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Array Antenna Weight Determination Method for Mobile Handsets Using Random Inner Test Sources

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Abstract This paper proposes a method for determining the optimum antenna weights needed to improve the radiation efficiency in the distributed-feed method for mobile handsets. A test signal from a random wave source embedded in a phantom is employed to optimize the weights. In order to eliminate the affects of polarized waves, the test signal source employs a tri-axial antenna and a random function. We describe the theory behind the proposed method and evaluate its validity through simulation and experimentation.

1. Introduction

The most significant factor contributing to decrease radiation efficiency in mobile handsets is the loss of electric power due to the human body [1], [2]. In order to improve the radiation efficiency, the distributed-feed method was proposed, which reduces the electric power loss due to the human body [3]. In this method, two or more antenna elements are employed and simultaneously fed power. This configuration makes it possible to disperse the current on the chassis and to decrease the high electric field at the feed point, to improve radiation efficiency.

In our previous study, we showed that the effect of this method was influenced by feed weights (phase and amplitude). Determining the optimum weight incurred repetitious trial and error work where the weights were set and the radiation efficiency was measured for each weight pair. The operation efficiency of this method was very low.

In order to improve the radiation efficiency using the distributed-feed method, the optimum weights must be efficiently determined. In this paper, we propose a method for determining the optimum antenna weights for the distributed-feed method using a test signal from a random wave source embedded in a phantom.

2. A Determination Method of Antenna Weight

2.1. The equipment composition

The configuration of the equipment used in the proposed method is shown in Fig. 1. A mobile handset model with two elements on a chassis is employed here. We also employ a cubic phantom that has physical parameters (conductivity and relative permittivity) similar to that of a human head [4]. The cube size is similar to the cube model of COST 244 [5], which is 200X200X200[mm]. The test signal source employing a tri-axial dipole antenna is embedded in the phantom. Each axial dipole antenna is connected to a signal generator. The elements on the handset model are connected to a transceiver.

In this case, we use multiple transceivers to determine the optimum weight, but the final product, i.e. mobile handset using the optimum weight, will not require the use of multiple transceivers.

This weight determination method can be used to determine the optimum weights for fixed weight composition or flexible weight composition methods such as in Adaptive array or MIMO.

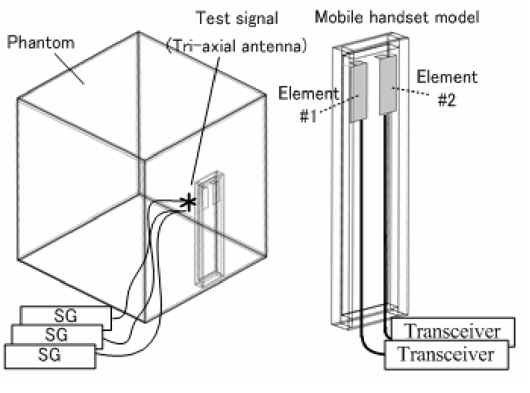

Fig. 1 System for antenna weight determination method

2.2. Test Signal Transmission

The flow of the determination method is given in Fig. 2. The wave source that radiates the test signal is embedded in the phantom. The frequency of this test signal is equal to the transmission frequency of the

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mobile handset. The test signal has a role similar to that of an undesired wave in null steering when using adaptive array techniques that have been studied for a base station. Each element of the mobile handset receives this signal. The weight must be determined to cancel these signals using negative phase superposition. The electric power is reduced at the wave source when the mobile handset employs the optimum weights as determined by the proposed method.

If the test signal has certain polarized characteristics, the weights generated using this method may reduce the electric power of only the polarized wave in the phantom, and this result does not reduce the total electric loss in the phantom. In order to avoid any adverse influence from the polarized wave, the tri-axial dipole antenna is employed as the wave source and a random wave pattern is employed as the signal source.

If the test signal source is fixed at a point in the phantom, the weights generated using this method may reduce the electric power only at this point, and this result does not reduce the total electric loss in the phantom. In order to avoid this, the test signal source scans the phantom, and the data obtained from each point are used to determine the weights.

2.3. Analysis of Signal Received at Mobile Handset

The probability density distribution of the transient electric field in terms of the phase differential and the amplitude ratio is obtained through measuring the phase and amplitude of the test signal at mobile handset elements for a given length of time. Because the random wave source varies the phase, amplitude, and polarization characteristics moment to moment, the signal received at the mobile handset is in a transient state. In the probability density distribution, the weight that is most often repeated (hereafter high repetition weight) is reflected in the propagation conditions between the test signal source and the elements in the mobile handset. The electric power is increased at the wave source when the mobile handset employs the high repetition weight. This weighted transmission has the same phase and is superposed at the test signal source.

2.4. Weight Determination

The high repetition weight increases the electric power in the phantom due to superposition. Conversely, a weight can decrease the electric power in the phantom by negative superposition at the phantom. This weight can cancel the high repetition weight. Therefore, the weight that reduces the electric loss is determined by the high repetition weight using the probability density

2.5. Weight Assessment

In order to assess the determined weight, the Specific Absorption Rate (SAR) or the radiation efficiency of the mobile handset employing the weight is measured.

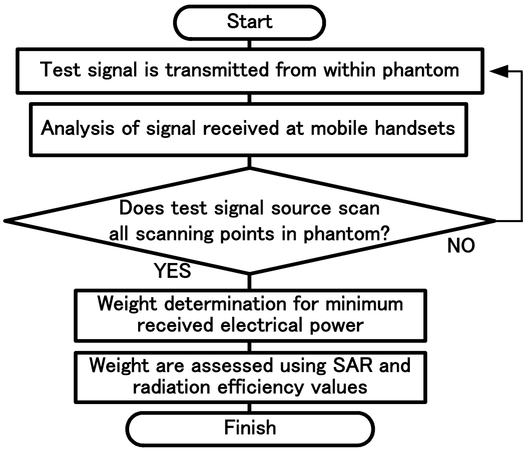


Fig. 2 Flow of determination method

3. Numerical Simulation

This determination method is carried out in numerical simulations to evaluate the validity of the method. The simulation parameters are given in Table 1. The Finite-Difference Time-Domain (FDTD) method is employed to obtain electric field data at the elements of the mobile handset. A transient wave analysis, similar to that at the random wave source, is difficult to perform using the FDTD method. Therefore, transient electric field data at the elements are obtained by functional calculus of the steady electric field data (which can be obtained using the FDTD method, and this steady electric field is generated by each axial (x-axis, y-axis, or z-axis of the tri-axial dipole antenna) wave source employing a sine wave) and the random function matrix described in Sub-section 3.1.2.This process loses certain polarized characters of the test signal source.

Table 1. Numerical Simulation Parameters

Frequency	2 GHz
Element type	PIFA
Number of elements	2
Chassis shape	Straight
Element alignment	Parallel
Output power	1W
Amplitude of elements	Equal
Phantom shape	Cube
Relative permittivity (εr)	41.0
Conductivity (σ)	1.3 S/m

3.1. Test Signal Source

As mentioned earlier, the uniformity of the polarized characteristics of the test signal is an important factor in reducing the electric power in the phantom. This uniformity is achieved by using a tri-axial dipole antenna and a random wave source.

3.1.1. Tri-axial dipole antenna

The tri-axial dipole antenna comprises three orthogonal dipole antennas as shown in Fig. 3. The size of the antenna is a half wavelength in the phantom. We assume that there is no interference to either dipole element. Therefore, the other dipole element is excluded when each axial wave source is calculated using the FDTD method.

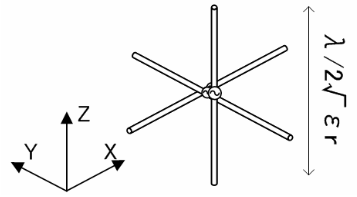


Fig. 3 Tri-axial dipole model

3.1.2. Random wave source

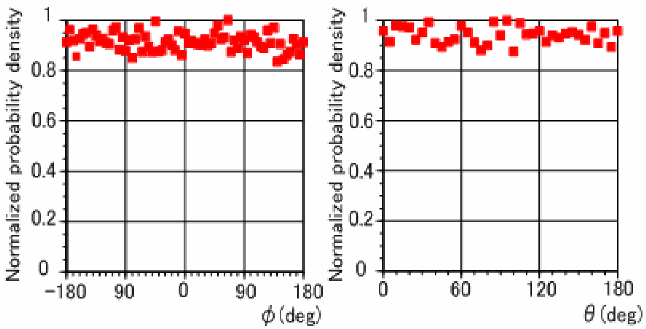
White Gaussian noise is employed as the random wave source. The amplitude and phases of the test signal are changed in random order every moment by the source, but the frequency is fixed here. In the numerical simulation, transient electric field data are obtained using a random function. Equation (1) is the formula used to obtain the transient electric field data from the steady electric field data and the random function. Transient electric field data at Elements #1 and #2 are denoted as $E_1(t)$ and $E_2(t)$, respectively. The steady electric field data at each element from each axial dipole are denoted as E_{1x}, E_{1y}, E_{1z}, E_{2x}, E_{2y}, and E_{2z}. The random functions, which are non-correlated at each axis, are denoted as $n_x(t)$, $n_y(t)$, and $n_z(t)$.

$$\begin{pmatrix} E_1(t) \\ E_2(t) \end{pmatrix} = \begin{pmatrix} \mathrm{E}_{1x} & \mathrm{E}_{1y} & \mathrm{E}_{1z} \\ \mathrm{E}_{2x} & \mathrm{E}_{2y} & \mathrm{E}_{2z} \end{pmatrix} \begin{pmatrix} n_x(t) \\ n_y(t) \\ n_z(t) \end{pmatrix} \qquad (1)$$

3.1.3. Polarized characteristics

Polarized characteristics of the test signal that employ the tri-axial dipole antenna and random wave source are shown in Fig. 4. The test signal source is regarded as a virtual single dipole antenna inclined at a certain angle at a particular moment and spin because the phases and amplitudes of each axial dipole antenna change from moment to moment by the random wave source.

The probability density distribution of the three dimensional axial angle of the virtual single dipole antenna is represented as a θ direction - ϕ direction distribution. Figure 4 shows that the θ direction - ϕ direction distribution is uniform. Therefore, we clarify that the polarized characteristics of the test signal are uniform.



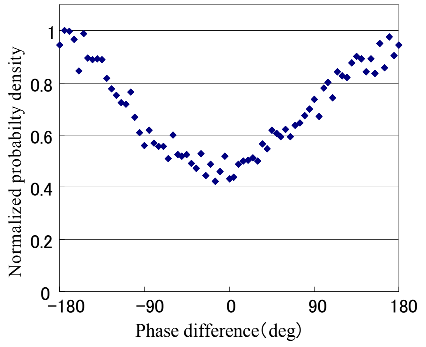
(a) θ direction (b) ϕ direction

Fig. 4 Polarized characteristics of test signal

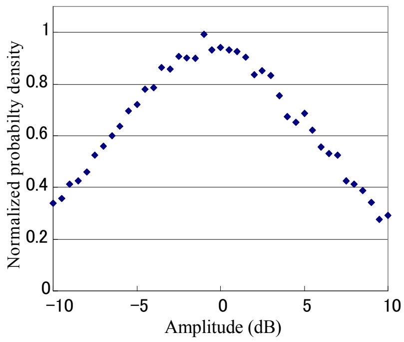
3.2. Probability Density Distribution of Transient Electric Field Data

From the signal received at the elements of the mobile handset, the probability density distribution of the phase differential and that of the amplitude ratio between elements are calculated using the FDTD method. Because the phase differential and the amplitude ratio vary over time, the values are not constant, but distributed. The probability density distribution of the phase differential and that of the amplitude ratio are shown in Fig. 5. Figure 5(a) is the probability density distribution of the phase differential. Figure 5(b) is the distribution of the amplitude ratio. Figure 5(c) is the total distribution of the phase differential and the amplitude ratio.

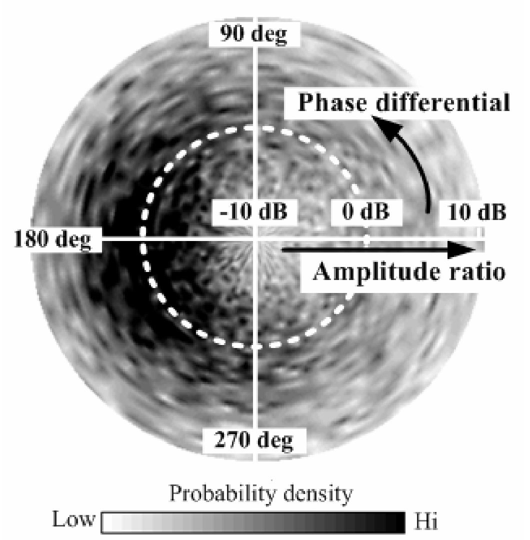
Based on these results, the high repetition weight from this probability density distribution is ±180 degrees phase differential and 0 dB amplitude ratio.



(a) Phase



(b) Amplitude



(c) Phase and amplitude

Fig. 5 Probability density distribution of transient Electric Field Data

3.3. Weight Determination and Assessment

In this case, because there are only two elements in the mobile handset model, it is simple to determine the weight that reduces the electric loss in the phantom. The transmission using a high probability density weight is superposed with the same phase in the phantom. The differential phase of the electric field is 0 degrees in the phantom.

In order to reduce the electric power in the phantom, negative phase superposition is achieved using a 180° phase differential and the same amplitude in the phantom. Consequently, the degree of electric power loss is reduced by the weight that cancels the weight of the high probability density. The weight of the high probability density is ±180 degrees and 0 dB (Fig. 4). Therefore, the weight that cancels the high probability density weight is 0 degrees and 0 dB.

The validity of this determined weight is evaluated using the SAR and radiation efficiency measurement. The radiation efficiency is derived by using the Radiation Power Integration (RPI) method [6]. The SAR is measured using an electric field sensor employed by a scanning robot arm. The radiation efficiency and 10g normalized SAR are given in Table 2. The results show that the transmission by 0 degrees and 0 dB, which are determined using this method, reduces the 10g SAR and improves the radiation efficiency.

Table 2 Radiation Efficiency and 10g Normalized SAR

Weight (phase, amplitude)	Radiation efficiency (%)	Normalized 10gSAR
0 degrees, 0 dB	57.1	0.57
180 degrees, 0dB	15.1	3.6
Single element	42.7	1.0

4. conclusion

In order to improve the radiation efficiency using the distributed-feed method, this paper proposed a method for determining the optimum antenna weights using a test signal source embedded in a phantom. This method employs a tri-axial dipole antenna and a random wave function as the test signal source. We achieved uniformity of the polarized characteristics of the test signal and eliminated the affects of polarized waves by determining the optimum weight. This determination method was verified in numerical simulations. The validity of the determined weight is evaluated based on SAR and radiation efficiency measurements. The results showed that transmission using this weight improves the radiation efficiency by reducing the 10g SAR.

These results clarified that the weight determined using the proposed method decreases the loss in electric power due to the human body.

Refference

[1] K. Sato, K. Nishikawa, and A. Ogawa, "Analysis of Antennas Mounted on Portable Equipment near Human Body" IEICE (B-II), vol.J79, no.11, pp.892-900 (1996)

[2] J. Toftgard and S.N. Hornseleth, and J.B. Andersen, "Effects on Portable Antenna of the Presence of a person," IEEE Trans. Antenna and Propag., vol.AP-41, no.6, pp.739-746 (1993)

[3] R. Yamaguchi and S. Uebayashi, "Improvement of Radiation Efficiency for Mobile Handsets by using Distributed Feed" IEICE Society Conference B-4-4,2003

[4] Guy, A.W. and Chou, C.K, "Specific absorption rates of energy in man model exposed to cellular UHF model-antenna fields", IEEE Trans. Microwave Theory & Tech ., MTT-34, pp.671 (1986)

[5] G. d'Inzeo (Coordinator), "Proposal for numerical canonical models in mobile communications" Proc. COST244 Meeting on Reference Models for Bioelectromagnetic Test of Mobile Communicaton Systems, Nov.1994.

[6] Qiang Chen, Kunio SAWAYA "Measurement of Power absorption by human model in the vicinity of Antennas" IEICE Trans. Comun., VOL.E80-B, NO.5 1997