Uncertainty Dependencies in Computational Array Antenna Design Considerations

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An important aspect of array antenna design is the control of uncertainties in the selected validation parameters. Today, most array design is done using full-wave electromagnetic simulation. A measurement validation of the antenna behavior is mainly conducted at the end of the design process. Furthermore, with higher frequencies, as seen in 5G and beyond, it is expected that the electrical size of the array will grow considerably. This, in turn, impacts the computational methods used for array design and optimization. Approximate computational methods such as macro (or characteristic) basis functions [1], and adaptive cross approximation [2] will find more extensive use. Such computational aspects of array design require a better understanding of how the associated uncertainties affect antenna properties. Investigations in uncertainty of antennas have a long history starting with Ruze [3]. More recent results include [4, 5]. These results focus on geometrical, element position, and/or port-signal uncertainties and their impact on the antenna gain and side-lobe levels.

In this work, we determine an explicit relationship between the local uncertainty of the array's current density and the associated uncertainty of the far field in any radiation direction of the antennas and arrays. Practically, this is accomplished by using a spatial mesh over the support of the current density. The current coefficient associated with a given cell has its uncertainty proportional to the amplitude of the real- and imaginary parts of the mean of the local current density. Thus, each spatial position of the current density over the antenna geometry has a specified uncertainty. The impact of this kind of uncertainty on the antenna arrays' far-field behavior is examined in this work. Simplifying assumptions of independent and identically Gaussian distributed probability densities function (pdf) of the (normalized) current density provides the possibility to explicitly determine the resulting pdf of the magnitude of the far field in any direction. We show that analytical considerations reduce these high-dimensional integrals down to a single finite one-dimensional integral, explicitly giving the probability density. Furthermore, this integral is straightforward to integrate numerically.

The obtained relation is used to numerically determine the pdf of a few antennas and arrays for a wide range of directions of the far field. The pdf associated with a given direction is explicit, and the standard deviation is determined for each polarization. The results work equally well for broadside as for scanned arrays. In the investigated cases, we show that the pdf becomes much more narrow; e.g., the standard deviation of the far-field pdf reduces substantially. This can be interpreted as a measure of the robustness of the far field. One conclusion of this work is a practical method to deal with functional-space uncertainty for antenna currents. Another conclusion is the explicit method to obtain the pdf and the resulting observation of the robustness of the far-field properties of the antenna.

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