DEVELOPMENT AND MODELLING OF NEW WIDEBAND MICROSTRIP PATCH ANTENNAS WITH CAPACITIVE FEED PROBES

by

Gordon Mayhew-Ridgers

Submitted in partial fulfillment of the requirements for the degree

Philosophiae Doctor
(Electronic Engineering)

in the
Faculty of Engineering, Built Environment and Information Technology
UNIVERSITY OF PRETORIA

July 2004

Synopsis

DEVELOPMENT AND MODELLING OF NEW WIDEBAND MICROSTRIP PATCH ANTENNAS WITH CAPACITIVE FEED PROBES

Author:	Gordon Mayhew-Ridgers
Promoter:	Prof. J. W. Odendaal
Co-promoter:	Prof. J. Joubert
Department:	Electrical, Electronic and Computer Engineering
University:	University of Pretoria
Degree:	Ph.D. (Electronic Engineering)

Keywords: Wideband antennas, microstrip patch antennas, antenna arrays, capacitive feed probes, multilayered substrate, full-wave analysis, basis functions, attachment modes, moment method, spectral domain.

The principal contributions of this study include the development of a new capacitive feeding mechanism for wideband probe-fed microstrip patch antennas as well as the implementation of a spectral-domain moment-method formulation for the efficient analysis of large, but finite arrays of these elements. Such antenna configurations are very useful in the wireless communications industry, but extremely difficult to analyse with commercially available software.

Probe-fed microstrip patch antennas have always been a popular candidate for a variety of antenna systems. Due to their many salient features, they are well suited for modern wireless communication systems. However, these systems often require antennas with wideband properties, while an inherent limitation of probe-fed microstrip patch antennas is its narrow impedance bandwidth. This can be overcome by manufacturing the antenna on a thick low-loss substrate, but at the same time it also complicates things by rendering the input impedance of the antenna very inductive. In this thesis, a new capacitive feeding mechanism is introduced that can be used for probe-fed microstrip patch antennas on thick substrates. It consists of a small probe-fed capacitor patch that

is situated next to the resonant patch. The benefits of this configuration include the fact that only one substrate layer is required to support the antenna. It is also very easy to design and optimise.

The use of full-wave methods for an accurate analysis of microstrip antennas, has basically become standard practice. These methods can become very demanding in terms of computational resources, especially when large antenna arrays have to be analysed. As such, this thesis includes a spectral-domain moment-method formulation, which was developed for the analysis of probe-fed microstrip patch antennas or antenna arrays that comprise of the new capacitive feeding mechanism. Here, entire-domain and subdomain basis functions are combined in a unique way so as to minimise the computational requirements, most notably computer memory. It is shown that, for general antenna array configurations, memory savings of more than 2500 times can be achieved when compared with typical commercial software packages where only subdomain basis functions are used. Some of the numerical complexities that are dealt with, include various methods to evaluate the spectral integrals as well as special algorithms to eliminate the recalculation of duplicate interactions. The thesis also contains a quantitative comparison of various attachment modes that are often used in the moment-method modelling of probe-to-patch transitions.

Various numerical and experimental results are included in order to verify the spectral-domain moment-method formulation, to characterise the new feeding mechanism and to illustrate its use for various applications. These results show that, in terms of accuracy, the spectral-domain moment-method formulation compares well with commercial codes, while by comparison, it demands very little computer memory. The characterisation results show that the input impedance of the antenna can be fully controlled by only adjusting the size of the capacitor patch as well as the width of the gap between the capacitor patch and the resonant patch. In terms of applications, it is shown how the new antenna element can effectively be employed in linear arrays with vertical polarisation, horizontal polarisation or dual slant-polarisation. These represent some widely-used configurations for modern base-station antennas.

Samevatting

ONTWIKKELING EN MODELLERING VAN NUWE WYEBAND MIKROSTROOK PLAK-ANTENNES MET KAPASITIEWE VOERPENNE

Outeur:	Gordon Mayhew-Ridgers
Promotor:	Prof. J. W. Odendaal
Medepromotor:	Prof. J. Joubert
Departement:	Elektriese, Elektroniese en Rekenaar-Ingenieurswese
Universiteit:	Universiteit van Pretoria
Graad:	Ph.D. (Elektroniese Ingenieurswese)

Sleutelwoorde: Wyeband antennes, mikrostrook plak-antennes, antenne-samestellings, kapasitiewe voerpenne, multilaag substraat, volgolf analise, basisfunksies, hegmodusse, momente metode, spektrale domein.

Die vernaamste bydraes van hierdie studie is die ontwikkeling van ’n kapasitiewe voermeganisme vir wyeband mikrostrook plak-antennes wat deur middel van voerpenne aangedryf word, asook die implementering van ’n spektrale-domein momente-metode formulering vir die effektiewe analise van groot, maar eindige samestellings van hierdie antenne-elemente. Sulke antenne-konfigurasies is baie bruikbaar in die draadlose kommunikasie-industrie, maar geweldig moeilik om te analiseer met kommersieel-beskikbare sagteware.

Mikrostrook plak-antennes wat deur middel van voerpenne aangedryf word, was nog altyd gewild vir gebruik in ’n verskeidenheid van antenne-stelsels. Hierdie antennes het verskeie eienskappe wat hulle veral voordelig maak vir gebruik in moderne draadlose kommunikasie-stelsels. Hierdie stelsels vereis egter dikwels antennes met wyeband eienskappe, terwyl mikrostrook plak-antennes wat deur middel van voerpenne aangedryf word, die inherente limitasie het dat hulle nouband is in terme van intree-impedansie. Hierdie limitasie kan oorkom word deur die antenne op ’n dik lae-verlies substraat te vervaardig, maar kompliseer die situasie verder deurdat die intree-

impedansie van die antenne baie induktief word. In hierdie proefskrif word ’n nuwe kapasitiewe voermeganisme voorgestel wat geskik is vir mikrostrook plak-antennes op dik substrate en wat deur voerpenne aangedryf word. Die nuwe voermeganisme bestaan uit ’n klein kapasitorstrokie wat langs die resonante strook van die plak-antenne aangebring word. In plaas daarvan dat die resonante strook direk met ’n voerpen aangedryf word, word die kapasitiewe strook met ’n voerpen aangedryf. Sommige voordele van hierdie konfigurasie is dat net een laag substraat benodig word en dat die ontwerp, sowel as optimisering, van antennes met sulke voermeganismes baie maklik is.

Die gebruik van volgolf metodes vir die akkurate analise van mikrostrook antennes het basies standaard praktyk geword. Hierdie metodes kan baie veeleisend word in terme van rekenaar-infrastruktuur, veral wanneer die analise van groot antenne-samestellings benodig word. As gevolg hiervan, sluit hierdie proefskrif ’n spektrale-domein momente-metode formulering in wat spesifiek ontwikkel is vir die analise van antennes en antenne-samestellings wat gebruik maak van die nuwe kapasitiewe voermeganisme. In hierdie formulering word volledige-domein en subdomein basisfunksies op ’n unieke wyse gekombineer sodat die hoeveelheid rekenaar-infrastruktuur wat benodig word vir ’n analise geminimiseer word, veral in terme van rekenaargeheue. Dit word byvoorbeeld gewys dat, wanneer hierdie formulering vergelyk word met kommersiële kodes wat net subdomein basisfunksies gebruik, besparings van meer as 2500 keer in terme van rekenaargeheue bereik kan word wanneer tipiese antenne-samestellings geanaliseer word. Sommige van die numeriese kompleksiteite wat behandel word, is die verskeie metodes wat gebruik word om integrale in die spektrale domein te evalueer, sowel as spesiale algoritmes om die herberekening van duplikaat interaksies te elimineer. Die proefskrif bevat ook ’n kwantitatiewe vergelyking van spesiale basisfunksies, oftewel hegmodusse, wat benodig word in ’n momente-metode formulering om die oorgang tussen die voerpen en die mikrostrook te beskryf.

Die proefskrif bevat verskeie numeriese en eksperimentele resultate om die spektrale-domein momente-metode formulering te verifieer, die nuwe voermeganisme te karakteriseer en te illustreer hoe dit gebruik kan word in verskillende toepassings. In terme van akkuraatheid, vergelyk die spektrale-domein momente-metode formulering goed met kommersiële kodes, terwyl dit ook heelwat minder rekenaargeheue gebruik. Die karakteriserings-resultate wys dat die intree-impedansie van die antenne volledig beheer kan word deur slegs die grootte van die kapasitorstrook, sowel as die wydte van die gaping tussen die kapasitorstrook en die resonante strook, te verander. In terme van toepassings, word dit gewys hoe die nuwe antenne-element in lineêre samestellings met vertikale polarisasie, horisontale polarisasie of dubbele skuins-polarisasie gebruik kan word. Hierdie konfigurasies is verteenwoordigend van tipiese basisstasie-antennes.

Acknowledgements

I would like to start by thanking the Lord, without whom the completion of this work would not have been possible. He has entrusted me with the abilities and provided me with the courage to complete a long journey.

My advisors, Prof. Wimpie Odendaal and Prof. Johan Joubert, deserves a special word of appreciation. They have always been there with support and guidance throughout the duration of my graduate studies. I would like to thank Mr. Lukas Naude of the Compact Antenna Test Range at the University of Pretoria and also Mr. Daan Janse van Rensburg, formerly with the Compact Antenna Test Range, for all their time and assistance with the construction of antenna prototypes and many antenna measurements. A word of thanks goes to Dr. Frans Meyer and Dr. Gronum Smith of EM Software and Systems in Stellenbosch for providing me with a copy of the FEKO electromagnetic simulation software. Prof. Jim Aberle of the Arizona State University in the United States of America and Dr. Massimo Sereno-Garino, formerly with the Politecnico di Torino in Italy, provided me with valuable information and advice regarding various aspects of the spectral-domain moment-method formulation that was implemented. I would like to thank them for their time and patience.

My parents, family and friends definitely deserve a special word of thanks for always being there to support and encourage me. They have always showed a great deal of interest in my studies. Finally, I must express my sincere gratitude to my wife, Francis. She knows more than anyone else about the sacrifices that had to be made. I would like to thank her for her love, encouragement, patience and understanding throughout all of my studies. It is much appreciated.

Preface

The purpose of this preface is to point out some notation that is used throughout this thesis as well as some information that is assumed, but not clearly pointed out elsewhere. Throughout this thesis, numbers in parentheses ( ) refer to equations, whereas numbers in brackets [ ] refer to references. In this thesis, all the fields and currents densities are assumed to be time-harmonic with a $e^{j\omega t}$ time convention that is suppressed throughout the thesis. The variables are therefore complex-valued, with a magnitude and phase as for any phasor analysis. Furthermore, vectors are indicated by boldface symbols (e.g. $\mathbf{E}$), vector components are indicated by italic symbols (e.g. E_x), unit vectors are indicated by italic symbols with circumflexes (e.g. $\hat{x}$), while dyadic functions are indicated by boldface symbols with overbars (e.g. $\bar{\mathbf{G}}$). Spectral functions, vectors and dyads are indicated with a tilde (e.g. $\tilde{f}$, $\tilde{\mathbf{E}}$ and $\tilde{\bar{\mathbf{G}}}$). Although the theoretical formulation, which was implemented for the purposes of this study, can handle multilayered media with magnetic properties, it is assumed that, for all the examples in this thesis, the relative permeability is equal to one (i.e. $\mu_r = 1$) and the magnetic loss tangent is equal to zero (i.e. $\tan\delta_\mu = 0$).

Contents