SPECTRAL-DOMAIN MOMENT-METHOD ANALYSIS OF WIDEBAND PATCH ANTENNA ARRAYS WITH CAPACITIVE PROBE FEEDS

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Abstract: This paper deals with a spectral-domain moment-method formulation that was specifically developed to analyse and design wideband patch antenna arrays employing a new variation on the capacitive probe-fed patch antenna element. The capacitive probe-fed patch antenna elements each consist of a rectangular resonant-sized patch on a thick multilayered substrate that is excited by a small probe-fed disk that is positioned right next to it. Entire-domain basis functions are used as far possible in the moment-method formulation in order to handle realistic array sizes on a personal computer. It is also shown that the results that can be obtained agree very well with actual measurements.

INTRODUCTION

One way to realize a wideband probe-fed patch antenna is to position the radiating patch on a thick low-loss substrate and to excite it with a small probe-fed disk that is positioned some distance below the radiating patch [1]. The small disk adds a capacitive component to the input impedance that effectively cancels out the inductive component that is normally associated with a long probe. In a large antenna array, however, such a stacked configuration can increase the cost significantly as the small disk has to be manufactured on a separate layer. A new approach has recently been proposed by the authors where the small disk is placed next to the radiating patch and on the same layer [2]. By adjusting the size of the small disk and the gap between itself and the radiating patch, the input impedance can be matched precisely. The advantage of this configuration is that all the parts of the antenna reside on a single layer and would therefore reduce the manufacturing costs. A little bit of cross-polarisation is added to the antenna element, but as will be shown in this paper, it can be reduced substantially by using proper array geometries.

Due to the complexity of the structure, full-wave analysis techniques are normally required for a rigorous analysis of its radiating characteristics. The moment-method technique has been proved to be the most popular for multilayered patch antennas and can be used with a variety of basis functions. Most commercial codes employ subdomain basis functions in order to cater for arbitrary geometries, but the computational cost, especially in terms of computer memory, increases rapidly when analysing full-sized arrays. Another option is to use entire-domain basis functions as far as possible, albeit somewhat limited to a specific geometry. The advantage of entire-domain basis functions is that relatively large arrays can be analysed without relying on extreme computational resources. The spectral-domain form of the moment method is well suited to entire-domain basis functions and multilayered substrates, and as such, have been used to develop a formulation that can analyse finite arrays, consisting of the new capacitive probe-fed patch, quite effectively. The following two sections will describe the general formulation and also show some results for a typical application.

THEORETICAL FORMULATION

As shown in Fig. 1, the general antenna geometry consists of a grounded multilayered substrate with several rectangular radiating patches as well as some small probe-fed disks on the top layer. It is assumed that the patches, disks, probes and ground plane are all perfectly conducting and that the multilayered substrate is isotropic and possibly lossy. For arrays, a feed network will usually be situated below the ground plane.

The analysis is based on a Green’s function/moment-method approach where the electric field integral equation, representing the boundary condition that the total tangential electric field must vanish on the perfectly conducting parts of the structure, is discretised by the Galerkin method and the unknown coefficients are evaluated by solving the resulting matrix equation. Other parameters, such as the input impedance and radiation patterns of the antenna, can then also be calculated.
The unknown current density on the patches, disks and probe is approximated by a set of vector basis functions with unknown coefficients. The basis functions on the rectangular patches is taken as a set of entire-domain sinusoidal functions that originate from a cavity model analysis [3]. These functions represent the modes that reside on the rectangular patch. The basis functions on the probes are taken to be overlapping piecewise sinusoids, also taking into account the finite radius of the probe. The feed region is modelled as a delta-gap voltage generator between the base of each probe and the ground plane. The current density on the each small disk as well as its connection to the associated probe is modelled by a single attachment mode. The probe part of the attachment mode is modelled by one half of a piecewise sinusoid right below the probe-to-disk junction, while the disk part of the attachment mode is represented by a radial current density, spreading from the centre of the disk to its edge (almost similar to that in [3]). Such a single attachment mode has been found to model the current density on each disk sufficiently well and also aids in the efficiency of the formulation.

Many spectral-domain implementations of the moment method use regular grids to increase computational efficiency and to use asymptotic extraction techniques when performing numerical integration for interactions involving basis functions that are widely separated [3]. In this formulation, a variation on the method as reported [4] has been used to speed up the integration for such interactions and has the advantage that the basis functions can be arbitrarily positioned and orientated. A preprocessor has also been implemented to find all identical basis function interactions so that they need not be calculated more than once.

PRACTICAL APPLICATION
The antenna geometry as shown in Fig. 1 is a +45°/−45° polarised array for the 1.8 GHz frequency band and can typically be used in a cellular base station environment. The antenna elements are arranged in such a way that the top four patches radiate the +45° polarisation, while the bottom four patches radiate the −45° polarisation. The probe-fed disks are grouped in pairs where two adjacent disks are fed 180° out of phase. This is done to suppress the overall cross-polarisation of the array.

This antenna has been analysed with nine entire-domain basis functions per polarisation on each of the square patches and four basis functions (excluding the attachment mode) on each probe, requiring only 0.25 MB of computer memory. The calculated antenna gain, return loss, coupling between the ports and radiation patterns are compared to measurements in Figs. 2 through 6. From these it can be seen that the agreement is very good. The measured gain is slightly lower than the calculated gain due to the losses in the feed network that were not modelled.

CONCLUSIONS
It has been shown that the spectral-domain moment-method, employing entire-domain basis functions to model wideband antenna arrays consisting of patches with capacitive probe feeds, can be very effective in terms of computational resources when compared to most commercial codes and also provides results that agree well with measurements. Some drawbacks of the formulation include its limitation to specific geometries and some experience that is normally required in choosing the appropriate entire-domain modes on the radiating patches.

REFERENCES
Fig. 1. Antenna geometry.

Fig. 2. Antenna gain.

Fig. 3. Return loss at one of the feed network ports.

Fig. 4. Coupling between the two feed network ports.

Fig. 5. Co-pol and x-pol radiation patterns in the azimuth \((x-z)\) plane of the antenna.

Fig. 6. Co-pol and x-pol radiation patterns in the elevation \((y-z)\) plane of the antenna.