Average Element Pattern for a Three Dimensional Array

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***Abstract*—With 5G communication technology on the horizon, the number of wireless elements that can be connected to a single base station is going to be increased. This increase in the number of wireless elements means that there is increased density in elements which could allow antenna arrays to be created. These wireless elements will be randomly scattered in three dimensions and there is currently not a method to optimize this scenario into a coherent array system. One advance needed to allow for the optimization for a three dimensional array is determining ways to understand and deal with the effects of the mutual coupling between elements in three dimensions. This paper discusses the method needed to find an average active element pattern by following two basic steps.**

I. Introduction

In the next 10 years the technology in communication systems is due for an upgrade that will greatly increase the number of available wireless elements. 5G technology is expected to increase the number of users and sensors that can be controlled simultaneously by a single base station to the hundreds and thousands [1]. With this increase in wireless elements, a system that can properly optimize each element to coherently propagate with the other group elements, is needed. Thinned array optimization techniques can be used to do this optimization.

Thinned array techniques are currently used as a way of controlling the radiation pattern of an antenna array without using complicated internal hardware. Modern thinned array methods focus on optimizing full arrays to achieve the desired radiation pattern [2]–[5]. These methods do no mention the use of optimization methods as a possibility for elements that are already scattered randomly and then optimizing, however that is the origins of thinned array techniques. In the early 1960's thinned array techniques were investigated as ways of optimizing randomly scattered elements [6]–[8]. With these origins in mind, modern methods should be able to be applied to a three dimensional randomly scattered element scenario. One of the major concerns with this approach, as with any antenna array technique, is taking into account the mutual coupling effects.

Antenna arrays need to take into account the mutual coupling effects so that the resulting simulated far field pattern is comparable to reality. The main approach to account for mutual coupling is to find an active element pattern and then use that for each element in the array pattern calculations, instead of the free space element pattern [9]. The issue with this is that there is no set way of producing an active element pattern for a group of elements that are randomly scattered in three dimensions and with random orientations. The rest of this paper discusses the methodology and assumptions needed for finding an average active element pattern for a three dimensional randomly scattered antenna array.

II. Background

The key concept to array pattern equations is the assumption of periodicity. Periodicity allows for the effects of the individual elements (element factor) to be separated from the effects of the spacing and weighting of each element in the array (array factor). This is the classic setup that is considered when talking about antenna arrays. The issue with this assumption is that there are mutual coupling effects between the elements that cause changes in the current distributions on each element in the array. These current distribution changes cause the element pattern for an single element to change to something known as an active element pattern. Without using the active element pattern as the element factor in the array pattern equation the far field pattern estimation will be incorrect.

There are two ways to work around the mutual coupling effects in two dimensional arrays. One way is to reduce the mutual coupling between elements so that the active element pattern is similar to the single element pattern. The second way is to determine an average active element pattern that can be applied to all elements in the array [9]. Working around the mutual coupling effects in a three dimensional element array scenario requires both of these methods.

Being able to introduce some assumption of periodicity in a three dimensional array scenario requires two steps. First, find a minimum distance between elements in three dimensions that will produce an active element pattern similar to that of a single element pattern. If the active element pattern and the single element pattern are comparable then it can assumed that the mutual coupling effects between elements has been reduced. The second step is to find a pattern that can be applied to all elements, and average element pattern. The average element pattern can be found by finding the main beam pointing angle value at all angles and then reducing by the number of elements left in the array. The average element pattern in this specific scenario works out to be an isometric radiator, with directivity lower than the single element case.

III. Results

Figure 1 shows a contour plot of the far field directivity pattern for a single half wave length dipole. This will be the pattern that the three dimensional array active element pattern will be compared to in the first step in finding the average active element pattern for the three dimensional array scenario.

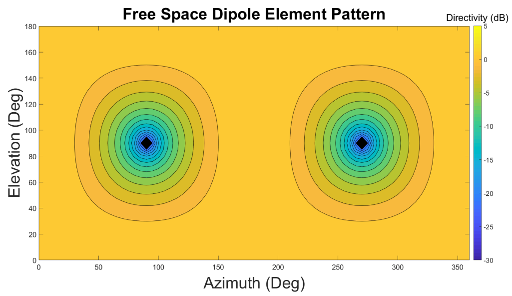

Fig. 1. Contour plot of a single dipole radiation pattern, directivity, in dB.

The active element pattern was simulated by placing a single live element in the center of a 5 x 5 x 5 dipole array. Each element was also given a random orientation, so that the element patterns for each element cannot be assumed to be the same with the respect to bore-sight of the array. An iterative process was then used to find that the minimum spacing between the dipole elements needed to reduce to the differences between the two patterns to an acceptable level. Through the iterative process it was found that the minimum distances needed between elements was about 3 wavelengths. This spacing leads to the active element pattern and the free space pattern to be within ten percent average difference, with most of the difference being in the null areas. Figure 2 shows the contour plot for this active element pattern.

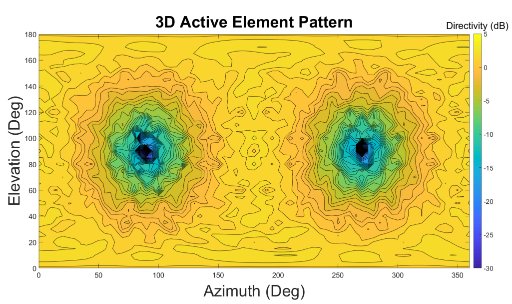

Fig. 2. Contour plot of the active element pattern, directivity, in dB for a dipole with 25 adjacent elements in a three dimensional setup.

Now that the free space or active element pattern can be used for each element, the next step is to find the average element pattern. As mentioned before this is done by finding the main beam maximum at every possible scan angle and then dividing by the number of elements in the array. Figure 3 shows the results of this calculation. The difference between the maximum and minimum pattern directivity is less than .5 dB, with the maximum value being close to .7 dBi. This allows for one to assume an isotropic element with only small variations from reality.

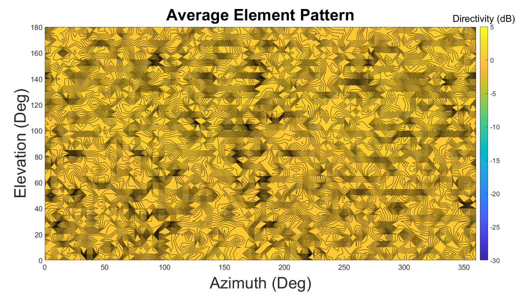

Fig. 3. Contour plot of the average active element pattern, directivity, in dB for a group of elements randomly scattered in three dimensions with random orientations.

IV. Conclusion

This paper describes how an isometric radiation pattern can be assumed for the elements in a three dimensional randomly scattered environment scenario. With two steps, all the complicated electro-magnetic interactions in a three dimensional antenna array can be reduced. This has currently only be done for dipole antenna, patches and horn antennas are being studied. Patches and horns cause more of an issue due to the radiation patterns not being as wide.

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