CHAPTER 6

Summary and Conclusion

This chapter summarizes and concludes the research work presented in different chapters of the thesis. The future scope and extension of the present work are also described in this chapter.

6.1 Summary and Conclusion

Miniaturized components/systems with improved performance are required for wireless communication as well as UWB systems in present times. An antenna and a bandpass filter (BPF) are most common and essential components employed at the front-ends of any wireless system. Antennas and BPFs are ordinarily designed separately and connected through impedance matching circuit so that maximum power is transferred from the filter to the antenna in the transmitter and the antenna to the filter in the receiver. But this extra impedance matching circuit would increase the size of the system, and corresponding losses will increase. Also, it would increase manufacturing cost of the combination of antenna and filter. In addition, finite length of transmission line connecting the antenna to filter will increase the system losses. Therefore, to design and develop compact and cost effective filter-antenna system having reduced losses and improved signal-to-noise ratio (S/N) performance, one has to get rid of the matching network between antenna and filter. This can be done by directly integrating the antenna with filter, and this combination is called filtering antenna which performs filtering and radiation functions simultaneously.

The present work is motivated in part by the need to design and investigate through simulation and/or experimentally the miniaturized versions of some BPFs, monopole antennas, and filtering antennas with improved passband and stopband performances. The research work carried out for the present thesis is described in six chapters as given below.

The thesis starts with the discussions pertaining to brief introduction of filters, antennas and integration of filters with antennas along with some basic concepts concerning microstrip filters and antennas in **chapter 1**. Thereafter, literature survey on filters, antennas and filtering antennas has been presented at the end of this chapter.

In **chapter 2**, the compact modified microstrip interdigital bandpass filter (IBPF) having low insertion loss in the passband, sharp roll-off and wide stopband with high out-of-band unwanted harmonics rejection capability for L-band applications has been presented. In the first part, conventional IBPF (using fifth order Chebyshev lowpass prototype with a passband ripple of 0.1 dB) has been analyzed. In the second part, a combination of two pairs of spurlines and a pair of stepped impedance resonator (SIR)-shaped defected ground structures (DGSs) have been introduced in the conventional IBPF which results in the proposed compact BPF with the desired response. The reduction in size and wide stopband characteristic of the filter result from band-notched characteristic of spurline, and harmonic suppression along with miniaturization characteristic of DGS. The spurious response suppression characteristics of spurlines and DGS are validated using the computed values of respective equivalent circuit parameters (*R*, *L*, and *C*). Details about different stages of the filter design using a pair/pairs of spurlines and a pair of SIR-shaped DGS are discussed and all the required simulation and measurement results are presented in this chapter. The simulated 3-dB fractional bandwidth of the proposed filter is 80 % over the frequency range 0.89–2.05

GHz. The simulated roll-off rates in the lower and upper transition bands for the proposed filter are respectively equal to 75.9 and 60.7 dB/GHz. The proposed BPF has stopband attenuation better than 17 dB upto a frequency of approximately six times the centre frequency of the desired passband. For the validation of the simulation results, the prototype of the proposed filter was fabricated using RT/duroid 6010 substrate (ε_r = 10.2, tanδ = 0.0023 and thickness = 1.27 mm) and its characteristics, viz. variations of *S*–parameters, group delay and phase responses of the filter versus frequency were measured experimentally. The experimental results for the proposed BPF are nearly in agreement with the respective simulation results. The results for performance comparison of the proposed filter with those reported in the literature in respect of the fractional bandwidth (FBW), insertion loss (IL), stopband response, dielectric constant of material used (ε_r) and filter size show that proposed filter is more compact, has lower insertion loss and wider stop- and pass-bands as compared with the filters reported in the literature. The compactness of the filter along with its wide pass- and stop-bands, sharp roll-off and low insertion loss makes it suitable for L-band wireless communication applications, such as satellite communication, global positioning system, aircraft surveillance system as well as radar and navigation applications. Further, in order to achieve compact integrated system (combination of filter and antenna) with improved performance for use in the front-end of wireless communication circuitry, the proposed compact L-band BPF can be integrated with the antenna.

Hence, in **chapter 3**, an integrated design of compact L-band filtering antenna having sharp cut-off performance and reasonably suppressed unwanted harmonics for various L-band wireless communication applications has been reported. In the initial phase, a modified wideband elliptic-shaped monopole antenna has been designed and analysed through numerical simulation software for its input characteristic, radiation patterns, realized gain-frequency characteristic, and total efficiency-frequency characteristic. Further, the prototype of the proposed antenna was fabricated for experimental study in order to validate the simulation results for antenna's input characteristics, radiation patterns and realized gain-frequency characteristics. The operating frequency range of the antenna covers the frequency range 1.0 – 2.6 GHz. Furthermore, the modified IBPF reported in chapter 2 was integrated with the proposed wideband monopole antenna without any extra matching circuit to achieve compact integrated system with good impedance matching within the desired passband and reasonably suppressed out-of-band (unwanted) harmonics. The proposed integrated system will henceforth be referred to as filtering antenna. The proposed L-band filtering antenna is analysed through numerical simulation software. The simulated -10 dB reflection coefficient bandwidth of the proposed filtering antenna covers the frequency range 1.01 – 1.96 GHz with improved band-edge selectivity and unwanted harmonic suppression up to 8 GHz (= 5.4 f_0, where f_0 is the centre frequency of passband). It has nearly stable omnidirectional radiation patterns over the entire frequency band. The proposed wideband monopole antenna and the L-band filtering antenna were fabricated using RT/duroid 6010 substrate (ε_r = 10.2, tanδ = 0.0023 and thickness = 1.27 mm) and experimentally tested. The experimental results are nearly in agreement with corresponding numerical simulation results. The results for performance and dimension based comparison of the proposed filtering antenna with those reported in literature show that proposed filtering antenna is smaller as compared with the filtering antennas reported in literature and provides better harmonic suppression capability with sharp roll-off. Hence, the proposed compact filtering antenna can be a good candidate for various L-band wireless communication applications, such as satellite communication, global positioning system, and aircraft surveillance system.

Since UWB technology has great potential in the development of various modern transmission systems, for instance, through-wall imaging, medical imaging, vehicular radar, indoor and hand-held UWB systems. Additionally, UWB BPF is one of the key components in UWB systems. Therefore, in **chapter 4,** the compact UWB BPF having sharp roll-off and wide stopband with high rejection capability has been presented. The proposed filter uses modified multi-mode resonator (MMR), open- as well as short-circuited stubs at input and output ports, and DGS-based compact lowpass filter (LPF). The modified MMR, which consists of meandered coupled-lines, stepped-impedance stubs, open-circuited stubs and coupled-line sections is responsible for compactness alongwith good impedance matching in passband of the UWB filter. Stepped-impedance stubs, which are used to nullify the effect of mutual coupling between meandered-lines have been analysed in detail. To obtain wide stopband characteristics for compact size UWB BPF, DGS-based LPF has been used. The DGS-based LPF was realized using four non-uniform-cascaded configurations of DGS units along with a 50 Ω microstrip line. Each DGS unit, which consists of a combination of three isosceles U-shaped DGSs has been analyzed in terms of an equivalent *RLC* circuit model. Further, an equivalent *RLC* circuit model of the LPF has been proposed to validate its results obtained through numerical simulation and experimental studies. The proposed compact UWB BPF formed by integrating modified MMR-based UWB BPF with the DGS-based LPF has been numerically simulated to obtain its characteristics: variations of scattering parameters, surface current distributions, and group delay versus frequency. The proposed UWB BPF has simulated passband (3-dB bandwidth) frequency range 3 – 11 GHz with wide stopband: attenuation better than 40 dB and 25 dB over the frequency ranges 11.7 – 20.5 GHz and 11.2 – 30 GHz respectively. The roll-off rates in the lower and upper transition bands are respectively equal to 18.7 and 54.8 dB/GHz.

The prototype of the proposed filter was fabricated using RT/duroid 5880 substrate (ε_r = 2.2, tanδ = 0.0009 and thickness = 0.787 mm) for experimental investigations. The experimental results for variations in S-parameters and group delay of the proposed UWB BPF are nearly in agreement with corresponding numerical simulation results. The results for performance comparison of the proposed UWB BPF with those reported in the literature show that the proposed filter is more compact and provides better out-of-band suppression as compared with the filters reported in the literature. Hence, the proposed compact UWB BPF can be used as an important component/device in modern UWB communication system and in portable UWB systems. Further, in order to achieve compact UWB integrated system (combination of filter and antenna) with improved performance for use in the front-end of wireless communication circuitry, the proposed compact UWB BPF has been integrated with the UWB antenna in chapter 5.

Hence, in **chapter 5,** a new compact UWB filtering antenna having good passband cut-off performance and highly suppressed out-of-band (unwanted) harmonics has been reported. The proposed UWB filtering antenna has been obtained by integrating UWB monopole antenna (-10 dB reflection coefficient frequency range 2.96 – 11.36 GHz) with optimized version of compact UWB BPF (-10 dB reflection coefficient frequency range 3.05 – 10.8 GHz, 3-dB passband frequency range 2.81 – 10.85 GHz, minimum stopband attenuation of 39.3 dB (upto 20.7 GHz) and 21.8 dB (upto 30 GHz)) described in chapter 4. The UWB BPF is responsible for obtaining improved cut-off performance with suppression of unwanted harmonics of the proposed UWB filtering antenna. Initially, a compact UWB antenna was designed and investigated through numerical simulation software for its input characteristic, radiation patterns, realized gain-frequency characteristic, total efficiency-frequency characteristic and pulse handling capability. The prototype of the proposed UWB antenna was fabricated for experimental study in order to validate the simulation results for antenna's input characteristic, radiation patterns and realized gain-frequency characteristic. Further, the geometrical parameters of UWB BPF reported in chapter 4 were optimized to obtain desired reflection and transmission characteristics using numerical simulation software for its integration with the UWB antenna. Furthermore, the optimized UWB BPF was integrated with the proposed UWB antenna without any extra matching circuit to achieve compact integrated system with good impedance matching, improved cut-off performance and wide stopband with good unwanted harmonic suppression capability. The proposed integrated system is called the UWB filtering antenna. The proposed UWB filtering antenna was analysed through numerical simulation for its input as well as radiation characteristics along with surface current distributions of the proposed UWB monopole antenna with and without the integration of the UWB BPF. Further, the time domain analysis of the proposed UWB filtering antenna was also carried out through CST MWS software to ascertain its pulse handling capability. Roger RT/duroid 5880 substrate (ε_r = 2.2, tanδ = 0.0009, and thickness = 0.787 mm) was used for design, simulation and experimental studies of the proposed UWB filtering antenna. The simulated -10 dB reflection coefficient bandwidth of the proposed UWB filtering antenna covers the frequency range 3.07 – 10.72 GHz with improved band-edge selectivity and highly Suppressed unwanted harmonic suppression up to 30 GHz (= 4.35 f_0, where f_0 is the centre frequency of passband). It has nearly stable omnidirectional radiation patterns over whole UWB frequency band. The proposed filtering antenna was fabricated and experimentally tested for obtaining measured variations of its reflection coefficient, radiation patterns, and realized gain versus frequency. The experimental results for the filtering antenna are nearly in agreement with respective numerical simulation results. For demonstrating the superiority of the proposed UWB antenna and the proposed UWB filtering antenna, the dimension and performance based comparison of these components with the respective components reported in the literature was done and the results for the comparison depict the superiority of the proposed components. Therefore, the proposed filtering antenna can be a suitable candidate for UWB applications.

6.2 Scope for Further Work

After going through the work presented in this thesis, it can be said that scope still exists for further work in the related area.

In the present thesis, IBPF and compact filtering antenna have been presented for L-band communication applications. Hence, future work may be done on the design and development of multi-band microstrip filter along with filtering antenna for various wireless communication applications.

In the present thesis, a compact UWB BPF having good band-edge selectivity and wide stopband with high rejection capability has been presented. Possible future work could focus on design and development of compact UWB BPF with notched bands to avoid interference among usable bands.

Studies may also be performed on design and development of dielectric filters. Further investigation may be carried out on the design and development of reconfigurable filters along with reconfigurable filtering antennas.

Finally, an effort may be made on design and development of compact filtering antenna for microwave and millimeter wave multiple-input-multiple-output (MIMO) systems.