A Miniaturized End-Coupled Tunable Bandpass Filter
With Reduced Varactors

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I. Introduction

In wireless communication system, a filter is essential in order to select wanted signal. To do this, a system requires tunable bandpass filter which passes desire signal what we want. There are many tunable bandpass filters which can be categorized into three groups [1]. For example, YIG, varactor diode filters, and RF MEMS filter. Especially, a digital-type tuning three-pole RF MEMS filter shows good performance [2]. But, the size of capacitor bank imposes constrains on the design of the digital-type filter. To overcome constrains, therefore, it is useful to design the filter applied continuous tuning approach [3].

In this study, we present a four-pole end-coupled tunable bandpass filter with proposed size-reduction method. This proposed method can make the resonators shorter and lessen the number of used varactor diode. As a result, the experiment shows that the proposed method has application to reduce the number of varactor diode. In this paper, we designed and tested an end-coupled tunable bandpass filters using an existing size-reduction method [4] and the proposed method. Fig. 1 shows layout of the each end-coupled bandpass filter when we use two different size-reduction methods.

II. Analysis and Design Equations

A. Properties of End-Coupled Bandpass Filter

We can design easily an end-coupled filter fitting with specification [5]-[6]. As shown in Fig. 2, this filter consists of four quarter-wavelength resonators having characteristic impedance 50Ω and J, K-inverters. And each immittance inverter can be expressed as transmission lines and reactive element. Also, we design an inductive component of K-inverter to shorted stub whose length is shorter than λ/4 and a capacitive component of J-inverter to capacitor or gap between resonators.

B. Equation of Proposed Size-Reduction Method

In this section, we show that how to derive design parameters to use proposed size-reduction method. If we use an existing size-reduction method, a quarter-wavelength resonator can be modeled as a PI-section, which is a shortened transmission line having two capacitive components on both ends as shown in Fig. 3(b). However, two capacitive components can be reduced to only one capacitive component by using following proposed size-reduction method, modeled as a T-section, as shown in Fig. 3(c).

The ABCD-matrixes of Fig. 3(a) and Fig. 3(c) are

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix} = \begin{bmatrix}
\cos \theta & -1 \\
0 & \cos \theta
\end{bmatrix} \begin{bmatrix}
0 & 1 \\
-1 & 0
\end{bmatrix}
\]

(1)

\[
\begin{bmatrix}
A' & B' \\
C' & D'
\end{bmatrix} = \begin{bmatrix}
\cos \frac{\theta_r}{2} & jZ_r \sin \frac{\theta_r}{2} \\
jY_r \sin \frac{\theta_r}{2} & \cos \frac{\theta_r}{2}
\end{bmatrix} \begin{bmatrix}
1 & 0 \\
0 & 1
\end{bmatrix}
\begin{bmatrix}
\cos \frac{\theta_r}{2} & jZ_r \sin \frac{\theta_r}{2} \\
0 & \cos \frac{\theta_r}{2}
\end{bmatrix}
\]

(2)
Comparing (1) and (2), each element between two matrixes should be equal. Thus, we can get following two simultaneous equations.

\[
\theta_r = \cos^{-1}\left(\frac{\cos \theta}{\sqrt{1 + (\pi C_f Z_f)^2}}\right) - \tan^{-1}(\pi C_f Z_f) \quad (3)
\]

\[
C_f = \frac{Z_f \sin \theta_r - Z_0 \sin \theta}{\omega^2 \sin^2 \left(\frac{\theta_r}{2}\right)} \quad (4)
\]

The solution of the equation (3) and (4) can be easily obtained. For example, graphical method can be used. Now, we can design bandpass filter with proposed size-reduction method by making use of these design parameters.

**C. Tunability and Coupling Relation**

For bandpass filter, it is the variable reactance components that allow us to tune the central frequency. Now, we see that the central frequency of the bandpass filter varies when we change the reactance value on the resonator. To do this, it is convenient for us to use varactor diode to change reactance of the resonator.

Besides, the coupling coefficient of J, K-inverter varies with changing the tuning frequency [7]. In this end-coupled bandpass filter, we can control coupling values between resonators by using varactor diodes, replacing the capacitive component of the J-inverter with varactor diodes.

**III. Experimental Results**

To overcome discrete tuning constrains, new design of end-coupled tunable bandpass filter is designed and fabricated. In order to verify proposed size-reduction method design approach, the filter was built with Rogers RO3003 substrate and it is tested. The substrate has a thickness of 20mil and relative dielectric constant of 3.

The measured S-parameters of each different size-reduction method, conventional size-reduction method and proposed size-reduction method, are presented in Fig. 4 and Fig. 5. In this work, the performance with the proposed size-reduction method is almost same comparing to when we design the bandpass filter using conventional size-reduction design method.

**IV. Conclusion**

In this paper, we proposed new size-reduction method so that we can miniaturize the filter. This proposed size-reduction method makes the resonator into a shortened transmission line shorter than \(\lambda/4\). And besides it reduces the number of varactor diode. The T-section equivalent circuit has only one capacitive component in the middle of the resonator. By changing the reactance value on the resonator using varactor diodes, the central frequency of the bandpass filter could vary continuously covering from 1.6GHz to 2.0GHz, tuning range of 22.2%.

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References


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![Fig. 1. Layout of end-coupled bandpass filter when (a) an existing size-reduction method, (b) the proposed size-reduction method is applied.](image1)

![Fig. 2. The equivalent circuit of a four-pole end-coupled bandpass filter using quarter-wavelength resonators and J, K-inverters. (θ has negative length.)](image2)

![Fig. 3. (a) A transmission line. (b) PI-section shortened transmission line. (c) T-section shortened transmission line.](image3)
Fig. 4. Implemented filter with conventional method.
(a) A photograph. (b) Measured S-parameters.

Fig. 5. Implemented filter with proposed method.
(a) A photograph. (b) Measured S-parameters.