

QUASI-ELLIPTIC MICROSTRIP BANDSTOP FILTER USING TAP COUPLED OPEN-LOOP RESONATORS

Kenneth S. K. Yeo^{*} and Punna Vijaykumar

School of Architecture, Computer and Engineering, University of East London, UK

Abstract—In this paper, we will present a quasi-elliptic bandstop filter using asynchronously tuned resonators. To demonstrate this technique, a novel broadband microstrip bandstop filter is also proposed using distributed resonators. To achieve wide bandwidth using distributed resonators, strong couplings are required. This is achieved using tap coupled to avoid very narrow gaps which are costly to manufacture. The filter exhibits a fractional bandwidth of approximately 35%. A simple practical transformation technique for transforming Chebyshev bandstop filter to asynchronously tuned quasi-elliptic bandstop filter will be presented.

1. INTRODUCTION

Bandstop filter is an important component in communication systems [1]. It is normally used to stop a selected chunk of frequency spectrum while letting other frequency spectrum through. Bandstop filters can also be used to design duplexer [2] by incorporating them with couplers.

The commonly used planar microwave filters are either quasi-lumped element filters or distributed element filters. In planar structure, i.e., microstrip, quasi-lumped element filter can achieve high miniaturisation but suffers from low unloaded quality factor. Meanwhile, distributed element filter can achieve higher unloaded quality factor in the expense of its size. In this paper, the discussion is only focused on distributed element bandstop filter. However, the technique is applicable to quasi-lumped element design as well.

Elliptic and quasi-elliptic filter responses have higher selectivity in comparison to Chebyshev filter response. In bandpass filter, quasi-elliptic response will exhibit finite frequency transmission zero/s at the

Received 19 October 2012, Accepted 22 November 2012, Scheduled 25 November 2012

^{*} Corresponding author: Kenneth Siok Kiam Yeo (k.yeo@uel.ac.uk).

stop-band, which is an out-of-band response, to improve selectivity. For bandstop filter, the transmission zeros are also exhibited at the stop-band to improve selectivity. However, the stop-band in a bandstop filter is an in-band response. The main difference between a Chebyshev and a quasi-elliptic bandstop filter responses is the number of different finite frequencies transmission zeros at the stop-band. For a pure Chebyshev bandstop filter, all its transmission zeros are located at a single finite frequency which is the center frequency of the filter whereas for an elliptic or quasi-elliptic bandstop filter the transmission zeros are located in more than one finite frequencies.

There are many methods to achieve an elliptic or quasi-elliptic bandstop filter design [3–5]. Here, a simple and practical approach in designing a quasi-elliptic bandstop filter is proposed. A novel microstrip filter is designed by employing the presented technique. The microstrip filter will be used as an example to further illustrate the design procedure. Simulation and experimental results of the designed microstrip filter will also be presented.

2. BANDSTOP FILTER CIRCUIT MODEL

A bandstop filter can be achieved by cascading series of inductor (L) and capacitor (C) resonator to ground with shunt of LC resonators in series [6] as shown in Figure 1. However, at microwave frequencies, lumped LC components are difficult to realise. Therefore, the circuit model shown in Figure 1 is transformed to a more appropriate and more representative circuit model so that it can be achieved using either quasi-lumped elements or distributed element resonators.

The circuit model in Figure 1 is transformed into only shunt of LC resonators in series connection with impedance inverters (K -inverters) as shown in Figure 2. The input and output port impedances are maintained in the normalised impedance form, i.e., $Z_{port1} = 1\Omega$ and

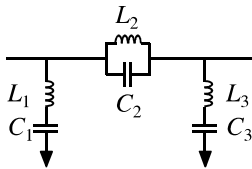


Figure 1. A standard 3rd order bandstop filter circuit model, reproduced courtesy of The Electromagnetics Academy

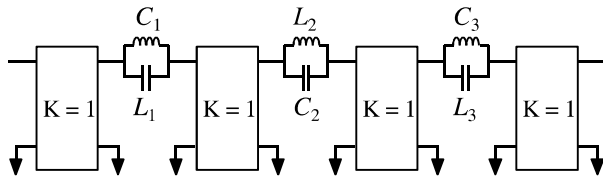


Figure 2. A 3rd order bandstop filter circuit model with shunt LC resonators in series connections with impedance inverters, reproduced courtesy of The Electromagnetics Academy

$Z_{port2} = 1 \Omega$. The transformed resonators will have the capacitance and inductance values interchanged as compared to the original resonators [6].

The circuit model shown in Figure 2 can be achieved using quasi-lumped element circuit at microwave frequencies. However, quasi-lumped element circuit exhibits lower unloaded quality factor in comparison to distributed element resonators. To achieve a bandstop filter using microstrip distributed element resonators, one end of the resonators must be ground. This is mainly because the capacitance of planar distributed elements is distributed between the signal line and the ground plane. In view of this, all the shunt resonators are further transformed into shunt of LC resonators to ground using admittance inverters [7] as shown in Figure 3. By transforming all the shunt of LC resonators in Figure 2, the final circuit model of the bandstop filter can be constructed as in Figure 4. The values of the capacitance and

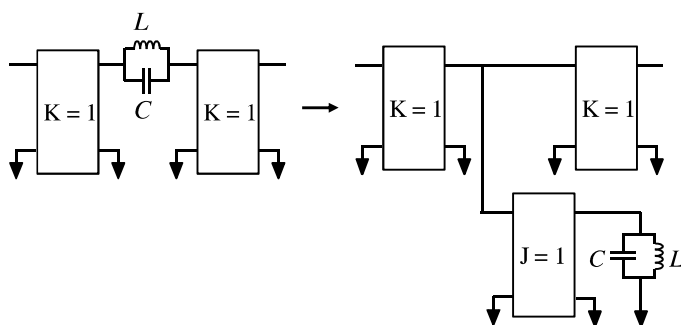


Figure 3. Transformation of a shunt LC resonator in series connection to a shunt LC resonator in shunt connection, reproduced courtesy of The Electromagnetics Academy

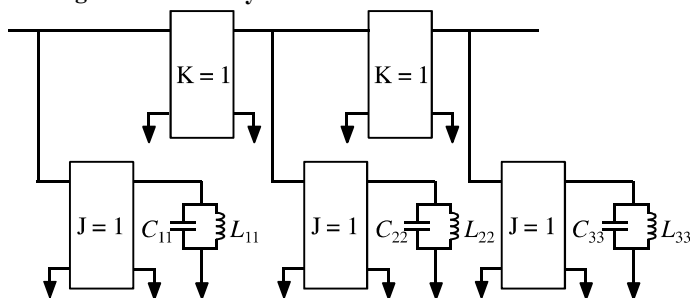


Figure 4. A 3rd order bandstop filter circuit model with only shunt LC resonator in shunt connection, reproduced courtesy of The Electromagnetics Academy

inductance for all the resonators are as given in Eq. (1).

$$C_{ii} = L_i \quad \text{and} \quad L_{ii} = C_i \quad \text{where} \quad i = \text{odd} \quad (1a)$$

$$C_{ii} = C_i \quad \text{and} \quad L_{ii} = L_i \quad \text{where} \quad i = \text{even} \quad (1b)$$

3. QUASI-ELLIPTIC BANDSTOP MODEL

A Chebyshev bandstop filter can be easily achieved using standard filter transformation [6]. However, Chebyshev bandstop filter suffers from low roll-off. Furthermore, by using standard transformation, the usable bandwidth is much smaller than designed. This is mainly because the design bandwidth is the passband ripple bandwidth. Therefore, if a 40 dB stop-band bandwidth is required, the usable bandwidth is much smaller than designed. This has made bandstop filter design rather challenging. A very wide bandwidth bandstop has to be designed in order to achieve a small usable stop-band bandwidth.

To improve the roll-off of standard Chebyshev bandstop filter and at the same time increase the usable bandwidth, some of the transmission zeros can be detuned from the centre frequency. This can be achieved by detuning the resonators from the centre frequency of the bandstop filter. This type of filter is also known as quasi-elliptic bandstop filter. Here, a simple method is proposed by altering the capacitance and inductance of the Chebyshev bandstop filter circuit model. To move a transmission zero to a specified angular frequency, ω_i , the capacitance and inductance of the resonator can be altered according to Eq. (2).

$$C'_{ii} = \frac{1}{\omega_i} \sqrt{\frac{C_{ii}}{L_{ii}}} \quad (2a)$$

$$L'_{ii} = \frac{1}{\omega_i^2 C'_{ii}} \quad (2b)$$

where $\omega_i = 2\pi f_i$, $f_i = f_o + \delta f$ and $i = 1, 2, 3$.

To verify this technique, the following examples are presented. These examples will start off with a standard Chebyshev bandstop filter with a centre frequency of 1793 MHz, a fractional bandwidth of 34.6%, i.e., 620 MHz bandwidth, and passband return loss of 20 dB. Table 1 presents the circuit parameters of the original standard Chebyshev filter. To move the transmission zeros to ± 35 MHz, ± 70 MHz and ± 100 MHz from the centre frequency, Eq. (2) is applied and the results are presented in Table 2, Table 3 and Table 4, respectively.

The bandstop filter circuit model for each individual scenario is simulated using Agilent Advance Design System. Figure 5 presents the simulated responses of the bandstop filters. From the graph,

Table 1. Capacitance and inductance values for $\delta f = 0$ MHz (Pure Chebyshev), reproduced courtesy of The Electromagnetics Academy

i	f_i/MHz	$C'_{ii} = C_{ii}/\text{pF}$	$L'_{ii} = L_{ii}/\text{nH}$
1	1973	301.3	0.0262
2	1793	231.9	0.0340
3	1973	301.3	0.0262

Table 2. Capacitance and inductance values for $\delta f = \pm 35$ MHz, reproduced courtesy of The Electromagnetics Academy

i	f_i/MHz	C'_{ii}/pF	L'_{ii}/nH
1	1828	295.5	0.0257
2	1793	231.9	0.0340
3	1758	307.2	0.0267

Table 3. Capacitance and inductance values for $\delta f = \pm 70$ MHz, reproduced courtesy of The Electromagnetics Academy

i	f_i/MHz	C'_{ii}/pF	L'_{ii}/nH
1	1863	289.9	0.0252
2	1793	231.9	0.0340
3	1723	313.5	0.0272

Table 4. Capacitance and inductance values for $\delta f = \pm 100$ MHz, reproduced courtesy of The Electromagnetics Academy

i	f_i/MHz	C'_{ii}/pF	L'_{ii}/nH
1	1893	285.3	0.0247
2	1793	231.9	0.0340
3	1693	319.0	0.0277

it is clearly shows that two transmission zeros have moved away from the centre frequency when resonators 1 and 3 are detuned from the filter centre frequency. It is also showed that the roll-off has steepen when the transmission zeros are detuned. However, there is a compromise between improving the roll-off steepness and the stop-band insertion loss. By moving the transmission zeros too far from the centre frequency, the insertion loss at the stop-band will reduce. In the example where the resonators 1 and 3 are detuned by ± 70 MHz, respectively, the stop-band insertion loss is approximately 40 dB or great. Although the Chebyshev bandstop filter was designed to have a bandwidth of approximately 680 MHz, the usable bandwidth is only approximately 100 MHz (assuming an insertion loss of 40 dB or great is required over the stop-band). Detuning the transmission zeros by ± 70 MHz from the centre frequency, the 40 dB stop-band bandwidth has improved to approximately 160 MHz, i.e., approximately 60% improvement.

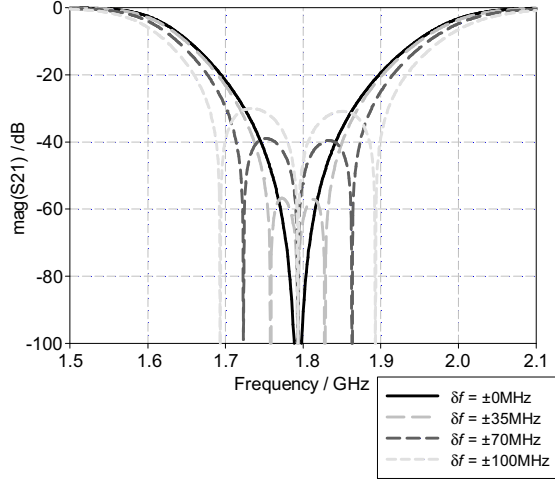


Figure 5. Simulation results of the circuit model in Figure 4 with different transmission zero locations, **reproduced courtesy of The Electromagnetics Academy**

4. MICROSTRIP DESIGN

The bandstop filter circuit model in Figure 4 can be easily realised using microstrip transmission line circuit. The impedance and admittance inverters can be achieved using quarter wavelength microstrip transmission line. The impedance and admittance inverter values are all equal to one and the input and output port impedances are also equal to one in the circuit model. In a practical circuit, the impedance needs to be scaled to 50Ω . As the result, the quarter wavelength microstrip transmission lines used to emulate the impedance and admittance inverters will need to have a characteristic impedance of 50Ω .

The resonators are achieved using rectangle open-loop resonators with an effective length of half a wavelength long. The interface between the admittance inverter and the resonator is achieved using magnetic coupling, i.e., tapping [7, 9] directly onto an open ended half-wavelength resonator or open-loop resonator [8]. The tap location controls the loading of the resonator. From the circuit model, the required loading or external quality factor can be determined by using Eq. (3) [10]

$$Q_{ext} = \frac{\omega_i C'_{ii}}{J} \quad \text{where} \quad i = 1, 2, 3 \quad (3)$$

The bandstop filter is fabricated using Roger RT/Duroid 6010 substrate with a dielectric constant of 10.8 and a thickness of 1.27 mm.

The microstrip bandstop filter is designed using the circuit parameter given in Table 3. The required external quality factor of the filter can be calculated using Eq. (3) and the results are presented in Table 5. In the microstrip circuit, the external quality factor of the individual resonator can be determined by simulating a doubly loaded bandstop resonator [7] as shown in Figure 6. The external quality factor can be extracted from the insertion loss graph of the doubly loaded bandstop resonator using Eq. (4).

$$Q_{ext} = \frac{f_o}{2(f_2 - f_1)} \quad \text{where} \quad f_2 - f_1 = 3 \text{ dB bandwidth} \quad (4)$$

Figures 7–9 show the external quality factor curves of resonators 1, 2, and 3, respectively. Note that the external quality factor required in the design is very low, i.e., very strong couplings between the admittance inverter and the resonator are required. This sort

Table 5. The calculated external qualify factor for filter with parameter given in Table 3 ,**reproduced courtesy of The Electromagnetics Academy**

<i>Resonator-i</i>	<i>f_i</i> /MHz	<i>Q_{ext}</i>
1	1863	3.4
2	1793	2.6
3	1723	3.4

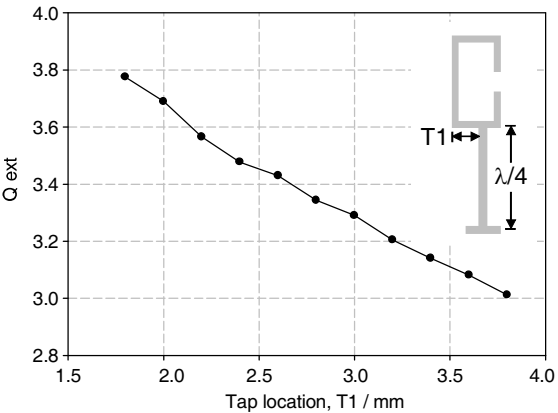
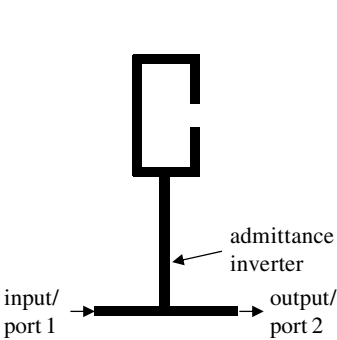


Figure 6. A doubly loaded bandstop resonator for extraction the tap coupled location ,**reproduced courtesy of The Electromagnetics Academy**

Figure 7. The simulated external quality factor with the corresponding tap coupled location for resonator 1 ,**reproduced courtesy of The Electromagnetics Academy**

of coupling strength cannot be easily achieved using gap coupled bandstop filter [8]. By introducing the tap coupling, a very strong coupling between the admittance inverter and the resonator can be achieved.

From the graph in Figures 7–9, the tap locations corresponding to the required external quality factors can be determined. Referring Figure 7, a tap location, T1, of approximately 2.7 mm is required to achieve an external quality factor of 3.4 for the first resonator. For the second resonator, the tap location, T2, is approximately 3.5 mm to achieve an external quality factor of 2.6 according to Figure 8. And according to Figure 9, the tap location, T3, is approximately 3.7 mm

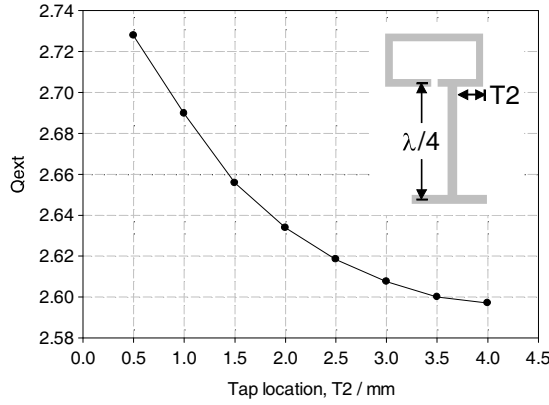


Figure 8. The simulated external quality factor with the corresponding tap coupled location for resonator 2, reproduced courtesy of The Electromagnetics Academy

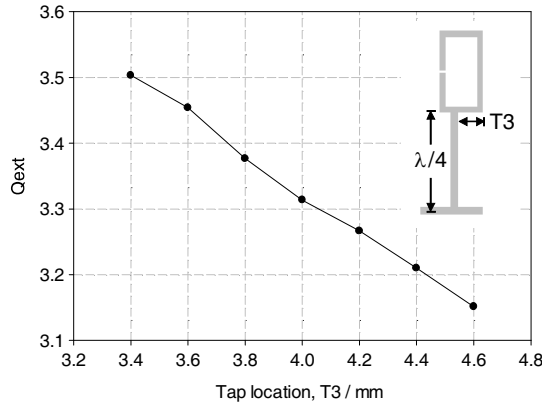


Figure 9. The simulated external quality factor with the corresponding tap coupled location for resonator 3, reproduced courtesy of The Electromagnetics Academy

to achieve an external quality factor of 3.4 for the third resonator.

With all the tap locations determined, the bandstop filter can be easily layout. Figure 10 shows the layout of the quasi-elliptic microstrip bandstop filter with dimensions clearly labelled. The filter is measured approximately a guided wavelength long and 0.7 of a guided wavelength wide.

5. SIMULATION AND MEASUREMENT

The quasi-elliptic bandstop microstrip filter was simulated using Agilent ADS Momentum. The microstrip filter is also fabricated using micro-milling technique on a Roger RT/Duroid substrate. The fabricated microstrip filter is shown in Figure 11. The fabricated filter is measured approximately 6.5 cm in length with 4.0 cm in width. The microstrip bandstop filter was analysed and measured using Agilent ENA series vector network analyser. Figure 12 shows the EM simulated results together with the measured results.

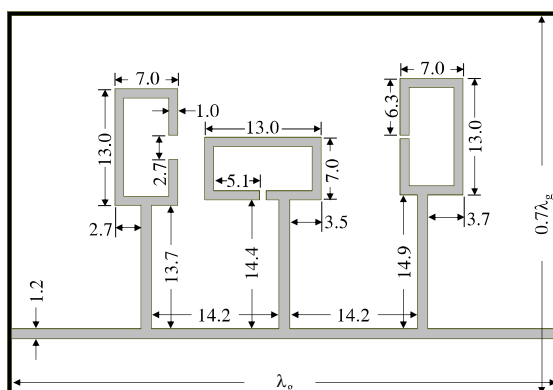


Figure 10. Microstrip bandstop filter layout with dimension. All dimensions are in millimetre, reproduced courtesy of The Electromagnetics Academy

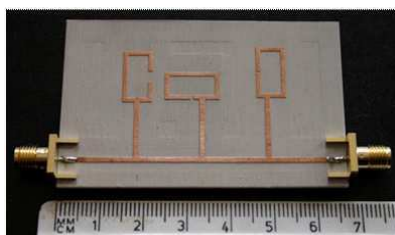


Figure 11. Fabricated microstrip bandstop filter on RT/Duroid 6010, reproduced courtesy of The Electromagnetics Academy

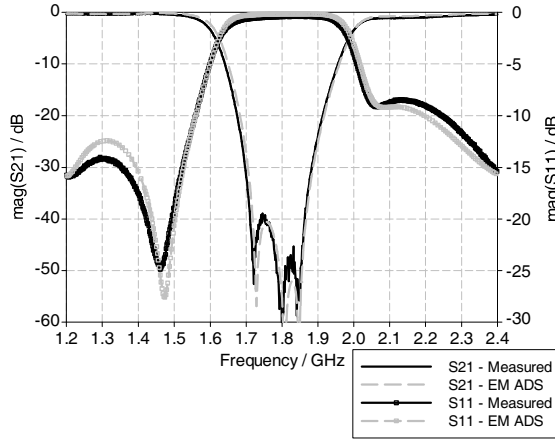


Figure 12. A comparison of the measured results with EM simulated results , reproduced courtesy of The Electromagnetics Academy

The results presented in Figure 12 shows a very good agreement between the measured responses with the EM simulated responses. The measured bandstop filter achieved a bandwidth of approximately 150 MHz with insertion loss of 40 dB or greater. This also agreed reasonably well with the original circuit model which has a bandwidth of approximately 160 MHz. The measured return loss at the mid-band of the bandstop filter is approximately 0.38 dB. With the insertion loss of the mid-band of the bandstop filter greater than 50 dB, it is safe to assume that the loss of the filter is approximately equal the return loss of the filter which is approximately 0.38 dB.

6. CONCLUSION

A novel quasi-elliptic bandstop filter design technique has been presented. The quasi-elliptic bandstop filter exhibits high selectivity with huge improvement in the usable bandwidth for a bandstop filter. A detailed design procedure from circuit models to physical layout dimension extraction has been present. The technique has been verified using distributed microstrip open-loop resonators. It is also demonstrated in this paper that a wide bandwidth bandstop filter can be achieved using open-loop resonator. This has been achieved using tap coupled which has clear advantages over conventional gap coupled. The presented microstrip bandstop filter does not have any narrow gap in the layout. This will make the filter cheap and easy to fabricate and also less susceptible to fabrication tolerance.

ACKNOWLEDGMENT

The authors would like to thank Mr. Bernie Hanreck for fabrication of the microstrip circuit.

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