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Performance of Multi-band Multi-antenna for Mobile Terminal Employing Folded Inverted-L Antennas

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1. Introduction

The rapid growth in mobile communication systems leads to a great demand for Multi-Input Multi-Output (MIMO) and multi-band systems to enhance the data rate and the capacity of the radio network [1]-[4], thus both multi-antenna and multi-band technologies must be employed for mobile terminals. In regard to the link budget, the performance of antennas is a vital element since the performance will not only affect the quality and the coverage of the mobile network but also the capacity of the entire networks. Hence, clarification of the performance of multi-band and multi-antennas mounted on actual mobile terminals is currently urgently needed. This is especially true in practical usage situations and since the size and style of mobile terminals have changed significantly over the last several years.

This paper presents the available performance of multi-band and multi-antennas designed for 4x4 MIMO and triple-band operation covering the 800 MHz, 1.7 GHz, and 2 GHz bands, when the antennas are mounted on an actual mobile terminal. We first propose a multi-band folded inverted-L antenna in this study. Then we investigate the influence of mutual coupling, implementation losses and multi-antenna performance when employing the multi-band folded inverted-L antennas. The investigation is based on the measurement in an anechoic chamber. The developed measurement facility that employs the multi-channel antenna pattern measurement system enables us to acquire the amplitude and phase patterns of multi-antennas at high speed.

The rest of this paper is organized as follows. Section 2 describes the proposed antenna configurations and Section 3 presents the measured results for the antenna characteristics. The simulated Maximum Ratio Combining (MRC) beamforming gain and the MIMO channel capacity based on the measured radiation patterns are discussed in Section 4 and the concluding remarks are given in Section 5.

2. Antenna configurations

The proposed antenna configuration is shown in Fig. 1. A folded inverted-L structure comprising a wire element is employed in this antenna and it is designed in a way to produce several resonances. We use a commercial Personal Digital Assistance (PDA) as a mobile terminal to consider the actual implementation loss. The antennas are arranged symmetrically at the four corners of the PDA chassis for a 4×4 MIMO transmission. Feeder cables are connected to all antenna elements, and the ground lines of the antenna are connected to a printed circuit board installed inside of the PDA. The feed points of the non-fed elements are electrically connected to the 50 Ω terminators using a SP4T PIN switch to evaluate the effect of the mutual coupling between antennas. The volume of the antenna and terminal is $30\times10\times10$ mm^3 and $80\times15\times125$ mm^3, respectively. The considered frequency bands are the 800 MHz, 1.7 GHz and 2.0 GHz bands in this paper. The distance between the feed points in the *x*/*z*-direction is 0.2/0.4 λ for the 800 MHz band, 0.5/0.8 λ for the 1.7 GHz band, and 0.6/0.9 λ for the 2 GHz band.

3. Measurement Results for Antenna Characteristics

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The measured antenna input characteristics and mutual coupling characteristics are shown in Fig. 2. The s_{11} characteristic represents the antenna input characteristics of ANT #1 showing in Fig. 1. The s_{21}, s_{31}, and s_{41} characteristic represent the mutual coupling characteristics. From the s_{11} characteristics, we confirm that the proposed antenna covers all the considered frequency bands. The s_{31} and s_{41} are below -15 dB for all the frequency bands, whereas s_{21}, which represents one of the most severe alignments with mutual coupling in terms of the distance between antennas, is approximately -5 dB for the 800 MHz band and from -10 to -5 dB for the 1.7 GHz and 2 GHz bands. This is due to the narrow element spacing between ANTs #1 and #2, which is less than 0.5 λ for the actual mobile terminal. These results confirm that ensuring sufficient isolation between antennas will be an important issue in the installation of multi-antennas into an actual mobile terminal.

Measured radiation patterns in the azimuth plane (*x*-*y* plane) of ANT #1 are shown in Fig. 3. We employed a network-analyzer based multi-channel antenna pattern measurement system with a SP4T PIN switch to measure the radiation patterns considering the influence of the mutual coupling. This system can acquire the amplitude and phase pattern at high speed by switching the measurement channel concurrently with rotations of a turntable. Moreover, we improved the measurement accuracy by employing optical fiber cables instead of coaxial feeder cables. Figures 3(a) and 3(b) show the radiation patterns in the azimuth plane for a terminal tilted 45 degrees in free space and for a data mode case where the terminal is held in front of a real human body at a 45-degree tilt, respectively. The data mode is a severe degradation case due to the loss caused by the body since the antennas placed at bottom of the terminal are covered by the user's hand and the mobile terminal is placed in the vicinity of the user's body. Figure 3 shows that the antenna cross polarization discriminations (XPD) values are below 3 dB for all the frequency band, thus the measured radiation patterns can be said as the dual polarized properties (*E*-theta components is comparable with *E*-phi component). This result is not expected because the current distribution should be changed as the frequency is increased. So from this point of view, the polarization diversity configuration at a base station will be a good candidate for maximizing the transmission performance for all the frequency bands. The figure also shows that the radiation patterns in the data mode have many ripples due to the human body.

Figure 4 shows the radiation efficiency and the pattern averaging gain (PAG) [5]. These are the average values of four antennas. The PAG is derived in the case that the cross-polarization ratio (XPR) of the arriving waves at the mobile terminal is -6 dB [6]. As shown in Fig. 4, the radiation efficiency is approximately -3 dB although higher efficiency is generally required for the antennas. The degradation in the radiation efficiency should be caused by the implementation losses and the influence of the mutual coupling. Moreover, the measured PAG values for the data mode are lower than those for free space. This is because the antennas at the bottom of the terminal are very close to the user's hand in the data mode and the radiated power is absorbed into the hand. The degradation in the PAG is approximately 3 dB for the 800 MHz band and approximately 4 dB in the 1.7/2 GHz band. This leads to the degradation in the average PAG that exceeds 3 dB for all the frequency bands.

4. Simulated MRC Beam-forming Gain and MIMO Channel Capacity

We employ three criteria to evaluate the multi-antenna performance in this paper: MRC-beamforming gain, correlation coefficient, and MIMO channel capacity. Figure 5 shows the simulated MRC-beamforming gains and the correlation coefficient [7]-[10] derived from the measured radiation patterns. The MRC-beamforming gains are normalized by the value of the single antenna. The correlation coefficients represent the worst value of all pairs. We assume that the angular density function of the arriving waves in the azimuth plane is uniform in this paper.

Figure 5 shows that 3 to 4 dB of the MRC-beamforming gain is obtained in free space for all the frequency bands. On the other hand for the data mode, the MRC-beamforming gains are 1 to 2 dB lower than those for the free space case. These results indicate that applying the multi-antenna configuration does not obtain ideal improvement in the data mode, a popular mode of usage requiring high data rate transmission.

As for the correlation coefficient, we observe that the correlation coefficient is in the range of 0 to 0.4 for all the frequency bands. Note that there is a difference between free space and the data mode in the correlation coefficients. The correlation coefficient is elevated above 0.3 for the 1.7 and 2 GHz bands, whereas a low correlation coefficient of less than 0.1 is obtained in free space. The radiation patterns in the data mode differ from those in free space as shown in Fig. 3. This probably produces the shift in the correlation coefficient.

The MIMO channel capacity is also of considerable interest to future mobile communications. The cumulative distribution functions of the simulated MIMO channel capacities [11][12] for a 4 × 4 MIMO system, which are derived from the measured radiation patterns, are shown in Fig. 6. We assume that the antennas at the base station site are uncorrelated to focus the investigation on the performance of the mobile terminal antennas. The capacities are normalized by the value obtained using a Single-Input Single-Output (SISO) configuration at the Signal-to-Noise-Ratio (SNR) of 10 dB. As shown in Fig. 6, we can obtain double to triple the channel capacity compared to that for SISO in free space for 50% of the cases. This means that the proposed multi-band multi-antenna configuration is still feasible even when the antennas are installed in an actual mobile terminal. However, the data mode provides a lower overall capacity in all the frequency bands compared to free space. The mean channel capacity in the data mode is decreased by approximately 40% for all the frequency bands. It should also be noted that the 800 MHz band resulted in a 20% lower channel capacity compared to those for the 1.7 and 2 GHz bands. It is considered that these results are explained by the influence of the PAG and the correlation coefficient. Since the PAG is low in the data mode, the channel power obtained at the mobile terminal deteriorates. In addition, the correlation coefficient is elevated to more than 0.3 in the data mode for all the frequency bands and in free space in the 800 MHz band. Consequently, the channel capacity is degraded especially in the data mode and 800 MHz.

5. Conclusions

Multi-band multi-antenna for a mobile terminal employing the folded inverted-L antennas was presented in this paper. It was shown that the proposed antenna configuration provides triple band operation covering the 800 MHz/1.7 GHz/2 GHz bands. The mutual coupling was from -10 to -5 dB for all the frequency bands, and these properties have a negative impact on the radiation efficiency and PAG in a multi-antenna configuration. Moreover, it was shown that the degradation of the PAG in the data mode exceeded 3 dB for all the frequency bands due to the user’s hand. We also evaluated the multi-antenna performance based on the measured radiation patterns. The correlation coefficient was from 0 to 0.4 and we showed that there is a difference between free space and the data mode. The proposed antenna configuration with four elements achieved the MRC-beamforming gain of 3 to 4 dB and the double to triple the channel capacity compared to SISO in free space, whereas deterioration of 40% and 20% was found in the data mode for all the frequency bands and in the 800 MHz band, respectively.

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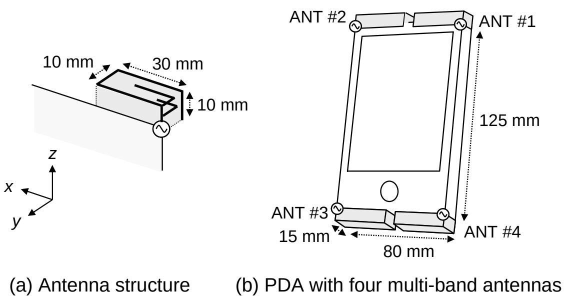

Figure 1: Antenna Configuration

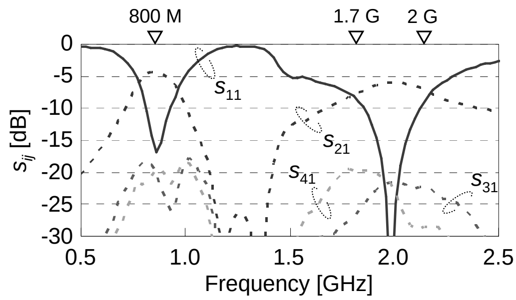

Figure 2: Antenna Input Characteristics

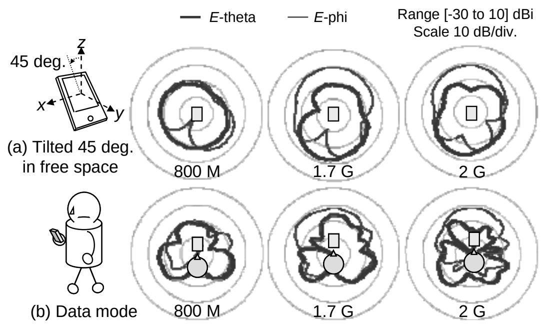

Figure 3: Radiation Patterns

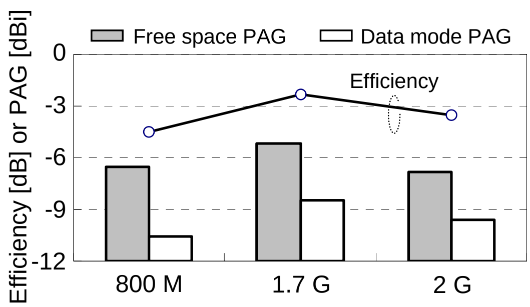

Figure 4: Efficiency and Pattern Averaging Gain

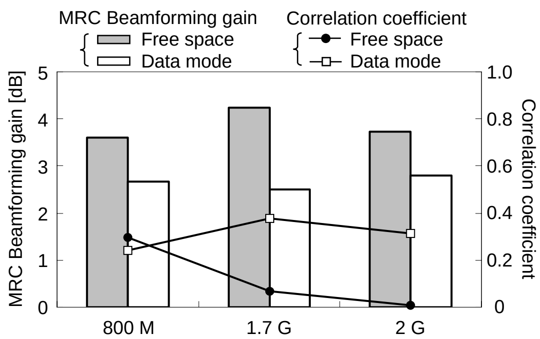

Figure 5: Beam-forming Gain

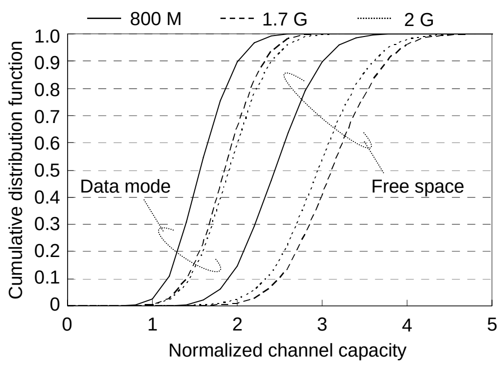

Figure 6: MIMO Channel Capacity