Product Compliance Assessments of Low Power Radio Base Stations with Respect to Whole-Body Radiofrequency Exposure Limits

Björn Thors, Lovisa Nord, Davide Colombi, and Christer Törnevik
[1] Ericsson Research, Ericsson AB, Stockholm, Sweden, bjorn.thors@ericsson.com

***Abstract*—This paper discusses the suitability of different standardized approaches for product compliance assessments of low power radio base stations with respect to general public whole-body radiofrequency exposure limits. Using numerical simulations, two standardized procedures based on spatially averaged field strengths, for comparison against the reference levels, and based on SAR assessments, for comparison against the basic restrictions, are evaluated in the frequency range 300 MHz – 5000 MHz. It is shown that the currently standardized whole-body SAR measurement procedure is overly conservative for small phantom-antenna separation distances and may lead to unphysical results. To avoid these problems, a new distance dependent correction factor is proposed to account for effects of tissue layering. Furthermore, a new box-shaped phantom for child whole-body SAR measurements is proposed which may be used to obtain more accurate whole-body SAR results compared with currently standardized procedures. The proposed approach is shown to produce conservative results with respect to numerical simulations using the anatomical child phantom Roberta from the Virtual Classroom set of phantoms.**

Index Terms — radio base stations, heterogeneous network, EMF exposure, whole-body SAR, product compliance assessments.

I. INTRODUCTION

The traffic in the mobile communication networks is expected to increase significantly during the years to come with the continued growth of mobile broadband. To cope with user expectations of high data rates and traffic capacity, a densified infrastructure is needed. For scenarios where many users are located within a small geographical area, deployment of heterogeneous networks, where the macro layer is complemented with one or more low power nodes, has been proposed to meet the traffic and data rate demands.

Before placing radio base station (RBS) products on the market, manufacturers are responsible to make sure that these are designed and tested to comply with international safety guidelines and regulations regarding exposure to radiofrequency (RF) electromagnetic fields (EMF). The most widely adopted RF EMF exposure guidelines have been specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. Exposure limits are given both in terms of basic restrictions and reference levels. For mobile communication frequencies, basic restrictions are given in terms of localized and whole-body SAR to prevent from established adverse health effects related to whole-body heat stress and excessive localized tissue heating [1]. The basic restrictions are given with large safety margins. The reference levels, derived from the basic restrictions on whole body SAR for practical exposure assessments, are given in terms of electric and magnetic field strengths or power density. They are to be assessed in free space without presence of the exposed individual. Furthermore, the reference levels are intended to be spatially averaged values over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded [1]. The reference levels were derived for maximum coupling conditions and compliance with the reference levels should ensure compliance with the basic restrictions [1].

For the European market, product compliance assessments[1] may be performed according to the specifications in the CENELEC standard EN 50383 [2]. This standard specifies assessment methods for field strengths and localized SAR. For assessments against the whole-body exposure limits, no SAR measurement method is specified. Conservative power limits are given, however, below which the whole-body absorption is implicitly compliant. Thus, using ICNIRP's basic restrictions, pure SAR based product compliance assessments are only possible according to EN 50383 if the maximum transmitted power is equal to or below 1 W [2]. For products transmitting at higher power levels, methods for comparison against the reference levels will have to be used.

In the international standard IEC 62232 [3], procedures for both localized and whole-body SAR measurements are specified. Whole-body SAR for adults is to be assessed by first measuring the total absorbed power in a box-shaped phantom with lateral dimensions of 1540 mm × 339 mm, then multiplying the obtained result with a factor of 1.8 to consider effects of tissue layering, and finally normalizing to a mass of 46 kg. The measurement procedure and the dimensions of the adult box phantom were derived to obtain conservative whole-body SAR results for adults [3], [4]. For whole-body SAR assessments related to child exposure, an additional conservative assumption is employed by requiring that the power absorbed within in the "adult" phantom is divided with a mass of 12.5 kg, corresponding to the 3rd percentile body weight data for a 4-year old girl [3].

[1] Product compliance assessments are normally conducted for free space conditions without ambient sources or scatterers present [2].

For product compliance assessments it is important to distinguish between occupational and general public exposure. Not only are the exposure limits different [1], but also the applicable exposure configurations may differ. For occupational exposure, the whole-body SAR assessments are to be conducted with an adult phantom, while for general public exposure two different configurations are possible depending on the product type. For products that may be placed arbitrarily in homes, offices, and other places, the whole-body SAR assessments are conducted assuming child exposure. Other products, however, might be installed in a way that will prevent children from entering the immediate vicinity of the transmitting antenna(s). Here, it is relevant to conduct the whole-body SAR assessments assuming adult exposure.

When assessing whole-body absorption for EMF compliance assessments of products emitting more than 1 W of power, both standards discussed above are likely to produce more or less conservative results. The purpose with this paper is to evaluate the suitability and accuracy of different EMF exposure assessments methods, applicable to medium range[2] RBS products and for comparison against the whole-body exposure limits, in order to facilitate the deployment of heterogeneous networks.

II. Method

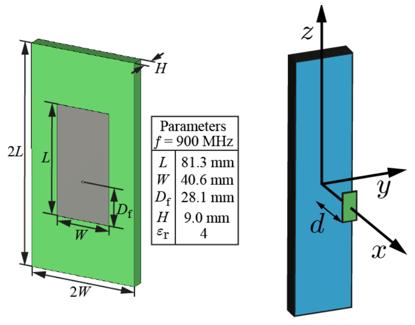
The following exposure assessment methods are included in the evaluation:

- Measurements of whole-body SAR according to the specifications in IEC 62232 [3].
- Measurements of whole-body SAR, in large according to the specifications in IEC 62232, but using a smaller box-shaped phantom to better mimic child exposure. The dimensions of this phantom (960 mm × 233 mm × 59 mm) were derived to produce conservative whole-body SAR results for children at the age of 4 and older following the approach in [4]. The mass of this phantom, referred to as the child box phantom, is 13.1 kg.
- Electric and magnetic field strengths averaged over an area of 600 mm × 400 mm according to EN 50383 [2].

The antenna type used for the analysis was a single patch element commonly used with low-power RBS products. A sketch of the antenna element is given in Fig. 1a together with its dimensions at 900 MHz. For the other frequencies considered, the antenna dimensions were scaled accordingly.

The different exposure assessment methods were evaluated using numerical simulations with the commercial electromagnetic solver CST Microwave Studio based on the Finite Integration Technique (FIT). At least 10 mesh lines per medium wavelength were used throughout the calculation domain. Around all metal edges, the mesh density was refined with a factor of twelve.

As a reference, numerical whole-body SAR simulations were conducted for the anatomical phantom Roberta corresponding to a five year old girl [6], [7]. This phantom consists of 66 different tissue types with dispersive dielectric properties [8].



(a) (b)

Figure 1. (a) Patch antenna element used for the analysis.
(b) Adult (IEC) box-shaped phantom with patch antenna.

Although the focus of this paper is on exposure assessments with respect to the whole-body exposure limits, practical compliance assessments also require that the limits on localized exposure are considered. The resulting compliance distance is determined as the maximum distance obtained from the localized and whole-body exposure assessments. For comparison purposes, simulations of peak 10g averaged SAR, determined using the adult box phantom [3], were also conducted.

III. Results & Discussion

A. Whole-body SAR measurement procedures applicable to children

In this section, simulated whole-body SAR results corresponding to the IEC 62232 procedure for child exposure are compared with results obtained using the smaller child box phantom. From a practical point of view, it is of interest to reduce the number of physical phantoms needed to conduct SAR measurements. Results are therefore also given for the case when the absorbed power is assessed using the adult box phantom but within a sub-volume corresponding to the child box volume. Also results for the anatomical phantom Roberta are included for comparison.

In Fig. 2, results obtained at 450 MHz are given in terms of the transmitted power required to obtain an exposure equal the ICNIRP exposure limits as function of separation distance between the antenna and the assessment point.

As shown in Fig. 2, the methods produce conservative results with respect to the whole-body SAR obtained using the Roberta phantom. As expected, the accuracy in measured whole-body SAR is improved, especially for larger phantom-antenna separations, by introducing the smaller child box phantom. Shown in Fig. 2 is also the theoretical limit in transmitted power which can lead to a whole-body SAR value equal to the ICNIRP basic restriction for a body with a mass of 13.1 kg. This limit corresponds to the case that all power transmitted is being absorbed by the body. From the figure it is evident that currently standardized SAR measurement methods are overly conservative for small phantom-antenna separation distances and may lead to unphysical results.

The corresponding results obtained at 900 MHz, 2100 MHz, and 3500 MHz are provided in Fig. 3 – Fig. 5.

[2] Medium area RBS are transmitting with a maximum output power of 10 W (including tolerance of +2 dB) [5].

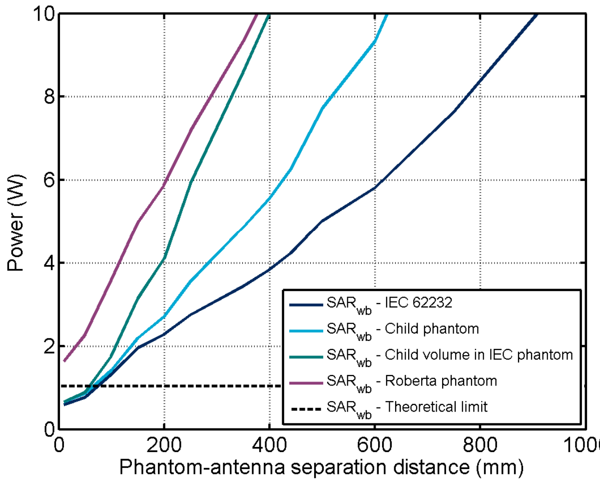


Figure 2. Comparison between different approaches for measuring child whole-body SAR (f = 450 MHz).

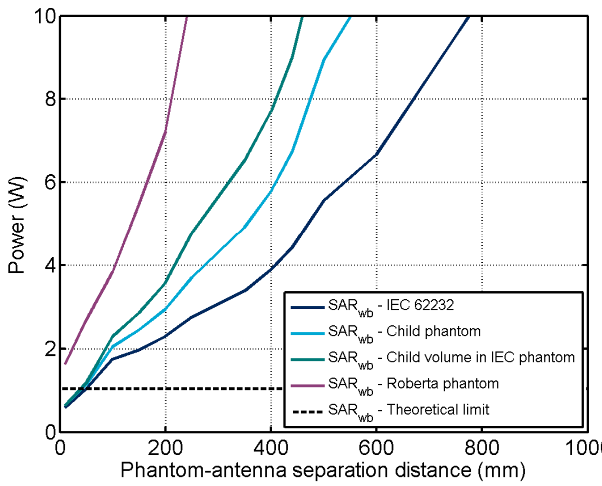


Figure 3. Comparison between different approaches for measuring child whole-body SAR (f = 900 MHz).

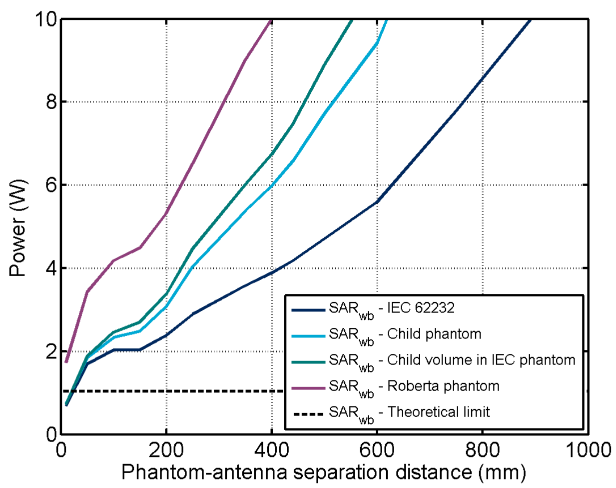


Figure 4. Comparison between different approaches for measuring child whole-body SAR (f = 2100 MHz).

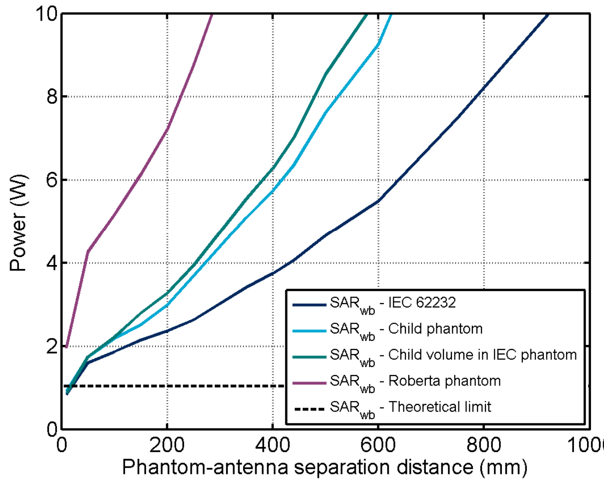


Figure 5. Comparison between different approaches for measuring child whole-body SAR (f = 3500 MHz).

Also for these frequencies, the currently standardized procedure produces overly conservative results. The explanation for this behavior lies in the usage of the previously mentioned correction factor of 1.8 to account for effects of tissue layering. This correction originates from the SAR estimation work by Gosselin *et al.* [5], which resulted in estimation formulae valid for antenna-phantom separation distances larger than 200 mm. Using the same correction all the way down to 0 mm separation distance, as specified in IEC 62232, produces overly conservative results as the effects of tissue layering in this region is small. In fact, for localized SAR measurements, EN 50383[2] and IEC 62232 [3] specifies a distance dependent correction factor to account for tissue layering, which reaches its maximum value at a phantom-antenna separation distance of 400 mm. For practical purposes, any correction shall be easy to apply while producing reasonable results. As a trade-off between simplicity and accuracy, the following correction factor is proposed to account for effects of tissue layering

$$C_1 = \begin{cases} 1 + 0.8d/400 & d < 400\text{ mm} \\ 1.8 & d \geq 400\text{ mm} \end{cases}, \qquad (1)$$

where d is the phantom-antenna separation distance in mm. The effect of using this correction factor is illustrated in the following subsections.

The difference between the ‘child phantom’ and the ‘child volume in IEC phantom’ results is mainly a consequence of different contributions to the total absorbed power entering through the phantom side walls. For practical SAR measurements it is desirable to be able to assess both adult and child exposure using the same physical phantom. This will introduce a bias as shown above. The level of this bias has been assessed from the simulation results by determining the ratio between the whole-body SAR in the child phantom and the whole-body SAR in the child volume of the adult phantom, see Fig 6. As expected, the difference is negligible for small phantom-antenna separation distances and gradually increasing as the phantom moves away towards the far-field region. In

Table 1, the corresponding results are given for normally incident plane waves of different polarizations.

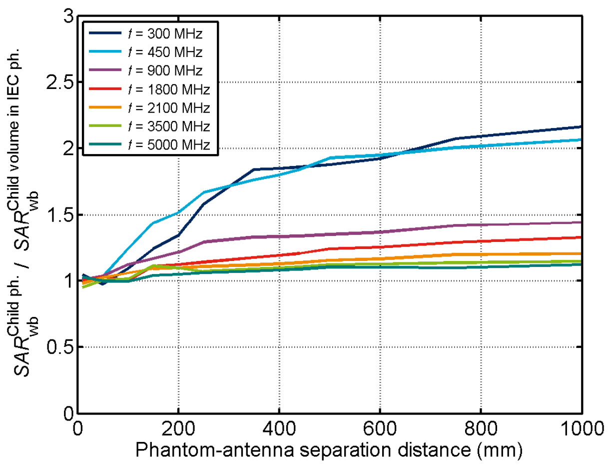


Figure 6. Bias introduced by assessing child whole-body SAR from the absorbed power within 'child volume' of the adult phantom for the patch antenna excitation.

TABLE I. RATIO BETWEEN WHOLE-BODY SAR IN THE CHILD PHANTOM AND WHOLE-BODY SAR IN THE CHILD VOLUME OF THE ADULT PHANTOM FOR NORMALLY INCIDENT PLANE-WAVES.

Freq. (MHz)	$SAR_{\text{wb}}^{\text{Child phantom}} / SAR_{\text{wb}}^{\text{Child volume in IEC phantom}}$	
	V-pol. ($\boldsymbol{E}_{\text{inc}} = \hat{\boldsymbol{z}} E_0 e^{jkx}$)	X-pol. ($\boldsymbol{E}_{\text{inc}} = \frac{(\hat{x}+\hat{z})}{\sqrt{2}} E_0 e^{jkx}$)
300	2.4	1.7
450	2.3	1.6
900	1.5	1.4
1800	1.3	1.3
2100	1.3	1.3
2600	1.2	1.2
3500	1.2	1.2
5000	1.2	1.2

B. Comparison between general public whole-body SAR measurements results for adult and child exposure

As mentioned above, some RBS products are installed in a way which prevents children from gaining access to the immediate vicinity of the transmitting antenna(s). The use of an adult phantom will lead to a shorter compliance distance as illustrated in Fig. 7. The whole-body SAR values were in this case determined using the correction factor in (1), and as a consequence, the overly conservative results for small phantom-antenna separation distances are avoided.

C. Comparison between SAR and field-based general public exposure assessment methods

In Fig. 8, a comparison between SAR and field-based general public exposure assessment methods is made for the frequencies 450 MHz and 900 MHz. The whole-body SAR results were obtained using the child phantom and the correction factor in (1). To illustrate the approximate level of conservativeness, results obtained using the anatomical phantom Roberta were also included.

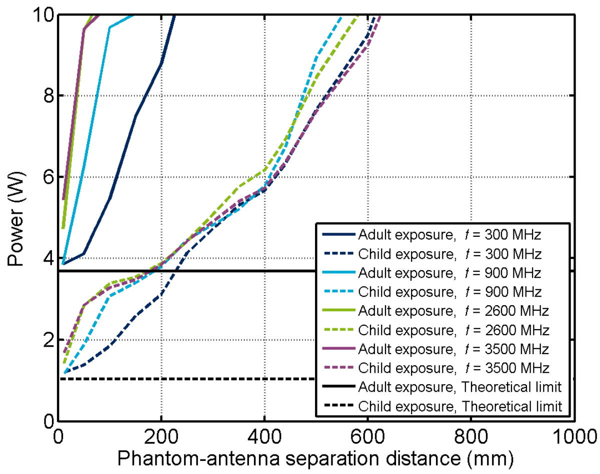


Figure 7. Comparison between general public whole-body SAR measurements results for adult and child exposure.

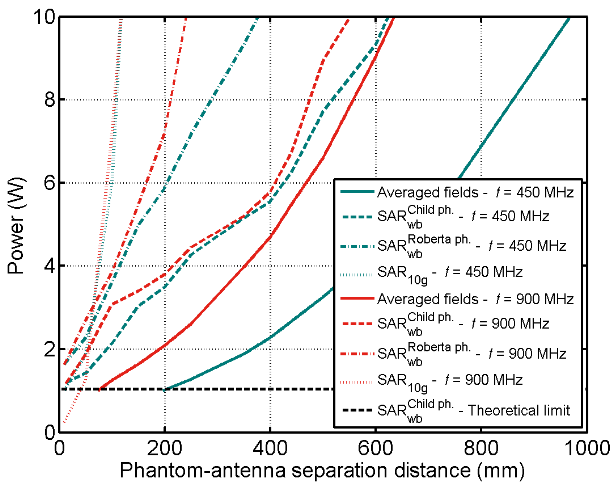


Figure 8. Comparison between SAR and field based general public exposure assessment methods (f = 450 MHz & f = 900 MHz).

For the lowest frequency, a quite significant difference is observed between the averaged field method [2] and the whole-body SAR approach. This difference is reduced as the frequency is increased as a consequence of the frequency dependent reference levels between 400 MHz – 2000 MHz [1]. For both frequencies, the proposed child whole-body SAR measurement approach produces conservative results with respect to the results obtained for the anatomical phantom.

As shown in Fig. 8, for low power levels the resulting compliance distance is determined by the requirements on localized exposure. For power levels above the theoretical whole-body exclusion limit, whole-body exposure requirements determine the compliance distance at these frequencies if the average field strength assessment method is used.

The corresponding results for frequencies between 1800 MHz and 5000 MHz are shown in Fig. 9 and Fig. 10.

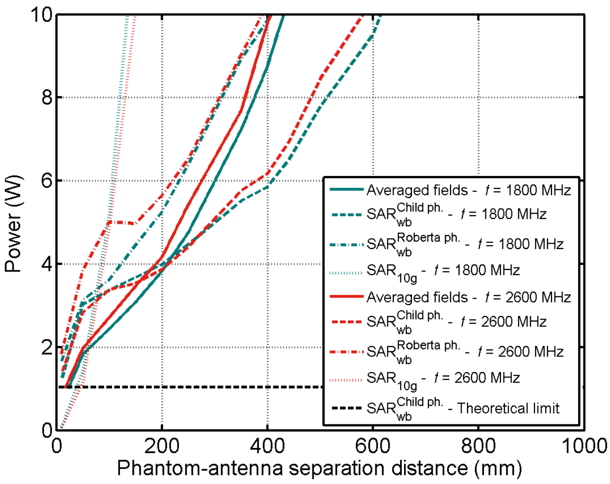


Figure 9. Comparison between SAR and field-based general public exposure assessment methods (*f* = 1800 MHz & *f* = 2600 MHz).

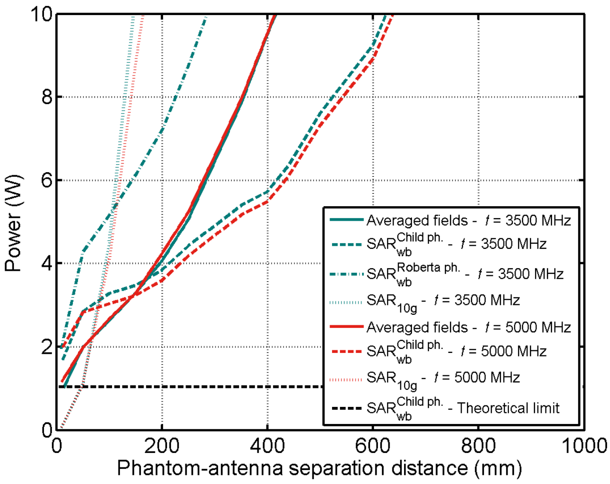


Figure 10. Comparison between SAR and field-based general public exposure assessment methods (*f* = 3500 MHz & *f* = 5000 MHz).

For these frequencies and for transmitted power levels above approximately 3 W - 4 W, the averaged field method produces shorter compliance distances than the whole-body SAR measurement method. Given the behavior of the localized SAR curves, there is actually only for a quite small transmitted power range, starting at approximately 2 W, where the more cumbersome whole-body SAR measurement method may be used to obtain a more accurate compliance distance compared with if whole-body exposure limit compliance is assessed using the averaged field method.

For cases where RF EMF compliance is ensured for the general public using adult whole-body SAR measurements, these will produce shorter compliance distances than the field averaging approach, cf. Fig. 7 – Fig. 10.

IV. Conclusions

In this paper, numerical simulations have been used to evaluate the accuracy and suitability of different methods for product compliance assessments of low power radio base stations with respect to whole-body RF EMF exposure limits in the frequency range 300 MHz to 5000 MHz. It has been shown that the currently standardized whole-body SAR measurement procedure is overly conservative for small phantom-antenna separation distances and may lead to unphysical results. To avoid these problems, a new distance dependent correction factor has been proposed to account for effects of tissue layering.

Furthermore, a new phantom for child whole-body SAR measurements has been proposed which may be used to obtain more accurate whole-body SAR results compared with currently standardized procedures. The proposed approach has been shown to produce conservative results with respect to numerical simulations using an anatomical child phantom.

A comparison between the proposed whole-body SAR measurement approach and the field averaging method in EN 50383 [2] has been made illustrating the suitability of the techniques for different exposure configurations.

References

[1] ICNIRP, “Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz),” *Health Physics*, vol. 74, pp. 494–522, 1998.

[2] CENELEC, “Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz – 40 GHz)”, *CENELEC EN 50383*, August 2010.

[3] IEC, “Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure”, *IEC 62232*, May 2011.

[4] M.-C. Gosselin et al., “Estimation formulas for the specific absorption rate in humans exposed to base-station antennas,” *IEEE Trans. Electromagn. Compat.*, vol. 53, no. 99, pp. 909–922, 2011.

[5] 3GPP, “Technical Specification Group Radio Access Network; Base Station (BS) radio transmission and reception (FDD)”, *3GPP TS 25.104*, version 11.3.0, Sept. 2012.

[6] IT’IS, “High-Resolution Human Models: Virtual Population”, Internet: www.itis.ethz.ch/vip, [Jan. 11, 2013].

[7] A. Christ et al., “The Virtual Family - development of surface-based anatomical models of two adults and two children for dosimetric simulations,” *Phys. Med. Biol.,* vol. 55, no. 2, pp. N23–N38, 2010.

[8] FCC, “Body Tissue Dielectric Parameters,” Internet: http://www.fcc.gov/oet/rfsafety/dielectric.html, Aug. 4, 2010 [Jan. 11, 2013].