

Performance evaluation of 2-port MIMO LTE-U terminal antenna with user's hand effect

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ABSTRACT

This paper presents the performance evaluation of 2-port MIMO antenna for LTE-U sub 6 GHz band. The evaluation focuses on the effect of user's hand in a uniform environment and the analysis were carried out on simulation and measurement data of antenna ports. Results show that the highest performance of the design is on the frequency range from 4.5 GHz to 5.5 GHz, and the ports have low envelope correlation coefficient (ECC) less than 0.16 in both cases of without and with user's hand. However, the presence of the user's hand reduces mean effective gain (MEG) of ports and diversity combining gain by more than 1.6 dB compared with no-hand case. The multiplexing efficiency is around 81% and reduced by the presence of the user's hand to 55%. Despite this reduction; the design shows high spatial multiplexing capability in both cases. The capacity carried by the second transmission eigenmode is about 39% from the total capacity under water-filling algorithm transmit power allocation.

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1. INTRODUCTION

MIMO antennas and higher frequencies with wider bands are the key-design to fulfill the growing demands for higher data rates in different applications of modern wireless communication systems [1-3]. However, the user's hand has a significant impact on the performance of the MIMO antenna design in mobile communications [4]. The user's hand can affect the performance of the mobile antenna by changing the impedance matching, the radiation patterns and the amount of radiated power which is absorbed by the lossy hand tissue. These changes will generally cause degradation in the performance of the communication systems [5, 6]. In this paper, the performance of 2-port MIMO antenna design operating in the frequency range from 4 GHz to 6 GHz has been evaluated in the presence of user's hand and compared with the performance without the user's hand. A prototype of the design has been fabricated and the 3-D complex-valued far-field radiation pattern has been measured in an anechoic chamber with and without the user's hand phantom. Different performance metrics, listed in next section, have been used for evaluation. This paper is organized as follows: section 2 describes the evaluation metrics. Section 3 presents the details of MIMO antenna, fabrication and measurement. Section 4 for results then the paper is concluded.

2. PERFORMANCE EVALUATION METRICS

Following parameters are used to evaluate the performance of the MIMO design and to show the effect of the user's hand.

2.1. Envelope Correlation Coefficient (ECC) and Mean Effective Gain (MEG)

ECC parameter shows the isolation of ports. Higher isolation (less ECC) means that the MIMO link has higher capacity [7]. ECC can be calculated using data of the far field radiation pattern or the data of S-parameter. However, the first method provides most accurate results and always recommended to be used. In this paper we used simulated and measured data of the far field radiation pattern to analyze the ECC of the design and the hand effect on it. Mathematically, ECC between two ports j and k is described by [8]:

$$\rho_{j,k} = \frac{\left| \iint_{4\pi} (XPR E_{\theta j} E_{\theta k}^* P_{\theta} + E_{\varphi j} E_{\varphi k}^* P_{\varphi}) d\Omega \right|^2}{\prod_{i=j,k} \iint_{4\pi} (XPR E_{\theta i} E_{\theta i}^* P_{\theta} + E_{\varphi i} E_{\varphi i}^* P_{\varphi}) d\Omega} \quad (1)$$

where XPR is the cross polarization discriminator whose value is 0 dB in case of a uniform distribution of the incident wave. $E_{\theta j}$ and $E_{\theta k}$ are the three dimensional complex-valued far-field radiation pattern fields in elevation direction of ports j and k respectively and $E_{\varphi j}$ and $E_{\varphi k}$ are the same fields in azimuth direction. The operator $*$ denotes to the complex conjugate. P_{θ} and P_{φ} represent the distribution of the incident wave in elevation and azimuth directions, respectively. In this paper, a uniform distribution is assumed with $P_{\theta} = P_{\varphi} = 1/4\pi$ and $d\Omega = \sin(\theta) d\theta d\varphi$ [9].

Second MIMO antenna parameter is the mean effective gain (MEG) of the ports which quantifies the ability of each antenna to collect the electromagnetic energy available in the surrounding environment [10]. MEG is described by the following equation:

$$MEG = \iint_{4\pi} \left[\frac{XPR}{XPR+1} E_{\theta} E_{\theta}^* P_{\theta} + \frac{1}{XPR+1} E_{\varphi} E_{\varphi}^* P_{\varphi} \right] d\Omega \quad (2)$$

where XPR , E_{θ} and E_{φ} are the cross polarization discriminator and the three dimensional complex-valued far-field radiation patterns in elevation and azimuth directions, respectively. P_{θ} and P_{φ} represent the distribution of the incident wave in elevation and azimuth directions, respectively.

2.2. Channel capacity

In case of channel state information (CSI) is available at the receiver only; the link capacity is calculated by [11]:

$$C = \log_2(\det(\mathbf{I} + \frac{\rho}{n_T} \mathbf{H}(\mathbf{H})^H)) \quad (3)$$

where \mathbf{I} is the identity matrix, ρ is the SNR, n_T is the number of transmit antennas and \mathbf{H} is the MIMO channel matrix whose coefficients includes the effect of the antenna ports on both sides on the link, $(\)^H$ is the Hermitian operator. C is a random variable because of the random coefficients of the channel matrix \mathbf{H} so ergodic capacity, which is the mean value of C , is used to present the link capacity. Moreover, the link capacity is presented also using cumulative density function (CDF) of the random variable C either on the whole range from 0 to 1 or at certain horizontal levels (outage levels) e.g. 0.1, 0.5 and 0.9. Capacity C in (3) can be broken up further into sub-capacities of individual eigenmodes as follows [12, 13]:

$$C = \sum_{k=1}^K \log_2(1 + \frac{\rho}{n_T} \lambda_k^2) \quad (4)$$

where λ_k is the k^{th} eigenvalue of $\mathbf{H}(\mathbf{H})^H$. On the other hand, when the channel state information (CSI) is available at the transmit side also; water-filling algorithm is used to maximize link total capacity in (4) by assigning higher transmission power to stronger eigenmodes as follows [11]:

$$C = \sum_{k=1}^K \log_2(1 + \frac{\rho}{n_T} \lambda_k^2 \gamma_k) \quad (6)$$

where γ_k is the power allocation coefficient associated with k^{th} eigenvalue to maximize the total capacity under constraint:

$$\sum_{k=1}^K \gamma_k = 1 \quad (6)$$

Last performance evaluation metric is the multiplexing efficiency which links the antenna parameters ECC and the total efficiency with the link capacity. This parameter quantifies the effectiveness of

the MIMO antenna design to achieve high capacity close to the capacity of iid channel. Multiplexing efficiency of two port-MIMO antennas at high SNR can be approximated by the following relation [14, 15]:

$$\eta_{mux} = \sqrt{\eta_1 \eta_2 (1 - \rho)} \quad (7)$$

where η_1 and η_2 are the total efficiencies of ports 1 and 2 respectively. ρ is the ECC between the two ports.

3. MIMO ANTENNA DESIGN AND MEASUREMENT

This work evaluates the effect of user's hand on the performance of two-port MIMO mobile antenna designed to operate on the LTE-U sub 6 GHz band. The two ports are placed on the top of the device as shown in fabricated prototype Figure 1(a). The prototype has been inserted inside a methacrylate box as shown Figure 1(b). The user's hand phantom holding the prototype and the type of the hand grip are shown in Figure 1(c).

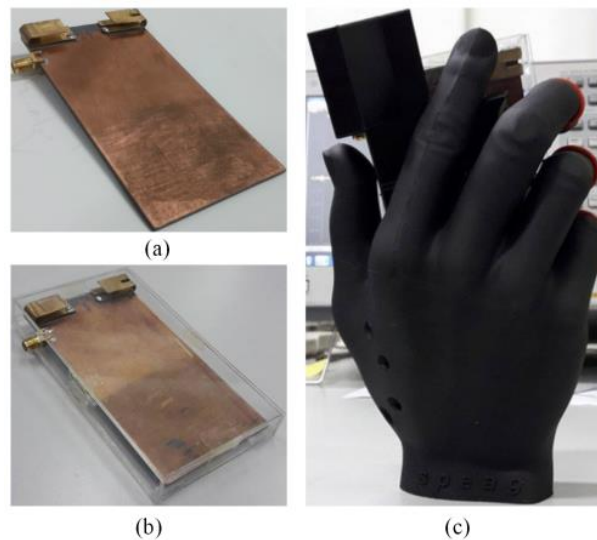


Figure 1. Prototype of the design (a) Two ports placed on top of the device (b) Prototype inside the methacrylate box (c) Prototype with user's hand

The three dimensional complex-valued far-field radiation pattern has been measured in an anechoic chamber with and without user's hand phantom with step size of 10 degree in both elevation and azimuth directions and the measurement swept frequency range from 4 GHz to 6 GHz. Matlab has been used to process the measurement data and to compare measured antenna parameters with simulation results. Comparison is to show the quality of the prototype fabrication and the accuracy of the measurement process; then further performance evaluation carried out with measurement data only.

4. RESULTS

4.1. ECC and MEG

Figure 2 shows the ECC over the operating frequency range calculated from both simulation and measurement data in both cases of without and with user's hand. Both simulation and measurement curves follow the same pattern where the ECC has higher values at the edges of operating frequency range and practically zero at the center frequencies. Moreover, the presence of user hand increases the ECC between ports. However, even in the presence of the user's hand the ports can be considered low correlated since the maximum ECC value in the figure is 0.16 at frequency 6 GHz from the measurement data with user's hand. MEG curves are shown in Figure 3 with and without user's hand effect. It can be noticed that the center frequency range from 4.5 GHz to 5.5 GHz has highest MEG values for the two ports whereas the MEG values decrease outside this range by more than to 2 dB. From Figure 3 in case of no user's hand; the average

simulated MEG on the center frequencies are about -3.99 and -3.47 dB of port 1 and 2 respectively whereas these values are around -3.84 and -4.01 dB of the measurement data. However, the presence of user's hand reduces the MEG as shown in second panel in the same figure, simulated MEG of ports 1 and 2 on the center frequency range reduced to -5.74 dB and -5.96 dB, respectively and -5.46 dB and -5.69 dB from the measurement data. The effect of the user's hand on the MEG of the two ports can be summarized as a reduction by amount more than 1.6 dB.

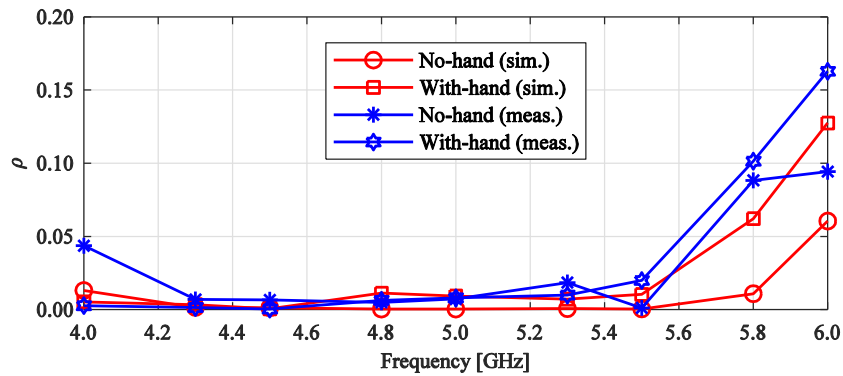


Figure 2. Envelope correlation between ports

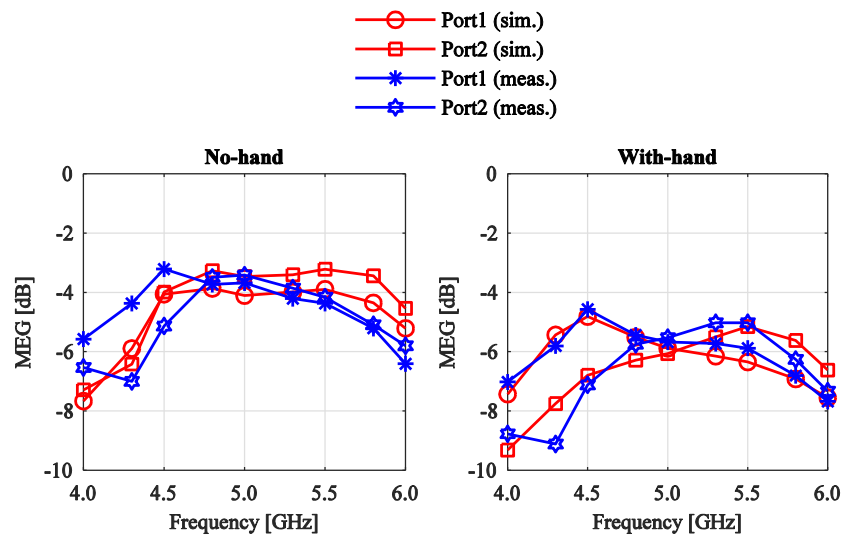


Figure 3. Mean effective gain of ports with and without user's hand

Since simulation and measurement results in Figure1 and Figure 2 show good agreement; measurement data only of the three dimensional complex-valued far-field radiation pattern will be used in the next results for brevity reason.

4.2. Diversity gain

Two combining techniques have been used in the evaluation, namely selection combining (SC) and maximal ratio combining (MRC). Figure 4 shows the CDF curves of both combining techniques of the center frequency 5 GHz. In general, it is shown that there is an improvement in the combined SNR with MRC over SC and the reduction in SNR caused by user's hand in both techniques. The analysis in Figure 4 has been repeated over the whole frequency range and the results are plotted in Figure 5 and in Figure 6 for different outage levels i.e. 0.1, 0.5 and 0.9. In both techniques, highest SNR is achieved on the central frequency range from 4.5 GHz to 5.5 GHz and the SNR drops outside this range by amount up to 2 dB at the edge frequencies. SC achieves SNR on the center frequency range of the following values -8.22 dB, -3.08 dB and 0.81 dB at outage levels of 0.1, 0.5 and 0.9 respectively. The user's hand reduces the SNR to lower levels of

values -9.85 dB, -4.71 dB and -0.80 dB at the same outage levels, respectively. Comparing the numbers above shows the hand effect reduces the SNR gain by amount more than 1.6 dB on all outage levels. The SNR gain provided by MRC can be described briefly as 1.5 dB higher than the results of SC with the same behavior of higher gain on the center frequency range and the same gain reduction by user’s hand presence.

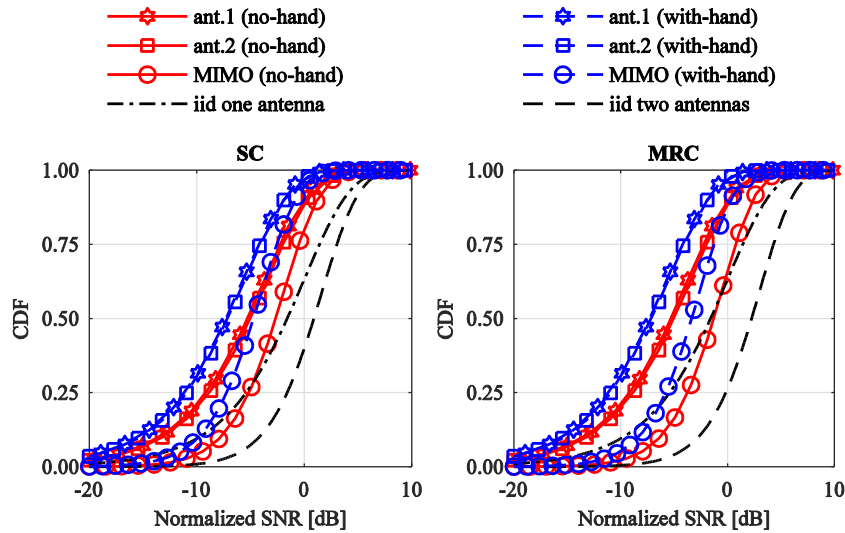


Figure 4. CDF curves of SC and MRC gains at 5 GHz with and without user’s hand

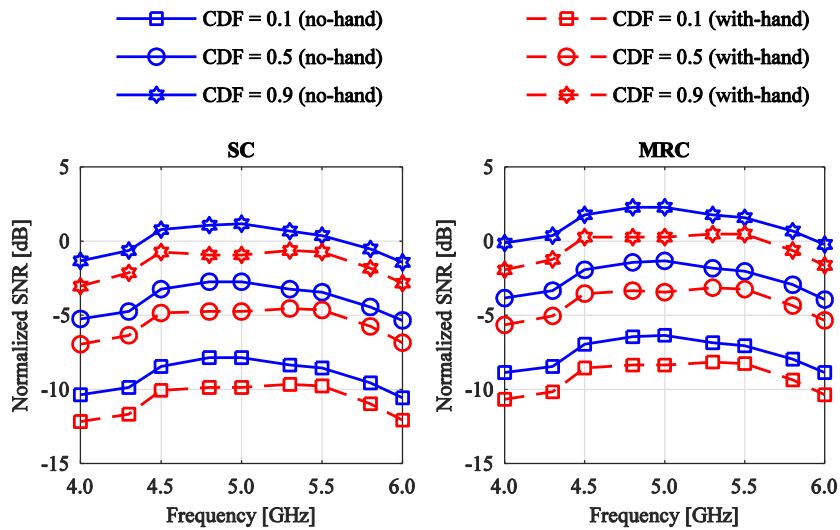


Figure 5. Normalized gains of SC and MRC techniques with and without user’s hand

Figure 6 shows the diversity gain (DG) which is the gain of the MIMO antenna relative to the highest gain among two individual antennas. Lower DG is observed at frequencies 4.3 GHz and 4.5 GHz compared with other operating frequencies in both combining techniques. For the SC, the average DG is around 5.28 dB, 2.25 dB and 0.93 dB at outage levels of 0.1, 0.5 and 0.9, respectively and the MRC provides higher DG above these values by 1.53 dB, 1.41 dB and 1.17 dB at the same outage levels, respectively.

4.3. Multiplexing efficiency

Multiplexing efficiency curves shown in Figure 7. On the center frequency range from 4.5 GHz to 5.5 GHz the multiplexing efficiency is around 81% on average with maximum value of 88% at 5 GHz. This efficiency decreased to less than 50% at the edge frequencies. The user’s hand reduces the multiplexing efficiency to 55% at the center frequencies and 32% at the edges of the operating bandwidth. In general, the

effect of user’s hand presence on the multiplexing efficiency can be summarized as a drop by around 27% over the operating band.

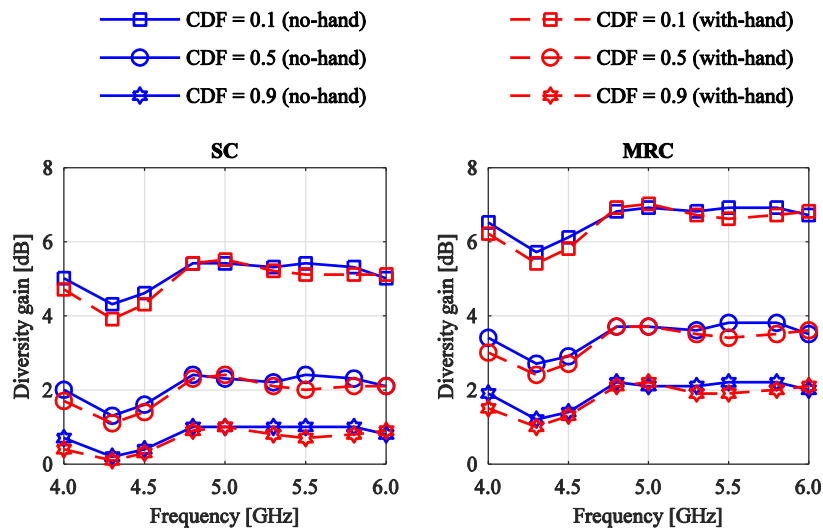


Figure 6. Diversity gain of SC and MRC techniques with and without user’s hand

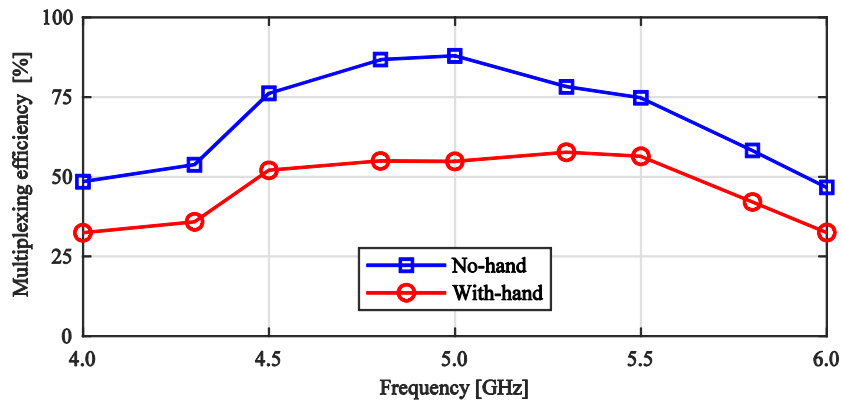


Figure 7. Multiplexing efficiency with and without user’s hand

4.5. Water-filling capacity

Last result is the link capacity of each transmission eigenmode based on water-filling algorithm. Capacity curves of individual eigenmodes and total capacity are shown Figure 8. Three frequencies have been selected namely the center frequency of 5GHz and the two edge frequencies of 4 and 6 GHz. Highest total capacity is achieved at the center frequency i.e. 5 GHz which is the same result concluded before from capacity multiplexing analysis in Figure 7. At high SNR i.e. 30 dB, this capacity is higher than the total capacity at edge frequencies of 4 and 6 GHz by around 1.72 bit/s/Hz and 1.45 bit/s/Hz for with and without user’s hand, respectively. Moreover, the second eigenmode still has big contribution in the total capacity in the presence of the user’s hand over all frequencies. The percentage of the capacity carried by the second eigenmode is around 39% from the total capacity of the link. This indicates that the system supports spatial multiplexing data transmission efficiently and the presence of the user’s hand does not have an effect on this property despite the reduction in the total capacity.

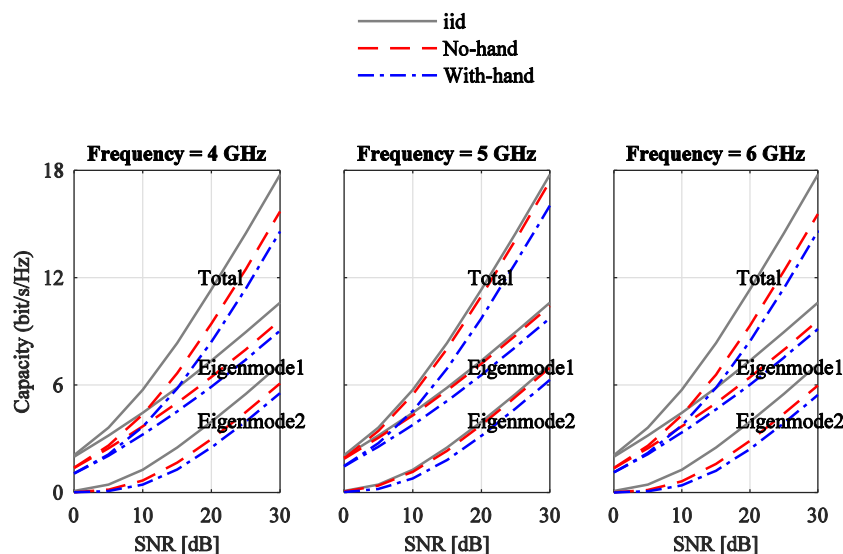


Figure 8. Water-filling capacity

5. CONCLUSION

The performance of 2-port MIMO antenna design has been evaluated in the presence of user's hand and compared with the performance without user's hand in a uniform environment. Results show good agreement between simulation and measurement. The effect of user's hand is small on the ECC between ports and on the spatial multiplexing. However, the user's hand reduced the diversity combining gain by around 1.6 dB and the multiplexing efficiency by 27%. Future work will focus on performance evaluation of different user's hand grips as well as the effect of different environments where the incident wave assumed to come from certain directions.

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