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A Research on Microstrip Ultrawide Band Filters using Defected Ground Structure Techniques

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Abstract: ***In this paper, microstrip ultra-wideband (UWB) filters using various defected ground structures are studied. Miniature microstrip filters employed in transceiver of modern wireless communication systems play vital role in controlling and regulating frequency response. DGS techniques are etched in ground plane to design compact microstrip based low pass, high pass, bandpass and band reject filters used in modern wireless systems. Various modified and hybrid defected ground structure techniques are employed to achieve high return loss, low insertion loss, ultra compactness, good selectivity and linearity in filters. Study reveals that the proper selection and incorporation of DGS techniques while designing microstrip ultra wideband filter optimizes the various vital parameters which enhances its performance and practicability for various modern wireless communication applications.***

Keywords: ***Defected ground structure (DGS), Filters, Microstrip, Ultrawide band (UWB).***

I. INTRODUCTION

UWB technology has a great potential and hence employed in modern wireless communication systems and sensor applications. Federal Communications Commission (FCC) in year 2002 authorized the use of unlicensed UWB frequency spectrum ranging from 3.1 GHz to 10.6 GHz. Academically as well as practically, UWB devices find a huge applications especially in modern wireless wideband transceiver systems like antennas, filters etc. Microstrip ultrawide band filters play vital role in wideband applications to shape frequency response as per requirements.

Design of microstrip filter at these ultra wideband frequencies is most challenging in the environment where out of band harmonics i.e. stop band spurious harmonics affects the response of the designed filter. To mitigate this effect, the filters with sharp selectivity, low insertion loss and high return loss are designed through various etching and ground defects techniques.

A variety of techniques has been reported by various researchers to develop harmonics free response in UWB filters in past years. The passband response can be smoothen along with stopband characteristics by incorporating defects in ground plane as well as in feed microstrip line on the substrate of the designed filter. This way, microstrip filter can achieve high performance and good efficiency in terms of size, selectivity, insertion loss, cost, harmonics suppression and pass band performances.

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A DGS may have single or multiple defects (periodic or non-periodic) on the ground plane. The ground plane engraved with single or multiple defects induces slow wave characteristics thereby enhancing stop band behavior and suppresses higher mode harmonics. The defects incorporated in the ground plane disturb current density in its vicinity thereby optimizing effective inductance and capacitance of the structure. As a consequence, a DGS exhibits slow wave characteristics and rejects harmonics thereby improves the performance of filters.

Various topologies of DGS are recommended by researches to enhance the performance of ultrawide band filters. Among them, spiral, dumbbell, split ring shaped (SSR), complementary SSR and fractals are most commonly employed in practical designs. The frequency response of the UWB microstrip filters can be optimized by changing the dimensions of the defects. Additionally the feature of bandwidth tunability can be introduced using varactor diodes and interdigital pattern. The defect shape/geometry incorporated in proposed microstrip filter depends on the parameter requirements and applications.

The resonant frequency and cut off frequency can also be controlled and regulated by proper selection of etched structure on the ground plane. The proper selection of substrate, design methodology and relevant losses calculations must be considered for acquiring desired frequency response of the designed UWB microstrip filter by DGS techniques.

In a nutshell, the primary motivation of this study is to compare various methods to design UWB microstrip filters in context to various parameters like size, bandwidth, insertion loss, return loss, selectivity, data rate, tunability, harmonics suppression etc. The design of various UWB microstrip filters carried out using high frequency simulation software is studied with their simulation results. Finally, simulated and measured results are studied which form the basis of comparison of various techniques with their salient features.

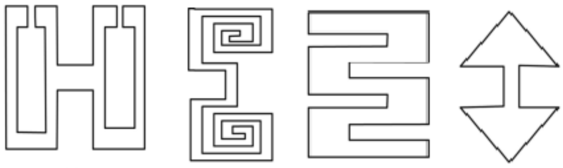
II. VARIOUS DGS DESIGN CONFIGURATIONS IN MICROSTRIP FILTER

Extensive researches on the design of ultra-wide band microstrip filters using various techniques have been presented in the following sections:

A. Defected Ground Structure Topology

Defected ground structure techniques are developed from its predecessor technology Photonic Band Gap (PBG) [36]. Various geometries etched in ground plane are presented viz. spiral, square loop, interdigital, dumbbell etc. The transmission characteristics of these models are explained in detail.

Various equivalent LC circuit models of DGS structures are analyzed. The salient features of DGS are explored which makes them compatible to be employed in microwave circuits. Figure 1 shows some of the most commonly employed DGS defects in the fabrication of UWB microstrip wideband filters with enhanced passband and stop band characteristics.



(a) (b) (c) (d)

Fig. 1. (a) Dumbbell shaped DGS (b) Spiral Head DGS (c) Interdigitated DGS (d) Arrowhead-slot (Weng et al. 2008)

The harmonics suppressed DGS based Hairpin bandpass filters are investigated with different geometries are studied in [4]. The stop band characteristics are improved by engraving U shape slot in ground plane. By modifying the dimensions of DGS structure the center frequency, passband and stop band behavior of the designed microstrip bandpass filter can be controlled. Hairpin DGS resonator introduces two transmission zeros in order to achieve sharp selectivity in filter response.

A microstrip bandpass filter is designed through DGS technique is presented in [11]. The design shows that by cascading multiple DGS units, the response of the microstrip filter can be enhanced. Further, filter response can be enhanced by varying the geometry and dimensions of the DGS section engraved in ground plane.

A new approach is used to design high quality and wider bandwidth band pass and band stop filter is proposed in [12]. The combination of defected ground structure with defected microstrip structures techniques employed to improve the frequency response of the designed filter. The bandpass characteristics and hence frequency response of proposed filter can be controlled by changing dimensions of DGS and cascading the resonator structures in some regular fashion. The designed filter with DGS shows reasonable slow-wave characteristics in its passband along with wideband response.

The tunable microstrip dual-band bandpass filter using DGS and varactor diode is presented in [5]. The tunability of passband works on the principle of variable characteristics impedance by employing DGS techniques. The stub loaded resonator with open ended shunt stubs whose characteristics impedance varies by employing DGS and varactor diode contribute the tuning of second passband of the filter. The filter has great selectivity factor in its first passband as well as tunable second passband due to creation of three transmission zeros. The reasonable value of reflection coefficient and transmission coefficient are achieved which makes it fit for various modern communication systems like GPS, WLAN's etc.

A harmonics suppressed BPF incorporating DGS technique is designed [26]. A newly proposed DGS technique employed in the shape of rectangular SRR in the ground plane of designed filter. To enhance the selectivity and to eliminate the unwanted spurious harmonics, the modified π-shaped DGS structure is introduced. This leads in creation of tunable transmission zeros which in turn gives sharp selective response of filter. The enhancement of various filter parameters viz. quality factor, selectivity, bandwidth etc. makes the filter fit for radar, navigation and imaging systems.

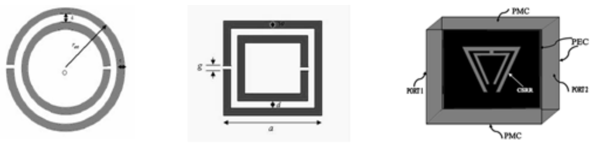
The enhancement in compactness of planar filters is discussed in [14] using combination of two techniques viz. fractal geometry and DGS approach. The low return loss in passband and very high attenuation in stop band is contributed by incorporating the fractal geometry. The simulation results revealed that the fractal microstrip DGS topology gives low insertion loss, high return loss, worse selectivity but size of filter is compact. On the contrary, the fractal coplanar filter of lower order exhibits lower return loss, high insertion loss, poor selectivity and large size as compared to that of novel compact filter.

A tri-mode resonator based compact UWB single band BPF is presented [6]. A strong coupling effect can be produced by employing DGS structure at input-output terminals in order to achieve wide band performance of the designed filter. Moreover, a digital microstrip structure engraved with stub loaded stepped impedance resonator designed in [35] that exhibits tri-band response and ultra compactness can be achieved. The interdigitated coupling provided between input-output port and DMS structure strengthens and improves out-of-band performance of designed filter. The even-odd mode analysis of filter is done in order to optimize various vital parameters like resonant frequencies, characteristic impedance etc. of microstrip planar filters.

The modified DGS structure introduced with metal strips loaded in dumbbell shaped DGS is presented in [15]. This modified DGS enhances passband and bandstop characteristics of microstrip filters as compared to conventional dumbbell-shaped DGS. The metal strip loaded in DGS cell increases effective capacitance and decreases effective inductance which enhances the selectivity factor of the filter response.

In [37] researchers proposed the LC equivalent circuits for microstrip bandpass filters engraved DGS as well as without DGS. The simulated results reveal that bandwidth obtained with DGS employed in ground plane far exceeds than that of without DGS. The percentage increase in bandwidth is approximately 36% which is remarkable improvement.

In [16], various microstrip filters are fabricated employing complementary split ring resonator as DGS topology. Various geometries of CSSR-DGS like dumbbell, rectangular, circular, square, triangular, hexagonal etc. are analyzed. The overall performance of triangular geometry CSSR-DGS is found better in various parameters such as bandwidth, selectivity, roll off rate, return loss etc. The low pass, high pass and bandstop filters are realized. Various complementary split ring resonator designs are presented in figure 2.



(a) (b) (c)

Fig. 2. (a) Circular SRR (b) Square SRR (c) Triangular SRR (courtesy: www.microwaves101.com)

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B. UWB Microstrip Filter with Multimode Resonator

An UWB bandpass filter designed using shunt stub with a capacitor is presented in [38]. By using lumped capacitor with shunt stubs, a large gap between two consecutive resonant frequencies is observed which exhibits wide passband. The developed filter is compact and meets desired response in its passband and stop band. The vital parameters of fabricated microstrip BPF are met with FCC's standard and had a good agreement with designed filter.

The microstrip UWB notch filter at WLAN frequency is proposed and designed in [13]. The filter is incorporated with complementary single split ring resonator that imparts the feature of notch response at 5.5 GHz i.e. WLAN signal frequency. The filter exhibits sharp selectivity and smooth passband response. The proposed filter incorporated with CSSRR exhibits reasonably high passband as well as stop band performance. Rejection level at notch frequency i.e. 5.5GHz is more than 30 dB which mitigates the interference between UWB signals and WLAN radio signals. In conjunction with this, a T-shaped DGS structured compact microstrip filter is also investigated. The 50 ohm microstrip line is incorporated with interdigital structure in this filter which induces capacitance effect and hence increase coupling between input-output ports at resonant frequency. The filter was designed to be used for WLAN applications. The results reveal a good compromise between various transmission coefficients.

A compact multi band band-pass filter incorporated with spiral-shaped resonators designed in [9]. The filters are designed to produce dual, triple bands along with multi bands by proper selection of zeros location in filter response. These filters are compact and easy to fabricate. They are specially designed for GSM as well as WLAN applications.

An improved quality factor microstrip filter employing cross shaped multi-mode resonator and impedance transformer is investigated in [22]. Tuning elements requirement in wideband tunable filters can be minimized using cross-shaped MMR. Different circuit models are presented to tune external quality factor of proposed UWB BPF. The centre frequency tuning at constant bandwidth is achieved by cross shaped MMR along with external quality tuning structures incorporated in filter.

A triple passband compact microstrip UWB BPF is designed and fabricated in [19]. The designed incorporates short stub stepped impedance resonator (SIR) with high impedance and low impedance section. The selectivity of filter is enhanced by employing pseudo interdigital structure which in turn creates transmission zeros at the edge of filter's frequency response. The coupling between input-output ports and resonators controls the tuning of resonating frequencies. The designed filter has sharp selectivity, compactness and greater flexibility that make it useful in various modern wireless communication systems applications.

A multi-mode resonator (MMR) based microstrip bandpass filter for wideband applications is proposed in [33]. The filter has sharp selectivity at lower and upper stopband. The filter has capability to pass resonant frequencies in whole passband. The strong coupling is provided using interdigital structure engraved between input-output section and resonator. The filter exhibits excellent passband and stop band characteristics. The compactness and ease of fabrication leads this filter to be used is various UWB applications.

A compact wideband common mode suppressed microstrip filter is designed using half mode dumbbell DGS is proposed in [20]. T shaped multi-mode resonator (MMR) in addition with short ended stubs are incorporated in proposed filter. The passband characteristic of the filter is enhanced by employing interdigital structure between input-output port and MMR. The half-mode DGS topology is utilized to design balanced UWB filter for ultra compactness and suppression of spurious harmonics.

An UWB BPF with compact size is designed and fabricated through defected microstrip structure resonator [18]. Lower frequency selectivity is enhanced using interdigitated coupled structure in the middle of DMS. The upper stopband is extended by employing SRR structure in ground plane. The filter reveals low insertion loss that corresponds to flat passband response. The achieved bandwidth is more than 8.0 GHz with high return loss.

C. Suppression of Harmonics in Microstrip Filter using DGS Techniques

The microstrip tunable balanced filter designed and implemented [17] has both constant fractional as well as absolute bandwidth. To enhance the quality factor of the filter capacitors are employed at input-output ends. Differential and common mode analysis is done by adding various elements in the middle of resonator. The key feature of this filter is to suppress higher order harmonics keeping fractional and absolute bandwidth as constant. A harmonics suppressed microstrip BPF incorporated with short stubs for ISM application is fabricated in [28]. The open stubs are incorporated in the form of inverted T shape along microstrip line for removal of second and third order harmonics. The stub length is kept equal to quarter wavelength in order match impedance at input-output port. The proposed filter has sharp selectivity, compact and easy to fabricate on Teflon substrate.

A stepped impedance DGS resonator that suppresses second and third order harmonics is proposed [23]. The selectivity factor is enhanced by employing open stubs on substrate due to creation of transmission zeros. The filter designed has second order configuration and considered good for GPS applications. The proposed filter also has good power handling capability. An X-band filter [10] is designed and fabricated for high date rate applications. The substrate integrated waveguide structure combined with defected ground structure to optimize its design. DGS technique is employed to enhance the stopband characteristics. Metallized via-holes in the form of linear arrays are engraved by PCB technology. The stopband rejection of more than 30 dB is achieved in out of frequency band. The filter is 3-poles with sharp frequency selectivity. This type of filter finds its application in radar systems. An easily fabricated compact microstrip dual band BPF on FR4 substrate is investigated [29]. The filter is designed using three sections viz. hairpin line resonator, interdigital structure and open stubs. Interdigital structure exhibits high passband transmission characteristics, hairpin exhibits low passband characteristics and open stubs contributes to creation of zeros for sharp selectivity. The filter designed is so compact to be used in WiMax/WLAN applications.

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III. COMPARATIVE ANALYSIS

Based on various microstrip UWB filter design using various DGS techniques, a comparative table is developed as follows:

Table- I: Performance Analysis of Filter Design with Different DGS Techniques

Ref. No.	Techniques Used	Achievements@ Specific parameters	Salient features
[1]	Fractal Peano Shaped Open Stub Resonators with high space filling property.	Second harmonic gain level more than -10 dB.	Helpful in filtering out or notched out certain frequency components from compact microstrip antennas designs used in UWB communications.
[3]	A combination of slotted ground structure (SGS) and multilayer techniques.	1. Achieved extremely low insertion loss (IL) i.e. less than 0.25 dB. 2. Stop band attenuation of 20 dB in frequency range of 4.7 to 8 GHz.	Using overlapping and SGS techniques, the size of the new SGS BPF is 49 % less than conventional BPF.
[4]	Coupled DGS resonator in Hairpin bandpass (BPF) microstrip filter.	Return loss of more than 20 dB with very low 0.15 dB of insertion loss in UWB frequency spectrum.	BPF is very compact, in addition, the filter has extended stop band region with two transmission zeroes.
[5]	DGS + MMR + Tuning element as Varactor diode	1. Return loss 18.9 dB. 2. The insertion loss around 1 dB in whole passband is achieved.	Due to low loss in passband i.e. low insertion loss characteristics it is employed in GPS and wireless LAN systems.
[6]	Tri-mode resonator + Defected ground structure.	1. Insertion loss (<0.5dB) while return loss (>20dB) at centre frequency 3.6 GHz. 2. About 50% of fractional bandwidth is recorded.	Ultra compact single band filter design with higher bandwidth and data rate.
[7]	Stepped impedance resonator (SIR) + Capacitor coupling.	1. Insertion loss (1-3 dB) in 0.77 to 1.42 GHz passband. 2. Tuning range of more than 80% recorded.	Microstrip bandpass filter with wide range of frequency shifting capability widely used in radar applications in varying atmospheric conditions.
[9]	Spiral shaped half wavelength resonators with quarter wavelength spacing.	Insertion loss (0.7-1 dB) recorded at frequency (0.9 GHz-1.8GHz).	Filter can be employed for navigation and Wireless LAN applications.
[10]	Defected ground structure incorporated with substrate integrated waveguide technique.	1. Stop band attenuation of more than 35 dB is recorded. 2. Low insertion loss (<1.5dB) and high return loss (>20 dB) is recorded in its passband.	Highly recommended for navigation and radar system applications.
[11]	Cascaded DGS units in ground plane.	20% of fractional bandwidth at 3.3 GHz centre frequency.	Fractional bandwidth at 3.3 GHz has been increased by 6%.
[12]	Defected Ground Structure for Planar Wide Band Filters.	1. The stop band rejection is now more than 40 dB. 2. The bandwidth of the pass band is 51%.	This filter can be used for wide band and high Q applications.
[13]	Complementary single SSR	1. Fractional bandwidth of 113% at centre frequency of 6.85 GHz. 2. Notch band with attenuation (>30 dB).	Exhibits least hindrances with wireless LAN frequency band and hence can be employed in a large number of UWB communications systems.
[14]	Fractal defected ground approach.	1. Insertion loss up to 0.5 dB with return loss better than 15 dB is recorded. 2. The filter has bandwidth of more than 3.0 GHz and sharp selectivity better than 40 dB/GHz is recorded.	The filter has remarkable attenuation in its stop band which helps to eliminate higher order harmonics and makes the filter suitable for imaging and radar tracking systems.
[15]	Defected ground structure incorporated with metal strips.	1. Effective size of filter 0.0065λg x 0.0064 λg. 2. Insertion loss of designed filter (<1dB).	The filter exhibits good skirt factor with sharp selectivity in its passband which makes it suitable for various wireless applications.
[16]	DGS + CSSR	1. At centre frequency 2.4 GHz, selectivity factor is 212.5 dB/Hz. 2. Quality factor is 8.00.	This topology is effective in designing various microstrip filters as they exhibits sharp selectivity and good external quality factor. These filters adjust their filter response with change in

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			frequency in stop band.
[17]	Microstrip resonators with tuning feature by proper selection of coupling region.	The tuning range marked more than 30% with ripple in passband upto 4 dB.	The filter exhibits fine tuning and great attenuation in stop band with high harmonics suppression/rejection capability.
[18]	Defected microstrip structures resonator with interdigitated parallel coupled lines and complementary split ring resonators.	1. Reasonable return and insertion loss in its passband recorded. 2. High fractional bandwidth of 129% is achieved.	This miniature designed filter is efficient to be employed in modern wireless communication systems.
[20]	T shaped MMR + Half mode dumbbell DGS structure.	Remarkable common mode attenuation (upto 30 dB) recorded in whole UWB range.	Unwanted harmonics suppressed filter which is fit to be employed in advanced wideband wireless communication systems.
[22]	Cross shaped multi-mode resonator (MMR) and N: 1 transformer based external tuning structure.	1. At frequency range 0.67-1.215 GHz, insertion loss upto 2 dB while upto 3.5 dB at frequency range of 0.6-1.45 GHz is recorded. 2. The tuning range at high frequency range is almost double than that of lower one.	Fewer components are needed to realize this filter which increases its compactness and makes it suitable for various UWB applications.
[26]	Rectangular SSR.	1. Return loss of (>15 dB) and skirt factor of (>95 dB/GHz) at 2.0 GHz centre frequency is recorded. 2. The fractional bandwidth achieved upto 30% at lower and upper cut off frequency.	The designed filter has good quality factor, roll off rate and sharp selectivity. The proposed filter can be used in various mobile and modern wireless communication systems.
[28]	T-type inverter using tapped-line geometry structure.	1. Unwanted harmonics removal in whole passband upto 30 dB is recorded. 2. At centre frequency of designed filter passband ripple (<1.5 d) and return loss upto 20 dB is	The filter has good passband and stopband response. These filters can be fitted with various microwave systems due to its compact size and ease of fabrication.

		recorded.	
[29]	Stub loaded Interdigital Structure with Hairpin structure.	1. Insertion loss is recorded as low as 0.2 dB with good return loss of more than 15 dB. 2. The filter has multi passbands feature with 3 GHz and 6 GHz frequencies.	The fabricated microstrip filter has less complexity due to lack of DGS structure. The cost of device drops dramatically due to its simple structure which makes it attractive in various modern RF applications.
[33]	Multiple-mode resonator with aperture backed interdigital coupled lines.	1. A good compromise in insertion loss (<1.3 dB) and return loss (>11 dB) is recorded. 2. Sharp skirt factor of 0.8 and fractional bandwidth greater than 125% are recorded in UWB range.	The proposed filter finds a large number of applications in communication systems due its ease of fabrication, low cost and effective stopband characteristics.
[35]	DGS + Stub loaded SIR.	1. Multi passbands (four) filter centred at different frequencies are achieved. 2. The maximum return loss of 15 dB recorded for all passbands. 3. The insertion loss for these four passbands recorded in between 0.67 to 2.7 dB.	The fabricated multi-mode filter has excellent performance in terms of size, cost, bandwidth, sharpness etc. These features push this filter to be used in multimode high frequency communication systems.
[36]	Various DGS techniques like dumbbell DGS unit.	NA	NA
[37]	Equivalent circuit of DGS structure.	1. Microstrip BPF without DGS has bandwidth 3.9 GHz. 2. Microstrip BPF using DGS has 5.3GHz bandwidth.	The bandwidth of designed filter with DGS is 35% more than that of without DGS.
[38]	Shunt stub with lumped capacitor.	1. Very low insertion loss -0.26 dB at centre frequency 6.85 GHz. 2. Group delay 0.13 ns.	Excellent performance in UWB spectrum and used in wireless applications.

IV. CONCLUSION

This paper reviews the various defected ground structure techniques employed in the design of microstrip filters needed for ultrawide band communications applications. Microstrip ultra wideband filters plays vital roles in modern wireless communication systems due to their compactness, ease of fabrication and low cost. Besides these advantages the performance of lowpass, highpass, bandpass and bandstop filters can be enhanced by incorporating various defected ground structure techniques in ground plane of the substrate. The study revealed that modified and hybrid DGS structures i.e. DGS with stepped impedance resonator, split ring resonators, complementary split ring resonator, interdigitated coupled structure, defected microstrip structure, open/short stub loaded resonator etc. exhibits slow wave characteristics which not only enhances stopband characteristics but also smoothens passband behavior. These techniques also introduce more transmission poles which increases filter's flexibility and transmission zeros which sharpens selectivity factor of designed filter. Moreover the contribution of researchers towards increasing the applicability of these filters by introducing tunability in bandwidth, resonant frequencies, quality factors etc. is explored. Based on proper selection of DGS techniques, the UWB microstrip filters can be implied in various high date rates and wideband applications viz. radars, imaging systems, wireless communication systems and precision location tracking.

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