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Influence of Breast Organisms and UWB Antenna Array Configuration on the Resolution of Breast Cancer Detection

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1. Introduction

Ultra-wide-band (UWB) is a carrierless short range communication technology which transmits and receives the signals in the form of very short pulses such as Gaussian monocycle pulses (GMP) [1, 2]. It has been reported that the permittivity and conductivity of breast cancer tissues were higher than that of normal breast tissue [3] so that radar-based breast cancer detection systems using UWB signals have been developed [4-8].

In this paper, the confocal imaging technique using 4x4 UWB antenna array was developed and the influence of skin layer and UWB antenna array configuration on the resolution of breast cancer detection were investigated.

2. Confocal Imaging

Confocal imaging was performed according to eq. (1) and eq. (2).

$$I(r_p) = \sum_{(m,n)} w(r_p) \int_0^{\tau(r_p)} \left(A_{m,n}(t) - A_{Average\,m,n}(t) \right) dt \qquad (1)$$

$$\tau(r_p) = \left\{ \left(|r_p - r_m| + |r_p - r_n| \right) \sqrt{\varepsilon_{r,substrate}} \right\} / c \qquad (2)$$

$I(r_p)$ is the intensity of a pixel at the position r_p in the confocal image. As shown in Fig 1, m and n are the indices of transmitting and receiving antennas, respectively. $A_{m,n}(t)$ stands for the amplitude of waveform transmitted by antenna #m and received by antenna #n. $\tau(r_p)$ is the propagation delay for the path r_m-r_p-r_n, where r_m and r_n are the positions of the transmitting and receiving antennas, respectively. $\varepsilon_{r,substrate}$ is the permittivity of the dielectric substrate. c is the speed of light, and $w(r_p)$ is the compensation factor for attenuation of propagation[9]. The reference waveform was made by averaging waveforms obtained by the 24 combinations of adjacent antennas using eq.(3)

$$A_{Average,m,n}(t) = (1/24) \sum_{(m,n)} A_{m,n}(t) \qquad (3)$$

3. Modeling of Breast Organism

Figure 2 shows a three-dimensional simulation structure. The frequency characteristics of the breast organisms were analyzed by Debye model shown in eq.(4),

$$\varepsilon^*(\omega) = \varepsilon_r(\omega) - \frac{\sigma(\omega)}{\omega\varepsilon_0} j = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_m}{1 + j\omega\tau_p} + \frac{\varepsilon_m - \varepsilon_\infty}{1 + j\omega\tau_Q} \qquad (4)$$

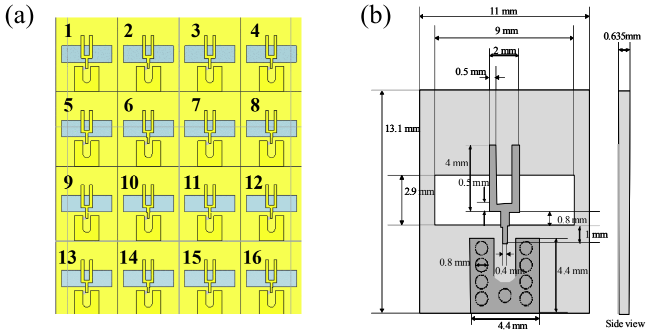

Fig 1. Antenna array structure. (a) Antenna array configuration. (b) Dimension of a slot antenna.

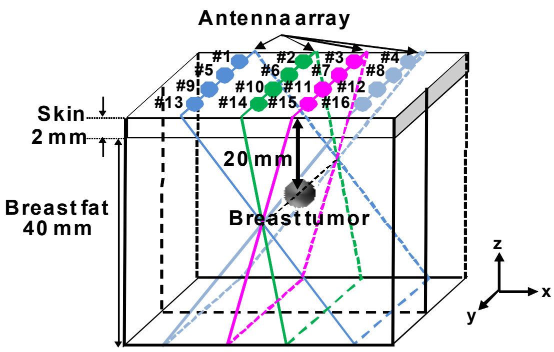

Fig 2. Three-dimensional simulation structure.

Table 1 Debye model fitting parameters of breast organisms

Breast Organisms	Parameters				
	ε_∞	ε_m	ε_s	τ_p	τ_Q
Skin	13.045	34.502	78.961	5.21E-10	1.67E-11
Breast tumor	11.318	56.782	184.41	1.04E-09	1.52E-11
Breast fat	4.8908	5.7072	7.6272	3.62E-10	3.88E-11

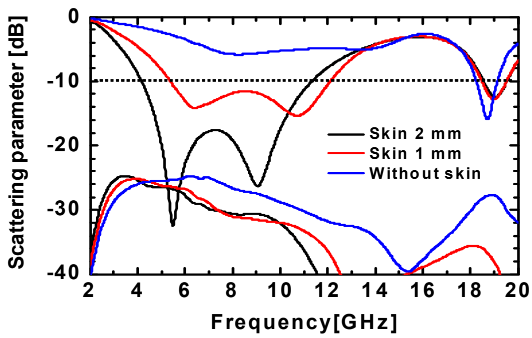

Fig 3. Scattering parameter of antenna versus frequency depended on skin layer.

where ω is the angular frequency , $\varepsilon_r(\omega)$ and $\sigma(\omega)$ is frequency dependency of permittivity and conductivity. ε_∞ is permittivity of high frequency limit, ε_m is permittivity of middle frequency, ε_s is permittivity of low frequency limit ,τ_p is relaxation time of low frequency, and τ_Q is relaxation time of high frequency. Fitting parameters are shown in Table 1. The ε_m of breast tumor and fat ware 56.8 and 5.7, respectively. In this case the ε_m of the tumor is approximately 10 times larger than that of breast fat. The ε_m of skin was 34.5.

4. Results and Discussion

Figure 3 shows scattering parameters of antenna versus frequency when skin thicknesses are changed from 0 mm to 2 mm. Since the skin is lossy material, the confocal image of a tumor through thicker skin layer becomes less apparent than that of thinner skin layers. The antenna bandwidth with the skin thickness of 2 mm was 4-10 GHz and the transmission gain decreased -5 dB in comparison with that without skin. Figure 4 shows received waveforms by 4x4 antenna array and a confocal image. The subtracted waveform was distorted due to the failure of averaging as shown in Figs. 4 (b) and (c). Consequently the confocal image was distorted and the position of the tumor was not correct as shown Fig. 4 (d). Figure 5 shows the waveforms and a confocal image by use of 6x6 antenna array. The 6x6 antenna array is composed of 4x4 transmitter and receiver antennas and surrounding dummy antennas. By using 6x6 antenna array, correct subtracted signal was obtained as shown in Fig. 5 (c) so that the precise position of the tumor was obtained as shown Fig. 5 (d). Figure 6 shows a three-dimensional confocal imaging of two breast tumors using 6x6 antenna array. The space resolution of 10 mm was achieved.

5. Conclusion

Breast organisms were modeled by Debye function for three dimensional confocal imaging. Two separate breast tumors having the size of 5x5 mm^2 with the separation distance of 10 mm were resolved by use of 6x6 antenna array, in which 4x4 transceiver antennas and surrounding dummy antennas were formed.

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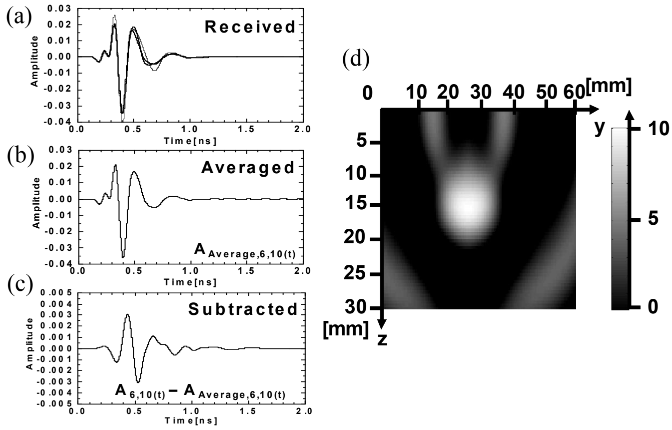

Fig. 4. Received GMP waveforms after signal processing and confocal imaging using 4x4 antenna array.
(a) As received. (b) Averaged for a reference. (c) Subtracted.
(d) Confocal imaging

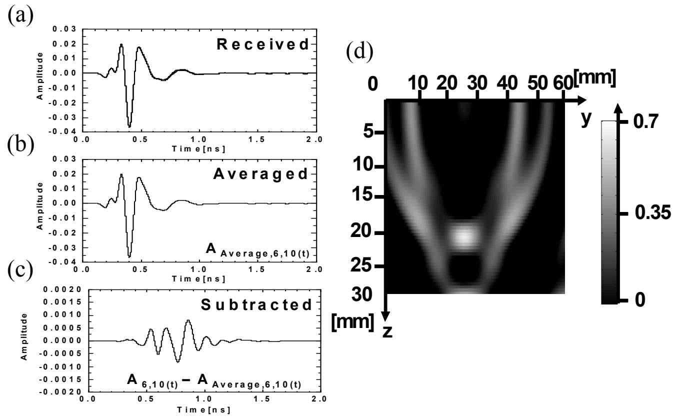

Fig. 5. Received GMP waveforms after signal processing and confocal imaging using 6x6 antenna array.
(a) As received. (b) Averaged for a reference. (c) Subtracted.
(d) Confocal imaging

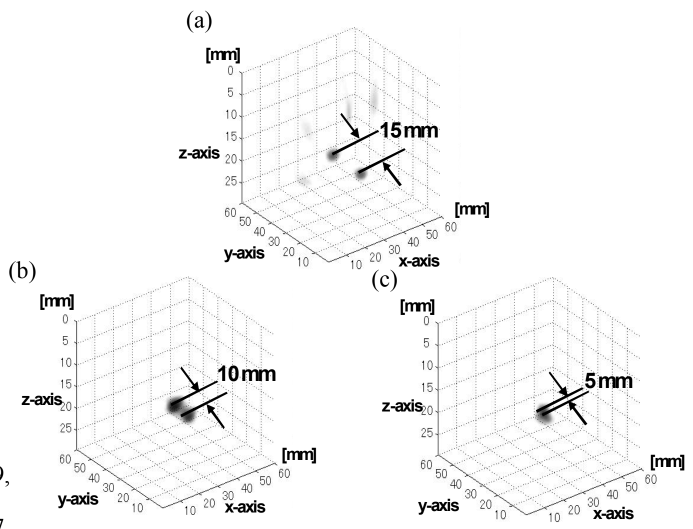

Fig. 6. Three-dimensional confocal imaging of the breast tumor by using 6x6 antenna array. (a) Breast tumor distance: 15 mm. (b) Breast tumor distance: 10 mm. (c) Breast tumor distance: 5 mm.