Review on UWB microstrip Filtennas

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ABSTRACT*:* Ultra wide band (UWB) microstrip filtennas exhibiting filtering characteristics of antenna along with overall size reduction of radio frequency (RF) front end wireless communication system have been proposed because of huge bandwidth. Size compactness of filtennas with reasonable characteristics is necessary in modern wireless communication system. Miniaturization is achieved by embedding different components in a single module or develop a system with having multitasking capability. Filtenna or filtering antenna is such a kind of approach in which there exists both simultaneous radiation and filtering characteristics in desired band. Different techniques like filter synthesis design approach, co-design method, insert filter in feedline of antenna etc. are used by researcher to integrate antenna and filter. This paper reviews the state of art for UWB filtennas with detailed discussion about UWB antennas and filters along with integration techniques to achieve Filtenna module.

Key words: Antenna, delay time, filtenna, filter, insertion loss, UWB

From last three decades, continuous research is going on UWB system using analog/digital electronics and antennas. A very short pulses with having low energy is the key feature of UWB communication systems. UWB technology, first used for ground penetrating radar system has been developed by the US military. In 1998, the Federal communication commissions (FCC) has admitted the potential of UWB technology and initiated the regulatory review process of the technology. In February 2002, US FCC has announced UWB regulation by defining its bandwidth from 3.1 to 10.6 GHz for data communication, safety and radar applications. UWB system is complementary of wireless communication system in present era. An antenna is a very important & key integral device of any wireless communication system for transmitting/receiving the signals. Huge bandwidth of UWB is a prime attraction for new growing technology in the area of wireless communication system. Due to large bandwidth, design of antenna is a challenge to maintain its characteristics flat over the UWB region (Nikookar *et al*., 2008). It is not easy task to design an electrically small UWB antennas with having efficient gain and efficiency. It may be a tradeoff among compactness, cost & simplicity of antenna with required characteristics in UWB range (Jung *et al.,* 2005). Despite narrow bandwidth, microstrip antenna is popularly & commonly used due to its low profile, compact size and light weight. To achieve wide bandwidth, different techniques like defected ground structure, modifications in conventional shape of patch, use of stubs etc. are employed. Among these methods, monopole antennas are quite popular to cover wide bandwidth and UWB by using simple configuration like square, circular, elliptical, pentagonal, hexagonal triangle etc. (Ellis *et al*., 2014; Cicchetti *et al*., 2017; Ray, 2008).

Ensuring the propagation of signal within the band is an important issue for wireless communication system. At the transmitter, band pass filter is used to transmit signal before being sent to the antenna. Received signal by the antenna is processed to bandpass filter (BPF). At the receiver side, filter is an essential component of RF front end communication system (Nugoolcharoenlap, 2015). Filter is two port devices having the characteristics of transmitting the signal in pass band and attenuate the signal out of band. The most common filters are designed for low pass, high pass, band pass and band stop characteristics. Ideal filter signal has zero insertion loss in passband and infinite attenuation in stop band or out of band (Matthaei, 1964).

Overall performance of wireless communication system in terms of size, losses and cost depends on RF front end that consists of prime components as antenna, band pass filter, low noise amplifier etc. In RF communication, transmission line resonators are generally used as filter. The size of transmission line filter is an issue which is solved by integration of antenna and filter to make overall system compact (Abbaspour *et al.*, 2002). Impedance mismatching between antenna and filter causes insertion and transition losses which worsen functioning of system. It is a prime issue for researchers to lower down the losses and to make system compact. Miniaturization can be achieved by integrating different devices in a single module. Integration of filter and antenna with having proper matching between themselves to make one single structure are commonly known as filtering antenna or filtenna (filter+ antenna=filtenna). Filtenna may be

Table 1: Summary of UWB antennas reported by various researchers

References	Structure	Feed line	Substrate used/ε_r/ tanδ / height(mm)	Size(mm^2)	B.W. (GHz)	Peak Gain (dBi)	Simulator
Liang *et al.*,2005	Circular	Microstrip	FR4/4.7/N.G./1.7	50 x 42	2.78 -9.78	N.G.	CST
Jung *et al*., 2005	Rectangular	Microstrip	FR4/4.4/0.02/1.6	16 x 18	3.1-11	5.26	HFSS
Lotfi-Neyestanak, 2008	Rose leaf	Coaxial	Air/foam/1/0.8	100 x 100	4.3-8.3	5.9	HFSS
Zhang *et al.*,2009	Circular	Microstrip	PTFE/2.65/ N.G./1	35 x 35	3.1-10.6	N.G.	N.G.
Xiao *et al.,* 2010	Trapezoidal	Microstrip	Taconic CER/10/0.0035/1.5	15 x 15	3-12.4 one notch at4.8-5.4	N.G.	N.G.
Liu and Yang, 2010	Hook	Microstrip	FR4/4.4/0.02/1.6	10 x 10	3-10.7	≃ 5	HFSS
Srifi *et al.,* 2011	Circular (two design)	Microstrip	N.G./3.38/ N.G./0.83	25 x 25	First design2.5-11.7 Second design3.5-31.9	N.G.	N.G.
Azim *et al.,* 2011	Rectangular	Microstrip	FR4/4.6/0.02/1.6	22 x 24	3-11.2	5.4	IE3D
Yang and Tian , 2011	Heart	Coplanar	FR4/4.4/0.0018/1	30 x 35	2.1 -11.5	9.9	HFSS
Isik and Topaloglu, 2013	Heart	Microstrip	Roger/ N.G./ N.G./0.5	25 x 26	4.1-19	1	N.G.
Torres *et al.* , 2014	Heart	Microstrip	FR4/4.08/0.019/1.5778	48 x 40	2.2-27	4.5	CST
Shen and Zhang, 2014	Heart	Microstrip	N.G./3.52/0.02/ 1	21 x 25	3.1-11	≃ 3	HFSS
Islam *et al.,* 2015	Circular	Microstrip	FR4/4.6/0.02/1.6	25 x 31	3.05-10.6 With five notches	≃ 5	N.G.
Mahmud *et al*.,2016	Hibiscus petal	Microstrip	Rogers/2.33/0.0012/1.57	31 x 31	3.5-10.2	N.G.	N.G.
Rahman *et al*.,2017	Broken heart	Microstrip	N.G./4.6/0.02/N.G.	18 x 30	2.9-10.7	5.3	HFSS/CST
Djidel *et al*., 2018	Plant leaf	Microstrip	FR4/4.4/0.002/1.6	35 x 31	3.5-10.2	N.G.	HFSS/CST

Table 2: Summary of UWB microstrip filters reported in various research papers

References	Substrate used/ε_r / tanδ / height(mm)	Size(mm^2)	B.W.(GHz)	Insertion loss (dB) in pass band	Group delay (ns)
Zhu *et al*., 2005	N.G./10.8/N.G./1.27	16 x 1.08	2.5 - 11.5	< 2	0.2-0.43
Shobeyri and Vadjed-Samiei, 2008	Roger/2.2/N.G./0.787	15 x 30	3.1 - 10.6	≃ 0	N.G.
Wei *et al.,* 2008	RT duroid/2.2/N.G./1	N.G.	3.1 - 10.6	≃ 0	N.G.
Thirumalaivasan & Nakkeeran, 2011	FR4/ 4.4/ 0.0004/ 1.6	10.7 X 3	2.5 - 9.5	≃ 0.5	0.02
Neelamegam *et al.* ,2013	FR4 / 4.4/ 0.0004/ 1.6	2.7 x 26.2	3.4 - 12.4	< 2.03	N.G.
Salem *et al.,* 2014	Roger/10.2/N.G./0.635	21 x 24.2	3 - 9.5	< 0.2	0.5
Louazene *et al.,* 2015	N.G./10.8/N.G./1.27	10.42 x 2	3.2-10.7	< 0.2	N.G.
Wang *et al.,* 2015	Roger /10.2/0.002. /0.635	24.7 X 6.5	2.92 - 10.6	< 1.6	0.52
Upadhyay *et al*.,2017	Roger/ 2.2/ 0.0009/1.57	11.9 x 6	3.12 – 12.43	< 0.6	0.98
Sahoo *et al*.,2017	Roger/2.2/ 0.0009/ 0.787	14 x 5.9	3-11	< 0.9	0.9
Zhou *et al.,* 2017	Roger/ 3.55/ 0.0027/ 0.508	16 x 14.5	3.1 -10.4	< 1.6	N.G.

Table 3: Summary of UWB microstrip filtennas reported in different research paper

References	Substrate used, ε_r / tanδ / height(mm)	Size (mm^2)	B.W. (GHz) of Antenna	B.W. (GHz) of Filter	B.W. (GHz) of Filtenna	Peak Gain (dBi)
Pele *et al.,* 2007	Teflon/2.55/N.G./ 1.58	Size: N.G.	2-11	3-10	3.8- 10.5	N.G.
Lee *et al.,* 2008	FR4/4.4/N.G. /0.8	30 x 41.2	3.1-10.6	3.1-5.2	3.1-5.2	3
Chen and Zhou, 2009	N.G./ 4.5/N.G. / 1	44.2x 31.2	N.G.	N.G.	3.3 - 10.4	N.G.
Gσmez Calero *et al.,* 2010	fiber glass/4.4/N.G./ 0.9	40 x 55	3.1-12	3-12 with notch at 5.3	3.1-10.6 with notch at5.2 - 5.4	2.2
Panda *et al.,* 2010	FR4/4.4/0.0018 / 1	31.2x 44.2	2.65-8.52	2.27-10.33	3.65- 10.16	N.G.
Djaiz *et al.,* 2011	Rogers-/2.2/N.G./ 1.575	68 x 27	3.1-12	3-9.5 with notch at 5.8	3.1 - 10.6 With notch at 5.8	N.G.
Wu and Chu, 2012	N.G./ 2.55/N.G./ 0.8	30 x 34	N.G.	3-11 with notch at 5.3 & 5.7	3 - 10.8 & 5.62-5.86 with notch at5.06-5.37	N.G.
Wong *et al.,* 2012	N.G./ 2.55/0.003 / 0.8	28.5 x 28	3-12	N.G.	3.1 – 10.6 with notch at 5	3.48
Wang, and Gao, 2014	FR4/4.4/0.02/ 0.8	32 x 26	N.G.	N.G.	2.8-12 with notch at 5.5-6	4.4
Tang *et al.,* 2015	Roger/3.48/0.0038/1.524	37 x 25	2.855-14	2.824-10.76	2.949 – 10.817	2.21
Liu *et al*., 2016	Taconic /3.5/0.02/ 0.79	20 x 48.4	3.2-10.5	N.G.	3.25-10.5 with notch at 5.5 & 7.5	7
Li and Gao, 2016	FR4/4.4/N.G./1.6	60 x 60	3.14-o 13.66	N.G.	2.43-11 With notch at 3.3-3.82	4.18
Alhegazi *et al*., 2017	N.G./ 4.3/N.G./1.6	30 x 35	3-14	N.G.	3 -14 with notch at 5.5	4.46
Sahoo *et al.,* 2017	Rogers/2.55/0.002/ 0.77	53 x 42	2.5-12	N.G.	3.1 - 10.6	4
Deng *et al.,* 2017	FR4/4.4/0.02. /2	40 x 45	2.2-11	2.4-2.6 &5-6	2.4 – 2.6& 5-6.2	2
Kindo *et al.,* 2018	Rogers/2.55/0.02/ 0.77	35 x 24	N.G.	N.G.	3.1 - 10.6	N.G.
Yang *et al.,* 2019	Rogers/3.38/0.002/1.524	32 x 25	3-14	3-11	3-11	3

considered as a method to fulfill the objective of compactness with desired characteristics of the antenna and the filter (Mansour *et al*., 2014).

A practical filtering antenna is demonstrated by using methods of coupling (Plebanski, 1929). Integration of unipolar slotline dipole antenna with band pass filter directly has been discussed using multi-layer technology (Le Nadan *et al.*, 1998). Further, they have proposed integration of CPW- fed microstrip patch antenna on a composite ceramic -foam substrate with band pass filter using global synthesis technique. Band-pass filter is integrated on the back-side of composite substrate and the patch antenna is on the upper side of dielectric substrate. This integration technique results in a compact multi-function filter antenna module (Le Nadan *et al.,* 1999). In last two decades, a lot of research work is reported in field of integrated filter antenna (filtenna) module using different integration techniques. Integration of filter and antenna can be done basically two ways, namely, filter synthesis technique and co-design technique. Filter synthesis technique is a traditional and common method of integrating filter and antenna by using cascading them. In this technique last resonator and output feed line of filter is replaced by radiating microstrip antenna. Proper matching is required between antenna and filter to maintain the insertion loss of filter in pass band (Chuang and Chung, 2011; Wu *et al*., 2011).

In co-design techniques, three-layer substrates are used. Upper layer and bottom layer of substrate are used for implanting antenna & filter, respectively. Middle ground plane is shared by both antenna and filter (Zuo *et al*., 2009; Li and Liu, 2016). As an example, filtenna using both tradition cascading approach and co-design technique are shown in Figure 1(a) & (b). Fabrication of filtenna is somewhat difficult in case of co-design integration technique as compared to cascaded method (Zuo *et al.,* 2009).

In addition to these techniques/methods, some other untraditional methods are also introduced by researchers. Modifications incorporated in feedline and patch which provide coupling between antenna and ground plane by using cutting slot in ground, using differential feed, multilayer aperture coupled and coupled end-edge techniques are also reported by authors to get filtering characteristics in antenna (Hsieh *et al.,* 2015; Chen, *et al*., 2013; Chuang and Chung, 2011; Wong, *et al.,* 2012). In recent years, many filtennas are designed for various wireless standard like UWB, UMTS, WLAN, Wi-Fi, WiMax, cognitive radio etc. This paper discusses research work done on UWB microstrip filtennas. This review paper is organized as study of major component UWB microstrip antenna and UWB microstrip band pass filter in section 2 & 3, respectively. Key review in field of UWB microstrip filtenna is discussed in section 4.

UWB MICROSTRIP ANTENNAS

A microstrip antenna is a first prime component in designing of microstrip filtenna. A microstrip antenna is a one port device to transmit/receive an electromagnetic wave carrying audio/video data. Operating frequency, bandwidth, gain and radiation patterns are some important characteristic parameters of antenna. Broad cast type wireless services require omnidirectional radiation pattern in all directions whereas point to point radio services require radiation in one specific direction. Design from single resonant frequency narrow band antenna to multi band antenna, and to wide band antenna is carried out for applications for specialized band like industrial scientific medical (ISM), Wi -Max, wireless local area network (WLAN), UWB etc. This section deals with a brief review of UWB microstrip antennas which attract attention by various scientists/researchers/antenna designers in this field (Siwiak, 2001; Leeper, 2003; Washington, 2002). A lot of research is going on in the area of UWB microstrip antennas. Microstrip antenna has narrow bandwidth. To get a wider band width, there are different techniques employed like using defected ground structure (DGS) (Khandelwal *et al.,* 2017; Syed and Aldhaheri, 2016; Wang and Wei, 2018), applying reactive element for impedance matching (Pues and Van De Capelle, 1989), use of meta material (Islam *et al.* , 2015; Pandey *et al.,* 2014), modification in patch structure by providing unique shape as leaf shapes (Fakharian and Rezaei , 2014), UB logo shape (Yuwono *et al.,* 2014), sawtooth shape(Muktadir *et al.,* 2018), increasing the thickness of substrate by stacked technique (Legay and Shafai, 1994) and many more techniques also. DGS and partial ground plane are the popular approaches to enhance the bandwidth. Removal of the ground plane beneath the patch provides a theoretical infinite ground plane for patch to enhance bandwidth for covering UWB spectrum. Printed monopole antenna is designed using this special approach of removing ground plane beneath the patch. It provides a very large bandwidth (Ray *et al.*, 2001; Ammann and Chen, 2003). A number of articles reported in last few decades of using simple rectangular, circular, elliptical structure to attractive heart shape, flower shape compact UWB antennas are reported in (Honda *et al.,* 1992; Suh *et al.,* 2004; Lin *et al*., 2005; Rahman *et al.,* 2017; Kim *et al.,* 2013). Table 1 displays some key work already done in the field of UWB microstrip antennas in terms of structure, feedline, substrate, size, bandwidth, peak gain and simulator. N.G. means not given in the papers. The review of UWB microstrip filters is discussed in the following section.

UWB MICROSTRIP FILTER

Controlling of frequency response within a specific frequency range is carried out by filter which is a two-port network. Filters which are classified in four ways viz low pass filter, high pass filter, band pass filter and band reject(stop) filter depend on their characteristics to transmit the signal in desired band and attenuate the signal out of band (Pozar, 2009). The work done by noble laurates, H. A. Bethe and J. Schwinger and others like N. Marcuvitz, E. M. Purcell etc. in early advancement time of microwave filter since 1930's is still mark bench (Levy and Cohn, 1984). In earlier time, waveguide and coaxial line are used to realize microwave filters. Growth in planar technology has facilitated advancement in realizing compact and light microstrip filters. Microstrip filters are very attractive and widely used due to of their low profile and compactness. Practical realization of interdigit filters (basically folded coupled parallel transmission line) has been firstly presented by George Matthaei. The book on microwave filter written by Matthaei, Young and Jons is often called bible of the filter world (Matthaei *et al.,* 1964). There are different ways to physically realize microstrip band pass filters such as end-coupled, parallel-coupled half-wavelength resonator, Hairpin-line, Interdigital, Comb line, and half or quarter wavelength stub filter (Hong and Lancaster, 2004). In general, analytic Butterworth, Chebyshev, Cauer, Bessel function etc. is used to get desired filter specifications. Butterworth filters are preferred for maximally flat condition in pass band. As compared to the Butterworth filter, Chebyshev filter provides sharper attenuation slope with ripples in the pass band. The characteristics of the filter are described in terms of insertion loss, return loss and delay time which is a function of frequency. Table 2 displays key literatures on UWB BPF in terms of substrate, size, bandwidth, insertion loss and group delay in which N.G. denotes not given. The brief review of the UWB microstrip filtenna is given in following section.

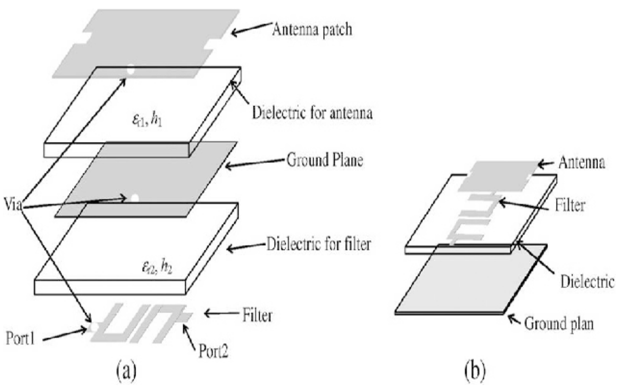

Fig.1: (a) Co-design method for filtenna (b) Traditional cascading method of filtenna (Zuo *et al.*, 2009)

UWB MICROSTRIP FILTENNA

Based on the bandwidth criteria, filtennas are generally classified as narrow band filtenna or wide band filtenna. A narrow band filtenna is designed specifically for an operating frequency as well as very low bandwidth. In comparison to narrow band, wide band covers a huge range of bandwidth for entire UWB spectrum in many cases. Filtenna system is obtained by integrating UWB filter and an antenna which has greater bandwidth than that of UWB filter. Again, UWB filtenna can be categorized as UWB microstrip filtenna (covers whole UWB spectrum), UWB filtenna with notch (not covering frequency/band such as WiMax, WLAN etc. as required in UWB range) and reconfigurable UWB filtennas. In case of UWB microstrip filtenna, filter and antenna are separately designed and then integrated as a single module. In some cases, the antenna does not cover the entire UWB but shows improvement to cover UWB spectrum after integration (Sahu *et al.*, 2019; Ranjan *et al*., 2017). In case of UWB filtenna with notches, UWB antenna is firstly designed and notches are then produced by cutting different slots of proper dimensions according to specific frequency in patch, feedline or in ground (Kahng *et al*., 2009; Barbarino and Consoli, 2010; Jiang *et al.,* 2010; Zhu *et al.*, 2011). Reconfigurable UWB filtennas are tunable in required frequency which is shifted by inserting PIN diode or another switch in filter, antenna or integrated filtenna (Sam and Zakaria*,* 2015). Any integrating techniques like cascading or co-design method can be used to make filtering antenna module. In (Sahu *et al.,* 2019; Ranjan *et al*., 2017) UWB filtenna using cascading techniques is reported. Authors have firstly designed antennas which have greater bandwidth than that of UWB range. However, the bandwidth of filter lies within range of UWB. Both the antennas and filters are integrated to make filtennas whose bandwidth is in the range of UWB with improved radiation characteristics. Other key literature review in field of UWB filtennas in terms of substrate, size, bandwidth and peak gain are summarized in tabular form as given in Table 3.

CONCLUSION

This paper has presented a review on UWB microstrip filtenna (integrated ûlter and antenna) with including a brief review of UWB microstrip antennas and filters. Different integration techniques for the antenna and the filter are explained with help of earlier quoted research work. On the basis of various research papers reviewed for UWB application, monopole antenna is favorable choice for researchers due to of its simplicity, easy fabrication, and also compatibility with other devices. Parallel coupled MMR filter is attractive design approach because of its simplicity. Cascading, codesign and modifications in microstrip feed lines are the popular integration methods which are generally employed. The recent advances of UWB filtenna and its application have been briefly discussed. Review studies show that microstrip filtenna is preferable due to its size compactness with front end communication module. However, impedance matching between antenna and filter is a very important and challenging issue. This review paper will be helpful in understanding the basic idea of UWB microstrip antenna, filter, and recent development trends in terms of integration techniques of UWB microstrip filtenna. It will also help to generate research interest in making the size of filtenna more compact and to search new integration techniques to reduce overall size of RF front end wireless communication system with better performance.

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