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Thermal Loss and Soldering Effect Study of High-Q Antennas in Handheld Devices

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***Abstract*—High-Q antennas are attractive because, besides being narrow-band, they have the advantage of being more compact and therefore occupy less volume in a mobile device. However, they can become very lossy especially at lower frequencies. In this paper it is investigated how low a thermal loss, in a very good conductor as copper, may be achieved. The effect from solderings on the antenna efficiency is also investigated and the effect has shown to be small. The resistance value, based on the extra loss due to the solderings, is estimated to be 0.25 Ohm. It is also shown that two different high-Q antennas, having the same Q value, can have difference in efficiency. Furthermore, it is discussed why it is so difficult to compare the electrical size and volume of different antenna types.**

***Index Terms*—High-Q antenna; soldering; thermal loss; efficiency**

I. INTRODUCTION

According to Long Term Evolution (LTE) standard, the mobile terminals will have to operate on more than 20 bands over frequencies between 700 MHz and 2700 MHz. It is well known that the antenna design is in general challenging due to the fundamental limitation of antennas [1], [2]. With the introduction of LTE, the challenge gets even bigger for an antenna designer to cover the whole frequency spectrum due to size constraints and very limited available space for antennas in close proximity to components such as camera, speaker, batterie and other hardware. One way to cover the whole spectrum is to use reconfigurable antennas. These reconfigurable antennas can be designed to be very narrow-band, since they only need to cover one channel instead of a full band, and tuned to resonate at different frequencies. Channels in LTE are between 1.4 MHz and 20 MHz [3]. This way, the reconfigurable antenna can cover a large bandwidth. A tunable antenna has the advantage that it can reuse its entire volume at different operating bands so the physical size of the antenna can be reduced [4]. This narrow-band advantage of tunable antennas allows for designs with a high Quality factor (Q).

High-Q antennas have relative high current and field density per area. Due to the high current density associated with high-Q many challenges, such as more loss in the antenna conductor, interconnection, carrier and tuning/matching components, are introduced.

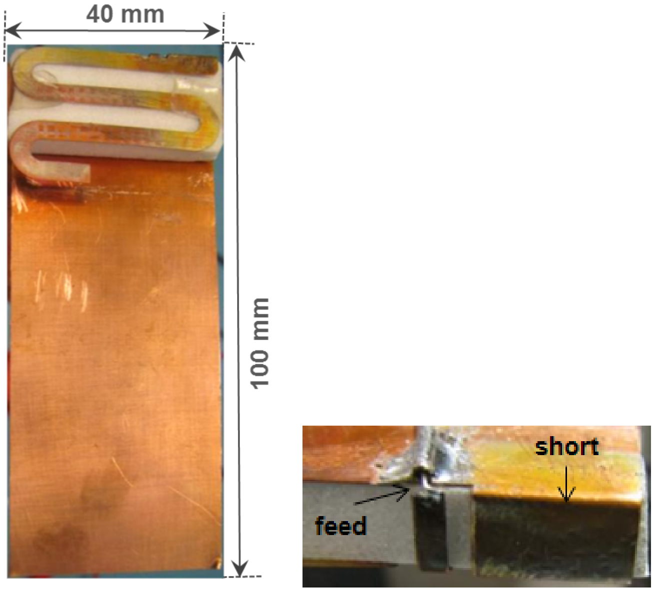

Fig. 1. Geometry of the antenna structure. (Right) antenna element on top of the PWB. (Left) the feeding point connected to a coaxial cable.

One of the main concerns with an high-Q antenna is the undesired high thermal loss in the conductor. Solder can, due to worse conductivity than copper, cause more thermal loss in the conductor. In this paper it is investigated: 1) how good an efficiency can be achieved with an high-Q antenna made of copper, and 2) how much the antenna thermal loss increases due to the solderings at high current paths of an high-Q antenna. The antenna designs for the soldering effect and thermal loss investigations are presented in Section II. The results are shown and discussed in Section III and finally conclusion is disclosed in section IV.

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II. ANTENNAS FOR THE SOLDERING EFFECT AND THERMAL LOSS STUDY

An Inverted F Antenna (IFA), which is widely used in mobile phone industry because of its integrated and low profile design, is designed for the soldering effect and thermal loss study. A patch antenna, having same Q as the IFA, is designed for the thermal loss comparison.

A. *Inverted F Antenna*

Figure 1 shows a sort of meandered IFA on top of a PWB. The Printed Wire Board (PWB) has the total dimensions of 100x40 mm^2 and the IFA has the dimensions 40x20x5 mm^3. The PWB and the antenna is designed as one structure, and the antenna part is then bent in order to create the IFA. In this way, soldering is only needed at the feed point (se Figure 1). The soldering at the feed should not cause much loss as the impedance is relatively high here - some 50Ω.

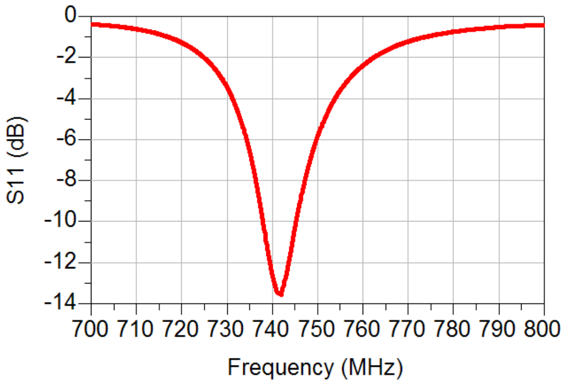

Fig. 2. Log Magnitude impedance plot of the IFA antenna.

The antenna is selfmatched, so no matching components are used. This in order to see how good an efficiency can be achieved with an antenna consisting of just copper. Air is preferred between the antenna element and the PWB in this study, because the effect of carrier loss is undesirable. However, a support material is necessary in order to make the antenna stable. Rohacell 31 HF [5], ϵ_r=1.050 and tan $\delta <$ 0.0002, is used as support material because of very low loss. The investigation is made at frequencies in the 700 MHz band because this band is the toughest band in terms of loss. The antenna impedance is seen in Figure 2, where the abs(S_{11})=-6 dB matched bandwidth is 14 MHz and the Q = 60.

As seen in Figure 3, different positions at the short of the antenna are soldered due to the high current density there. The antenna efficiency is measured with and without the solderings in order to see how much the loss increases due to the solderings. All the measurements are done using an RF choke (se Figure 4) in order to avoid efficiency contribution from currents flowing on measurement cable.

B. *Patch Antenna*

Solder only at feed	
Solder at short corner	
Solder at both short corners	
Short cut & soldered at corners	
Short cut & soldered all the way	

Fig. 3. Different soldering positions at the short of the IFA.

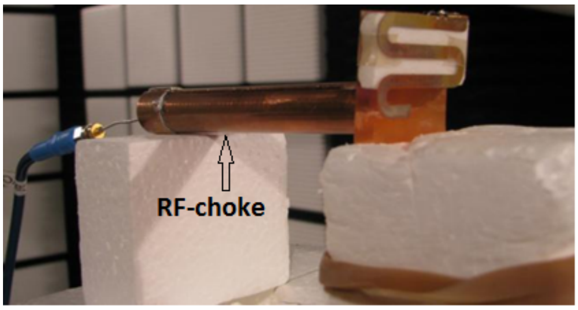

Fig. 4. Measurement setup of the mock-up with IFA antenna in the anechoic chamber.

A patch antenna is designed in order to find out if a better efficiency can be achieved compared to the IFA when the two antenna Q are comparable. Figure 5 shows an quadratic patch antenna. This patch antenna has the dimensions 70x70x10 mm^3. The whole patch is designed as one structure and then bent, so the solder is only used at the feed point (se Figure 5).

The patch antenna is also selfmatched (no matching components) in order to see how good an efficiency can be achieved with the patch antenna build of copper. Small brick of

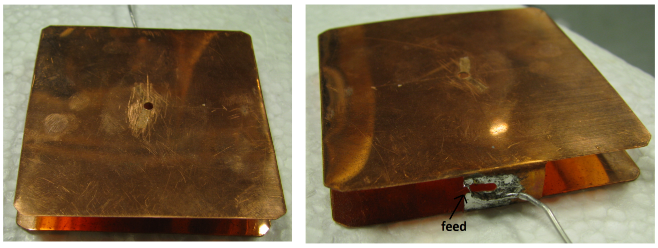

Fig. 5. Geometry of the patch antenna structure.

Rohacell 31 HF is used, as supoort material between the two patch plates, in order to make the patch antenna stable. The patch antenna is also designed to resonate at 700 MHz band (resonance is about 20 MHz lower in frequency compared to the IFA resonance). The patch antenna is designed to have the same impedance bandwidth (14 MHz) and Q (60) as the IFA (see Figure 6).

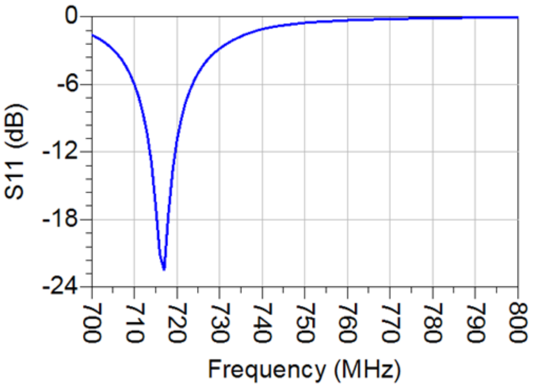

Fig. 6. Log Magnitude impedance plot of the patch antenna.

III. MEASUREMENT RESULTS

TABLE I

MEASURED EFFICIENCY RESULTS FOR DIFFERENT SOLDERING POSITIONS AT SHORT OF THE IFA.

		Frequency in MHz		
		735	740	749.5
Solder only at feed	S_{11} (dB)	-6.4	-12.2	-6.2
	Mismatch loss (dB)	1.1	0.3	1.2
	Thermal loss (dB)	**0.2**	**0.6**	**1.4**
	Total Efficiency (dB)	-1.4	-0.9	-2.6
Solder at short corner	S_{11} (dB)	-6.1	-11.6	-6.9
	Mismatch loss (dB)	1.2	0.3	1.0
	Thermal loss (dB)	**0.4**	**0.6**	**1.4**
	Total Efficiency (dB)	-1.7	-0.9	-2.4
Solder at both short corners	S_{11} (dB)	-6.0	-12.0	-6.3
	Mismatch loss (dB)	1.2	0.3	1.1
	Thermal loss (dB)	**0.5**	**0.6**	**1.7**
	Total Efficiency (dB)	-1.7	-0.9	-2.9
Short cut and soldered at corners	S_{11} (dB)	-6.2	-12.3	-7.3
	Mismatch loss (dB)	1.2	0.3	0.9
	Thermal loss (dB)	**0.5**	**0.7**	**1.9**
	Total Efficiency (dB)	-1.7	-0.9	-2.8
Short cut and soldered all the way	S_{11} (dB)	-6.1	-12.1	-5.7
	Mismatch loss (dB)	1.2	0.3	1.4
	Thermal loss (dB)	**0.5**	**0.7**	**1.3**
	Total Efficiency (dB)	-1.7	-0.9	-2.7

TABLE I shows the measured efficiency results for different soldering positions at short of the IFA. The thermal loss is affected by how good the antenna is matched. There is a tendency of thermal loss increasing when mismatch loss decreases and vice versa (se TABLE I). This inverse relation is not one to one. Therefore, for each case S_{11}, mismatch loss, thermal loss and total efficiency measurements are shown. The first measurement shows how good an efficiency which can be achieved with an antenna made of just copper. The measurement shows thermal loss of 0.6 dB with a mismatch loss of 0.3 dB. If the antenna was fully matched, then the thermal loss would probably be slightly higher. However, it seems that an antenna efficiency of -0.9 dB can be achieved with mock-up made of only copper.

The next four measurements show the effect of solderings at the short of the antenna. The solderings have in general little effect on the thermal loss. An increase of up to 0.3 dB is seen in the thermal loss due to the solderings. A resistance value, based on the loss due to the solderings, can be estimated in order to see how much ohmic loss it corresponds to. This resistance value can then be used in simulations to equivalate the loss due to the solderings. The resistance value, using ADS simulations, is estimated to be 0.25 Ohm.

TABLE II

MEASURED EFFICIENCY RESULTS OF THE PATCH ANTENNA.

		Frequency in MHz		
		711	718	724
Quadratic patch	S_{11} (dB)	-7.0	-22.8	-6.1
	Mismatch loss (dB)	1.0	0.0	1.2
	Thermal loss (dB)	**0.8**	**0.4**	**0.4**
	Total Efficiency (dB)	-1.7	-0.4	-1.6

TABLE II shows the measured efficiency results of the patch antenna. The results in TABLE II are compared to the first measurement in TABLE I. The patch antenna shows to have better efficiency than the IFA antenna on top of a PWB, even though they have equal Q values. The measurements were repeated in order to verify the correctness of the results, but with the same outcome. The patch antenna has thermal loss of 0.4 dB with no mismatch loss, where the IFA has thermal loss of 0.6 dB and mismatch loss of 0.3 dB. If the IFA antenna was fully matched, then the thermal loss would probably be slightly higher, due to the tendency of increasing thermal loss with decreasing mismatch loss.

IV. CONCLUSION

One of the objectives, in this paper, was to study the effect of solderings on the antenna efficiency. The measurements have shown a degradation in thermal loss, up to 0.3 dB, due to the solderings. It seems that solderings at high current paths of a high-Q antenna have very little effect on the thermal loss. The resistance value, based on the extra loss due to the solderings, is estimated to be 0.25 Ohm.

Another objective was to show how good an efficiency that can be achieved with an high-Q antenna made of a very good conductor as copper. It seems that no better than some -0.9 dB of efficiency can be achieved with an IFA antenna on top of a PWB. However, the patch antenna, having the same Q value, shows to have efficiency of around -0.4 dB. The difference in efficiency is significant between the two antenna types.

One way to explain this difference in efficiency, is to look at the structure of the two antenna types. The IFA antenna will have high current density per area due to its meandering structure. The patch antenna on the other hand has a simple structure and is therfore expected to have lower current density per area, which imply lower loss. The mock-up with the IFA antenna, due to the meandering structure, has longer current path compared to the patch antenna. Long current path also causes more loss in the structure.

The patch antenna and IFA on top of a PWB are compared in terms of Q value only, which can be an unfair comparison. The comparison will be more equitable if electrical size, based on antenna volume of both antenna types, are also taken into account, because Q and antenna electrical size have inverse relationship (Q grows rapidly as antenna electrical size decreases). The problem is how to compare the electrical size and volume of different antenna types. In the following it will be discussed why it is so immensely hard to compare the two different antenna types in terms of electrical size and volume.

The IFA is a monopole antenna on top of a PWB, where the PWB is the main radiator and the IFA acts more as a coupler, specially at low band frequencies (700 MHz). The volume of an antenna, in a mobile phone, is typically defined as the area between the antenna element and the PWB. However, this definition is vague since it is very difficult to define what is the antenna and what is not. The volume of the patch antenna can be explicitly expressed, but cannot be directly compared to the IFA antenna volume, because the patch antenna volume is the whole structure volume (70x70x10mm^3), where the IFA antenna volume is the area between the antenna element and the PWB. The patch antenna has a dipole mode, meaning that the currents run in phase on both patch plates. On the contrary, the IFA and the PWB has opposite phase currents.

While the electrical length of a mobile phone is typically calculated taking the length + width of the PWB into account, it becomes more blurry to express the combined electrical length when adding the antenna into the equation, because increasing e.g. the length of the PWB will mean increased electrical size. However, this does not imply lower Q, since the PWB moves away from its resonance frequency and therefore the combined PWB + IFA will result in lower bandwidth.

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