Dielectric Band-Pass Filter with Attenuation Poles at Desired Frequencies

Moon-Que Lee†

Abstract - An analytic design formula is proposed for a TEM mode dielectric bandpass filter with attenuation poles at desired frequencies in the stop band. In order to sustain the constant ripple in the passband due to attenuation poles, the initial resonant frequencies of the various resonators adopted in a filter with attenuation poles are newly calculated. The proposed design theory is verified by designing various bandpass filters with attenuation poles in the stop band.

Keywords: attenuation poles, asymmetric filter, bandpass filter, dielectric band pass filter.

1. Introduction

The most important parameters of dielectric Band-Pass Filters (BPFs) are their volume and weight as well as their electrical performance. Since attenuation poles placed in the stop band enable a filter to have greater rejection than a conventional BPF without increasing the number of dielectric resonators, filter designers are interested in techniques for properly inserting attenuation poles in the stop band. Various design techniques for inserting attenuation poles in the stop band have been studied [1-4]. They are suitable for elliptic filters [2] or iteratively solved methods [3]. In this letter, the Initial Resonant Frequencies (IRFs) of the various resonators used in the filter are newly calculated in a closed form so that a BPF with attenuation poles has a (nearly) constant ripple in the passband.

2. Design Theory

A conventional Chebyshev BPF design requires four input design parameters; the IRF (or center frequency), the fractional bandwidth, the susceptance slope of the resonator, and Chebyshev polynomials [5]. Among these parameters, the IRF represents the parallel resonant frequency of a resonator before adding the values of adjacent J or K inverters into the resonator. A TEM mode dielectric BPF with attenuation poles, as introduced here, is composed of three types of resonators, which are shown in Fig. 1.

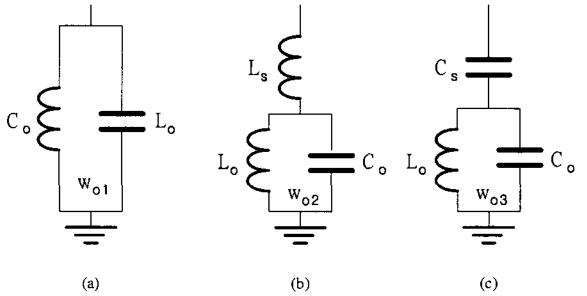

Fig. 1 Three types of resonators used in BPFs with attenuation poles: (a) Type I, (b) Type II, and (c) Type III.

Susceptances of these three types of resonators can be written in a simple form as

$$B_{ri}(\omega)=j\omega_{oi}C_o\frac{x}{K_i(\omega)}. \tag{1}$$

In (1), $K_i(\omega)$ can be differently written for the three types as

$$K_o(\omega)=1 \qquad \text{for type I} \tag{2}$$

$$K_u(\omega)=1-\left(\frac{L_S}{L_o}\right)\left(\frac{\omega}{\omega_o}\right)x=\frac{\omega^2-\omega_S{}^2}{\omega_o{}^2-\omega_S{}^2} \quad \text{for type II} \tag{3}$$

$$K_l(\omega)=1+\left(\frac{C_o}{C_S}\right)\left(\frac{\omega_o}{\omega}\right)x=\left(\frac{\omega_o}{\omega}\right)^2\frac{\omega^2-\omega_S{}^2}{\omega_o{}^2-\omega_S{}^2} \quad \text{for type III} \tag{4}$$

where

$$\omega_{oi}=\frac{1}{\sqrt{L_oC_o}}, \tag{5}$$

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$$x = \left(\frac{\omega}{\omega_{oi}} - \frac{\omega_{oi}}{\omega} \right), \qquad (6)$$

and the radian series resonant frequencies ω_S's of type II and type III are

$$\omega_S = \frac{1}{\sqrt{C_o \left(\frac{L_o L_S}{L_o + L_S} \right)}} \quad \text{for type II} \qquad (7)$$

$$\omega_S = \frac{1}{\sqrt{L_o (C_S + C_o)}} \quad \text{for type III} \qquad (8)$$

The attenuation poles are implemented by the series resonances of type II (upper band) and type III (lower band), at which the resonators are shorted. Thus, the series resonance frequencies of type II and type III are the same as the frequencies of attenuation poles. However, the introduction of an additional element to the resonator for the purpose of placing an attenuation pole changes the susceptance slope parameter of the resonator [3, 4]. In order to sustain a constant ripple in the passband, the IRF of a resonator should be de-tuned before adding the values of adjacent J inverters into the resonators. In this section, the IRFs of the three types of resonators shown in Fig. 1 are calculated from the following susceptance relationship, which is a modified form of the mapping function linking the low-pass characteristics to band-pass,

$$B_{ri}(\omega_1) + B_{ri}(\omega_2) = 0, \qquad (9)$$

where ω_1 and ω_2 are the upper and the lower corner radian frequencies of BPF, respectively. For a conventional LC resonator (Type I), substituting (1) and (2) into (5) gives the IRF ω_{01} for type I as

$$\omega_{o1} = \sqrt{\omega_1 \omega_2} \qquad (10)$$

which is the geometric mean of the bandwidth, known as the center frequency of the conventional Chebyshev filter.

The IRFs for the type II and type III resonators with additional series resonances have more complex forms than that of type I. Applying (1) and (3) into (9) gives the IRF ω_{o2} of type II resonator as

$$\omega_{o2} = \sqrt{\frac{\omega_S^2 \left(\omega_1^2 \omega_2 + \omega_1 \omega_2^2 \right) - \omega_1^2 \omega_2^2 (\omega_1 + \omega_2)}{\omega_S^2 (\omega_1 + \omega_2) - \left(\omega_1^3 + \omega_2^3 \right)}} \qquad (11)$$

Similarly, the IRF ω_{03} of type III can be obtained from (5) as

$$\omega_{o3} = \sqrt{\frac{\omega_1^2 \omega_2^2 (\omega_1 + \omega_2) - \omega_S^2 \left(\omega_1^3 + \omega_2^3 \right)}{\omega_1 \omega_2 (\omega_1 + \omega_2) - \omega_S^2 (\omega_1 + \omega_2)}}. \qquad (12)$$

After allocating the attenuation poles to the conventional resonators (Type I), the admittance inverters are calculated from the fractional bandwidth, Chebyshev polynomials, and the admittance slopes at newly calculated IRFs (ω_{o1}, ω_{o2}, and ω_{o3}) [5]. These admittance inverters can be added into the adjacent resonators using the dipole impedance transformation [6].

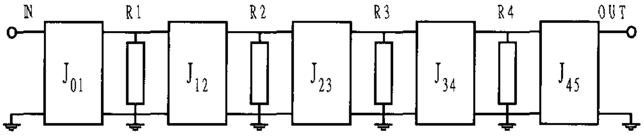
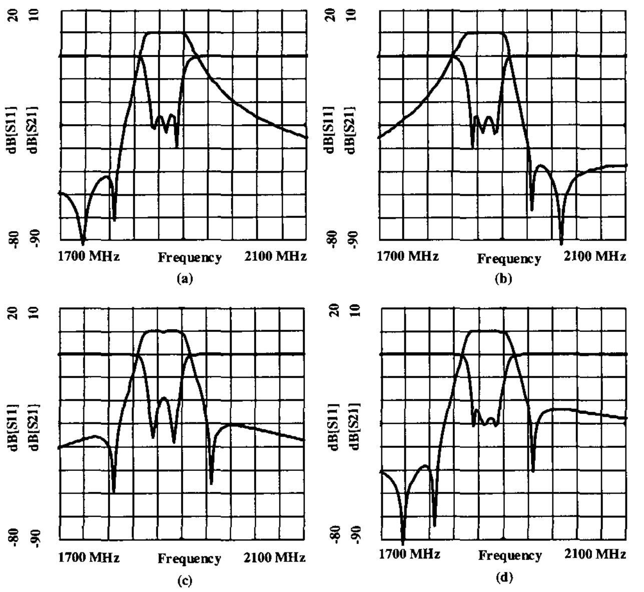


Fig. 2 The configuration of a passband filter with attenuation poles. R1, R2, R3, and R4 are selected among the resonators shown in Fig. 1.

Four BPFs with attenuation poles have been designed to verify the design theory. The designed filters have a passband of 1850 MHz to 1950 MHz. Filter configuration is presented in Fig. 2. Attenuation poles (ω_{s1} and ω_{s2}) of BPF-A, BPF-B, and BPF-C are implemented in R1 and R4, respectively. For the case of BPF-D, ω_{s1}, ω_{s2} and ω_{s3} are implemented in R1, R2, and R4, respectively. Allocation of attenuation poles on the resonators is listed in Table I. Their frequency responses as shown in Fig. 3 indicate that the newly calculated IRFs successfully compensate the distortion of frequency response in the passband.

Table 1 Allocation of attenuation poles over the resonators provided in Fig. 2.

	R1(ω_{s1})	R2(ω_{s2})	R3	R4 (ω_{s2} or ω_{s3})
BPF-A	Type III (1790)	Type I	Type I	Type III (1740)
BPF-B	Type II (1950)	Type I	Type I	Type II (2000)
BPF-C	Type III (1790)	Type I	Type I	Type II (1950)
BPF-D	Type III (1740)	Type II (1790)	Type I	Type III (1950)

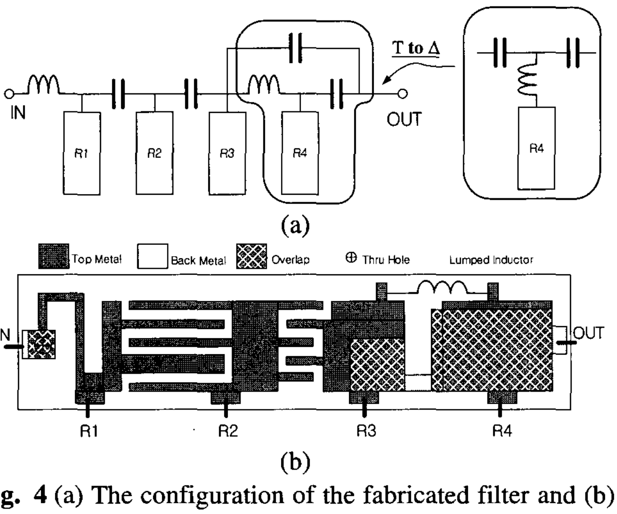


(a) (b) (c) (d)

Fig. 3 Various BPFs with attenuation poles designed by the proposed method.

3. Experiment

A four-pole BPF with an attenuation pole has been designed and constructed with a center frequency of 1.9 GHz, a bandwidth of 100 MHz, and an attenuation pole at 2050 MHz. Fig. 4 shows the circuit configuration and a coupling pattern on a two-layer alumina substrate. The attenuation pole is implemented by the Delta-network converted from the T-network. The relative permittivity of a TEM mode dielectric resonator is 34. Fig. 5 shows the experimental results of the designed BPF. The EM simulation for the coupling pattern is performed using an EM field simulator (Sonnet^{TM}). The measured data demonstrates good agreement with the simulation result.



(a) (b)

Fig. 4 (a) The configuration of the fabricated filter and (b) its coupling pattern on an alumina substrate with double side layers. Total size: 12 [mm] X 3.8 [mm].

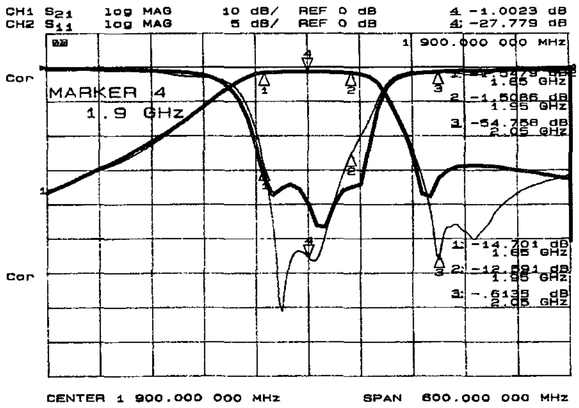


Fig. 5 Simulated and measured data of an implemented filter around the passband (Bold lines: Simulated, Thin lines: Measured).

4. Conclusion

An analytic design formula for a BPF with attenuation poles has been introduced. Various design examples have verified that newly calculated IRFs of various resonators can be successfully applied to compensating the distortion of the frequency response in the passband. Since the proposed analytic design formula is the same as the conventional BPF design formula except for the IRFs of resonators, the proposed design method can be easily applied to the design of a BPF with attenuation poles.

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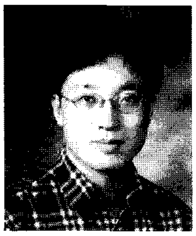

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He received his B.S. degree in Electrical and Electronics Engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejon, Korea, in 1992, and his M.S. and Ph.D. degrees in Electronics Engineering from Seoul National University, Seoul, Korea, in 1994 and 1999, respectively. Following graduation, he joined the Satellite Communications System Department, Electronics and Telecommunications Research Institute (ETRI), Daejon, Korea, as a Senior Member of the Research Staff where he was involved with the development of microwave components and millimeter-wave MMIC's for satellite payloads. He is currently an Assistant Professor in the Department of Electrical and Computer Engineering, University of Seoul, Seoul, Korea. His research interests are the design of RF-CMOS and MMIC.