GENERALISED PERIODIC GREEN'S FUNCTION
ANALYSIS OF MICROSTRIP DIPOLE ARRAYS

BY

Stephen K.N. Yeo

A thesis submitted in fulfilment of the requirement for the degree of
Doctor of Philosophy
in
The University of Adelaide
Department of Electrical and Electronic Engineering
Faculty of Engineering

August, 1996
# Contents

Abstract vi
Statement of Originality viii
Acknowledgements ix
List of Author’s Related Publications x
List of Principal Symbols xi
List of Abbreviations xvi

1 Introduction 1

1.1 Microstrip Phased Arrays 1

1.2 Generalised Periodic Green’s Function - Spectral Window Technique 3

1.3 Outline of Thesis 7

2 Methods for Analysis and Design of Microstrip Arrays 14

2.1 Introduction and Overview 14

2.2 Methods of Analysis for Microstrip Arrays 16

2.2.1 Reduced Analysis Methods 18

2.2.2 Full-wave Analysis Methods 19

2.3 The Generalised Periodic Green’s Function Technique 23

2.3.1 Modelling of Mutual Coupling 23
3 The Generalised Periodic Green's Function: Derivation and Properties

3.1 Introduction and Overview

3.2 The Spatial Periodic Green's Function

3.2.1 Spatial Periodic Green's Function for a Triangular Grid Lattice

3.3 The Spectral Periodic Green's Function

3.3.1 Spectral Periodic Green's Function for a Triangular Grid Lattice

3.4 Properties of the Periodic Green's Function

3.4.1 Integration over the Sources

3.4.2 Singularities and Numerical Convergence

3.4.3 Propagation Floquet Modes and Grating Lobes

3.4.4 Contribution of Floquet Modes to Active Impedance

3.5 Summary

4 Generalised Periodic Green's Function Analysis of Infinite Arrays
4.3 Maximising Computational Efficiency

4.3.1 Integration of the Periodic Green's Function over the Sources 60

4.3.2 Convergence Acceleration of the Spectral Periodic Green's Function for the On-plane Case 65

4.3.3 Exploiting Toeplitz-like Symmetries in the Moment Matrix 74

4.3.4 Look-up Tables for Repeatedly Used Parameters 76

4.4 Modelling of Sources Distributed Perpendicular to the Array Plane 77

4.4.1 Integrating in the Z-Dimension 78

4.4.2 Convergence Acceleration for On-plane Points 80

4.5 Summary 83

5 Infinite Array Analysis of Metal Strip Structures in Various Configurations 85

5.1 Introduction and Overview 85

5.2 Convergence Acceleration for the Near On-plane Case 87

5.2.1 Requirement for Convergence Acceleration 87

5.2.2 Formulation for an Infinite Array of Vertical Monopoles 91

5.3 Modelling of Metal Strip Junctions 97

5.3.1 Survey of Approaches to Junction Modelling 97

5.3.2 A New Junction Model for Metal Strips 100

5.3.3 Convergence Acceleration of the Spectral Periodic Green's Function for Junction Segments 101

5.3.4 Formulation for infinite Arrays of Folded Dipoles 104
5.4 Feedline Modelling

5.4.1 Formulation for Infinite Arrays of Metal Strip Folded Dipoles with Coplanar Strip Feedlines

5.5 Summary

6 Infinite Array Analysis of Microstrip Dipole Antennas

6.1 Introduction and Overview

6.2 Formulation for an Infinite Dielectric Slab Structure

6.2.1 Integral Equation Formulation

6.2.2 Numerical Implementation

6.2.3 Design Examples

6.3 Formulation for a Structure with Semi-infinite Dielectric Sheets

6.3.1 Numerical Implementation

6.3.2 Design Examples

6.4 Formulation for a Structure with Finite Dielectric Substrates

6.4.1 Metal Strip Dipoles with Idealised Feed

6.4.2 Metal Strips Dipoles with Coplanar Strip Feedlines

6.4.3 Metal Strip Folded Dipoles with Coplanar Strip Feedlines

6.5 Summary

7 Generalised Periodic Green’s Function - Spectral Windowing Analysis of Finite Arrays

7.1 Introduction and Overview

7.2 Generalised Periodic Green’s Function for a Finite Array
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2.1 Finite Array Spatial Periodic Green's Function</td>
<td>182</td>
</tr>
<tr>
<td>7.2.2 Finite Arrays Spectral Periodic Green's Function</td>
<td>184</td>
</tr>
<tr>
<td>7.3 Generalised Periodic Green's Function - Spectral Windowing Technique</td>
<td>188</td>
</tr>
<tr>
<td>7.3.1 Modelling of the Ground Plane</td>
<td>188</td>
</tr>
<tr>
<td>7.3.2 Evaluation of the Infinite Array Periodic Green's Function</td>
<td>189</td>
</tr>
<tr>
<td>7.3.3 Evaluation of the Spectral Window Function</td>
<td>189</td>
</tr>
<tr>
<td>7.3.4 Evaluation of the Convolution</td>
<td>192</td>
</tr>
<tr>
<td>7.3.5 Design Examples</td>
<td>194</td>
</tr>
<tr>
<td>7.4 Finite Arrays of Metal Strip Dipoles with Coplanar Strip Feedlines</td>
<td>208</td>
</tr>
<tr>
<td>7.5 Finite Arrays of Metal Strip Dipoles Supported on a Dielectric Substrate</td>
<td>212</td>
</tr>
<tr>
<td>7.6 Summary</td>
<td>218</td>
</tr>
<tr>
<td>8 Conclusions and Recommendations</td>
<td>221</td>
</tr>
<tr>
<td>8.1 Conclusions</td>
<td>221</td>
</tr>
<tr>
<td>8.2 Recommendations for Future Work</td>
<td>228</td>
</tr>
<tr>
<td>A Specifications of Computer Used in this Thesis</td>
<td>230</td>
</tr>
<tr>
<td>B Transformation from the Spatial to the Spectral Form of the Periodic Green's Function</td>
<td>231</td>
</tr>
<tr>
<td>C Convergence Acceleration of the Spectral Form of the Periodic Green's Function</td>
<td>235</td>
</tr>
<tr>
<td>D Simplified Feedline Model</td>
<td>240</td>
</tr>
<tr>
<td>Bibliography</td>
<td>243</td>
</tr>
</tbody>
</table>
Abstract

The development of phased array antennas is an area of considerable current interest, driven by the demand for high performance electronic systems for personal communication systems, mobile satellite communications, wireless local networks and vehicular radar systems. With the increasingly congested frequency usage in the traditional lower frequency bands, attention is becoming focused on high frequency systems which make use of the millimetre and sub-millimetre wavelength parts of the spectrum. Where commercial interest is involved, issues such as low development and production cost assume a key significance with regard to the viability of any technology used to realise the systems described above. This thesis presents techniques that may be used to evaluate the performance of a wide variety of practical microstrip phased arrays in an efficient and insightful manner.

Microstrip phased arrays form a class of antennas suitable for operation at millimetre wavelengths. In order to meet modern system specifications, practical microstrip antennas have become increasingly more complex, comprising metallic radiators and feedlines as well as dielectric substrates and superstrates which may be continuous or discontinuous in the aperture plane. Moreover, for small to medium size arrays, the correct design of elements on the periphery of the array is important, precluding the use of traditional infinite array analyses without appropriate modification. Additional factors influencing the analytical and numerical techniques used in the design of microstrip arrays include the need to compute the scanning performance to a degree of accuracy sufficient to avoid costly experimental optimisation of the element design, and the need for realistic computing requirements in the numerical implementation. The objective of this work is to demonstrate that a generalised periodic Green's function integral-equation approach to practical phased arrays can achieve sufficient flexibility to model a variety of geometries, computational efficiency such that a desktop computer implementation is feasible, and accuracy sufficient for engineering design purposes.
This thesis presents a brief overview of microstrip antenna analysis, and describes the connections between spectral and spatial domain periodic Green's functions in integral equation methods. These ideas are developed into an efficient hybrid formulation which combines the benefits of both methods. The hybrid formulation is applied to a variety of problems from simple metal strip dipoles to more complicated microstrip geometries with different substrate and feed line configurations to demonstrate the performance of the technique. A further development to finite array analysis is described, in which spatial Fourier windowing is used to account for the effect of the array periphery. An improvement in the accuracy of this approximate technique is explored by an iterative technique to obtain a more accurate current window to be used in the convolution process.

The research described provides a unified view of the spatial and spectral periodic Green's functions and their application in a hybrid form to infinite and finite phased array analysis. The implementation of numerical analysis algorithms is shown to be highly efficient and accurate for modern microstrip array design.