Design of Generalized Chebyshev Lowpass Filter with Defected Stripline Structure (DSS)

Z. Zakaria, M. A. Mutalib, M. S. M. Isa, A. A. Md Isa, N. A. Zainuddin and W. Y. Sam
Centre of Telecommunication Research and Innovation (CeTRI), Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia
zahriladha@utem.edu.my, ariffinmutalib@gmail.com

***Abstract*—This paper presents the design of generalized Chebyshev lowpass filter (LPF) and integrated with Defected Stripline Structure (DSS) using Suspended Stripline Structure (SSS). The study involves circuit analysis to determine generalized Chebyshev responses with a transmission zero at finite frequency in order to produce a reduced number of elements values of prototype circuit. The LPF provides a cut-off frequency at 6 GHz with a return loss better than -19 dB, while the DSS exhibits a notch at frequency of 3.2 GHz with a stopband response better than -40 dB. Thus, the integrated LPF and DSS will produce lowpass and band reject response simultaneously. The design is implemented on a Roger Duroid RO4350 with a thickness of 0.168 mm and dielectric constant, ε_r of 3.48. The simulation performance results show promising results that could be proved in the experiment works. This new class of integrated LPF and DSS would be useful in any RF/ microwave communication systems particularly in wideband applications where the reduction of overall physical volume, weight and cost is critical to maintaining its good performance.**

Keywords—Microwave filter; lowpass filter (LPF); bandstop filter; Defected Stripline Structure (DSS); Suspended Stripline Strucutre (SSS).

I. INTRODUCTION

With the fast development of wideband wireless communication, LPF with characteristics of high performance, low-cost, low insertion loss (IL) and compact LPF are highly desirable. For the next generation of wireless communication system, the integration of the LPF and DMS into one structure brings many benefits especially in reducing the overall physical volume of the RF systems [1]-[4]. In [5] below, the multi-band filter was presented which uses 7th degree of Chebyshev based on lowpass filter prototype. However, this paper use coupling topology method to produce multi-band filter. The DMS with band reject response has the advantages in term of good frequency selectivity, low loss and simple circuit topology [6]. The DMS is made by defect the conductor line of the structure and etching a narrow slot in the microstrip line. DMS is more easily integrated with other microwave circuits in order to reduce the size compared to DGS. In DMS, there is no etching in the ground plane and this avoids any incremental leakage through the ground plane.

Recently, DMS [6]-[8] and DGS [9][10] have been proposed in the microstrip filters. The comparison between DGS and DMS is shown in [11]. The DMS can produce higher stopband and can apply in harmonic suppression, but the bandwidth of stopband is wider compared to the DGS. G. Yang et al. [12] introduce a wideband frequency with band reject was produced at certain frequencies. The method that they use is a meander line slot which produces a narrow notched band reject at desire frequency. However, this method cannot reach the lower frequency which provides a frequency from 4 GHz to 8 GHz. To provide a lower frequency, a longer structure is needed which increase the value of L_1 to fulfill the desired frequency. On the basis of DMS, the modified planar transmission line with the DSS is proposed which can be realized by the etching meander line slot on the signal pattern of stripline. The slot on stripline disturb current distribution on strip and grants the stopband characteristics in the frequency response [13].

In this paper, a new topology of integration between LPF and DSS is presented. The LPF is designed at a cut-off frequency of 6 GHz with minimum stopband insertion loss of 40 dB and minimum passband return loss of 20 dB. While, the DSS is designed at a frequency of 3.2 GHz with a band reject better than -40 dB with narrow bandwidth characteristics. The overall topology is designed based on SSS to produce good selectivity and low loss characteristics as well as exhibit lowpass and band reject response simultaneously.

II. DESIGN OF LOWPASS FILTER

A systematic filter design starts with a classical lowpass lumped element equivalent circuit or prototype [14]-[16]. It consists of series and shunt inductors and capacitors and their combination to form either series or parallel resonators.

The generalized Chebyshev has equiripple response in passband but with arbitrary placed transmission zeros in the stopband offering selectivity nearly as good as the same degree elliptic filter. Generalized Chebyshev filter prototype is more preferred due to the transmission zeros can be placed independently as accordance to design specification. Alseyab in [17] synthesize the element values for generalized Chebyshev low pass filter prototype which can be used to transform into any filter response. The doubly terminated low-pass prototype network satisfies the insertion-loss (IL) for the generalized Chebyshev response as described by:

$$\mathrm{IL} = 1 + \epsilon^2\cosh^2\left\{(\mathrm{N}-3)\cosh^{-1}\left[\omega\left(\frac{\omega_0{}^2-1}{\omega_0{}^2-\omega^2}\right)^{1/2}\right] + 3\cosh^{-1}\omega\right\} \quad (1)$$

where the transmission zeros are of order (n-1) at $\omega = \pm\omega_0$ and one at infinity. N is an odd number equal to the degree of the network,

$$\epsilon = \left[10^{(\mathrm{RL}/10)} - 1\right]^{-1/2} \quad (2)$$

and RL is the minimum return loss level (dB) in the passband.

A. *Design of Lowpass Filter*

The device is constructed and simulated by using Roger Duroid RO4350 with relative dielectric constant, $\varepsilon_r = 3.48$, substrate height, h = 0.168 mm. the thickness of copper 0.035 mm and the loss tangent is 0.019. The LPF with cut-off frequency of 6 GHz with the degree, N = 7, the minimum stopband insertion loss of -40 dB and minimum passband return loss of -20 dB are designed based on calculations in (1) and (2). The elements values for the lowpass prototype network show in Table 1 with its corresponding $\omega_0 = \alpha = 1.29516\ rad/s$ can be obtained in [17].

TABLE 1: COMPONENT VALUE FOR PROTOTYPE LUMPED ELEMENTS

Elements	Value
$C_1 = C_4$	1.02647
$C_2 = C_3$	1.10006
$L_1 = L_3$	1.08027
$L_4 = L_5$	0.541922
L_2	0.984147

The lowpass prototype operates in system impedance of 1Ω and cut-off frequency of 1 rad/s. The next step is to perform the transformation to lowpass filter with 50 Ω from the lowpass prototype using following equations [18]:

$$L'_r = \frac{Z_0 L_r}{\omega_c} \quad (3)$$

$$C'_r = \frac{C_r}{Z_0\omega_c} \quad (4)$$

By implementing Equation (3) and (4), values of each capacitor and inductors that operating in 50 Ω with cut-off frequency of 6 GHz can be calculated.

The element values of the equivalent circuit for lowpass filter are shown in Table 2. The lowpass filter circuit can now be seen in Fig. 1(a). The response of the lowpass filter is shown in Fig. 1(b). It is observed that the filter has a cut-off frequency of 6 GHz which are in line with the design specification.

TABLE 2: COMPONENT VALUE OF LUMPED ELEMENTS

Elements	Value
$C'_1 = C'_4$	0.54456 pF
$C'_2 = C'_3$	0.5836pF
$L'_1 = L'_3$	1.432756nH
$L'_4 = L'_5$	0.718748nH
L'_2	1.30526nH

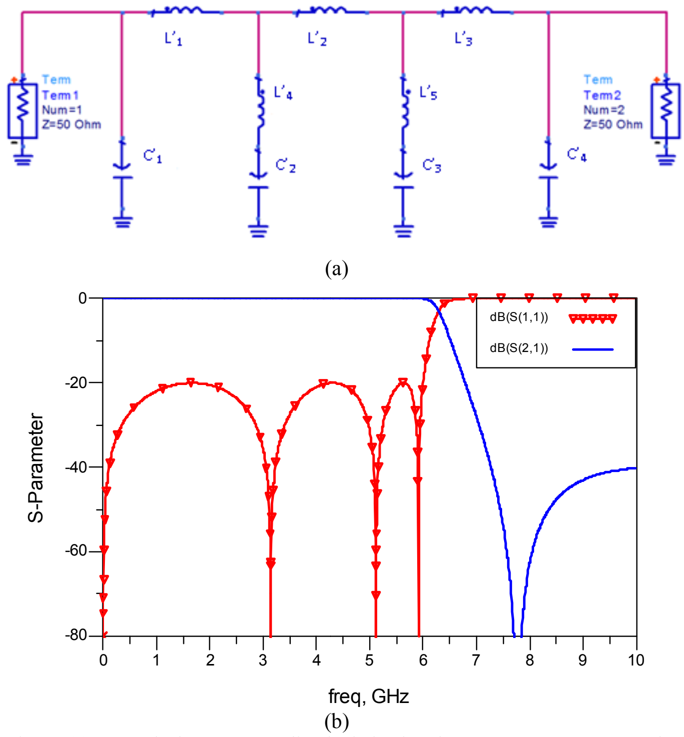


Fig. 1. (a) Seventh-degree generalized Chebyshev lowpass prototype network (b) Simulated frequency response of the generalized Chebyshev lowpass filter

B. *Physical Realization*

For realization, the lumped element lowpass filter is then transformed to open- and short-circuit transmission line segments by applying Richard's transformation [16].

The Richard's transformation allows to replace lumped inductors with short circuited stubs of characteristic impedance $Z_o = L$ and capacitors with open circuited stubs of characteristic impedance $Z_o = 1/C$. The resonator impedance can be represented as admittance of an open circuited stub by characteristic admittance $\alpha\, C/2$.

The length of the stub is one quarter wavelength at ω_0. Constant a can be obtained by applying Richard's transformation at the band-edge frequency ω_c. Thus

$$1 \rightarrow \alpha tan(a\omega_c) \quad (5)$$

and

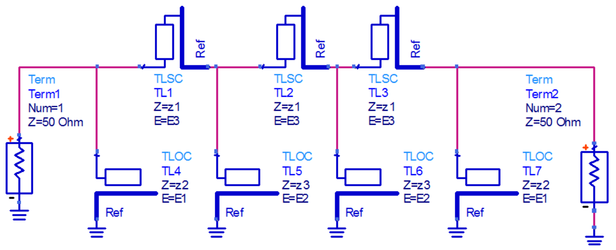
$$a = \frac{\omega_c}{f_c}\tan^{-1}\left(\frac{1}{\alpha}\right) \quad (6)$$

The structure of distributed element after applying the Richard's transformation is shown in Fig. 2 (a). The values of short- and open-circuit stubs are shown in Table 3.

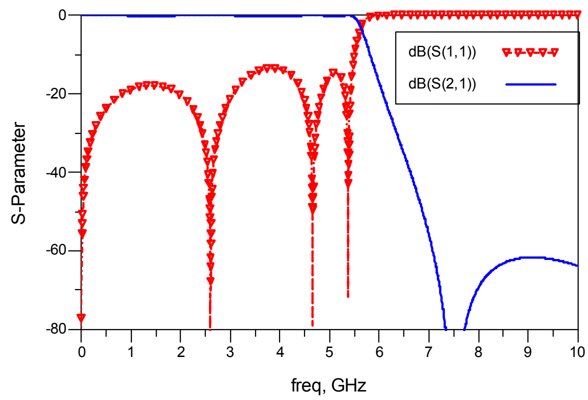
TABLE 3 : ELEMENT VALUE OF STUB ELEMENT

Elements	Value (Ω)	Elements	Value (θ)
z1	120	E1	29.13
z2	29.78	E2	72.0
z3	55.55	E3	29.9

The simulated results in Fig. 2 (b) show an insertion loss (S_{21}) is almost 0 and the return loss (S_{11}) better than -18 dB are obtained in the passband.



(a)



(b)

Fig. 2. (a) Generalized Chebyshev lowpass distributed filter (b) Simulated frequency response of the generalized Chebyshev lowpass distributed filter

C. *Suspended Stripline Structure (SSS)*

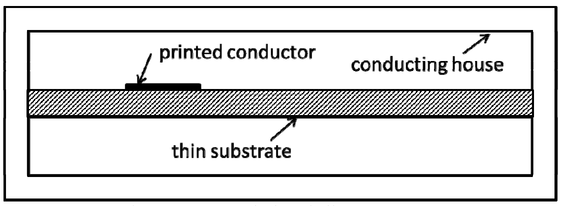


Fig. 3 : Suspended Stripline Structure

This LPF is then fabricated using SSS (as shown in Fig. 3) in order to improve the overall filter performance. The impedance of the SSS which is based on Tranverse Electromagnetic (TEM) transmission line is related to its static capacitance to ground per unit length as the following [18]:

$$Z_0\sqrt{\varepsilon_r} = \frac{377}{C/_{\varepsilon}} \tag{7}$$

where ε_r is the dielectric constant of the medium and $C/_{\varepsilon}$ is the normalized static capacitance per unit length of the transmission line. If a transmission line is suspended, the normalized static capacitance would include fringing capacitance.

$$\frac{C}{\varepsilon} = 2C_p + \frac{4C'_f}{\varepsilon} \tag{8}$$

and

$$C_p = \frac{w}{(b-t)/2} \tag{9}$$

where b is ground plane spacing and t is the thickness of the conductor. For a printed circuit, t is assumed as zero and hence

$$\frac{C}{\varepsilon} = \frac{4w}{b} + 1.84 \tag{10}$$

Therefore the line width of the stub, w can be obtained as:

$$w = \frac{b}{4}\left(\frac{377}{Z_0} - 1.84\right) \tag{11}$$

where b is a ground plane spacing in mm and Z_0 characteristics of impedance line. The length, l_a of the 1st and 7th open-circuit stub can be calculated using:

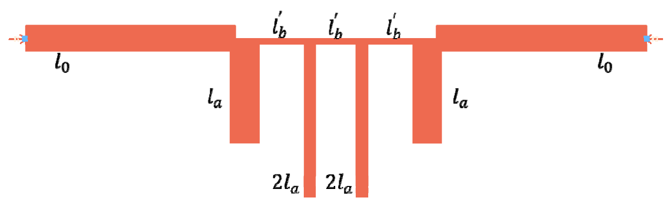
$$l_a = av \tag{12}$$

where $v = 3x10^8\, m/s$ and $s = 1\ and\ 4$
The length of the remaining open-circuit stub resonator is two times from the equation (12). The series short-circuit stubs are set to 120 Ω impedance transmission line for the ease of fabrication. Hence, the length, l_b' of the series short-circuit stubs are calculated using:

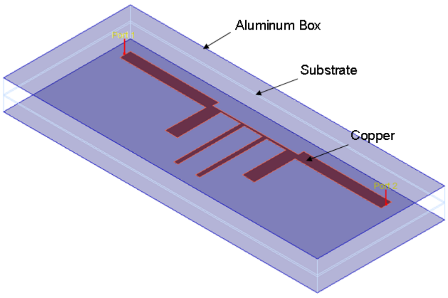
$$l_b' = \frac{3\times10^8}{\omega_c}\sin^{-1}\left(\frac{L_r}{Z_0}\right) \tag{13}$$

$b = 1, 2\ and\ 3$
L_r = element value of the component

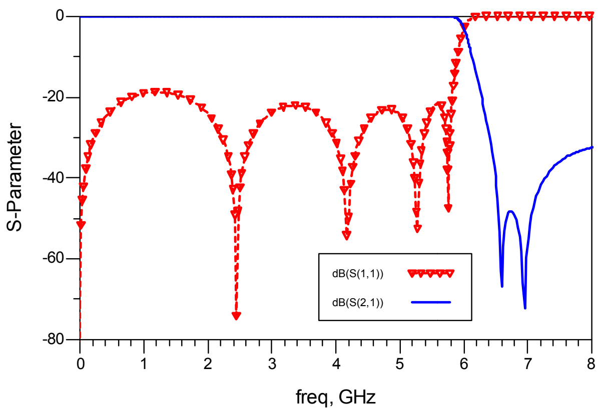
The SSS lowpass is modeled, simulated and optimized using ADS Momentum as shown in Fig. 4 (a) and the simulated response is shown in Fig. 4 (b). The simulated results show in Fig. 4 (c) insertion loss (S_{21}) is almost 0 dB and return loss (S_{11}) better -18 dB are obtained in the passband.



(a)



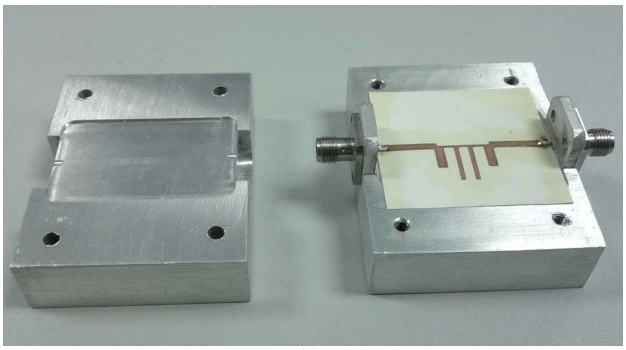
(b)



(c)

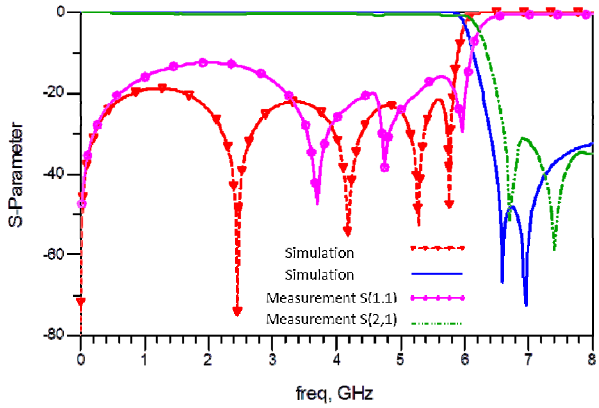
Fig. 4 : (a) Layout of generalized Chebyshev lowpass filter (b) 3-D view of Generalize Chebyshev lowpass filter (c) Simulated frequency response of the generalized Chebyshev lowpass filter in suspended stripline structure

The filter is manufactured on roger substrate with dielectric constant, ε_r = 3.48 and thickness of the substrate, t=0.168 mm. The filter is then built based on suspended stripline structure (SSS) using aluminium as shown in Fig. 5 (a) and (b). The roger substrate is suspended between the base and lid of the aluminium block. The simulated insertion loss and return loss performances of the filter are presented in Fig. 5 (c), and compared with measured results. As can seen from the Fig. 5 (c), a good agreement between the measured and the simulated results has been obtained. The measurement shows that a cut-off frequency at 6.2 GHz is achieved with insertion loss (S_{21}) is almost 0.3 dB and return loss (S_{11}) better than -15 dB are obtained in the passband.



(a)

(b)



(c)

Fig. 5 : Photograph of suspended stripline structure lowpass filter (a) inside (base – without lid) (b) overall filter structure with lid (c) comparison simulation and measurement result.

III. Defected Stripline Structure (DSS)

The DSS structure is produced by etching a slot in the conductor layout and it consists of horizontal slot and a vertical slot [6]. As well as the DGS structure, the DSS increases the electrical length of the microstrip and disturbs the current distribution. With this electric length increment, the filter size can be reduced. This DSS has no enclosure problems compare with DGS because there is no leakage through the ground plane [7]. Moreover, the DSS is easier to integrate with other microwave circuits.

In this study, the DSS is designed based on rectangular slot with length, l_s and width, w_s etched in the middle of the conductor line. The shape of the DSS is called a meander line slot which can produce a narrow notched band and at the same time the whole circuit area will be reduced. Fig. 6 (a) shows the meander line slot of DSS and Fig. 6 (b) shows the simulated results. The results show the notch response occurs at 3.2 GHz with narrow bandwidth. Thus, the characteristics of narrow band notch response will help to remove the undesired signal in wideband applications. In this study, the DSS will be integrated with lowpass filter based on SSS to exhibit bandpass and band reject response simultaneously.

The layout for integrated the DSS and lowpass filter is shown in Fig. 7 (a). Fig. 7 (b) shows the simulation results of integrated of the DSS and lowpass filter. In Fig. 7 (c), it shows that the response produces a notch at 3.2 GHz within the passband of the low pass filter.

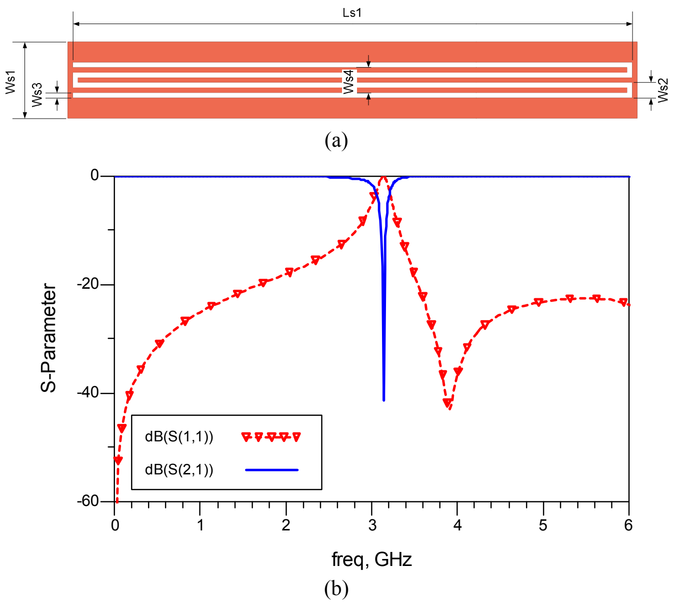


Fig. 6 : (a) Meander line slot, Ls1=10.7, Ws1=1.5, Ws2=0.3, Ws3=0.1 and Ws4=0.5, all in mm. (b) Simulated S-parameter of the meander line slot

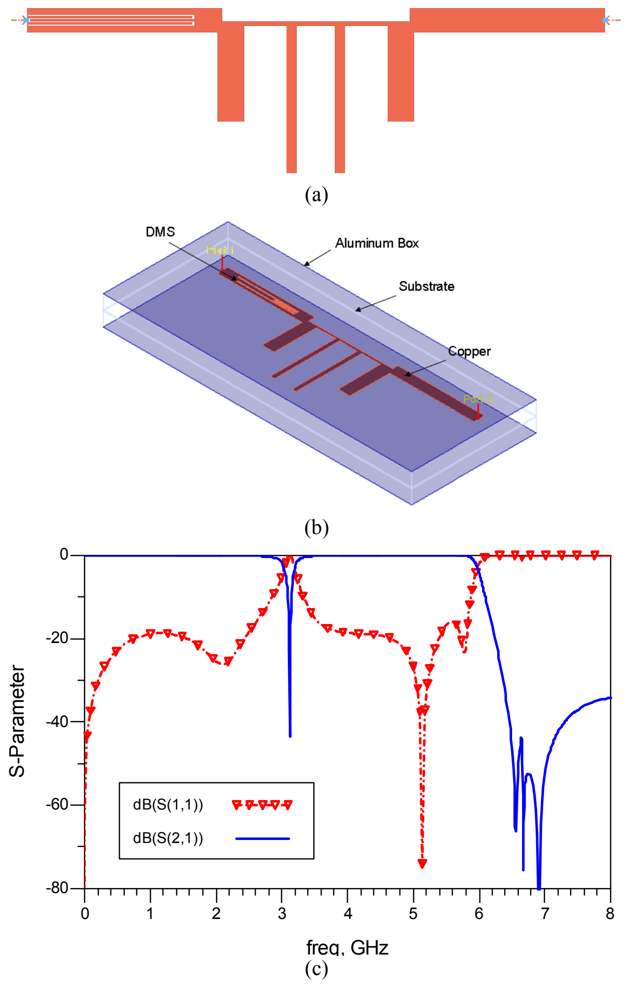


Fig. 7. (a) Structure 1 of integration between DSS and LPF (b) 3-D view of Generalize Chebyshev lowpass filter integrate with DSS (c) Simulation result of integration DSS and LPF

IV. Conclusion

A new technique for the integration of DSS and lowpass filter has been presented. The EM simulation shows promising and excellent results. Thus the study can be further explored and validated by developing the prototype of integrated DSS and lowpass filters based on SSS technology. This new class of the integrated DSS and lowpass filter to produce lowpass and band reject response simultaneously in a single device would be useful in microwave communication systems where the reduction of overall physical volume and cost is very important such as in a wideband applications.

Acknowledgment

The authors would like to thank UTeM for sponsoring this work under the short term grant, UTeM, PJP/2012/FKEKK(11C)/S01015.

References

[1] Z. Zakaria, M. A. Mutalib, K. Jusoff, M. S. Mohamad Isa, M. A. Othman, B. H. Ahmad, M. Z. A. Abd. Aziz, and S. Suhaimi, "Current Developments of Microwave Filters for Wideband Applications," *World Applied Sciences Journal*, vol. 21, pp. 31–40, 2013.

[2] Z. Zakaria, I. C. Hunter, and A. C. Guyette, "Design of Coaxial Resonator Filter with Nonuniform Dissipation," *IEEE MTT-S International Microwave Symposium Digest*, pp. 623–626, 2008.

[3] Z. Zakaria, and B. H. Ahmad. "Design of SIW Bandpass Filter with 6 dB Offset," *IEEE RF and Microwave Conference (RFM)*, pp.87-90, 2011.

[4] Z. Zakaria, A. Sabah, W. Y. Sam. "Design of Low-Loss Coaxial Cavity Bandpass Filter with Post-Manufacturing Tuning Capabilities," *IEEE Symposium on Business, Engineering and Industrial Applications (ISBEIA)*, pp. 733 – 736, 2012.

[5] S. Bila, R. J. Cameron, P. Lenoir, V. Lunot, and F. Seyfert, "Chebyshev Synthesis for Multi-Band Microwave Filters," *Microwave Symposium Digest, 2006. IEEE MTT-S International*, pp. 1221–1224, 2006.

[6] J. Xiao and W. Zhu, "New Defected Microstrip Structure Bandstop Filter," in *Progress In Electromagnetics Research Symposium Proceedings*, 2011, vol. 01, pp. 1471–1474.

[7] R. Sinhga and T. Moyra, "Design and Performance Improvement of Lowpass Filter by using Defected Microstrip Structure," *2012 International Conference on Communications, Devices and Intelligent Systems (CODIS)*, vol. 1, pp. 520–523, Dec. 2012.

[8] A. R. Mallahzadeh, B. Rahmati, M. Alamolhoda, R. Sharifzadeh, and A. H. Ghasemi, "Ultra Wide Stop Band LPF with Using Defected Microstrip Structures," *2012 6th European Conference on Antennas and Propagation (EUCAP)*, pp. 1–3, Mar. 2012.

[9] F. Bahmani, J. Ourinia, C. Ghobadi, and S. Pirani, "A Novel DGS Applied to Design Lowpass Filter," *Electrical Engineering (ICEE), 2011 19th Iranian Conference*, vol. 1, pp. 5–9, 2011.

[10] Z. Zakaria, N. A. Shairi, R. Sulaiman, and W. Y. Sam, "Design of Reconfigurable Defected Ground Structure (DGS) for UWB Application," *2012 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, vol. 2, pp. 195–198, Dec. 2012.

[11] J. A. Tirado-mendez and H. Jardon-aguilar, "Comparison of Defected Ground Structure (DGS) and Defected Microstrip Structure (DGS) Behavior at High Frequencies," *Electrical and Electronics Engineering, 2004. (ICEEE). 1st International Conference*, pp. 7–10, 2004.

[12] G. Yang, S. Member, R. Jin, C. Vittoria, V. G. Harris, and N. X. Sun, "Small Ultra-Wideband (UWB) Bandpass FilterWith Notched Band," *IEEE Microwave and Wireless Components Letters*, vol. 18, no. 3, pp. 176–178, 2008.

[13] G. Chaudhary, P. Kim, Y. Jeong, J. Lim and J. Lee, "Analysis and Circuit Modeling Method for Defected Microstrip Structure in Planar Transmission Lines," *Proceedings of the Asia-Pacific Microwave Conference, 2011,* pp. 999-1002.

[14] Z. Zakaria, I. C. Hunter, and A. C. Guyette, "Design of Coaxial Resonator Filter with Nonuniform Dissipation," in *2008 IEEE MTT-S International Microwave Symposium Digest*, 2008, pp. 623–626.

[15] Z. Zakaria, W. Y. Sam, MZ Abd Aziz, M Muzafar Ismail, "The Integration of Rectangular SIW Filter and Microstrip Patch Antenna based on Cascaded Approach", *Procedia Engineering, Elsevier*, vol. 53, pp 347-353, 2013.

[16] N. A. Shairi, B. H. Ahmad, P. W. Wong and Z. Zakaria, "Single Switchable Open Stub Resonator in SPDT Switch Design", *2012 IEEE Symposium on Wireless Technology & Applications (ISWTA 2012),* Bandung, Indonesia, Sept. 23 – 26, 2012.

[17] S. A. Alseyab, "A Novel Class of Generalized Chebyshev Low-Pass Prototype for Suspended Substrate Stripline Filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 30, no. 9, pp. 1341–1347, 1982.

[18] I. Hunter, *Theory and Design of Microwave Filters.* London, United Kingdom: The Institution of Engineering and Technology, 2001.