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MOBILE TERMINAL ANTENNAS IMPLEMENTED USING OPTIMIZED DIRECT FEED

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ABSTRACT: A novel antenna structure based on optimized direct feed is presented in this paper. The antenna structure consists of the chassis of a mobile terminal, a feed structure and a matching circuitry. The chassis is cut in two pieces, which are connected with an inductor. The value of the inductor is tuned so that the lowest resonant frequency of the chassis equals the center frequency of the operating band. The feed structure excites very strongly the resonant wavemode of the chassis and thus very large bandwidth is available. The feed structure can be integrated e.g. on the PCB of a mobile terminal and thus the antenna is very low-profile. The antenna structure has been demonstrated with a simulated and measured prototype that covers the GSM850/900 systems.

INTRODUCTION

It is well known that the lowest order wavemode of the chassis of a mobile terminal works as the main radiator below 1 GHz [1]. Since the antenna element itself is only a minor radiator, the volume occupied by the traditional antenna structure can be decreased significantly by introducing compact coupling structures whose principal function is only to couple currents to the chassis wavemode [1,2], which is very advantageous because the volume reserved for the antennas inside the device is very limited. The natural next step is to avoid the use of the antenna element and use the chassis alone as the radiator. The thoughts of integrating the feed structure in the printed circuit board led to the introduction of so called *direct feed* antenna structure, ideas are presented in [3-6]. The idea behind the direct feed structures is to galvanically couple to the chassis wavemode across an impedance discontinuity (e.g. a slot). This way the coupling to the chassis wavemode becomes relatively strong and the antennas can have very high bandwidth potential [6]. In addition, the volume occupied by the 'antenna' decreases fairly much. Since the whole antenna structure is designed to be on the same plane as the chassis, the height of the antenna is extremely low and the height does not cause any limitations for the bandwidth.

The direct-feed-based antennas introduced in [4-6] are designed for handheld digital television (DVB-H). The same kind of direct feed principle can also be applied for other systems. In this paper an *optimized direct feed structure* is studied for GSM850/GSM900 systems. In the end of this paper, an extremely low profile penta-band prototype for GSM850/900, GSM1800/1900 and UMTS is presented.

OPTIMIZED DIRECT FEED ANTENNA STRUCTURE

In order to maximize the bandwidth of a mobile terminal antenna, the chassis of the antenna can be manipulated. This includes at least two means: first of all, the resonant frequency of the chassis wavemode should be equal to the center frequency of the system [1] and secondly, the coupling to the chassis wavemode should be optimized [7]. In principle, the resonant frequency of the chassis could be decreased by introducing more slots in the chassis [5,6]. However, the use of additional slots may not be feasible in current mobile terminals since the printed circuit area is needed for electronics. Secondly, no conductive elements (such as display and/or battery) should be placed above slots [5,6]. Instead of using additional slots, we propose to place an inductor across the slot in order to tune the resonant frequency of the chassis to the interesting frequency band. The inductor value is chosen so that the resonant frequency of the combination of the feed structure and chassis equals the center frequency of the operating band and thus the largest possible bandwidth can be achieved. The coupling between the feed structure and the chassis dominant wavemode can be optimized by modifying the feed structure as will be presented in the following paragraph.

The behavior of the optimized direct feed structure, presented in Fig. 1, was studied by simulations. The effect of the length l of the feed structure was studied systematically. The length of the feed structure was changed from 100 mm to

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2 mm (2 mm is the width of the slot). First, the input impedance of the antenna structure was simulated with *IE3D*. Then the inductor value L was tuned so that the resonant frequency of the combination of the feed structure and chassis equaled the center of the frequency of the operating band, i.e. 890 MHz in the case of GSM850/900 systems (as L increases, the resonant frequency decreases). After that, a matching circuitry consisting of a shunt inductor followed by a series capacitor (see Fig. 1) was used to match the antenna around 0.89 GHz. The reflection coefficients and achievable 6 dB return loss bandwidths are shown in Fig. 2.

With l = 100 mm, the size of the dual-resonant impedance loop (or a dip) on the Smith chart is very small. One can notice that the coupling to the chassis lowest order wavemode is too weak in order to give the largest possible bandwidth [7]. When the feed structure is made shorter, coupling to the lowest order wavemode of the chassis increases and thus the size of the loop increases [7]. This results in an increase of the 6 dB return loss bandwidth (here 6 dB return loss is used as the matching criterion). With l = 2 mm, coupling to the lowest order wavemode is so strong that the impedance loop on the Smith chart hardly fits inside the 6 dB return loss circle. In addition, the coupling to higher order wavemodes (e.g. at 1.7 GHz) of the chassis also increases with small l. The length of the feed approximately $l = 40 - 70$ mm seems to be a reasonable choice from the system (GSM850/900) point of view.

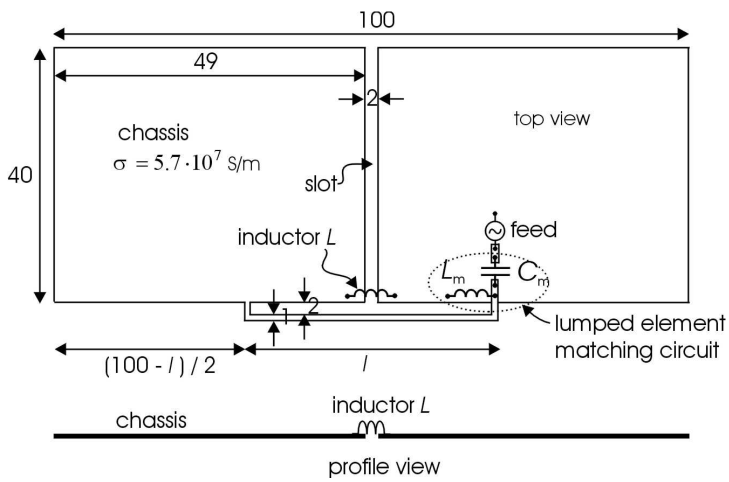
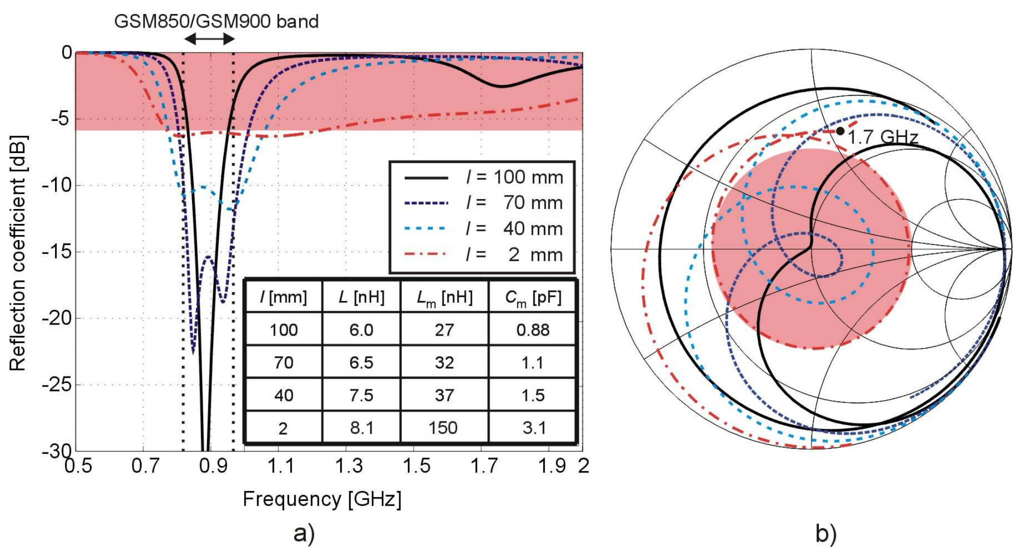


Fig. 1. Principle of optimized direct feed.



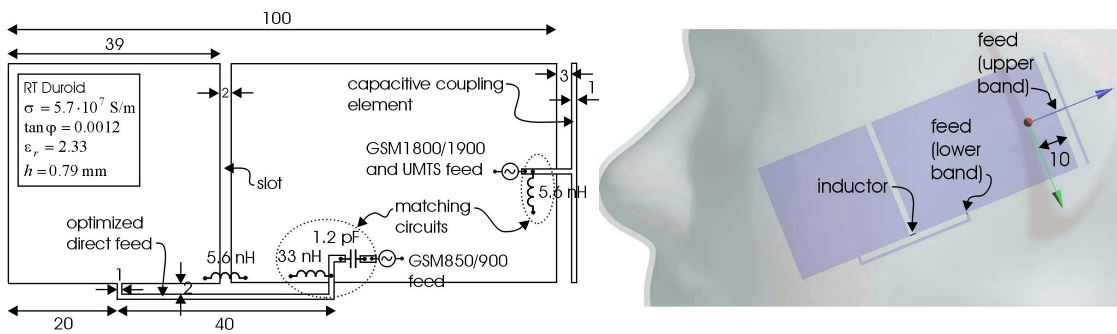
l [mm]	L [nH]	L_m [nH]	C_m [pF]
100	6.0	27	0.88
70	6.5	32	1.1
40	7.5	37	1.5
2	8.1	150	3.1

Fig. 2. Effect of the length *l* of the feed structure on the matching a) in the Cartesian coordinate system and b) on the Smith chart.

PENTA-BAND PROTOTYPE ANTENNA FOR GMS850/900, GSM1800/1900 AND UMTS

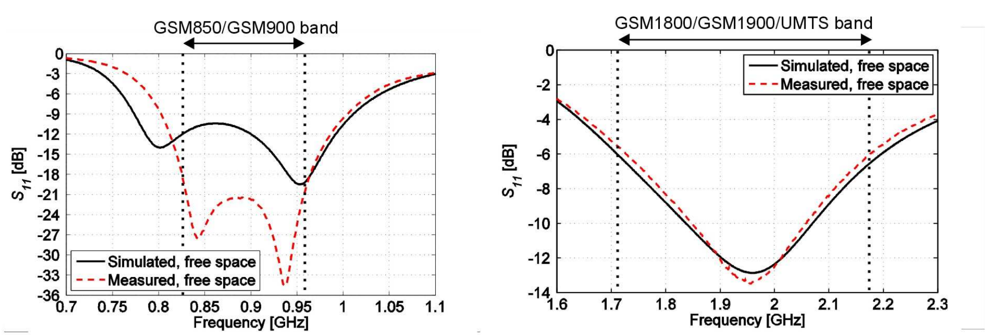
A penta-band (GSM850, GSM900, GSM1800, GSM1900 and UMTS) antenna structure for mobile terminals was designed, manufactured, and measured. Antenna functionality for the GSM850/900 systems was implemented using the idea of the optimized direct feed structure, see Fig. 3. Antenna functionality for the GSM1800/1900 and UMTS systems was implemented by using the idea of capacitive coupling elements [1,2]. The place of the slot was chosen in such a way that the longer part of the chassis has the lowest order wavemode resonant frequency at the center frequency of the GSM1800/1900 and UMTS systems (1.940 GHz) [1]. As told, no conductive elements (such as display and battery) should be placed above the slot. Hence, the display and battery can be superposed with the longer part of the chassis and thus they do not significantly affect the operation of the antenna. The length of the feed structure ($l = 40$ mm) was found to be a good compromise between the matching and reasonable size.

The whole antenna structure can be integrated on a PCB, i.e. it is practically two-dimensional. The metal parts of the prototype antenna were manufactured by photoetching on a 0.79 mm thick piece of RT Duroid 5870, which is needed for mechanical support only. The characteristics of the printed circuit board are shown in Fig. 3. The lumped inductors for the prototype antenna were from the LQW18A-series of Murata. The lumped capacitor for the prototype antenna was from the 600S-series of ATC (American Technical Cheramics). The matching circuits are shown in Fig. 3. The simulated and measured frequency responses of the reflection coefficient of the prototype are shown in Fig. 4. As can be seen, the prototype antenna has very good (at least 10 dB return loss) impedance matching at the whole GSM850/900 frequency range. The IE3D-simulated radiation and total efficiencies of the prototype are higher than 92% and 85% at the GSM850/900 bands, respectively. The prototype antenna structure almost covers the frequency bands of GSM1800/1900 and UTMS systems (1710 MHz – 2170 MHz) with 6 dB return loss impedance matching criterion. The bandwidth could be easily increased e.g. by using dual-resonant matching network [7,8]. The simulated radiation and total efficiencies are higher than 96% and 72% at the GSM1800/1900 and UMTS bands, respectively. If desired, the total efficiency at the band edges can be improved with a dual-resonant matching network.



a) b)

Fig. 3. a) Penta-band prototype antenna for GMS850/900, GSM1800/1900 and UMTS and b) orientation of the prototype in the standard talk-position.



a) b)

Fig. 4. Simulated and measured reflection coefficient of a) GSM850/900 and b) GSM1800/1900 and UMTS.

The maximum 10-g average SAR and radiation efficiency in the standard talk-position were simulated and measured at 0.90 and 1.80 GHz. The simulations were performed with SEMCAD-X (version 13.0 Bernina). The measurements were performed with DASY 4 measurement system at STUK (Radiation and Nuclear Safety Authority in Finland). The distance between the SAM head model and the chassis was 4 mm and the loudspeaker location of the phone was assumed 10 mm from the upper end of the chassis, see the orientation of the antenna in the talk-position in Fig. 3 b). The SAR and radiation efficiency results were compared with a simulated antenna structure with a solid 100 mm x 40 mm chassis and a capacitive coupling element (CCE) [2] with dimensions 40 mm x 11 mm x 6.6 mm (width x length x height) placed at the end of the chassis. The results are shown in Tab.1.

Tab.1. Simulated and measured maximum 10-g average SAR and radiation efficiency for the prototype.

	Max 10 g average SAR at 0.9 GHz (0.25 W) [W/kg]	Rad. effiency in talk-position at 0.9 GHz [%]	Max 10 g average SAR at 1.8 GHz (0.125 W) [W/kg]	Rad. effiency in talk-position at 1.8 GHz [%]
Measured	2.09	-	1.72	-
Simulated	2.29	9.3	1.84	25.1
CCE ref.	1.80	20.8	0.65	51.9

At 0.90 GHz, the SAR maximum is located near the inductor connecting the two parts of the chassis and at 1.80 GHz the SAR maximum is located near the middle part of the longer part of the chassis. As can be seen, the drawback of the antenna is that the simulated SAR at 0.9 GHz increases about 27% and the radiation efficiency decreases 55% compared to the simulated capacitive coupling element reference. At 1.8 GHz the simulated SAR increases 183% and the radiation efficiency decreases 52% compared to the reference. Although the SAR values are relatively high, one should note that the main importance in this paper has been put on the optimization of the bandwidth and the size of the antenna, while SAR and radiation efficiency have been a smaller issue. Research for SAR decreasing methods has been made and the results will be published in the near future. However, part of the very broad impedance bandwidth could be sacrificed in order to optimize SAR. In addition, a parasitic radiator method, introduced in [9], could be used for SAR reduction.

CONCLUSIONS

In this paper, a novel optimized direct feed structure for mobile terminals has been studied. By utilizing the idea of the studied antenna concept, antenna functionality can be implemented with exceptionally broad bandwidth, and within very low volume (virtually zero-volume). This has been demonstrated with both simulated and measured antenna prototype for GSM850/900. However, the presented idea is system independent. It could be used for ground planes of different size and for systems operating at even lower or higher frequencies than GSM850/900. The price paid from the very broadband and low-volume antenna structure is increased SAR and decreased radiation efficiency compared to the capacitive coupling element reference.

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