Specific Absorption Rate for Agri-Food Materials from Multiple Antenna Exposure

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Abstract **─** This paper presents an evaluation of the Specific Absorption Rate (SAR) in agri-food when it is exposed to wireless communication devices with multiple transmitting antennas. In particular, we model a simplified coconut which is exposed to antennas working at the frequency of 2.45 GHz. Two antenna configurations are being considered. One is a single dipole antenna, and the other is two co-polarized dipole antenna array. As a result, we observed that the SAR of the coconut for single antenna case is relatively smaller than that for multiple antenna one.

Index Terms **─** Agri-food, coconut, multiple antennas, SAR, RF exposure.

I. INTRODUCTION

In recent years, exposure to electromagnetic fields becomes more and more important issues for both electrical engineers, and public concerns. Environmental exposure has been increasing rapidly as many kinds of wireless communication systems are being developed. In such living environments, not only human, but also other living things such as animals or crops/fruits are also exposed. While there are a number of publications about human body exposed to electromagnetic sources, quite a few publications addressing the issues of agri-food exposed to electromagnetic fields. In fact, microwave applications in agri-food are an innovative and promising research trend. Microwave treatment could be a sustainable solution for food security, rural/agricultural development, and healthy food for healthy life. The knowledge of dielectric properties of food is important in designing and developing dielectric heating equipment. Therefore, it is important to evaluate the effects of RF exposure on food and in particular how the treatment affects the organoleptic properties of food. The evaluation of SAR (Specific Absorption Rate) gives an insight about the dosimetric parameters.

The exposure to electromagnetic fields of a communication system can be evaluated in different schemes. When the system is near to human body or objects such as crops/fruits, the specific absorption rate (SAR) should be evaluated, and the maximum SAR value should be below a limited number. The SAR is the amount of power absorbed per unit mass of a biological object, and can be computed as:

$$\mathrm{SAR} = \frac{\sigma |E|^2}{\rho} \qquad [\mathrm{W/Kg}], \tag{1}$$

where σ is the conductivity, ρ is the mass density, and E is the electric field measured in the biological object.

For human body exposure, the SAR is required to report in form of spatial-average SAR in 1g or 10g according to RF safety international standards [1-3]. The limited value of SAR is 2 W/Kg for 10g spatial-average SAR or 1.6 W/Kg for 1g spatial-average SAR. For agri-foods, there is no guideline or limitation of the exposure level. Since they are living things, and may be affected from exposure to electromagnetic fields, the investigation on SAR of agri-foods will be important for safety food issues.

In this paper, we will carry out a simple study on the exposure of coconut (an example of agri-food materials) to electromagnetic fields radiated from single and multiple sources. A simplified four-layer spherical coconut is modeled and exposed to one antenna and two-antenna cases in Section II. Results and discussions of SAR distributions and levels will be presented in Section III, which is followed by concluding remarks in Section IV.

II. MODELS

For an initial study on the respond of argi-foods to exposure of electromagnetic fields, we will investigate on coconut's fruits as an example. A coconut is simplified as a spherical model, and the size is an averaged-size of real ones. The coconut model consists

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of four layers, including the green skin layer (exocarp), the pulpy layer (mesocarp), the hard shell layer (endocarp), and the coconut liquid (endosperm). The electrical parameters of the layers at the frequency of 2.45 GHz is shown in Table 1 which have been presented in [4]. Instead of far field exposure - modeled by a plane wave - in [4], in this paper the coconut is exposed to electromagnetic fields radiated from antennas placed close to it. Two antenna configurations are considered. One is a single dipole, and the other is a multiple antenna scheme which consists of two co-polarized dipoles, spacing a quarter of wavelength. All the antennas are working at 2.45 GHz. The reason to take examinations on multiple antennas is that there will be microwave applications utilizing multiple antennas on treatments or supervisions of food security, rural/agricultural development, and safety foods. Such applications can be the exposure sources for the agri-food. Thus, evaluation of SAR of such systems will be necessary for dosimetric evaluations.

Since we are interested in examining the responds of argi-foods to exposure of electromagnetic fields, the exposure apparatus will be considered in simplified configurations. The dipoles are fed by ideal sources in simulations. However, ones can improve the models with more practical issues including feeding systems as standard dipoles for compliance tests [1, 2]. The lengths of the dipole antenna are chosen so that its reflection coefficient (S11) is well below -10 dB when they are operating near the coconut model. Figure 1 illustrates the coconut model and antenna configurations. Dimensions of both coconut model and antennas are given in millimeter.

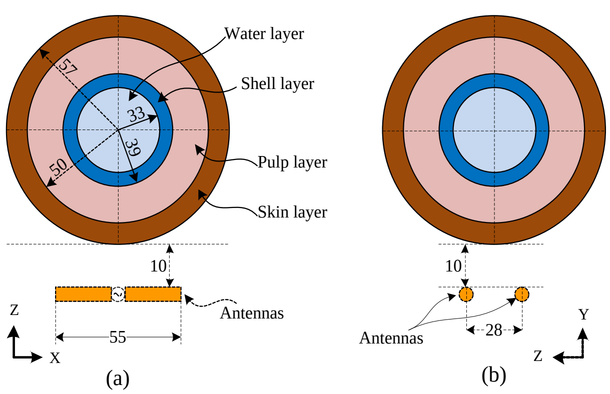

Fig. 1. The simplified four-layer coconut model and radiating antennas working at the frequency of 2.45 GHz: (a) front view XZ plane (for both cases of single and multiple antennas), and (b) side view – YZ plane (for the case of multiple antennas). All dimensions in mm.

The coconut and antennas are modeled and simulated using the electromagnetic simulation software CST Microwave Studio (CST MWS) with transient analysis computations in order to calculate the SAR [6]. The SAR will be examined in terms of 1g, 10g spatial average as well as the point SAR to analyze SAR distributions inside the coconut.

Table 1: Electrical properties of coconut layers at the frequency of 2.4 GHz [4]

Layer	ε_r	tagδ	Mass (ρ) [Kg/m^3]
Skin	19.5	0.53	1064
Pulp	37	0.67	976.5
Shell	120	0.68	1013.6
Water	75.4	0.22	1013

III. RESULTS AND DISCUSSIONS

The input powers to each antenna in the multiple antenna configurations are kept equally. In addition, the SAR is computed for incident power being normalized to 1 W. Table 2 shows the values of spatial-average SAR for 1g and 10g, and maximum local point SARs in different configurations. It is interesting that the SAR values for multiple antenna case can be lower than those for single antenna case. It is because the SAR for multiple antenna case depends on the change of the relative phase of signals from two antennas. In addition, the two antennas are spaced by a quarter of wavelength that would cause a strong mutual coupling between the antennas, thus reducing radiated energy from them.

Figure 2 shows the SAR distributions of the coconut in YZ and XZ planes when it is exposed to one antenna. The SAR is normalized to its maximum point value. As can be seen from this figure, there is only one peak SAR point and it is right close to the expose source (antenna). In addition, Fig. 3 illustrates the SAR distributions of the coconut in YZ plane for the case of multiple antennas. The SARs for three values of the relative phase of signals (β of 0, 90 and 180 deg.) are taken in simulation (respectively called SAR_0, SAR_{90}, and SAR_{180}). We can see that while there is only a local peak SAR in the single antenna case, there may be more than one local peak SAR in the case of multiple antennas.

Table 2: Evaluated SAR [Kg/W] in different models. Incident power is normalized to 1 W

Model	SAR_{1g}	SAR_{10g}	Maximum point SAR
Coconut 1 antenna	16.92	41.11	76.14
Coconut 2 antennas ($\beta = \pi$)	0.75	1.73	2.64

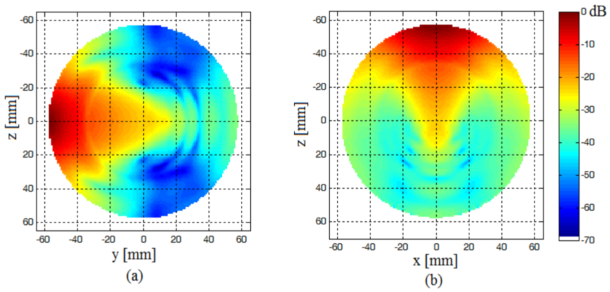

Fig. 2. SAR distributions for one dipole antenna case: (a) in YZ plane, and (b) in ZX plane.

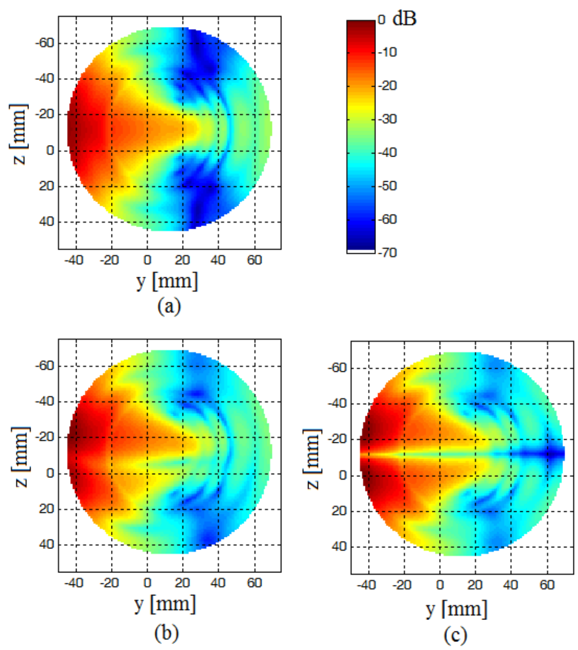

Fig. 3. SAR distributions for different relative phases between two dipole antennas: (a) for β of 0 deg., (b) for β of 90 deg., and (c) for β of 180 deg.

In order to find the value of relative phase that cause the maximum SAR, we utilize the estimation technique developed in our research group in previous works [5]. The three SAR values, i.e., SAR_0, SAR_{90}, and SAR_{180}, will be used to estimate the SAR for other value of β accordingly to the following expression [5]:

$$\mathrm{SAR} = C_1 + C_2 \cos\beta + C_3 \sin\beta, \qquad (2)$$

where C_1, C_2, and C_3 are estimation factors which can be determined by:

$$\begin{cases} C_1 = (\mathrm{SAR}_0 + \mathrm{SAR}_{180})/2 \\ C_2 = (\mathrm{SAR}_0 - \mathrm{SAR}_{180})/2 \\ C_3 = (2\mathrm{SAR}_{90} - \mathrm{SAR}_0 - \mathrm{SAR}_{180})/2 \end{cases}.$$

By utilizing the estimation in Equation (2), we can find the relative phase β_{max} that causes the maximum SAR. Figure 4 shows the maximum point SAR for different relative phases between two dipole antennas. Here, we can see that the peak maximum point SAR corresponds to the relative phase of 145 deg.

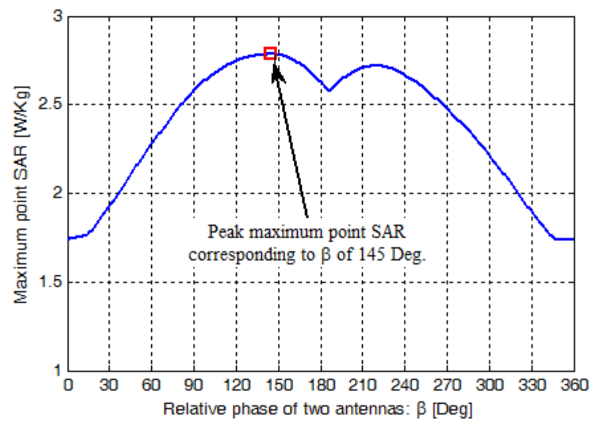

Fig. 4. Maximum point SAR for different relative phases between two dipole antennas. The peak maximum point SAR corresponds to the relative phase of 145 deg.

Figure 5 shows the SAR distribution inside the coconut when it is exposed to electromagnetic fields radiated from the two dipole antennas with the relative phase of 145 deg. Compared to the SAR in Fig. 4, the peak SAR point in Fig. 5 is slightly greater, yielding a higher SAR value.

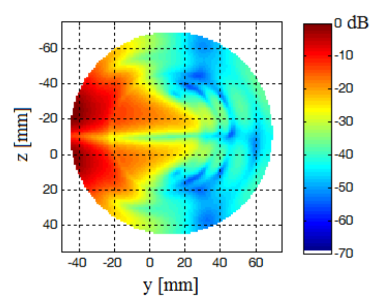

Fig. 5. SAR distribution for the relative phase between two dipole antennas of 145 deg.

The above analysis is based on computational data where the antennas and the coconut are modeled and simulated in the CST Microwave Studio. Experiment on SAR measurements for this case could be very complicated because it might require multi-layer dielectric materials for the coconut model, and complex electric field probes inside the model to capture E-filed or SAR values. The measurement procedures can be similar to the procedures to evaluate SAR of human model specified in [1] and [2], where E-field probes measure the electric fields inside a phantom filled by liquids or dielectric materials. The measured E-field will be then converted into SAR for evaluation. For the case of multiple antenna exposure, it is necessary to set the phase difference between the antennas in every measurement in order to determine the maximum SAR.

IV. CONCLUSION

This paper presents an initial study on the respond of agri-food materials exposed to electromagnetic fields radiated from multiple antennas. A coconut model is taken as an example of agri-food materials, and two antenna configurations at 2.45 GHz are examined as exposure sources. As a result, several SAR distributions inside the coconut are presented and analyzed. For multiple antenna exposures, due to the correlation and the change of relative phase of signals, the SAR might be lower than that of single antenna exposure. Since there is quite limited number of research on SAR of agri-foods, we expect that this research can be a reference for further works on the fields.

ACKNOWLEDGMENT

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