Industrial Engineering Letters
ISSN 2224-6096 (Paper) ISSN 2225-0581 (online)
Vol.5, No.11, 2015

SINRD Filter Optimization using Heuristic Algorithm

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Abstract

In this paper, new SINRD designs are explored thanks to an original modelling method. A heuristic algorithm using this method is developed to reduce the number of holes in an SINRD filter. Simulations are processed with a modal modeling method called WCIP. Optimal results are successfully compared to measurements. The number of holes is reduced of 44% with comparable filter performances.

Keywords: SINRD filter, heuristic algorithm.

1. Introduction

The development of millimeter and submillimeter devices has revolutionized the telecommunication systems; they require ease of integration, low loss and high performance [1]. First attempts in this domain appear with the Non Radiative Dielectric waveguide (NRD), first proposed by Yoneyama and Nishida [2] in 1981. It consists in a strip of dielectric substrate inserted between two metallic planes. With technological evolutions, this structure was transposed on substrate which is called SINRD circuits [3, 4]. The SINRD waveguide uses a network of holes, which reduces the dielectric constant of the substrate in the regions of interest. These specific structures often require high memory storage if fully simulated. Therefore, most of the time this substrate is replaced by an effective dielectric instead of the real substrate, which supposed that the lattice is periodic.

In [5], a Substrate Integrated Non Radiative Dielectric (SINRD) filter is designed with the help of a method based on modal expansions called Wave Concept Iterative Procedure (WCIP). The circuit is decomposed on a regular grid composed of cells. If the via exists, it is centred in the cell. The number of unknowns corresponds to the number of cells. In [5], the method is validated by comparison with a Finite Element Method (FEM) commercial software (HFSS). For this validation, the drilled substrate is replaced by a homogeneous equivalent condition in the FEM code. The main advantage of this method is that the number of unknowns is the number of cells and therefore the structure can be fully simulated without condition on the lattice periodicity. Actually rigorous method (such as FEM) cannot solve such structures since the memory storage is too large; the Method of Moments (MoM) also requires more unknowns than the presented method and presents therefore longer computation time.

In this paper, the optimization of this SINRD filter is presented using the WCIP. An original Heuristic Algorithm is developed to find the minimum number of holes necessary in the circuit to meet the specifications. With a reduction of the number of holes, the fabrication cost is reduced. Results are successfully compared to measurements since the FEM software is not able to compute it.

2. Heuristic Algorithm

In the method, four kinds of cells exist (with metallic via, no via only dielectric, drilled dielectric or source) and are affected in the spatial matrix called Sspa. Sspa structure is directly the image of the repartition of cells. Its dimension corresponds to the number of cells, of dimensions dx=dy=d in [2]. At each cell position (p,q) in the grid, a coefficient is affected in Sspa that depends on the king of cell:

- Sspa(p,q) = - 1 if a metallic via is centred in the cell,
- Sspa(p,q) = 1 if there is no via, the cell is said empty in future development,
- Sspa(p,q) = $(\varepsilon_g - j(\varepsilon_g-\varepsilon_r))/(\varepsilon_g + j(\varepsilon_g-\varepsilon_r))$ for drilled dielectric, with εg the relative permittivity of the via (here εg =1) and εr the relative permittivity of the substrate,
- Sspa(p,q) = $(Z_{os}-Z_0)/(Z_{os}+Z_0)$ if there is a source, with Z_0 the reference impedance and Z_{os} the source internal impedance (here $Z_{os}=Z_0$), therefore Sspa(p,q)=0.

The matrix definition is not frequency dependent; changing the coefficient is equivalent to a change in the circuit shape. The heuristic algorithm is detailed below. The circuit is bordered with metallic vias, no changes are admitted on it, positions of sources are not modified. The initial circuit is composed of 21x35 cells, symmetries are conserved in the algorithm. The substrate dielectric permittivity is ε_r=2.55(1-j0.0015), the corresponding Sspa value is -0.4131+j0.9131.

If the frequencies f_1 and f_4 correspond to the frequency limits of the rejection band of level Astop (in dB), f_2 and f_3 correspond to the frequency limits of the pass band of level ripple (in dB), the transmission coefficient S21 should be lower than Astop at f_1 and f_4 and higher than the ripple at f_2 and f_3 to achieve the filter specifications.

The implemented algorithm is detailed in Figure 1. The algorithm tends to reduce the number of cells in Sspa that contains the value -0.4131+j0.9131 (drilled cell) and to increase the number of cells in Sspa that contains the value 1 (cell with no via).

3. Results

The initial bandpass filter specifications are: a center frequency of 3.8 GHz, a relative bandwidth of 15%, a ripple of 0.2dB and an order 2 (Astop=-10dB). The bandpass filter design is represented in Figure 2, see dimensions in [2], it presents a relative bandwidth of 17% and a ripple of 0.05dB. Our heuristic optimization technique described in section II is applied on four frequency points corresponding to the limits of the rejection and the pass bands (f_1=0.5GHz, f_2=3.515GHz, f_3=4.085GHz, f_4=5.9488GHz).

Our heuristic algorithm, developed on MATLAB R2012b, allowed a reduction of the number of vias holes from 480 to 212 with a frequency shift of 0.08 GHz and a center frequency of 3.72 GHz, a relative bandwidth of 17.2% and a ripple of 0.11dB. The obtained filter is presented in Figure 3. Scattering parameters, reflexion and transmission, are represented in Figure 4 and Figure 5 respectively.

4. Conclusion

Here, the optimization of an SINRD bandpass filter is obtained with a Heuristic Algorithm technique. The number of holes in this circuit is reduced from 480 to 212 while maintaining equivalent performance of the filter. With fewer holes, the costs are reduced and the manufacturing is easier. Results are successfully compared to measurements. Other optimization techniques may be tested (genetic algorithms) to improve the presented solution. External dimensions and source position could be modified by such algorithm to reduce size and number of drilled holes.

References

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Input DATA: Sspa f1 f2 f3 f4 Astop ripple
Begin
  for p=2:10,
     for q=2:17,
        sd:=Sspa(p,q);
        if Sspa(p,q) = -0.4131+j0.9131 % the cell was drilled, the cell has now no via
           Sspa(p,q) :=1; Sspa(20-p+1,q) :=1; Sspa(20-p+1,34-q+1) :=1; Sspa(p,34-q+1) :=1;
        end
        Computation of the filter response by WCIP, S21(f1,f2,f3,f4)
        if db(S21(f1))>Astop or db(S21(f4))>Astop of db (S21(f2))<ripple or db(S21(f3))<ripple
           % the filter constraints are no met, the initial value is kept, else the new value is kept
           Sspa(p,q):=sd; Sspa(20-p+1,q):=sd; Sspa(20-p+1,34-q+1):=sd; Sspa(p,34-q+1):=sd;
        end
     end
  end
End
Output DATA: Sspa
```

Figure 1. Heuristic Algorithm

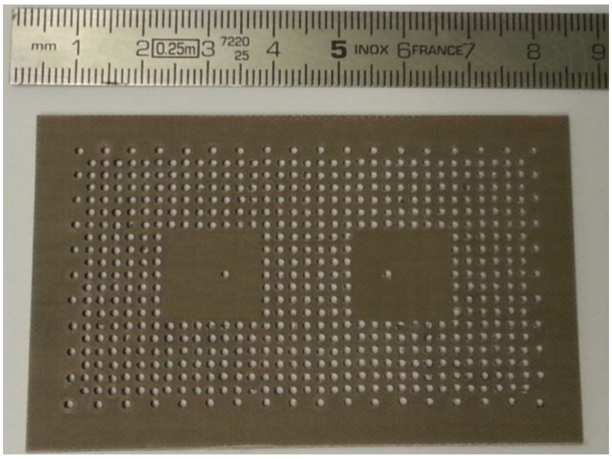

Figure 2. Bandpass SINRD filter

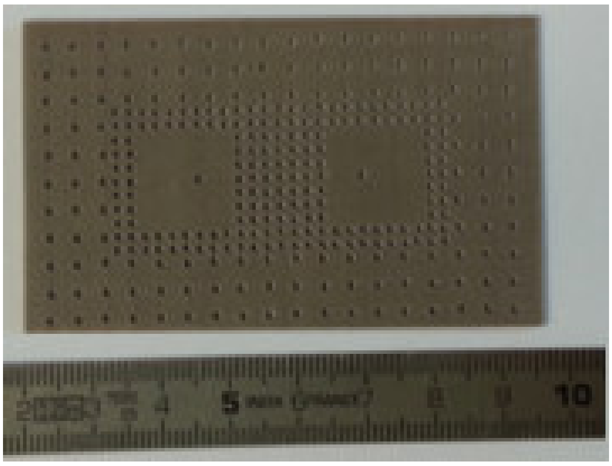

Figure 3. Bandpass SINRD filter optimization

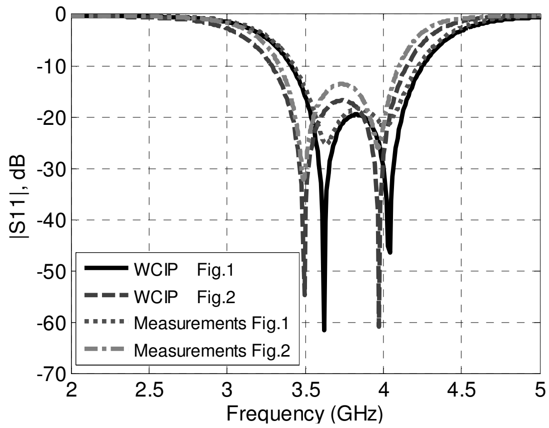

Figure 4. Reflexion parameters (S11) of the SINRD filter

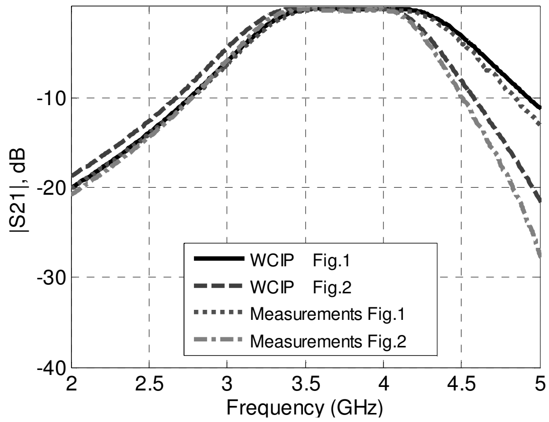

Figure 4. Transmission parameters (S21) of the SINRD filter