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Adjusting Radiation Pattern of Small Antennas

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***Abstract*—The antenna clusters have been used to control the impedance properties of the antenna, but they have potential also in radiation pattern reconfigurability. We demonstrate the benefits of multi-feed antennas using a mobile antenna as an example.**

***Index Terms*—antenna, multi-feed, radiation pattern**

I. Introduction

Multi-feed antennas are used for many purposes, such as for beam-steering, impedance matching and power combining on an antenna. The most common multi-feed antenna is the array, where several elements are phased to direct the radiated wave to a certain direction. In antenna arrays, low coupling between elements is preferred to avoid (active) impedance changes due to beam steering.

We have studied the use of multiple feeds in a new type of concept. Antenna clusters combine together many elements, which are fed in a collaborative manner. The operation of the antenna is modified through differently weighted input signals. Multiple weighted feeds can be used to maximize impedance matching [1] and we have also applied the approach to MIMO antennas [2], where the coupling to neighboring antenna clusters has to be considered to determine the optimal feeds. An essential difference to antenna arrays is that the elements need to be coupled to each other, and they may not be so much spatially distributed.

So far antenna clusters have been used exclusively for controlling the impedance properties of the antenna, but multiple weighted feeds also affect the radiation pattern. We use here a mobile antenna as an example to demonstrate how the excitation of a certain characteristic mode can be improved with this technique. In addition, we illustrate the benefit of radiation pattern manipulation when the device is in user's hand.

II. Use of multiple feeds

Weighted antenna feeds can be utilized in multiple ways as illustrated in Fig. 1. In a traditional antenna array, all elements are identical and uniformly spaced, and are progressively phased depending on the desired beam steering direction. Uniform excitation amplitudes are commonly used. The antenna cluster design has more flexibility when both amplitude and phase can be tuned and also shape of the elements and their positions are design parameters.

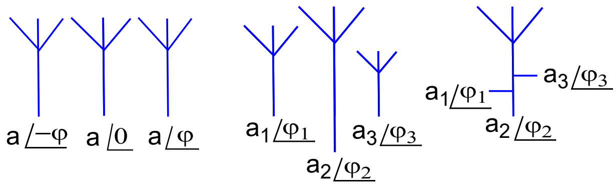


Fig. 1: Different ways to utilize weighted feeds, from the left: 1) antenna array, 2) antenna cluster with separate elements, 3) antenna cluster consisting of one multi-feed element

One option is to use several different antenna elements [1], [2] to form an antenna cluster. Moderate coupling is required to benefit from weighted feeding [3]. The feeds can have even a galvanic connection, i.e. they are strongly connected to the same antenna element [4]. If matching level is better, less coupling is required and the antenna cluster can also be distributed [5]. Thus, the antenna clusters operating at other frequencies can be placed to interlocked positions to the device.

A. Determining the feeding signals

The feeding coefficients for the antenna cluster elements can be calculated either from scattering parameters or from far-field pattern. If the goal is to optimize the radiation properties, we have to use far-field data to separate radiated and dissipated powers. The efficiency can be formulated as a Rayleigh quotient

$$\eta_{\text{tot}} = \frac{\mathbf{a^H D a}}{\mathbf{a^H a}} \tag{1}$$

where the input signals fed to the ports are in vector $\mathbf{a}$ and radiation matrix $\mathbf{D}$ consist of terms

$$D_{i,j} = \frac{1}{4\pi} \iint_{4\pi} F_i \cdot F_j^* \mathrm{d}\Omega \tag{2}$$

and F_i is the far-field pattern of the ith port [2].

The value of Rayleigh quotient is always between the smallest and largest eigenvalue of $\mathbf{D}$ and the solution $\mathbf{a}$ is obtained directly as an eigenvector corresponding to the desired eigenvalue. Furthermore, the radiation could be integrated to a certain sector only to steer the radiation to wanted direction.

Note that the solution is obtained directly without iteration, although such algorithms are presented too [6]. For a lossless antenna in lossless environment, the same result can be

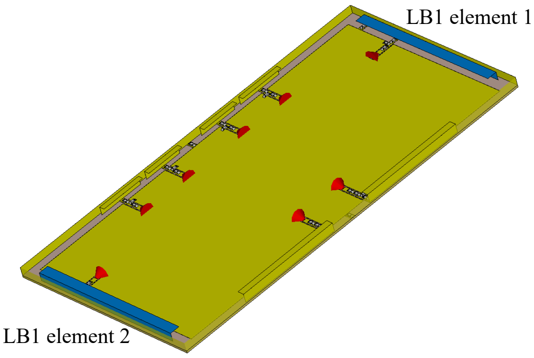


Fig. 2: Mobile device with a low-band antenna consisting of two separate elements in the short edges of the rim. The other antennas of the device are not discussed in this paper.

calculated directly from the scattering parameters of the antenna [1].

III. Mobile device examples

Manipulation of radiation pattern using antenna cluster technique is demonstrated with two examples. Fig. 2 shows the antenna used in this paper. The low-band antenna is designed to a metal-rimmed mobile handset and it consist of two elements placed to the short edges of the phone. The operational principle and details of the design are described in [5].

All the results in this paper are based on measurements. First, the far-field patterns of individual feeds are measured while all the other ports are terminated with $50\,\Omega$ terminations. Based on this data, the feeding weights are calculated and the overall performance is studied combining results together computationally.

A. Pure excitation of characteristic modes

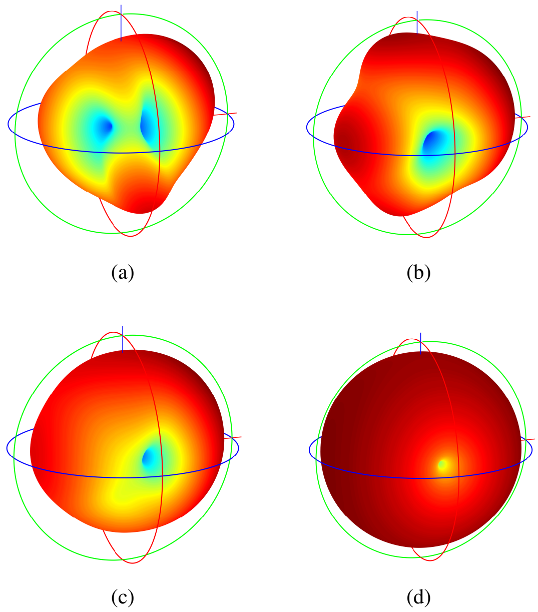
First, we show how the excitation of a characteristic mode can be improved using multiple distributed feeds. This is essential with small antennas, where we typically have only one or few modes which can be utilized.

In an ideal case, we could perfectly excite the lowest characteristic mode with almost omnidirectional radiation pattern. However, by using only one feed point, the radiation pattern becomes distorted as shown in Fig. 3 (a) and (b). With antenna cluster technique, we can combine the operation of two elements and the obtained radiation pattern is clearly closer to the ideal one as shown in Fig. 3 (c). Thus, the potential of small antenna volume can be utilized more effectively.

B. Compensation of hand effect

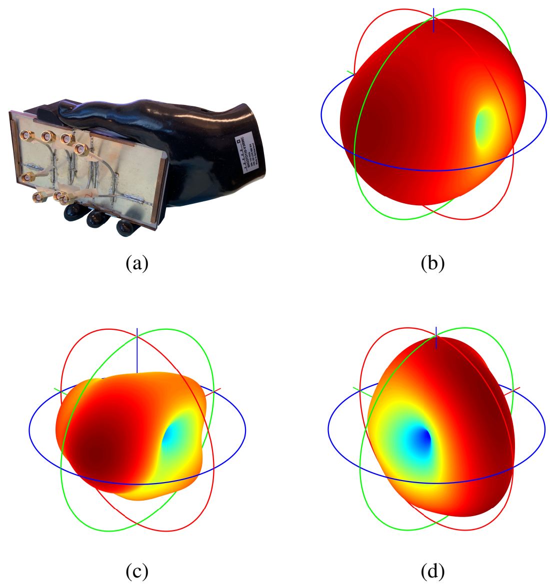
The second example illustrates that antenna cluster technique can be used to adjust the raditation pattern, when the user's hand is holding the device. Hand results are measured with a Speag SHO3T0110-V3RWC hand phantom.

We study the radiation pattern when the device is kept in a hand as shown in Fig. 4 (a). In the free space, the radiation



(a) (b) (c) (d)

Fig. 3: Measured free-space radiation patterns of (a) element 1 of LB1, (b) element 2 of LB1, and (c) LB1 at 900 MHz. (d) Characteristic pattern of mode 1 at resonance frequency.



(a) (b) (c) (d)

Fig. 4: (a) Mobile device in hand and radiation pattern of mobile device in three cases: (b) free space, (c) original free space weights with hand, and (d) re-calculated weights with hand at 720 MHz.

pattern in Fig. 4 (b) is symmetrical. When the device is in user's hand, the radiation is degenerated to many directions as seen from Fig. 4 (c). By re-calculating the feeding signals $\mathbf{a}$, we can affect the radiation pattern and compensate the hand effect. More power can be fed to the element, which is less affected due to the hand. Fig. 4 (d) shows that the radiation pattern is clearly re-shaped and wider space is covered than with original feeds. In addition, efficiency η_{tot} improves from 18% to 28%.

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