EFFICIENT COUPLING PATTERNS DESIGN OF MINIATURIZED DIELECTRIC FILTER USING EM SIMULATOR AND EPO TECHNIQUE

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Abstract- *An efficient field theoretic CAD method is proposed for the design of a coupling pattern of a kind of circuits where the error parameter can be defined. In this method, the EM simulator is used in conjunction with EPO (Error Parameter Optimization) technique to expedite a coupling pattern design. The proposed technique is applied to the design of an asymmetric dielectric filter in 1900 MHz band. Only two or three iterations are needed for the coupling pattern design of a prototype filter satisfying the object response. This technique is shown to be simple and effective, and it dramatically saves computational time for electromagnetic pattern design.*

I. Introduction

The accurate EM characterization of a circuit pattern becomes more and more important for the success of MMIC and some HMIC where the post tuning is not easy. Nowadays, various EM simulators are available to the passive circuit designers and they often have opportunities to use EM simulators to characterize passive planar circuits. Although these EM simulators are user-friendly and predict the circuit characteristics quite accurately, they still have a problem of high simulation time compared with circuit simulators. Therefore the design of circuit patterns using EM simulator only is impeded by the high simulation time problem. Recently, the space mapping concept is proposed by Bandler et al [1][2] as an alternatives to the entire EM domain approach. The technique use a mapping concept between the EM domain and the circuit domain in order to obtain the optimum EM domain solution in terms of the optimum circuit domain result. In this paper, we propose a new method, EPO technique, for the pattern design of circuits whose error parameters can be defined. The proposed method is conceptually similar to the space mapping in the sense that it use the optimization results in circuit domain to obtain the EM domain solution. However, it use the error parameter concept in the mapping process between the EM domain and circuit domain. Also, the mapping functions in this method are so simple that it can be easily applied.

As an application, we design a complex shaped coupling pattern of DRF(dielectric resonator filter) in which resonators' lengths are the only post tunning parameters. All carefulness is needed on the coupling pattern design since the accurate design of MIM capacitors, interdigital capacitors, line inductors, and other distributed components is essential to the successful fabrication of miniaturized dielectric filters. Using this method, we can obtain a quite similar response to the original circuit response in three iterations.

II. Error Parameter Optimization Technique

Fig.1 (a) shows the perspective view of a miniaturized DRF together with coupling pattern(EM domain) which are actually an implementation of the circuit shown in Fig.1 (b)(circuit domain). In this case, it is essential to design the coupling patterns accurately to obtain the desired response. Fig.2 shows the EP(Error Parameter) concept where the EP is inserted between the ports of the coupling pattern to represent the difference between the object circuit and EM coupling pattern. The EPO(Error Parameter Optimization) is a method in which we can obtain the object circuit response by using the optimization of circuit error parameters in circuit domain, whose results are exploited to modify the EM domain. The EPO concept can be applied to the structures that have ports for inserting the circuit error elements. Error parameter obtained through the EPO is implemented in EM domain by using the simple linear mapping functions. When the error parameter is realized in the EM domain, the objective function of EM pattern is not the original circuit response but the result of the previous error parameter optimization. This object response of EM pattern varies with each iteration since each result of EPO is not exactly same as the original circuit response. Fig.3 shows the brief flow chart of the proposed method. We design the prototype EM pattern, X_{EM}^1 , and perform EPO which satisfies the convergence equation in circuit domain.

$$\forall_{X_c}, \quad \sum_{f_{band}} \| \zeta_C(X_C) - \zeta_C(\zeta_{EM}^i, E_{opt}^i, F_C^i) \| \leq \epsilon \qquad (1)$$

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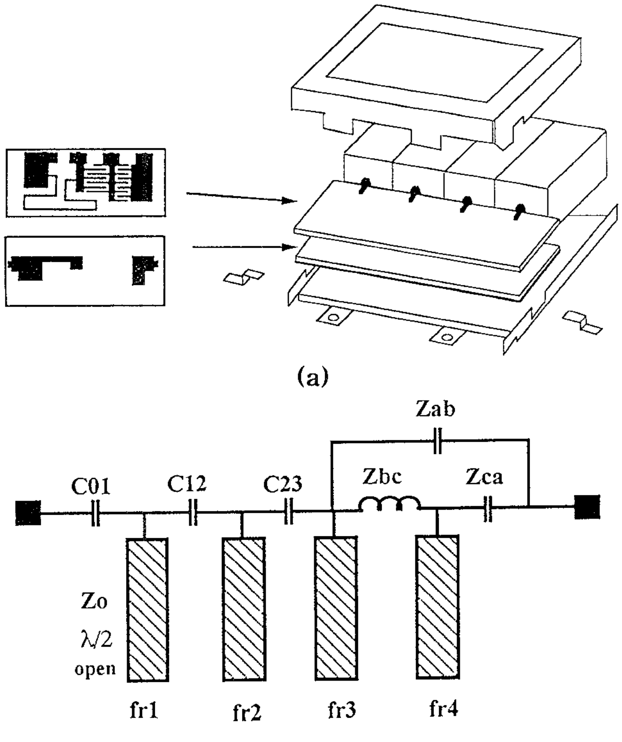


Fig. 1. (a) Construction of DRF with an attenunation pole and its EM coupling patterns. (b) Equicalent circuit of DRF with an attenuation pole.

where $\zeta_C(\bullet)$ denotes the circuit analysis function for the given circuit parameter, X_C denotes the lumped circuit parameter vector to be realized, $\zeta_{EM}(\bullet)$ denotes the electromagnetic analysis function for the given EM pattern, X^i_{EM} denotes the i-th EM pattern, E^i_{opt} is the i-th error parameter vector in the EPO, F^i_C is the i-th resonance frequence vector in the EPO.

In the Eqn (1), $\zeta_{EM}(X^i_{EM})$ represents the $n \times n$ electrical parameter data matrix for prototype design obtained by the EM simulator. Note that E^i_{opt} and F^i_C in Eqn. (1) are determined by using circuit optimization technique not by EM domain optimization. To implement the E^i_{opt} on the previous EM pattern, X^i_{EM}, we divided the subpattern of EM pattern into MIM type, interdigital type, and line inductor type. That is, the elements of E^i_{opt} are $\triangle C^i_{EA}$ (MIM capacitor type), $\triangle C^i_{EL}$ (interdigital capacitor type), $\triangle L^i_{EL}$ (line inductor type). These values are used to modify the pattern by using the following simple linear mapping functions.

$$\triangle A^{i+1}_C = \frac{\triangle C^i_{EA}}{C_{CA} - \triangle C^i_{EA}} A^i_C \tag{2}$$

for the MIM capacitor type,

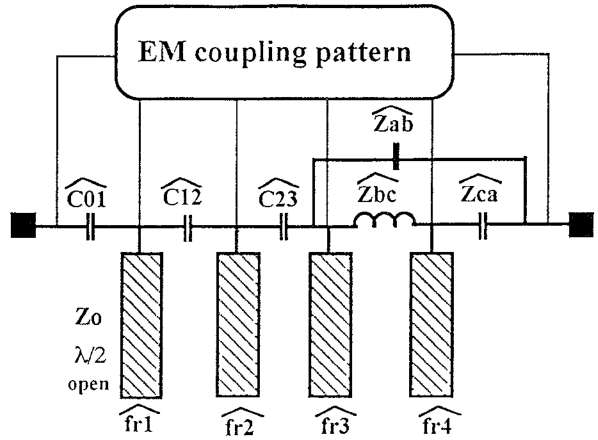


Fig. 2. Equivalent circuit for EPO(Error Parameter Optimization)

$$\triangle l^{i+1}_C = \frac{\triangle C^i_{EL}}{C_{CL} - \triangle C^i_{EL}} l^i_C \tag{3}$$

for the interdigital capacitor type,

$$\triangle l^{i+1}_L = \frac{\triangle L^i_{EL}}{L_C L - \triangle L^i_{EL}} l^i_L \tag{4}$$

for the line inductor type.

where $\triangle A^i_C$ is the overlaped area of MIM capacitors to be added on the i-th EM pattern, $\triangle l^i_C$ is the coupling length of interdigital capacitors to be added on the i-th EM pattern, $\triangle l^i_L$ is the length of line inductor to be added on the i-th EM pattern. The interaction is continued until the $\| E^i_{opt} \|$ is less than a suitable positive constant.

III. EM coupling pattern design of Asymmetric Band Pass Filter

The coupling pattern of a four-pole asymmetric band pass filter shown in Fig.1-(b) is designed by using the proposed technique. The coupling structure has a transmission zero in the upper stop band[3][4]. This pole improves the attenuation characteristics in the upper side of the out of band. The input and output coupling capacitors, C01 and Zca, are MIM types and the coupling capacitors between resonators, C12, C23, and Zca, are interdigital types. Magnetic coupling component, Zbc, between the 3-th resonator and the 4-th resonator is a line inductor type. Fig. 4 shows the coupling pattern of DRF with an attenuation pole. The dielectric constant of the resonators is 90. The characteristic impedance of resonator, 8.75 [Ω], is obtained from the measured data and its resonce type is $\Lambda/2$ and open-circuited. Quality factor of resonators is 300. The thickness of bottom alumina substrate is 25 mil, and that of coupling alumina substrate is 10 mil. The design specification are as follows.

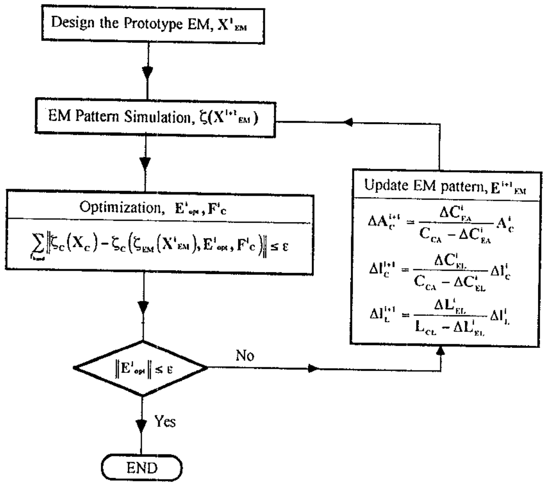


Fig. 3. Flow chart for EPO(Error Parameter Optimization) technique

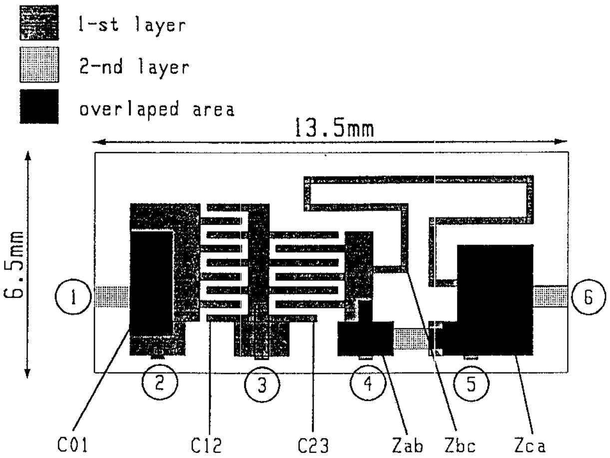


Fig. 4. The shape of the coupling pattern for DRF with an attenuation pole.

Center frequency	;	1890 [MHz]	,
Bndwidth	;	50 [MHz]	,
Attenuation pole	;	1940 [MHz]	.

Fig. 5 (a) shows the characteristics of prototype EM pattern satisfying Eqn.(1) simulated by using EM^{TM}. The E^i_{opt} and resonance frequencies are determined by using circuit optimization technique. The results of EM simulation considerably depend on the contact points of resonators, the feeding points of MIM capacitors, and shape of line inductor. But the implementation by the linear approximation, Eqn(2)-(4), dramatically reduces the error parameters of next EM pattern as shown in Fig. 4 (b) to Fig. 4 (e). During the iteration, some error parameters may increase due to the effects of neighboring patterns. However, the total error parameters reduce systematically.

IV. Conclusion

In this paper, we present an efficient field theoretic CAD method for the coupling pattern design of a circuit where the error parameters can be defined. The method uses the EPO concept to accelerate the design process of a coupling pattern. This technique is easily applied to the planar circuit implementation of lumped coupling circuits of an asymmetric DRF in 1900MHz band. In the example, three iterations are enough to obtain the similar original object response through linear mapping functions. This method does not require any accurate and complete EM mapping model. It converges very fast to the object response provided we suitably design the prototype EM pattern. It is so simple and fast that the process can be accomplished by manual operation.

References

[1] 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 and Tech., vol. 42, 1994, pp.2536-2544.

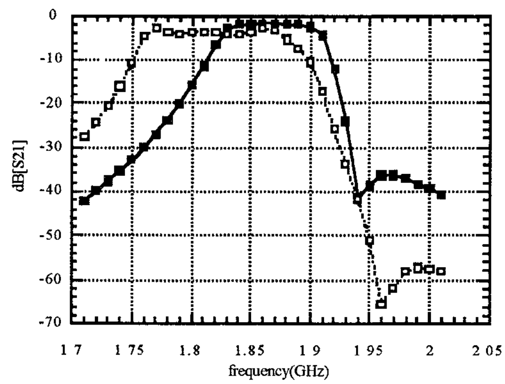
[2] J.W. Bandler, R.M. Biernacki, S.H. Chen, R.H. Hemmers and K. Madsen, " Aggressive space mapping for electromagnetic design," IEEE MTT-S Int. Microwave Symp. Dig. , 1995, pp.1457-1456.

[3] J. D. Rhodes and S. A. Alseyab, " The generalized Chevyshev low-pass prototype filter," Int. J. Circuit Theory Appl., vol. 8,1985, pp.113-125

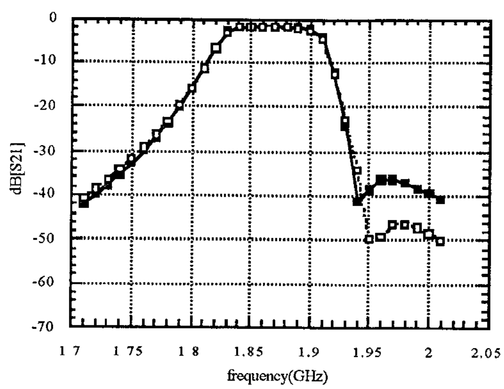
[4] David S. G. Chambers and John David Rhodes, " A low-pass prototype network allowing the placing of integrated poles at real frequencies," IEEE Trans. Microwave Theory and Tech., vol. 31, 1983, pp.40-45.

Table 1. The procedure for error parameter optimization

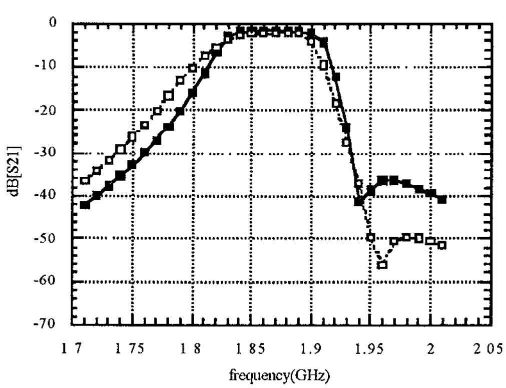
error parameters		Prototype design		after 1-st optimization		after 2-nd optimization	
parameter	circuit model	error value	percentage	error value	percentage	error value	percentage
$C_{01}[pF]$	1.3	0.61	46%	0.02	1.5%	0.01	0.8%
$C_{12}[pF]$	0.5	−0.26	52%	− 0.04	8.0%	−0.03	6.0%
$C_{23}[pF]$	0.45	−0.14	31%	0.01	2.2%	0.003	0.7%
$Z_{ab}[pF]$	1.5	−0.02	1.3%	0.54	36.0%	0.14	9.3%
$Z_{bc}[pF,nH]$	5.8 nH	0.21 pF	17.5%	0.09	7.5%	0.19	15.8%
$Z_{ca}[pF]$	2.7	1 04	39%	−0.04	1.5%	−0 02	0 7%
fr_1[MHz]	1954	1991 5		1997 0		1992 9	
fr_2[MHz]	1924	1967 3		1963 1		1966 3	
fr_3[MHz]	1874	1922.3		1931 0		1924 3	
fr_4[MHz]	1907	1951.2		1966 3		1960 4	



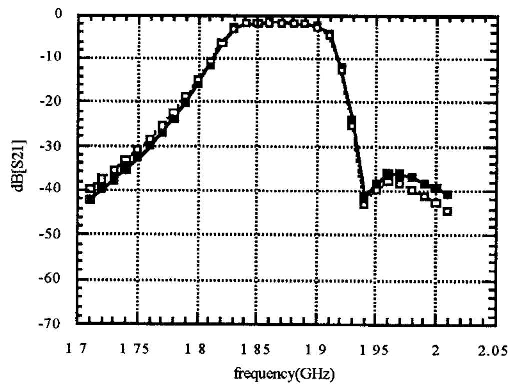
(a)



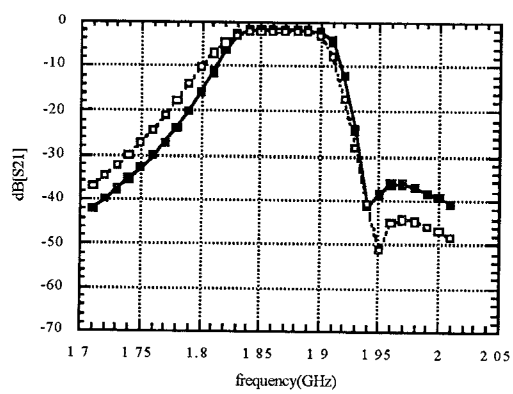
(b)



(c)



(d)



(e)

Fig. 5. (a) $|S_{21}|$ response before EPO. Original object circuit response (black square) and EM simulation for prototype pattern (white square) (b)$|S_{21}|$ response after EPO. Original object circuit response (black square) and new object response for implementation obtained from 1-st EPO (white square) (c)$|S_{21}|$ response. Original object circuit response (black square) and EM simulation for 2-nd EM pattern (white square) (d)$|S_{21}|$ response after 2-nd EPO. Original object circuit response (black square) and new object response for implementation obtained from 2-nd EPO (white square) (f)$|S_{21}|$ response after 2-nd EPO. Original object circuit response (black square) and new object response for implementation obtained from 2-nd EPO (white square)