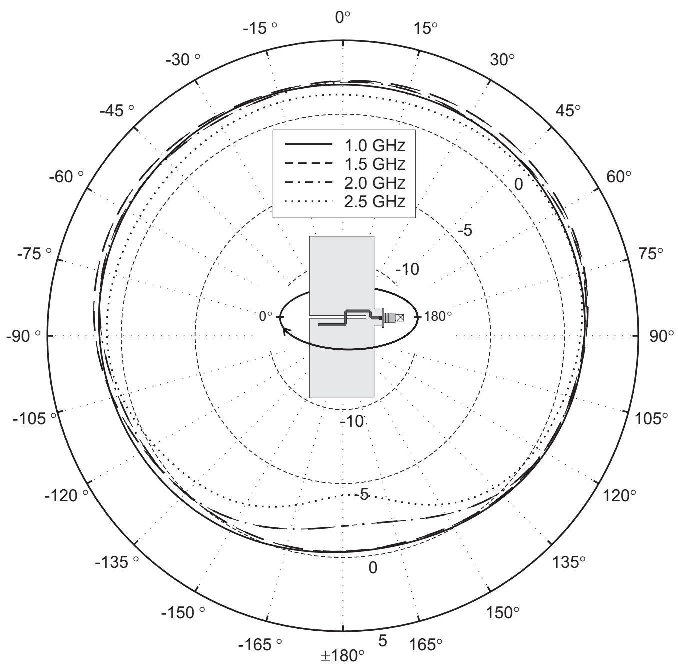

Fig. 5. Measured H-plane ($\theta = -180^0 \rightarrow +180^0$ and $\varphi = 90^o$) radiation pattern for 1-2.5 GHz. Chassis in xz-plane with slot oriented along z-axis.

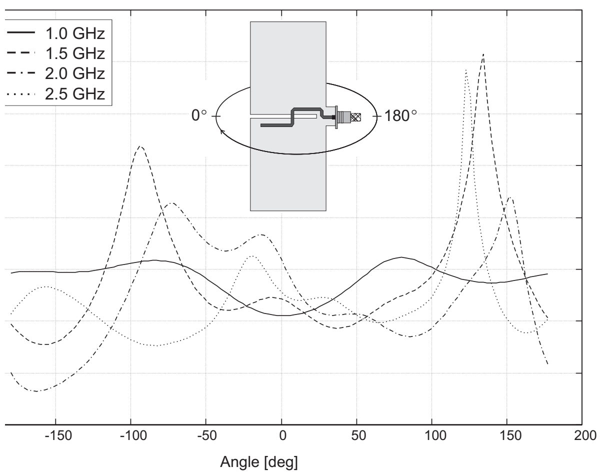

Fig. 6. Measured axial ratio ($Gain_\varphi(dB) - Gain_\theta(dB)$) in H-plane of slot antenna.

A. Antenna to signal line coupling

Any signal lines between circuit modules on different sides of the ground plane slot are subjected to coupling to and from the antenna. To simulate the magnitude of this coupling effect, the structure in Fig. 8 was used. The antenna feed line has been relocated to the open ended side of the slot so that the test signal line can be routed over the rightmost ground. Since the feed line has a 50 Ω characteristic impedance, this has very little effect on the antenna parameters. The test line also uses a 50 Ω characteristic impedance and is terminated in both ends by 50 Ω ports.

Several different configurations of line height H above ground plane were tested. For all cases, the line is centered above the 5 mm wide ground-to-ground connection at the rightmost part of the chassis, and the width W is adjusted for a 50 Ω characteristic impedance of the microstrip line. Furthermore, one configuration with the line crossing the slot

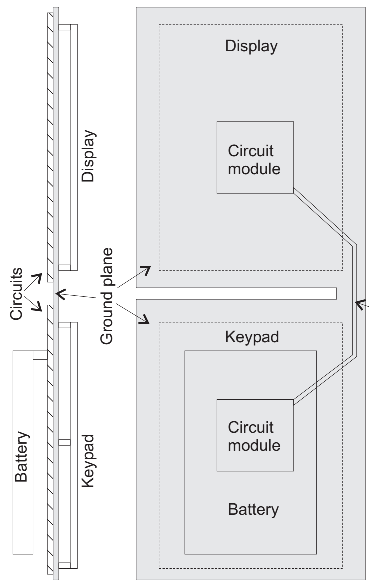

Fig. 7. Circuit floor planning of wireless terminal with ground plane slot antenna.

at D = 4.3 mm was evaluated in addition to one arrangement where a metal shield was used. The metal shield is 6 mm long and consists of sidewalls, which could be implemented by using a series of vias, and a top cover at a distance H above the line (for a symmetric coaxial transmission line type of shielding). The signal line section inside the shield uses a reduced width W to keep a constant characteristic impedance.

The simulated coupling from the antenna port to the lower signal port (which is identical to the coupling to the upper signal port from symmetry reasons) for all tested configurations is shown in Fig. 9. As expected, the smallest isolation is obtained for the case with the signal line crossing the slot. Substantial improvement is achieved by routing the line above the ground section instead, and still further improvement is seen from the case with the shielding box. Due to the tighter field distribution between signal line and ground when the distance H is reduced, the isolation between antenna and signal line also improves. Finally, additional isolation can of course be obtained by using standard low pass filters.

IV. Conclusion

A wideband slot antenna for hand-held terminal applications has been proposed and evaluated. Simulations and measurements of return loss, radiation efficiency and radiation patterns on a prototype antenna have been presented, indicating satisfactory performance in the targeted 0.9-2.7 GHz cellular (GSM and UMTS) and complementary (WLAN) frequency bands. In a real application, it is expected that this frequency range will be shifted down in frequency due to dielectric loading from e.g. the plastic cover of a mobile phone so that GSM850 will also be supported. By routing signals between the upper and lower parts of the PCB over the ground connection at the rightmost part of the chassis, using a low height above ground plane and optionally a shield box, >30 dB isolation between antenna and signal line is obtained without extra filtering. This implies that the antenna design and signal routing can be done independently without significant mutual coupling.

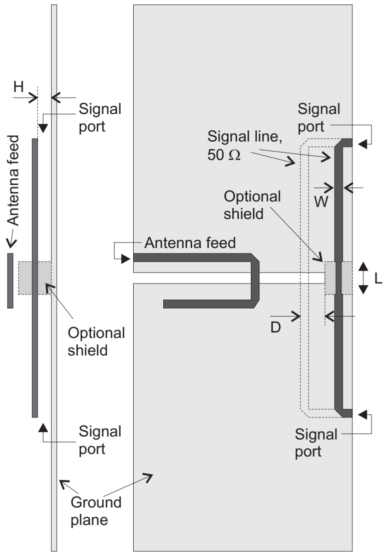

Fig. 8. Configuration for study of coupling from antenna to signal line. Signal line width W is adjusted for a constant characteristic impedance of 50 Ω for different line height above ground plane H. An optional metal shield of length L=6 mm is indicated as a dashed box at the rightmost edge of the slot.

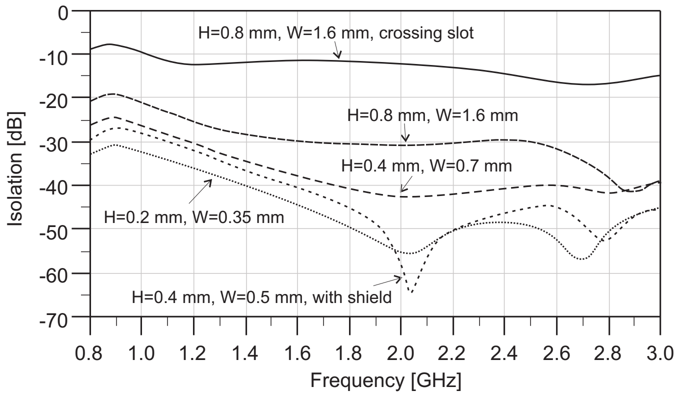

Fig. 9. Simulated signal coupling from antenna to transmission line. H is the signal line height above ground plane, W is the width of the signal line

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