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Recent Trends on Dual- and Triple-Band Microwave Filters for Wireless Communications

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Abstract: In the past few years, several designs of dual- and triple-band microwave filters satisfying various objectives have been proposed for wireless communication. Several designs are new concepts, whereas others are inspired from previous works. The development trends of these designs can be reviewed from this compilation of studies. This paper begins with an explanation of dual- and triple-band microwave filters, followed by a discussion on several designs in terms of size, measurement, performance, and technology use. Among various designs, microstrip band-pass filters are extensively used because of their simple design procedures and because they can be integrated into circuits easily. Furthermore, most researchers use low frequencies in their designs because of the demands of current wireless applications. Finally, designs are proposed to produce compact microwave filters with good performance.

Key words: Microwave filters, Dual and triple bandpass filter.

INTRODUCTION

Wireless communication has been rapidly developing in recent years. The evolution has started with Global System for Mobile Communications (GSM) and has proceeded to Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Code Division Multiple Access (CDMA), and the latest, Long Term Evolution (LTE). A microwave system is a wireless communication system operating at a medium to extremely high frequency. The frequency ranges from 300 MHz to 300 GHz (Pozar, 1993; Sorrentino and Bianchi, 2010). Operators and subscribers prefer signal with strong reception in wireless communication. Therefore, filters are required in microwave systems to separate wanted from unwanted signals. Microwave filters are discussed thoroughly in this paper, particularly dual- and triple bands in microwave backhaul networks. In addition, an effort has been made to present recent trends on dual- and triple-band microwave filters developed by various researchers to satisfy the current demands of wireless communication systems, particularly microwave backhaul networks. This paper presents various designs with different frequencies and technologies. This information is expected to provide researchers with reference for developing future designs.

Currently, researchers are focused on the requirements of multichannel transceivers in various systems. Therefore, dual- and triple-band microwave filters are extensively used in wireless backhaul systems. Three types of media are used in backhaul systems, namely, fiber, copper, and microwave.

In this section, only fiber and microwave media are discussed because copper has higher data loss and higher implementation cost compared with fiber. Microwave presents several advantages, such as being more cost effective (Ceragon, 2013) than fiber. Moreover, microwave is considered as more flexible because this medium can be reused as a network changes (Ceragon, 2013).

In addition, microwave provides more secure and robust signals compared with fiber because service is lost in the latter when it is accidentally cut (Little, 2009). Deployment speed is also faster in microwave than in fiber because the former is easy to install and operate; thus, microwave is more suitable in urban areas because it does not require reconstruction (Ceragon, 2013). Even though fiber has unlimited capacity which provides a significant advantage, using microwave backhaul can also satisfy the requirements of 4G, LTE, and beyond. Figure 1 shows an example of a microwave backhaul.

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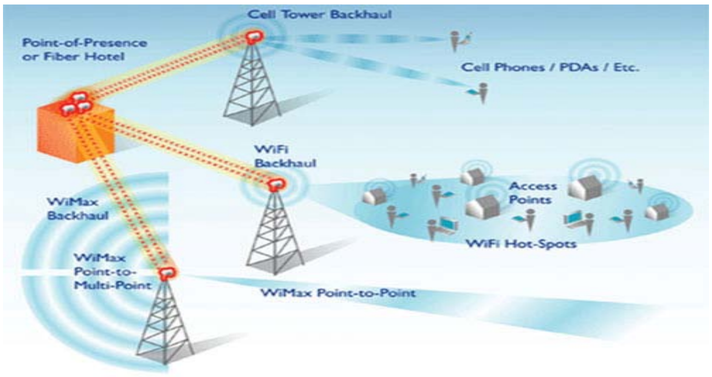

Fig. 1: A microwave backhaul network (Urvirl, 2013).

Microwave backhaul can achieve high capacity by using co-channel operation, link aggregation, and Adaptive Coded Modulation (ACM) technology (Little, 2009). Co-channel operation is adapted to increase microwave capacity. The strategy is performed in a single channel, and a double amount of traffic is attained by allowing both polarizations of the microwave to link. Then, the operation employs cross-pole interference cancellation (XPIC) radio to allow significant traffic availability. This process is achieved by removing leakage signals among different polarizations. As a result, high-link capacity is realized using XPIC radio. Another means of achieving high capacity involves combining two or more multiple links and implementing link aggregation, thus providing one logical link with the capacity of both links. ACM is also used to optimize capacity in a wireless data link. This technique enhances link capacity by managing power output, modulation level, and coding according to propagation conditions (Little, 2009). Other methods for enhancing capacity include using header compression and multi-carrier schemes (Little, 2009). To summarize, microwave backhaul can achieve high-capacity requirements through next-generation LTE and LTE-advanced networks by using the aforementioned methods (Little, 2009).

Microwave filters have an important role in wireless communication systems. Currently, the demand for new designs and approaches of this filter type is increasing. In the past, only single-band filters which can operate in single-frequency bands are used. As time changes and technology develops, users are currently demanding higher-level applications which can support dual- and triple bands in a single device. For instance, GSM and CDMA mobile phones operate at 900 MHz and 1.8 GHz. WLAN, IEEE 802.11a/b/g, works at 2.4 and 5.2GHz (Chang *et. al*., 2005). In addition, these filters cause less hardware complexity compared with other numerous-frequency-selective circuits (Edson and Wakabayashi, 1970). This characteristic is attributed to integrated radio frequency transceivers with varying applications to support wireless systems. Therefore, dual-band filters are significant elements at microwave frequencies for wireless communication.

However, the demands for triple-frequency devices are also high, thus contributing to the development of triple-band filters. For instance, the triple-band Universal Mobile Telecommunication System (UMTS) device operates at 900, 1800, and 1900 MHz frequency bands in Europe. Moreover, North and South American devices work at 800 or 950, 1800, and 1900 MHz frequencies. At present, the ability to work in multiple frequencies is one of the requirements for a universal device (Brady, 2013).

Development of Dual-Band Microwave Filters:

Given that technology has rapidly developed, demands for dual-band microwave filters still exist because different wireless applications use different frequencies to operate. Therefore, the need for multichannel wireless communication systems is very high. Considering the high demand, researchers have started searching for the best methods and designs with appropriate specifications, and have begun implementing them. Given that research has begun a few years ago, numerous designs have already been successfully developed. In this paper, we reviewed several designs with different specifications and technological methods.

Table 1 presents a summary of the studies. The studies are arranged chronologically, thus information on trends and development can be obtained. Furthermore, the main ideas of the researchers and the frequencies that need to be concentrated on are shown in the fourth column of the table.

From Table 1, the trends and development of dual-band microwave filters can be analyzed based on the concept that filters are designed in various years using different methods and technologies. A microstrip structure is more popular compared with LTCC and waveguide structures because it is easier to design. Furthermore, the design can accommodate low frequencies such as 2.4 GHz and 5.2 GHz because of the high requirement of WLAN devices to support multiple frequencies in a single device. The studies presented in Table 1 are described further in the succeeding paragraphs.

Table 1: Dual-Band Microwave Filter Designs of Several Researchers.

No.	Year	Scholar(s)/Researcher(s)	Focus of study	References
1	2004	Lin-Chuan and Ching-Wen	Combination of wide-band bandpass filter (BPF) and bandstop filter at 2.4 GHz and 5.2 GHz frequencies	Tsai and Hsue, 2004
2	2004	Hong-Ming, Chung-Rung, Chin-Chuan and Chih-Ming	Dual-band microstrip filter design using new coupling structures	Lee *et. al.*, 2004
3	2004	Jen-Tsai and Hung-Sen	Two types of filters at 2.4/5.2 GHz and 2.45/5.75 GHz using compact miniaturized hairpin resonators	Kuo and Cheng, 2004
4	2005	Jen-Tsai, Tsung-Hsun and Chun-Cheng	Single filter with a dual-band bandpass response in vertically stacked and well-known parallel-coupled configurations at 2.45/4.00 GHz, 2.45/5.20 GHz and 2.45/5.80 GHz	Kuo *et. al.*, 2005
6	2005	Sun and Zhu	Microstrip-band BPF with modified half-wavelength stepped impedance resonators (SIRs) at 2.4 GHz and 5.2 GHz	Sun and Zhu, 2005
7	2005	Chih Ming, Hong-Ming and Chin-Chuan	Planar filter design at 1.0/2.5 GHz and 2.45/5.25 GHz	Tsai *et. al.*, 2005
8	2006	Chi-Feng, Ting-Yi and Ruey-Beei	Microstrip technology with alternately cascading resonators at 2.8/4.2 GHz	Chen *et. al.*, 2006
9	2006	Ke-Chiang, Chun-Fu and Shyh-Jong	Dual-band filter at 2.4/5.0GHz using low temperature co-fired ceramics (LTCC) technology	Lin *et. al.*, 2006
10	2006	Chao Hsiung and Tatsuo Itoh	Microwave filter at 1.0/1.9 GHz using metamaterial transmission lines (TLs)	Tseng and Itoh, 2006
11	2006	Ming-Iu and Shyh-Kang	Microstrip design using genetic algorithm technique	Lai and Jeng, 2006
12	2006	Jian-Xin, Jia-Lin and Quan-Xue	Dual-band filter using a stacked loop structure at 1.70/2.15GHz	Chen *et. al.*, 2006
13	2006	Chu-Yu and Cheng-Ying	Microstrip design filters using folded open-loop ring resonators at 2.4/5.7 GHz and 2.4/5.2 GHz	Chen and Hsu, 2006
14	2007	Fahim and Slim	Wideband CDMA/WIMAX dual-band BPF design using frequency transformation and circuit conversion at 2.14 GHz and 2.5 GHz	Hassam and Boumaiza, 2007
15	2007	Hong-Ming and Chih-Ming	Dual-band filter at 2.45 GHz and5.25 GHz using LTCC structure	Lee and Tsai, 2007
16	2007	Min-Hang, Hung-Wei and Yan-Kuin	Dual-band filters using pseudo interdigital SIRs for WLAN at 2.4/5.2 GHz.	Weng *et al*., 2007
17	2007	J. W. Fan, C.H. Liang and X.W. Dai	Dual-band BPF using equal-length split-ring resonators at 2.4/3.1 GHz	Fan *et. al.*, 2007
18	2007	Min-Hang, Sean, Shih-Bin, Yu-Chi and Maw-Shung	Dual-band BPF using a cross-slotted patch resonator at 2.4/5.27 GHz	Weng *et. al.*, 2007
19	2008	Priyanka and Mrinal	Microwave filter at 2.80/4.40, 2.45/5.25, and 2.45/5.80 GHz using stub-loaded open-loop resonators	Mondal and Mandal, 2008
20	2008	An-Shyi, Ting-Yi and Ruey-Beei	Dual-wideband BPF using the frequency mapping approach at 0.96 GHz to 1.6 GHz, 2.02 GHz to 2.68 GHz, 3.1 GHz to 4.85 GHz and 6.2 GHz to 9.7 GHz	Liu *et. al.,* 2008
21	2008	Qing-Xin and Fu-Chang	Dual-band filter using meandering SIRs with a new coupling scheme at 2.4/5.2 GHz and 2.4/5.7GHz	Chu and Chen, 2008
22	2008	Kwok-Keung and Carlos	Dual-band filter with extremely wide upper bandstop at 1/2 GHz	Cheng and Law, 2008
23	2008	J. P. Wang, B. Z. Wang and Y. X. Wang	Microstrip stepped impedance BPF with a defected ground structure (DGS) at 2.45 GHzand 5.2 GHz	Wang *et. al.*, 2008
24	2009	Sánchez-Renedo and Gómez-García	Microstrip parallel coupled-line dual-band BPF at 1.1 GHz to 1.5 GHz	Manuel and Roberto, 2009
25	2009	Geonho, Chul Shin, Cheon-Hee, Chul-Min and Sungtek	Microstrip metamaterial BPF using zeroth order resonance	Jang *et. al.*, 2009
26	2009	Jen-Tsai and Huei-Ping	Dual-band filter at 2.4/5.2GHz with improved performance in extended upper rejection band	Kuo and Lin, 2009
27	2009	Xiu Yin, Jian-Xin and Quan	Planar dual-band BPF based on a novel feed scheme at 1.8/2.4GHz	Zhang *et. al.*, 2009
28	2009	Jia-Sheng and Wen-Xing	Dual-band filters based on a dual-mode microstrip slow-wave open-loop resonator at 0.86/1.39 GHz	Hong and Tang, 2009
29	2010	Seungku andYongshik	Planar dual-band filter based on parallel coupled lines at 2.4/5.2GHz	Lee and Lee, 2010
30	2010	Sha Luo, Lei Zhu and Sheng Sun	Dual-band ring-resonator BPF at 2.38/4.87 GHz	Luo *et. al.*, 2010
31	2010	Chao-Hsiung and Hsin-Yung	Dual-band microstrip BPF using net-type resonators at 1/2 GHz	Tseng and Shao, 2010

Several studies on dual-band microwave filters have been investigated. For example, in Hassam and Boumaiza (2007), the authors produced dual-band filters by converting a single-band BPF into a narrowband dual-band BPF. This method used frequency transformation and circuit conversion inproducing the filter.

Ming in (Lee and Tsai, 2007) designed a dual-band BPF by combining open- and short-circuit stubs. This filter was inspired from the work of Tsai *et. al*., (2005), and thus, was named type 3 filter. The advantage of this filter over that of the filter presented by Tsai *et al*., (2005) was its varying stub length according to demand. Therefore, this design had no limitation in bandwidth. Moreover, a miniaturized circuit could be produced using this method. Other parameters, such as bandwidth and frequency ratio, also varied accordingly. However, high insertion losses of -6dB at 2.42 GHz and -5.3dB at 5.24 GHz were obtained because of the LTCC process.

In Tseng and Itoh (2006) used composite right-/left-handed (CRLH) metamaterial TLs. This design was inspired by the method of Hong and Lancaster (2001) which used quarter-wave short-circuited and open-circuited stubs to create bandpass and bandstop filters. The first bandpass/bandstop of this type of filter was designed based on the following factor. The first bandpass frequency is f_0 and that of the second bandpass is threetimes f_0. However, this factor could not be used in implementing dual-band filters because present wireless standards could not accept the operating bandpass frequency separated by that factor. Therefore, by substituting conventional TLs with CRLH TLs, the filter could have two arbitrary operating frequencies at f_1 and f_2 , with f_1 at 1 GHz and f_2 at 1.9 GHz. Despite its easy design, the circuit size of this filter was not miniaturized, which was a disadvantage. To achieve a small circuit size, the right-hand sections of CRLH TLs could be realized by using chip components in the future.

Three types of BPFs designed by Priyanka were presented in Mondal and Mandal (2008). Filter 1 operated at 2.80/4.40 GHz, filter 2 at 2.45/5.25 GHz, and filter 3 at 2.45/5.80GHz. Filters 1, 2 and 3 were designed using open-loop resonators loaded with open stubs. By implementing open-loop and shunt stubs, a miniaturized design was implemented by the slow-wave effect. These miniaturized designs offered improved rejection characteristics. The filters differed from each other based on the fractional bandwidth related to frequency. The insertion loss for filter 1 is 2.94 dB at the first bandpass and 3.68 dB at the second bandpass. Compared with filter 1, the insertion loss for filter 2 was 3.5 dB and 3.55 dB, respectively. For filter 3, the insertion loss was 1.87 dB at 2.45 GHz and 1.68 dB at 5.7 GHz. The high insertion loss could be attributed to the low unloaded quality factors of the resonators. However, the return loss ofthe three filters was better than 10 dB.

In Kuo *et. al*. (2005), the authors introduced a new idea for designing dual-band BPF. This idea was based on the resonance attributes of SIRS. Parallel-coupled configuration and vertical stacks were implemented in this design. To produce two center frequencies, the authors adjusted the SIR dimensions. The primary frequency was at 2.45 GHz, whereas the secondary frequency was determined by adjusting the SIR dimension. The authors used coupling length and coupling gap to determine the coupling coefficients for implementing dual band.

Weng *et. al*. (2007) proposed a new method for designing BPFs using pseudo-interdigital SIRs. The filter was developed by modifying the impedance ratio (K) and physical length of SIRs. Before this idea came up, only a few authors used SIRs to implement the aforementioned BPF (Huang *et. al*., 2006; Chang *et. al*., 2003; Sun and Zhu, 2005). Weng, *et al*. (2007) used this method to create a second bandpass for the BPF. The inter-coupling degree was adjusted properly to achieve transmission zero. Based on Figure 2, the measured return loss for 2.4 GHz was less than 20 dB, but larger than 20 dB for 5.2 GHz.

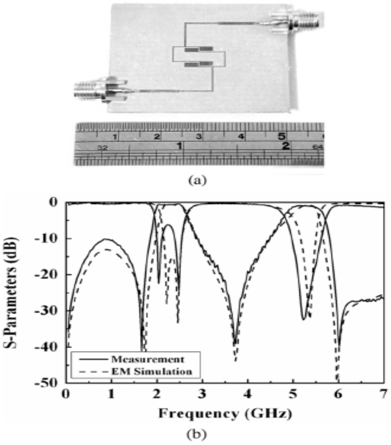

Fig. 2: a) Photograph of fabricated dual-band BPF b) Simulated and measured frequency responses (Weng *et. al*., 2007).

Chu and Chen (2008) presented the concept of using meandering scheme SIRs with a new coupling scheme to produce a small dual-band narrow BPF. The compact design was 50% smaller than the existing design but had the same frequency. The high-impedance section cascaded with the low-impedance sections to produce an SIR. These impedances were combined and configured to have a hairpin structure, thus resulting in a compact structure. Moreover, the insertion loss value was improved by introducing a new coupling scheme (Zhang and Sun, 2006) to the input/output of the filter. Two types of BPFs were produced by the author, with filter 1 operated at 2.4/5.2 GHz filter 2 operated at 2.4/5.7 GHz. For filter 1, at 2.4 GHz, the return loss was greater than 20 dB, where as the insertion loss was less than 4 dB. At 5.2 GHz, the insertion loss was less than 1.6 dB. Meanwhile for filter 2, at 2.4 GHz had a return loss greater than 19 dB with an insertion loss less than 1.2 dB. At 5.7 GHz, the return loss was greater than 16 dB with its insertion loss was less than 1.8 dB.

Development of Triple-Band Microwave Filters:

The demand for triple-band BPFs is increasingevery year. As technology develops, numerous applications have to be supported. Several studies have been conductedrecently to accommodate suchneeds. Some of these studies are investigated in this paper. The summary of several studiesrelated to triple-band microwave filters is presented in Table 2.The function of Table 2 is similar to that ofTable 1,thatis,to show the trendsof development of microwave filters.Furthermore, the present study focusesonwhich frequencies are extensivelyused by researchers indesigning filters.

Table 2: Triple-Band Microwave Filter Designsof Several Researchers.

No.	Year	Scholar(s)/researcher(s)	Focus of study	References
1	2006	Chi-Feng, Ting-Yi,and Ruey-Beei	Microstrip technology with alternately cascading resonators at 2.5/3.6/5.1 GHz and 2.3/3.7/5.3 GHz	Chen *et. al.*, 2006
2	2006	Marjan, Jens, K. Rambabu and Smain	Triple-band filters using the coupling matrix at 2.65/3.00/3.35 GHz	Mokhtaari *et. al.*, 2006
3	2006	Ching-Her, Chung-I. G. and He-Kai	Microstrip BPF using combined quarter-wavelength SIRS at 1.57/2.54/5.25 GHz.	Lee *et. al.*, 2006
4	2007	Min-Hang, Hung-Wei, Jau-Rung, Ru-Yuan and Yan-Kuin	Triple-band BPF using multilayer-based substrates for WiMAX at 2.3 to 2.7/3.3 to 3.9/5.15 to 5.85 GHz	Weng *et. al.*, 2007
5	2008	Chung-I G, Ching-Her and Yi-Huan	Triple-band BPF design using tri-section SIRS at 1.57/2.45/3.5 GHz.	Hsu *et al.*, 2008
6	2008	Juseop and Kamal	Triple-band microwave filters using frequency transformations	Lee and Sarabandi, 2008
7	2009	Fu-Chang and Qing-Xin	Triple-band BPFs using assembled resonators and pseudo interdigital structure at 2.40/3.50/5.25 GHz	Chen and Chu, 2009
8	2009	Bo-Jiun, Tze-Min and Ruey-Beei	Triple-band filters with improved band allocation at 2.10/2.25/3.65 GHz and 3.00/4.22/4.55 GHz	Chen *et. al.*, 2009
9	2010	Xin, Chang-Hong, Hao and Bian	Triple-band filter based on stub-loaded resonator (SLR) and DGS resonator at 2.45/3.50/5.25 GHz	Lai *et. al.*, 2010
10	2010	Xiu Yin, Quan Xue and Bin Jie	Triple-band BPF with SLRs and half-wavelength resonators at 1.84/2.45/2.98 GHz	Zhang *et. al.*, 2010
11	2010	L. Y. Ren	BPF based on a dual-plane microstrip/DGS slot structure at 2.15/2.89/3.13 GHz and 1.68/2.04/2.97 GHz	Ren, 2010
12	2012	M. Manoj and M. Ganesh	Triple-band BPF using a trisection SIR at 925 MHz and 1.575/2.4475 GHz	Prabhakarl and Madhan, 2012

The analysis showed that the development of triple-band filters occurred later than the development of dual-band filters because the demand was not high at the time when application devices supporting triple band were not yet widely used. The latest design presented in 2012 showed that the triple band is still being developed by researchers to be able to accommodate current applications.

Numerous studies were reviewed and some of these were discussed in detail in this paper. For instance, Lai *et. al.* (2010) developed a triple-band filter using SLR and DGS resonator. The first bandpass was implemented through DGS resonator, whereas the other two bandpass were implemented by SLR. The combination of the two resonators, which were also called passage 1 for SLR and passage 2 for DGS, results in a triple-band BPF**.** Proper external coupling of the two passages with minimal effect on each other was achieved by designing a pair of T-shaped microstrip feed lines. The first bandpass frequency was at 2.45 GHz, then at 3.5 GHz and 5.25 GHz. Based on the measurement results, the insertion loss for the three frequencies were 0.9 dB, 1.7 dB and 2.1 dB respectively, whereas the return loss was larger than 13 dB.

Zhang *et. al.* (2010) proposed a planar triple-band BPF with a compact size. This design combined SLRs and a uniform half-wavelength resonator. The first and third bandpass frequencies, namely, 1.8 GHz and 3GHz, were implemented by SLR, whereas the half-wavelength resonator was implemented at the second bandpass frequency, namely, 2.4 GHz. A compact size was achieved by embedding on the resonator into another. Another advantage of this design was that it allowed the frequency tobe adjusted easily by modifying the size of related resonators. In addition, the fabrication cost of this design was low because the structure design was planar.

According to Figure 3, the insertion loss of the first bandpass was 0.9 dB, whereas the return loss was greater than 20 dB. For the second bandpass, the insertion loss was 1.6 dB and the return loss was greater than 15 dB.

Lee and Sarabandi (2008) developed a triple-band bandpass microwave filter using frequency transformation techniques. In Macchiarella and Tamiazzo (2005); Cameron *et. al*. (2005); and Lee and

Sarabandi (2008), this technique was used in developing a dual-band BPF. Therefore, inspired by these studies, the aforementioned design used the same techniques for developing a triple-band BPF.

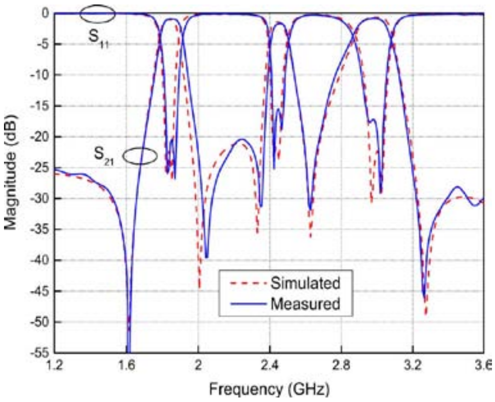

Fig. 3: The simulated and measured results (Zhang *et. al.*, 2010).

A triple-band BPF using multilayer-based substrates for WiMAX was developed by Weng *et. al.* (2007). The three bandpass were implemented using a multilayer structure with three pairs of coupled resonators put together. This BPF was inspired by the designs of Orlenko *et. al.* (2005); Chang *et. al.* (2003); and Kuo *et. al.* (2005), which were large in dimension. Therefore, by using a multilayer-based substrate, a miniaturized size could be realized. Moreover, the cross-coupling effect could also be generated to improve bandpass performance. This design was accomplished by arranging resonators 1 and 2 at the first substrate, and resonators 3, 4, 5, and 6 at the second substrate. The first bandpass frequency at 2.5 GHz was provided by resonators 1 and 2. Meanwhile, resonators 3 and 4 were responsible for producing the second bandpass frequency at 3.5 GHz. The rest of the resonators produced the third bandpass frequency at 5.7 GHz. According to Figure 4, the return loss for 2.5 GHz was 18.5 dB, whereas those for 3.5 GHz and 5.7 GHz were 25 dB and 20 dB, respectively.

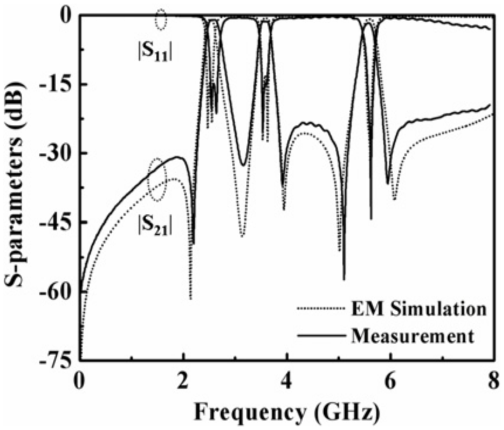

Fig. 4: The measured and simulated results of the triple-band BPF based on multilayer substrates (Weng *et. al.*, 2007).

Proposed Topology of a Hybrid Structure:

Several studies were reviewed, and each presented unique ideas for developing dual- and triple-band BPFs. Based on the designs, the most sought-after characteristics of filters at present are a miniature size, freedom in selecting frequencies, low insertion loss, and easy to design (Wang *et. al.*, 2008). Several designs can be combined to achieve the aforementioned characteristics. In this paper, two new designs were proposed. The first design was based on the combination of meandering SIRs and DGS technique.The second design combined substrate-integrated waveguide (SIW) filter and DGS.

The first design presented in Chu and Chen (2008) stated that the meandering SIR with the new coupling scheme resulted in a size reduction of 50% compared with a conventional direct coupling structure. To reduce size, the U-shaped SIRs were joined. The dual-band response was achieved by controlling the impedance ratio and physical length ofthe SIRs.

In wireless communication systems, a rectangular waveguide is extensively used because of its high-power handling capabilities and low radiation loss (Chuang *et. al*., 2007). However, this waveguide shapehas several disadvantages, such as a large dimension and highcost (Grubinger *et. al*., 2009). A rectangular SIW was applied on the rectangular waveguide, thus allowing it to be mixed with any planar structure (Liu *et. al*., 2012). Therefore, a small size could be achieved with low cost because SIW is cheaper than a conventional rectangular waveguide. The structure of SIW consists of a planar substrate with periodic arrays of metalized via holes (Deslandes and Wu, 2002). To avoid prevent electromagnetic fields from escaping from the SIW cavity, the array of viaholes of SIW is used as a border (Zakaria *et al*., 2013).

DGS was used in both designs to provide high bandpass performance. DGS is beneficial because it can provide a wide range of applications and a slow wave characteristic (Weng *et. al.,* 2008). DGS has numerous benefits, including high precision with regular defect structures and being easy to design and fabricate, thus making it extremely useful in designing microwave filters (Weng *et. al.*, 2008).

Conclusion:

Dual- and triple-band microwave filters have important roles in wireless communication system. Design modifications can yield a compact size, high bandpass performance, and good measurement results. Various designs are currently being reviewed, most of which aim for a miniaturized design and good performance. Several designs are being developed based on previous designs, whereas others are based on a combination of several designs. Among the various designs reviewed in this paper, most researchers tend to favor a microstrip structure. This structure is easy to fabricate, low cost, and easy to integrate into microwave circuits. A low bandpass frequency is mostly used in the designs because of the high demands of current wireless applications. Therefore, the challenge to produce a miniaturized design is high. This workis helpful in understanding the development trends of microwave filters. Itaims to provide a reference for researchersinterested in improving dual- and triple-band microwave filter designs to achieve better measurement performance and compact size.

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