# THE INFLUENCE OF A PHANTOM SHELL ON SAR MEASUREMENT IN THE HIGHER FREQUENCY RANGE (3-6GHZ)

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Abstract: In this paper, numerical results using the transmission line method and the Finite-Difference Time-Domain (FD-TD) method are presented, with respect to the effect of a phantom shell on the Specific Absorption Rate (SAR) measurement in the 3 - 6GHz. The thickness and electrical properties of the shell have been already defined in some SAR measurement standards for 300 MHz to 3 GHz. Another SAR measurement procedure, for which the frequency range is expanded to 30 MHz to 6 GHz, is being developed. It is expected that the influence of the phantom shell will increase at the higher frequencies.

As a result, when the frequency is higher than 3 GHz, the SAR when a shell is used will be approximately 20 - 30% higher than that without a shell. Additionally we show that this value depends on not only the frequency, but also the relative permittivity of the shell and distance between the antenna and the phantom.

Key words: SAR, Phantom Shell, FD-TD method, Transmission line method

## 1. Introduction

Recently, Specific Absorption Rate (SAR) measurement procedures with respect to a mobile phone, which is intended to be used at the side of the human head, have been standardized in Europe [1], USA [2], and Japan [3] and by the International Electrotechnical Commission (IEC) [4]. In these standardized procedures, a liquid phantom, which is a shell filled with liquid simulating biological tissue, has been employed in order to measure the SAR. The measurement frequency range is defined as 300 MHz to 3 GHz. The thickness and electrical properties of the shell are defined such that they do not affect the SAR, i.e.,  $2mm\pm0.2mm$ , relative permittivity  $(\epsilon_r) \le 5$ , and a loss tangent  $(\tan\delta) \le 0.05$  respectively.

Another SAR measurement procedure that covers various conditions other than that above is being developed by IEC [5]. The frequency range is expanded to 30 MHz to 6 GHz. The same electrical properties of the shell are also applied. It is hypothesized that the influence of the shell on the

SAR measurement will be increased in the range of 3 – 6 GHz compared to lower frequencies.

In this paper numerical investigation with respect to the effect of the shell is presented. The numerical investigation is conducted based on the transmission line method and the Finite- Difference Time-Domain (FD-TD) method.

As a result, when the frequency is higher than 3 GHz, the SAR when a shell is employed is approximately 20 - 30% higher than that without a shell. Additionally, we show that this value depends on not only the frequency, but also the relative permittivity of the shell and distance between the antenna and the phantom.

## 2. Numerical Investigation Methods

In this paper, the following frequencies are applied: 0.9, 2.0, 3.8 and 5.2 GHz. The electrical properties of the phantom are given in Table I. Note that the properties for 3.8 and 5.2GHz are derived by linear interpolation from the values for 3.0 and 5.8 GHz, respectively, defined by FCC [6]. The thickness of the shell is also set to 2.0 mm.

Table I Electrical properties of phantom

Frequency (GHz)	$\epsilon_{\rm r}$	σ(S/m)
0.9	41.5	0.97
2.0	40.0	1.40
3.8*	40.8	2.45
5.2*	39.0	3.66

## 2.1 Transmission line Method

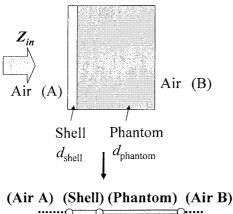
In order to know to what degree the shell affects the SAR at each frequency, the transmission line method is used. In this method, a model replaces the transmission line, which is based on assumptions such as plane waves are normally incident to an infinite-plane object. Fig. 1 illustrates the transmission line model that corresponds to the two dimensional phantom model where  $Z_0$ ,  $Z_1$ , and  $Z_2$  are the characteristic impedance of air, the phantom, and

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the shell, respectively, and can be calculated using (1).

$$Z_{i} = \sqrt{\frac{\mu_{0}}{\varepsilon_{0} \left(\varepsilon_{ri} - j\sigma_{i}/\omega\varepsilon_{0}\right)}} \tag{1}$$

where  $\varepsilon_0$ ,  $\varepsilon_{ri}$ ,  $\mu_0$ ,  $\sigma_i$  are the permittivity in a vacuum, the relative permittivity of the material, permeability in a vacuum, and the conductivity respectively. Term  $\omega$  is the angular frequency. This transmission model may be simplistic when considering the shell effect, however, we expect that the basic shell effect can be obtained. The thicknesses,  $d_{shell}$  and  $d_{phantom}$ , are 150 mm for 0.9 and 2.0 GHz, and 100 mm for 3.8 and 5.2 GHz, respectively. The reflection coefficients at the interfaces are calculated using (1) and the electric fields in the medium can be computed recursively [7].



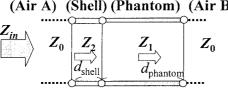


Fig. 1 Transmission line model

## 2.2 FD-TD method

A more detail numerical investigation is performed by the FD-TD method. This method is a numerical simulation technique and enables calculation of the electromagnetic field in three dimensions even though an antenna exists close to a lossy material. Fig. 2 shows the model used in this investigation, which comprises a phantom ( $W \times L \times H$ ), a shell, and a dipole antenna. Distance "d" is defined as the distance between the center of the dipole and the surface of the phantom. The shape of the phantom is assumed as a rectangular parallelepiped, which is similar to the one defined by the IEC [5]. The dimensions, W, L and H are  $2.0\lambda_0$ ,  $2.0\lambda_0$ , and 150

mm for 0.9 and 2.0 GHz and 100 mm for 3.8 and 5.2 GHz, respectively, where  $\lambda_0$  is the wavelength in free space. In the investigation, a four layer PML absorbing boundary condition is adopted in order to avoid unnecessary reflection waves from the computational boundaries. The cell size at each frequency is set to less than  $\lambda/10$ , where  $\lambda$  is the wavelength in free space or the phantom.

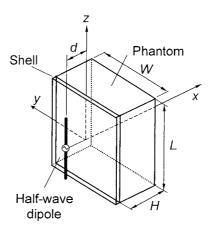


Fig. 2 Model used in the investigation

## 3. Results and Discussions

#### 3.1 Results

The difference in the SARs between with and without the shell is defined as (2). Namely, if the SAR with the shell is larger than that without the shell, difference ( $\Delta$ ) will be a positive value.

$$\Delta = (SAR_{with} - SAR_{without}) / SAR_{without} \times 100(\%)$$
 (2)

Fig. 3 shows the results calculated using the transmission line model with respect to the relative permittivity of the shell. It should be noted that when the relative permittivity equals 1, this means that the shell does not exist.

It is obvious from the results that value of  $\Delta$  is always positive. It is also clear that the results are frequency and relative permittivity dependent. This means that the SAR with the shell is higher compared to that without the shell if the frequency or relative permittivity is higher or grater, respectively. As a result, it is expected that the SAR with the shell is higher than that without the shell.

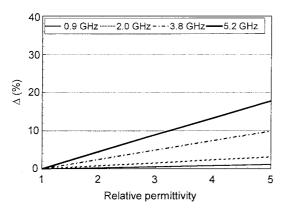
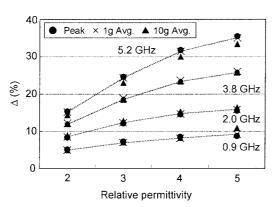


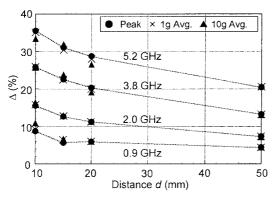
Fig. 3 SAR difference (Δ) versus relative permittivity (Transmission model)

Figures 4 (a) and 4 (b) show results calculated using the FD-TD method pertaining to the relationship with the relative permittivity of the shell (d=10mm,  $tan\delta=0$ ) and distance d ( $\varepsilon_r=5$ ,  $tan\delta=0.05$ ), respectively. It should be noted that all SARs are normalized to the antenna feed-point current.

No major difference among difference ( $\Delta$ ) of the local, 1g and 10g -average peak SARs at each frequency can be seen in either figures. This means that the SAR distributions within 10g average volume are almost the same in each case.



(a) Relative permittivity (d = 10 mm,  $tan\delta = 0$ )



(b) Distance ( $\epsilon_r = 5$ ,  $tan\delta = 0.05$ ) Fig. 4 Simulated results (FD-TD method)

Fig. 4 (a) shows the same tendency as the results obtained from the transmission line method even though the values are not the same. The two methods confirm that the relative permittivity of the shell and/or frequency affects the SAR. In this case the absolute values of  $\Delta$  are greater than those from the transmission line method. The maximum difference ( $\Delta$ ) in this graph exceeds 30% (f = 5.2 GHz).

On the other hand Fig. 4(b) shows characteristics with respect to distance d (between the dipole and the surface of the phantom). When d is increased, the difference ( $\Delta$ ) is decreased and seems to converge to the results obtained by the transmission line method.

## 3.2 Discussions

In order to investigate the above phenomenon, the transmission line method is employed again. Total impedance  $Z_m$  can be derived using (2) and (3). Term  $Z_m$  is also the total impedance when the observation point is located on the left hand side of the original model.

$$Z_{in} = Z_{shell} \frac{Z_{in\_phantom} + Z_{shell} \tanh \gamma_{shell} d_{shell}}{Z_{shell} + Z_{in\_phantom} \tanh \gamma_{shell} d_{shell}}$$
(2)

$$\gamma_{shell} = j\omega \sqrt{\varepsilon_0 \mu_0 \left(\varepsilon_{r shell} - j\sigma_{shell} / \omega \varepsilon_0\right)}$$
 (3)

where  $Z_{in\_phantom}$  represents the total impedance involving the phantom and air (B in Fig. 1). This can be calculated in the same manner as  $Z_{in}$ .

The results related to the relative permittivity are plotted in Fig. 5. The calculated results are normalized to characteristic impedance  $Z_0$  (377 $\Omega$ ) in free space. Note that numbers within parentheses denote differences (%), which are calculated in the same manner as (1), with respect to impedance. As a result, the total impedance,  $Z_{in}$ , becomes larger as the frequency or the relative permittivity increases. This is a similar phenomenon to that mentioned above. Therefore, one reason why the shell affects the SAR although the thickness is relatively small is that the absorbed power may increase as the frequency or the relative permittivity increase due to the effect of impedance matching. Results from the transmission line method and the FD-TD method have the same tendency, but different values. This may be due to electromagnetic interaction between the dipole antenna and the phantom with the shell in the results from the FD-TD method.

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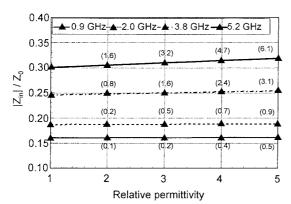


Fig. 5 Impedance characteristics (Transmission line model)

#### 4. Conclusion

This paper presented results of the effect of the phantom shell using the transmission line method and the FD-TD method with respect to the SAR measurement.

The results indicated that the phantom shell affects the SAR on its measurement. The maximum difference between the SAR with and without the shell exceeds 30% at 5.2 GHz. This value depends on not only the frequency, but also the relative permittivity of the shell and distance between the antenna and the phantom.

Therefore, further study including experiments with respect to the shell effect is necessary in the higher 3 - 6 GHz frequency range.

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