DESIGN OF LOW-LOSS TEM COAXIAL CAVITY BANDPASS FILTER

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Abstract— This paper presents a design of coaxial cavity bandpass filter that utilizing the method of tapped-input coupling. The design procedures have assumed lossless lowpass prototypes, thus yielding lossless bandpass filters. A systematic filter development using lowpass prototype as a starting point to produce four-pole Chebyshev bandpass response is demonstrated. The coaxial cavity filter has the center frequency of 2.5 GHz and bandwidth of 160 MHz. The insertion loss of 0.1 dB insertion loss and return loss better than 20 dB is achieved especially in the passband. This class of filter would be useful in 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 wanted and unwanted signal frequencies. Cellular radio provides particularly stringent filter requirements both in the base stations and in mobile handsets.

II. TEM TRANSMISSION LINE FILTER

TEM (Transverse Electro-Magnetic) transmission lines use specific construction such as precise conductor dimensions and spacing, and impedance matching, to carry electromagnetic signals with minimal reflections and power losses. Types of transmission line include ladder line, coaxial cable or conductors, dielectric slabs, stripline, and microstrip. The combline, interdigital and coupled-line filters are the most common types of microwave filters that utilize TEM transmission lines.

III. COAXIAL COMBLINE CAVITY FILTERS

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 to design, and possess excellent stopband and high selectivity. More importantly they have post-manufacturing tuning capabilities. The filters also provide outstanding performance from the UHF region up to 10 GHz with relatively higher Q factor than the microstrip technology [1].

IV. DESIGN AND SIMULATION

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 combline bandpass filter. The theory behind the transformation is explained in detail in [2].

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 [2]

$$N \geq \frac{L_A + L_R + 6}{20 Log 10 [S + \sqrt{S^2 - 1}]} \qquad (1)$$

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

Element values for the chebshev lowpass prototype are calculated by using the following formulas:

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

$$K_{r,r+1} = \frac{\left[\eta^2 + \sin^2 \left(\frac{r\pi}{N} \right) \right]^{1/2}}{\eta} \qquad (3)$$

where C_{Lr} is the r_{th} of capacitor and $K_{r,r-1}$ is the r_{th} of inverter.

The lowpass prototype network can now be transformed to combline bandpass filter by applying the following equation [3-5]:

$$Y_{rr} = \alpha C_{Lr} \tan(\theta) \qquad (4)$$

Equation (4) 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 equivalent circuit of combline filter is given by:

$$C_r = \beta Y_{rr} \qquad (5)$$

where Y_{rr} is the admittance of resonator, and β is represented by:

$$\beta = \frac{1}{\omega_0 \tan\theta} \qquad (6)$$

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

The Figure 1(a) shows combline bandpass filter circuit and its components which are operating in a 50 Ω system. The element values of equivalent combline bandpass filter in a 50 Ω system are shown in Table 1. The simulated response of combline bandpass filter is shown in Figure 1(b). It has design specification as follows: Center frequency of 2.5 GHz with 160 MHz bandwidth. The insertion loss of 0.1 dB insertion loss and return loss better than 20 dB is achieved especially in the passband.

(a)

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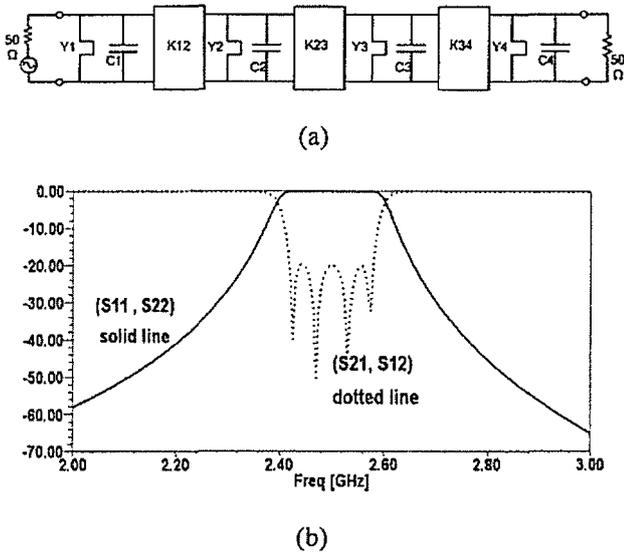
Figure 1: (a) Combline filter operate in a 50 Ω system, (b) Frequency response of bandpass filter.

Table1: Element values for 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
$K_{1,2} = K_{3,4}$	1.3193
$K_{2,3}$	1.5751

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.
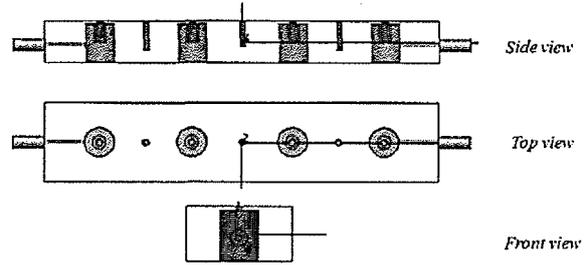
Figure 2: Physical filter layout
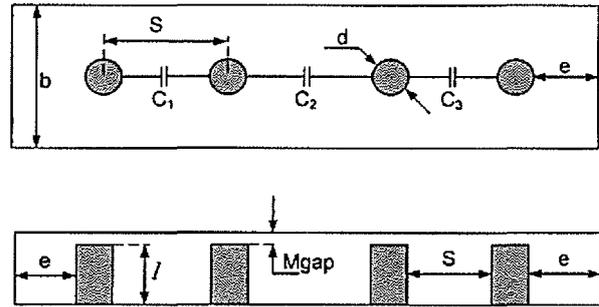
Figure 3: Dimensions of physical filter (a) top view, (b) side view

The dimensions of the physical filter can be determined using the following formulas:

Cavity diameter, b, in mm:

$$\lambda < b < 0.2\lambda \qquad (7)$$

where λ is the wavelength at 2.5 GHz.

Resonator diameter, d, in mm:

$$0.2b < d < 0.4b \qquad (8)$$

Rod diameter is a function of its impedance and cavity diameter. Hunter [2] gives the characteristic impedance, $Z_\circ$, of round rod between two ground planes as:

$$Z_\circ = 138 \times \log\left[\frac{4b}{\pi d}\right] \qquad (9)$$

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

$$e = \left(\frac{b}{2}\right) + \left(\frac{d}{2}\right) \qquad (10)$$

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

$$M_{gap} = \frac{0.695d^2}{100C - 2.61d} \qquad (11)$$

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

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

$$S_{comb(i,j)} = \frac{b}{1.37}\left[\left(0.91\frac{b}{d}\right) + 0.048 - \log\left(\frac{4}{\pi} \cdot f(\theta) \cdot K_{i,j}\right)\right] (12)$$

where

$$f(\theta) = \frac{1}{2}\left[1 + \frac{2\theta}{\sin 2\theta}\right] \qquad (13)$$

and

$$\theta = 2\pi\frac{l}{\lambda} \qquad (14)$$

The physical layout parameters are listed in Table 2.

Table 1: dimensions of real layout filter

Physical layout parameters	Values (mm)
Cavity diameter (b)	20
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 as shown in Figure 4.
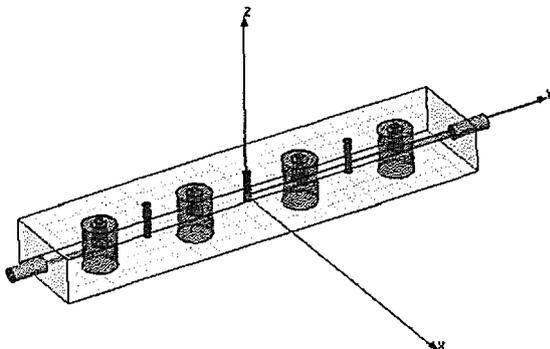
Figure 4: 3D HFSS Model of physical filter

The response of filter simulation by HFSS software is shown in the Figure 5. The insertion loss of about 0.1 dB

insertion loss and return loss better than 13 dB is achieved especially in the passband.
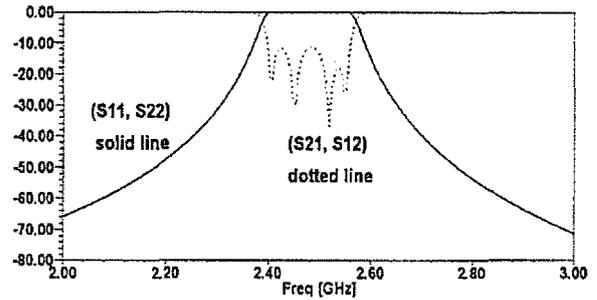
Figure 5 response of real physical filter simulation as 3D

The filter requires further tuning and optimization in order to obtain good response [6]. However, due to the structure of this non-planar filter, it requires a powerful and high performance of computer to perform the optimization.

V.   FABRICATION AND MEASUREMENT

The filter was manufactured in workshop at the Faculty of Manufacturing Engineering (FKP), Universiti of Teknikal Malaysia Melaka, (UTeM) using CNC machine and aluminum as its material (Figure 6). The photograph of the filter is shown in Figure 7.
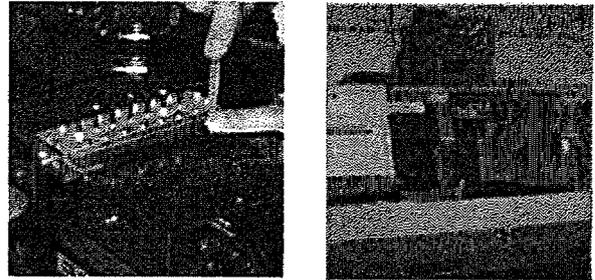
Figure 6: Manufacturing of the filter
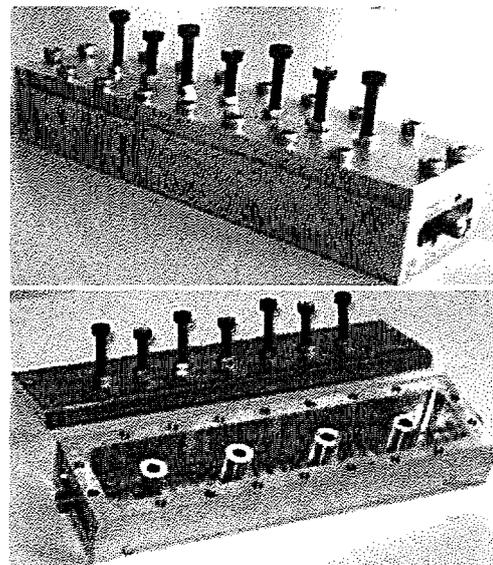
Figure 7: Photograph of physical filter

The filter was tested and measured using Vector Network Analyzer. The measured response is shown in Figure 8. Table 3 shows the comparison between the simulated and measured results. An excellent agreement between the EM simulations and measurement has been achieved especially in the passband.
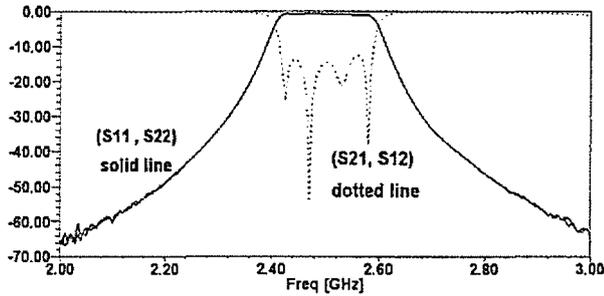
Figure 8: Measured response of physical filter

Table 3: Comparison between EM Simulations and Measurement

	Equivalent distributed circuit	Simulation 3D	Measurement
Center Freq. GHz	2.5	2.48	2.5
Pass-band B.W [MHz]	160	170	173
Stop-band B.W [MHz]	320	300	290
S11 [dB]	-20	-12	-15
S12 [dB]	-0.04	-0.35	-0.87
S21 [dB]	-0.04	-0.34	-0.85
S22 [dB]	-15	-15	-15

VI. CONCLUSION

This paper has demonstrated a systematic development and design of combline filter based on coaxial resonators technology. This class of microwave filter would be useful in any transceiver systems where the low-loss and high selectivity performance are required. The main advantage of coaxial resonator filter has been with its post-manufacturing tuning capabilities and good selectivity. Thus, the filter could easily be tuned and optimized in the laboratory in order to obtain the desired response. In addition, a diplexer or multiplexer is recommended be designed for practical applications such as in radio base station and satellite transponder.

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