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Improvement in Radiation Efficiency for Mobile Handsets Using Distributed Feed

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Abstract A method for improving the radiation efficiency of mobile handsets using a distributed feed is proposed. Higher level efficiency is achieved by decreasing the local electric field in the vicinity of the feed point using an array feed and by reducing the lost electric power due to the human body using the optimum feed weight. The distributed feed technique and the investigation model are described and the electric field in a phantom and the radiation efficiency are evaluated by experiment. Furthermore, the variations in the radiation efficiency and Specific Absorption Rate (SAR) due to phase shift between elements are evaluated.

1. Introduction

The factors that lower the radiation efficiency of mobile handsets are the loss from matching, the circuit loss, the loss from polarized waves, and the loss of electric power due to the proximity to the human body. The loss caused by the human body is the most significant factor and presents an important problem in the design of small and thin mobile handsets because the loss increases as the distance between the mobile handset and the human body decreases [1]. Many techniques were proposed to improve the radiation efficiency of mobile handsets such as the directive antenna using a director and reflector [2], a parasitic element and line antenna [3], or a patch antenna. These techniques were used to achieve directivity of the electromagnetic wave in order to avoid the human body. However, the antenna elements tend to become cumbersome when using these techniques. Another technique employing a magnetic plate was proposed [4]. The electromagnetic field near the mobile handset is controlled by a magnetic plate thereby improving the radiation efficiency. However, problems affecting this technique are miniaturization and weight reduction of the magnetic plate.

On the other hand, the quality and the performance of mobile handsets must be improved. Techniques employing elements such as the Adaptive Array Antenna (AAA) or using Multiple Input Multiple Output (MIMO) have been studied [5],[6]. These array antenna techniques are implemented to achieve high gain, high-speed data transfer, and to suppress interference; however, these do not achieve high radiation efficiency or lower the electric-power loss due to the human body.

In order to lower the electric-power loss due to the human body and improve the radiation efficiency, a method is proposed that utilizes distributed feeding. The method uses some elements for transmission that are supposed to be used for reception diversity. This method can utilize pre-existing elements space and there is no need for additional weighty material.

Many types of mobile handsets employ several elements for reception diversity, and use only one element for radiation. At the feed point that supplies electric power to the radiating element, the electrical current is concentrated causing a strong electric field to be generated. This field causes an increase in the loss of electric power. Therefore, it is thought that the electrical current must be distributed over the chassis.

This paper describes the distributed-feed technique and the investigation model. Then, the validity of this method is clarified by experimentation.

2. Distributed Feed Method

In the distributed feed method, two or more elements are installed into the chassis and these elements are fed at the same time. The current is distributed on the chassis due to some set feeding point (Fig.1). If the feed power is constant, the feed power in each element is lower and the current is distributed. By controlling the phase and amplitude weights, the current on the chassis and the radiation pattern of the mobile handset can be controlled to a certain degree. Thereby, a decrease in the electromagnetic near-field is achieved in the direction of the human body and the radiation efficiency is improved.

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Next, the investigation model for the distributed feed method is described.

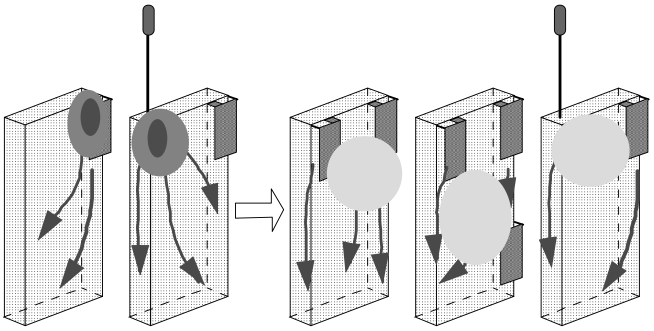


Fig. 1 Distributed feed and single feed

In order to assess the validity of this method, a mobile handset model and a phantom, which has physical parameters (conductivity, relative permittivity) that are similar to the human head, are used (Fig. 2). A planar inverted-F antenna (PIFA) is employed in the mobile handset model because the antenna is easy to construct, adjusts to match the impedance, and its transmission characteristics are well known.

The shape of the mobile handset model is straight. A cube model is used as the phantom because there are no curved surfaces and the distance assessment is straightforward. Therefore, the characteristics of the distributed feed method are easy to evaluate. The simulation model for this cube phantom is also simple. The cube is similar to the cube model of COST 244[7], i.e., 200X200X200[mm]. The mobile handset model is set on the cube phantom as shown Fig. 2. The indicated position on the cube assumes the case when talking on a mobile terminal. In this study, we compare the distributed model in which two PIFAs are set parallel in the top part of the chassis to the single feed model in which one PIFA is set in the chassis. The investigation parameters are given in Table I.

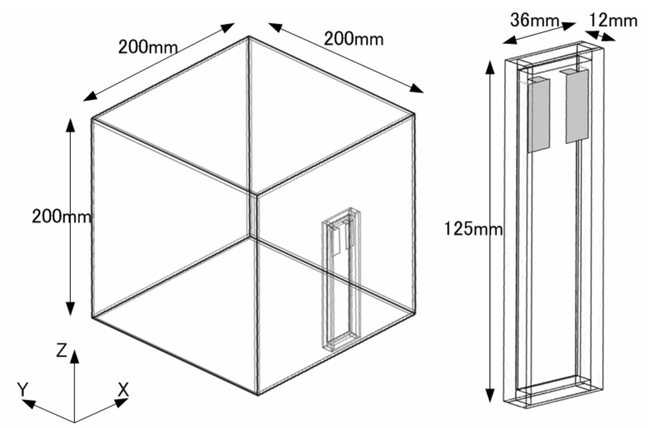


Fig. 2 Mobile handset model and phantom

Table 1. Investigation parameters

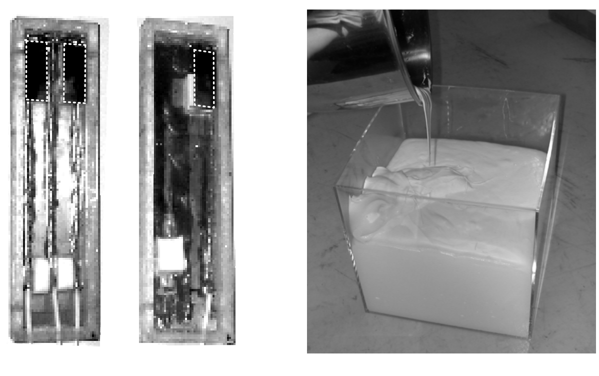
Frequency	2 GHz
Element type	PIFA
Number of elements	1 or 2
Chassis shape	Straight
Element alignment	Parallel
Output power	1W
Amplitude of elements	Equal
Phantom shape	Cube
Relative permittivity (εr)	41.0
Conductivity (σ)	1.3 S/m

3. Experiment

3-1 Distributed feed model and phantom

The prototype mobile handset model for the distributed and single feed methods is constructed in order to evaluate experimentally the validity of the proposed method. Photographs of the model are shown in Fig. 3. The model is constructed using a 200X200X200 mm acrylic casing with the wall thickness of 3 mm, and the element is set on a plain print board. The phase of the feed condition for the elements used in the distributed feed method is control by a phase shifter.

The phantom comprises Polyethylene Powder (PEP) and NaCl, SUPER STUFF [8], and H_2O. PEP is used to control the relative permittivity in the phantom. The more PEP that is used, the lower the relative permittivity becomes. NaCl is used to control the degree of conductivity and the more that is used, the degree of conductivity increases. The SUPER STUFF is used as a thickening agent. Therefore, since the PEP is insoluble, it can be interfused by using the SUPER STUFF. This phantom is placed in the acrylic case described above.



(a) Handset model (b) Phantom

Fig. 3 Prototype mobile handset model for distributed and single feed methods and the phantom

3-2 Measurement System for Radiation Efficiency, Electric field, SAR

The radiation efficiency (η) is derived by measuring the radiation pattern and using the Radiation Power Integration (RPI) method [8]. The RPI formula is

$$\eta = \frac{\mathrm{Prad}}{\mathrm{Pin}} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}(G\theta + G\phi)\sin\theta \, d\theta \, d\phi \qquad (1)$$

As shown in Fig. 4, the radiation pattern is measured using a horn antenna and the mobile handset model and phantom (hereafter test model) on the turntable. In this measurement, the test model is turned in the ϕ' direction in intervals of a set degree. The turntable is rotated in the θ' direction in intervals of 5 degrees. The degree of rotation in the ϕ' direction (Δϕ') pertains to the operation efficiency and measurement accuracy. The optimum Δϕ' in degrees is determined using the Finite-Difference Time-Domain (FDTD) method. The relation between Δϕ' and the radiation efficiency is given in Table 2. This numerical simulation model represents the single-feed mobile handset model, and the simulation parameters are the same as those for the distributed-feed mobile handset model. The results show that the radiation efficiency converges at Δϕ' = 15 degrees. Therefore, Δϕ' in this measurement is 15 degrees.

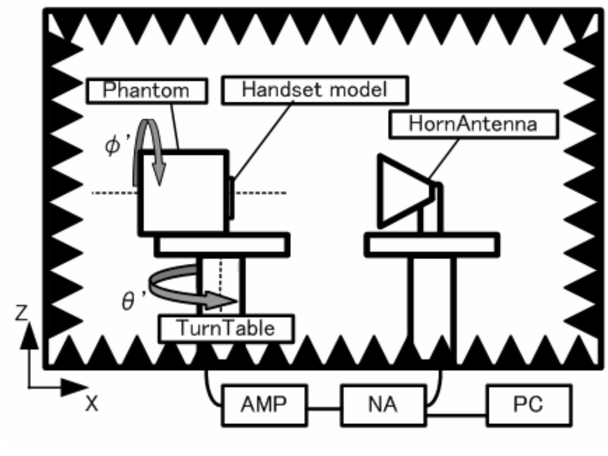


Fig. 4 Measurement system for radiation efficiency

The electric field and Specific Absorption Rate (SAR) are measured using an electric field sensor employed by a scanning robot arm as shown in Fig. 5. A liquid phantom with physical parameters that are the same those of a human head and the cube phantom are employed for this measurement. This phantom is in a water bath (wall thickness of water bath is 2 mm) under the robot arm. The handset model is set under this water bath.

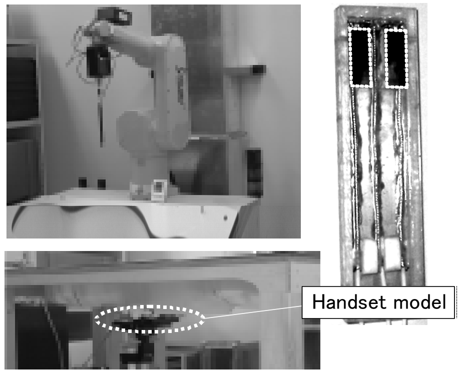


Fig.5 Electric field and SAR measurement by scanning robot arm

Table 2. Relation between Δϕ' and radiation efficiency (η) determined using FDTD method (single feed model)

Δϕ' (degree)	5	15	45	90	180
η(%)	41.6	41.6	41.9	42.2	48.0

4. Result

4-1 Electric field in phantom

The results of the electric field in the phantom are shown in Fig. 6. The electric field distribution of the distributed feed model (Fig. 6(a)) is dispersed compared to that of the single feed model (Fig. 6(b)). The peak point value of the electric field in the distributed-feed model is 75% compare to that of the single-feed model. When the phase difference of the feed conditions for the elements in the distributed feed model is 180 degrees, the electric field distribution in the distributed feed model (Fig. 6(c)) is concentrated near the elements and the peak value is 180% compare to that of the single-feed model.

These results show that the distributed-feed method lowers the electric field in the phantom when the element weight is set to the optimum value.

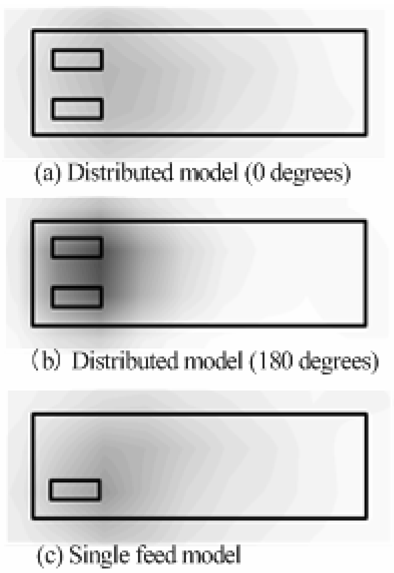


Fig.6 Electric field distribution in phantom

4-2 SAR in Phantom

The normalized 10g SAR value in the distributed feed model is shown in Fig. 7. The phase difference of the elements is changed from 0 to 360 degrees. At the phase difference of 0 degrees, the 10g SAR value is 0.16, which is the lowest. At the phase difference of 180 degrees, the 10g SAR value is 1, which is the highest. It is shown that the 10g SAR value fluctuates about six times between the highest and lowest values. On the other hand, the 10g SAR value in the single-feed model is 0.3. Therefore, the distributed-feed method reduces the SAR to nearly half. However, if the phase difference in the distributed-feed method is not set to the optimum value, the SAR value may become higher than that of the single feed method.

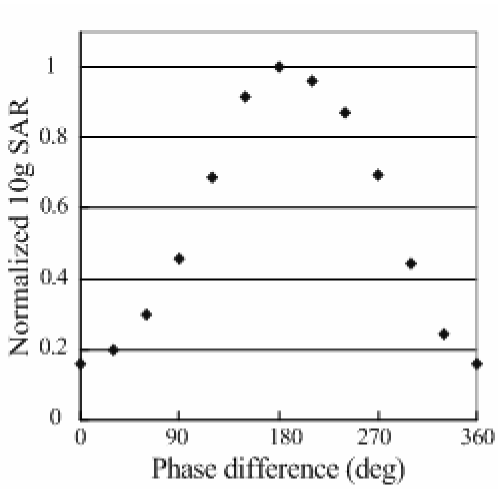


Fig. 7 Normalized 10g SAR and phase difference

4-3 Radiation Efficiency

The radiation efficiency of the distributed-feed model (phase difference is 0 and 180 degrees) and that of the single-feed model are measured. The distributed feed model with the phase difference of 0 degrees has the highest radiation efficiency of 57.1%. The single-feed model exhibits a radiation efficiency of 42.7%. The distributed-feed model with the phase difference of 180 degrees has the worst radiation efficiency of 15.1%. These results show that in the model with a high radiation efficiency, the 10g SAR is low, and in the model with a low radiation efficiency, the 10g SAR is high as indicated in Table 3. The values in parentheses in this table are the radiation efficiency values from the numerical simulation and they show the validity of the experimental values.

Table 3. Radiation efficiency and 10g SAR

	Distributed feed (0 degrees)	Distributed feed (180 degrees)	Single feed
η (%)	57.1 (55.9)	15.1 (21.0)	42.7 (41.2)
10gSAR	0.16	1	0.3

5. Conclusion

This paper proposed the distributed-feed method, which reduces the loss of electric power due to the human body and improves the radiation efficiency of mobile handsets. The performance of this method was evaluated by experiment. The electric field distribution and SAR in the phantom were measured. The results indicated that the distributed-feed method (phase difference of 0 degrees) reduces the peak electric field value and SAR compared to the single-feed method. The radiation efficiency using the proposed method (phase difference of 0 degrees) was improved. These benefits were concluded to be derived through the reduction in the loss of electric power due to the human body, and this power was used for radiation.

Variations in the electric field distribution, the 10g SAR value, and radiation efficiency were exhibited when the phase difference of the distributed-feed method was changed. Therefore, when using the proposed method to improve the radiation efficiency, the optimum feed weight must be set. In a practical application of the proposed method in a real mobile handset model, complex parts, circuits, and different elements may be required. Determining the optimum weight seems difficult. The method for determining the optimum weight for mobile terminals will be investigated.

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