Design of Low-Loss Coaxial Cavity Bandpass Filter with Post-Manufacturing Tuning Capabilities

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***Abstract*—This paper presents a low-loss of coaxial cavity bandpass filter with post-manufacturing tuning capabilities.A systematic filter development using the lowpass prototype as a starting point to produce 4th degreeChebyshevbandpass response is demonstrated. The coaxial cavity filter based upon TEM mode of propagation has the center frequency of 2.5 GHz and bandwidth of 168MHz. The insertion loss of 0.15 dB insertion loss and return loss better than 15 dB areobtained particularly in the passband. This type of microwave filter would be useful in any microwave systems where the low insertion loss and high selectivity are crucial, such as in a base station, radar and satellite transceivers.**

Keywords-Microwave Filters; Coaxial Filters; Combline Filters.

I. INTRODUCTION

Microwave systems have an enormous impact on modern society. Applications are diverse, from entertainment via satellite television, to civil and military radar systems. In the field of communications, cellular radio is becoming as widespread as conventional telephony. Microwave and RF filters are widely used in all these systems in order to discriminate between the wanted and unwanted signal frequencies. Cellular radio provides particularly stringent filter requirements both in the base stations and in mobile handsets.

Combline cavity filters are the most common microwave filters and used in modern system such as cellular phone base stations, satellites etc. They are compact, ease of design, and possess excellent stopband and high selectivity. More importantly they havean advantage withthe post-manufacturing tuning capabilities. The filters also provide outstanding performance from the UHF region up to 10 GHz with relatively higher Q factor (ranging between 2,000 to 5,000) than the microstrip technology [1]. In addition, they have many attractive features, including an electromagnetic shielding structure, low-loss characteristics, and a small size [2].

II. DESIGN OF CAVITY FILTER

In this section, a systematic combline cavity filter development using the lowpass prototype as a starting point will be demonstrated. A Chebyshev response will be used in the example because it is widely used and has a relatively high selectivity compared to the Butterworth response.

For realization, the lowpass prototype is then transformed to comblinebandpass filter. The theory behind the transformation is explained in detail in [3].

Low-pass prototype networks are two-port lumped-element networks with an angular cutoff frequency of 1 *rad/s* and operating in a 1Ω system.

The formula to calculate the degree of Chebyshev filter is [3];

$$N \geq \frac{L_A + L_R + 6}{20Log10[S + \sqrt{S^2 - 1}]} \qquad (1)$$

whereL_A is the stopband insertion loss, L_R is the passband return loss and S is the ratio of stopband to passband frequencies.

The element values can now be calculated by determining the level of insertion loss:

$$\varepsilon = (10^{L_R/10} - 1)^{-1/2} \qquad (2)$$

The equations of prototype elements introduce new parameter η:

$$\eta = \sinh\left[\frac{1}{N} sinh^{-1}\left(\frac{1}{\varepsilon}\right)\right] \qquad (3)$$

Element values for the Chebyshevlowpass prototype are then calculated using the following formulas:

$$K_{r,r+1} = \frac{\left[\eta^2 + \sin^2\left(\frac{r\pi}{N}\right)\right]^{1/2}}{\eta} \qquad (4)$$

and

$$C_{Lr} = \frac{2}{\eta} \sin\left[\frac{(2r-1)\pi}{2N}\right] \qquad (5)$$

where$K_{r,r+1}$ is the r_{th} of admittance inverter andC_{Lr} is the r_{th} of capacitor.

The lowpass prototype network can now be transformed to comblinebandpass filter by applying the following equation [3]-[6]:

$$Y_r = \alpha C_{Lr} \tan(\theta) \qquad (6)$$

Equation (6) represents the admittance of a short circuited stub of characteristic admittance, where C_{Lr} is the r_{th} capacitor in prototype network and the θ represents the electrical length of the resonators at the center frequency ω_0 of the filter, α is bandwidth scaling factor.

The equivalent circuit of the combline filter is obtained simply by adding shunt capacitor C_r from the r_{th} node to ground. The formula to calculate the capacitor C_r of the combline filter equivalent circuitis given by:

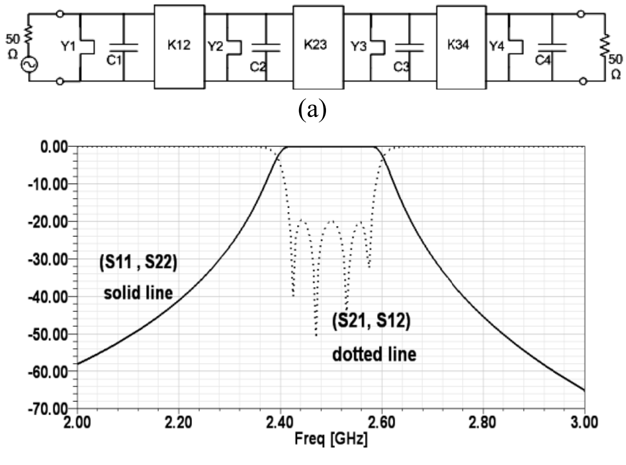
$$C_r = \beta Y_r \qquad (7)$$

where$\beta$is represented by:

$$\beta = \frac{1}{\omega_0 \tan\theta} \qquad (8)$$

whereω = 0 in the lowpass prototype maps to ω_0 in the combline band-pass filter. The impedances of all the circuit elements in the filter are then scaled to 50 Ω system.

Figure 1 (a) shows comblinebandpass filter circuit and its element which are operating in a 50 Ω system. The element values of the equivalent comblinebandpass filter in a 50 Ω system are shown in Table 1. The simulated response of the comblinebandpass filter is shown in Figure 1 (b). It has a design specification as follows: Center frequency of 2.5 GHz with 160 MHz bandwidth. The insertion loss of 0.04dB insertion loss and return loss better than 20 dB are achieved especially in the passband.



(a)

(b)

Figure 1. (a) Combline filter operates in a 50 Ω system, (b) Frequency response of a bandpass filter.

TABLE I. ELEMENT VALUES OF COMBLINE BANDPASS FILTER

Element of combline bandpass Filter	Values
$C_1 = C_4$	15.9894 pF
$C_2 = C_3$	38.1670 pF
$Y_1=Y_4$	9.1327 mho
$Y_2=Y_3$	22.0488 mho
$K_{12} = K_{34}$	0.026
K_{23}	0.031

The equivalent circuit of the combline band filter can now be transformed to physical layout as shown in Figure 2. Figure 3 shows the dimension of physical filter.

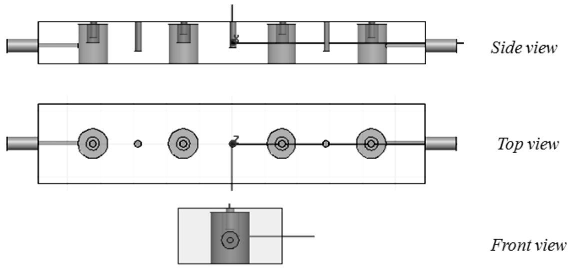


Figure 2. Physical filter layout

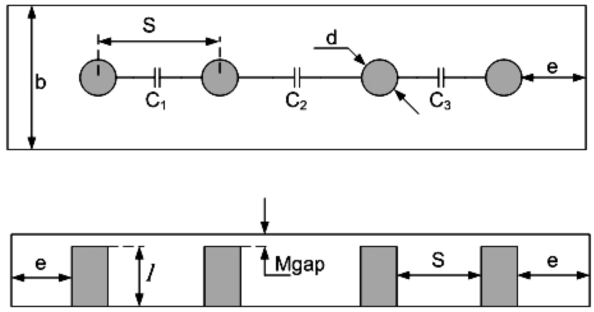


Figure 3. Dimensions of physical filter (a) top view, (b) side view

The dimensions of the physical filter can be determined using:

Cavity diameter, *b*, in mm:

$$\lambda < b < 0.2\,\lambda \qquad (9)$$

where λ is the wavelength at 2.5 GHz.

Resonator diameter, *d*, in mm:

$$0.2b < d < 0.4b \qquad (10)$$

Rod diameter is a function of its impedance and cavity diameter. Hunter [3] gives the characteristic impedance, $Z_\circ$, of round rod between two ground planes as:

$$Z_\circ = 138 \times \log\left[\frac{4b}{\pi d}\right] \qquad (11)$$

The distance between the end wall and first or last resonator, *e*, can be found using:

$$e = \left(\frac{b}{2}\right) + \left(\frac{d}{2}\right) \qquad (12)$$

The gap between the lid and resonator should be sufficient to provide the necessary capacitance, and can be calculated using;

$$M_{gap} = \frac{0.695d^2}{100C - 2.61d} \qquad (13)$$

where$C$ is the loading capacitance, and d is rod diameter.

The distance between resonators, $S_{comb(i,j)}$, can be calculated using:

$$S_{comb(i,j)} = \frac{b}{1.37}\left[\left(0.91\frac{b}{d}\right) + 0.048 - \log\left(\frac{4}{\pi}\cdot f(\theta)\cdot K_{ij}\right)\right] (14)$$

where

$$f(\theta) = \frac{1}{2}\left[1 + \frac{2\theta}{sin2\theta}\right] \qquad (15)$$

and

$$\theta = 2\pi \frac{l}{\lambda} \qquad (16)$$

The physical layout parameters are listed in Table II.

TABLE II. DIMENSIONS OF REAL LAYOUT FILTER

Physical layout parameters	**Values (mm)**
Cavity diameter (*b*)	24
Resonator diameter (*d*)	8
Resonator length (*l*)	12
Tap point distance from the ground	3.5
Minimum gap (*Mgap*)	0.5
Center to center spacing between resonators (*Si,j*)	19.5,21.5,19.5
Distance between end wall to center of end rod (*e*)	14

The physical layout filter is modeled and simulated using 3D Ansoft HFSS software shown in Figure 4.

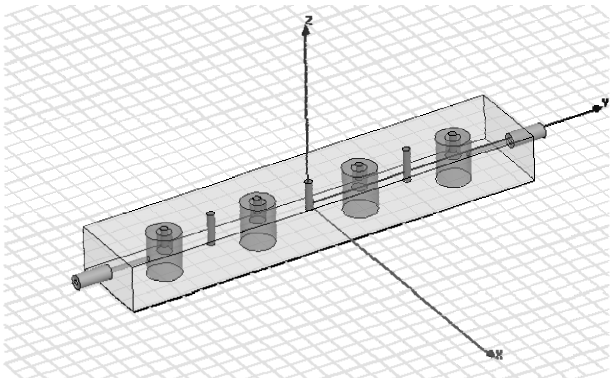


Figure 4. 3D HFSS Model of physical filter

The EM simulated response is shown in the Figure 5. The insertion loss of about 0.1 dB and return loss better than 13 dB are achieved particularly in the passband.Figure 6 shows the field distribution of the coaxial resonators.

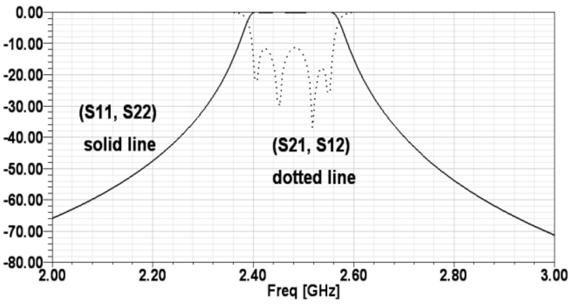


Figure 5. 3D Electromagnetic (EM) response

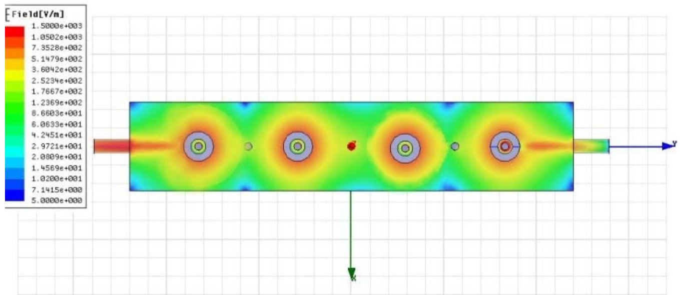


Figure 6. Field distribution of the resonators

The filter requires further tuning and optimization in order to obtain good response. However, due to the structure of this non-planar filter, it requires a powerful and high performance of a computer to perform the optimization.

III. FABRICATION AND MEASUREMENT

The filter is manufactured in-house using CNC machine and aluminum as its material (shown in Figure 7).

Figure 7. Manufacturing of the filter

The filter is measured and verified using the Vector Network Analyzer as shown in Figure 8. The photograph of the filter is shown in Figure 9.In order to overcome manufacturing tolerances, screws between the resonators are inserted. The inter-resonators couplings are then tuned using the inserted screws, and an optimized return loss of better than -15 dB is achieved over the required bandwidth.The measured response is shown in Figure 10. The insertion loss of about 0.15 dB and return loss better than 15 dB have been achieved. Table III shows the comparison between the ideal and EM simulations with the measurement results. An excellent agreement between the EM simulations and measurement has been achieved.

Figure 8. Photograph of physical filter, (a) with lid, and (b) without lid

(a)

(b)

Figure 9. Photograph of physical filter, (a) with lid, and (b) without lid

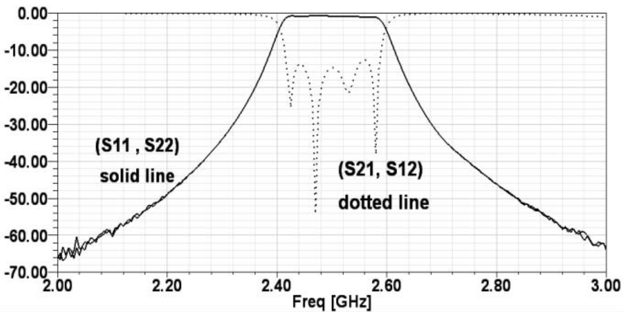


Figure 10. Measured response of physical filter

TABLE III. COMPARISON BETWEEN SIMULATIONS AND MEASUREMENT

	Ideal circuit	3D Electromagnetic	Measurement
Center Freq. (GHz)	2.5	2.48	2.5
Pass-band BW (MHz)	160	170	168
Stop-band BW (MHz]	320	300	290
S11 [dB]	-20	-13	-15
S21 [dB]	-0.04	-0.10	-0.15

IV. CONCLUSION

The coaxial cavity comblinebandpass filter has been successfully designed, fabricated, and measured. The filter development from the Chebyshev low-pass prototype as a starting point has been demonstrated followed by a systematic physical realization. The resulting filter exhibits an excellent agreement between ideal simulated and measured response.The main advantage of the coaxial resonator filter has been with its post-manufacturing tuning capabilities and good selectivity. This class of microwave filter would be useful in any transceiver systems where the low-loss and high selectivity performance are required. A diplexer or multiplexer is recommended be designed in the future for practical applications such as in radio base station and satellite transponder.

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