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USER EFFECT ON ANTENNA CLUSTER BASED MIMO ANTENNA

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Abstract

This paper studies the benefits of the antenna cluster technique in exciting the orthogonal modes of a metal rim for MIMO operation in the low-band frequencies. The user effect with antenna clusters is studied with measurements of antenna prototype held by a hand phantom. On average, better than 20% total efficiency is achieved over the low-band frequencies and almost 30% average efficiency over the higher frequencies which suggests that the antenna cluster technique can be used to design user effective mobile device antennas.

1 Introduction

Modern smartphones challenge antenna designers as new requirements are constantly introduced, but the basic laws of physics limiting the operation have not changed. To meet the demands for increasing data rates from the antenna point of view, multiple-input multiple-output (MIMO) techniques and new frequency ranges, such as the 3.5 GHz band, are required. Due to the fact that the appearance of the device is one of the most important features for the users, devices with an unbroken metal rim would be desirable but it makes the antenna design more difficult [1]. However, meeting these requirements is still not enough. User effect is well known challenge for mobile devices. Although required performance could be achieved when the antenna is in free space, the user's hand holding the device degrades the performance significantly. In addition, the antenna systems usually cannot adapt their operation to different operation environments.

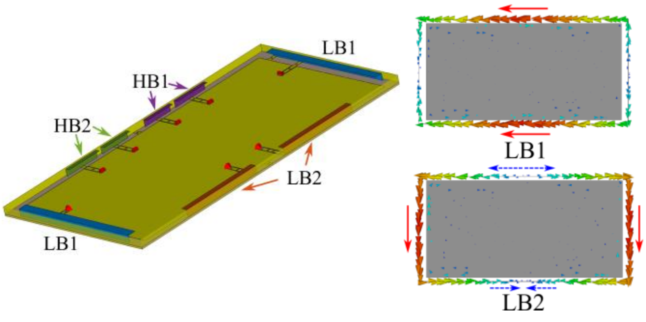
Designing low-band MIMO antennas requires effective excitation of two different modes. In the low-band frequencies, both ground plane modes and metal rim modes have been used [2]. The challenge is to excite these modes efficiently to cover the required bands. A new type of MIMO antenna system for a mobile device with an unbroken metal rim has been proposed in [3]. The antenna design is based on the antenna cluster technique [4], [5] which allows collaborative use of multiple antenna elements and more efficient excitation of the metal rim modes, especially in the low-band frequencies.

In this paper, we study how the antenna cluster technique improves the excitation of the wanted modes of the metal rim. We study the measured radiation patterns of the antenna prototype and the simulated characteristic mode radiation patterns. The results show that the antenna cluster technique and distributed elements provide benefits in the excitation of the modes of the metal rim.

The effect of user's hand on the performance of antenna clusters is also studied with measurements of the proposed antenna system. In the previous publications with antenna cluster based designs, e.g., [3-5], the feeding weights have been optimized for the free-space use only and user effect has not been considered. In this work, we utilize the possibility to re-optimize the feeding weights of the antenna clusters to adapt them to different operation environments. Thus, improved performance in the realistic use case can be achieved. The results show that the proposed design has good performance in the presence of the user and that in certain cases, the cluster technique can be used to compensate for the losses caused by the hand holding the device.

2. Antenna Structure

The antenna structure used in this study is shown in Fig 1(a). The structure has a 140×69 mm^2 ground plane and 150×75×4 mm^3 unbroken metal rim. The characteristic modes of the metal rim are excited with non-resonant inverted-L shaped coupling elements, which are supported with matching



(a) *(b)*

Fig. 1 (a) The proposed antenna structure and (b) characteristic surface current distributions of the first two modes of an unbroken metal rim.

Table 1 Operation frequencies of the antenna clusters

Cluster	Operation frequency (GHz)	MIMO order
LB 1	0.70-0.96	0.70-0.824: 1
LB 2	0.824-0.96	0.824-0.96: 2
HB 1	1.56-4.0	2
HB 2	1.56-4.0	

circuits. Each antenna cluster is formed from two elements that are marked with the same colour in Fig 1(a). Fig. 1(b) shows the characteristic currents for the two orthogonal modes in the low-band frequencies which are excited with clusters LB1 and LB2. The frequency bands at which the clusters are designed to operate and the number of MIMO antennas in each band are listed in Table 1. More detailed description of the antenna can be found in [3].

3 Efficient Mode Excitation

Characteristic mode analysis (CMA) is generally used as a design tool to determine optimal placement of excitation elements in mobile terminals for good MIMO operation [6]. Based on the CMA results, orthogonal radiation modes with low correlation can be excited separately. In the case of an unbroken metal rim and a rectangular ground plane, as shown in Fig. 1, there are two modes in the 700-960 MHz low band. The first mode has a surface current distribution with maxima on the long edges and minima on the short edge and the second one has maxima on the short edges and minima on the long edges.

To effectively excite both of these modes with good efficiency and low correlation across the wanted frequency bands is a difficult task with traditionally used single feed exciting elements. By using the antenna cluster technique, we can more efficiently excite the wanted modes. In addition to only looking at the efficiencies, as was done in [3], we can also compare the measured radiation patterns and the ideal characteristic patterns calculated with CMA. This way we can study how well the modes are excited and gain more insight about the benefits of the antenna cluster technique.

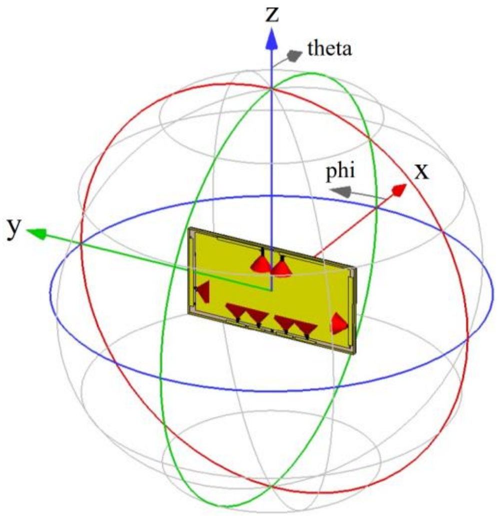


Fig. 2 Coordinate system.

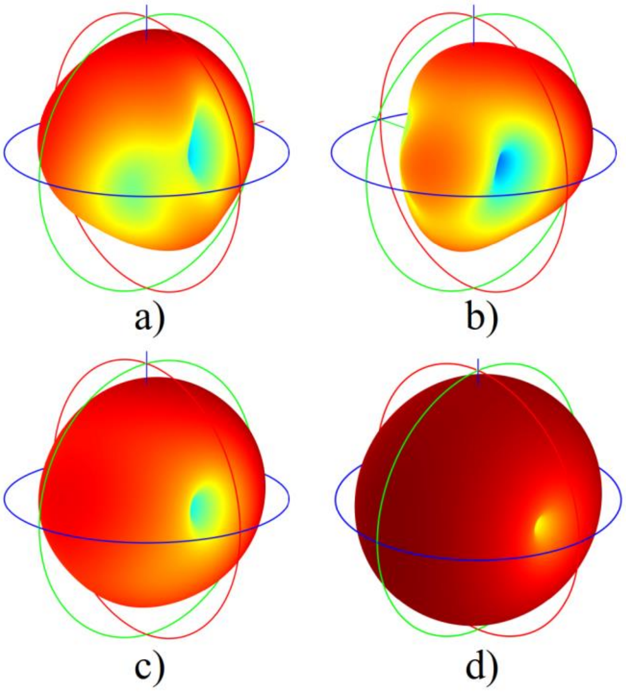


Fig. 3 Measured free-space radiation patterns of (a) element 1 of LB1, (b) element 2 of LB1, and (c) LB1 at 830 MHz. (d) Simulated characteristic mode 1 pattern at the resonant frequency.

Fig. 2 shows the coordinate system used in this work relative to the antenna model. Fig. 3(a) and Fig. 3(b) show the measured radiation patterns of the individual elements of LB1. Fig. 3(c) shows the total pattern of the cluster LB1 at 830 MHz, which is very similar to the simulated pattern of the first characteristic mode at the resonant frequency shown in Fig. 3(d). The results show that by combining the operation of the two elements, the dipole-type radiation mode is almost perfectly excited compared to the more distorted single element cases. Fig. 4 shows the same results for the second cluster exciting mode 2 using elements of LB2. The results show that in this case, the individual element patterns and the cluster pattern are almost identical. Because both elements are placed on the same edge of the device, the radiation pattern is a little bit tilted from the xy-plane compared to the pattern of the second characteristic mode. However, the results show that the mode orthogonal with the first mode is excited also well.

4 User Effect

The cluster technique is based on changing the feeding weights of multiple antenna elements to tune the antenna to operate at maximum efficiency over the operational frequency bands. In real products, multi-channel transceiver ICs could be used to realize this but in this work, we measure each port separately

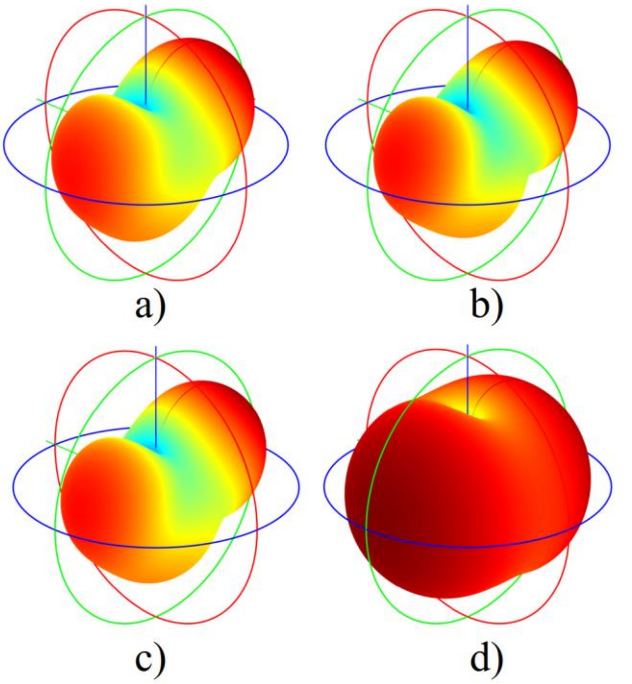


Fig. 4 Measured free-space radiation patterns of (a) element 1 of LB2, (b) element 2 of LB2, and (c) LB2 at 830 MHz. (d) Simulated characteristic mode 2 pattern at the resonant frequency.

and combine the results computationally. In addition to tuning the antennas' operation frequency, we can also use the same technique to modify the operation for different environments. In this work, we study the effect of re-calculating the weights for the case when the device is held by the user.

The hand effect is studied with measurements of the antenna prototype with a hand phantom shown in Fig. 5. First, the far-field patterns of all feed ports are measured while other ports are terminated with 50Ω loads. These patterns are then used to calculate the optimal feeding weights for the antenna clusters.

Fig. 5 Antenna prototype and the hand phantom.

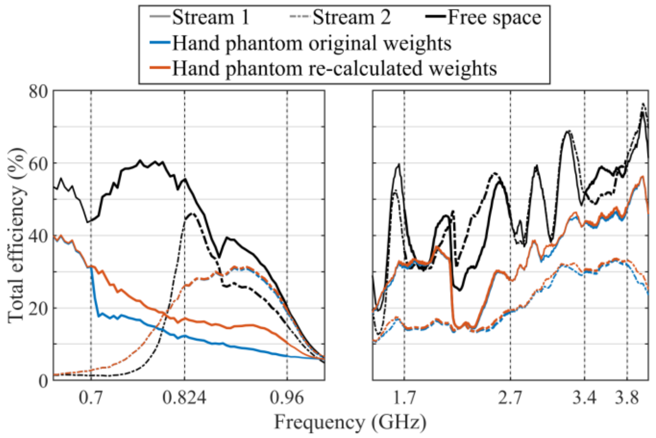


Fig. 6 Measured total efficiencies for free space and with the hand phantom with original and re-calculated feeding weights.

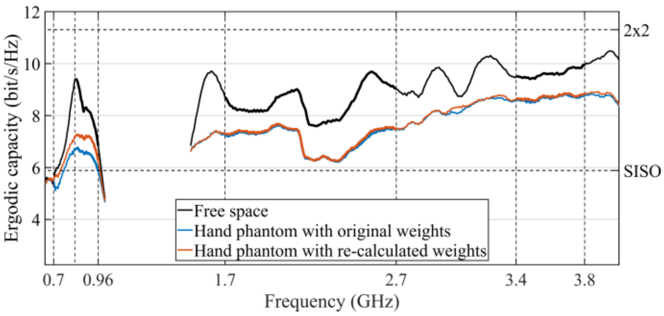
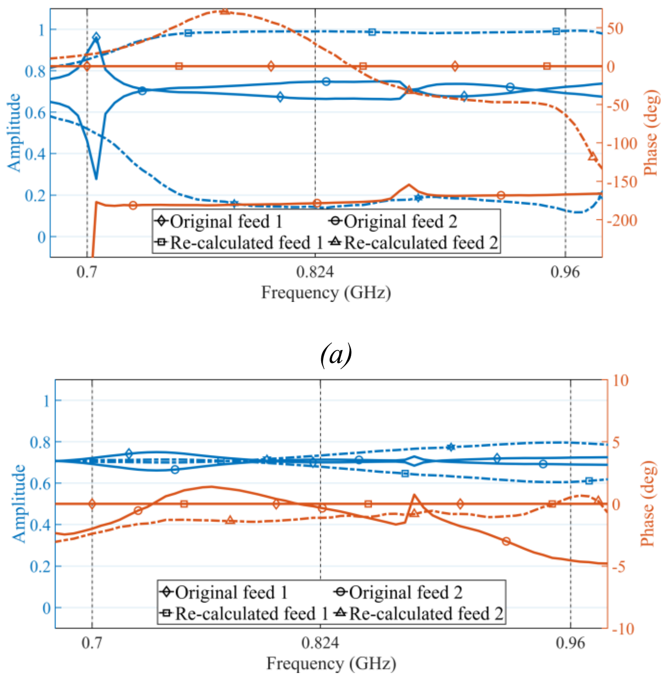


Fig. 7 MIMO capacities calculated from the measured antenna properties. Also ideal SISO and 2×2 MIMO capacities are shown.

Finally, the total efficiency and the ergodic capacity for the clusters are evaluated using the calculated weights. In the capacity calculation, Rayleigh fading channel with 10^4 channel realizations and 20 dB SNR are used.

Fig. 6 shows the measured total efficiencies in free space, with the hand phantom and the original free-space feeding weights, and with the re-calculated weights for the hand case. Corresponding MIMO capacities are shown in Fig. 7. The results show that by re-optimizing the feeding weights, the performance degradation caused by the hand can be compensated in the low-band frequencies. It should be noted that the user effect was originally not taken into account in the antenna design in [3] and even larger benefits could be achieved with improved design.

From the low-band results, it can be seen that data stream 1 (LB1) is more affected by the user than data stream 2 (LB2). On the other hand, it can also benefit more from the re-calculated weights than data stream 2. This is mainly caused by the difference in placement of the elements and the surface current distributions they excite. Because the current distribution of cluster LB1 has maxima along the long edges, the hand causes higher losses than for the currents of cluster LB2 which have minima along the long edges, see Fig. 1(b). Also, the second element of LB1 is closer to the palm than the first one and is therefore more affected. The feeding weights for the low-band antennas in Fig. 8 show that in free space, the power is divided equally between the two elements. With the



(a)

(b)

Fig. 8 Feeding weights for (a) data stream 1 and (b) data stream 2 in the low band. Note different scales for the phases.

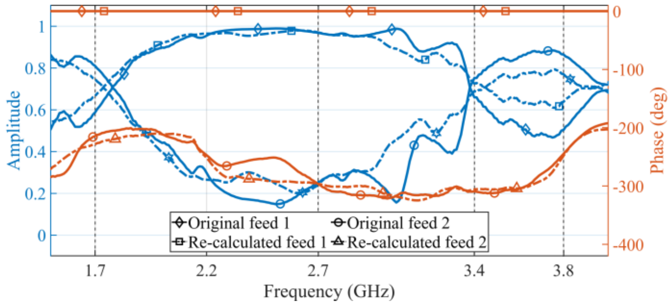


Fig. 9 Feeding weights for the high band antennas.

hand, however, the power balance can be adjusted leading to higher efficiency. With the second stream, both elements are affected similarly and therefore the feeding weights do not significantly change. On average, better than 23% total efficiency is achieved with the low band antennas.

The high-band elements are used as two clusters: HB1 and HB2. The results show that the second cluster is more affected by the hand than the first cluster because the fingers are covering it more. Because both elements in the clusters are affected in a similar manner due to the placement of the hand, re-optimizing the feeding weights cannot provide major improvement in this case as can also be seen from the almost identical weights in Fig. 9. However, both clusters work relatively well with the user's hand. On average, almost 30% total efficiency is achieved with the high band antennas.

The previously published antenna designs with an unbroken metal rim have studied the user effect mostly with single antenna case in [7]-[10] and with low-band MIMO only in [11]. In [7]-[10], average efficiencies in the range of 15-30% for the 824-960 MHz low band and 25-30% for the 1.7-2.7 GHz middle-high band have been achieved. In [11], average efficiencies of 21% and 9% for MIMO operation in the 850-980 MHz band have been achieved. The results achieved with the proposed antenna cluster design show several benefits over these. First, the 700 MHz band can be covered with the first low-band stream and the 3.5 GHz band can be covered with 2 element MIMO. Second, the achieved capacity results in Fig. 7 show that better than the ideal single-input single-output (SISO) capacity is achieved both in the 824-960 MHz low band and in the whole 1.5-4 GHz high band; a result that has not been presented in previous publications. These results show that by using distributed elements and the antenna cluster technique, good performance level can be retained even when the user is holding the device. Depending on the way the elements are distributed along the rim, and the placement of these elements relative to the hand, the feeding weights can be re-optimized to adapt to the changing operation environment and to compensate for the user effect.

5 Conclusion

This paper studied the antenna cluster technique in mobile MIMO antenna applications. The benefits of the distributed antenna elements used collaboratively as clusters in exciting the modes of the metal rim are studied. The obtained results show that the two orthogonal low-band modes can be excited more purely with multi-feed clusters compared to traditional single feed antennas. Thus, designing better MIMO antennas is possible. Secondly, the user effect with antenna clusters is studied and promising results are obtained. Better than the ideal SISO capacity throughout the designed frequency bands can be achieved with the user's hand holding the device. Also, the possibility of using the antenna cluster technique to compensate for the user effect is demonstrated with the low-band antennas.

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