# Deign of Broadband Lightweight Phantom Composed of Wave Absorber for Simplified SAR Measurement

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## Abstract

This paper presents the design of broadband lightweight phantom for simplified specific absorption rate measurement and its surface electric field distributions at 300 MHz to 6 GHz. The electrical parameters of the lightweight phantom at higher frequency can be designed by identifying the surface impedance. For lower frequency, the required electrical parameters and size of the lightweight phantom are clarified.

**Keywords :** Specific absorption rate Phantoms Electromagnetic measurement Moment methods

## 1. Introduction

Internationally standardized methods for measuring specific absorption rate (SAR) are available for hand-held devices used in close proximity to the ear at up to 3 GHz [1], and wireless communication devices used in proximity to the human body at up to 6 GHz [2]. A simplified SAR measurement method using a lightweight phantom comprising a wave absorber as an alternative to a liquid or solid phantom has been proposed [3]. The design of the electrical parameters and the estimation procedure of the spatial-average SAR are clarified at single frequency of 1,850 MHz [4]. This paper presents the design of broadband lightweight phantom for simplified SAR measurement and its surface electric field distributions at 300 MHz to 6 GHz.

## 2. Design of Broadband Lightweight Phantom

SAR can be calculated as

$$SAR[W/kg] = \frac{\sigma E^2}{\rho} \tag{1}$$

where $E$ is the effective value of the electric field [V/m], $\sigma$ is the conductivity [S/m] and $\rho$ is the density of the human tissue [kg/m$^3$]. The internal electric field of the liquid phantom can be estimated by using surface electric field intensity of the lightweight phantom. Therefore, the high accuracy estimation of the surface electric field distribution is required. Figure 1(a) shows the analytical model of a dipole antenna near phantom with $L = W = \infty$. The length of the dipole antenna is varied to achieve impedance matching in proximity to the phantom at each frequency. $h$ is 15 mm at frequency lower than 1 GHz and $h$ is 10 mm at frequency higher than 1 GHz. Figure 1(b) shows the transmission line model that is equivalent to the normal incident of a plane wave. The surface impedance $Z_{\mathrm{in}}$ is used as the design indicator obtained as

$$Z_{in} = Z_s \frac{Z_0 + Z_s \tanh \gamma_c d}{Z_s + Z_0 \tanh \gamma_c d} \tag{2}$$

where $Z_0$ is characteristics impedance of free space, $Z_{\mathrm{s}}$ is the characteristic impedance of phantoms, $\gamma_{\mathrm{c}}$ is the propagation coefficient, and $d$ is thickness of phantoms. Figure 2 shows the electrical parameters of the phantom at 300 MHz, 1.85 GHz, and 6 GHz. The symbol ● represents the electrical parameters of the liquid phantom. The lines are the electrical parameters that $Z_{\mathrm{in}}$ of Eq.(2) is equal to the amplitude of surface impedance of liquid phantom $|Z_{\mathrm{in\_liq}}|$. Figure 3 shows maximum electric field intensities when $d$ is varied at 300 MHz. $d$ = 150 mm is selected for convergence of the maximum electric field on both liquid and lightweight phantoms.

## 3. Surface Electric Field Distributions

Figure 4 shows surface electric field distributions at 300 MHz. The surface electric field distributions are simulated by moment methods. The error of the maximum electric field of the lightweight phantom with $\varepsilon'$ = 10, $\sigma$ = 1.14 is 8.0%. The strong electric field is distributed in the large area with 400 mm × 200 mm. This is expected to require the large size of the wave absorber as the lightweight phantom. Figure 5 shows surface electric field distributions at 6 GHz. The error of the maximum electric field of the lightweight phantom with $\varepsilon'$ = 10, $\sigma$ = 12.5 is 1.6%. The strong electric field is distributed in the small area with 30 mm × 30 mm.

Figure 6 shows the errors of maximum electric field on phantoms from the maximum electric field on liquid phantom at 300 MHz to 6 GHz. The lines are the electrical parameters that $Z_{in}$ of Eq.(2) is equal to the amplitude of surface impedance of liquid phantom $|Z_{in\_liq}|$. The large errors of lightweight phantom with small $\varepsilon'$ are found at frequency lower than 1.85 GHz due to near field source environment. The design method by identifying the surface impedance cannot be adopted at lower frequency range. However, the typical wave absorber has large $\varepsilon'$ and small $\sigma$ as frequency decreases. At frequency higher than 1.85 GHz, the electrical parameters that are equal to the amplitude of the surface impedance of liquid phantom are identical to small error of the maximum electric field. The utility of using surface impedance as design indicator is verified. The wave absorber with small $\varepsilon'$ and large $\sigma$ are required at higher frequency range.

## 4. Conclusion

In this paper, we have presented the design of the broadband lightweight phantom for simplified SAR measurement. The feasibility of the lightweight phantom is verified by using the wave absorber with large $\varepsilon'$ and small $\sigma$ at frequency lower than 1.85 GHz and small $\varepsilon'$ and large $\sigma$ at higher frequency range. The peak spatial-average SAR can be estimated by using the obtained surface electric field on the broadband lightweight phantom.

## References


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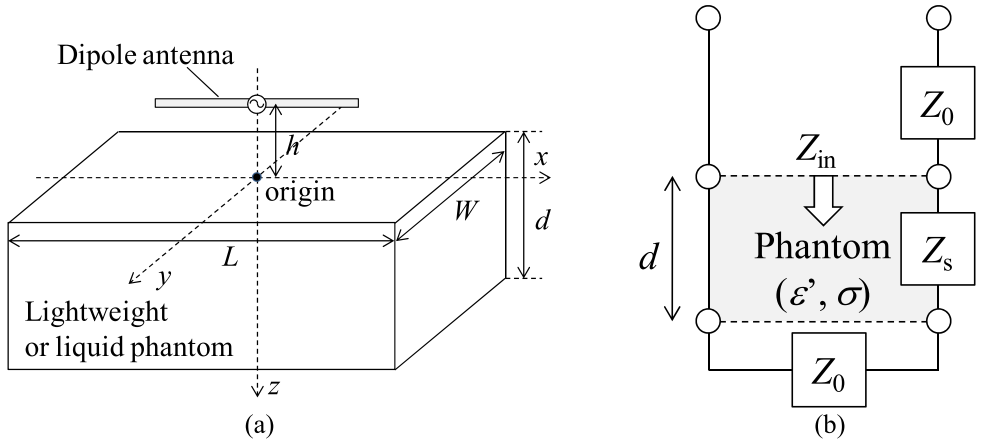


Figure 1: Configuration of the broadband lightweight phantom. (a) Analytical model of a dipole antenna near phantom. (b) Transmission line model.

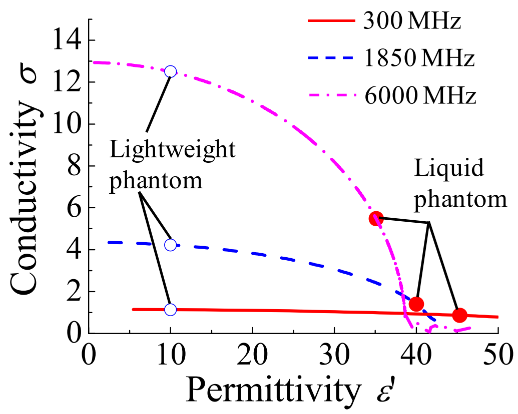


Figure 2: Electrical parameters of lightweight phantom.

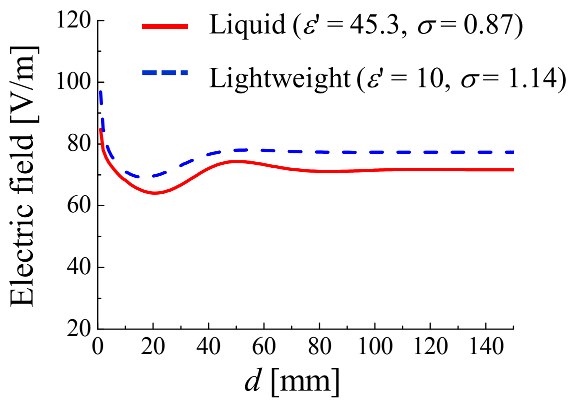


Figure 3: Maximum electric field intensities when $d$ is varied at 300 MHz.

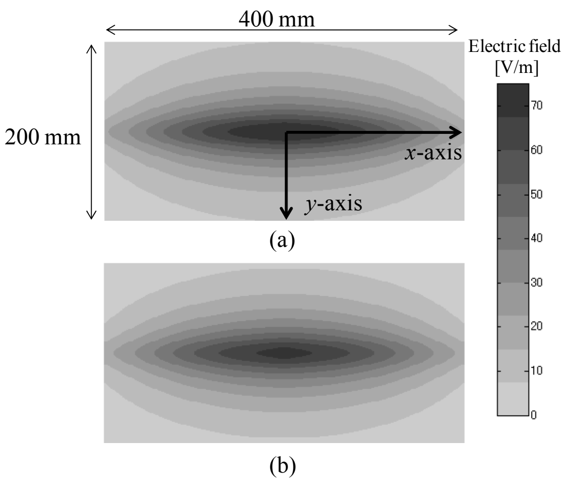


Figure 4: Surface electric field distributions at 300 MHz on (a) lightweight phantom, and (b) liquid phantom.

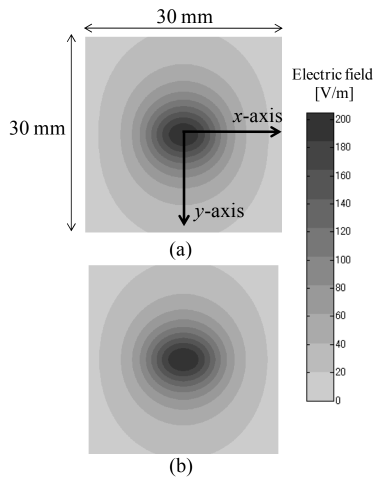


Figure 5: Surface electric field distributions at 6 GHz on (a) lightweight phantom, and (b) liquid phantom.

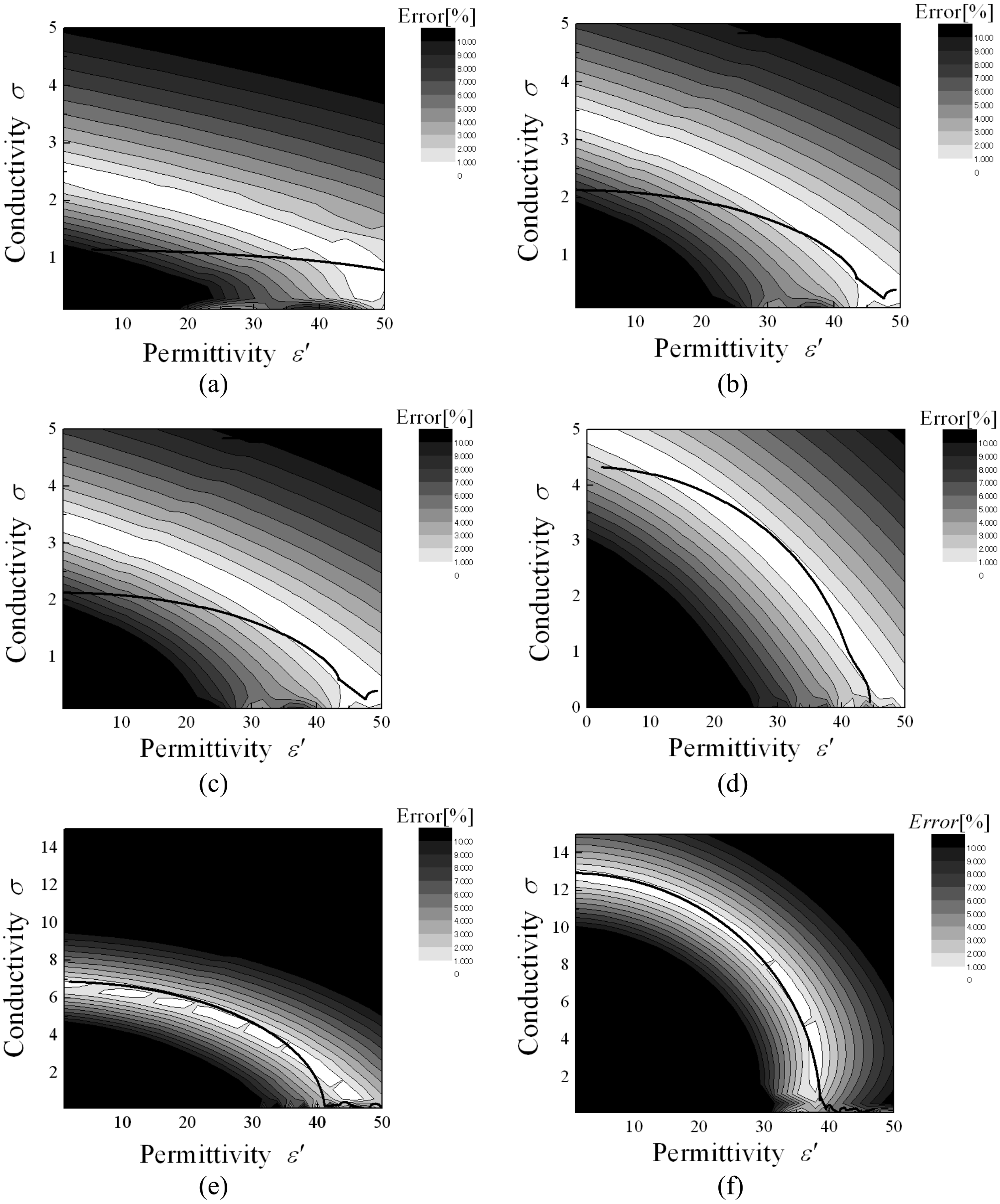


Figure 6: Errors of maximum electric field on phantoms from the maximum electric field on liquid phantom at (a) 300 MHz, (b) 835 MHz, (c) 1.45 GHz, (d) 1.85 GHz, (e) 3 GHz, and (f) 6 GHz.