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Published in:
Antenna Technology: "Small Antennas, Novel EM Structures and Materials, and Applications" (iWAT), 2014 International Workshop on

DOI (link to publication from Publisher):
10.1109/IWAT.2014.6958653

Publication date:
2014

Document Version
Accepted author manuscript, peer reviewed version

Effect of Antenna Bandwidth and Placement on the Robustness to User Interaction

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***Abstract*—Modern smart phones require antenna systems that can deal with an ever-growing number of bands. This study compares two different approaches to the coverage of large bandwidths: Wide-band (WB) antennas covering a whole band at once and tunable narrow-band (NB) antennas covering only one channel at a time but tunable to all channels within the band of interest. To investigate the effect of antenna placement the antennas are placed both at the top and the bottom of the phone. All antenna configurations are simulated in talk position with a head and hand included. The hand is constructed with a movable index finger and the index finger is swept at 6 positions on the backside of the phone. The study shows that WB antennas detune a lot more than NB antennas and that top-mounted antennas are experiencing more than 6 dB higher losses than bottom-mounted antennas. It is proposed to expand this study with more antenna types and placements as both of these parameters are known to influence the immunity to the user. It is also proposed to compare the simulation results to measurements to increase the confidence in the results.**

***Index Terms*—Tunable Antenna, Coupling Element, Propagation Losses, Electromagnetic reflection.**

I. INTRODUCTION

THE required bandwidth of mobile phone antennas is increasing with every new generation of mobile telephony. For the 2^{nd} generation (GSM/GPRS) only 4 bands were defined world-wide. With Long-Term Evolution (LTE) the number of bands has risen to 40, thereof 23 FDD bands [1]. The LTE bands are situated in the frequency range between 700 MHz and 2.69 GHz. To cover all of these bands one can either make the antenna wide band (WB) and cover all frequencies of interest simultaneously with multi-resonant matching [2]–[4] or make the antenna tunable and adjust it for the frequencies of interest [5]–[7]. By making the antenna tunable, the bandwidth requirement is significantly reduced meaning that a smaller element can be used. The reduced volume of narrow-band (NB) antennas is very attractive for handset manufacturers since a significant part of the handset volume is taken up by antennas. The purpose of this study is to investigate the robustness of such a NB antenna to the proximity of the hand and head of a user. A comparison is made to a similar type of antenna with a larger height and five times larger bandwidth.

The effect of the user has long been acknowledged as a major influence on mobile antenna performance. It both absorbs power as well as detunes the center frequency of the antenna. Absorption loss is intrinsic to the interaction with a user. The absorption loss varies depending on the antenna type and user hand and head size and grip style [8]–[11]. For an active antenna the mismatch can be reduced by retuning. This requires closed-loop operation based on measurements of the mismatch. Since this is adding complexity to the transceiver it should only be considered if the mismatch loss is significant. The main objective of this study is to quantify how severe the mismatch loss can get for a NB tunable antenna compared to a conventional WB antenna.

In this study four different antenna configurations are compared based on CST simulations. For each configuration the free space performance is compared to the performance under influence of the CTIA Specific Anthropomorphic Mannequin (SAM) head phantom and the CTIA hand model for talk position [12].

This article is based on transient simulations done in CST [13]. The simulated setup is described in Section II. In Section III a description of the simulation procedure is given while Section IV contains the results of the simulations. Section V concludes on the results and proposes possible future investigations.

II. SIMULATION SETUP

All simulations are performed on a WB and a NB antenna in the presence of the CTIA SAM head and the CTIA hand. A simple Inverted-F-Antenna (IFA) with a width of 48 mm and a thickness of 6 mm is designed. The bandwidth of the antenna is controlled by the height of the antenna. This design is chosen to keep the WB and NB antennas as similar as possible with respect to the distance to the CTIA hand and the SAM phantom to get the most comparable results. The total height of the ground plane (GND) and antenna is kept constant at 106 mm. This is enclosed in a housing with sides made of 1 mm thick plastic and front and back made of 0.5 mm plastic. All dimensions of the antennas and housing are listed in Table I. This table also includes a list of materials and their parameters.

To quantify the effect of the antenna placement on the immunity to the user both antennas are simulated both in the top of the phone (close by the ear) and in the bottom

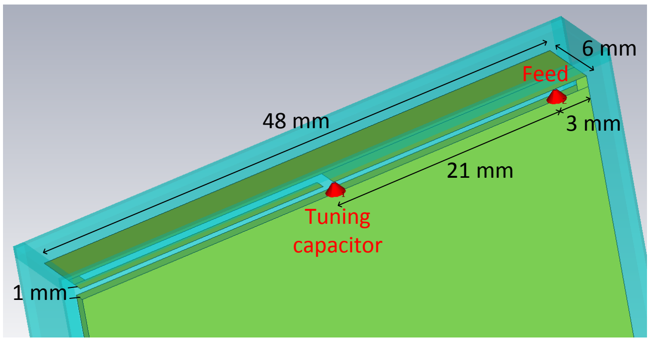


Fig. 1. Narrow-band antenna element design for the simulation. W = 48 mm, T = 6 mm, H = 1 mm.

of the phone. Both positions are likely to be used for an LTE phone since the requirement for Multiple-Input Multiple-Output (MIMO) means that at least two antennas must be fitted inside the volume of the phone. This means that a total of four configurations were simulated. The naming can be seen in Table I and is comprised of the antenna bandwidth and placement. Fig. 1 and 2 show the NB and WB antennas respectively.

The phone models are placed into a modified CTIA hand where the index finger has been replaced by a parameterized model that can be moved over the back plane of the phone. The dimensions of the parameterized finger are taken from [12]. This is of course an approximation of the index finger of the CTIA hand but since the material is the same and all dimensions are kept in line with the CTIA specification the results are deemed to be comparable to those with the default CTIA hand. The angles of the bends in the finger are changed within the realistic movement of the finger. The finger tip is swept across the six positions shown on Fig. 3.

To get a realistic simulation of the losses the influence of the head must also be included. This is done by adding a model of the CTIA specified SAM. This consists of an outer shell filled by a liquid that emulates the properties of the human head.

TABLE I
ANTENNA ELEMENT DIMENSIONS, MATERIAL PROPERTIES AND NAMING

Antenna Dimensions [mm]:			
Name	**H**	**W**	**T**
NBTM & NBBM	1	48	6
WBTM & WBBM	12	48	6
Housing	110	52	8
Material properties @ 751 MHz:			
Part	**Material**	ε_r	**tan** δ
Casing	Plastic	2.8	0.002
Hand	CTIA spec	31.8	0.421
Head shell	CTIA spec	3.5	0
Head fill	IEEE1528 liquid	41.8	0.504
Antennas	Copper	σ = 5.96e7 S/m	
NBTM & WBTM are top mounted			
NBBM & WBBM are bottom mounted			

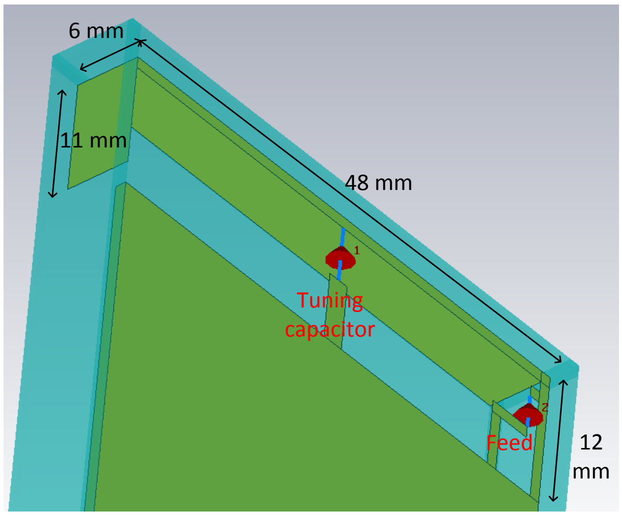


Fig. 2. Wide-band antenna element design for the simulation. W = 48 mm, T = 6 mm, H = 12 mm.

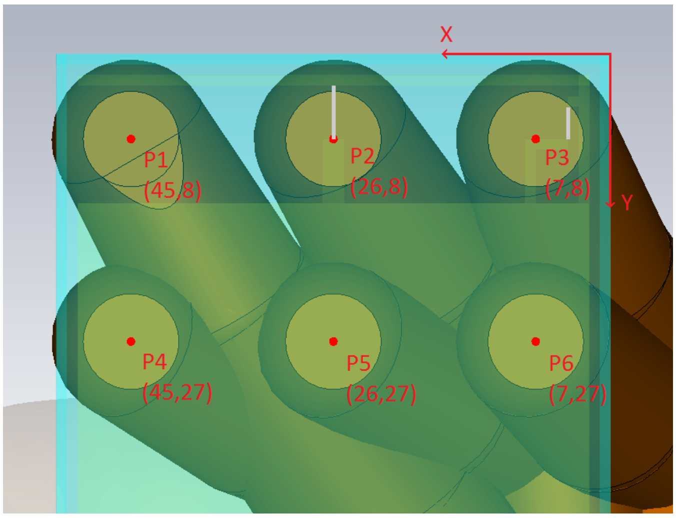


Fig. 3. Index finger positions used for simulations of hand effect. Coordinates are in mm from the top right corner of the phone. Finger tip is touching the backside of the phone in the light brown regions.

The properties are listed in Table I. The complete simulation setup can be seen in Fig. 4.

III. SIMULATION METHODOLOGY

The simulations presented are done using the transient solver of CST. This is utilizing the Finite Element Method (FEM) to simulate the response of the 3D structure to a short pulse that is exciting all frequencies of interest. For these simulations the frequency range is set to 0 - 3 GHz.

First a baseline simulation is done for the antenna, GND and housing without the SAM phantom and CTIA hand. The tuning capacitor on the antenna is adjusted to optimize S11 of the antenna at 751 MHz which is the center frequency of the down-link in LTE band 13. Then the head and hand are added and the position of the tip of the index finger is swept

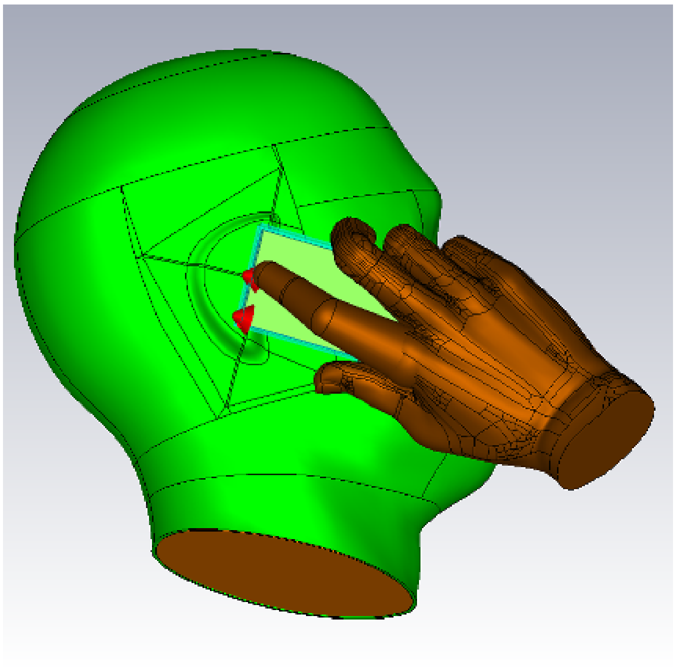


Fig. 4. Full simulation setup including phone, CTIA SAM head and CTIA hand with parameterized index finger.

across the six positions shown on Fig. 3. For each position a simulation is done and the results are compared to the free space baseline.

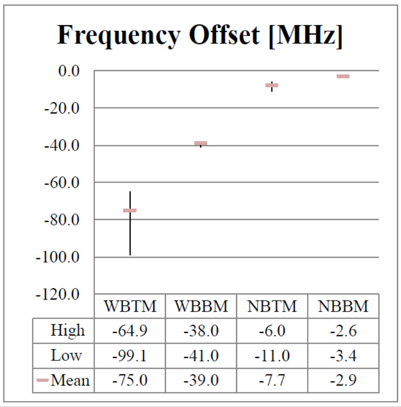
IV. SIMULATION RESULTS

The four different antenna configurations have been specified and simulated as described in the last two sections. Based on the results for the 6 different finger positions, Fig. 5 through 8 have been created. All charts are showing the maximum, minimum and average value based on the 6 finger positions. The results are both shown graphically and in the tables below the graphs for numerical accuracy.

Fig. 5 shows the detuning of the antennas calculated as the shift in frequency of the minimum of S_{11}. The frequency detuning is about 10 times worse for the WB antennas where frequency offsets in the order of 40 - 100 MHz are seen. The top mounted antennas experience about twice as much detuning and a lot more variation in detuning than the bottom mounted antennas.

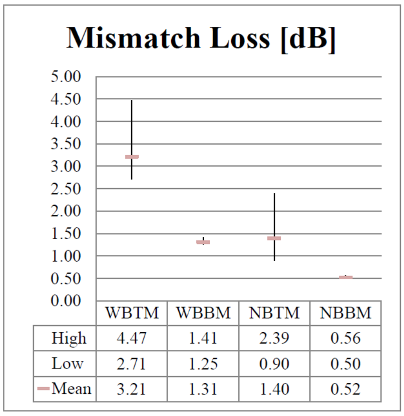
Fig. 6 shows the mismatch loss calculated as the difference between the radiation efficiency and the total efficiency. The mismatch loss is 1 - 2 dB worse for the WB antennas due to the larger detuning. Losses of up to 4.5 dB are registered for the WBTM antenna. The mounting position has a large influence on the variation in mismatch loss with the top-mounted antennas being more sensitive to the movement of the index finger.

Fig. 7 shows the absorption loss calculated as the difference between the radiation efficiency with head and hand and the radiation efficiency with only the casing. The absorption loss is about 2 dB worse for WB than for NB antennas. For the



	WBTM	WBBM	NBTM	NBBM
High	-64.9	-38.0	-6.0	-2.6
Low	-99.1	-41.0	-11.0	-3.4
Mean	-75.0	-39.0	-7.7	-2.9

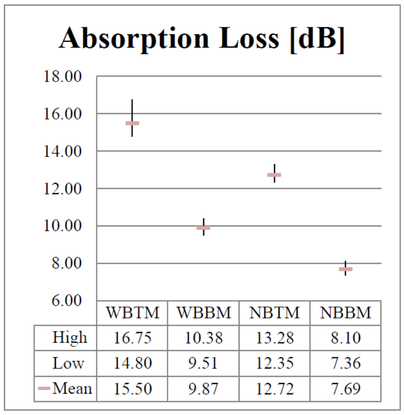
Fig. 5. Frequency detuning of the four antenna configurations.



	WBTM	WBBM	NBTM	NBBM
High	4.47	1.41	2.39	0.56
Low	2.71	1.25	0.90	0.50
Mean	3.21	1.31	1.40	0.52

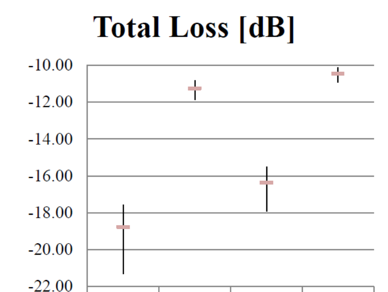
Fig. 6. Mismatch loss of the four antenna configurations.

WB antennas the loss including only the casing is 0.07 dB. This is not realistic as the copper itself will have some loss so it can be concluded that not all losses are modeled correctly. For the NB antennas the loss including only the casing is 2.25 dB. This shows that a lot more of the radiated fields are absorbed in the phone casing. This can explain why less power is absorbed in the head and hand compared to the WB antennas. The placement has an influence of 3 - 5.5 dB.



	WBTM	WBBM	NBTM	NBBM
High	16.75	10.38	13.28	8.10
Low	14.80	9.51	12.35	7.36
Mean	15.50	9.87	12.72	7.69

Fig. 7. Absorption loss of the four antenna configurations.



	WBTM	WBBM	NBTM	NBBM
High	-17.59	-10.84	-15.52	-10.11
Low	-21.30	-11.86	-17.92	-10.91
Mean	-18.78	-11.25	-16.37	-10.46

Fig. 8. Total loss of the four antenna configurations.

The total loss is shown in Fig. 8. Here it is evident that the mounting position of the antenna has a lot larger influence than the bandwidth of the antenna. The total loss is about 18 dB for top-mounted and 11 dB for bottom-mounted antennas and slightly worse for WB than for NB antennas.

V. CONCLUSION

This paper has investigated the degradation of the antenna performance due to the interaction with a user's hand and head. It has been demonstrated that the total loss of a NB and a WB antennas are comparable, however worse in the case of the WB antenna. It has also been seen that the placement of the antenna (top or bottom) is the most significant parameter. Both NB and WB antennas are predominantly suffering from absorption loss in proximity to the user. The antenna configurations with top mounted antenna are suffering more than 6 dB more total losses than with top mounted antenna.

Detuning is about a factor of ten worse for WB antennas than for NB antennas. Even with the larger bandwidth the WB antennas are suffering from larger mismatch losses than NB antennas. This means that for the WBTM antenna of this study there would be a benefit in implementing closed-loop antenna tuning. For bottom-mounted antennas the influence of the head and the hand is half that of the top-mounted antennas. It is however likely that a user with a different grip style could detune the antenna more for the bottom-mounted position as well. The influence of the movement of the index finger is much stronger for the top mounted antenna which makes sense since the movements are happening at the top end of the phone.

For modern smart phones the antenna system must support a multitude of standards of which some require MIMO meaning that it is not possible to avoid top mounted antennas. For the top mounted antenna the moving of the index finger is providing more realistic insight into the change in mismatch and absorption that the phone will experience than the static CTIA grip.

The conclusion of this study is that for the chosen antenna configurations there is 0.5 to 4.5 dB to gain by retuning the antenna to account for the user influence. The biggest losses are due to absorption in the users head and hand. It is furthermore concluded that the detuning is much more severe for the WB antenna of this study.

Further investigations include extending the study to more antenna types and placements as well as to verify the simulation results with measurements. Since the user effect is known to vary for different antenna types it is necessary to investigate their immunity to the moving index finger. Also side-placed antennas are often used and should therefore be examined with respect to the effect of the moving finger. Measurements should be done to get experimental data for the user effect and to compare with the simulations.

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