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Miniaturized six port MIMO antenna using T-shaped conductor and reactance-loaded notch antenna

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Abstract: In this letter, a miniaturized six port Multiple-Input Multiple-Output (MIMO) antenna is presented and evaluated based on simulation. The proposed antenna consists of three planar inverted-F antennas (PIFA) and three notch antennas. The combination of these elements yields low mutual couplings among them since electric field directions of them are orthogonal to each other. Furthermore, PIFA and notch antenna are miniaturized by using T-shaped conductor and loading reactance, respectively. From the antenna characteristics results, it is found that all mutual couplings were suppressed less than −10 dB. From the channel capacity characteristics results, the channel capacity was improved by 10.62 Bits/s/Hz compared with six dipole antennas with same aperture width of the proposed antenna.

Keywords: MIMO, miniaturized antenna, decoupling, channel capacity

Classification: Antennas and Propagation

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1 Introduction

In order to achieve high speed wireless communication, Multiple-Input Multiple-Output (MIMO) system is used even in compact mobile communication terminals [1]. However, MIMO antenna performance is deteriorated by the effect of a mutual coupling between the elements in array. Especially, the high mutual coupling is observed in a small terminal since the elements are closely packed. To reduce the mutual coupling, various decoupling techniques, such as decoupling network and parasitic element are used [2, 3]. However, the decoupling network leads to narrow band property and complicated circuit configuration [4, 5], and the use of the parasitic element needs implementation of additional antennas [6]. Therefore, these methods are not suitable for small terminals since these methods require additional component. On the other hand, the use of the polarization orthogonality can effectively reduce mutual couplings without such additional components [7]. However, it is difficult to achieve both miniaturization and polarization orthogonalities because polarization orthogonality is easily deteriorated by folding the element for miniaturization.

In this letter, a miniaturized six port MIMO antenna suitable for small terminal is presented [8, 9]. The proposed antenna consists of three planar inverted-F antennas (PIFA) and three notch antennas. PIFA and slit length of notch antenna are miniaturized by using T-shaped conductor and loading reactance, respectively. The inherently decoupled pair of the antenna elements, i.e. T-shaped PIFA and reactance-loaded notch antenna is used to co-locate multiple antennas within a small space. In the following section, the proposed antenna configuration is explained first. Next, the proposed antenna characteristics are evaluated based on the simulation. Also, it is found that channel capacity of the proposed antenna is improving from comparison with dipole array with same aperture width as the proposed antenna, which has not been well considered in [8, 9].

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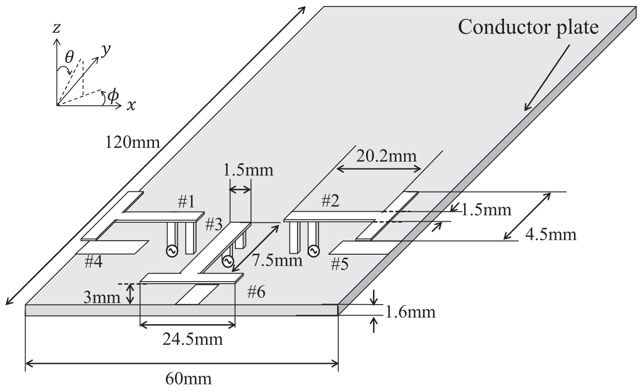
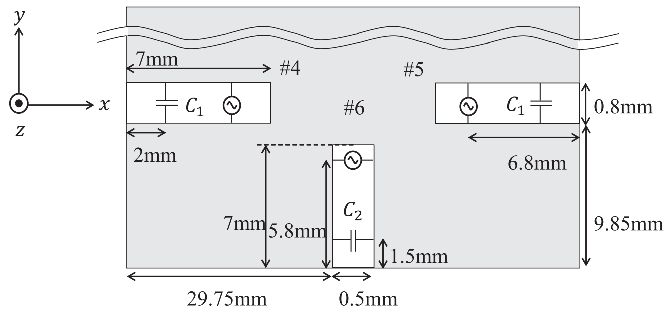


(a) Proposed antenna configuration



(b) Reactance-loaded notcha antenna configuration

Fig. 1. Antenna configuration

2 Proposed antenna configuration

Fig. 1(a) shows the proposed antenna configuration. The proposed antenna consists of three PIFAs and three notch antennas on the substrate with relative permittivity, ϵ_r, of 2.2. Center frequency f_c is 2.4 GHz. The dimensions of #1 and #4 are same as those of #2 and #5. PIFA and notch antenna are miniaturized by T-shaped conductor and loading reactance, respectively. Fig. 1(b) shows reactance-loaded notch antenna configuration, which is a part of the proposed antenna. C_1 and C_2 represent capacitances loaded to the notch antennas. The following describes determination method of loading capacitance.

Fig. 2(a) shows notch antenna model with feeding (#1) and termination ports (#2). Fig. 2(b) shows an equivalent circuit explained by S-parameters model when the termination port is loaded by a reactance. $\boldsymbol{S}_{ant}$ and Γ represent S-parameter of the notch antenna without loading reactance and reflection coefficient of loading reactance, respectively when the reference impedance is Z_0. If an impedance of the loading reactance is Z, the reflection coefficient, Γ, is expressed as

$$\Gamma = \frac{Z - Z_0}{Z + Z_0}. \tag{1}$$

Further, $\boldsymbol{S}_{ant}$ is definded as

$$\boldsymbol{S}_{ant} = \begin{pmatrix} S_{ant11} & S_{ant12} \\ S_{ant21} & S_{ant22} \end{pmatrix}, \tag{2}$$

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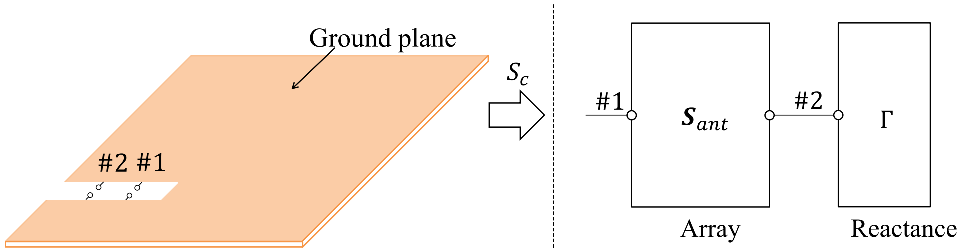

(a) Single element model of reactance-loaded notch antenna

(b) Circuit model by S-parameter

Fig. 2. Determination of loading reactance

where S_{ant11} and S_{ant22} represent reflections of #1 and #2, respectively, and S_{ant12} and S_{ant21} represent transmission characteristics between #1 and #2. S_c is S-parameter when the termination port terminated by Z, and expressed as,

$$S_c = S_{ant11} + S_{ant12}(\Gamma^{-1} - S_{ant22})^{-1} S_{ant21}. \tag{3}$$

Then, appropriate impedance value and loading position are determined so that S_c is reduced. Miniaturization of the notch antenna is realized by giving appropriate impedance value and position of loading. In this configuration, C_1 and C_2 are 0.51 pF and 0.59 pF, respectively. In the proposed antenna, a pair of T-shaped PIFA and reactance-loaded notch antenna has inherently a low mutual coupling because electric field directions of the T-shaped PIFA and reactance-loaded notch antenna are orthogonal at the feed ports, as shown in Fig. 1(a).

3 Simulation results

3.1 Antenna characteristics

Fig. 3(a) and 3(b) show the simulated S-parameter of reflection and mutual coupling characteristics, respectively. Note that, the reflection and mutual coupling characteristics for #2 and #5 are omitted due to symmetrical antenna arrangement. From Fig. 3(a), it can be seen that the reflection coefficients of both T-shaped PIFA and reactance-loaded notch antenna are less than -10 dB at the center frequency. Furthermore, the fractional bandwidths defined as the frequency ranges where the reflection coefficient are less than -10 dB, are 0.94%, 0.94%, 0.83%, 1.78%, 1.78%, and 4.06% for #1, #2, #3, #4, #5, and #6, respectively. This result show that the reactance-loaded notch antennas yield relatively broadband matching. From Fig. 3(b), it can be seen that all mutual couplings are less than -10 dB at the center frequency. The highest mutual coupling is $|S_{41}|$, and is -10.5 dB at the center frequency. This is because current distribution around notch antenna is asymmetry, and the electric field orthogonality is deteriorated.

3.2 Channel capacity characteristics

Fig. 3(c) shows Cumulative Distribution Function (CDF) of channel capacity. The MIMO channels are calculated by a geometric based three dimensional scattering model [10]. In this model, path distribution is assumed to be Rayleigh environment, and polarization of channel rotates randomly at the scatters. In the simulation, two type of the receiving antennas are used. One is the proposed antenna, and the other

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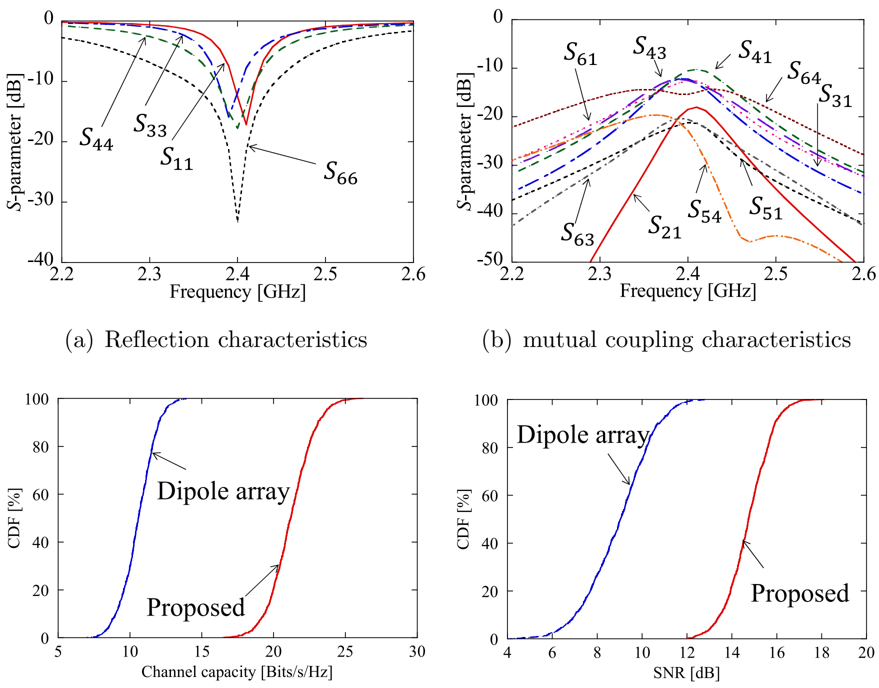

(a) Reflection characteristics
(b) mutual coupling characteristics
(c) CDF of the channel capacity
(d) CDF of SNR

Fig. 3. Simulation results

is six element dipole array with same aperture width as the proposed antenna. As for Tx arrays, one comprises three vertical and three horizontal polarized dipoles for proposed antenna, and the other comprises six vertical polarized dipoles for dipole array. Element spacing of the transmitting antennas is one wavelength, Signal-to-Noise Ratio (SNR) is set to 20 dB, and the number of trials is set to 1000 for Monte Carlo simulation. The channel capacity is calculated by,

$$C = \log_2 |\boldsymbol{I} + \boldsymbol{H}\boldsymbol{H}^H \gamma / N_t|, \tag{4}$$

where, $\boldsymbol{I}$, $\boldsymbol{H}$, N_t and γ represent an unit matrix, channel matrix, the number of transmitting antennas, and SNR, respectively. In Fig. 3(c), the solid and dashed lines express the channel capacity of proposed antenna and dipole array, respectively. From the figure, it is found that the channel capacity of the proposed antenna is 10.62 bits/s/Hz higher than that of the dipole array. Fig. 3(d) shows the mean SNR characteristics. The solid and dashed lines in Fig. 3(d) express the mean SNRs of the proposed antenna and dipole array, respectively. SNR of the proposed antenna and dipole array are 14.74 dB and 9.03 dB at 50% value, respectively. Mean spatial correlations of the proposed antenna and dipole array are 0.45 and 0.57, respectively. Therefore, it is considered that the improvement of the channel capacity was brought from both the increase of SNR and improvement of spatial correlation.

4 Conclusion

In this letter, the miniaturized six port MIMO antenna suitable for small terminal has been proposed. The proposed antenna consists of three PIFAs and three notch antennas, and these elements are miniaturized by using T-shaped conductor and

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loading reactance, respectively. The inherently decoupled pair of the antenna elements, i.e. T-shaped PIFA and reactance-loaded notch antenna is used to co-locate multiple antennas within a small space. From simulation results, the mutual coupling among all elements was suppressed less than -10 dB at the center frequency. Also, the channel capacity of the proposed antenna was 10.62 bit/s/Hz higher than that of the dipole array at the 50% value. These results demonstrate that the proposed design can offer both miniaturization of antenna element and improvement of the channel capacity.

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