A Simple Algorithm For the Control of Reactances in Beam Steering Applications With Parasitic Elements

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SUMMARY

I. INTRODUCTION

Wireless systems frequently employ electronic beam steering capabilities in order to enhance channel capacity and reduce problems associated with multi-path propagation. Most configurations in use rely on digital beam forming (DBF) networks [1]. Indeed, they offer several advantages such as high channel capacity in multiple input, multiple output (MIMO) systems [2]; programmable control of the antenna radiation patterns; direction-of-arrival (DOA) estimation; and adaptive beam steering. The main disadvantage of DBF systems lies in the fact that one transmitter/receiver per antenna element is required.

Therefore, a different approach has been introduced in [3]. It is based on aerial beam forming (ABF) and utilizes a circular array of parasitic radiators. The beam direction is controlled by adjusting the phases of currents in the passive radiators. Tunable capacitors (varactors), as shown in Fig. 1, are the obvious choice for such an application. Compared to DBF, the advantages are, first, that the related circuitry required to locate an incoming signal is simpler and responds much faster; second, since only one of the array elements is active, ABF requires only a single receiver; and third, the dynamic range is larger since the signals are coherently combined before detection and do not suffer from quantization errors in individual elements.

A crucial part in the design of an ABF system is the calculation of a number of sets of capacitances, which are required to focus the beam in the application-specific directions. Here, optimization schemes are usually employed [4] which are known to become bottlenecks in an accurate and speedy design process.

Therefore, this paper presents an *analytical* algorithm to calculate the capacitances added to the parasitic elements. For given directions, the resulting capacitance sets are always realizable, conform to a specifiable accuracy, and maximize the directed E-field. The procedure is straightforward and completely avoids the use of any optimization routines.

II. THEORY

The structure in Fig. 1 is first analyzed for its impedance matrix containing self and mutual impedances. This can be done by moment methods or, assuming relatively thin wires, a modified induced electromagnetic force technique, e.g. [5]. For the far-field analysis, each monopole is treated as a dipole with a center capacitor (parasitic radiators) or a voltage source (center element). The N parasitic elements are located at a radius of ë/4 around the center radiator.

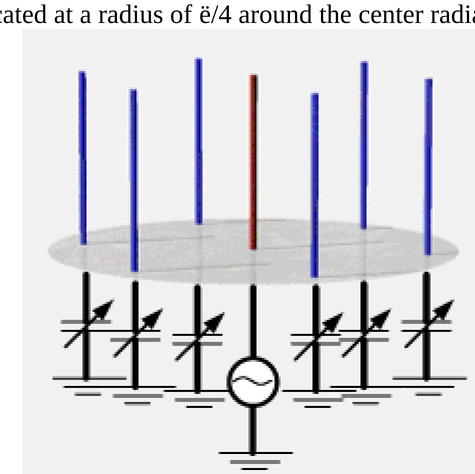

Fig. 1 Basic antenna arrangement.

For a specified beam direction, the required phase excitations ($á_0 \ldots á_n$) of each parasitic element is calculated from the array factor. Since this process neglects mutual coupling, we have to reproduce the array factor *including* the mutual interactions of the elements.

In order to calculate capacitances $C_0 \ldots C_n$, we first represent the complex element currents by their amplitudes I_n and phase factors α_n. Using the current of the center element and the fact that the influence of the capacitances is purely reactive, we can reformulate the real part of the system and obtain a set of N equations

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$$0 = Re\left[\sum_{m=0}^{N} I_m a_m Z_{nm} \Big/ a_n \right], \qquad n = 1 \ldots N \tag{1}$$

where Z_{mn} are the entries of the impedance matrix, and m=0 refers to the center element.

By inserting the current of the center dipole and solving the resulting equation system, the amplitudes of the currents are determined and are used to estimate $C_1 \ldots C_n$. In order to avoid the occurrence of non-realizable capacitances and to maximize the electric field in the specified direction, we can adjust the phase á$_0$ of the center element.

III. Results

For a system of seven elements with radii of 0.001ë, a frequency of 2.484 GHz and a specified beam direction of 300 degrees, Fig. 2 shows a comparison of results obtained with this method and those of NEC2. Excellent agreement is obtained. The maximum E-fields deviate by less than five percent.

By specifying a number of different angles and solving for the respective sets of capacitances, the beam can be rotated.

This is demonstrated at a few example patterns for configurations involving nine and twelve parasitic elements (Fig. 3 and Fig. 4, respectively). Note that the principal beam pattern is not compromised by a higher number of elements and maintains its basic shape through the entire rotation (not shown for lack of space). The number of beam positions resulting in the maximum possible E-field, though, increases. We can demonstrate (also not shown) that for six parasitic elements and a one-degree beam-steering resolution, the maximum field variation in the respective beam directions will not exceed ±0.7 dB.

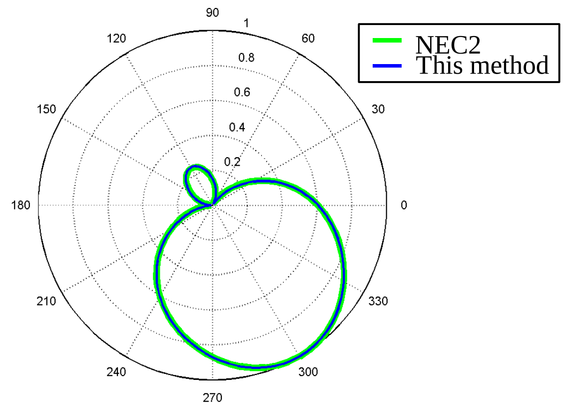

Fig. 2 Principal plane *E*-field pattern for 300° beam position; array with seven elements.

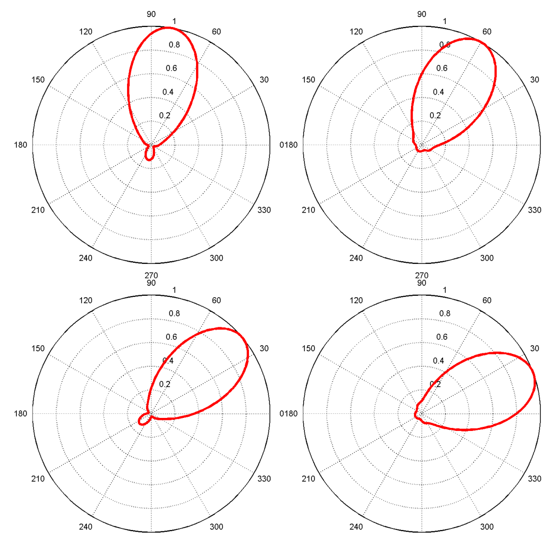

Fig. 3 Array of nine parasitic elements; resolution of 20° for maximum E-field directions.

Fig. 4 Array of twelve parasitic elements; resolution of 15° for maximum E-field directions.

IV. Conclusions

A simple algorithm for the control of reactances in parasitic circular aerial beam forming arrays is presented. The computation of the capacitances is straightforward and eliminates the use of optimization procedures. Different sets of capacitances for rotating-beam applications are easily obtained. The beam shape is maintained during rotation.

References

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