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Diagnosis of Coupled Resonator Bandpass Filters Using VF and Optimization Method

Rui Wang*, Le-Zhong Li, Long Peng, Xiao-Qiang Tu, and Xiao-Xi Zhong

Abstract—This paper presents a hybrid method combining a vector fitting (VF) and a global optimization for diagnosing coupled resonator bandpass filters. The method can extract coupling matrix from the measured or electromagnetically simulated admittance parameters (Y-parameters) of a narrow band coupled resonator bandpass filter with losses. The optimization method is used to remove the phase shift effects of the measured or the EM simulated Y-parameters caused by the loaded transmission lines at the input/output ports of a filter. VF is applied to determine the complex poles and residues of the Y-parameters without phase shift. The coupling matrix can be extracted (also called the filter diagnosis) by these complex poles and residues. The method can be used to computer-aided tuning (CAT) of a filter in the stage of this filter design and/or product process to accelerate its physical design. Three application examples illustrate the validity of the proposed method.

1. INTRODUCTION

The filter tuning is essential especially in the design of complex microwave filters. In the stage of a filter design and/or product process, the designer can obtain an acceptable filter frequency response by tuning this filter. Filter diagnosis greatly simplifies the filter tuning, which allows the designer to rapidly tune the filter.

Early filter diagnosis techniques can be traced back to the 1970s and 1980s [1, 2]. In the past years, interest is growing on the filter diagnosis methods for extracting the coupling matrix of microwave filters from the measurements (or simulations) with losses [3–15]. These filter diagnosis or coupling matrix (CM) extraction techniques require two sorts: 1) CM extraction techniques are based on optimization (as in [3–5]) for matching the measured scattering parameters, whose elements are the problem unknowns. The optimization techniques are either greatly influenced by the initial values assigned to the variables, number of the resonators and topology of the filters, or are time consuming; and 2) CM extraction techniques are based on a polynomial model, which matches the measured (or the simulated) parameters and then extract the CM of the filter with a specified topology (by using well-known established methods as in [16]). Polynomial models may refer to the Y-parameters as in [6–9] or to the scattering parameters (S-parameters) as in [10–15]. When using the S-parameters models to diagnose a filter including losses, the loss effect associated to each resonator must be removed in advance using either the optimization method (as in [12, 13]) or a modified frequency transformation including unloaded Q in [11]. The main advantage of the CM extraction method based on the Y-parameters is that the loss effect is not required to be removed before the filter diagnosis. However, all these extraction methods based on the polynomial models must remove the phase shift of the measured S-parameters or the Y-parameters, which are caused by the phase loading and the transmission lines at the input/output ports of a filter. Only the phase shift is properly removed, and the filter can be diagnosed correctly. The phase shift effect can be removed by the analysis method (as in [6]) or optimization method (as in [12,13]). Recently, a

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* Corresponding author: Rui Wang (rfywr@163.com).

The authors are with the College of Optoelectronic Technology, Chengdu University of Information Technology, No. 24 Block 1, Xuefu Road, Chengdu 610225, China.

vector fitting (VF) based the analytical extraction method, which is capable of accurately extracting the coupling matrix and uneven unloaded quality factor (unloaded Q) of each electric resonator of a filter, was presented by Hu and Wu in [7]. However, how to de-embedding the phase loading effects from the filter responses was not discussed.

In this paper, a hybrid method combining a VF and a global optimization, which can extract the CM and the unloaded quality factor (unloaded Q) of each resonator from the measured (or simulated) Y-parameters of lossy cross-coupled resonator bandpass filters, is proposed. The established VF is exploited to extract the complex system poles and residues from the measured (or the simulated) Y-parameters of the filter. The coupling matrix can be extracted by these complex poles and residues. A simple and efficient error function is proposed to remove the phase loading effects at the input/output ports of a filter. With respect to our previous proposed methods [12, 13], the number of optimized variables was reduced, and the proposed method can be used in the filter diagnosis with non-uniform unloaded Q. Three practical examples, including one measured filter and two electromagnetically simulated filters, are provided to show the effectiveness of the approach for the practical filter diagnosis.

2. THEORY

2.1. Calculation of Characteristic Polynomials Using VF

The measured or the simulated Y-parameters can be expressed as [7, 16]:

$$\begin{bmatrix} Y_{21} \\ Y_{22} \end{bmatrix} = j \begin{bmatrix} M_{SL} \\ 0 \end{bmatrix} + \sum_{k=1}^{N} \frac{1}{s - j\lambda_k} \begin{bmatrix} r_{21k} \\ r_{22k} \end{bmatrix} \tag{1}$$

where, M_{SL} is the source-load coupling coefficient; r_{21k} and r_{22k} are the residues of Y-parameters; λ_k is the poles of Y-parameters; N is the filter order; s is the normalized lowpass domain, which can be obtained by converting from the bandpass domain f to the lowpass domain s as

$$s = j\frac{1}{FBW}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) \tag{2}$$

where, FBW and f_0 are the fractional bandwidth and center frequency of the filter, respectively.

The measured or simulated Y-parameters can also be expressed using the poles and zeroes as [7]

$$Y_{22}(s) = \frac{\prod_{k=1}^{N} s - Z_{22k}}{\prod_{k=1}^{N} s - j\lambda_k}, \quad Y_{21}(s) = \frac{d\prod_{k=1}^{N} s - Z_{21k}}{\prod_{k=1}^{N} s - j\lambda_k} \tag{3}$$

where, Z_{22k} and Z_{21k} are the zeros of $Y_{22}(s)$ and $Y_{21}(s)$, respectively. $d = jM_{SL}$.

These zeros and poles (or residues) can be solved using VF method. VF is a popular tool for system identification of a linear system. The core procedure of VF method is briefly reviewed in [7, Section 2].

2.2. Extraction of Unloaded Q and Coupling Matrix

Once determining the residues (r_{21k} and r_{22k}) and poles (λ_k) of the Y-parameters in Eq. (1), an initial $N+2$ transversal CM [7], namely $\bar{M}$, can be directly restored based on those poles and residues found in Eq. (1) by

$$\begin{aligned} \bar{M}_{kk} &= -\lambda_k, \\ \bar{M}_{Lk} &= M_{kL} = \sqrt{r_{22k}}, \\ \bar{M}_{Sk} &= M_{kS} = r_{21k}/M_{Lk}, \quad k = 1, 2, \ldots, N \end{aligned} \tag{4}$$

The source-load coupling coefficient M_{SL} can be obtained from the highest degree (the Nth degree) coefficient of the numerator of $Y_{21}(s)$ in Eq. (3) as

$$jM_{SL} = d \tag{5}$$

M_{SL} is equal to zero except for $nz = N$, where nz is the number of the finite-position transmission zeros of a filter. Filter diagnosis does not focus on how to control the locations of the transmission zeros. However, the number of finite-position transmission zeros of a filter needs to be known for a filter diagnosis, which is a known parameter in the filter design. For a lossless or loss filter, $\bar{M}$ can be constructed using Eqs. (4) and (5). $\bar{M}$ in Eq. (4) is a complex CM. The differences between a loss filter and a lossless filter are that r_{21k}, r_{22k} and λ_k are all real numbers [16] for a lossless filter, that r_{21k} and r_{22k} are real numbers, that λ_k is a complex number for a loss filter with uniform Q for all resonator, and that r_{21k}, r_{22k} and λ_k are complex numbers for a loss filter with non-uniform Q for each resonator.

The finally extracted CM must correspond to the actual filter's physical coupling topology. Therefore, the obtained transversal CM $\bar{M}$ must be further transformed to the targeted topology through a series of matrix similarity transformations [16]. The CM after the similarity transformations is named M', in which the dominant loss is distributed on the diagonal terms in a correct order to reflect the unloaded Q of each resonator of a filter, and the loss on off-diagonal elements becomes considerably small and is neglected [7]. So, M' can be expressed as

$$[M'] = [M] - j[G] \tag{6}$$

where, M is the desired extracted CM corresponding to the actual filter's physical coupling topology, and $[G]$ is the diagonal matrix $[G] = \text{diag}[0, G_{11}, G_{22}, \ldots, G_{NN}, 0]$, which represents the loss of a filter. The unloaded Q for the kth resonator Q_{uk} can be calculated via the following equation:

$$Q_{uk} = \frac{1}{FBW \cdot G_{kk}} \quad (k = 1, 2, \ldots, N) \tag{7}$$

The extracted S-parameters, calculated using M', can be obtained via the relation between the S-parameters and the CM [12, Eq. (7)] as

$$\begin{aligned} S_{21} &= -2j[A^{-1}]_{N+2,1}, \quad S_{11} = 1 + 2j[A^{-1}]_{1,1} \\ S_{12} &= -2j[A^{-1}]_{1,N+2}, \quad S_{22} = 1 + 2j[A^{-1}]_{N+2,N+2} \end{aligned}. \tag{8}$$

Here, $A = [\Omega U - jR + M']$, Ω, $[R]$ and $[U]$ can refer to [17].

2.3. Removal of the Phase Shift of Y-Parameters

A phase shift φ connected to each port of a filter can be very well approximated by the following function in a wide frequency range [12]:

$$\varphi = \varphi_0 + \beta\Delta l \tag{9}$$

Here, the frequency invariant constant term φ_0 is called phase loading, which is revealed for the first time in the field of filter diagnosis [6]. $\beta\Delta l$ is the electrical length of the transmission line. $\beta\Delta l$ can be easily derived as $\beta\Delta l = f\theta_0/f_0$ [12], where θ_0 is the equivalent electrical length of the transmission line at f_0 in radians.

So, the phase shift φ connected to I/O port of a filter can be expressed as

$$\varphi_1 = \varphi_{01} + f\theta_{01}/f_0, \quad \varphi_2 = \varphi_{02} + f\theta_{02}/f_0. \tag{10}$$

where φ_{01} and φ_{02} are the phase loading at I/O ports, respectively; θ_{01} and θ_{02} are the equivalent electrical length of the transmission line at f_0 in radians at I/O ports, respectively; f_0 is the center frequency of the filter.

The phase shift of the measured (or the simulated) S-parameters can be removed via the following equation:

$$\begin{aligned} S_{11}(s_i) &= S_{11}^{mea}(s_i) \cdot \exp(j2\varphi_1); \quad S_{21}(s_i) = S_{21}^{mea}(s_i) \cdot \exp[j(\varphi_1 + \varphi_2)] \\ S_{22}(s_i) &= S_{22}^{mea}(s_i) \cdot \exp(j2\varphi_2); \quad S_{12}(s_i) = S_{12}^{mea}(s_i) \cdot \exp[j(\varphi_1 + \varphi_2)] \end{aligned} \tag{11}$$

where $S_{21}^{mea}(s_i)$, $S_{11}^{mea}(s_i)$, $S_{12}^{mea}(s_i)$, $S_{22}^{mea}(s_i)$ are the original measured (or the simulated) S-parameters at the frequency point s_i ($i = 1, 2, \ldots, Ns$). Ns is the number of frequency points. Frequency points s_i map into the physical frequency points f_i by Equation (2). Note that the measured (or the simulated) samples in Equation (11) should be chosen around the passband.

Using classic two-port S-matrix to Y-matrix transformation formulas with normalized characteristic impedances [18], the Y-parameter functions can be derived as:

$$Y_{21} = \frac{-2S_{21}}{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}$$
$$Y_{22} = \frac{(1+S_{11})(1-S_{22}) + S_{12}S_{21}}{(1+S_{11})(1+S_{22}) - S_{12}S_{21}} \tag{12}$$

It is observed that Y-parameters without the phase shift at I/O ports can be obtained, once knowing parameters φ_{01}, θ_{01}, φ_{02}, and θ_{02}. Then, the unloaded Q and coupling matrix can be extracted using Sections 2.1 and 2.2 in this paper.

Four unknown parameters φ_{01}, θ_{01}, φ_{02}, and θ_{02} are obtained by minimizing the following objective error function using the genetic algorithm (GA):

$$\begin{aligned} F \;=\; & \sum_{i=1}^{Ns} [|S_{21}^{ext}(s_i)| - |S_{21}^{mea}(s_i)|]^2 + [|S_{11}^{ext}(s_i)| - |S_{11}^{mea}(s_i)|]^2 \\ & + [|S_{12}^{ext}(s_i)| - |S_{12}^{mea}(s_i)|]^2 + [|S_{22}^{ext}(s_i)| - |S_{22}^{mea}(s_i)|]^2. \end{aligned} \tag{13}$$

where $S_{21}^{ext}(s_i)$, $S_{11}^{ext}(s_i)$, $S_{12}^{ext}(s_i)$, $S_{22}^{ext}(s_i)$ are the extracted S-parameters at frequency points s_i ($i = 1, 2, \ldots, Ns$) via Equation (8).

GA can be used to solve the global minimum value of a multivariate function. In this paper, the GA toolbox for Matlab provided by the University of Sheffield is chosen to minimize the error function in Eq. (13).

3. EXAMPLES

3.1. Diagnosis of a Sixth-Order Filter with Four TZs (Filter 1)

The diagnosis technique presented here is first applied to the simulated S-parameters of the sixth-order filter with $f_0 = 0.85$ GHz, $nz = 4$ and $BW = 40$ MHz (filter 1), which is designed on a Rogers RO3010 substrate with a relative dielectric constant of 10.2, thickness of 1.27 mm and dielectric loss tangent of 0.0035, as shown in Fig. 1(a). The conductivity of the metal is set to $5.8. \times 10^7$ S/m in the simulation.

The filter is simulated using a full-wave simulator IE3D. The proposed algorithm is applied with $N = 6$, $nz = 4$, $Ns = 41$ (frequency interval 0.81–0.89 GHz). The desired parameters are obtained as follows: $r_{21k} = (0.0319 + 0.0019i, -0.0896 - 0.0016i, -0.0660 + 0.0002i, 0.1648 - 0.0006i, 0.2183 - 0.0004i, -0.2586 + 0.0003i)$; $r_{22k} = (0.0060 - 0.0006i, 0.2110 + 0.0012i, 0.0847 - 0.0011i, 0.1498 + 0.0002i, 0.2262 - 0.0004i, 0.2521 - 0.0003i)$; $\lambda_k = (1.1555 + 0.1325i, 1.1298 + 0.1342i, -1.0513 + 0.1334i, -0.9148 + 0.1361i, 0.4386 + 0.1339i, -0.2771 + 0.1344i)$; $k = 1, 2, 3, 4, 5, 6$.

The normalized N+2 coupling matrix is extracted as

$$M = \begin{bmatrix} 0 & 0.9576 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.9576 & -0.0421 & 0.7697 & 0 & 0 & 0 & 0.0235 & 0 \\ 0 & 0.7697 & -0.1556 & 0.5947 & 0 & -0.2451 & -0.0180 & 0 \\ 0 & 0 & 0.5947 & 0.0171 & 0.6495 & 0.0847 & 0 & 0 \\ 0 & 0 & 0 & 0.6495 & -0.1366 & 0.5901 & 0 & 0 \\ 0 & 0 & -0.2451 & 0.0847 & 0.5901 & -0.1112 & 0.7732 & 0 \\ 0 & 0.0235 & -0.0180 & 0 & 0 & 0.7732 & -0.0522 & 0.9642 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.9642 & 0 \end{bmatrix} \tag{14}$$

$$G = -\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.1342 & -0.0009 & 0.0006 & 0.0001 & 0.0012 & 0.0002 & 0 \\ 0 & -0.0009 & -0.1341 & -0.0007 & -0.0022 & 0.0001 & 0.0012 & 0 \\ 0 & 0.0006 & -0.0007 & -0.1336 & 0.0005 & 0.0018 & 0 & 0 \\ 0 & 0.0001 & -0.0022 & 0.0005 & -0.1337 & -0.0004 & 0 & 0 \\ 0 & 0.0012 & 0.0001 & 0.0018 & -0.0004 & -0.1345 & -0.0003 & 0 \\ 0 & 0.0002 & 0.0012 & 0 & 0 & -0.0003 & -0.1344 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{15}$$

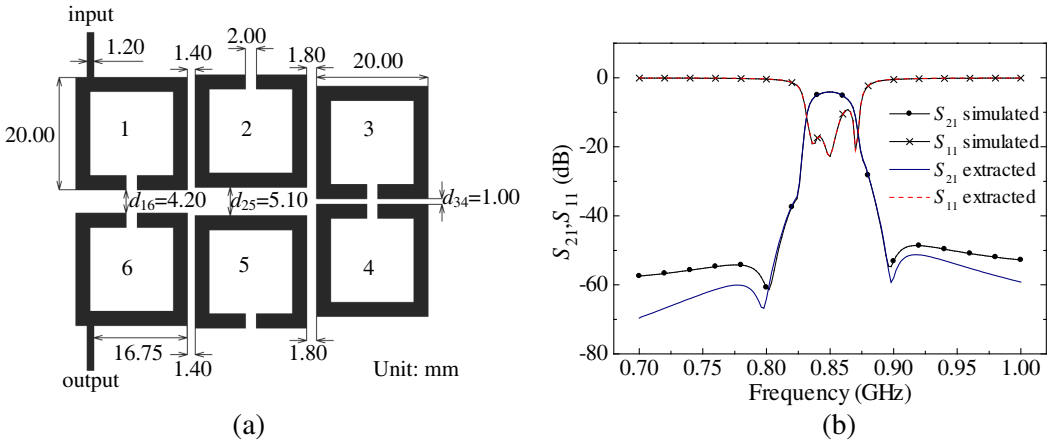

Figure 1. (a) The physical dimensions and (b) the simulated and the extracted S-parameters of filter 1.

As can been seen, the dominant loss is distributed on the diagonal terms of the matrix G in a correct order to reflect unloaded Q of each resonator of a filter, and the loss on off-diagonal elements becomes considerably small and is neglected. Using Eqs. (7) and (15), the effective unloaded Q is diagnosed as Q_{uk} = (158.3518, 158.5180, 159.0886, 158.8866, 157.9610, 158.1049).

In Fig. 1(b), the simulated response of filter 1 is compared to the extraction one calculated by the extracted CM in Eq. (14). Very good agreement between the simulated and extracted responses can be observed.

Now, let us deliberately change d_{25} shown in Fig. 1(a) from 5.10 mm to 4.10 mm. The new state of filter 1 is simulated by IE3D and then diagnosed by the proposed method. The CM is extracted as

$$M = \begin{bmatrix} 0 & 0.9595 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.9595 & -0.0392 & 0.7668 & 0 & 0 & 0 & 0.0236 & 0 \\ 0 & 0.7668 & -0.1494 & 0.5971 & 0 & \underline{-0.3395} & -0.0263 & 0 \\ 0 & 0 & 0.5971 & 0.0201 & 0.6463 & 0.0982 & 0 & 0 \\ 0 & 0 & 0 & 0.6463 & -0.1439 & 0.5928 & 0 & 0 \\ 0 & 0 & \underline{-0.3395} & 0.0982 & 0.5907 & -0.1210 & 0.7679 & 0 \\ 0 & 0.0236 & -0.0263 & 0 & 0 & 0.7696 & -0.0528 & 0.9642 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.9642 & 0 \end{bmatrix} \quad (16)$$

By comparing Eq. (14) with Eq. (16), we observe that coupling element M_{25} between resonators 2 and 5 is changed from -0.0235 to -0.3395. It should be noted here that changing influences the resonance frequency of the adjacent resonators 1, 6, 3 and 4. This can be observed from the extracted frequency offset associated with those resonators in Eq. (16).

The simulated and extracted S-parameters of this new state of filter 1 are shown in Fig. 2.

3.2. Fabricated Fourth-Order Bandpass Filter (Filter 2)

The diagnosis technique will be applied in the measured S-parameters of a fourth-order filter (filter 2). Filter 2 is fabricated on a Rogers RT/duroid 5880 substrate with a relative dielectric constant $\varepsilon_r = 2.2$, thickness $h = 0.508$ mm, and loss tangent $\delta = 0.0009$. The physical dimensions and a photograph of filter 2 are shown in Fig. 3(a) and Fig. 3(b), respectively.

The novel algorithm is applied with $N = 4$, $nz = 2$, $Ns = 21$ (frequency interval 1.70–1.90 GHz), $f_0 = 1.80$ GHz and $BW = 60$ MHz.

The desired parameters are obtained as follows: $r_{21k} = (-0.2062+0.0563i, 0.1787-0.1042i, 0.3851-0.0536i, -0.3447+0.0744i)$; $r_{22k} = (0.1399+0.0317i, 0.2682-0.0390i, 0.3422-0.0046i, 0.3219-0.0380i)$; $\lambda_k = (-1.9068 + 0.4119i, 1.4531 + 0.1364i, -1.0757 + 0.1385i, 0.3976 + 0.1408i)$; $k = 1, 2, 3, 4$.

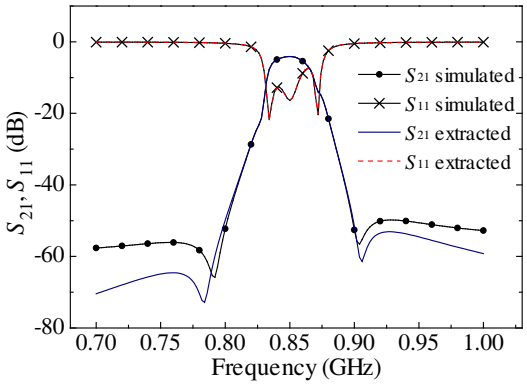

Figure 2. The simulated and the extracted S-parameters of the new state of filter 1.

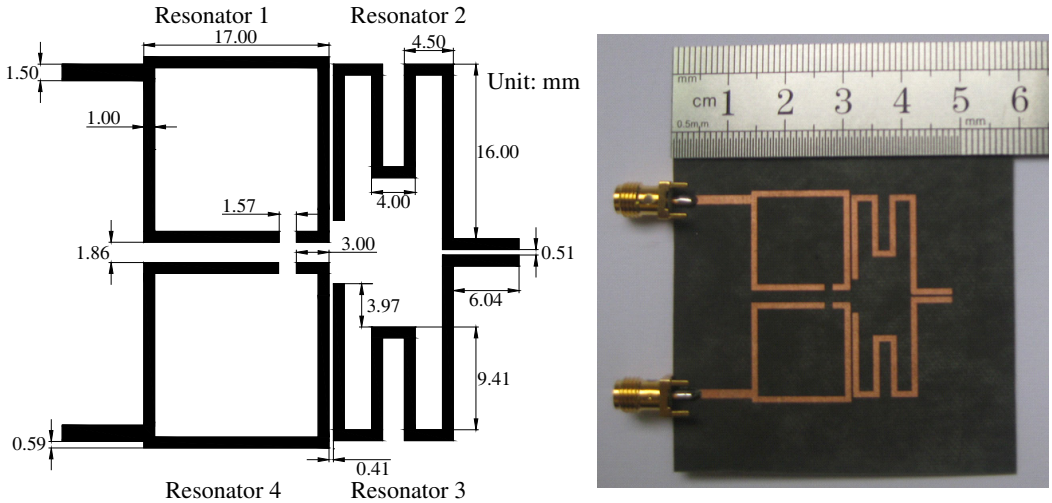

Figure 3. (a) The physical dimensions and (b) the photograph of the filter 2.

The normalized $N+2$ coupling matrix is extracted as

$$M = \begin{bmatrix} 0 & 1.1070 & 0 & 0 & 0 & 0 \\ 1.1070 & 0.5921 & 1.1045 & -0.0103 & 0.0953 & -0.0117 \\ 0 & 1.1045 & 0.1837 & 0.8021 & -0.0582 & 0 \\ 0 & -0.0103 & 0.8021 & 0.2484 & 1.1874 & 0 \\ 0 & 0.0953 & -0.0582 & 1.1874 & 0.1114 & 1.0354 \\ 0 & -0.0117 & 0 & 0 & 1.0354 & 0 \end{bmatrix} \tag{17}$$

$$G = -\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.2067 & 0.0774 & 0.1468 & 0.0510 & 0 \\ 0 & 0.0774 & 0.2285 & 0.1141 & 0.1348 & 0 \\ 0 & 0.1468 & 0.1141 & 0.2207 & 0.0585 & 0 \\ 0 & 0.0510 & 0.1348 & 0.0585 & 0.1755 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{18}$$

Using Eqs. (7) and (18), the effective unloaded Q for each resonator is diagnosed as Q_{uk} = (145.11, 131.26, 135.91, 170.97).

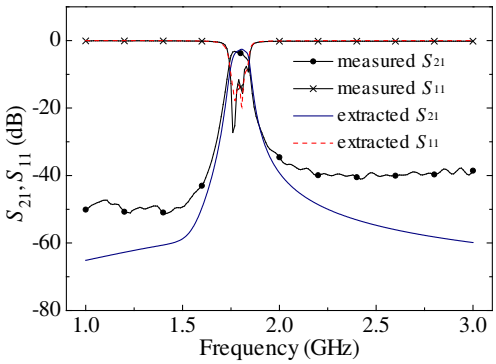

Figure 4. The measured and extracted S-parameters of the filter 2.

In Fig. 4, the measured responses of filter 2 are compared to the extracted results. Good agreement between the measured and extracted responses can be observed.

3.3. Simulated Eighth-Order Bandpass Filter (Filter 3)

In the third example, the diagnosis technique is applied to the simulated S-parameters of an eighth-order filter (filter 3), which is designed on a Rogers RT/duroid 5880 substrate ($\varepsilon_r = 2.2$, $h = 0.508$ mm, and $\delta = 0.0009$). The physical structure and dimensions of filter 3 are shown in Fig. 5. The filter is simulated using a full-wave simulator IE3D. The loss factors (conductor loss and dielectric loss) are included in the simulated response. The conductivity of the metal is set to 5.8×10^7 Siemens/m in the simulation.

The diagnosis technique is applied to filter 3 with $N = 8$, $nz = 2$, $Ns = 36$ (frequency interval 2.61–2.79 GHz), $f_0 = 2.70$ GHz and $FBW = 3.70\%$. The diagnosed results are shown in Table 1. Filter 3 is also diagnosed by the previous method in [13]. For comparison, the diagnosed results obtained by [13] are also shown in Table 1. As can be seen from Table 1, the $(4N + 1)$ optimized variables were reduced with respect to our previous proposed method in [13]. In addition, the optimized variable was reduced and the proposed method can be used in the filter diagnosis with non-uniform unloaded Q with respect to our previous proposed method in [12].

In Fig. 6, the original simulated S-parameters are compared with the extracted S-parameters by this paper and the diagnosed method in [13]. Very good agreement between the simulated and extracted responses can be observed.

In the diagnosis of filters 1, 2 and 3, there are also some discrepancies between the simulated (or measured) and extracted S-parameters at frequencies far away from the passband, which is due to second order effects of a physical filter such as spurious passbands, frequency dispersive behavior, presence

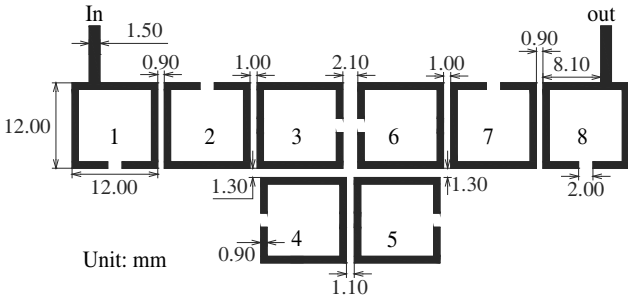

Figure 5. The physical structure and dimensions of filter 3.

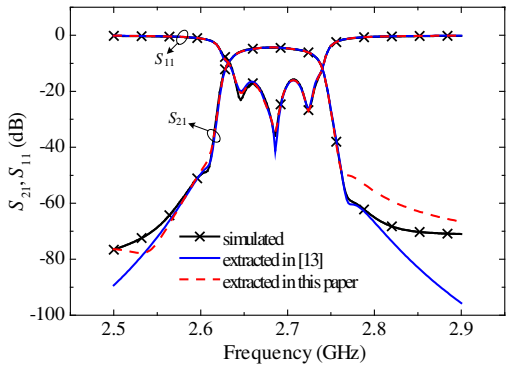

Figure 6. Comparison between the measured and extracted S-parameters of the filter 3.

Table 1. The comparison of the diagnosed results for filter 3 between [13] and this paper.

name	symbols	[13]	this paper
The number of optimized parameters	-	$5+4N$	4
The extracted unloaded Q for each resonator	Q_{u1}	268.07	249.14
	Q_{u2}	279.01	252.53
	Q_{u3}	276.47	232.94
	Q_{u4}	276.49	206.37
	Q_{u5}	271.22	214.77
	Q_{u6}	275.82	253.69
	Q_{u7}	268.07	268.44
	Q_{u8}	272.64	256.33
The extracted normalized coupling matrix coefficient	M_{S1}	1.0790	1.0843
	M_{L8}	1.0106	1.0625
	M_{12}	0.9323	0.9146
	M_{23}	0.6298	0.6460
	M_{34}	0.5591	0.6412
	M_{36}	-0.1418	-0.1749
	M_{45}	0.8075	0.7460
	M_{46}	-0.0977	-0.103
	M_{56}	0.5393	0.5910
	M_{67}	0.6226	0.6501
	M_{78}	0.8824	0.9024
	M_{11}	0.3260	0.3474
	M_{22}	0.3067	0.3072
	M_{33}	0.3093	0.3618
	M_{44}	0.3063	0.3032
	M_{55}	0.5237	0.1821
	M_{66}	0.3360	0.3424
	M_{77}	0.3270	0.2791
	M_{88}	0.3340	0.4985

of spurious couplings and frequency-dependent couplings. In an ideal extraction circuit model, it is assumed that the coupling coefficient is independent of the frequency. However, the coupling coefficient inevitably depends on the frequency for the actual physical filter, which leads to the difference between the simulated (or the measured) and extracted S-parameters, and the greater this difference is, the farther away the frequency is from the passband, So the frequency samples should be chosen around the passband to obtain the correct diagnosis results. The proposed method is only applicable to the diagnosis of a narrow band coupled resonator bandpass filter ($FBW < 5\%$).

4. CONCLUSION

A hybrid method combining a vector fitting (VF) and a global optimization is proposed to diagnose the coupled resonator bandpass filters. The optimization method is used to remove the phase shift effects at the input/output port in the filter. VF is applied to determine the complex poles and residues of the Y-parameters without the phase shift, and then the coupling matrix corresponding to the filter can be extracted by these complex poles and residues. With respect to our previous proposed methods, the number of optimized variables is reduced. Three diagnosis examples, including two simulated filters and one fabricated filter, are provided to illustrate the validation of the proposed technique.

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