PARAMETERIZATION OF ARBITRARY GEOMETRICAL STRUCTURES FOR AUTOMATED ELECTROMAGNETIC OPTIMIZATION

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OSA-96-MT-14-V

May 31, 1996

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presented at

1996 IEEE MTT-S International Microwave Symposium, San Francisco, June 18-20, 1996

Abstract

This paper reveals and discusses the theoretical foundation of the Geometry Capture™ technique. Geometry Capture facilitates user-parameterization, through graphical means, of arbitrary 2D and 3D geometrical structures. This makes it possible to optimize the shape and dimensions of geometrical objects in an automated electromagnetic design process by adjusting the user-defined parameters subject to explicit numerical bounds and implicit geometrical constraints.

Introduction

we address the critical issue of parameterization of geometrical structures for the purpose of layout-based design, in particular automated EM optimization

explosion of available electromagnetic (EM) simulators and advances in computer hardware make EM optimization feasible, though still very CPU intensive

expected widespread use of EM optimization in the future

as the optimization process proceeds, revised structures must be automatically generated

each structure must be physically meaningful and should follow the designer's intention w.r.t. allowable modifications and possible limits

leave the parameterization process to the user

Previous Approach: A Library of Predefined Elements
(*Empipe Version 1.1, 1992*)

EM simulators deal directly with the layout representation of circuits in terms of absolute coordinates

in our earlier work we created a library of predefined elements (lines, junctions, bends, gaps, etc.), already parameterized and ready for optimization

the applicability of that approach is limited to structures that are decomposable into the available library elements

the library approach inherently omits possible proximity couplings between the elements

no library, however comprehensive, can satisfy all microwave designers, simply because of their creativity in devising new structures

Previous Work: Challenges of Automated EM Optimization
(*Bandler et al., 1993, 1994*)

drastically increased analysis time

reconciling and exploiting

discrete nature of numerical EM solvers

continuity of optimization variables

gradient information

geometrical interpolation and modeling

integrated data bases

parallel computation

Space Mapping™ - a pivotal role in effective utilization of EM design tools

Geometry Capture™
(*Empipe Version 2.0, 1994*)

EM simulators are capable of handling fairly arbitrary geometrical structures

to take full advantage of EM simulators the structures may need to be simulated as a whole

microwave designers expect to be able to optimize increasingly more complex structures

geometrical parameterization is needed for every new structure

to provide a tool for parameterizing such structures, we created the user-friendly Geometry Capture technique

here we examine theoretical and implementational concepts and reveal the mathematical foundation of the Geometry Capture technique

Mathematical Description of Geometrical Objects

structures consist of a number of 2D or 3D objects

each object is uniquely defined by its attributes and a finite ordered set of numerical values

the attributes determine the class of objects (e.g., a polygon) and how the numerical values are interpreted

we concentrate on the object vertices described in terms of absolute coordinates and represented by a vector

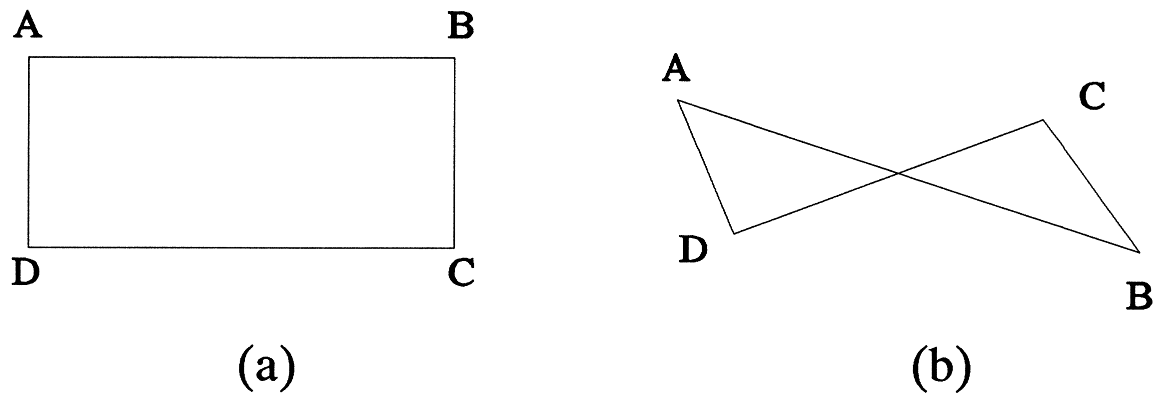
$$x = [x_{v1}^T \; x_{v2}^T \ldots x_{vm}^T]^T$$

where

m the total number of vertices

x_{vi} the vector of the vertex coordinates

Possible Pitfalls of Arbitrary Movement of Vertices



(a) initial geometry

(b) an unwanted result due to an arbitrary and independent movement of vertices

Implicitly Constrained Coordinate System

impose constraints on the movement of vertices

a function T mapping designable parameters $\boldsymbol{\phi}$ into X

$$x = T(\boldsymbol{\phi})$$

the parameters are allowed to vary within an orthotope

$$\phi_{i\,\min} \le \phi_i \le \phi_{i\,\max}, \quad i = 1, 2, ..., n$$

normally there are very few parameters $\boldsymbol{\phi}$ as compared with the number of vertices ($n << m$)

process of parameterizing an object

- selecting the parameters $\boldsymbol{\phi}$
- defining and determining the function T
- establishing the constraints
- discretization of the parameters $\boldsymbol{\phi}$

Defining Controlling Parameters

defining the parameters ϕ should be left to the designer

designers know best what changes to the object are desired and allowable

the process is intuitive

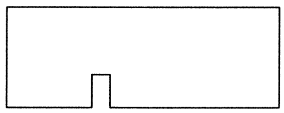
rules to follow

- as few parameters as possible
- parameters must not be dependent
- basic understanding of the mapping

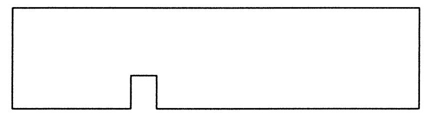
the parameter values, as seen by the optimizer, are intermediate to the process of generating actual layouts

parameter transformations such as scaling or normalization can be used to link the optimizable parameters with the actual layout design parameters

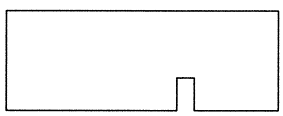
Various Object Evolutions



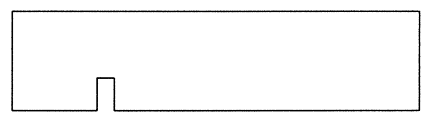
(a)



(b)



(c)



(d)

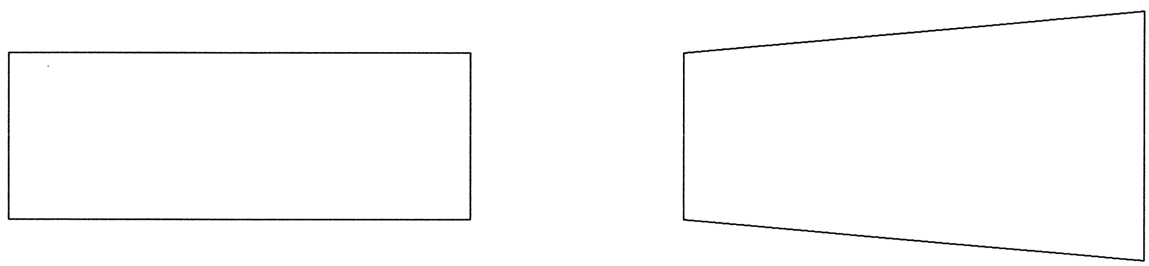
(a) initial geometry

(b) proportional expansion of the whole structure along the x axis

(c) only the location of the slit in the fixed line is allowed to change

(d) only the segment to the right of the slit is allowed to expand

Evolution of a Rectangle to a Tapered Line



one parameter controls the length of the right edge in a symmetric manner

Defining the Mapping

we consider the following form of the mapping T

$$T(\phi) = T(\phi^0) + F(\phi - \phi^0)$$

where

$x^0 = T(\phi^0)$ the starting, or nominal, object

ϕ^0 the nominal values of the parameters ϕ

only the function F needs to be identified

individual vertices move w.r.t. the nominal object as

$$x_{vi} = x_{vi}^0 + f_i(\phi - \phi^0)$$

where

$$F = [f_1^T \; f_2^T \ldots f_m^T]^T$$

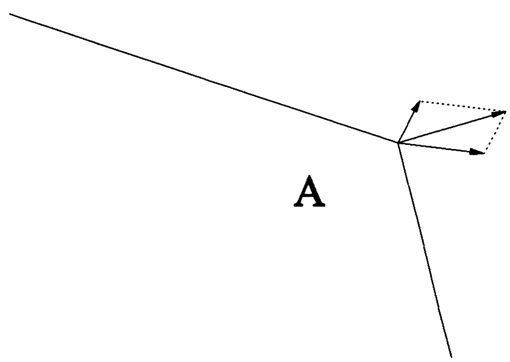
Principal Assumption of Geometry Capture

we assume that the movement of individual vertices is additive w.r.t. the contributions due to incremental changes in individual parameters

mathematically this is expressed as

$$f_i(\phi - \phi^0) = \Sigma f_{ij}(\phi_j - \phi_j^0)$$

for example, in the case of two parameters

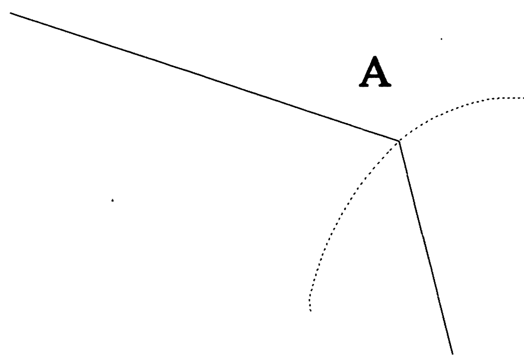


under this assumption, defining the mapping can be carried out by identifying the functions f_{ij}

Capturing Object Evolution

each f_{ij} determines the trajectory of the movement of a specific vertex due to a change in one parameter alone

possible trajectory of the movement of a vertex with a change in a parameter



the overall change F can be expressed as

$$F(\phi - \phi^0) = \Sigma F_j(\phi_j - \phi_j^0)$$

each term on the RHS indicates the evolution of the whole object due to a change in one parameter alone

the process can be split into steps in which the user characterizes the evolution of the whole structure in response to changes in one parameter at a time

Discretization of Controlling Parameters

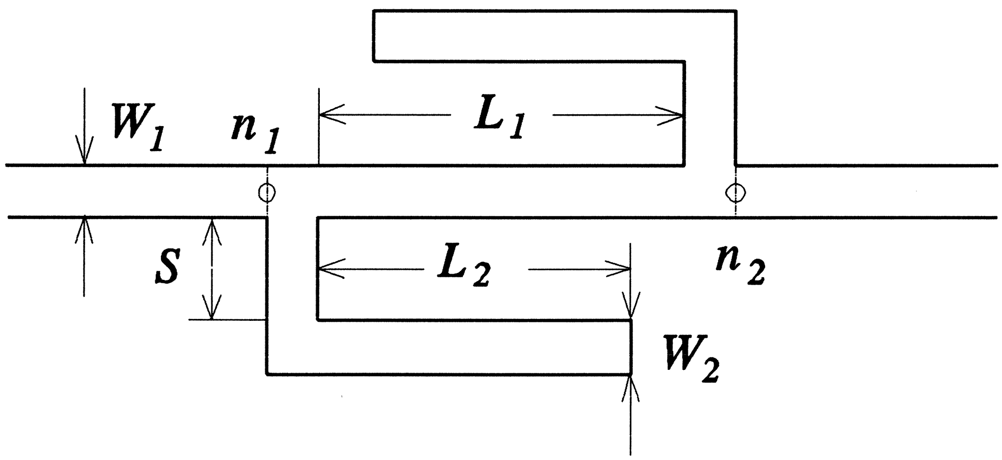
parameter discretization may arise out of necessity if the particular EM simulator used is a fixed grid solver

> all the (user-defined) parameters must be discretized in such a manner that for on-grid parameter values the mapped vertices are also on the grid
>
> this can be assured in an intuitive way using a graphical editor

parameter discretization might also be desirable in order to take advantage of the techniques that allow significant improvement of efficiency

> utilization of a data base of already simulated structures
>
> efficient interpolation and modeling
>
> efficient gradient evaluation, handling of tolerances, efficient model evaluation in Monte Carlo analysis and yield-driven design

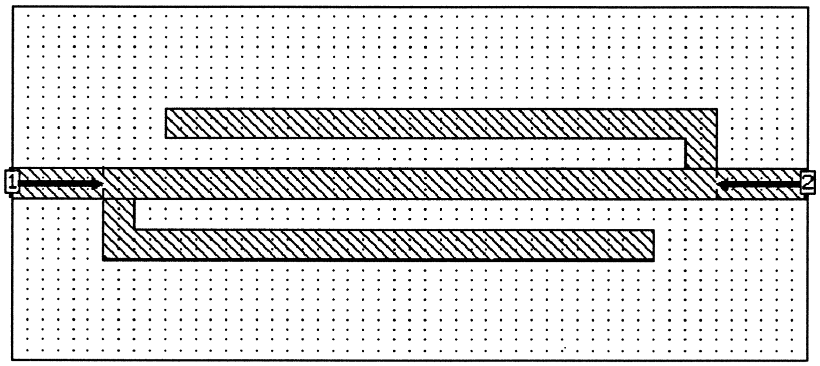
A Double Folded Stub Filter
(*Rautio, 1992*)



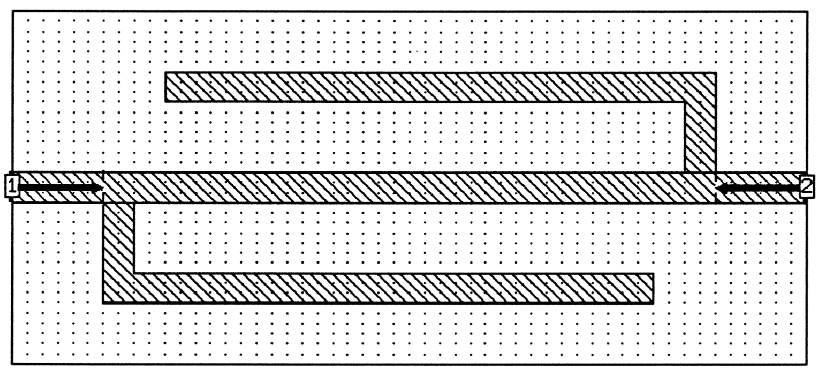
the intended filter evolution is controlled by

L_1 and L_2	the lengths of the overall filter and of the folded segments of the stubs
S	the spacing of the folded segments of the stubs
W_1 and W_2	the widths of the main line and of the stubs

Evolution of the Double Folded Stub Filter



(a)



(b)

(a) the filter structure for S=4.8 mil

(b) the filter structure for S=11.2 mil

similar structures reflecting modifications due to other parameters need to be drawn

Conclusions

theoretical concepts and formulations relevant to parameterization of arbitrary geometrical structures

for automated layout-based optimization using EM tools

to facilitate friendly user-parameterization of user-defined geometrical objects

theoretical derivations are not linked to any particular EM solver

certain assumptions have been made to keep the technique simple and manageable

parameterized structures become available for automated optimization

parameterized structures can be saved and reused, augmenting a customized library of elements

we expect that our innovations will become widely used in optimization-oriented layout-based applications, not only in microwave hybrid and monolithic IC design, and not only in conjunction with EM simulators