2006년도 한국정보통신설비학회 하계학술대회 논문집 (2006.8.25-26)

무 결합계수-회전변환의, 최적화된 유리함수 Fitting에 의한 효율적인 RF 대역 여파기 설계기법

An Efficient Design Method of RF Filters via Optimized Rational-Function Fitting, without Coupling-Coefficient Similarity Transformation

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Abstract : A new method is presented to design RF filters without the Similarity Transform of their coupling coefficient matrix as circuit parameters, which is very tedious due to pivoting and deciding rotation angles needed during the iterations. The transfer function of a filter is directly used for the design and its desired form is derived by the optimized rational-function fitting technique. A 3rd order Coaxial Lowpass filter and an 8th order dual-mode elliptic integral function response filter are taken as an example to validate the proposed method.

Keywords: RF filters, Coupling matrix, Similarity transform, Optimization, Rational-function fitting

I. Introduction

Given the specifications of a filter, its transfer function needs evaluating for its design as a first step, as always. Then the primary coupling matrix $\bar{\bar{M}}$ as its circuit parameters can be obtained following the methods in [1][2], which describes the entire relation of the resonance modes of the filter network. In most of the design cases, the required coupling structure differs from that of the primary $\bar{\bar{M}}$. For this purpose, the similarity transform is carried out to modify the 1st matrix to the target matrix and is pointed out that entails cumbersome pivoting and rotation-angle decision[1-5].

Finding the transfer function suitable for the target coupling structure is the best way possible to handle the filter design. However, using the conventional fitting techniques with many a frequency sample point on the specification mask, it ends up with extended computation time and inefficiency of losing important poles and zeroes.

The Genetic-Algorithm(GA) is proposed to optimize the transfer function that meets the specifications. This is faithful to finding the poles and zeroes in need and makes the design remove the aforementioned tedious pivoting and rotation angles. $\bar{\bar{M}}$ of an 8th order dual-mode elliptic filter is evaluated for the target structure as an example.

II. Theory

To design a filter, as the first step, the transfer function can be found, expressed as

$$Trans(S) = u_0 \frac{S^m + B_{m-1}S^{m-1} + \cdots + B_2S^2 + B_1S^1 + B_0}{S^n + A_{n-1}S^{n-1} + \cdots + A_2S^2 + A_1S^1 + A_0} \qquad (1)$$

where , $S = \sigma + jr$, $j = \sqrt{-1}$ and n>m . Coefficients A_i ($i = 0,\ 1,\ \cdots,\ n-1$) and B_h ($h = 0,\ 1,\ \cdots,\ m-1$) of the deno-mi-nator and numerator of *Trans*(*S*), respectively, are determined by the reflection zeros and transmission zeros for the desired frequency response. The transfer function can be equated to S21 and goes through some manipulation that leads to $\bar{\bar{M}}$ of the filter[1-5]

$$\bar{\bar{M}}^{(0)} = \begin{bmatrix} 0 & m_{12} & 0 & 0 & 0 & 0 & 0 & m_{18} \\ m_{12} & 0 & m_{23} & 0 & 0 & 0 & m_{27} & 0 \\ 0 & m_{23} & 0 & m_{34} & 0 & m_{36} & 0 & 0 \\ 0 & 0 & m_{34} & 0 & m_{45} & 0 & 0 & 0 \\ 0 & 0 & 0 & m_{45} & 0 & m_{56} & 0 & 0 \\ 0 & 0 & m_{36} & 0 & m_{56} & 0 & m_{67} & 0 \\ 0 & m_{27} & 0 & 0 & 0 & m_{67} & 0 & m_{78} \\ m_{18} & 0 & 0 & 0 & 0 & 0 & m_{78} & 0 \end{bmatrix} \qquad (2)$$

$\bar{\bar{M}}^{(0)}$ as the primary or initial is for the case of a canonical 8th order filter. If this agrees with the target structure, no more modification on it is needed. In fact, most of practices show that the final coupling structure is not the same as $\bar{\bar{M}}^{(0)}$ Conventionally, Eqn(2) is transformed through the similarity transform.

$$\bar{\bar{M}}^{(r)} = \bar{\bar{R}}^{(r)} \cdot \bar{\bar{M}}^{(r-1)} \cdot \bar{\bar{R}}^{(r)t} \text{ and } r \geq 1 \qquad (3)$$

논문접수 : 20xx. x. x., 채택확정 : 200x. x. xx.

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※ 본 연구는 기초전력연구원의 전력선행기술 신규과제지원으로 함.

$$\bar{\bar{R}}^{(r)}=\begin{bmatrix}1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&\cos\theta_r&0&0&0&-\sin\theta_r&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&\sin\theta_r&0&0&0&\cos\theta_r&0\\0&0&0&0&0&0&0&1\end{bmatrix}\quad(4)$$

Here, $\bar{\bar{M}}^{(r-1)}$ s the r-th rotation of $\bar{\bar{M}}^{(0)}$, and rotation matrix $\bar{\bar{R}}^{(r)}$ and its transpose $\bar{\bar{R}}^{(r)t}$ are also shown. The pivot of $\bar{\bar{R}}^{(r)t}$ means $R^r_{ii}=R^r_{jj}=\cos\theta_r$, $R^r_{ij}=-R^r_{ji}=-\sin\theta_r$ with $i,j\neq 1$ or n. Plus, θ_r is the angle for rotation. The decision of the pivoting points and angles are made not by a generalized formula but by trial-and-error based steps until the finalization.

Eqn(1) is a rational function and is decomposed as follows, as long as the difference of the orders of its denominator and numerator is no greater than 1(considering normal cases).

$$Trans(s)=\sum_{i=1}^{n}\frac{Res_i}{S-P_i}+C+Q\cdot S\quad(5)$$

Depending on the combination of the three terms, the result becomes bandpass, or lowpass filters. The Genetic-algorithm is suggested to figure out the terms including Residues Res_i, poles P_i, constants C and coefficient of 1st order Q to optimally fit the given frequency responses[6].

III. Computation and Design Results

Firstly, the design problem of a lowpass filter(LPF) is referred to. The specifications are the cutoff frequency of 0.45GHz, the insertion-loss less than 2dB, the passband ripple less than 0.5dB, and attenuation greater than 5dB at 0.45GHz, as is often wanted in the cable-related EMT research areas. Aimed at implementing the coaxial cable-type LPF, the circuit parameters will be evaluated by performing the optimization(GA)-based rational-function fitting technique mentioned before, for the following physical structure.

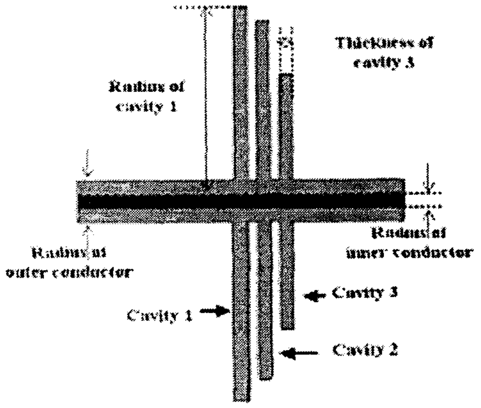

Fig. 1 A coaxial-cable filter with 3 cavities

Though looking a little complicating, the physical sizes such as radii and thicknesses of cavities for the fixed outer and inner radii of the coaxial cable, can be easily obtained from the circuit parameters that are directly related to Res_i, P_i, C and Q. What should be done prior to this is determining GA. parameters and applying it to Eqn(5). As for GA., undergoing watching the level of complexity or what not, the present method adopts 8 bits, 10 parameters, 100 individuals, 50 generations and crossover rate of 0.75. All the variables as unknown real and imaginary parts vary from 1 to +1 in terms of normalized complex frequency. The error function is effectively defined as the locations of poles for the desired frequency response. And physical passivity is enforced on poles in the right half plane of s. Fig. 2 shows the error function with three mutation rates and con-vergence over 35 of the generation number. 0.095 is chosen as the mutation rate.

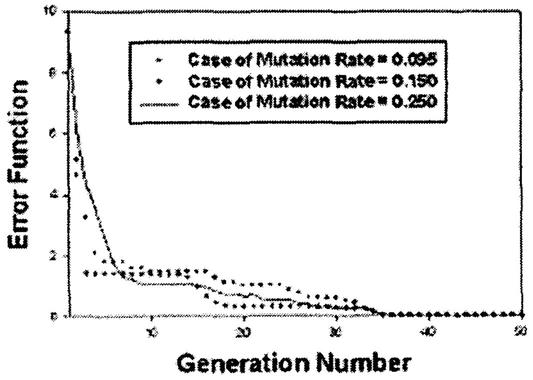

Fig. 2 Error function behavior vs mutation rate

What must be noted for improving the design method as our contribution is that the attenuation poles are placed as we desire and the optimized rational-function fitting will do good to the finding of the desired poles. This can not be accomplished by the traditional filter methodology of maximally flat or equi-ripple types. For better sharpness than that of 5dB at 0.45GHz, attenuation poles 0.45GHz and 0.6GHz near the cutoff frequency are wanted, and Eqn.(5) is evaluated as in the following table.

Table 1. Computed unknowns of Eqn.(3)

	Computed values
$Im(P_1)=w$ Res_1	: 2.805G[rad/s] : (-0.202j*0.060)G[rad/s]
$Im(P_2)=w$ Res_2	: 3.797G[rad/s] : (-0.085j*0174)G[rad/s]
$Im(P_3)=w$ Res_3	: 5.362G[rad/s] : (0.002j*0.001)G[rad/s]
C	0.056

This table shows three pairs of poles and residues and a constant in order. Nonetheless, it is found out that is not needed for this case. It needs stating that the first two poles almost coincide with the desired ones. And then, the design result of this work is given.

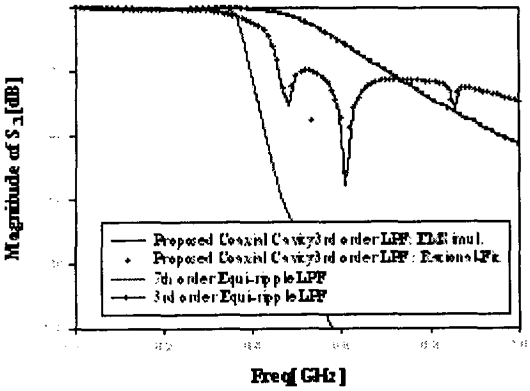

Fig. 3 Design result, superior to other cases

With the computed values of Eqn.(3), the circuit parameters have been converted to their corresponding radii and thicknesses of the coaxial LPF(radii=250mm, 200mm, 140mm, and thickness=40mm, 37mm, 30mm for cavities 1, 2 and 3 in order). This proposed RF filter has only three cavities, and has superiority to the 7th ordered equi-ripple LPF from the compactness point of view. Compared to the same order of the usual equi-ripple LPF, the present structure has far better sharpness. Let alone, the computed data by Eqn.(3) overlaps the Electromagnetic simulation.

Lastly, finishing the validation work of the proposed method, the design of an 8th order dual-mode Bandpass filter(BPF) is tackled to have cross-couplings and a higher level of sharpness.

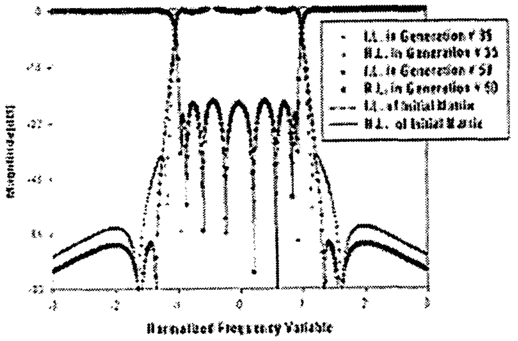

Fig. 4 Design result of an 8th order BPF

The same process of the suggested method has been applied and results in the sharpness with -19dB attenuation at 65MHz offset point from the center frequency and -20dB or less than that with return-loss(reflection).

IV. Conclusion

n this paper, a novel design method is presented for RF filters' implementation, avoiding cumbersome Similarity Transform of their coupling coefficient matrices. The transfer function of a filter itself takes part in the design and its desired circuit parameters are extracted by the optimized rational-function fitting technique with passivity enforcement. An 8th order dual-mode elliptic integral function response filter as well as a 3rd order coaxial filter have been chosen validate the proposed method and successful design results have proved it.

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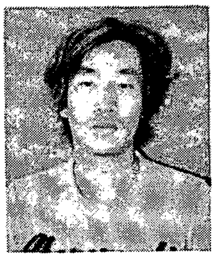

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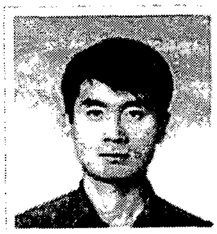

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