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Non-Linear Optimization of Small Size Microwave Directional Coupler design Using Implicit Space

A. SAADI[1], **S. BRI**[2]
[1]ENSAM Meknes, Morocco, rayhan_achraf@yahoo.fr
[2]High School of Technology Meknes, Morocco, L_bri2000@yahoo.fr

ABSTRACT

The design of traditional microwave components is widely developed in the literature, but their optimizations with conventional techniques suffer from the handicaps of exorbitant time computation, which hampers any technological developments because of the tedious task of their algorithms. In this paper, a Non-linear optimization technique recently developed based on the spatial mapping with a surrogate model is presented; it is an implicit space mapping. We formulate in detail the optimization implicit spatial mapping algorithm, this algorithm has been successfully applied to the optimization of a microstrip directional coupler with coupled lines in a frequency band leading to a small size component.

Key words: Non-linear optimization, coupled-lines, Implicit space mapping, Small size microstrip coupler, surrogate model.

1. INTRODUCTION

Coupled transmission lines have been extensively used in RF circuits to design directional couplers and electric filters [1]. Directional couplers implemented were an extremely useful tool for microwave engineers because of their unique property of separating forward- and backward-traveling waves. The most important device made using directional couplers was the reflectometer, which enabled the invention of many important devices such as power detectors and network analyzers. The coupling theory explaining the coupling mechanisms through small apertures. Although rectangular waveguides for very high-power applications were extensively used in designing directional couplers, TEM structures, such as coaxial lines, were also employed. Then, as the development of printed circuits advanced, printed TEM or quasi-TEM structures started to be used extensively in designing directional couplers The fast development of printed circuit technology eventually enabled compact and cost-effective designs of microwave components in microstrip or stripline structures. Microwave components design using coupled lines also has a very well-established theory in RF and microwave engineering [2–4]. Coupled line theory is also applied to the calibration of differential circuits, because the differential circuits are best characterized by considering both of the propagating modes [5]. the chief application areas for coupled-line theory in microwave engineering, is where the coupling between the line elements is enhanced in a such a way that coupled lines can be used to design directional couplers, electrical filters, The general analysis of TEM coupled lines is performed through multiconductor transmission line (MTL) equations, where matrix theory is used, resulting in a very compact analysis. An interesting result of matrix analysis of coupled lines is the possibility of decoupling the governing differential equations of the structure using similarity transformations [6–8]. However, analytical studies have many problems to describe the structures. The non-linear optimization space mapping technique can solve the problem otherwise [9-12]. We present, in primarily, the brief theory of this technique and we applied it at directional coupler with coupled lines in order to find the correct dimensions of the specified coupler, using ADS tool [13-14]. To master this technique, we present the practical details of all the steps necessary to achieve and the implementation of the ISM algorithm.

2. IMPLICIT SPACE MAPPING IMPLEMENTATION

2.1 Basic Concept of Implicit Space Mapping Algorithm

SM characterize by replacing the optimization of fine model with high fidelity by a coarse model, using the iterative optimization and adopting its substitute. In general terms, the coarse model is fast but less accurate where the fine model is very accurate despite a very large computation time. When SM is applied to structures of microwave circuits, the model "fine" is often solved by an electromagnetic full wave simulator, and the coarse model is typically solved by the microwave circuitry theory. The ISM optimization problem is widely studied in the literature [15-19], it can be enunciated as follows. We denote:

$$R_f : X_f \rightarrow R^m \qquad (1)$$

The response vector of the m frequency selected, and

$$x_f : X_f \rightarrow R^n \qquad (2)$$

The vector of the n parameters of the design. The original optimization problem is given by:

$$x_f^* = \text{argmin}_{(x_f \in X_f)} \; U(R_f(x_f)) \qquad (3)$$

Where x_f^* is the optimal design of the model vector "Fine", and U is the objective function, U might be a mini-max function with upper and lower specifications. As mentioned above, since the high-fidelity EM simulators consume a lot of time, solving above using the direct optimization method is prohibitive. To do this, we have two resolvers, the first is very accurate but time-consuming calculation, the second is less accurate but very fast. It applies to both solvers to study the same structure, and we identify two different responses, the first response of the model is called Fine model response noted R_f and a second coarse model response R_c.

2.2 Practical implementation of the ISM technical

The coarse model is produced on the ADS tool (Fig. 1), which is an a pproximate model. This model includes the actual parameters of the structure, such as the characteristics of the substrate (permittivity, dielectric loss and height). On Momentum tool representing the rigorous solver, we launched the first simulation with a vector of parameters to optimize taken initially arbitrary (Fig. 2), but in general depending on the microwave expertise engineering, this vector is in the area space mapping algorithm convergence. The results of the various output parameters that will be the subject of optimization, in the case of the coupler are the S11, S12, S13 and S14 coefficients are stored in a block made for this purpose (Fig. 3).

Optimization using the technique of implicit spatial mapping with a surrogate model to achieve the same results of simulations made by the rigorous solver, and by adapting the characteristics of a substrates set used in this model. In the surrogate model, each element of the structure is set on a separate substrate. The initial vector xf is: [L=5 mm,S=1 mm, W=1.5mm],

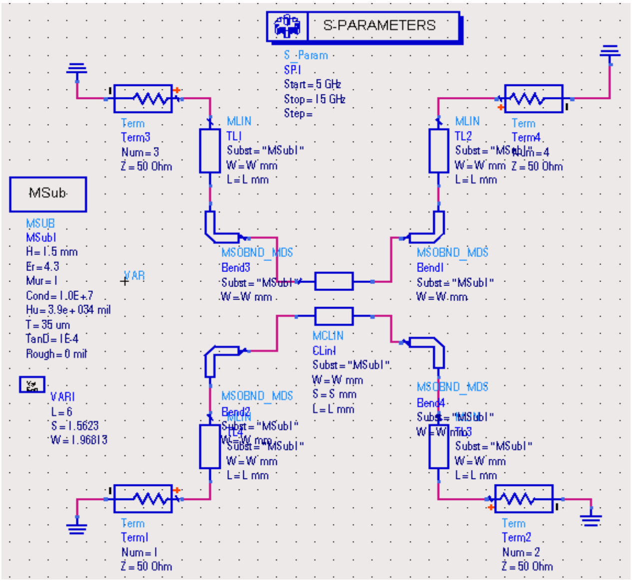


Figure 1: Coarse model in ADS Tool

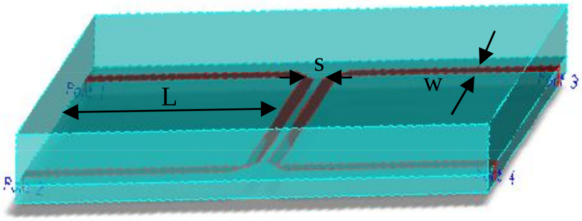


Figure 2: Coupler with coupled lines in Momentum tool

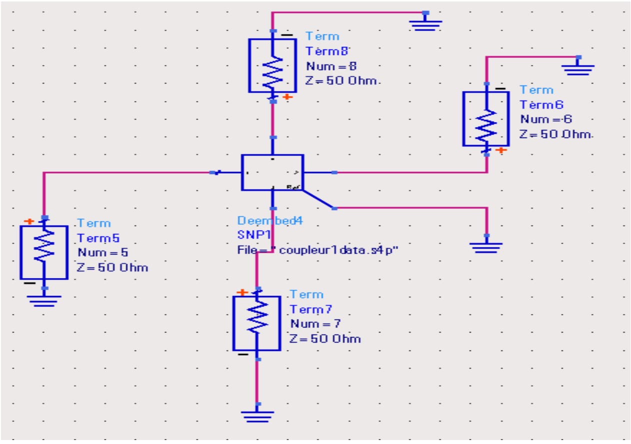


Figure 3: Diagram block to save the results of the fine model on ADS

Specific objectives are defined as goals on ADS tool as follows:

The structure of the coupler with coupled lines is shown in Figure 4, the specifications for the optimization are given as follows, and the termination impedances are the same value 50Ω:

For $5GHz \leq f \leq 7GHz$ and $9GHz \leq f \leq 15GHz$

$\{(-20dB \leq S_{11} \leq -10dB)$ and $(-20dB \leq S_{14} \leq -10dB)\}$

For $7GHz \leq f \leq 9GHz$

$\{(-40dB \leq S_{11} \leq -35dB)$ and $(-35dB \leq S_{14} \leq -25dB)\}$

For $5GHz \leq f \leq 15GHz$

$\{(-10dB \leq S\_12 \leq 0dB)$ and $(-5dB \leq S\_13 \leq 0dB)\}$

The substrate used is FR4 with permittivity $\varepsilon r = 4.3$, the height h=1.5mm, the loss angle $tg\alpha = 0.0004$ and the metal is copper, its thickness is T = 35µm. The vector to be optimized is x=[L S W] in mm.

GOAL

Goal
OptimGoal1
Expr="db(S11)"
SimInstanceName="SP1"
Min=-20
Max=-10
Weight=1
RangeVar[1]="freq"
RangeVar[2]="freq"
RangeMin[1]=5 Ghz
RangeMin[2]=9 Ghz
RangeMax[1]=7 Ghz
RangeMax[2]=15 Ghz

GOAL

Goal
OptimGoal5
Expr="db(S11)"
SimInstanceName="SP1"
Min=-40
Max=-35
Weight=1
RangeVar[1]="freq"
RangeMin[1]=7 Ghz
RangeMax[1]=9 Ghz

GOAL

Goal
OptimGoal4
Expr="db(S12)"
SimInstanceName="SP1"
Min=-10
Max=0
Weight=1
RangeVar[1]="freq"
RangeMin[1]=5 Ghz
RangeMax[1]=15 Ghz

GOAL

Goal
OptimGoal3
Expr="db(S13)"
SimInstanceName="SP1"
Min=-5
Max=0
Weight=1
RangeVar[1]="freq"
RangeMin[1]=5 Ghz
RangeMax[1]=15 Ghz

GOAL

Goal
OptimGoal6
Expr="db(S14)"
SimInstanceName="SP1"
Min=-20
Max=-10
Weight=1
RangeVar[1]="freq"
RangeVar[2]="freq"
RangeMin[1]=5 Ghz
RangeMin[2]=9 Ghz
RangeMax[1]=7 Ghz
RangeMax[2]=15 Ghz

GOAL

Goal
OptimGoal7
Expr="db(S14)"
SimInstanceName="SP1"
Min=-35
Max=-25
Weight=1
RangeVar[1]="freq"
RangeMin[1]=7 Ghz
RangeMax[1]=9 Ghz

Figure 4: Definition of objectives on the ADS software

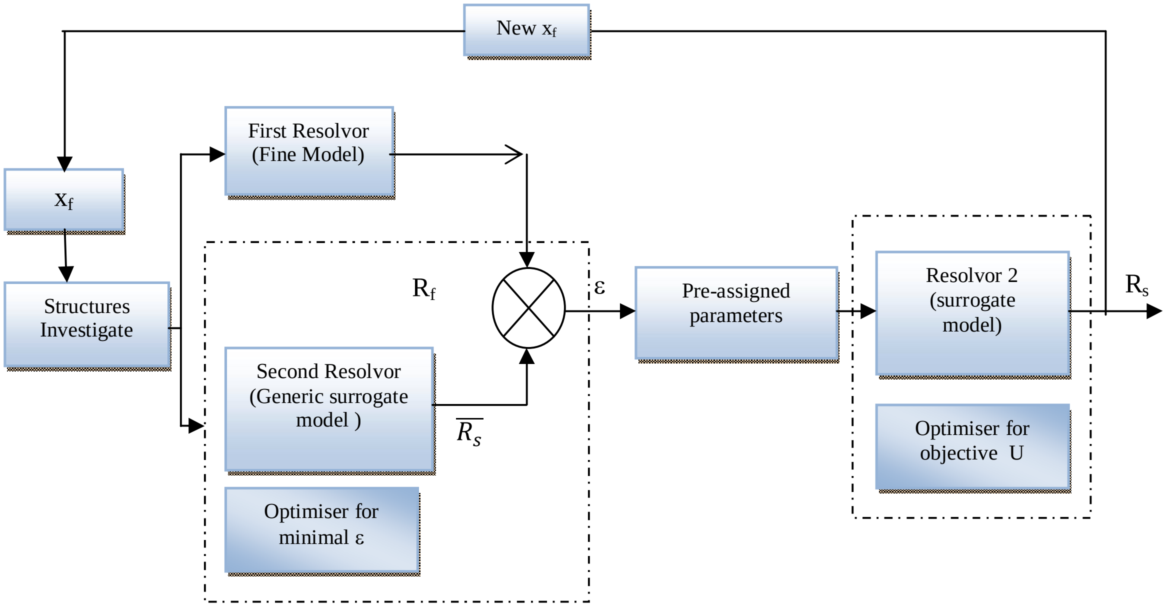


Figure 5: ISM implementation concept

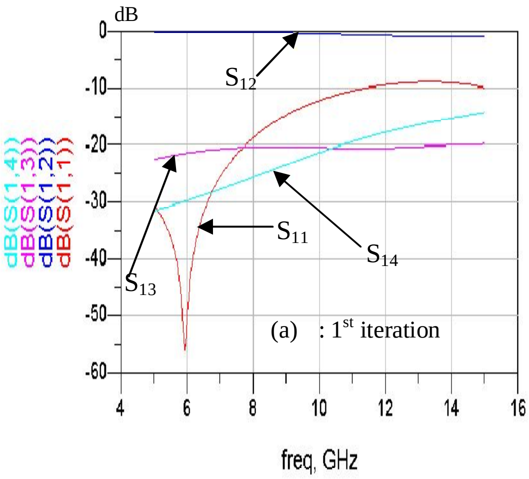
The coarse model now has a calibration parameters that are assigned heights and permittivity of different substrates used in the surrogate model, in implicit space mapping technique, we proceed to optimize the coarse model with the objectives set out in the specifications goals, its realization on ADS is made in the figure 4. The vector obtained at the end of this optimization is the candidate vector for optimal response resolver rigorous. It gives explanatory blocks diagram (Fig. 5) of the algorithm realizing the implicit space mapping technique.

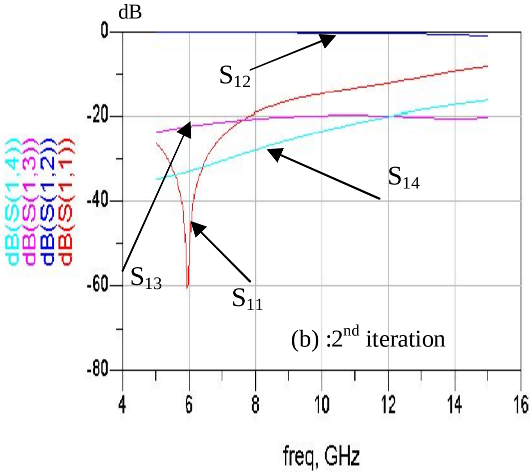
Table 1**:** vector values to optimize for each iteration

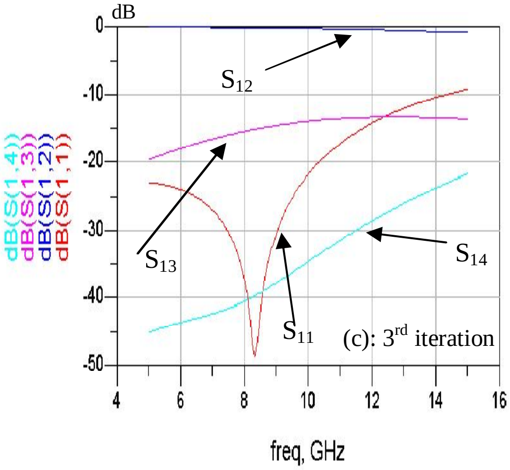
Iteration/Dimensions in mm	L	S	W
1st iteration	3.5935	0.8250	0.6411
2nd iteration	3.0719	0.8433	0.5734
3rd iteration	1.8761	0.3409	0.6256
4th iteration	2.0755	0.1000	0.8613
5th iteration	1.2462	0.1	0.9978

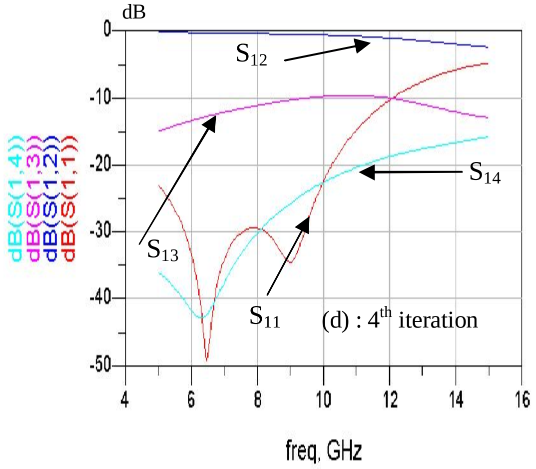
3. SIMULATION RESULTS

In the figures (Fig. 6 a, b, c, d, e), the simulation results of output parameters of directional coupler with coupled line is presented, for each iteration, we find that from one iteration to the next the outputs approaching those desired, the time allocated for each iteration is that required for the fine model, because the time taken by the coarse model is considered negligible. Note that the time allocated to the optimization of directional coupler is significantly reduced compared to optimization techniques using only rigorous formulations such as FDTD, MoM, etc…









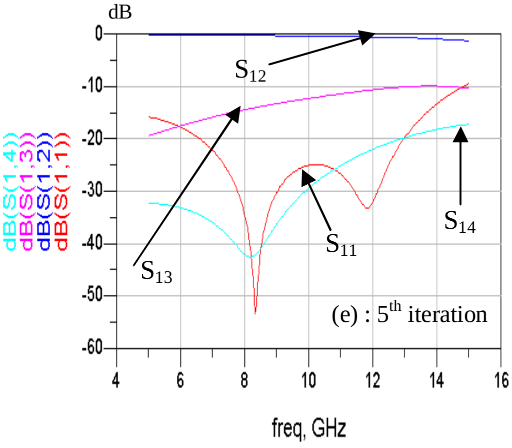


Fig 6 : Different S_{ij} coupler parameters simulated with ADS Momentum for different values

Figure 6 represents the final result of the simulation with optimized vector x, the reflection coefficient reaches -53dB at the frequency of 8.2Ghz, isolation S14 is of about -42dB, the direct coupling represented by S12 is -3dB, only the S13 coupling remains between -15dB and-10dB, which is a major handicap of this type of coupler for dividing power. This coefficient can be improved by a suitable choice of the substrate and the frequency band used. Figure 7 shows the small size coupler fabricated.

Fig 7: photo of coupled lines microstrip directional coupler fabricated

5. CONCLUSION

The engineering expertise helped delimiting the vector field to be optimized, which allows the optimization technique by implicit spatial mapping in a few iterations to design a directional coupler coupled lines with small size, according to specifications predefined. The simulation results are very satisfactory and the time needed to design the microwave component show the adaptation and the robustness of this technique in microwave engineering.

REFERENCES

1. C. G. Montgomery, R. H. Dicke, and E. M. Purcell (Eds.). **Principles of Microwave Circuits**, IEE Electromagnetic Waves Series, London, England: Peter Peregrinus Ltd., 1987.
2. Rajesh Mongia, Inder Bahl, and Prakash Bhartia**. RF and Microwave Coupled-Line Circuits**, Norwood, MA: Artech House, 1999.
3. T. C. Edwards and M. B. Steer. **Foundations of Interconnect and Microstrip Design**, New York: John Wiley and Sons, 2000.
4. David M. Pozar. **Microwave Engineering**, New York: John Wiley and Sons, 1998.
5. David E. Bockelman and William R. Eisenstadt. **Combined Differential and Common-Mode Scattering Parameters: Theory and Simulation,** IEEE Trans. Microwave Theory and Tech., vol. 43, pp. 1530–1539, July 1995.
6. R.Clayton Paul. **Analysis of Multiconductor Transmission Lines**, New York: John Wiley and Sons, 1994.
7. K. D. Marx**. Propagation Modes, Equivalent Circuits, and Characteristic Terminations for Multiconductor Transmission Lines with Inhomogeneous Dielectrics**, IEEE Trans. Microwave Theory and Tech., vol. 21, pp. 450–457, July 1973.
8. R.Clayton Paul. **Decoupling the Multiconductor Transmission Line Equations**, IEEE Trans. Microwave Theory and Tech., vol. 44, pp. 1429–1440, Aug. 1996.
9. J.W. Bandler, R.M. Biernacki, S.H. Chen, P.A. Grobelny and R.H. Hemmers. **Space mapping technique for electromagnetic optimization**, IEEE Trans. Microwave Theory Techniques, Vol. 42, pp. 2536–2544, 1994.
10. J. W Bandler,., Q. S. Cheng, S. A. Dakroury, A. S. Mohamed, M. H. Bakr, K. Madsen, and J. Sondergaard. **Space mapping: The state of the art**, IEEE Trans. Microwave Theory Tech., Vol. 52, No. 1, pp.337-361, Jan. 2004.
11. S. Koziel, J.W. Bandler, and K. Madsen. **A space mapping framework for engineering optimization Theory and implementation**, IEEE Trans Microwave Theory Tech 54, N°.10, pp. 3721–3730, October 2006.
12. S. Tavakoli, M. Zeinadini, Sh. Mohanna. **Modelling and design of microwave devices using space mapping techniques,** Canadien Journal on Electrical and Electronics Engineering Vol.1, N° 5, pp 116-120, September 2010.
13. Agilent ADS, Version 2008, Agilent Technologies, 1400 Fountain grove Parkway, Santa Rosa, CA 95403-1799, 2008.
14. S. Qingsha. Cheng,John W. Bandler,and Slawomir Koziel. **A Simple ADS Schematic for Space Mapping**, 2009 IEEE MTT-S International Microwave Workshop Series on Signal Integrity and High-Speed Interc. (IMWS2009-R9), pp.35-38, Guadalajara, Mexico, Feb. 19-20, 2009.
15. J.W. Bandler, Q.S. Cheng, N.K. Nikolova and M.A. Ismail. **Implicit space mapping optimization exploiting preassigned parameters**, IEEE Trans Microwave Theory Techniques, Vol. 52, pp. 378–385, 2004.
16. Q.S. Cheng and J.W. Bandler. **An implicit space mapping technique for component modeling**, Proc 36th European Microwave Conf, Manchester, UK, pp. 458–461, 2006.
17. S. Koziel and L. Leifsson. **Low cost parameter extraction and surro-gate optimization for space mapping design design using EM-Based coarse models**, Progress In Electromagnetics Research B, Vol. 31, pp.117-137, 2011.
18. S. Bri, A.Saadi, M.HABIBI. **Microwave Filters Design Optimisation by Implicit Space Mapping Technique**, Inter. Journ. Of Emmer. And Tren. in Engineering and Development (rs publication), pp 367-379, Issue 2 vol. 7, November 2012.
19. F. Zhong, B. Zhang, Yong Fan, Minghua Zhao and Guan Gui. **Application of Implicit Space Mapping in the Design of Hammerhead Filter in Millimeter-Wave Band,** Research Journal of Applied Sciences, Engineering and Technology, pp. 670-674, March 15, 2012.