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SAR Investigation of Array Antennas for Mobile Handsets

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SUMMARY The peak SAR values of two-element array antennas for mobile handsets in the vicinity of a spherical phantom of a human head are evaluated numerically as a function of the distance between the array antenna and the head phantom when the two elements of a two-element array antenna are either co-phase voltage-fed or reverse-phase voltage-fed. It is found that relation between the worst case of the SAR and the phase difference of array elements strongly depends on the distance. When part of the head phantom is located in the reactive near-field region of the array antenna, although the co-phase feed SAR value is slightly smaller than the reverse-phase feed SAR value, the SAR value is practically independent of the phase difference, but when the head is completely outside the reactive near-field region, the co-phase feed SAR value is larger than the reverse-phase feed SAR value.

key words: *antennas, arrays, mobile antennas, mobile communication, SAR, biological effects of electromagnetic radiation*

1. Introduction

Since antennas for mobile handsets are often used in the vicinity of the human body, the electromagnetic wave radiated by the antennas is partly absorbed by the human body. Some regulations and standards have been issued to limit the radiation exposure by the mobile handsets. The exposure guidelines employ a unit known as the Specific Absorption Rate (SAR). Therefore, it is very important to investigate the SAR value caused by the radiation from the mobile handsets in designing antennas for mobile handsets.

Many researches on the SAR value of a single antenna for mobile handsets have been carried out [1]–[7]. Since the use of adaptive array antennas is one of the most effective ways of increasing the frequency efficiency and improving the communication quality in the mobile communication system, a great deal of attention has turned to how to design array antennas on mobile handsets to meet the needs of significantly increasing the bit-rates for the next-generation wireless communications [8]–[11]. A study on the SAR value of a half wavelength dipole antenna array near a rectangular lossy object has been carried out at frequency of 900 MHz [12]. An Investigation on the SAR caused by array antennas at 1.9 GHz has been reported and it was shown that the SAR value reaches a maximum when the phase difference is near 180 degrees, and a minimum when the phase difference is approximately 0 degree [13].

In our study, the peak SAR value at 2 GHz and 5 GHz is evaluated numerically as a function of the distance between the array antenna and a spherical head model when the two elements of a two-element array antenna are voltage-fed co-phase or reverse-phase. A two-element dipole array antenna and a two-element monopole antenna are used as the analysis model for the investigation.

2. Analysis Model

Two types of array antennas located in the vicinity of a head phantom are used as the analysis model. One is a two-element $\lambda/2$ dipole array antenna with array spacing of $\lambda/2$ shown in Fig. 1, and the other one is a two-element $\lambda/4$ monopole array mounted on a finite ground plane with array spacing of $\lambda/2$ shown in Fig. 2.

The analysis is performed at 2 GHz and 5 GHz. The human head phantom is a sphere with a radius of 100 mm. The relative permittivity and the conductivity of the phantom are $\epsilon_r = 40$ and $\sigma = 1.5$ S/m at 2 GHz, while they are $\epsilon_r = 39$ and $\sigma = 4.3$ S/m at 5 GHz, respectively. The distance between the antenna and surface of the phantom is D.

The dipole array is used together with the spherical phantom as the analysis model because it has a simple geometry for us to obtain clear theoretical observations from the numerical results and to easily compare our results with other's, while the monopole array is similar to the realistic model and therefore, more practical.

FDTD method with 8-layer PML absorbing boundary conditions and the multigrid technique is applied to the nu-

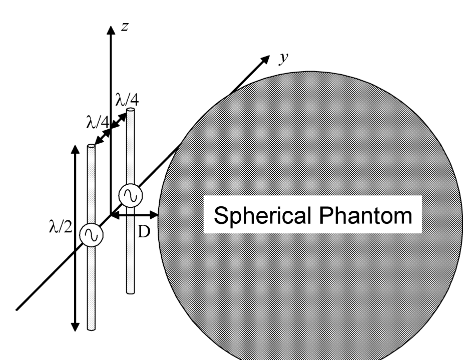

Fig. 1 Two-element dipole array antenna near head phantom.

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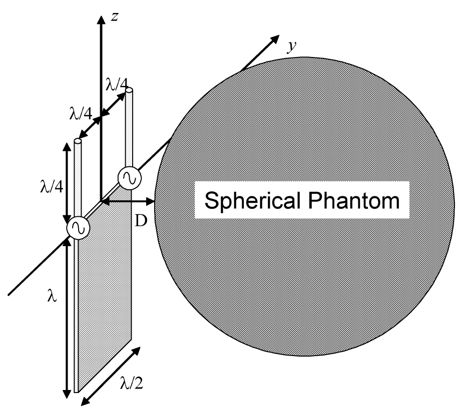

Fig. 2 Two-element monopole array antenna near head phantom.

merical analysis. The Yee-cell size is 1 mm × 1 mm × 0.5 mm in the fine-grid region including the dielectric sphere and it becomes 2 mm × 2 mm × 2 mm in the coarse-grid region. Athough 1 mm side of the cell is a little bit larger than the usually used constraint of the one-tenth of wavelength inside the phantom at 5 GHz, the convergence study of the SAR value to the cell size shows that the present cell size is acceptable. A sinusoidal time-varying voltage is excited continuously over one-cell gap at the feed point until the field components in the FDTD region becomes stable. The two elements are fed simultaneously with the same phase in the case of the co-phase feed, but with a 180-degree phase difference in the case of the reverse-phase feed.

3. Numerical Results

1-g averaged local peak SAR value inside the spherical phantom near the dipole array antenna and the monopole array antenna are shown in Fig. 3 and Fig. 4, respectively. When D/λ is relatively small, the peak SAR value of the reverse-phase feed is slightly larger than the value of the co-phase feed. However, as D/λ increases, the peak SAR value of the reverse-phase feed becomes much smaller than the value of the co-phase feed. The intersection occurs at the range of $D/\lambda = 0.1$ to $1/(2\pi)$ for both 2 GHz and 5 GHz, regardless whether the dipole array or the monopole array is used.

It is well known that the region surrounding an antenna with radius less than $\lambda/(2\pi)$ is called the reactive near-field region where the reactive field is dominant over the radiation, while beyond this region, the radiating field becomes dominant. Therefore, Fig. 3 and Fig. 4 indicate that when part of the user's head is in the reactive near-field region, the co-phase feed yields a slightly smaller peak SAR value than the reverse-phase feed, but when the user's head is completely outside the reactive near-field region, the co-phase feed has a larger SAR value than the reverse-phase feed.

The physical explanation for the numerical results is given in the following. The total phase shift resulting from the feed phase value at each element and the propagation delay over the distance of $\lambda/2$ between the two elements

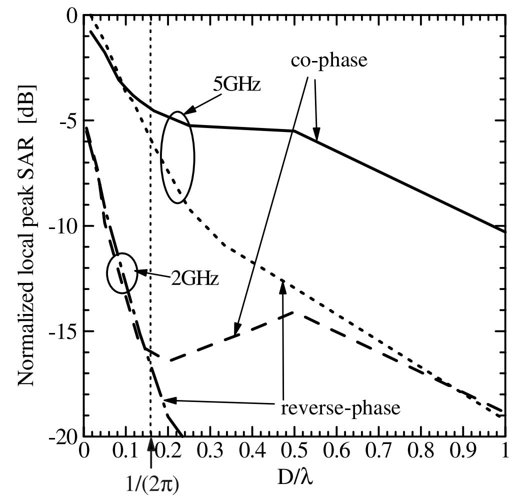

Fig. 3 1-g averaged local peak SAR value in the spherical phantom near the dipole array antenna.

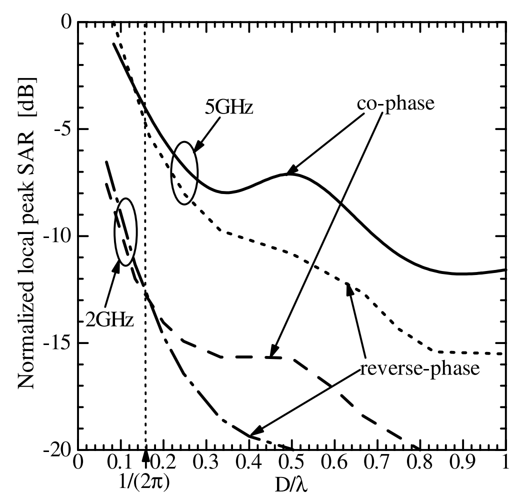

Fig. 4 1-g averaged local peak SAR value in the spherical phantom near the monopole array antenna.

causes the field of one element to arrive either in-phase (for the reverse-phase case) or out-of-phase (for the co-phase case) at the site of the other element, thereby causing by superposition of the field from each element, a slightly smaller or larger value of total field in the vicinity of the other element, and thus causing a correspondingly smaller or larger SAR value, respectively. On the other hand, the electromagnetic field in the far-field zone is dominated by the combined radiation of the two array elements. In this region, when the two elements are fed in co-phase, the peak SAR value should occur on the center line of the two array elements, and when the two elements are fed in reverse-phase, the SAR value falls to zero on the center line.

The SAR value of co-phase is about 8 dB larger than that of inverse-phase in the case of dipole array when the phantom distance is 0.5 wavelength as shown in Fig. 3. The result is a little different from the result given by [12], where the SAR difference is not so significant. This is because the rectangular phantom in [12] has a cross section of only 0.6 by 0.6 wavelength toward the antenna at 900 MHz, the SAR peaks appear at both the center and the vertical edges of the relatively small rectangular phantom. However, the spherical phantom in the present study has diameters of 1.3 wavelength at 2 GHz and 3.3 wavelength at 5 GHz, the SAR peak occurs at only the center when the phantom is located outside the reactive near-field zone.

It should be noted that voltage-feeding is discussed instead of current-feeding. However, the feed phase value that should be considered should be that of the current, not that of the voltage, because the radiation depends directly on the current, not the voltage. In the case of this paper, the entire geometry of the problem is symmetrical about the centre-line and thus a difference of 180 degrees in voltage-feed also results in a difference of 180 degrees in current feed. But generally current-feeding should be discussed instead of voltage feeding if the geometry were not symmetrical about the centre-line. Another point to be noted is that the radius of reactive near-field region should be dependent on the array spacing. When the array spacing is large enough compared with the observation distance so that the array element is regarded as being separated each other, the radius of $\lambda/(2\pi)$ is true. Otherwise, the radius of $\lambda/(2\pi)$ becomes meaningless.

4. Conclusion

The peak SAR value of two-element array antennas used for mobile handsets has been evaluated numerically as a function of the distance between the array antenna and the spherical head phantom when the two elements of a two-element array antenna are voltage-fed co-phase or reverse-phase. It has been found that the relation between the worst case of the peak SAR value and the phase difference for two-element array antennas depends on the distance between the array antenna and the user's head. When part of a human head is present in the reactive near-field region of the array antenna, although the co-phase feed SAR value is slightly smaller than the reverse-phase feed SAR value, the SAR value is practically independent of the phase difference between the two elements of the array. But when the human head is completely outside the reactive near-field region, the co-phase feed SAR value is larger than the reverse-phase feed SAR value.

The SAR values of a more practical geometry of array antennas in the vicinity of a more accurate human head phantom are under investigation.

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