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Current Developments of Microwave Filters for Wideband Applications

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Abstract: This paper presents a compilation of important review in the development of microwave filters for wideband technology used in previous years. The major research work for each year is reviewed. Several wideband filters based on the planar and non-planar circuits are compared and examined in order to propose a new topology of wideband filter using Suspended Stripline Structure (SSS). More importantly, this new proposed structure will be integrated with the Defects Ground Structure (DGS) to form an advanced hybrid system for wideband applications. This system will produce the band-pass and band-stop responses simultaneously in order to discriminate between the desired and undesired signals in the wideband spectrum. The proposed system outlined in this paper, featuring new innovation in hybrid structure as well as providing an insight of the direction of future research works. The contribution of this study is useful for applications where the reduction of physical volume is very important, while maintaining its good performance such as Ultra-Wideband (UWB), commercial radar as well as the wideband warfare receiver. As for future works, integration techniques between the UWB filter and DGS will be designed and analyzed to form an advanced new microwave device in order to produce bandpass and bandreject response in the same structure simultaneously.

Key words: Hybrid Microwave Device % Microwave Filter % Defected Ground Structure (DGS) % Suspended Stripline Structure (SSS)

INTRODUCTION

In communication, the system can be termed as wideband when the message bandwidth considerably exceeds the coherence bandwidth of the channel. The wideband bandwidth is forced to use for any communication link due to a high data rate. But another link may have slightly low data rates intentionally use a wider bandwidth in order to gain another advantage. The UWB is another modulation technique that uses the same purpose, follows on transmitting duration pulses. Wireless technologies such as 802.11b and short-range Bluetooth radios eventually could be replaced by the UWB products that would have a throughput capacity of 1,000 times greater than 802.11b (11 Mbit/sec). Those numbers mean UWB systems have the potential to support larger number of users, at much higher speeds and lower costs than the current wireless LAN systems. Current UWB devices can transmit data-up to 100 Mbps, compared to the 1 Mbps of Bluetooth and the 11 Mbps of 802.11b. Moreover, it involves a fraction of current technologies like Bluetooth, WLANs and Wi-Fi [1].

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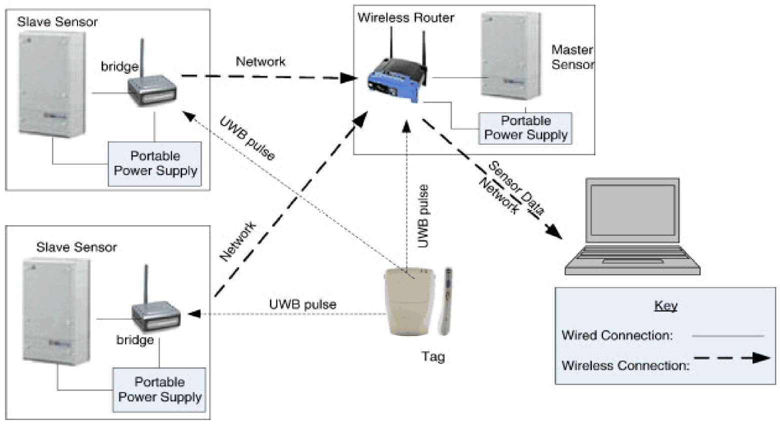


Fig. 1: Untethered wireless UWB tracking system architecture (more slave sensors can be connected) [1]

UWB is a technology for transmitting information which spreads over a large bandwidth (>500 MHZ) that should, in theory and under the right circumstances, be able to share spectrum with other users. Regulatory setting of Federal Communications Commission (FCC) in United States is planned to offer an effective use of scarce radio bandwidth while allowing both great data rate "Personal Area Network" (PAN) wireless connectivity and longer-range, low data rate applications as well as radar and imaging systems [1].

UWB devices can be used for a multiplicity of communications applications including the transmission of very high data rates over short distances without suffering the effects of multi-path interference. UWB communication devices might be used to wirelessly allocate services such as cable, phone and computer networking through a building or home. These devices can also be used by police, fire and rescue personnel to provide undercover, protected communications devices. Figure 1 shows the untethered wireless UWB tracking system architecture. The UWB can be used in various applications which widely used in the home environment.

There are some advantages by using UWB frequency with the communication speed up to 1 Gbps can be achieved for modern living. By utilizing Time of Arrival (TOA) of UWB, the high resolution of 3-D location system can be reached. The interference between electrical equipment can be decreased with less penetration of the human body. The power consumption could be minimized because less wireless communication devices is being carried. Some applications use the UWB system like High Resolution Wireless Surveillance Camera and Wireless Video Adapter. This camera uses high resolution video image to transfer capability and the wireless video adapter may connect personal computer and projector in wireless.

In designing the microwave filter, researchers focus on how to produce the wideband frequency and apply them to ultra-wideband. In order to avoid the interference with WLAN radio signal, different methods and structures have been used to develop a UWB bandpass filter. In UWB, it has some interference with other signal frequency. Research on how to reject the unwanted signal has to be developed and studied. A novel compact structure that integrates bandpass filter and DGS in a single device to reduce the overall physical size will be discussed. The resulting structure will exhibit bandpass and band reject response simultaneously. This will overcome the problem face by the UWB application in order to remove undesired signal, i.e. 5.2 GHz and 7.75 GHz Wireless Local Area Network (WLAN) radio signal [1].

In this paper, an effort has been made to describe and show the exciting advances in microwave filter in term of their technologies. The structure to produce the wideband frequency signal is shown with some comparison based on planar and non-planar structure of the filter. This paper also shows the hybrid structure of integrating with DGS in order to produce bandpass and bandstop filter simultaneously. From this structure, it provides small size, light weight and helps to reduce the cost of the manufacturing. It is expected that the information from this paper will help researchers to get a broader perspective of hybrid structure of the filter and perhaps can be considered as an alternative to produce other methods.

Microwave Filters: The history of microwave filter began in 1937 when Mason and Sykes initiated the development of waveguide filter [2]. Most researches were conducted in various laboratories in the US. For example, at the Massachusetts Institute of Technology (MIT) Radiation

Laboratory, researchers were concentrating on the waveguide cavity filters for radar systems. In other laboratories, the researches were conducted with different methods such as developed on broadband low pass, high pass and band pass coaxial filters and narrow-band tunable filter for receivers. The development of UWB microwave filters has been increasing ever since the Federal Communications Commission (FCC) approved the commercial use of UWB in 2002 [1]. Since then, there has been a considerable research effort geared into UWB radio technology worldwide. Radio Frequency (RF) filter or microwave filter is a type of passive device with two portent works because it passes the desired signal and blocks the unwanted signal. Filters are commonly employed in microwave and millimeter-wave transceivers as channel separators. Basically, it has four types of frequency responses which are lowpass, highpass, bandpass and bandstop characteristics. A compact communication system works in this UWB frequency band require a small bandpass filter (BPF) with a notched band in the UWB passband in order to avoid being interfered by the WLAN radio signals.

The defects in the ground plane and which have disturbances in the shield current of distribution, either in etched periodic or non-periodic cascade configuration defect, (e.g. microstrip, coplanar and conductor backed coplanar waveguide) are known as DGS. This disturbance occurs in the ground plane will alter the characteristics of a transmission line such as line capacitance and inductance. In other words, the effects of capacitance and inductance can be increased if the ground plane of microstrip has a defect etched [3]. The DGS can also eliminate the unwanted frequency which produces the band rejection and the frequency range can be tuned by controlling one physical dimension of DGS pattern [4]. Quasi-lumped inductive element was offered in DGS structure. It can be used to replace the high impedance narrow microstrip line which is normally used as an inductor for designing high-low impedance low-pass filter (LPF) [5]. The drawback with the very narrow width microstrip line section is the difficulty in fabricating the LPF. In addition, the increased length of the filter will increase the dimensions of physical layout. Therefore, DGS acts as an inductor and can reduce the length of the LPF. A resonant gap or slot in the ground metal is the basic element of DGS which placed directly under a transmission line and aligned for efficient coupling to the line.

A microstrip with a conductor trace on one side of the substrate and a single ground plane on the other side is the most popular microsrip line produced by DGS. Basically, researchers are focusing on analysis, synthesis and calculation of the microstrip circuit. It includes configuration, dimension and structure of the microstrip conductor, while the ground side remains a complete metallization structure. However, by disturbing the ground plane structure, it can increase the effectiveness of capacitance and inductance. Some modifications are needed to improve electrical performance and reduce the size of microstrip circuit. In recent years, DGS structures with reconfigurable by active device have been investigated. Several solid state devices such as PIN diode, Varactor or Tunnel Diode and Field Effect or Bipolar Transistor can be used to vary the resonant frequency of DGS structure.

Due to the demand of wide operating frequency for the UWB bandpass filter, this study offers a synthesis technique based on generalized Chebyshev characteristic which is proposed to produce bandpass filter with sharp response and good performance. The main advantage of the generalized Chebyshev characteristic is the finite frequency can be mathematically placed at the location of two transmission zeros (pole-zero plot). Hence, it produces good selectivity and improve the filter’s performance Moreover, the number of elements can be reduced by using this method and absolutely the physical size can be decreased [6]. Therefore, the UWB bandpass filter can be integrated with the DGS in order to remove undesired signal frequency within the UWB frequency range. For example, in WLAN, the operated frequency of 5.2 GHz and 5.75 GHz can be eliminated. Therefore, the integration technique can produce bandpass and band reject with the same structure simultaneously.

Development of Microwave Filters for Wideband Application: The motivation of this study is driven by the fact that for the UWB technology, UWB signals must comply with the spectrum mask as required by the FCC Rules and Orders. Therefore, the design of UWB microwave bandpass filter is very critical in order to achieve broad bandwidth, while has the capabilities to remove any undesired signal within the UWB frequency range. To provide the hybrid structure of the application, the UWB can be applied at the microwave filter and DGS to produce bandpass and rejection frequency signal simultaneously. In order to fulfill the satisfaction for the users, this application can be used in the modern living; PAN. Therefore, the suitable method which has been used to produce the hybrid structure and to apply at modern technology can be regarded as a hybrid bandpass filter with the DGS.

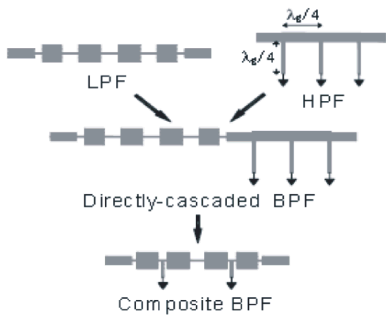


Fig. 2: Evolution of the proposed composite BFR[10]

Several methods and structures have been studied in order to develop new structures of these UWB filters. UWB filter was produced by mounting a microstrip line in a lossy composite substrate with the higher insertion loss [7]. However, at the lower frequency, the filter lacks of sharpness and produces a larger insertion loss which is greater than 6.0 dB with poor impedance matching at the high frequency. In other studies, a microstrip ring UWB is constructed by allocating transmission zeros below 3.2 GHz and above 10.6 GHz [8, 9]. This filter with a ring resonator is larger in size and produces narrow, lower and upper stopbands. The results show that, insertion loss is better than 0.53 dB and return loss is greater than 10 dB in the passband from 3.8 GHz to 9.2 GHz and indicates the group delay below the 0.6 nsec within the passband UWB.

Hsu *et al*. [10] used a different technique to produce UWB by combining lowpass and highpass structures. Figure 2 shows the evolution of the purpose composite BFR. Both BPF consist of a hi-Z, low-Z LPF and an HPF structure designed with shunt quarter-wave short-circuited stubs separated by $8_g/4$ sections which act as impedance inverters. In [11-13], a broadside-coupled Microstrip-coplanar Waveguide (CPW) structure with a tightened coupling degree is utilized to design an alternative UWB filter with one, two and three sections. The two microstrip line are separated with a gap and broadside coupled to one open-end CPW which is a basic section of the filter. The tight coupling will provide very wide bandpass operation.

The most important part of the structure in Figure 3 is a broadside-coupled microstrip-coplanar waveguide (CPW). This structure is fabricated on the ground of the microstrip line. The reasons for introducing the extra high rejection filter (HFR) are the BPF needs to have good bandpass performance and requires not only in-band but also out-band. By using this type of structure, the performance of out-band up to 16 GHz with attenuation larger than 22 dB and the group delay is 0.27 ns.

Zhu *et al*. [14] constructed a UWB BPF by using single multiple-mode resonator (MMR) that is driven at two sides by two identical parallel-coupled lines. Stepped-Impedance Resonator (SIR) will effectively widen the upper stopband by enlarging the space between resonant modes (first and second order). Similarly, UWB BPF is produced by using open stub loaded (MMR), improved upper-stopband performance and reduced radiation loss [15]. The basic principle of UWB filter is originated in [16] and the compact and broadband BPF was discussed in [17]. However, the fractional bandwidths were only about 40% to 70%. The wideband BPF was implemented and produced a cascading of cascadable 180° hybrid rings by finite-ground coplanar waveguide [18]. UWB with hybrid Microstrip-Coplanar waveguide was produced but the stopband frequency is still only 16.0 GHz [19]. The structure in Figure 4 called an asymmetric parallel coupled-line has been attempted in bandpass filter design [20] but their shape of transmission line has some difference in the shape proposed in [21].

The new method to produce UWB by using WLAN notch was introduced [22, 23]. This UWB suspended stripline filter which has a single stopband by incorporating a resonant slot into one of its elements. In this method, a Duroid RT 6010 substrate with a dielectric constant of 10.2 and a folded slot are selected to ensure a resonance at a sufficiently low frequency. A slot resonator is included into the patch to provide the rejection of a small frequency band. The author connects a lowpass filter and highpass filter in series to improve the upper stopband performance of the filter. The notch leads to some additional ringing of a transmitted Gaussian monocycle, but the distortion is not very large compared to a UWB filter without notch.

Shaman and Hong [24, 25] designed the compact UWB filter by using the short stubs to create transmission zero. This paper proposed a filter with low insertion loss, sharp rejection and excellent performance both side and outside the band. For this method, the purpose filter with five short-circuited stubs as demonstrated in Figure 5 has been designed for an optimum stub filter whose connecting lines are non-redundant. The conventional 9-pole Chebyshev filter will allow the filter to exhibit high selectivity.

This filter in [25] is formed by using GML 1000 substrate with a relative dielectric constant of 3.05 and the thickness of 0.508 mm. This filter was fabricated on a microstrip substrate and connected using the SMA connectors. The filter improved the response by producing transmission zeros at desired frequencies. This was realized by placing the short-circuited stubs with

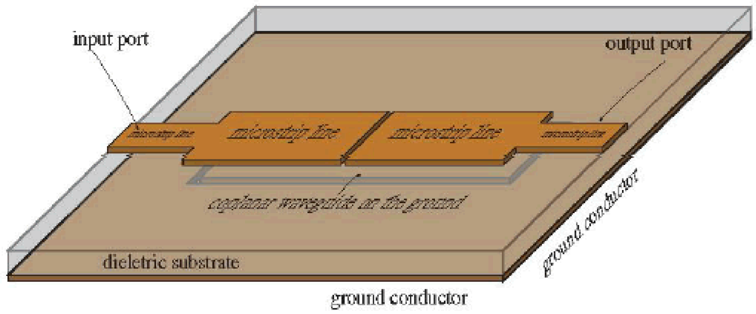


Fig. 3: UWB BPF using broadside-coupled microstrip-coplanar waveguide structure [11]

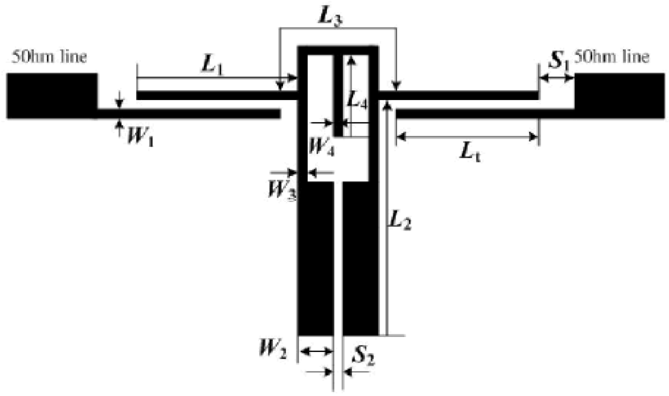


Fig. 4: UWB BPF using Microstrip Stub-Loaded Tri-Mode Resonator [20]

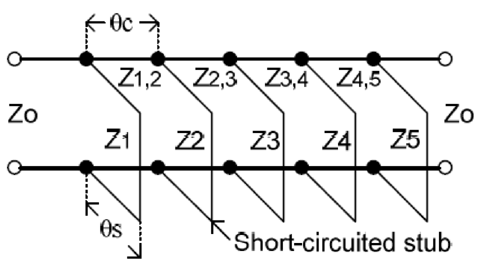


Fig. 5: Circuit model for UWB BPF with Transmission Zero[24, 25]

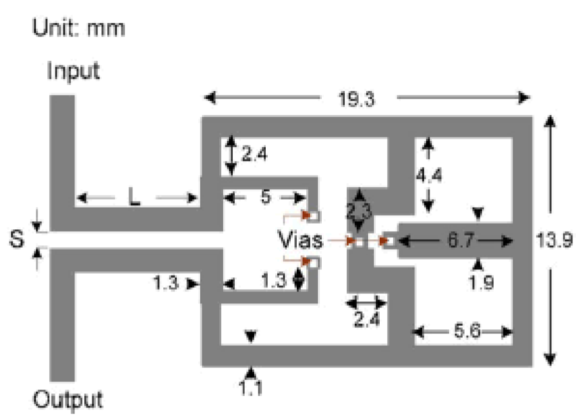
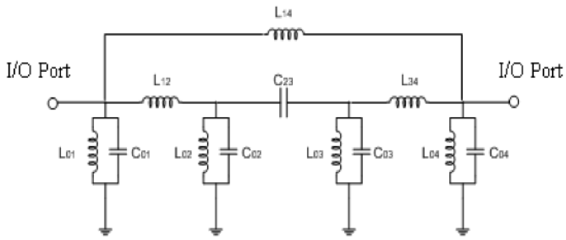


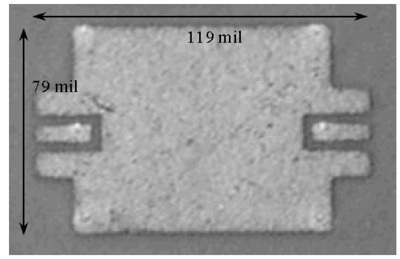
Fig. 6: Physical layout of UWB BPF with Pairs of Transmission Zeroes [25]

two-section open-circuited stubs. However, in this technique, the size of the filter is increased significantly. The new technique is very simple for implementation by placing two sections of the feed lines of the length, *L* parallel to each other separate spacing, *S* as shown in Figure 6.

The new transmission zeroes improved the filter performance outside the passband by widening the lower and upper stopbands. This filter exhibited low insertion loss which includes the losses from the SMA connector of about 1.1 dB at the midband frequency and a flat group delay of about 0.6 ns at the midband frequency. Overall, the new transmission zeroes enhanced the bandwidth of the lower and upper stopbands with only a few resonators. A UWB filter with the Low Temperature Co-fired Ceramic (LTCC) technology has been proposed [26]. A couple of transmission zeros can be generated in two-side of passband's skirt of the ultra-wideband filter. By this method, the filter can increase the sensitivity and linearity of the wireless communication. The multi-layered can reduce the size of the circuit. In this paper, the both equivalent capacitance B-network and equivalent inductance B-network are adopted to construct this UWB filter. This method can increase the filter's selectivity.



(a)



(b)

Fig. 7: (a) Equivalent circuit of four-resonator BPF with inductance feedback and (b) fabricated layout of UWB BPF [26]

Table 1: Comparison of different methods of UWB frequency

Filter/ Year	f_o(GHz)	Fractional bandwidth, FBW (%)	Insertion loss, S_{21} (dB)	Return loss, S_{11} (dB)	Size (mm^2)
[7] 2003	6.8	-	6.7	>10	20×50
[8] 2004	6.5	1.5	0.53	>10	-
[10] 2005	7.0	3	-	>15	15×30
[11] 2005	6.83	-	0.32	>10	20×50
[13] 2005	5.63	-	0.5	>10	9.8×11.8
[14] 2005	6.85	-	0.55	>10	17×2.16
[20] 2008	7.0	90	0.5	>10	20×15
[21] 2011	6.8	-	<1.0	>13	16×5
[25] 2007	6.85	110	0.3	>10	13.9×26.1

Figure 7(a) shows the circuit diagram for the four coupled transmission which is used to replace the four resonators. The gap of transmission lines can control the amount of coupling. This LTCC UWB filter is designed using the substrate of Dupont 951, with a dielectric constant of 7.8 and loss tangent of 0.0045. The compact UWB filters have been widely investigated for highly integrated low cost solutions by using LTCC technology and semi-lumped type filter circuits [27-30]. However, in the higher order, resonances were degraded and caused by parasitic electromagnetic (EM). Although the LTCC still suffers from certain temperature-related even the packaging and miniaturizing were effective.

A passive technology is applied by using PCB embeds to produce UWB [31]. The third-order Chebyshev and J-inverter transformation are modified to secure a large bandwidth and avoid the unwanted EM coupling between the circuit elements. Tree independence transmission zeros were formed in the desired stopbands by connecting a capacitor and two inductors in series with the parallel LC resonators in order to obtain high rejection characteristics. This UWB filter was fabricated into eight-layered PCB substrate. The second and third layers were embedded by Metal-Insulator-Metal (MIM) capacitor. The review and analysis among the available reported UWB frequency in the past few years has been done. The comparison and performance of the different methods and design were presented in Table 1. Each design of filter has its own advantage. Some modifications can be made by improving the structure of a design in order to produce a hybrid structure which is DGS.

Topology of Hybrid Structure: Bandpass filter is commonly used by researchers and applied for the wideband frequency. This study proposes a new hybrid structure which can be designed by combining suspended stripline structure and DGS to produce the required results. DGS can produce the outstanding performance in terms of sharp selectivity at the cut-off frequency, spurious free wide stopband and ripples in the passband [29, 30, 32-34].

A simple technique to design the seven poles lowpass filter using DGS was produced [35]. By using this technique, the length is decreased by 42.3% and the area has been reduced by 44.2% compared to the conventional lowpass filter. Figure 8 shows the structure of DGS in ground plane and the equivalent circuit applied at DGS. Lim *et al.* [36] used the similar method to produce lowpass filter with dumb-bell-shaped DGS. The defected area consists of two rectangular and one connects to slot corresponding to the equivalent of inductance (L) and capacitance (C). However, this design shows the higher N, the higher loss and the larger size. Hence, increasing N can affect the size of the designed structure.

(a)

(b)

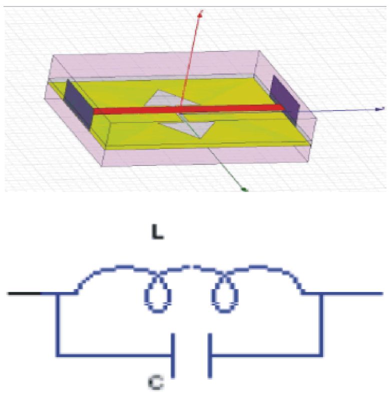


Fig. 8: (a) DGS in ground plane, (b) Equivalent circuit of DGS [35]

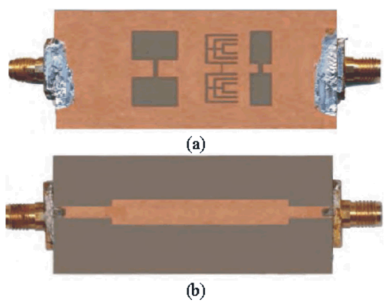


Fig. 9: Fabrication filter (a) Bottom view (b) Top view [37]

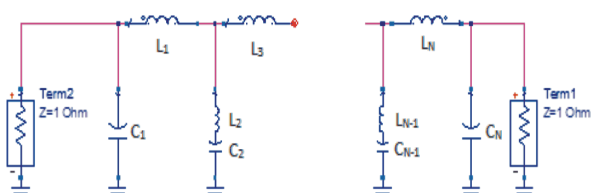
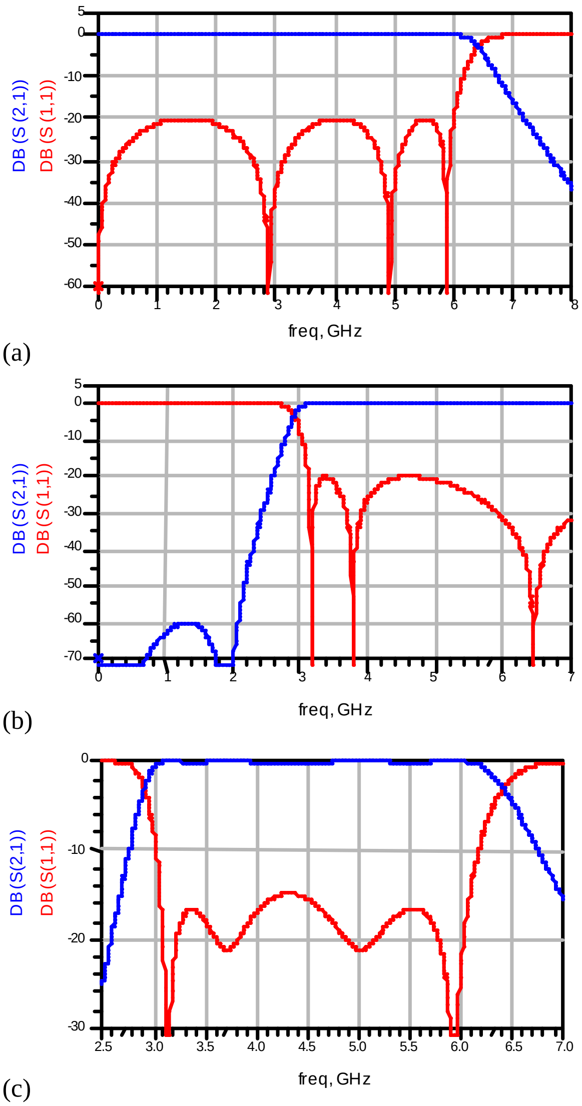


Fig. 10: Example of generalized Chebyshev lowpass prototype filter



(a)

(b)

(c)

Fig. 11: Preliminary Result for wideband frequency (a) Lowpass filter at 6 GHz (b) Highpass filter at 3.1 GHz (c) Bandpass filter at 3.1 to 6 GHz

Bahmani *et al.* [37] designed a compact slot geometry to produce the DGS for a microstrip line. By using U-shape slot, the capacitive of the structure and overall length of the pattern can be increased. This design of LPF produces the excellent stop band more than 30 dB from 2.8 to 10 GHz with 1.2 sharpness factor (f_s/ f_c). Figure 9 shows the fabrication structure of filter by applying the DGS. The measured filter has 3 dB cutoff frequencies at 2.4 GHz and the insertion loss in the passband is less than 0.6 dB. The transmission zeros at 2.9 GHz enhanced the roll off and stopband rejection.

There are some mathematical formulae that can be used in order to prove the method of designing the bandpass filter. The design will start from the lowpass prototype network which satisfies a generalized Chebyshev response with two transmission zeroes at finite frequencies as shown in Figure 10. The suitable lumped element needs to be chosen based on the number of order and attenuation of this design filter.

The lowpass prototype operates in a system impedance of 1 S and the cutoff frequency with 1 rad/s. To convert from 1 S to 50 S impedance, all the circuit elements must be scaled by 50 S. 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 the synthesis and mathematical modelling. The lowpass filter prototype and its element

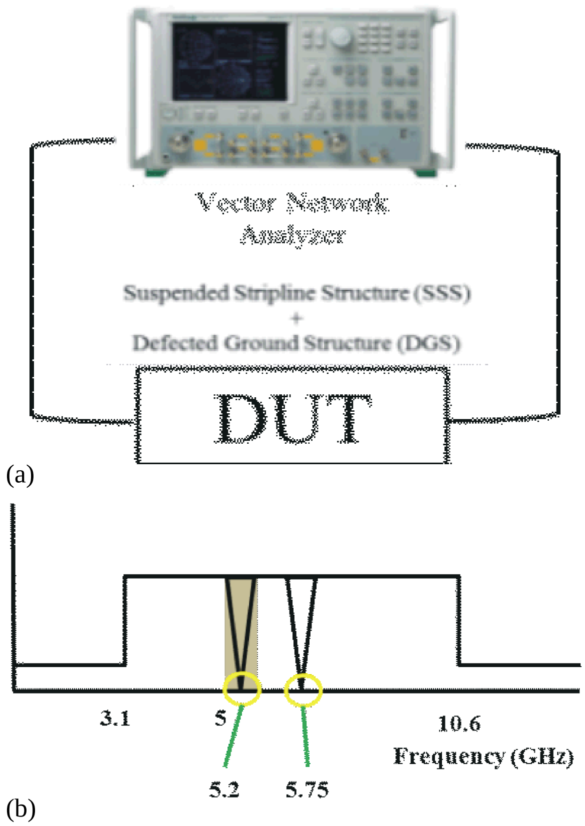


Fig. 12: (a) Method for Measuring Filter (b) Undesired signal at UWB spectrum

values can then be constructed and transformed to highpass filter in order to produce bandpass filter. The formula to transform this design from lumped element to distributed circuit and lastly to suspended is provided [38].

A combination of the lowpass and highpass filter in a cascaded method can produce a new class of bandpass circuit. The overall physical realization of the filter will be implemented based on suspended stripline structure. In this stage, the utilization of EM simulations will be required as well as the analysis of S-parameter and electromagnetic fields. The analytical modelling of DGS will be established based upon a Dumbbell-shaped structure by using a co-planar waveguide technology to produce a band reject characteristic. A PIN diode will be introduced in the DGS in order to activate the band reject response at the desired frequency.

A parametric study will be involved at this stage in order to identify and analyze the variation of DGS parameters. Further tuning and optimization on the DGS parameter will be carried out to obtain good appropriate responses. Figure 11 shows the preliminary results of the filter characteristics to produce a bandpass response which covers from 3.2 Ghz to 6 Ghz. Figure 12 (a) shows the measurement setup on the Device Under Test (DUT) using the Vector Network Analyzer (VNA) and Figure 12 (b) illustrates the undesired signals (5.2 GHz and 5.72 GHz) occur at UWB frequency that need to be removed.

CONCLUSION

In this paper, an effort has been made to relate some of the several advances in filter technology for modern applications such as in the UWB spectrum. This has led to the incessant development in both theoretical filter design methods and in the technology used for realizations. The hybrid technique for designing bandpass filter and defected ground structure is proposed in this study. This technology can be used for emerging digital home environment which can support the different consumer computer device, electronic device and mobile devices. It can be implied that microwave filters are not only restricted to UWB applications but can also be used in any wideband applications particularly in commercial radar as well as the wideband electronic warfare receiver. It is recommended that the integration techniques between the UWB filter and DGS can be designed and analyzed to form an advanced new microwave device in order to produce bandpass and bandreject response in the same structure simultaneously.

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