A Proposal for a Transmission Diversity for Mitigation of the Human Body Effect of Handset Antennas and its Performance Evaluation

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1. INTRODUCTION

With the expansion of cellular telephone services, there has been an interest in and much research directed towards antenna gain enhancement in ordinary use situations [1]-[3]. An analysis of the performance of a handset antenna in the vicinity of the human operator has been done at 900 MHz [4], [5]. The previous studies were made primarily on the power absorbed in a head, a hand and a shoulder, on the power loss due to impedance mismatch. However, little has been investigated on the effect of a finger holding a terminal on the performance of a handset antenna.

In the present cellular radio system in Japan (PDC), diversity reception techniques are employed for mobile terminals. The technique is essentially used to reduce multipath fadings in a land mobile communication environment because high diversity gain can be achieved with a compact diversity configuration. However, none of previous studies have been treated on diversity techniques for mitigation of the human body effect.

This paper proposes a novel method to overcome a performance degradation of a handset antenna due to operator’s fingers. The proposed method utilizes transmission diversity techniques to increase an average transmission power with a received power of diversity branches as a branch selection criterion. Transmission diversity has been extensively studied to enhance downlink performance of base station antennas [6], [7], but little for mobile terminal antennas.

In the first stage of our investigation, expected values of an increment of an average power received by a base station antenna are analyzed in relation to correlations and unequal median power conditions of diversity branches when the newly proposed method is applied. The effectiveness of the method is confirmed based on gain characteristics of the diversity antenna when a thumb of an operator’s hand is attached to an external antenna. Finally, an experiment conducted in an indoor environment verifies the theoretical investigation.

2. PROPOSED METHOD

Figure 1 shows a conceptual picture of the proposed transmission diversity for mitigation of the human body effect. In the conventional configuration of the PDC terminal, an external helical antenna functions only as a transmission antenna and a combination of a helical and a built-in antenna such as a PIFA as a receiving selection combining diversity antenna. In the conventional system, when a thumb of an operator’s hand touches an external helical antenna as shown in Fig. 1, there may be a significant gain reduction of the helical antenna, and diversity receiving method can rescue this degradation during receiving time slot. However, there is no way to restore radiation power from the helical antenna during transmitting time slot, resulting in a severe degradation of uplink performance.

To overcome this difficulty, we propose a transmission diversity with a branch selection criterion based on an ordinary receiving stronger-signal-choice basis. In the PDC system, frequency separation of more than 10 MHz exists between transmitting (TX) and receiving (RX) band, which is much greater than a coherence bandwidth. Thus, correlation between the two frequencies is expected to be sufficiently low. In this situation, there is no effect to overcome instantaneous signal fadings for TX-band signals even when the transmission diversity is applied. However, we can expect a significant increase in an average transmission power because a built-in PIFA suffers little degradation due to a thumb.

In the proposed method, branch selection for the transmission diversity is based on received signal strength as mentioned above. Thus a problem may arise when a thumb or other fingers touch a PIFA instead of a helical antenna because transmission power decreases if a low gain PIFA is eventually selected during transmission time slot under reception diversity algorithm. In order to clarify this phenomenon, theoretical investigation was made on a change of an average power received by a base station antenna in comparison with a conventional

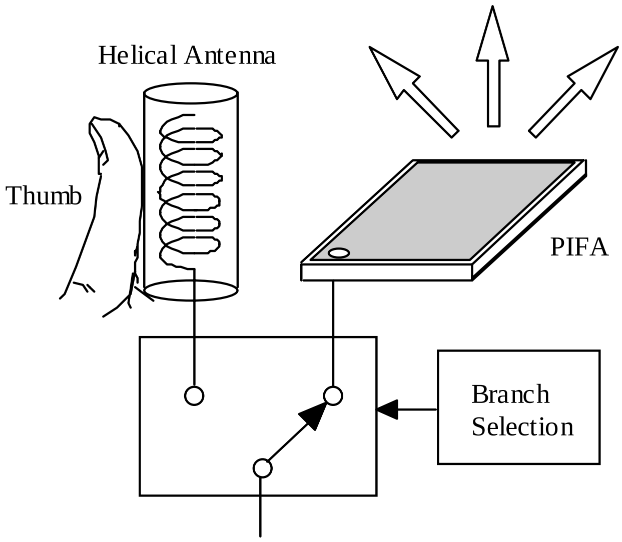

Fig. 1 Concept of the Transmission Diversity

system where a single helical antenna is used during transmission.

3. THEORETICAL INVESTIGATION

3.1 RECEIVED POWER CHANGE AT BS

When the proposed method is applied a change in received power at a base station, ΔG, can be estimated from a selection time percentage of diversity branches if effective gains of a helical and a PIFA equal each other and correlation between TX and RX signals is sufficiently low, in the followings;

$$\Delta G = \frac{P_1 (1-\Delta t) + P_2 \Delta t}{P_1} = (1-\Delta t) + r\,\Delta t \qquad (1)$$

where P_1 and P_2 are an average receiving power of a helical antenna (ANT1) and a built-in PIFA (ANT2), r is an unequal median value between two branches, i.e., P_2/P_1, Δt is a branch selection time percentage of ANT2.

Equation (1) shows a ratio of an average received power at a base station when the new method is adapted, to that when a single helical antenna is used. Therefore, effectiveness of the transmission diversity can be verified from the characteristic quantities that are used in ordinary reception diversity.

3.2 BRANCH SELECTION PERCENTAGE

A branch selection time percentage of ANT2, Δt is a probability that an envelope voltage of received signal of ANT2 (R_2) is greater than that of ANT1 (R_1), i.e., Prob(R_2>R_1). Δt can be obtained from the following equation, assuming that the envelope voltages, R_1 and R_2, are of Rayleigh distribution;

$$\Delta t = 1 - \int_0^{R1} \left[\int_0^{\infty} \frac{R_1 R_2}{r P_1^2 (1-\rho)} I_0 \left\{ \frac{\sqrt{\rho}\, R_1 R_2}{(1-\rho)\sqrt{r}\, P_1} \right\} \bullet \exp\left\{ \frac{-1}{1-\rho} \left(\frac{R_1^2}{2P_1} + \frac{R_2^2}{2 r P_1} \right) \right\} dR_1 \right] dR_2 \qquad (2)$$

where ρ is a correlation coefficient of two branches, and I_0 is the modified Bessel function of 0th order.

Figures 2 and 3 show Δt in eq. (2) and ΔG in eq. (1) as a function of an unequal median value, r, with correlation coefficient as parameters. Figures 2 demonstrates that Δt more than 90 % is obtained for r = 10dB, meaning that ANT2 (PIFA) is chosen as a receiving antenna for a large amount of time period when r is large enough. This situation can be interpreted from eq. (1) that an antenna gain for transmission time period is substantially determined from that of ANT2. In contrast, Δt less than 10 % is obtained in case of r = –10dB, implying that ANT1 (helical antenna) is chosen as a receiving antenna.

Figure 3 shows a relationship between ΔG and r. As can be seen from Fig. 3, ΔG agrees with r in the positive region of r, indicating that the gain degradation of ANT1 can be compensated by ANT2. This means that when a gain of a helical antenna (ANT1) is considerably reduced due to touch of a thumb a decrease in an average received power at a base station can be prevented by the use of a PIFA (ANT2) as a transmitting antenna.

On the other hand, ΔG is nearly 0 dB in the negative region of r. This phenomenon can be understood from the fact that when a gain of ANT2 is decreased there will be little influence on an average received power of a base station because a branch selection time percentage of ANT1 becomes larger as can be seen from Fig. 2. Those behaviors regarding ΔG vs. r accord with qualitative interpretations derived from Δt properties in Fig. 2.

A branch correlation can be high in such a situation that a branch separation is quite small, a problem inherent to a handset diversity antenna. However, Fig. 3 shows that, even in such a case, the same performance as for a low correlation is obtained since ΔG curve does not change even in the case of a high correlation of 0.8 as shown in Fig. 3.

4. EXPERIMENTAL RESULTS

4.1 BASIC EXPERIMENTS

An experiment was made in an indoor multiple radio wave environments to confirm the validity of the theory. The frequency is 900 MHz. An experimental setup is shown in Fig. 4. The experiment was conducted in a typical laboratory with concrete walls, and plastic boards on a concrete base for the floor and ceiling. The transmitting antenna of a half-wavelength dipole antenna and the receiving antennas of two parallel half-wavelength dipole antennas, distance of which quarter-wavelength apart, were located vertically on the floor and the receiving signals were sampled by an A/D converter with the receiving antenna that was moving around on a rotating arm of 0.7 m. The two parallel dipole antennas simulate a diversity branch (ANT1 and ANT2). The transmitting and receiving antennas were placed so that the out-of-sight condition was maintained. Both antennas were located at the same height of 1.5 m from the floor. In this configuration, it was confirmed that the incident waves are to have Rayleigh distribution.

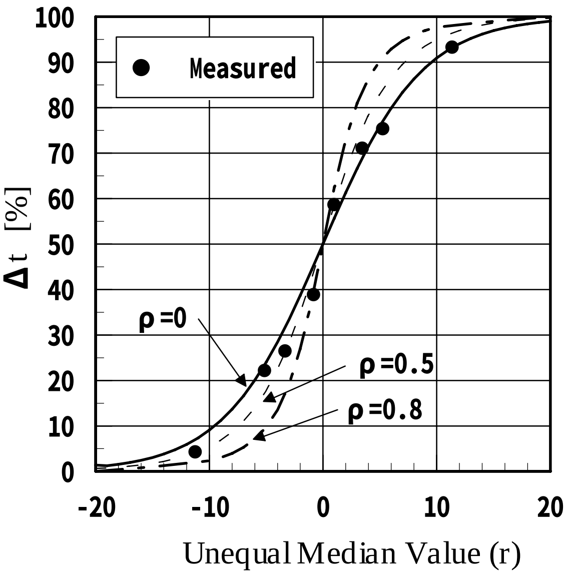

Fig. 2 Δt vs. Unequal Median Value

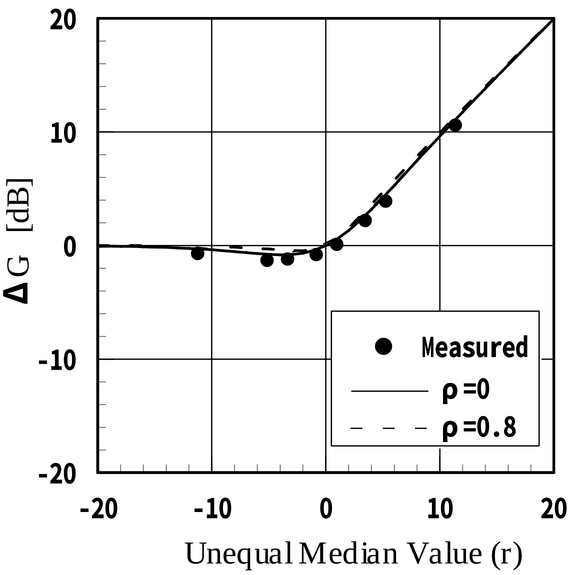

Fig. 3 ΔG vs. Unequal Median Value

In the experiment, a fixed attenuator (ATT) of 0 to 10 dB was connected to one of the receiving dipole antennas, which simulates the gain degradation of the antennas (ANT1 or ANT2). Table 1 and 2 show the measured results, along with the theoretical values of ΔG calculated by eq. (1), in which Table 1 corresponds to a gain reduction of ANT1 and Table 2 to that of ANT2. The correlation coefficient was measured to be less than 0.2.

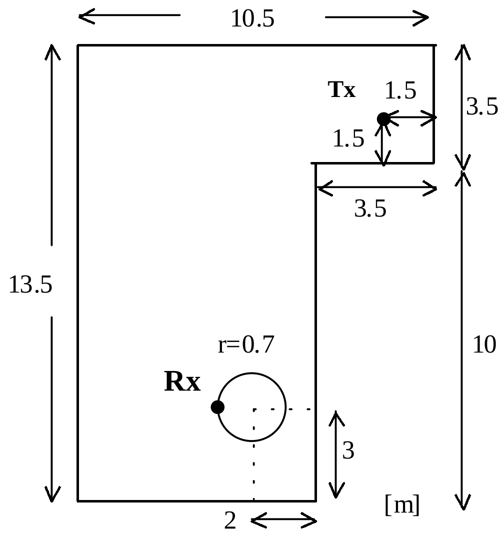

Fig. 4 Indoor Experimental Setup

Table 1 When a Gain of ANT1 is Reduced

ATT [dB]	P_1 [dBm]	P_2 [dBm]	r [dB]	Δt [%]	ΔG [dB]
0	-43.1	-42.2	0.9	59.9	0.6
3	-45.3	-41.9	3.4	72.3	2.7
5	-47.1	-41.9	5.2	76.6	4.4
10	-53.3	-42.0	11.3	94.5	11.1

Table 2 When a Gain of ANT2 is Reduced

ATT [dB]	P_1 [dBm]	P_2 [dBm]	r [dB]	Δt [%]	ΔG [dB]
0	-42.2	-43.1	-0.9	40.1	-0.3
3	-41.9	-45.3	-3.4	27.7	-0.7
5	-41.9	-47.1	-5.2	23.4	-0.8
10	-42.0	-53.3	-11.3	5.5	-0.2

Table 1 indicates that an unequal median value r increases with increasing a value of attenuator, resulting in a larger Δt. Table 1 also shows that ΔG almost agrees with r, meaning that a gain reduction of ANT1 is restored by ANT2.

It is seen from Table 2 that r decreases as the attenuator increases, which leads to a smaller Δt. However, in contrast to Table 1, a decrement in ΔG is very small. This fact means that almost the same average received power at a base station as that of the conventional diversity system can be expected even when a gain of ANT2 (PIFA) is reduced since ANT1 (helical antenna) is predominantly chosen. Δt and ΔG in Table 1 and 2 are also plotted on Figs. 2 and 3 with black dots. The measured and calculated values agree very well, which verifies the validity of the proposed method.

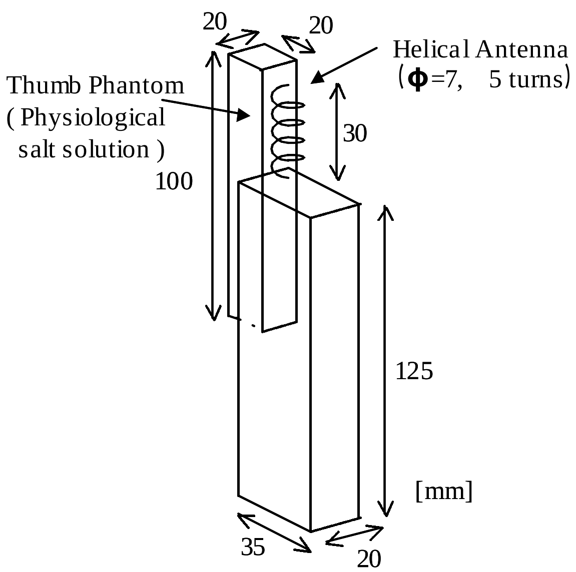

Fig. 5 Handset Model with a Thumb Phantom

Table 3 Radiation Efficiency of a Helical Antenna

Without Thumb Phantom	With Thumb Phantom	Δ
-1.4dB	-9.3dB	7.9dB

4.2 EXPERIMENT USING A HANDSET MODEL

An experiment was made using a model simulating a typical commercial handset at 900 MHz. Figure 5 shows a handset model, in which a thumb phantom in a rectangular shape is located close to a helical antenna. A distance between the thumb phantom and the helical antenna is 3 mm. A glycerin-based mixture [4] is contained in the phantom plastic case.

The measured results of radiation efficiency with and without the phantom are summarized in Table 3. It is shown from Table 3 that a decrement in radiation efficiency due to a touch of a thumb is 7.9 dB, and thus the same amount of improvement in an average received power at a base station can be expected by applying the proposed method if an effective gain of a PIFA is equal to that of a helical antenna.

5. CONCLUSION

A novel method to overcome a performance degradation of a handset antenna due to operators' fingers is presented. A drastic improvement in uplink performance can be expected. The theory and experiments confirm the validity of the method.

REFERENCES

[1] K. Noguchi, M. Ando, N. Goto, M. Hirose, T. Uno, and Y. Kamimura, "Directional antenna for portable telephones," IEICE Trans. Commun., vol. E79-B, no. 9, pp. 1234-1241, Sept. 1996.

[2] R. Y-S Tay, Q. Balzano, and N. Kuster, "Dipole configurations with strongly improved radiation efficiency for hand-held transceivers," IEEE Trans. Antennas & Propag., vol. AP-46, no. 6, pp. 798-806, June 1998.

[3] G. F. Pedersen and J. B. Andersen, "Integrated antennas for hand-held telephones with low absorption," in Proc. 44th IEEE Veh. Technol. Conf., Stockholm, Sweden, pp. 1537-1541, June 1994.

[4] K. Ogawa, T. Matsuyoshi and K. Monma : "An analysis of the performance of a handset diversity antenna influenced by head, hand and shoulder effects at 900 MHz: Part I -Effective gain characteristics," IEEE Trans. Vehicular Technology. vol. 50, no. 3, pp. 830-844, May 2001.

[5] K. Ogawa, T. Matsuyoshi and K. Monma : "An analysis of the performance of a handset diversity antenna influenced by head, hand and shoulder effects at 900 MHz: Part II -Correlation characteristics," IEEE Trans. Vehicular Technology. vol. 50, no. 3, pp. 845-853, May 2001.

[6] K. Suwa and Y. Kondo, "Transmitter Diversity Characteristics in Micro- cellular TDMA/TDD Mobile Radio," Proc. Of the 3rd IEEE PIMRC 1992.

[7] Y. Kondo and K. Suwa, "Linear Predictive Transmitter Diversity for Microcellular TDMA/TDD Mobile Radio System," Proc. Of the 43rd IEEE VTC, 1993.