Combining Near-field Over the Air (OTA) measurements with advanced post-processing link approach to evaluate Specific Absorption Rate (SAR) for a commercial smart phone

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***Abstract*—The Specific Absorption Rate (SAR) using the Link approach has been researched and validated over the past few years for passive antennas and certain active devices. This paper extends the Link approach to measure SAR for a commercial smartphone, where there is no prior knowledge or control over the power control mechanism or the antenna's position within the phone. A 10MHz bandwidth LTE signal communication between a commercial smartphone and a Radio Communication Tester (RCT) simulating a mobile Base Station was studied in this work. The E-field distribution and SAR values derived from the Link approach were compared to results from the same Device Under Test (DUT) measured with a traditional SAR measurement system (single probe with a robot and phantom). The SAR value measured with 5mm separation between the DUT and the phantom are within 2.8% (or 0.12 dB) for 10g SAR. Using the SAR data at different separation distances, the SAR value at 0mm (contact position between DUT and Phantom) is evaluated using extrapolation from the Link approach. The 10g SAR results at 0mm are within 2.7% (or 0.11 dB) between the reference measurement and proposed Link approach. It's worth noting that only one measurement is required to evaluate the SAR at different distances and orientations, using the Link approach. Hence enabling the user to have a fast method at the early stage of development up to the pre-compliance stage for SAR assessment.**

***Index Terms*— Over The Air, OTA, Specific Absorption Rate, SAR, Smartphone, LTE, Near-field measurements, Numerical simulations, Post-processing techniques.**

I. Introduction

There has been an increased interest in accelerating the evaluation process of wireless communication systems in general in recent years. With more and more wireless devices penetrating the market and becoming an essential part of our lives, the need of faster development cycles with minimizing risk is growing. The same is true for exposure evaluation from communication devices. The Specific Absorption Rate (SAR) is the standard metric used to quantify the exposure from radiated electromagnetic fields emitted by any wireless communication system (smart phones, fixed wireless devices, laptops, tablets, etc.) in the frequency range from 4 MHz up to 10 GHz. The method to evaluate the SAR is standardized in the IEC/IEEE 62209-1528 document published in 2020 [1]. The legacy method to evaluate SAR [2] has become too time consuming due to the simple fact that the number of frequencies, and technologies, that a modern wireless communication device supports, has increased significantly in recent years. Hence new approaches to do fast SAR evaluation have been studied [3],[4]. These methods propose to use multiple probes instead of a single one, to scan a human tissue equivalent liquid phantom, which is illuminated by the device under test (for example a smart phone). The gain in scan time is proportional to the number of probes constituting the multi-probe system in a single plane. While the scan in the planes normal to the plane of the probes still has to be done in discrete steps, in addition to the SAR evaluation of the device in different orientations, different distances, and in different use cases (head, trunk, body).

Another approach has emerged in recent years to further improve the SAR evaluation process. This approach is based on the idea to measure the near-field vector E-field data around a DUT in spherical region, and then using advanced post-processing techniques, create an equivalent current source model (or Huygen's box) representing the DUT [5]-[9]. The field inside the Huygen's box is set to zero. This box can then be exported to a full-wave Electromagnetic solver, and a phantom can be placed in proximity and in any orientation desired. The SAR can then be simulated using the real device digital twin and lossy phantom models easily. The human effort using this approach is significantly reduced, because there is need for only one measurement per frequency, and per protocol, to be done, without the need for tissue equivalent liquid phantoms (and their associated measurements, validation, and cleaning process). The SAR can be evaluated for any orientation, any separation distance, and any phantom shape using the equivalent current source, very rapidly and only machine time is required. This approach simplifies the process to a great deal and minimizes the probability of errors due to human intervention.

The Link approach based on the equivalent current source reconstruction from near-field measurements has also been applied to evaluate the SAR and incident power density [10] in recent works. Passive antenna SAR measurements using the Link approach ([11] & [12]) have shown close correlation with the legacy, single probe liquid phantom scan methods. SAR evaluation for active devices using Over The Air (OTA) measurements and Link approach have been presented recently in [13] (for a small cell) & [14] (for a golden wireless device) showing good comparison with legacy methods.

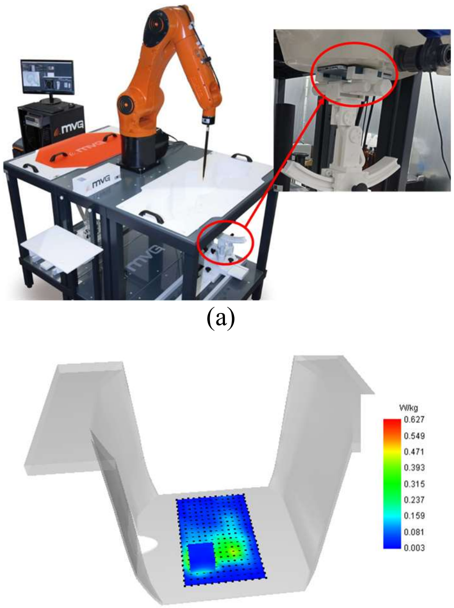
In this paper, we take a step further and apply the Link approach to a commercial smart phone device for LTE signals. The paper is organized as follows. Section II presents the Link work-flow and the reference measurement system. Section III focuses on results and analysis. Section IV concludes and presents the perspectives for future work.

II. MEASUREMENT SETUP

A commercial smart phone is selected for this study. The model of the smartphone is not disclosed. The LTE band 7, with 10 MHz channel bandwidth and center frequency of 2535 MHz, has been selected for this study. The communication with a base station is emulated using a commercially available Base station emulator for LTE services, also known as a Radio communication Tester (RCT). The RCT permits to maintain a stable communication link with the DUT, and ensuring that the DUT is emitting maximum power through out the measurement cycle. However, modern smart phones have several layers of power control mechanisms (proximity sensor, smart power control, etc.) which are not controlled by the RCT. The test labs, or phone manufacturers have access to these parameters and they can enable or disable them. In this study, there was no control over the DUT regarding the power control mechanisms. The objective was to identify whether the measurement of a commercial device as a black box, in free space (Link approach), and in proximity to a phantom (legacy approach) would yield similar SAR results. The power emitted from the DUT was monitored during the measurement period to ensure that it is constant.

A. Legacy SAR measurement (reference) system

The reference measurement system (MVG ComoSAR [2]) consists of a robotic arm with a wide band passive SAR measurement probe attached to its end (Fig. 1a). The SAR probe is an isotropic probe, capable to measure the three components of the E-field (magnitude only) at a given point in space. The DUT is positioned below the liquid phantom using a precise positioner. The DUT distance with the phantom is controlled by precise spacers with thickness varying between 2 mm up to 11.2 mm. MVG Open SAR software environment is used to control the robot, the RCT, the measurements from the SAR probe, and calculation of SAR results.



(a)

(b)

Fig. 1. (a) Legacy single probe SAR measurement system with DUT, (b) reference SAR measurement at 5mm separation for LTE B7 2535 MHz frequency with 10 MHz channel bandwidth signal.

The LTE settings for DUT set through the RCT for this study are the following. Uplink (UL) frequency = 2535 MHz, Downlink (DL) frequency = 2655 MHz, Channel bandwidth = 10 MHz, Resource block (RB) size = RB offset = 50, Modulation = QPSK. The SAR liquid and phantom parameters are summarized in the Table 1 below. The liquid values (permittivity and conductivity) are taken from the current SAR standard [1]. For the measurements and simulations, the measured values were used, which are within the allowed tolerances defined in the standard document [1] (i.e. ±10%).

Table 1: SAR Liquid and phantom characteristics @2535 MHz

Liquid (X xY x Z)	300 x 300 x 150 mm
Phantom (X xY x Z)	300 x 300 x 2 mm
ε_r (Phantom)	3.5
ε_r (SAR liquid)	39.1
Concductivity (SAR liquid)	1.9 [S/m]
Density (SAR liquid)	1000 [kg/m^3]

Fig. 1 (b) shows the SAR value representation for 5mm separation distance between the DUT and the phantom. The E-field is concentrated between the tissue volume and the base of the phantom, representing the DUT hot-spot for the measured E-field by the SAR probe inside the phantom.

B. Link methodology (spherical near-field measurements and advanced post-processing)

The digital twin of the commercial smart phone DUT is evaluated using the spherical near-field measurements form MVG StarLab OTA [15] system, and creating a Huygens box using MVG Insight post-processing tool [16]. The procedure is similar to the one used in previous work [11] and is summarized in Fig. 2 below.

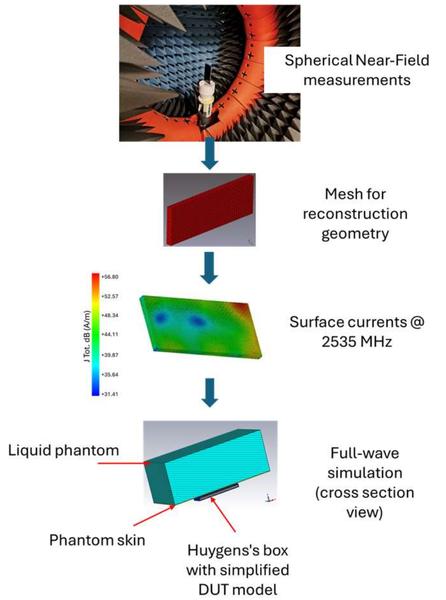


Fig. 2. Link approach methodology, digital twin for SAR evaluation.

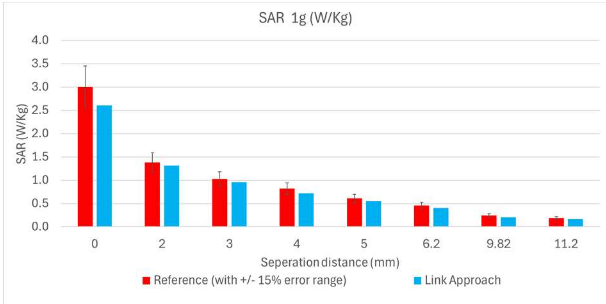
The Huygens box (or near-field source) obtained from Insight is exported to CST full-wave solver [17], and the phantom and liquid are introduced with the same parameters as for the reference measurement system (Table 1).

The Huygens box representing the DUT is slightly larger than the real DUT size (2mm each direction). Hence we can simulate the SAR with a minimum separation of 2 mm between DUT and phantom skin. In order to evaluate the SAR at 0mm (or contact position), an extrapolation is done from the SAR values obtained from Link approach at different separation distances (2, 3, 4, 5, 6.2, 9.82, & 11.2 mm).

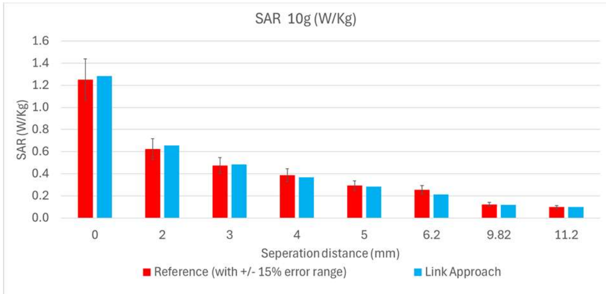
In order to emulate the coupling effect between the DUT and the phantom, a simplified model of DUT is inserted inside the near-field source in CST. The model consists of an aluminum block representing the chassis of the phone, and a thin glass plate with 0.8mm thickness on top [18].

III. Results

The SAR evaluated using the reference system (section II-A) and Link approach (section II-B) for 1g and 10g equivalent tissue volumes are compared in Fig. 3 below. The comparison is excellent between the two techniques, both for 1g and 10g SAR values, and at different separation distances. The error bars on the reference measurements represents a ± 15% (or 0.7 dB) variation. Almost all of the measurements are within these limits. For the 5mm separation case, the differences are -9.6% (-0.44 dB) and -2.8% (-0.12 dB) respectively for 1g and 10g SAR. For the 0mm separation distance or contact position between DUT and phantom skin, the differences are -13.1% (-0.61 dB) and +2.7% (+0.11 dB) respectively for 1g and 10g SAR. These variations are largely within the uncertainty interval of ± 30% (± 1.14 dB) mentioned in the IEC / IEEE standard document [1].



(a)

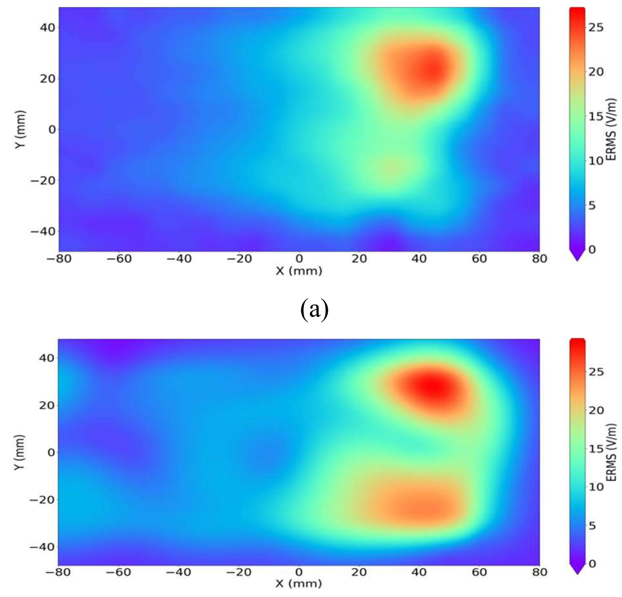


(b)

Fig. 3. (a) 1g SAR, (b) 10g SAR results, obtained from reference measurements and Link approach for a commercial smart phone with LTE B7 10MHz signal at 2535 MHz UL frequency.

In addition to the SAR results, the E-field distribution is also compared between the reference measurements and the Link approach. The results for 2mm separation between the DUT and phantom skin are shown in Fig. 4 below. The E-field evaluation plane is the same for both cases. It can be observed that the maximum E-field occurs at same location inside the phone, which confirms that the same antenna is activated for both measurement scenarios. For the test Labs, which have access to activate a specific antenna, and specific mechanisms for power control algorithms, this test should not be necessary.

The peak E-field magnitude is 26.29 V/m for the reference case, and 28.81 V/m for the Link approach (a difference of 9.6% or 0.4 dB). The slight differences between the two distributions can be due to different reasons. Mainly the positioning errors, the impact of positioning system on the E-field radiated by the DUT (which is different in the two cases), the power adjustment mechanisms which were not controlled in this study. The power emitted by the DUT was monitored and it was constant during the measurements.



(a)

(b)

Fig. 4. (a) Reference measurements, (b) Link approach. E-field distribution inside the liquid phantom at same plane, for the case of 2mm separation distance between the DUT and phantom skin.

IV. Conclusions

This paper presents the extension of the Link approach, previously validated for the passive elements and controlled active devices. A commercial smart phone was measured using the reference (Legacy) SAR measurement system, and using the Link approach with LTE band 7 connectivity. The 1g SAR results at 0mm and 5mm separation distances are between 13.1% (0.61 dB) and 9.6% (0.44 dB) of each other. The 10g SAR results are even closer with a difference of 2.7% (0.11 dB) and 2.8% (0.12 dB). The E-field distributions confirm that the same antenna is activated inside the smart phone. This confirmation would not be necessary for the SAR evaluation Labs, who have the access to control the antenna choice and the different power mechanisms inherent to the modern smart phones. The Link approach offers an alternative to the legacy SAR measurements, which consume a lot of human effort and are prone to errors in positioning, liquid manipulation, etc. This approach can save valuable time in pre-compliance stage of the development cycle.

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