Automated Filter Tuning by Optimizing Absolute Values of S Parameters

#Takayuki UCHIDA[1], Koichi ICHIGE[1], Koichi MIYAMOTO[2], Yoshio EBINE[2] and Yasuo HIROSE[1]

[1] Department of Electrical and Computer Engineering, Yokohama National University
79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan
E-mail: ucchi@ichilab.dnj.ynu.ac.jp, koichi@ynu.ac.jp, hirose@ynu.ac.jp
[2] Filter Business Division, Nihon Dengyo Kosaku Co. Ltd.
2-2-7 Asahi-cho, Nerima-ku, Tokyo 179-0071, Japan

1. Introduction

Frequency for mobile communication is nowadays divided into many narrowbands which are assigned for different purposes. Extracting target frequency component is a fundamental but significant operation for the use of limited frequency, and multi-pole dielectric band pass filter (BPF) is widely used for the separation of target frequency channel information. So far the tuning of BPF characteristics is performed by experienced engineer by adjusting positions of screws. This process is time consuming, high cost, and needs skilled engineers, and therefore automatic tuning procedure is desired.

The automatic tuning techniques using gradient-based optimization have already been proposed [1], [2]. These techniques approximately derive the transfer function of the equivalent BPF circuit from the measured S parameter, and optimize it by comparing the coefficients of the transfer function with the ideal coefficients. However, those methods have problems of convergence to local-optimum and computational cost due to slow convergence.

In this paper, we develop a novel approach of automatic filter tuning based on the optimization of the absolute values of S parameters. The accuracy and the speed of the proposed automatic tuning method are evaluated by experiments, and we will see how the proposed technique is effective in automatic BPF tuning.

2. Preliminaries

2. 1 Lowpass prototype filter

First we define the characteristics of lowpass prototype filter. The transmission coefficients $S_{21}(\omega)$ of the filter is given by

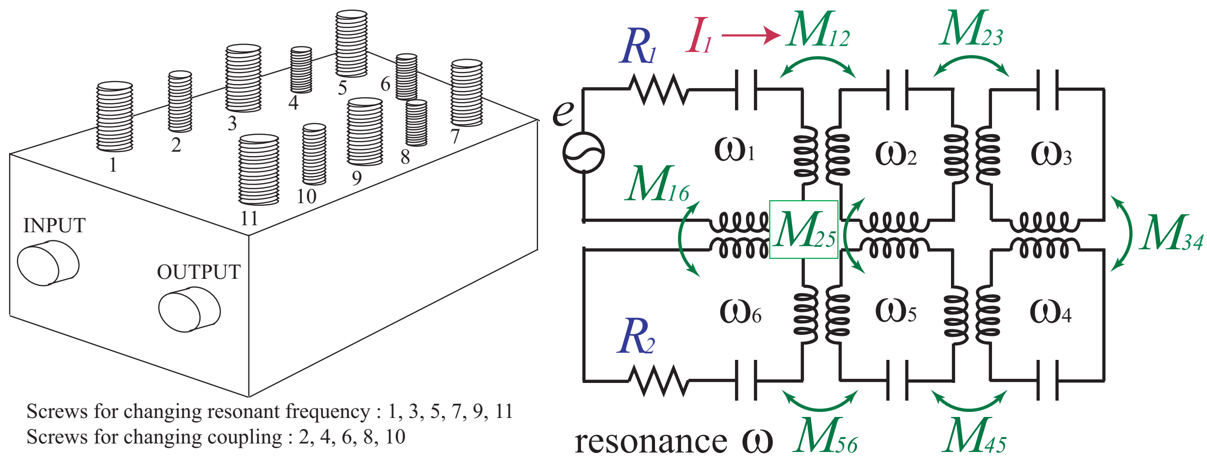
$$|S_{21}(\omega)|^2 = \frac{1}{1+\varepsilon^2 F_N^2(\omega)} \quad (1)$$

$$F_N(\omega) = \cosh\left(\sum_{n=1}^{N}\cosh^{-1}\left(\frac{\omega - 1/\omega_n}{1-\omega/\omega_n}\right)\right) \quad (2)$$

where ω denotes angular frequency, and ε is a constant related to the passband return loss R as $\varepsilon = (10^{R/10}-1)^{-1/2}$. Also ω_n is given as the location of the n-th transmission zero.

2. 2 BPF Tuning Using Its Equivalent circuit

Consider a 6-element cross coupling BPF as shown in Fig.1(a), where its equivalent circuit is given by Fig.1(b). In Fig.1(b), ω denotes normalized resonance frequency, ω_i is the frequency shift at i-th resonator, R_1 and R_2 are input/output impedances, and M_{ij} is coupling coefficient between i-th and j-th resonators.



(a) BPF image

(b) Equivalent circuit

Figure 1: 6 stage cross coupled filter

From Fig.1(b), the current vector $\boldsymbol{I}$ is defined by

$$\boldsymbol{I} \quad = \quad -j\boldsymbol{A}^{-1}\boldsymbol{e}. \tag{3}$$

where $\boldsymbol{e}^t = [1, 0, ..., 0, 0]$ denotes the excitation vector, and the matrix $\boldsymbol{A}$ is given by

$$A = \begin{bmatrix} \omega+\omega_1-jr_1-jR_{in} & M_{12} & 0 & 0 & 0 & M_{16} \\ M_{12} & \omega+\omega_2-jr_2 & M_{23} & 0 & M_{25} & 0 \\ 0 & M_{23} & \omega+\omega_3-jr_3 & M_{34} & 0 & 0 \\ 0 & 0 & M_{34} & \omega+\omega_4-jr_4 & M_{45} & 0 \\ 0 & M_{25} & 0 & M_{45} & \omega+\omega_5-jr_5 & M_{56} \\ M_{16} & 0 & 0 & 0 & M_{56} & \omega+\omega_6-jr_6-jR_{out} \end{bmatrix}$$

The network coefficients in $\boldsymbol{A}$ are determined by iterative gradient-based optimization [1], [2]. Using equation (3), S parameters are given by

$$S_{21} \quad = \quad 2\sqrt{R_1R_2}\boldsymbol{I}_N = -2j\sqrt{R_1R_2}\left[\boldsymbol{A}^{-1}\right]_{N1} \tag{4}$$

$$S_{11} \quad = \quad 1-2R_1\boldsymbol{I}_1 = 1+2jR_1\left[\boldsymbol{A}^{-1}\right]_{11} \tag{5}$$

3. Tuning Procedure

The proposed tuning procedure is developed in this section.

3.1 Tuning flow

The outline of the automatic tuning technique [1], [2] using gradient-based optimization is shown below. If the obtained characteristics does not satisfy the target specifications after step 5), go back to step 3) and iterate the procedures 3)-5).

step 1) Setting of the target coefficient values using filter synthesis.
step 2) Coarse tuning by the experienced engineer.
step 3) Measurement of S parameters after coarse tuning (base position).
step 4) Measurement of S parameters while rotating each screw from base position.
step 5) Coefficient analysis using gradient-based optimization.
step 6) Determine the optimal screw position (fine tuning).

3.2 Filter synthesis

The coupling values and input/output resistance are determined by gradient-based optimization so that the desired filter specifications are satisfied. Here we assume the ideal case where network losses and frequency shifts are zero. The coefficient values are calculated by the gradient method from S parameter of the designed Chebyshev filter shown in Fig.2(a). The cost function for optimization is given by

$$F = \sum_{freq.} \left[\left| S_{11}^{computed} - S_{11}^{chebyshev} \right|^2 + \left| S_{21}^{computed} - S_{21}^{chebyshev} \right|^2 \right] \quad (6)$$

where $S^{computed}$ is the calculated value given by (4) and (5), and $S^{chebyshev}$ is designed filter specification. This cost function is not sensitive on selecting initial values, and the convergence of the gradient method is guaranteed. The obtained coefficient values are set as the target value for filter tuning.

3.3 Parameter extraction

The example S parameters measured after coarse tuning in step 2) is shown in Fig.2(b). Here the unknown network coefficients are found by minimizing the following cost function.

$$F = \sum_{freq.} \left[\left| S_{11}^{network} - S_{11}^{measured} \right|^2 + \left| S_{21}^{network} - S_{21}^{measured} \right|^2 \right] \quad (7)$$

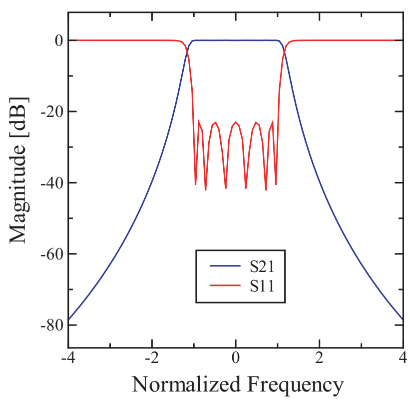
where $S^{measured}$ is measured S parameter, and $S^{network}$ are the response of the prototype network and a function of the unknown parameters. Both the real and imaginary parts of S parameters are optimized in [2], however we optimize the absolute values of S parameters in the present method.

3.4 Screw sensitivity

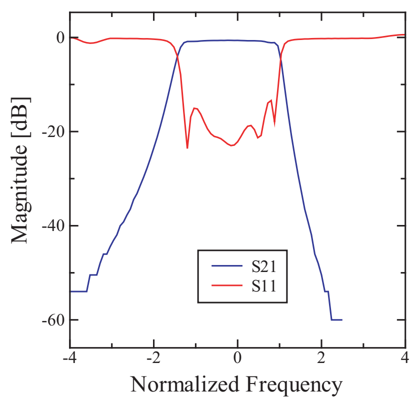
In step 5), the network coefficients are derived from S parameter when each screw obtained by steps 3) and 4) is slightly changed using the parameter extraction technique. At this time, the $(N+1)$ set of coefficients (N is the number of screw, $+1$ is for base position) are extracted. Then we have the relation between the changes screw rotation from base position and circuit coefficients. Note that each coefficient varies almost linear against the change of each screw rotation [1], the amount of screw rotation Δ^{depth} will determined so that the coefficients become the same with those of the desired coefficients in step 1).

$$\Delta^{depth} = [\Delta x^{sens}]^{+}(x^{base} - x^{desired}) \quad (8)$$

where $[\Delta x^{sens}]$ denotes the difference of the coefficients when rotating each screw, and $\cdot^{+}$ denotes generalized inverse matrix. Also x^{base} and $x^{desired}$ respectively indicate the coefficients for base position and desired characteristics.

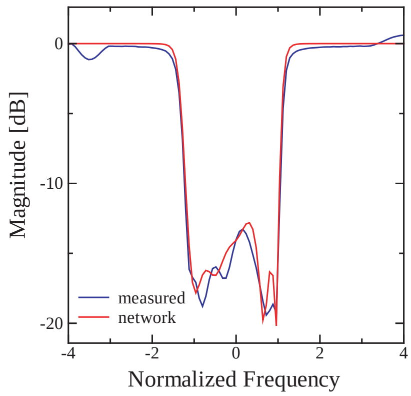


(a) Desired filter

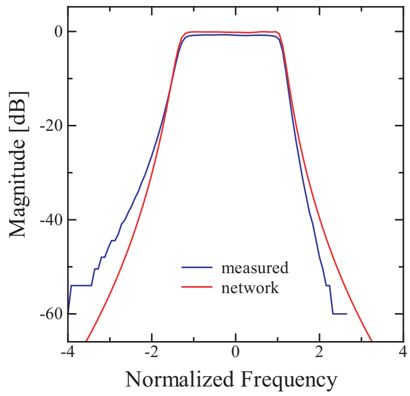


(b) Measured filter

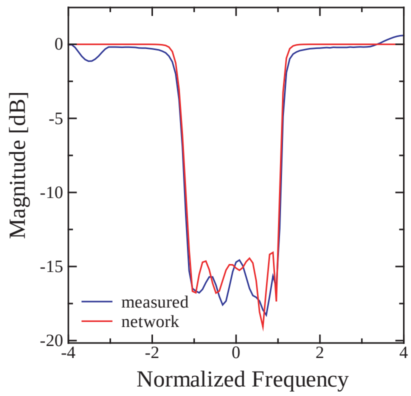
Figure 2: Examples of Six-resonator BPF responses



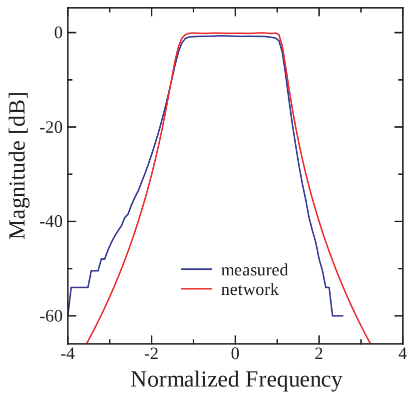
(a) S_{11}, before tuning



(b) S_{21}, before tuning



(a) S_{11}, after tuning



(b) S_{21}, after tuning

Figure 3: Behavior of S parameters before and after tuning

4. Experiment

The accuracy of tuning method is evaluated through some experiments in this section.

Figure 3 shows the behavior of S parameters before and after tuning. We see from Fig.3 that the measured characteristics approaches to calculated ones by optimization, but there exist some differences between measured and calculated values. The reason would be the difference of resonant frequencies, and it may result the wrong convergence in optimization. That should be studied as one of future studies.

5. Concluding Remarks

This paper presented a novel automatic tuning method for cross-coupled resonator BPF, that can be regarded as a modified version of conventional gradient-based methods. Through some experiments, the measured characteristics are improved by optimization but did not converge to the optimal one due to the difference of resonant frequencies. That remains as one of future studies.

References

[1] Harscher et al, "Automated Computer-Controlled Tuning of Waveguide Filters Using Adaptive Network Models", IEEE trans. MTT, vol. 49, pp. 2125-2130, Nov. 2001.

[2] Harscher et al, "Automated Filter Tuning Using Generalized Low-Pass Prototype Networks and Gradient-Based Parameter Extraction", IEEE trans. MTT, vol. 49, pp. 2532-2538, Dec. 2001.