THE ANALYSIS AND SYNTHESIS OF A NOVEL ULTRA-WIDEBAND MICROWAVE DIFFERENTIAL PHASE SHIFTER

Frederik Viljoen Minnaar

Thesis Submitted
For the Degree of Doctor of Philosophy in Engineering
in the
Faculty of Engineering
UNIVERSITY OF PRETORIA

March 2000

ABSTRACT: THE ANALYSIS AND SYNTHESIS OF A NOVEL ULTRA-WIDEBAND MICROWAVE DIFFERENTIAL PHASE SHIFTER.

(i) **NAME** : Frederik Viljoen Minnaar
(ii) **LEADER** : Prof. J. Joubert
(iii) **DEPARTMENT** : Electrical, Electronic and Computer Engineering.
(iv) **DEGREE** : PhD Eng. Electronic

Realising the shortfalls of conventional microwave differential phase shifters, an in-depth and broad study was launched into this area, focussing on the synthesis of ultra-wideband devices covering up to more than a decade of bandwidth. This study excluded ferrite, MMIC, waveguide and some other technologies which are relatively band-limited.

By noting the unique and very valuable frequency-independent quadrature property of symmetric TEM couplers, a novel class of phase shifter is proposed. Realising that the phase shift characteristics can be related to the coupling characteristics of the coupler, bandwidth and ripple performance is significantly enhanced. Comparison to the classical wideband Tresselt phase shifter is presented and the practical bandwidth-limiting obstacles are shown to be eliminated. The phase shifter is then analysed thoroughly to determine its sensitivity with respect to errors due to manufacturing tolerances. Error and performance parameters are defined and sensitivities calculated. These results clearly demonstrate the practicality of the idea and also pinpoint the areas of the phase shifter that are most sensitive to manufacturing tolerances.

The elements comprising the phase shifter are then separately analysed and practically explored. A unique splitter is developed to ensure phase and amplitude tracking at the coupler inputs. The periodic broadside coupled stripline (BCS) structure is also fully analysed and the structure's resonance nature predicted. The through-hole plated vias in the BCS structure are first analysed by both a full-wave and a finite element analysis to compare the results. An empirical element fit is conducted to provide future designers with very accurate via models. The splitter performance is then mathematically predicted and compared to an experimental example.

A tolerance analysis is also conducted on each element comprising the phase shifter, and compared to the phase shifter sensitivity analysis demands. Restrictions to the theory are discussed and the manufacturing requirements highlighted. A general synthesis procedure is derived to aid future

designs. Computer code was also developed to fully design the tapered coupler from material and electrical specifications.

The study concludes with a design example for a complete differential phase shifter, comparing analysis results with practical measured results and some general conclusions.

Keywords : microwave, differential, phase, shifter, bandwidth, quadrature, periodic, tracking, coupling, ripple.

OPSOMMING: DIE ANALISE EN SINTESE VAN 'N NUWE ULTRA-WYEBAND MIKROGOLF DIFFERENSIELE FASE VERSKUIWER.

(i) **NAAM** : Frederik Viljoen Minnaar

(ii) **LEIER** : Prof. J. Joubert

(iii) **DEPARTEMENT** : Electriese, Elektroniese en Rekenaar Ingenieurswese.

(iv) **GRAAD** : PhD Ing. Elektronies

Met begrip van die tekortkominge van konvensionele mikrogolf differensiële fase verskuiwers, is 'n diep en wye studie in hierdie veld aangepak. Daar is gefokus op ultra-wyeband komponente wat meer as 'n dekade bandwydte dek. Hierdie studie sluit ferriet, MMIC, golfleier en sommige ander tegnologieë, wat relatief band beperk is, uit.

Deur die unieke en baie waardevolle frekwensie onafhanklike kwadratuur eienskap van simmetriese TEM koppelaars toe te pas, word 'n nuwe klas fase verskuiwer voorgestel. Deur te besef dat die fase verskuiwing karakteristieke herlei kan word na die koppelaar se koppeling karakteristieke, word die bandwydte en riffel prestasie aansienlik verbeter. Hierdie word vergelyk met die klasieke Tresselt fase verskuiwer en aangetoon dat die praktiese band beperkende hindernisse ge-elimineer kan word. Die fase verskuiwer word dan deeglik ge-analiseer om sensitiwiteit ten opsigte van vakmanskap toleransie te bepaal. Fout- en prestasie parameters word gedefinieer en sensitiwiteite bereken. Die resultate demonstreer die praktiese implementeerbaarheid van die konsep en dui ook die areas aan waar die fase verskuiwer die meeste sensitief is vir toleransie.

Die verskeie elemente van die fase verskuiwer word apart ge-analiseer en prakties ondersoek. 'n Unieke drywingsverdeler was ontwikkel om fase en amplitude volging by die koppelaar insetpoorte te verseker. Die periodiese oorgekoppelde strooklyn (BCS) struktuur is deeglik ge-analiseer en die struktuur se resonansie karakter voorspel. Die deurgat geplateerde vias in die BCS struktuur is eers ge-analiseer deur beide 'n volgolf- en eindige element analise en die resuktate is vergelyk. 'n Empiriese element passing is gedoen om toekomstige ontwerpers met akkurate via modelle te voorsien. Die drywingsverdeler karakteristieke is dan wiskundig voorspel en vergelyk met 'n praktiese voorbeeld.

'n Toleransie analise is ook gedoen op elke element van die fase verskuiwer, en vergelyk met die fase verskuiwer se sensitiwiteit analise vereistes. Beperkinge tot die teorie is bespreek en die vakmanskap

vereistes uitgelig. 'n Algemene sintese prosedure is afgelei om toekomstige ontwerpe te steun. Rekenaar kode was ook ontwikkel om die tapsvormige koppelaar vanaf materiaal en elektriese spesifikasies te ontwerp.

Die studie sluit af met 'n ontwerp voorbeeld van 'n volledige differensiële fase verskuiwer, analise resultate word met gemete waardes vergelyk, asook algemene gevolgtrekkings.

Sleutelwoorde : mikrogolf, differensieël, fase, verskuiwer, bandwydte, kwadratuur, periodiese, volging, koppeling, riffel.

TABLE OF CONTENTS