Chapter 1

Introduction

1.1 Array Antennas

A source of electromagnetic radiation may take many different forms. It could be a conducting wire, horn radiator, waveguide slot, or one of many other possibilities. The radiation pattern of a single element is fixed for a given frequency of excitation and consists, in general, of a main beam and a number of smaller sidelobes [1:pp.15-19]. In many applications there is a need for improving the performance above that obtainable with a single radiating element. There are, broadly speaking, two methods available for this purpose. One technique uses a properly shaped reflector or lens fed by a radiating element, and the other employs a number of radiating elements correctly arranged in space and interconnected to form an antenna array. Whether the reflector or array option is to be used depends on a multitude of factors related to the particular application and environment in which the antenna will operate.

Up to the present time reflector antennas have dominated the antenna domain, mainly because antenna arrays are more expensive. But as antenna array elements can be mass produced the element cost will decrease [2]. Another factor limiting the use of antenna arrays is large heavy beam-formers. However, recent advances in optical beam-formers promise compact and light beam-forming networks [3, 4, 5]. Despite these disadvantages there is a number of potential advantages in using arrays. Electronic beam scanning is much faster than mechanical scanning, allowing greater flexibility in multiple target tracking. Digital beam-formers [6] allow reconfigurable arrays (that is, the excitation of the elements can be altered when the need for different radiation characteristics arise), that can adapt to future requirements. Arrays may present a more compact configuration since it can be so fabricated that it conforms to it's host's fuselage.

Array antennas can be divided into three main classes according to the geometry in which the elements are arranged. A number of radiating elements positioned in a straight line forms a linear array. A planar array, as the name indicates, is an array with all its radiating elements arranged to lie on a plane. Conformal arrays can have an arbitrary geometry, with the array elements mounted flush on a host surface [7:p.921].

1.2 The Synthesis Problem

Array antenna development can be divided into three stages: specification, synthesis and realization. These should not be taken as clear-cut divisions, however, as there is a considerable amount of overlap between the last two stages.

Three sets of parameters are accessible for variation in array synthesis with a given kind of element, namely the total number of elements, the spatial distribution of the elements and the relative complex excitation (amplitude as well as phase) of the elements. The synthesis problem involves the determination of these parameters to obtain the desired radiation characteristics. The synthesis problem is in general an ill-conditioned inverse problem as only a relative power level is specified (power synthesis), while the far-field phase is usually not of interest and is in general left unspecified. If some far-field phase distribution is assumed the synthesis problem, (now reduced to field synthesis) is less difficult, but not all of the available degrees of freedom are used. In the power synthesis problem the non-uniqueness of the solution can be used to select the most useful of the family of solutions. Synthesis is usually performed subject to a set of constraints. The latter may limit certain radiation pattern characteristics (eg. sidelobe levels), but may also include constraints on other quantities in an attempt to allow easier practical realisability. This second kind of constraint may include factors such as the sensitivity of the array performance to imperfections, or constraints on the complexity of the feed network. It is in the setting of constraints that engineering judgement must be exercised in the midst of the mathematical techniques.

The final step in the design of an antenna array is the actual establishment of the determined excitations in the form of hardware. The realization of the array includes the selection of the radiating elements to be used, though this would no doubt have been kept in mind during the synthesis stage (eg. the radiation pattern of the array elements may already be needed during synthesis). The realization phase would further involve the determination (theoretically and/or experimentally) of the element radiation characteristics and the coupling between elements, both externally and internally via the feed network. This information is then used to establish the correct excitation determined from the synthesis procedure.

1.3 Goals and Contribution of the Thesis

The objectives for the thesis are:

- A general transformation based synthesis method for contoured footprint patterns for planar arrays (Chaper 3). The synthesis procedure must allow for:

  - Arbitrary contoured footprint patterns.
  - Planar arrays with non rectangular boundaries.
  - Planar arrays with triangular lattices.

- Difference pattern synthesis of planar arrays with rectangular or triangular element lattices (Chaper 4).

- Contributions to general conformal array synthesis using generalised projections (Chaper 5). These contributions are:
  - The formulation of backward operators to enable conformal array synthesis.
  - The use of relaxation to increase the rate of convergence.
  - The proper selection of initial values to avoid local minima.
  - An investigation into the importance of accurate element patterns in the synthesis of conformal arrays.

1.4 Overview of the Thesis

This thesis deals exclusively with array synthesis. The complete electromagnetic evaluation of the array element in the array environment is not considered, existing techniques are used to compute the element patterns.

Essential information on array analysis relevant to this work is presented in Chapter 2. Firstly, definitions of numerous factors used in the literature that would be required to unambiguously specify the performance of antennas, irrespective of the particular type used, are summarised. Secondly, the development of the array synthesis techniques, on which the contents of the present thesis builds, are reviewed. Chapters 3 through 5 contain the principal contributions of the present work to the theory of array synthesis. A more detailed indication of the contents of these chapters is more appropriate after the limitations of existing synthesis techniques have been gauged; this is therefore postponed until the end of the second chapter (Section 2.9). Finally, Chapter 6 completes the thesis by drawing a number of general conclusions.