UNIVERSITI TEKNIKAL MALAYSIA MELAKA	UNIVERSITI TEKNIKAL MALAYSIA MELAKA CENTRE FOR RESEARCH AND INNOVATION MANAGEMENT
	PROJECT COMPLETION REPORT

PERHATIAN:

1. LaporanakhirprojekhendaklahdihantarkeCRIM **dalamtempohdua (2)**bulanselepasprojektamat.

2. Silalampirkandokumen yang berkaitanseperti yang dinyatakan.

3. Senaraisemak:

No.	Perkara	Tandakan (√)
1.	Borang RND13lengkap	√
2.	SertakanTemplate Profile Penyelidikan.	√
3.	Salinan Softcopy (CD).	√

A. PROJECT DETAILS

Principal Researcher :**DR. NOOR AZWAN SHAIRI**

Faculty/Centre :FakultiKejuruteraanElektronik dan KejuruteraanKomputer

Project Title :A Novel Integrated Generalized-Chebyshev Bandpass Filter and Notch Filter with Reconfigurable Capabilities for Next Generation Wireless Communications

Project No.: RAGS/1/2015/TK0/FKEKK/03/B00100

CoE: CeTRI

RG :Microwave Research Group

Project Duration : Starts Date 1 December 2015 Final End Date:30 November 2017

Budget Approved: 76600 Amount Spent Up to this period: 76492.76

Project Members :MultidiciplinaryMult [√] y [ ]

B. PROJECT ACHIVEMENT AND PERFORMANCE

OVERALL	**0 – 50%**	**51 – 75%**	**76 – 100%**
Work completion (please state %)	-	-	100%
Financial Utilization (please state %)	-	-	99.86%
RESEARCH OUTPUT			
I. PUBLICATION (Recorded at UTeMeRepository)	UTeM Press	Index Scopus/ISI	Others
a. No. of Journal Publication (Please attach the first page of publication)	5	Scopus	
b. No. of Conference Proceeding (Please attach the first page of publication)	1	Scopus	
c. No. of Other type of publication eg. monograph, books, chapters in book			
II. PROTOTYPE DEVELOPMENT		National	International
a. No. of Intellectual Property Rights		1	
b. Attended product exhibition & competition		1	1
c. No. of Industrial Collaboration MoU/NDA/MoA)			

III. HUMAN CAPITAL DEVELOPMENT

	Number of Human Capital	On-Going		Graduated	
		Malaysian	Non-M	Malaysian	Non-M
1	PhD Student			1	
2	Master Student			1	
3	Undergraduate Student (SRA)				
	Total			2	

IV. ASSETS AND INVENTORY PURCHASED (Cost more than RM 3000 per item)

NA

DECLARATION OF PRINCIPAL RESEARCHER

I acknowledged UTeM in providing the fund for this research work. (For University Grant only)

I certify that the information given in this final project report is true to the best of my knowledge.

Principal Researcher Signature :

Official stamp :
Name :Dr. Noor Azwan Bin Shairi
Designation : Senior Lecturer
Date : 20 July 2018

ENDORSEMENT BY DIRECTOR OF CRIM

(Please state /comment on the performance of the project)

____

____

Signature & Official Stamp   Date

CRIM Revised date: 1 July 2018

LAMPIRAN A

RESEARCH PROFILE / TECHNICAL REPORT

TITLE OF RESEARCH:
A Novel Integrated Generalized-Chebyshev Bandpass Filter and Notch Filter withReconfigurable Capabilities for Next Generation Wireless Communications

PROJECT NO: RAGS/1/2015/TK0/FKEKK/03/B00100

NAME OF RESEARCHERS:
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UTeM / FKEKK / CeTRI/ MRG

PROJECT DURATION:
1 DECEMBER 2015 – 30 NOVEMBER 2017

DATE OF REPORT: 20 July 2018

EXECUTIVE SUMMARY / ABSTRACT

Bandpass filter is an essential component, in microwave wireless communication systems, which is typically used in both receivers and transmitters. Bandpass filter with wideband passband has been attracting a lot of interests of the researcher to employing different methods and techniques. However, some existing radio systems that uses narrow band signals, such as IEEE 802.11a WLAN in the band 5.2 GHz and 5G WiFi has operating band from 5.15 to 5.85 GHz can cause an interference with the wideband systems (3-6 GHz). Moreover, to overcome the problem of very large numbers of standard to mitigate the strong interference signals, the flexibility device is really required. To overcome the problem, electronically reconfigurable bandpass filter and notch response will be introduced with tunable capabilities to solve the limitation of fixed pre-defined method. Therefore, this thesis presents new techniques for the design of microwave bandpass filter at 3 to 6 GHz which cover wideband with a fractional bandwidth of about 66.67%. The return loss is better than 16 dB and insertion loss is less than 0.9 dB. This filter was constructed by using microstrip short circuit stubs bandpass filter. This thesis also discusses about enhanced selectivity of bandpass filter by replacing the first short circuited stub with two sections of open circuited stub, the transmission zeros can be obtained at the desired frequency. This method is very useful to increase the selectivity where the number of elements can be reduced and also maintaining the overall performance. Varactor diode is placed at the end of open circuited stub. By properly adjusting the location of varactor diode, the constant fractional bandwidth can be achieved. In order to avoid the interference from existing system that operates in the frequency band, several methods was introduced to generate a narrow notch band. Then the notch structure will be integrated with the bandpass filter in order to provide high attenuation at 21 dB with narrow bandwidth with 1.08 % FBW and high Q-factor with 184.71. This structure is very useful for wireless systems as it can be easily integrated with other planar devices. Advanced Design System (ADS) software was used to simulate the design from circuit element to physical momentum realization. The experimental results showed good agreement with the simulated results. The benefits of the integrated bandpass filter and notch structure are the reduction of the overall size, easier to fabricate and high Q-factor. This new design of microwave filter is considered suitable and an alternative solution for wireless, radar and also 5G application without any addition of external components in the cascaded structure.

1. INTRODUCTION

Mobile communication becomes more promising for wideband technology and receives incredible interests in the field of academic and industry. The development of this spectrum has been used for various devices, such as antenna [1], filter [2], power amplifier and etc. However, there are many unwanted signal sharing and interference on the radio frequency band for different purpose inside the wideband frequency allocation. By introducing the notch response, the interference inside the wideband response can be eliminated. The Wireless Local Area Network (WLAN) at 5.2 GHz overlaps with wide frequency range for wideband spectrum [3]. This interference causes distortion to transmit the signal and loss of sensitivity in bandpass filters. However, the future cognitive radio makes it more critical to develop tunable microwave filters. Therefore, the development of tunable notch response is preferred in wideband bandpass filter to eliminate the interference signals [4]. With the increasing development of tunable filter in wireless communications, several researchers are attempting to form it in a compact size while at the same time maintaining the performance of the microstripfilter.

Several methods of developing notch response have been proposed recently, such as the Electromagnetic Bandgap (EBG) [5], Defected Microstrip Structure (DMS) [6][7] and Defected Ground Structure (DGS) [8]. The DMS is etched by defecting the stripline using some structures, making it to be easily embedded with other microwave devices. This structure is easier to design efficiently and reduces the circuit design in comparison with the DGS. The DMS has proven to have slow- wave properties, and it rejects (bandstop notch response) at desired frequencies by controlling the electrical length for the circuit design. The DMS will not affect the ground plane, when avoiding any leakage of the RF signal. Moreover, the DMS has been discovered and generally used for the development of a compact size microwavefilter.

In this study, a new design of bandpass filter integrated with the reconfigurable notch response is presented. The bandpass filter was designed with FBW recorded at 66.6% with transmission and reflection coefficient at 0.3 dB and 18 dB respectively. The notch response was designed using U-shape DMS and PIN diode (BAP 64-02) as switching element.

2. OBJECTIVES OF RESEARCH

1) To design novel structure of reconfigurable microwave bandpass filter and integrate with notch filter to exhibit bandpass and band reject response simultaneously for wideband application.
2) To analyse the structure of reconfigurable bandpass filter and notch filter using EM simulation in term of S-Parameter, group delay and power handling.
3) To fabricate, verify and evaluate the novel structure of integrated bandpass and notch filter through experimental works in laboratory.

3. RESEARCH METHODOLOGY

Description of Methodology.
This research has 5 stages as follows:

Stage 1

Design of microwave band pass filter to provide wide bandwidth from 3 to 6 GHz. This stage will involve:

i. Design and simulate the physical layout for filter. This will involve the analytical study and parametric analysis.
ii. This research will start from lowpass prototype network which satisfies a generalized Chebyshev response having two transmission zeroes at finite frequencies is shown in Figure 1.
iii.

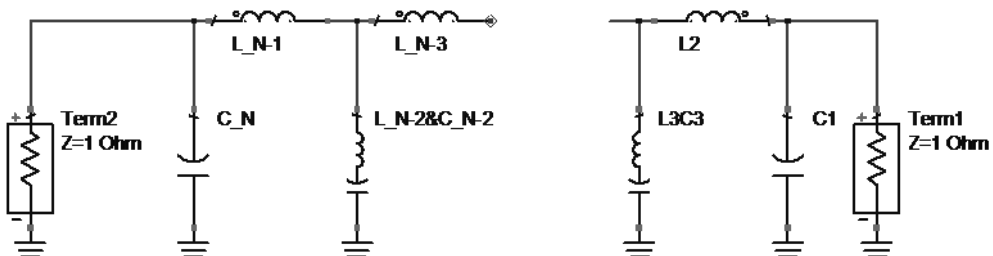

Figure 1: Example of generalized Chebyshev lowpass prototype filter.

In this research, a lowpass filter with 6 GHz cut-off frequency based on the generalized Chebyshev prototype of stopband insertion loss of 60 dB and minimum passband return loss of 20 dB will be used as a specification in synthesis and mathematical modelling. The lowpass filter prototype and its element values can then be constructed.

iv. Next, the transformation from 1 Ω to 50 Ω impedance system will be implemented by scaling the impedance to 50 Ω as follows.

For the inductors,

$$Z = L_p \Rightarrow Z_0 L_p = (Z_0 L)_p \tag{1}$$

That is,

$$L \Rightarrow Z_0 L \tag{2}$$

Thus the inductances are multiplied by Z_0.

For the capacitors,

$$Z = \frac{1}{C_p} \Rightarrow \frac{Z_0}{C_p} = \frac{1}{\left(\frac{C}{Z_0}\right) p} \tag{3}$$

That is,

$$C \Rightarrow \frac{C}{Z_0} \tag{4}$$

Thus, the capacitance are divided by Z_0.

v. The prototype is then transformed from normalized frequency of 1 rad/s to an arbitrary frequency

Applying this transformation to inductors,

$$Z = L_p \tag{5}$$

$$Z(j\omega) = j\omega L \Rightarrow \frac{j\omega L}{\omega_c} \tag{6}$$

That is,

$$L \Rightarrow \frac{L}{\omega_c} \tag{7}$$

Similarly, apply this transformation to capacitors,

$$Z = \frac{1}{C_p} \tag{8}$$

$$Z(j\omega) = \frac{-j}{\omega C} \Rightarrow \frac{-j}{\left({}^{\omega}/_{\omega_c}\right)C} \tag{9}$$

That is,

$$C \Rightarrow \frac{C}{\omega_c} \tag{10}$$

By implementing Equations (2), (4), (7) and (10), values of each capacitors and inductors in the lowpass prototype network operating in 1 Ω can now be transformed into low pass filter with cut-off frequency of 10.6 GHz with 50 Ω system impendence.

Then, a highpass filter can also be transformed from the lowpass prototype with arbitrary cutoff frequency, ω_c = 3.1 GHz. This will produce high pass response.

$$\omega \Rightarrow \frac{-\omega_c}{\omega} \tag{11}$$

This maps the lowpass filter prototype cutoff frequency to a new frequency.

Applying this transformation to inductors

$$Z(j\omega) = j\omega L \Rightarrow \frac{-j\omega_c L}{\omega} \tag{12}$$

$$Z(j\omega) = \frac{-j}{\omega\left(\frac{1}{\omega_c L}\right)}$$

$$Z(j\omega) = \frac{-j}{\omega C'}$$

Where

$$C' = \frac{1}{\omega_c L} \tag{13}$$

Hence the inductors are transformed into capacitors.

Applying this transformation to capacitors,

$$Z(j\omega) = \frac{-j}{\omega C} \Rightarrow \frac{j\omega}{\omega_c C}$$

$$Z(j\omega) = j\omega L' \tag{14}$$

Where

$$L' = \frac{1}{\omega_c C} \tag{15}$$

Stage 2

Design a bandpass filter with reconfigurable transmission zeros at arbitrary frequency. This transmission zeros will increase the selectivity of bandpass response in order to produce high performance, reduce the number of element and compact size. The fundamental of element bandpass filter with transmission zeros are shown in Figure 2. The generalized Chebyshev function provides an equiripple behavior in the passband and has a limited number of transmission zeros in the stopband.the generalized Chebyshev function is expressed as

$$|S_{21}(\omega)|^2 = \frac{1}{1 + \varepsilon^2 F_n^2(\omega)} \tag{16}$$

Where $F_n(\omega)$ is a function such that

$$F_n(\omega) = \begin{cases} \cos\left[(n - n_z)\cos^{-1}\omega + \sum_{k=1}^{n_z} \cos^{-1}\frac{1 - \omega\omega_k}{\omega - \omega_k}\right], & 0 \le |\omega| \le 1 \\ \cosh\left[(n - n_z)\cos^{-1}\omega + \sum_{k=1}^{n_z} \cosh^{-1}\frac{1 - \omega\omega_k}{\omega - \omega_k}\right], & 1 < |\omega| \end{cases} \tag{17}$$

In these expression, n_z is the number of purely imaginary zeros $(j\omega_1)$, $(j\omega_2)$,…, $(j\omega_z)$ that provide transmission zeros in the stopband.

When $n_z = 0$, the function $F_n(\omega)$ reduces the traditional Chebyshev polynomial:

$$F_n(\omega) = T_n(\omega) = \begin{cases} \cos(n\cos^{-1}\omega), & 0 \le |\omega| \le 1 \\ \cosh(n\cosh^{-1}\omega), & 1 < |\omega| \end{cases} \tag{18}$$

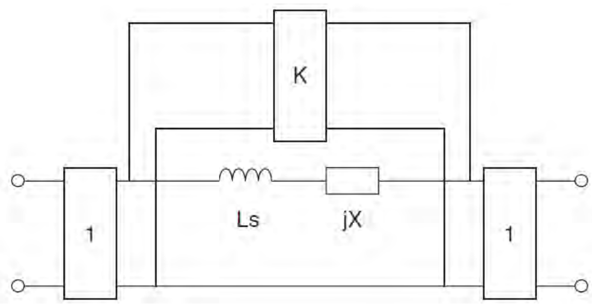

Figure 2: Fundamental element for bandpass filter with transmission zeros

Bandpass filter can be modeled as a symmetrical two-port network describe by its admittance and S matrices as shown in Figure 3:

$$Y = \begin{pmatrix} (Y_{ine} + Y_{ino})/2 & (Y_{ine} - Y_{ino})/2 \\ (Y_{ine} - Y_{ino})/2 & (Y_{ine} + Y_{ino})/2 \end{pmatrix} \tag{19}$$

$$S_{21} = \frac{Y_L(Y_{ino} - Y_{ine})}{(Y_L + Y_{ino})(Y_L + Y_{ine})} \tag{20}$$

Where Y_{ine} and Y_{ino} are the even- and odd-mode input admittance; Y_L is the load admittance. The transmission zeros can be obtained from $S_{21}(\omega_{TZ1}) = 0,$ leading to two possible solutions

$$\begin{cases} Y_{ino}(\omega_{TZ1}) = \infty \\ Y_{ine}(\omega_{TZ1}) = \infty \end{cases} \tag{21}$$

$$Y_{ino}(\omega_{TZ2}) = Y_{ine}(\omega_{TZ2}) \tag{22}$$

In the meantime, the well-established equations for synthesizing bandpass filter are

$$\mathrm{lm}(Y_{11}(\omega_0)) = 0 \tag{23}$$

$$k = Y_{12}/b = FBW/\sqrt{g_1 g_2,} \tag{24}$$

$$b = \frac{\omega_0}{2} \cdot \frac{\partial\,\mathrm{lm}(Y_{11})}{\partial\omega}\bigg|_{\omega=\omega_0} \tag{25}$$

$$Q_e = b/(J_{01}^2/Y_L) = g_0 g_1/FBW \tag{26}$$

Where FBW is the 3 dB fractional bandwidth; b is the slope parameter of the resonator; k is the coupling coefficient, Q_e is the external Q; g_1 and g_2 are derived from a classic low pass prototype filter. The transmission zeros defined by (21) and (22) can be independent of each other with certain bandpass filter structures so that the independent tenability of both central frequency and the bandwidth can be realized. The tunable transmission zeros can be realized by manipulating the equation (27) and (28). The input admittance of the bandpass filter can be expressed in terms of even and odd modes

$$\begin{cases} Y_{ine} = Y_{DOWN} + Y_{UPe} \\ Y_{ino} = Y_{DOWN} + Y_{UP0} \end{cases} \qquad (27)$$

Where

$$Y_{UPe} = jY_{u1} \cdot \frac{Y_{Se} + Y_{u1} \tan(\theta_{u1})}{Y_{u1} - Y_{Se} \tan(\theta_{u1})}, \qquad (28)$$
$$Y_{UPo} = jY_{u1} \cdot \frac{Y_{So} + Y_{u1} \tan(\theta_{u1})}{Y_{u1} - Y_{So} \tan(\theta_{u1})}$$

Y_{DOWN} is the admittance looking into T-line B from the junction between A and B. Y_{Se} and Y_{So} are the admittances looking into C-line C from the junction between A and C. (27) along with (19) and (20) gives the overall Y matrix of the bandpass filter its S_{21}.One is given by $Y_{DOWN} = \infty$, which is decided by T-line B and varactor C_1. Figure 4 shows the propose simulation response of tunable transmission zeros at arbitrary frequency. This transmission zeros can provide the high selectivity and high performance of the bandpass filter.

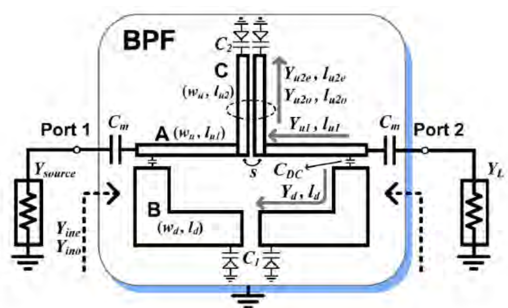

Figure 3: Propose bandpass filter with tunable transmission zeros

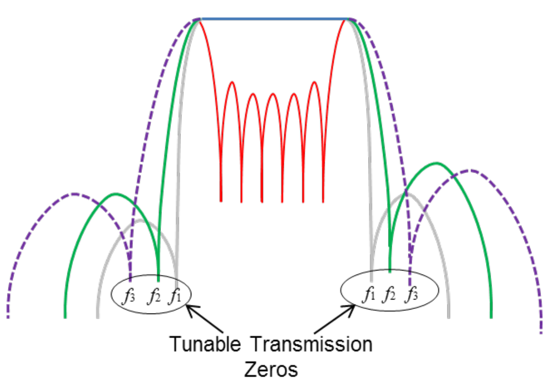

Figure 4: Tunable transmission zeros at arbitrary frequency

Stage 3

Design a notch filter in order to produce band reject response with a narrow bandwidth consists of Defected Misrostrip Structure (DMS), and Defected Stripline Structure (DSS). Defected Microstrip Structure (DMS) consists of a horizontal slot and a vertical slot in the middle of the conductor line, it is similar to the defected ground structure (DGS), the DMS increases the electrical length of microstrip line and disturbs its current distribution. The effective capacitance and inductance of a microstrip line increase. According to DMS characteristic, this method can be applied to the transmission line of SSS in order to produce a good response of band reject characteristics. As well as the DMS structure, the DSS also increase the electric length of the microstrip obtaining and increment in the associated inductance, with which an improvement in the filter and other stripline circuited can be achieve. A parametric study will also be involved at this stage in order to identify and analyze the variation of DSS parameters.

Further tuning and optimization on the DSS parameter will be carried out to obtain good appropriate responses. This is to ensure the design of notch filter can be implemented to produce a notch response. Figure 5 shows the switchable filter using PIN diodes on DMS structure. In this filter topology all PIN diodes are reverse biased to produce a filter central frequency, f_o and all PIN diodes when forward biased produce the frequency, f_1 central frequency. A PIN diode is attached at the open-end of the embedded stub. When the PIN diode is at the zero bias, it presents large impedance owing to its very small junction capacitance, and hence the embedded stub functions as an open-circuited stub that resonates. Figure 6 shows the simulation for the switchable notch response when the PIN diode is turned ON/OFF.

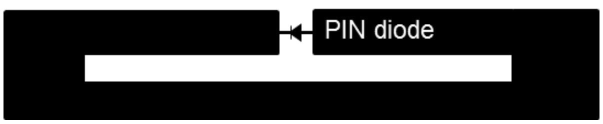

Figure 5: Switchable filter using PIN diode with constant bandwidth

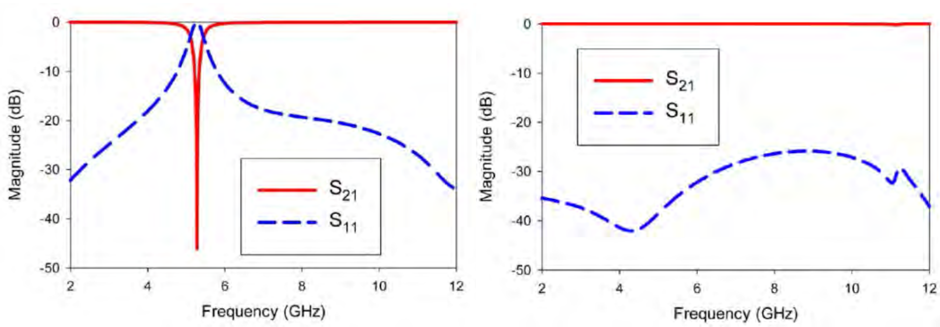

Figure 6: Simulation for the switchable notch structure (left) Notch switched on. (right) Notch switched off.

Varactor diodes are typically used for continuous tuned filters. Varactor diodes use the change in the depletion layer capacitance of a p-n junction as a function of applied bias voltage. Varactor tuned devices have been used for high tuning speeds; these devices do not exhibit hysteresis. Tuning speeds of varactor tuned filters are limited only by the time constant of the bias circuit. Varactor based tunable filters are mainly distributed. Figure 7 shows the tunable filter using varactor diodes. The expected simulation response of the tuning effect is illustrating in Figure 8. The presence of varactor diode allows the electrical tuning of the resonator through the application of the DC bias voltage from 0 to 6 volts.

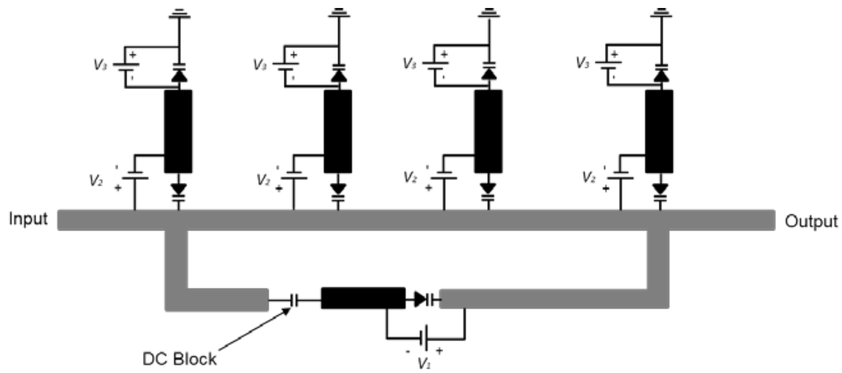

Figure7: Tunable filter using varactor diodes

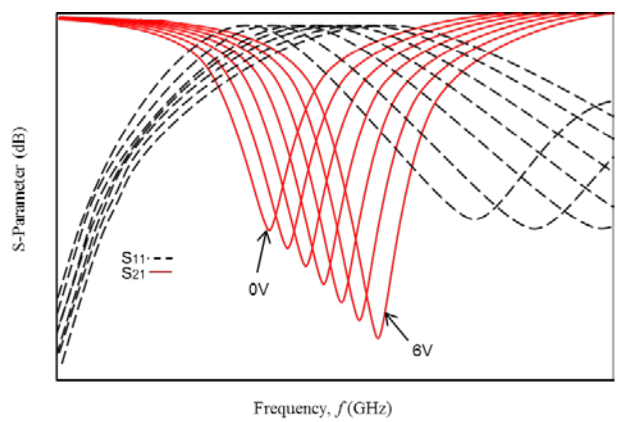

Figure8: Simulation tunable resonator with varactor diode

Stage 4

The new method of designing bandpass and band reject will overcome the problem faced by wideband application in order to remove the undesired signals, i.e 3.2 GHz and 5.2 GHz (Wireless Local Area Network (WLAN) radio signal). However, the previous researcher only focused on development of bandpass filter and only one fixed notched response is created. The existing undesired narrowband radio signals vary from place to place from time to time. Therefore, it is more desirable to introduce an electronically tunable notch band within the passband of a wideband bandpass filter. In this study, we design bandpass filter with electronically tunable transmission zeros along with reconfigurable notch response in a single device. The technique from stage 2 and stage 3 will combine to produce electronically tunable bandpass filter along with reconfigurable notch response in a single device.

Design a reconfigurable band stop filter using Notch response method (DMS, and DSS). This type of integration between bandpass filter and notch filter can be implemented to create reconfigurable capabilities as well as to avoid the strong interference signal. Figure 9 compares the conventional and the proposed new filter topology. This new design will exhibit bandpass and notch response simultaneously in a single device. This can be illustrated as in Figure 10 and

Figure 9 respectively. The response can be easily tuned and generated by controlling the varactor diode with a DC bias.

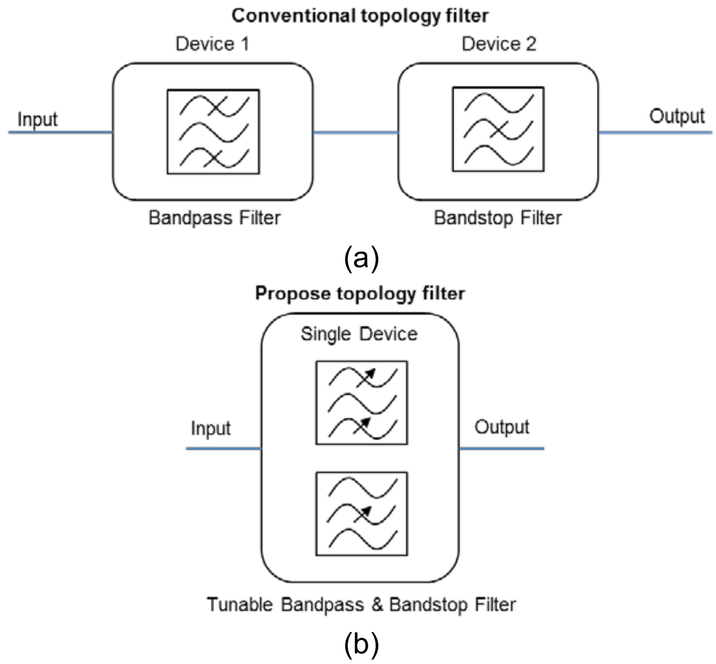

Figure9: Proposed topology of electronically tunable bandpass filter with switchable notch response

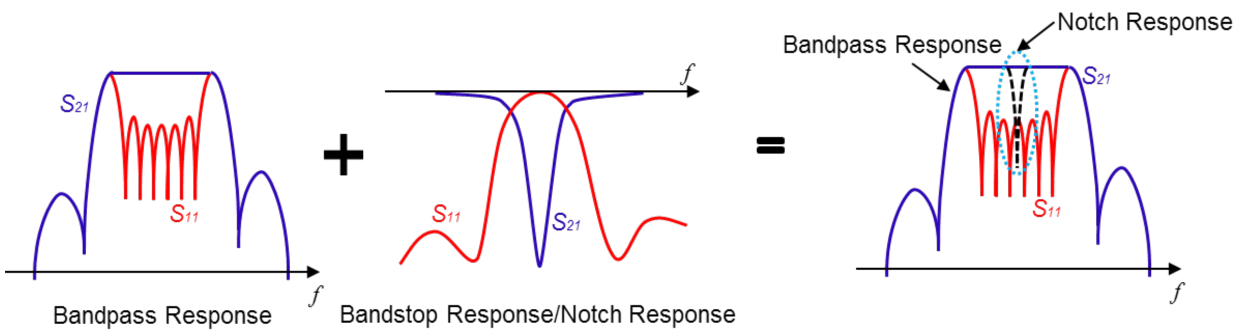

Figure 10: Existing technology to design bandpass filter with fix notch response

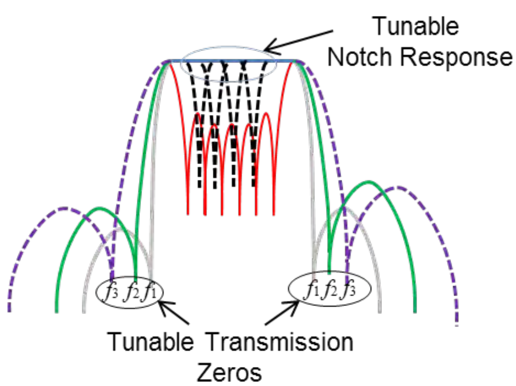

Figure11: Proposed simulation response of electronically tunable bandpass transmission zeros and notch response

This research will be concluded with a new technique of integration between wide-band microwave band pass filter and Notch filter. However, further investigation will be required in order to understand the appropriate techniques between band pass response and band reject response. This is because the significant difference exists in terms of propagation modes in both structures. Therefore, a deep understanding on the structures is crucial in order to analyze the electromagnetic pattern and obtain the optimized structure of the notch. This process will be intensively implemented and may require additional optimization in terms of tuning parameters between both structures in order to ensure of having identical characteristic of the ideal mathematical and analytical modeling done in the earlier stage. Therefore, a high-performance workstation with sufficiently large memory would be required for this process. This novel structure will exhibit band-pass and band-reject characteristics simultaneously.

The expected substrate material to be used during the experimental works is Rogers RO4350. The substrate material is chosen due to its low-loss, availability and relatively low-cost. More importantly, the material can be used at the proposed frequency.

Table 1

Properties	Typical Value
Frequency, *f*	3 – 6 GHz
Dielectric constant, ε_r	3.48
Loss tangent, $\tan\delta$	0.0037
Substrate thickness, H	0.508 mm
Copper cladding, *t*	35 um

Stage 5

The experimental works will be implemented in the laboratory using the existing equipment such as vector network analyzer and spectrum analyzer. The integrated microwave filter and antenna is expected to operate at 3 GHz – 6 GHz with insertion loss, S_{21} and return loss, S_{11} of 0.1dB and better than 20 dB respectively. The band-reject response will be introduced at 5.2 GHz. This study will provide an alternative solution for ultra-wideband application where the reduction of physical volume is very important. In addition, the resulting novel structure will also produce band pass and band reject response in the same structure simultaneously. The measurement and validation can be made at this stage using Vector Network Analyzer.

4. RESULTS / FINDINGS

The design of wideband bandpass filter is based on the previous works described in [9]. However, the improvement was made to miniaturize the structure in order to maintain the performance of the conventional short circuit stub bandpass filter. The proposed design is slightly modified to simplify the structure and reduce the fabrication cost. The synthesis of lumped element to the physical layout is obtained based on the characteristic impedance and the electrical length for each number of short circuit stubs and the connecting lines. The filter was designed by Roger Duroid 4350B with a dielectric constant of 3.48. The substrate thickness and tan δ was set to 0.508 mm and 0.019 respectively. The layout of wideband bandpass filter and its physical dimensions is shown in Figure 12. The curve bending discontinuities junction has been taken into account for this proposed wideband bandpass filter.

The simulated results showed a reflection and the transmission coefficient of greater than 15 dB and 0.3 dB respectively for passband response. The filter in Figure 13 shows a good performance and high selectivity with a fractional bandwidth of passband for about 66.67%. The group delay of the passband response varied between 0.6 to 0.78 ns and very flat in the passband with 0.76 ns. The results of quarter wavelength short circuit stubs are shown in Table 2.

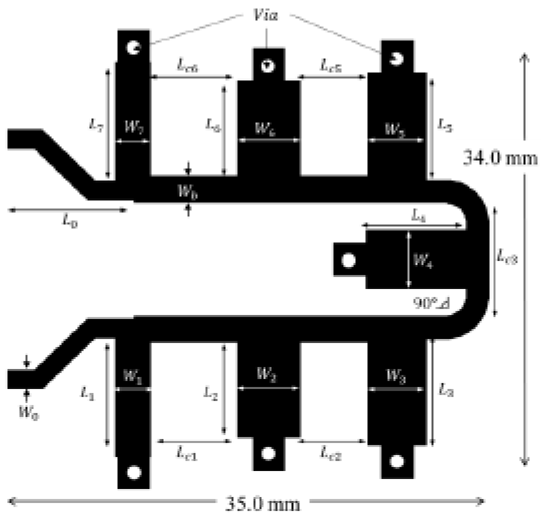

Figure 12: Proposed physical layout for 7th order short circuited stubs bandpass filter. *W0*=1.5, *W1*=*W7*=3.1, *W2*=*W6*=4.9, *W3*=*W5*=4.5, *W4*=4.5, *W7*=2.7, *Wb*=2.05, *L0*=11.8, *L1*=*L7*=8.45, *L2*=*L6*=7.35, *L3*=*L5*=8.2, *L4*=7.7, *L7*=9.1, *Lc1*=*Lc6*=7.45, *Lc2*=*Lc5*=5.2, *Via*=1.0. Unit in mm

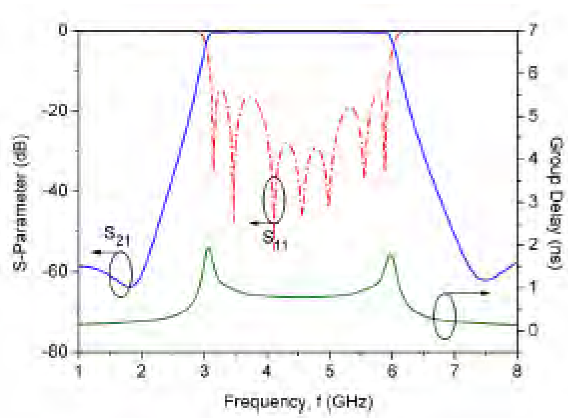

Figure 13: Simulation result of wideband bandpass filter

Table 2 Simulation Result for Wideband Bandpass Filter

Bandpass Filter	
Frequency Band (GHz)	3.0 – 6.0
Fractional Bandwidth, FBW (%)	66.67
Transmission Coefficient, *S21* (dB)	-0.3
Reflection Coefficient, *S11* (dB)	-15
Group Delay (ns)	0.74
Overall Dimension (*λg*)	0.663 x 0.685

A. Design of Defected Microstrip Structue (DMS)

This DMS structure unit was made by etching a slot on a microstrip line to produce a notch response at the desired frequency. The structure along with dimensions consisting of U-shape DMS can be realized, as shown in Figure 14. The notch response was constructed with a resonant frequency of 5.2 GHz, which represents a WLAN frequency spectrum. The U-shape DMS was designed by Roger Duroid RO4350B with a dielectric constant of 3.48, thickness of 0.508 mm and tan δ of 0.019 for all simulations. Figure 15 shows the equivalent circuit that consists of parallel-connected LC resonant circuit.The equivalent circuit parameters of U-shape DMS were obtained as *L*=0.261 nH and *C*=3.576 pF.

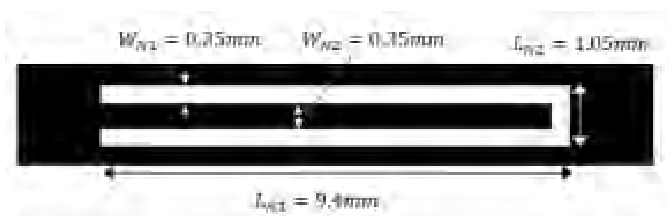

Figure 14: Proposed U-shape Defected Microstrip Structure

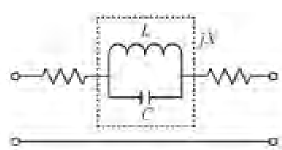

Figure 15: Equivalent circuit of U-shape DMS

To investigate the U-shape DMS, the structural effects by unit size *LN2*, *LN1* and *WN1* were analyzed in detail. The parametric analysis of the U-shape DMS is shown in Figure 16 (a). This is to determine the resonant frequency and the attenuation due to the increment on its length, *LN2*. In Figure 16 (b), the dimension of *LN1* was investigated due to the resonant frequency of 4.8 GHz, 5.0 GHz, 5.2 GHz and 5.5 GHz. The effects of resonant frequency are shown in Figure 16 (c) by varying the *WN1*. The bandwidth increases by the increment of *WN1* from 0.25 mm to 0.55 mm, hence decreases the selectivity of the response.

B. Tunable Notch Response

In this section, the general review of PIN diodes is discussed. The PIN diodes are normally used to provide discrete states of tunable filters and act as a tuning device for semiconductor. The concept of PIN diode for U-shape DMS with supply DC voltage on the island of the slot line is shown in Figure 17. PIN diode was employed as a switching device to turn ON / OFF the DC supply. Then, the external DC voltage supplies 10 V to turn ON the PIN diode with the incoming current of 1 mA. In this simulation, the tunable notch response was realized using PIN diode BAP 64-02. The biasing circuit consists of DC blocking capacitance with 47 pF, resistor of 100 Ω and DC feed of 22 nH. Figure 18 (a) shows the response of zero bias (OFF state) and Figure 18 (b) shows the response of forward bias (ON state). The simulation result shows that when PIN diode is ON, it produced a notch response at WLAN 5.2 GHz with FBW and attenuation for about 13.6%and 25 dB respectively. In the passband, the group delay was below 0.12 ns. However, when the PIN diode is OFF, the notch response disappeared and became all pass with a reflection coefficient better than 15 dB and transmission coefficient at 0.3 dB. The group delay for the U-shape DMS was very flat in the passband lower than 0.62 ns.

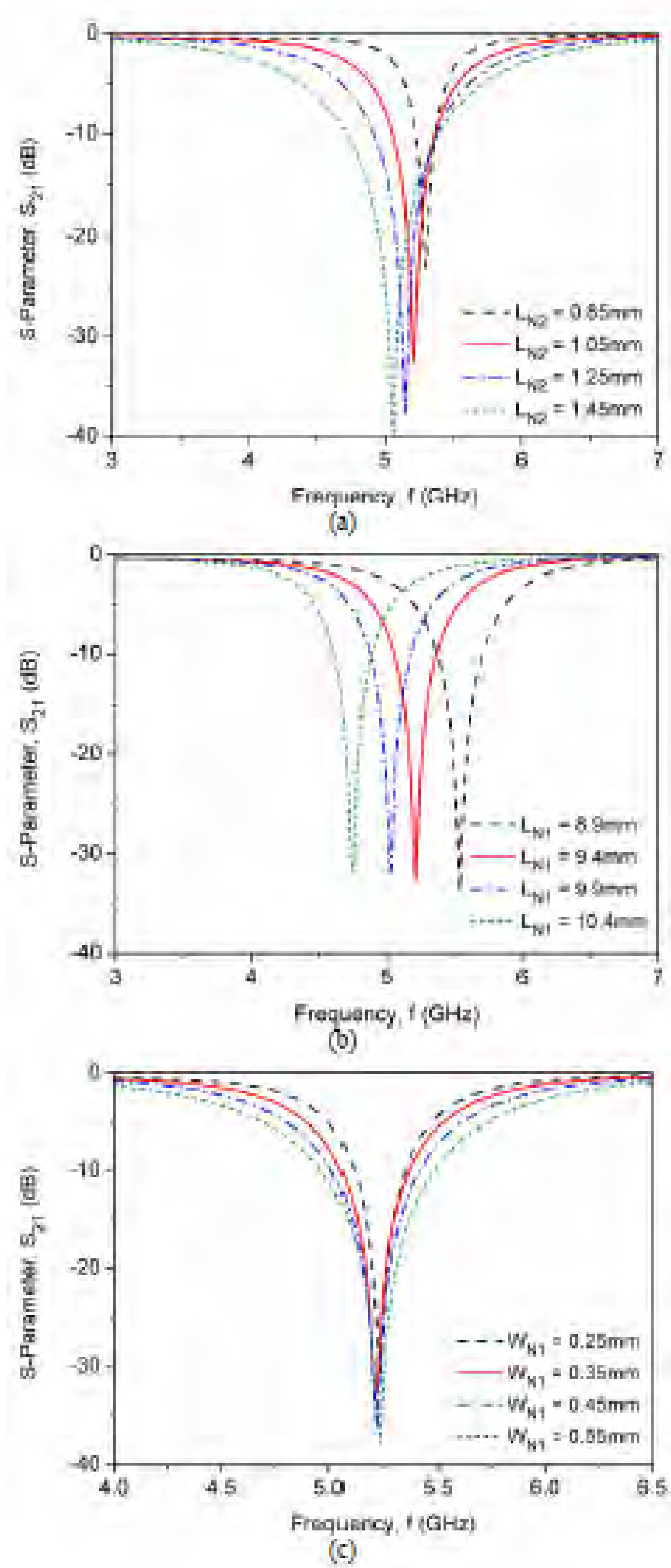

Figure 16: Simulated response of parametric analysis (a) *LN2*=1.0 mm, 1.2 mm, 1.4 mm and 1.6 mm varying (b) *LN1*=8.7 mm, 9.2 mm, 9.7 mm and 10.2 mm varying and (c) varying *WN1* 0.25 mm, 0.35 mm, 0.45 mm, and 0.55 mm.

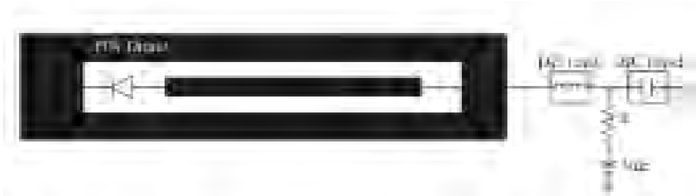

Figure 17: Proposed tunable U-shape DMS

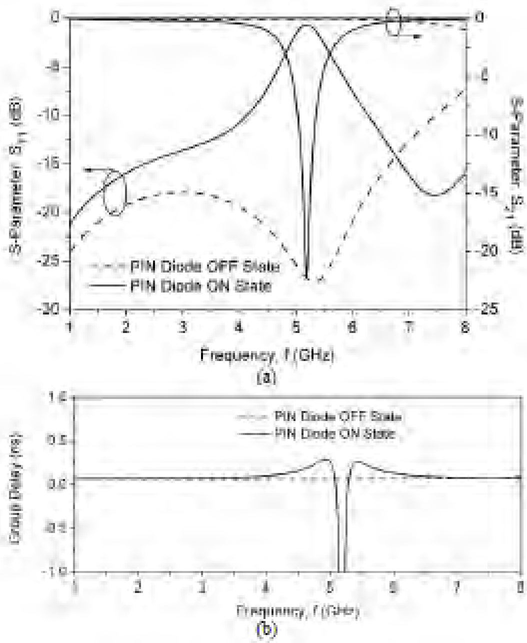

Figure 18: Simulation results of U-shape DMS with PIN diode (a) S-Parameter and (b) Group delay.

C. INTEGRATION OF SHORT CIRCUIT STUB BANDPASS FILTER WITH U-SHAPE DMS

The simulated result of short circuit stub bandpass filter with tunable notch response is described in this section. Figure 19 shows the equivalent circuit of bandpass filter with notch response. The biasing circuit consists of DC supply, resistor 110 ohm, capacitor 47 pF and inductor 2.1 nH. The integration of wideband bandpass filter with U-shape of DMS is illustrated in Figure 20. To produce the bandpass and notch response in a single device, the DMS can be placed at arbitrary microstrip line by integrating it inside the bandpass filter structure.

This integrated structure produces a wideband bandpass response from 3 GHz to 6 GHz and rejects the unwanted signal of 5.2 GHz WLAN frequency response. At the OFF state, the notch filter disappeared inside the wideband range and covered the 5.2 GHz WLAN frequency band. At the ON state, the external DC source of 10 V and 1 mA was supplied to turn on the PIN diode. The notch response was present at 5.2 GHz with attenuation of 14 dB and fractional bandwidth of 13.6%. The simulation result is shown in Figure 21(a). The simulation group delay at both ON/OFF state is depicted in Figure 21(b). The flat group delay was with 0.74 ns in the passband for the OFF state. It shows that the filter has a good linearity for signal transfer. Evidence from the ON state shows that the wideband response for the passbands the group delay was lower than 0.83 ns. Figure 22 shows the current flow visualization of integrated bandpass filter with DMS. The current flow focuses at 5.2 GHz with high concentrated red color (15.24 A/m). Table 3 shows the comparison of different topology of wideband bandpass filter.

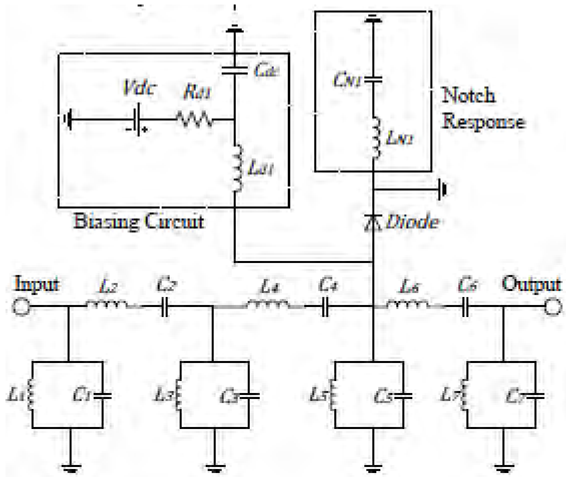

Figure 19: Equivalent circuit of integration bandpass filter with DMS (notch response)

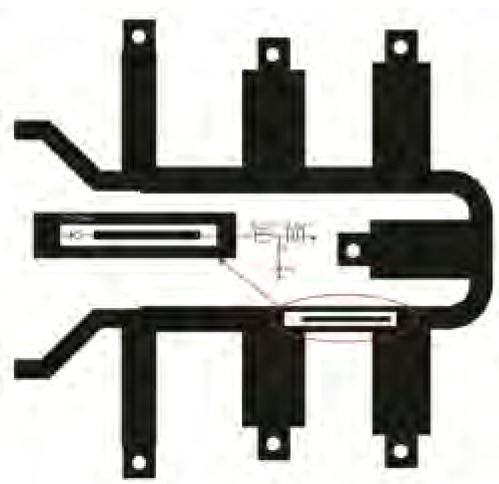

Figure 20: Physical layout of the proposed wideband bandpass filter with reconfigurable notch response.

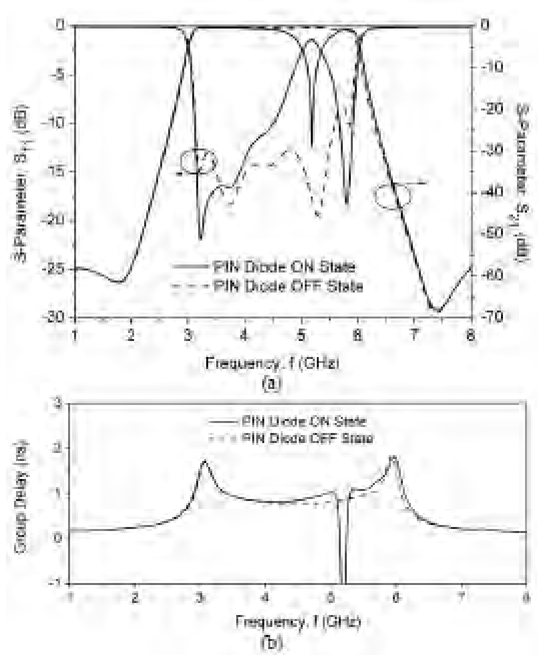

Figure 21: Simulation results of wideband bandpass filter with reconfigurable notch response (a) S-Parameter and (b) Group delay

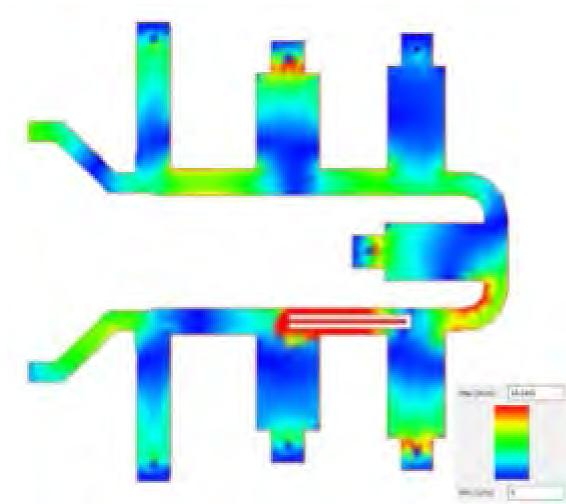

Figure 22: Current flow visualization of bandpass filter integrated with DMS

Table 3 Comparison between Different Topologies

Ref	S11 (dB)	S21 (dB)	3-dB FBW (%)	*fo*(GHz)	Dielectric Constant, *εr*	Size (*λg*x *λg*)
[2]	≥12	≤1.5	88.0	3.80	2.45	0.700 x 0.380
[3]	≥11	≤1.0	66.0	3.00	10.8	0.236 x 0.073
[4]	≥15	≤1.0	70.0	6.85	2.65	1.266 x 0.870
[5]	≥15	≤6.0	66.0	3.50	2.55	0.600 x 0.330
[6]	≥18	≤1.0	57.9	1.45	11.2	0.238 x 0.716
This Work	≥16	≤0.5	65.3	4.50	3.48	0.663 x 0.686

5. CONTRIBUTIONS OF RESEARCH

I. The optimized dimensions of filter structure.
II. Proof of Concept (POC) where designs can be customized at desired frequencies and Q-factors.
III. Significant contribution in the community of microwave theory and techniques.

This type of design is suitable to be implemented in any wideband application in order to remove undesired signal interference simultaneously. This type of filter also can be implemented in any ultrawideband (UWB) as well as civilian and military radar applications.

6. ACHIEVEMENT

i. Name of articles/ manuscripts/ books published

a. Mutalib, M. A., Zakaria, Z. and Shairi, N.A., 2017. High Selectivity Microstrip Bandpass Filter Integrate with Ring Resonator Bandstop Filter. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, *9*(2-13), pp.39-42. *(Scopus)*
b. Mutalib, M. A., Zakaria, Z., Shairi, N.A., Sam. W. Y., Masrukin, Y.E. and Zahari, M.K., 2017. Dual-Band Bandpass Filter using Defected Microstrip Structure (DMS) for WIMAX Applications. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, *9*(1-5), pp.111-114. *(Scopus)*
c. Mutalib, M. A., Zakaria, Z., Shairi, N.A. and Isa, M. S. M., 2016. Microstrip Bandpass Filter with Reconfigurable Notch Response at 5.2 GHz using Defected Microstrip Structure. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, *8*(5), pp.75-79. *(Scopus)*

d. Mutalib, M. A., Zakaria, Z. and Shairi, N.A., 2016. Microstrip Bandpass Filter withTunable Notch Response at 5.2 GHz Using Defected Microstrip Structure. *International Journal of Applied Engineering Research*, *11*(14), pp.8104-8108. *(Scopus/ISI)*
e. Mutalib, M.A., Zakaria, Z., and Shairi, N.A., 2016, Miniaturization of MicrowaveBandpass Filter for Wideband Applications. *International Journal on Communications Antenna and Propagation (IRECAP),* 6(4), pp. 239-243. *(Scopus)*

ii. Title of Paper presentations (international/ local)

a. Mutalib, M.A., Zakaria, Z., Shairi, N.A. and Sam, W.Y., 2016, April. Design of Microstrip Bandpass Filter With Electronically Tunable Notch Response. In *Radioelektronika (RADIOELEKTRONIKA), 2016 26th International Conference* (pp. 454-457). IEEE. *(Scopus)*

iii. Human Capital Development

a. MUHAMAD ARIFFIN MUTALIB (PhD Student) – Graduated in 2018
b. MUHAMMAD AIZAT SAZALI (Master Student)– Graduated in 2018

iv. Awards

a. Gold Medal – Seoul International Fair 2017 (2017)
b. Gold Medal – International Invention, Innovation & Technology Exhibition 2017(2017)
c. Bronze Medal – Innovation Carnival: MINIUTeMEX 2016 (2016)

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7. CONCLUSION

A novel wideband bandpass filter and integrated with reconfigurable notch characteristic has been successfully designed and simulated. A reconfigurable notch response was realized using PIN diode BAP 64-02 as a switching element. This technique was achieved by connecting the diode with external DC supply to provide a forward-bias connection (ON-state) or zero-bias (OFF-state). The biasing connection was completed by introducing the resistor and DC blocking throughout the circuit. The overall results with excellent characteristics have been successfully demonstrated. This new type of wideband bandpass filter with tunable notch response is highly suitable and can be applied for filtering the existing interference signal in radio systems.