# REVIEW ON DEFECTED GROUND STRUCTURE ANTENNA

**Abstract**

In this chapter the detiled discussion about various studies on microstrip patch antenna and defected ground structure antennas starting with EBG structure studies and later about defected ground structure antennas. Results based on different designs has been discussed througly in all papers publised, including history and other various designes related to microstrip patch antenna.

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## I. INTRODUCTION

Microstrip patch antenna have been extensively studied since from several decades, Microwave Engineering, Technologies and many pioneer Scientist have put in lots of effort in carrying out a lot of theoretical and experimental investigation in improvement of drawbacks of MSA's with various techniques and progressive efforts have been implemented in enhancing the parameters by various methods. In particular antennas developments for its miniaturization (size reduction), multiband operation with proper isolation between the bands, etc. Defected Ground Structures (DGS), have been proved to be as an efficient way for obtaining the efficient parameter enhancement, harmonics suppression and size reduction in patch antennas. Several theoretical modelling, simulation and experimental investigation have found in understanding DGS used in the development of patch and integrated antennas for wireless and mobile communication system. So, the thorough literature survey since 1953, is made and presented in this chapter. Moreover, the modelling, simulation and experimental validation of defecated ground structure antennas from 2000 to 2018. The reference papers from 1953 to 2018 are referred and chronologically discussed in this chapter which includes study of DGS and antenna of microstrip patch. Based on the literature survey, formulation of major research problem is presented here.

## II. LITERATURE SURVEY

The study has started with a generalized concept that originates from the optic domain and the solid-state physics of electromagnetic band gap (EBG) structures, where photonic crystal prohibited band gap for light radiations was first studied by Lord 42 Rayleigh and then widely investigated in the 1990's [24]. Thus, photonic band gap structures (PBG) is the terminology that was widely used in the earlier days [31] [32]. Since then, an ample of scientific creativity, the invention of new forms of electromagnetic structures has been witnessed both for microwaves and radio frequency. Nowadays, the usage of defect on ground planes of antenna applications also had gained a lot of attention on many researchers.

The ground planes of defected antenna are known for its capability where the mutual coupling is condensed between the antenna arrays and could improve the resonant frequency and impedance bandwidth, recent and forthcoming wireless systems that are retaining larger demands on the designs of antenna. Various systems function in equal to or additional frequency bands that requires dual, triple and also multiband operation of narrow band antennas which are fundamentally used. These consists of WLAN, satellite navigation systems and cellular systems such as 3G and 4G, and combination of all these systems.

## III. DEVELOPMENT HISTORY OF DEFECTED GROUND PLANES

Since the late 1980‘s, defects in solid structures have attracted the interest of many researchers, because of their interesting properties considering many terms such as surface waves suppression, size miniaturization, and arbitrary stop bands. Ever Since, most of them are utilized in most of the applications like band pass filters, low pass filters, waveguides, antennas and others. Additionally, this technique could also improve the frequency resonance and the impedance bandwidth of the antennas. For illustration, a unit cell of DGS is deliberately designed with a defect on ground plane that creates effective inductance and effective additionally. This was the technique that was used for designing microstrip lines considering characteristics that are desired mainly band rejection, higher impedance and slow-wave characteristics, when significantly where the size of a microstrip structure is reduced. The DGS structure that is first designed is the well-known DGS of dumbbell shaped, published in the year 2000 [38] [39]. Since then, this technique has gained lots of attention to many researchers. Many different shapes of the slots of DGS is considered in planar microstrip antenna designs [33-44], which offers most of the good performances - reduction in size (resonant frequency lower), improvement in impedance bandwidth (quality factor lower) and increase in gain. Moreover, author in [45] had revealed the usefulness of DGS in reduction of the mutual coupling within the antenna arrays elements. Furthermore, in [51] had shown the capability of DGS in eliminates the harmonic and thus improves the level of return loss.

As we have discussed in introduction chapter about the microstrip antenna and its applicability of DGS in antennas, we have made a literature survey as shown below.

In the year 2000, Chul-Soo Kim et al. [38], In their research article, "*A Novel 1- D periodic defected ground structure for planar circuits",* A new unit lattice of 1-D defected ground is proposed precise to improve the inductance effectively, which builds it easy to control the cut off frequency characteristics. The structure provides the excellent cut off and stop band characteristics. Three different structures have been fabricated to study effect of DGS, measurements on fabricated DGS circuits has shown that cut off and the characteristics of frequency for centric stop band is subjected to the dimensions physically of the unit lattices of proposed DGS. The circuit is simulated using FDTD technique and are matched to the fabricated structures results are observed to be having good agreement.

In the year 2001, Dal Ahn et al. [39], In their research article, "*A design of low pass filter using the novel microstrip defected ground structure",* the new methodology for improvement of parameters in the microwave filter designs. The DGS proposed with a unit structure can supply the bandgap features in some of the frequency band with a single or more-unit lattices. The corresponding circuit for the DGS proposed which is derived from some three-dimensional field analysis methods, by using circuit theory and parameters obtained the bandgap property is explained. The results drawn experimentally shows a great agreement with speculative results and validity of modelling method for proposed DGS is done. Simple dumbbell shaped is embedded using different methodology variation in dimensions of defect, the equivalent capacitance and inductance is calculated.

In the year 2002, Jong-Sik Lim et al. [40], In their letter "*A spiral-shaped defected ground structure for coplanar wave guide".* A coplanar waveguides with a new defected spiral-shaped ground structure was investigated, which was used for planar transmission line. Spiral defect is embedded on both side of coplanar wave guide, due to which a shunt inductance and slow wave effects increases, when compared with conventional design using photonic band gap method. In the article, the results that are simulated and calculated have noble agreement for each other.

In the year 2002, Jong-Sik Lim et al. [41], In their letter "*A vertical periodic defected ground structure and its application in reducing the size of microwave circuits",* in this article the defects are stacked on one another as vertical stack, the effect of a slow wave is explained using corresponding circuit model and its performance is shown in the results both simulation and measured are having good agreement, various parameter with different variation in dimension is performed, application is found to be in matching network for reduction in size when considering an amplifier. The series microstrip line in the reduction of up to 44.4% and 38.5% of original length in the matching networks of input response and output of the amplifier providing size reduction, owing to the increased slower wave effects, while amplifier performance is unaltered.

In the year 2003, Y. J Sung et al. [42]. In their research article, "*Harmonics reduction with defected ground structure for a microstrip patch antenna".* A simple SQMSA was embedded with the structure of defected ground to suppress harmonics of higher order was presented. Simple H-Shaped defect is ground plane embedded to create a band stop characteristics. It's found that simulation results show a drastic reduction in higher order harmonics. Simulation and fabricated antenna has good agreement between results obtained. Suppression obtained is about > 20 dB and has provided a good gain of 4.8 dBi and return loss < -10 dB, antenna designed finds application in low cost active circuits at microwave frequencies.

In the year 2004, Hai-Wen Liu et al. [43]. In their components letter, "*An improved 1-D periodic defected ground structure for microstrip line",* a novel design of 1-D DGS structure has been investigated for microstrip line periodic square patterned defects, variation in dimension is done proportionally to relative amplitude distribution of exponential function $e^{1/n}$ (n denotes positive integer). Two study was carried out one on uniform periodic and one on periodic circuits are presented. Measurement illustrates that the latter display more excellent performances main by supressing ripples and enlargement of the stopband bandwidth. It has given a significant improvement over ripples and enlarged stopband bandwidth are obtained.

In the year 2005, Xuehui Guan et. al [44]. In their research article, "*Optimized design of a low-Pass Filter using defected ground Structures",* a novel low-pass filter of three pole was designed with a microstrip line of low impedance and other DGS section has been presented, a comparable circuit model of DGS was applied to learn the DGS's characteristics. It is found to have acceptable agreement to that of the measured and EM simulated results. Circuit model is applied to understand the effect of DGS. Filter has sharp rate of attenuation in stop-band frequencies have a shape of a dumbbell which is embedded in it was provided in case of a wide improvement in all the parameters of filter by adding resonance.

In the year 2005, Debatosh Guha et. al [45]. In their letter, "*Microstrip patch antenna with defected ground structure for cross polarization suppression",* in this letter investigation for suppressing the cross polarization in microstrip patch antenna, proposed structure is so simple that it can be etched out on commercial available microstrip substrate. This structure of DGS only avoids cross polarization, without influencing the predominant mode for input impedance and also co-polarized radiation pattern of conventional antenna. Patch selected here is a circular to experiment a new concept using DGS, tested and estimated results have been provided with a good agreement to each other. It is tested that DGS can suppress about 5 dB to 8 dB of cross polarization value around broadside direction, backward radiation and gain as compared with those of conventional giving better performance and it's input impedance.

In the year 2005, Mohsen Salehi and Ahad Tavakoli [46]. In their research article, *“A novel low mutual coupling microstrip antenna array design using defected ground structure”*. Here, the development of DGS was studied and performed an investigation to find effect of DGS to the decrease in mutual coupling for two elements of microstrip antenna array element was studied using FDTD method. The antenna Proposed was related with conventional design and is tested using different modelling styles, antenna has shown an extraordinarily bring down of lowering the common coupling between two E-plane coupled components. Further antenna is tested and studied effect of DGS on modes of higher order and changes in the radiation pattern. Different techniques to measure mutual coupling like substrate removal, cavity backed, EBG, DGS is tested. It is noticed that surface wave of DGS is suppressed and creates band stop characteristics in antenna giving advantage of enhancement of parameters.

In the year 2005, Jia-Sheng Hong and Bindu M Karyamapudi [47]. In their research article, “*A General Circuit Model for defected ground structure in planar transmission lines”*. In this paper, a model of general circuit is shown on basic essential general circuit displayed of a planar transmission line utilizing DGS, it’s found that it shows band gaps of multi electromagnetic or stop bands with the responses of frequency. Proposed circuit has corresponding capacitance and inductance in circuit model, which is extracted from full wave EM simulation. The results elaborated to explain the usefulness of modelling to design the antennas with defected ground for getting improved and enhanced parameter. There is admirable agreement between EM simulation and the designed antenna with measured values using with and without DGS.

In the year 2006, Mrinal Kanti Mandal and Subrata Sanyal [48]. In their research article, “*A novel defected ground structures for planar circuit”*. The novelty of the design was proposed to understand effect of DGS on planar circuits to obtain a compact design. Different structures like circular and square dumbbell structures and also H- headed structures were elaborated. By embedding this DGs structures, there is a compactness achieved of 26.3% and the filter has sharper transition knee. The H-headed dumbbell shaped has provided 60.3% more compact in length-wise when it was set off the ground plane along with a filter. The superior stop band performance was also obtained.

In the year 2006, Duk-Jae Woo, et. al [49]. In their research article, “*Novel U- Slot and V-Slot DGSs for band stop filter with improved Q-factor”*. The antenna design provides band with property of rejection along with an improved Q-factor. Here, two different geometries of DGS were investigated, which provides most steep rejection characteristics. The Q-factor of U-slot antenna improves as a separation between two openings slots has been increased. Similarly, for V-slot DGS it provides higher Q-factor when there is reduction in angle of the slot. These two antennas were fabricated using cascaded U-slot DGS and V-Slot DGS respectively. U-slots shows high Q-factor of 38.6 and V-slot rejects the signal of frequencies of greater than 20 dB from 3.5- 4.3 GHz suppression.

In the year 2006, Han-Jan Chen et. al [50]. In their research letter titled “*A Novel cross-shape DGS applied to ultrawide stopband low pass filter”*. The filter that is proposed by the authors is comprised of new cross-shaped DGS by using DGS. A filter not only considers the conventional DGS performance with sharp refutation, but also shows ultrawide stopband. A designed filter is having insertion loss of 2 dB from dc to 3.5 GHz and rejection is better than

20 dB from 4.3 to 15.8 GHz. It shows that the filter is expanded and excavated stopband outside the low pass band. The designed filter simulated and computed results have good agreement to each other. Besides, the DGS configuration can be applied for some compact and widened microwave integrated circuits.

In the year 2006, Debatosh Guha et. al [51]. In their research letter, "*Concentric V-shaped defected ground structures for microstrip applications",* a novel concentric circular rings shaped structure is studied and tested experimentally to examine stopband characteristics of antenna unlike that of various DGS designs. Here, a shielding of metallic form is acquainted behind the DGS so that suppression of any leakage or radiation takes place. It serves a s an advantage for the microwave application. All the designed antennas are of X-band frequencies which provides applications to destroying mutual coupling in array antenna which is shown in the design. It also talks about the advantage of using backed by metallic plate that is utilized to reduce the harmonics or face noise. Antenna shows 5 dB improved isolation.

In the year 2007, Susanta Kumar PARUI and Santanu DAS [52]. In their research article, "*A new defected ground structure for different microstrip circuit application",* the microstrip transmission line that is combined with the new U- Headed, dumbbell shaped DGS was investigated, these slots were connected by thin transfers slot located on ground plane. The corresponding electric model is developed to understand the behaviour of DGS characterized by a parallel L-C resonant circuit in series with transmission line. It was that antenna provide a better low-cost filtering characteristic. The designed antennas were moulded using IE3D which built on Mom and was tested for practical measurement using vector network analyser. The effect of transverse slots width and gap between arms of U-Slot on the filter response curve were studied. By placing the DGS lower cut-off frequency was found. It was witnessed that the antenna provides improvement in coupling co-efficient. Most of its applications were used for filter designs.

In the year 2007, Petr Vagner and Miroslav Kasal [53]. In their research article "*Design of Microstrip lowpass filter using Defected Ground Structure",* a novel structure utilizing DGS has been presented. Its dimensions were varied to show the effect of inductance and capacitance. Influence of change in dimension of the slots introduced on ground plane was studied carefully to understand parametric changes and enhancement of the filters. It was also found that is a good agreement of a proposed antenna between simulated and calculated results.

In the year 2008, Ashwini K, et. al [54]. In their research article, "*Efficiency enhancement of microstrip patch antenna with defected ground structure",* drop in size of MSA patch was studied to understand the DGS, structure used is a Dumble shaped DGS is used at start and then a opening backed structure is used such that it can improve the performance, here electrical walls are located surrounding the patch, simulation is conducted by using IE3D.

In the year 2008, Himanshu Singh, et al [55]. In their research article, "*Microstrip patch antenna with defected ground structure and defected microstrip structure",* compact patch antenna with thin dielectric substrate devising low dielectric constant that is used to provide better efficiency, antenna proposed is designed for the purpose of more effective radiation element, all the various parameters have been tested both in simulation using HFSS and measured have a accepted results with each other. Insect feed antenna with round slots on patch is used and as of DGS H-shape structure is used on ground plane, various parameter is analysed and compared.

In the year 2008, L. H. Weng, et. al [56]. In their research article, "*An overview on defected ground structure",* This paper has explained a various DGS antenna designs and its characteristics with different parameters, many design was taken into concern defined for various applications in microwave engineering, LC equivalent models and different designs and methodologies have been elaborated to offer an overview of defected ground structures, parametric improvements such as pass bandwidth, wider stop band and ripple free transmission of the signals. The paper also defines various novel designs for size reduction and bandwidth enhancement.

In the year 2008, F. Y. Zulkifli, et. al [57]. In their research article, "*Radiation properties enhancement of triangular patch microstrip antenna array using hexagonal defected ground structures",* the designed antenna is based on two components triangular patch MSA array, location of DGS is varied from various specific positions and the antenna simulation is done to find different parameters. Simulation in measurement results are tested that antenna embedded with DGS had enhanced the antenna without DGS. The enhancement was done to obtain 10 MHz axial ratio bandwidth for a hexagonal defect with an improvement in return loss of about 35%. The decline in mutual coupling with 3 dB and enhancement in gain of about 1 dB was obtained. A large return loss was provided along with the bandwidth using the structures of novel design, actually when related to the conventional design.

In the year 2009, F. Karshenas et. al [58]. In their research article, "*Size reduction and harmonic suppression of parallel coupled-line bandpass filters using defected ground structure".* The novel miniaturized filter is designed and have given a novel filter with destruction of second, third and fourth harmonic frequencies, is validated the filter is designed based on slow wave effect given by using DGS embedded on ground plane to achieve size miniaturization, and specious responses are removed by band-rejection property. These above features have been studies to obtain performance of compactness and wide stopband. It's also shown that using DGS there is no need of recalculated for filter. The simulation and capacity of 2.0 GHz prototype bandpass filter is presented. Measured outcomes agree with simulated data, when the design is compared with conventional parallel coupled-line bandpass filters, the second, third, fourth noted spurious responses are suppressed to -45 -43 and -34 dB, respectively, in addition, size of prototype filter circuitry can be reduced up to 20%. The proposed parallel coupled-line filter has been modelled by equivalent circuit and simulation results of circuit modelling were in worthy agreement with EM simulation have been obtained. By use of DGS in the prototype for 2.0 GHz filter has obtained 10% fractional bandwidth 20% size reduction and rejection level of 34 dB until $4f_o$ in stop band can be achieved for various microwave circuits.

In the year 2009, M. Kazerooni et. al [59]. In their research article, "*Comparing the performance of defected microstrip structure (DMS) and Defected Ground Structures (DGS) in microstrip miniature circuits".* Two antennas having DGS and DMS defect on patch and ground plane respectively are compared to see the performance of antenna, by increasing effective inductance and making it easy to control the cut off frequency characteristics, it's found that DMS has better cut off stop band characteristics than that of DGS, circuit modelling is created to analyse the effect of effective inductance. It found that the various parameters depend on the area etched out either from patch or from ground plane, results of proposed models have been compared with those gained by full wave analysis. The assessment shows decent agreement in amplitude of all S-parameter. Proposed antennas have been found to have its application in CPW and MMIC application.

In the year 2010, M. Esa et. al [60]. In their research article, "*Antenna with DGS for Improved Performance",* in this paper they have introduced DGS for improving cross polarization, experimental investigation has been conducted by embedding V-slot shape DGS on microstrip patch antenna, the results have found that antenna is reducing cross-polarization. Antenna is found to have broadened impedance bandwidth. Designed antenna for 5.8 GHz has a frequency shift providing 42% size reduction. The V-Slot Shaped DGS has successfully amended the separation of both the E-Plane and H-Plane for co and cross-polarization radiation patterns, with improved impedance bandwidth.

In the year 2010, Debatosh Guha, et. al [61]. In their research article, "*Improved Cross-Polarization Characteristics of Circular Microstrip Antenna Employing Arc- Shaped Defected Ground Structure (DGS)",* The DGS introduced to suppress the cross- polarized present in the radiation from MSA has been investigated in the application. The geometry of new DGS is improved for better characteristics. The results that are simulated were examined with the defect of Arc-shaped which was used in pair and located symmetrically beneath a circular patch considering different parameters. The studies have proved experimentally that a set of undistinguishable prototypes, embedding with and without DGS. The occurrence of the DGS indicates about 30 dB segregation of the level of cross-polarization from its radiation at peak, and is matched with the conventional patch that has, without DGS showing an improvement of about 12 dB. The values in cross-polarization for relative suppression was noted to be approximately about 7–12 dB over the elevation of ± $75^0$ around the patch's boresight.

The new structure of DGS has made an improvement significantly from 18 dB to 30 dB in cross-polarization. Thus, for effective application in the area of sensors, the antenna that is designed was observed to be having purity with high polarization.

In the year 2010, Zhong-Wu Yu, et. al. [62]. In their research article, "*Wide Band Harmonic Suppression Based on Koch-Shaped Defected Ground Structure for a Microstrip Patch Antenna".* The suppression of Wide band harmonic was realized using Koch-Shaped defect on ground plane, feed line is modified by inserting parallel slots, its feed using 50 Ohm transmission line. The dominant frequency of 2.5 GHz and the spurious radiation up to 15 GHz are properly suppressed. It's found to have decent agreement between computed and simulated results. The antenna designed found to have extensive range of application in active integrated communication systems.

In the year 2010, A. Elboushi, et. al [63]. In their research article, "*Triangular Shaped Power Divider for C-Band Operation Using Defected Ground Structure (DGS)",* in this paper the structure with triangular shaped power divider is used as a patch to divide the power brought equally between three ports, for C-band frequencies. Microstrip power divider is simulated and tested using various simulation tool and is also fabricated and it's found to have a noble agreement between measured and simulated. The parametric study based on the influence of the parameters of DGS was carried out for understanding the characterization of the proposed designed microstrip power divider which is of triangular shaped. To obtain the better bandwidth, Substrate is utilized having permittivity equal to 2.2 for the parameters of S11 and S21. The result was tested and then measured where optimization performed is for the better performance using CST and HFSS simulation software.

In the year 2010, Jyoti R. Panda and Rakhesh S. Kshetrimayum [64]. In their research article, "*A Compact 3.5/5.5 GHz Dual Band-Notched Monopole Antenna for Application In UWB communication systems with defected ground structure",* have proposed a UWB monopole antenna, slots with Two symmetrical L-Shaped are formed on ground plane to get the understanding of DGS to make it operate as UWB, antenna has been tested to create notch resonance at 5.2/5.8 GHz frequency this is obtained by creating a U shaped structure on radiating patch which imitate the WLAN application. Further investigation is continued on the same antenna to make it resonate at C-band frequency i.e. at 3.0/4.0 Ghz which is band for WiMAX and C-band (3.7-4.2 GHz) an additional inverted U Structure is printed on back of the substrate, by the variation in the dimension of U-shaped structure antenna not only resonate at dual frequency it also have control over bandwidth from 1.91 GHz to 3.91 GHz (152%) with two shrill notch bands covering applications ranging from WiMAX to WLAN and other C-band application, antenna designed is properly optimized to obtain broadband impedance matching, with suitable radiation pattern and gain.

In the year 2011, Mohammad Saeid Ghaffarian et. al. [65]. In their research article, "*Harmonic suppressed slot antennas using rectangular/circular defected ground structures",* have designed a two-wide rectangle-shaped microstrip-fed for 2.6 GHz slot was embedded to attain wideband harmonic suppression. The circular and various DGS is etched into the ground plane, which have provided wideband-stop characteristic. The coefficients of reflection that indicates the reduction of 2$^{nd}$ and 3$^{rd}$ harmonics of up to 23 dB for the proposed two measured antennas is simulated within range of 3.5 and 10.5 GHz with the ripple rate maximum of 2.4 dB The gain and the radiation design of the antennas was suppressed at least to 17 dB and also 7.1 dBi respectively, at the frequency of third harmonic of 7.86 GHz. Thus, the proposed designed antenna are suitable for the antennas with active integration.

In the year 2011, Wen-Chung Liu et. al. [66]. In their research article, "*Design of Triple-Frequency Microstrip-Fed Monopole Antenna Using Defected Ground Structure",* have investigated the study on monopole antenna using DGS, they have used a rectangular patch antenna with twin inverted L-shaped strips gets excitation by cross-shaped stripline, for additional resonance and bandwidth enhancements. Overall size of antenna is found to be 20 X 30 $mm^2$, and has found to operate in frequency range, 2.14-2.52 GHz and 5.15-6.02 GHz which is found to be appropriate for both WLAN and WiMAX applications. It's also found that antenna designed gives good gain and radiation pattern like a monopole antenna, further strip length and dimensions of DGS for this design on the electromagnetic performance are examined. It's also found to have a noble agreement within the measured and simulated results. The effects of presence of the DGS, the prudent strips, and the cross-shaped stripline, and changing the measurements of structures on the antenna resonates frequency and impedance bandwidths has been presented.

 

In the year 2011, S. Rezvani et. al.[67]. In their research article, "*A Novel Miniaturized Reconfigurable Slotted Microstrip Patch Antenna with Defected Ground Structure", the* antenna runs in two unlike frequency bands in their investigation with the diversity of polarization pattern and characteristics in broad radiation. The size reduction of the antenna is greater than 34% when matched with the conventional antenna. The MSA which has four slots and a couple of truncated corners with the DGS fabricated on its ground on a substrate of thickness 0.762 mm with relative permittivity of 3.5. it's found that the diversity of circular polarization is gained by feeding using two probes, A and B that is located within a distance d from centre of patch. To obtain the reconfigurability four pin diodes are placed in across the width of slots for frequency band controlling. A prototype is successfully fabricated and verified. Good agreement is observed between simulation and experimental results.

In the year 2011, Bo-ran Guan and Zhong-Hai Zhang [68]. In their letter "A*n ultra-broadband antenna (UWB) loaded with defected ground structure (DGS)",* the circular patch of radiation is fed with stripline of 50 Ohm. By introducing DGS on ground below the feed line and hence the frequency selectivity is obtained. The fabricated circular patch with defect is having good match with simulation and experimental, this antenna is matched well in broadly bandwidth, when DGS is introduced to create stop band effect.

In the year 2012, Hamid Moghadas and Ahad Tavakoli [69]. In their research article, "*A semi-numerical design algorithm for defected ground structure in microstrip antenna arrays",* it is noted that the DGS has the surface wave suppressed in MSA arrays. The mutual coupling sandwiched between the elements of array is reduced and thus eliminates the scan blindness. The Trial and error method were the only solution to DGS design. The DGS model based on the analysis of sensitivity analysis is developed for DGS.

In the year 2012, Sudipta Das et. al. [70] in their paper, "*Compact multi frequency slotted microstrip patch antenna with enhanced bandwidth using defected ground structure for mobile communication",* have conducted a successful experiment in designing a novel compact small size single layer antenna, and obtained reduction in the resonant frequency was reduced by cutting unequal slots mainly at the edges of the patch. Overall size reduction obtained is 57%, varying the feeding point has given a sharp resonant frequency, the proposed antenna discoveries its application in S-band and C-band frequencies.

In the year 2012, Arjun Kumar et. al. [71] in their paper, "*A compact narrow band microstrip bandpass filter with defected ground structure (DGS)",* a compact narrow bandpass filter is designed using hexagon dumbbell shaped DGS, is noted that the design has provided them better coupling in pass band. Forward transmission loss is -0.5 dB and with -26.7 dB return loss at resonating frequency of 5.4 GHz with bandwidth of 500 MHz overall size reduction obtained in the filter is greater than 60% with reduced harmonics in passband frequencies. The physical dimension of the conventional coupled bandpass filter size is 1200 $mm^2$ and proposed design has given size of 225 $mm^2$. This approach has provided the study of filter and size reduction using DGS on ground plane of MSA.

In the year 2012, R S Ghoname et al. [72], in the paper, "*Novel compact spider microstrip antenna with new defected ground structure"*, has given an elaborated advantage of defected ground structures, they have proposed a new novel shape of defect design to minimize its area, the designed antenna has given an overall virtual size reduction of 90.5% when compared with conventional design. These antennas were designed and developed using software package Zealand-IE3D, also fabricated antennas have shown a good matching with simulated and when the antenna was tested using vector network analyser. The design has even provided two sharp stopband frequencies which are useful in the filter application.

In the year 2012, Amr M. E. Safwat[73]. Has made a systematic approach for designing and modeling letter shaped microstrip ground slots. In his research paper "*Letter shaped microstrip ground slots"*, twenty-three structures have been investigated. Analysis is made by generating circuit model for each. Among which 21 letter structures have unique parameters, the results have been testing with both simulation and measured using VNA has good agreement between both.

In the year 2012, Mrinmoy Chakraborty et al. [74]. In their paper "*Design and analysis of a compact rectangular microstrip antenna with slots using defected ground structure",* have designed a RMSA with slots. The antenna was designed for 5.22 GHz and the design was embedded with slots to provide a miniaturization of 91% and antenna is resonating at 1.56 GHz, both simulated and measured results are justified, bandwidth obtained after embedding slots is up to 60 MHz and -20 dB return loss facilitating the antenna to be used for wireless application.

In the year 2013, Hong Wei Yang, et. al. [75]. In their research article, "*A novel DGS microstrip antenna simulated by FDTD".* In their work they have represented to show the low pass properties of periodic structure, the resonating frequency of 5.8 GHz MSA is presented. It's found to restrain higher harmonics, antenna is analysed using FDTD method, which is found to be effective to suppress higher harmonics with improved the radiation efficiency of antenna. Antenna designed using FDTD method is found efficient to reduce back radiation, the etching area must be minimized.

In the year 2013, Yuanquing Zhao et. al. [76] in their paper, "*A Microstrip Antenna based on defected ground structure",* has been focused on broadening the bandwidth significantly using DGS, grid structure proposed has given an important improvement in the bandwidth of an antenna and has reduced the size of antenna as it has resonated in lower frequency, embedding defects on ground plane virtual size reduction in antenna is obtained. It also explains these antennas are low cost, simple in structure, omnidirectional radiation patterns. Here, the narrow bandwidth is the main concern of this kind of antenna. The authors proposed the MSA with DGS. The bandwidth of original antenna without using DGS was broadened. Also, it's found that proposed antenna has smaller size that has compared with the original antenna. Thus, the proposed DGS structure has an improvement of the bandwidth for microstrip antenna, with the broadened bandwidth and size of microstrip antenna was minimized. These features were proven by simulation results and its measurements.

In year 2013, S. N. Taib et. al [77], in their research article, "*An Analysis of Low Pass Filter Using Bowtie Defected Ground Structure (DGS) at 10 GHz for Radar Application",* has explained the bowtie DGS in the Low-pass filter's design in which the element of the filter was fabricated using inductors and capacitors prior to the conversion of short and open circuited stub by initiating from the lumped elements. In the radar application, the low-pass filter's operation with bowtie DGS at 10 GHz was needed. This filter design was simulated by considering the EM Simulation and schematic in Agilent Advanced Design System (ADS) software. In this work, a low- pass filter was designed with four different designs bowtie DGS. The transmission lines of a LPF using bowtie DGS was successfully designed and measured. The main objective was achieved. Furthermore, the characteristics and performance of a LPF using DGS bowtie were identified and discussed. Thus, the accurate calculations and design along with simulations is done to achieve a good performance.

In year 2013, Abdalla Abdulhadi Alsanousi Abdulhadi et. al [78], in their research article, "*Combined Shaped Microstrip Line and DGS Techniques for Compact Low Pass Filter Design",* for the implementation of a compact low pass filter (LPF), a U-shaped DGS with shaped microstrip line was proposed and the techniques such as Inset feed along with stub matching were used for filter characteristics enhancement. A double U-shaped DGS of units was composed and proposed filter at an ground plane along with a shaped microstrip line over the top. The response of a sharp cut off frequency with this structure was allowed that also suppressed high harmonics. The size of compact filter without cascading form of periodic DGS structures was provided. The depth of the inset feed with stop band attenuation was controlled by adjusting the depth and length of stub sections with a 3-dB cut off frequency at 2.7 GHz providing a size of 20 mm × 19 mm. The proposed filter had relatively flat pass band that was shown in the simulation results that indicate high stop band attenuation more than 30 dB having a broad range of the stop band frequencies. The performance of a designed LPF had a response that exhibits a sharp cut off frequency with a low insertion loss and excellent stop band.

In year 2013, Lana Damaj et. al. [79], in their research article, "*Compact wideband harmonic suppressed antenna using non-uniform cascaded defected ground structure",* presents the wideband bowtie antenna which was a coplanar waveguide-fed and suppressed harmonically using non-uniform cascaded DGS units. The bowtie antenna has reduced harmonics effectively that has operated within 2 GHz and 5.4 GHz. The size is 0.44 x 0.48, that has the free-space wavelength at 2 GHz. Simulation and measurement agree very well. description about the MSA's array was developed and its performance of a 2 by 4 element linear polarization was suspended. Based on a low cross-polarization suppression technique, the array was designed. The technique provided is novel and the cross-polarization suppression techniques was analysed in linear arrays with the geometrical configuration of the entire array that affected the SLLs.

In year 2013, Sujoy Biswas et. al [80], in their research article, "*Control of Higher Harmonics and Their Radiations in Microstrip Antennas Using Compact Defected Ground Structures",* a patch of microstrip line-fed antenna was proved successfully by adjusting the modes of higher order till the frequency of the third harmonic based on the fundamental operation. A designed DGS in the antenna of highly compact at its feed level along with the harmonic rejection was completed. The rejection characteristics were added with an open stub was improved at the feed line. The higher order modes that is sandwiched in the major and at $3^{rd}$ harmonic is identified. The proposed DGS was related with the designs made earlier wherever the area was occupied and documented over the reduction of 40–90% in size.

In year 2013, Preet Kaur et. al [81], In their research article, "D*esign of improved performance rectangular microstrip patch antenna using peacock and star shaped DGS",* to enhance the return loss, with compactness, better gain and radiation efficiency of RMSA. At precise position on ground plane, the functioning of antenna was defined by the shape, dimension & the location of DGS. Return loss was enhanced with a peacock shaped slot that was incorporated at a suitable location on ground plane, from -23.89 dB to -43.79 dB, with improved radiation efficiency from 97.66% to 100% and the compactness of 9.83% was acquired over the traditional antenna. The patch antenna having star shaped DGS embedded that has improved the impedance matching showing good return loss of -35.053 dB from -23.89 dB in the Simulation results with compactness of 9% was achieved. Finally, assessment of both DGS shapes was carried out. The analysis of the proposed antennas was simulated using ANSOFT HFSS (version 11.1) software.

In the year 2014, Chandrakant Kumar and Debatosh Guha [82]. In their research article, *"Defected ground structure (DGS)-integrated rectangular microstrip patch for improved polarisation purity with wide impedance bandwidth"* to improve polarisation purity in radiated fields. The authors have demonstrated the possibility of achieving high polarization purity to increase the impedance bandwidth. The complete description to improve the polarisation purity was investigated in a probe fed rectangular microstrip patches.

In the year 2014, Mohammad Ayoub Sofi et. al [83]. In their research article, "*Design and Simulation of a Novel Dual Band Microstrip Patch Antenna with Defected Ground Structure for WLAN/WiMAX Applications*", the planar rectangular fed patch of antenna of the microstrip for 2.4 GHz and 5.5 GHz. The designed antenna based on the technique of Finite Integration with the solver of CST Microwave Studio and later it is simulated. An H-shaped DGS called as HSDGS cell was operated by the antenna on ground plane with a triangular cut on one side.

In the year 2014, Tanning Zheng et. al [84]. In their research article, *"Design of a High-Power Superconducting Filter with Novel DGS Structures"* with improved power handling capability. DGS resonator's current density distribution was simulated and matched with non DGS resonator. Maximum current density of CGS resonator was greater than that of DGS resonator in the simulation results. The antenna was designed with a two four-pole bandpass at high temperature filters centred at 2.9 GHz. Its fractional bandwidth of 1.5% was designed and then fabricated. For the DGS filter, the measured power was 37.3 dBm, which was proved to be higher than 34.1 dBm for that of CGS filter. Finally, the authors described in the simulation results that DGS structure has the capability of refining the power handling competence of HTS filters.

In the year 2014, P. R. Prajapati et.al [85]. In their research article, "*Design of Single Feed Dual Band Dual Polarized Microstrip Antenna with Defected Ground Structure for Aeronautical and Radio Navigation Applications",* have proposed the MSA using dual frequency and dual polarized coupled with a proximity of a single feed. A spiral shaped DGS was integrated at lower band to attain the circular polarisation. Also, to recover and reduce the impedance matching and size of lower patch by 10.4% respectively, a DGS with dumbbell shape was integrated. The proposed antenna has circular polarization at lower band (1.59-1.61 GHz) and linear polarization at the upper band (2.45-2.52 GHz). The designed proposed antenna of using DGS was compared with single feed dual band dual polarized antennas.

In the year 2014, Rammohun Mud gal and Laxmi Shrivastava [86]. In their research article, *"Dual Band Slotted Microstrip Patch Antenna with Defected Ground Structure".* They have explained the designed antenna for a dual band frequency using DGS to obtain a patch antenna with small dimensions and satisfactory bandwidth, was matched to conventional patch antenna. The designed antenna has 3.75 GHz and 6.5 GHz frequencies for the dual bands.

In the year 2014, Rammohun Mud gal and Laxmi Shrivastava [87]. In their research article, *"Microstrip V Slot Patch Antenna Using an H-Slot Defected Ground Structure (DGS)",* have explained the MSA for WLAN applications with planar geometry. The proposed antenna is embedded with DGS. The authors have considered different dimensions of H slot, a Microwave studio software with frequency 5.20 GHz and consistent bandwidth of 310 MHz, to achieve optimized dimensions and antenna's properties. The final designed antenna with favourable characteristics and frequency of 5.20 GHz, the results were analysed and simulated. The return loss obtained was -51 dB which shows that the impedance matching was good.

In the year 2014, Muhammad Umar Khan et. al [88]. In their research article, *"Microstrip patch antenna miniaturisation techniques: a review",* has explained about dielectric substrate on a ground plane, which has included ease of design and fabrication and also ease of integration with circuit elements. The authors have discussed the min dimension of a conventional MSA to have half a wavelength, with the initiation of new standards and compact devices. The article, has discussed some of the major techniques to reduce the size of MSA. The functioning of the proposed miniaturization techniques was compared with the antenna Q of lower bound of Q for electrically small antenna (ESA).

In the year 2014, Mukesh Kumar Khandelwal et. al [89]. In their research article, "*Analysis and design of wide band Microstrip-line-fed antenna with defected ground structure for Ku band applications"* have described about a MSA with DGS for KU-band applications. In this article, the authors have proposed antenna which has impedance bandwidth ranging from 9.8 GHz to 17.55 GHz. Minimum isolation was obtained between co-planar and cross-polarization level in H-plane and E-plane. For the proposed structure, accurate designing equations were presented for a wideband Microstrip antenna.

In the year 2014, G. M. Rafiquzzaman et. al [90]. In their research article, *"A New Approach to Design Microstrip Low Pass Filter using Novel Defected Ground Structure",* the authors have discussed interleaving PBG's for a microstrip transmission line along with the Binomial distributed hybrid DGS. Different approaches were used to gain low pass filter (LPF)'s better performance. The authors have applied Binomial distribution on DGS and interleaving PBGS to improve the performance of LPF's. The best performance for design 5 was obtained by considering the performance improved in terms of RL, IL, ripples, passband and rejection band. Many structures were tested to evaluate performance of hybrid dumbbell shaped DGSs and dumbbell shaped DGSs. The best designs found were provided in this article. The main purpose of the design was to reduce the ripple from the passband of the LPF and to obtain portion of band rejection's improved performance.

In the year 2015, B. R. Sanjeeva Reddy and D. Vakula [91]. In their letter "*size miniaturization of slit-based circular patch antenna with defected ground structure*", proposed a novel compact circular patch antenna for various wireless applications that was simulated, fabricated, and measured. A T-shaped slits with circular antenna was modified with dual positioned on top and bottom. The triple band resonant frequencies were obtained and the Metallic ground plane with a dual E-shaped DGS was achieved behind the radiating patch which was enhanced at dual bands along with size reduction and bandwidth (BW). The performance was of antenna for obtaining gain was better with and without placement of DGS. BW's of 3.9 and 3.6% were obtained for 1.56 GHz and 2.47 GHz bands, respectively. The single layer probe feed antenna simulated using IE3D simulation tool and also tested.

In the year 2015, Chandrakanta Kumar and Debatosh Guha [92]. In their research article, "*Reduction in Cross-Polarized Radiation of Microstrip Patches Using Geometry-Independent Resonant-Type Defected Ground Structure (DGS)*", explained and suggested a new method on microstrip antenna using resonant-type defected for subduing cross-polarized (XP) radiation ground structure(R-DGS). Different microstrip geometries was proposed a linearly structure full wavelength R-DGS and verified experimentally. The design was investigated within R-DGS and XP generating fields on the physical interaction. This new approach was independent of patch geometry, unlike non-resonant-type defects that was explored previously. Also, different patch geometries were demonstrated experimentally with reliable suppression of the H-plane and XP fields below -30dB. A microstrip patch with resonant DGS for addressing cross- polarization issue was conjectured and experimentally demonstrated with few reasons that were advantageous: 1) very easy to design a linear shaped antenna with fabrication and 2) redesign was not required with change in patch geometry, with one linear DGS shared by two adjacent patches. This was in an array environment providing a scope of more compactness.

In the year 2015, Abhijyoti Ghosh et. al [93]. In their research article, *"Rectangular Microstrip Antenna on Slot-Type Defected Ground for Reduced Cross- Polarized Radiation",* proposed antenna with simple rectangular microstrip with a slot- type DGS for reduced cross-polarized (XP) radiation. The conventional MSA has reduced XP radiation field as that of without disturbing its co polarized (CP) radiation characteristics. In a wide angular region, a basic slot-type DGS was proposed with 15 to 25 dB of XP suppression. A co-XP ratio has been improved where high XP was a major limitation for wide angular range. However, for an array, the structure was bit difficult with large range of defect dimensions are a bit large.

In the year 2015, Shanshan Xu et. al [94]. In their research article, *"Novel Defected Ground Structure and Two-Side Loading Scheme for Miniaturized Dual-Band SIW Bandpass Filter Designs",* have reported about back-to-back E-shaped DGS and the SIW was loaded with evanescent-mode wave propagation under cut-off frequency of SIW. The two-side loading scheme was presented in the article to design reduced dual-band substrate integrated waveguide (SIW) bandpass filter (BPF). The two transmission poles at passband and two convenient transmission zero points was achieved along with the novel inserting scheme by embedding different sized DGS resonators on either side of SIW. This scheme was proposed by the authors to obtain designs for dual-band BPF. Based on the analysis and investigations, a 2.4/5.2 GHz BPF was designed and verified experimentally.

In the year 2015, Chi-Kai Shen et. al [95]. In their research article, *"Modelling and Analysis of Bandwidth-Enhanced Multilayer 1-D EBG with Bandgap Aggregation for Power Noise Suppression",* has described a circuit model with design of band gap aggregation of multilayer electromagnetic bandgap (EBG) structure. The main goal was to achieve optimized pitch and power/ground arrangement. The circuit model which was shown theoretically has only focused on the frequencies cut off. They have proposed antenna to achieve bandgap prediction efficiently. The accurateness of the proposed model was validated by comparing the results with simulation and measurement results. The results were shown and compared with a wide bandgap of insertion loss was obtained, that has ranged from 1.27 GHz to above 10 GHz by merging higher bandgaps.

In the year 2015, Chandrakanta Kumar and et. al [96]. In their research article, *"Microstrip Patch with Non-Proximal Symmetric Defected Ground Structure (DGS) for Improved Cross-Polarization Properties over Principal Radiation Planes",* has proposed on non-proximal defected ground structure had consists for a SQMSA to achieve high CP to XP isolation over the major radiation planes. The proposed antenna was ideal for some specific applications, such as dual-polarized with improved polarization purity. A illustrative design in C-band was discussed with experimental verification of 8–10 dB improvement in XP level, mainly in the H-plane.

In the year 2015, Ayman M. Ismaiel and Adel B. Abdel-Rahman [97]. In their research article, *"B5. Isolated Elements Dual-Band Microstrip Patch Antenna Array using C-Shape DGS",* has explained two patches that consisted of higher frequency centre to centre spacing. The antenna was designed on FR4 substrate with dielectric constant of 4.3 and thickness of 1.6 mm. By etching U-shape slot from each patch, the dual-band behaviour was obtained. The centre frequency band with C-shaped ground plane slot were 2.4 GHz and 3.5 GHz which was used to decrease the mutual coupling within the antenna array elements. The calculated results show a decrease in mutual coupling of 22 dB within array elements at 2.4 GHz without forfeiting the reduced mutual coupling at 3.5 GHz. The antenna array is designed, fabricated, and measured.

In the year 2015, B.R. Sanjeeva Reddy and D. Vakula [98]. In their research article, *"Compact Zigzag-Shaped-Slit Microstrip Antenna with Circular Defected Ground Structure for Wireless Applications",* has designed microstrip patch antenna of compact rectangular zigzag-shaped-slit with a circular DGS for wireless applications. A zigzag-shaped slit with dual T-shaped slits on either side of a rectangular patch and circular dumbbell-shaped DGS was optimized. The antenna was able to generate triple band distinct resonances to covering both the 2.45/5.28-GHz WLAN bands and the 3.5- GHz WiMAX bands. Antenna structure without and with defected ground plane was simulated and presented in the article.

In the year 2015, Amandeep Singh et. al [99]. In their research article, *"A novel CPW-fed wideband printed monopole antenna with DGS"* have proposed a monopole patch's basic design to obtain impedance bandwidth of 3.18 GHz. This basic initial design was modified to gain impedance bandwidth and a defective ground plane was added to the monopole patch. For WiMAX, WLAN bands and high-speed point to point wireless applications, the CPW-fed microstrip antenna was fabricated. The authors have analysed the results of proposed antenna to operate efficiently. The impedance bandwidth was improved from 3.18 GHz to 5.5 GHz for the final antenna design of CPW-fed microstrip patch.

In the year 2016, Kun Wei et. al [100]. In their research article, "*S-shaped periodic defected ground structures to reduce microstrip antenna array mutual coupling*", explained a novel DGS where mutual coupling was reduced between the elements. A centric frequency 2.57 GHz was obtained with same frequency band as that of using Coplanar placed antenna elements. The distance from centre-to-centre between antenna elements was 50 mm. A three

S-shaped in the PDGS was placed within microstrip antenna elements with DGS. The reduction achieved within the antenna elements in mutual coupling in the proposed PDGS was more than 40 dB. The currents between elements was induced to eliminate mutual coupling between two coplanar microstrip antennas.

In the year 2016, Anil K. Gautam et. al [101]. In their letter "*A Wideband antenna with defected ground plane for WLAN/WiMAX applications*", explained the microstrip fed wideband antenna using WLAN and WiMAX using DGS. The proposed antenna had an annular ring radiator surrounded by a rhombus shaped strip and the DGS. It had a rectangular-shaped slot in a ground plane that had formed a DGS. With variations in dimensions, the functioning of the antenna was shown in the parametric study. A prototype was designed to validate the results in simulations and fabricated on FR4 material. A good agreement was found with measured results compared to that of simulated results. The wide bandwidth of antenna obtained was 86.71% that covers the entire WLAN and WiMAX bands. In the year 2016, Dwipjoy Sarkar et. al [102]. In their research article, *"An improved parameter extraction scheme for dumbbell shaped defected ground structure",* have proposed an improved technique of dumbbell shaped DGS with parameter extraction. A dumbbell DGS was similar like a single pole LC-Butterworth filter. The L-C, R-L-C, quasi-static equivalent circuits for parameter extraction in dumbbell shaped DGS. In the article, the dumbbell DGS with R-L-C equivalent was re- formulated, and was confirmed through experimental analysis, that better accuracy was obtained in extraction of parameter. Finally, the improved model was used to extract R-L-C parameters against different variations in structures of dumbbell DGS unit cell.

In the year 2016, Khalid Subhi Ahmad et. al [103], in their research article, *Dual Microstrip Antenna Patches with Orthogonal I-Shaped Defected Ground Structure for Beam Steering Realization*, in this paper, accomplishment on evolution of 2 x 1 rectangular patches that resonates at 9.07 GHz is studied. The two patches are separated at 0.3962 λ and the microstrip line is fed to middle of patches to increase impedance matching. Afterwards, an orthogonal I-shaped DGS is incorporated in in the middle of two patches on ground plane. It is studied that by modifying the sizes of the OI-DGS, central lobe of the MPAA decreases from 15° to -35° while directivity of the arrays maintains at about 9.04 dB. Therefore, it could be better to utilize DGS to steer main beam of MPAA rather than employing additional phase shifters, which is massive and more sophisticated for connecting antenna with feed line.

In year 2016, Pravin R. Prajapati et. al [104], in their research article, *Improved DGS Parameter Extraction Method for the Polarization Purity of Circularly Polarized Microstrip Antenna*, using dumbbell shaped DGS which was an enhanced method of parameter extraction and also removed the problems of the earlier approaches of parameter abstraction methods. The proposed method with dumbbell formed DGS was validated and considered as a circularly polarized MSA which was integrated for many applications. The authors have experimentally studied, a set of fabricated prototypes embedding with and without DGS. The result was compared with the same patch in both case and proved that the polarization purity with integration of DGS in antenna was about 10 dB. The return loss bandwidth of 40% was enhanced. The simulated results, Good agreement amongst simulated and experimental results has qualified the is found effective tool for parameter study of the DGS.

In the year 2016, Ahmed Ghaloua, et. al [105], in their research article, *miniaturized microstrip antenna array using defected ground structure with enhanced performance* designed S band MSA array using DGS at 2.2 GHz. The patch antenna array was designed initially at C band which was resonated at 5.2 GHz. This array had reduction in size that was embedded ground plane with the DGS. Because of the cost of gain of the antenna, it was miniaturized. The patch radiator was adapted to retain its radiation properties and to increase the gain of miniaturized radiator. The shift within 5.2 GHz to 2.2 GHz in resonance frequency was observed primarily microstrip antenna array. The performance was better for miniaturization of up to 83% when compared to that of the conventional microstrip antenna. The gain of 1.94 dBi with the bandwidth 100 MHz was obtained in the simulated results.

In the year 2017, Anumoy Ghosh and Santanu Das [106], in their research article, *Design of Broadband Patch Antenna with Enhanced Gain by Using Defected Ground Artificial Magnetic Conductors*, 4.56 GHz on FR4 substrate investigated which is having a bandwidth of 5.26%. the antenna design was having interconnected rectangular slots which are incorporated on ground plane. Thus, the antenna is resonated from 3.96 GHz to 5.1 GHz showing an increase in antenna bandwidth from 5.26% to 25.17%. To achieve higher gain in the entire bandwidth, the surface of an artificial magnetic conductor (AMC) was introduced at a certain distance below the antenna's slotted ground. The AMC comprises of grounded periodic rectangular patches on FR4 substrate. Performance of antenna increases throughout its bandwidth which also increases gain. The structure proposed with radiation patterns are stable in the entire bandwidth with considerably low cross polarization level. The proposed structure was fabricated and the results measured were found in noble agreement with that of the simulated results. The key advantage of proposed technique was that it does not alter the patch radiating surface to achieve broadband characteristic or to enhance gain. Moreover, the structure is double layered. Hence, design complexity was much reduced as compared to structures having more than two layers. The BW of the antenna proposed is 25.17% and its highest gain obtained is 7.24 dBi. A study is carried out in detail on how the gain of proposed structure is affected by changing the dimensions of these slots which are included to modify the AMC ground.

In the year 2017, Shobit Agarwal and Raghuvir Tomar [107], in their research article, *A newly proposed multi-band rectangular patch antenna using defected ground structure*, the new MSA patch which resonates on frequencies that are more than one and thus produces adequately high bandwidth was investigated. Several variants of the design proposed were simulated by using practically already used dielectric materials. The plots of return loss of detailed input, VSWR, and radiation pattern respectively are presented. The comparative study was done. Compact MSA is found to operate at three different frequencies viz. 2.12 GHz, 2.63 GHz and 7.46 GHz. The design provides sufficiently large bandwidth at all three frequencies by introducing a dumb-bell type DGS helps in improving the antenna performance in better return loss and bandwidth. The design has been further optimized by introducing other types of DGS and by using different substrate materials.

In the year 2017, Bhanu Priya Kumawat et al. [108], in their research article, *Square shaped slotted multiband microstrip patch antenna using defect ground structure*. Square shape defect is presented on ground plane, the design of antenna was based on FR4 substrate and feed by 50-ohm, overall size of antenna is 50 x 50 mm. antenna is symmetric on both side. it's found that antenna resonated for three different frequencies as 2.3, 5.3, 6.7 GHz.

Various results have been investigated and the CST software is used which is simulated with the measurement of fabricated antenna and its found that there is a noble agreement between the results obtained for tested and simulated results.

In the year 2017, Vrishali Mahesh Belekar et al. [109], in their research article, *Improved microstrip patch antenna with enhanced bandwidth, efficiency and reducd return loss using DGS*, Two designs of rectangular patch antenna was investigated, to enhance the parameter, slots used was rectangular and polygonal slot. The simulation and design of the antennas has been done using high frequency structural simulator (HFSS), overall size of antenna is found to be 30.2 mm X 32.8 mm X 1.6 mm, parameters such as bandwidth is found to be doubled as that of conventional, return loss is improved by -10 dB, efficiency is enhanced to 15.8 when antenna was embedded with DGS.

In the year 2017, R. Er-Rebyiy et al. [110], in their research article, *A New Design of a Miniature Microstrip Patch Antenna Using Defected Ground Structure DGS,* the DGS has been employed circular defect on either side of the patch to miniaturize MSA patch and to obtain lower band resonance shift from 10 GHz to 3.5 GHz, by not altering original patch. The antenna is designed and enhanced by using CST MW.

In the year 2017, Ahmed Dherar Saleh Saif Shaif, et al. [111], in their research article, *Diamond-Shaped Microstrip Patch Antenna with Defected Ground Structure,* a broadband microstrip diamond-shaped patch antenna is investigated for broadband communication, simulation was conducted at 3.675 GHz and 10.35 GHz frequencies. The antenna was simulated within the frequency range of 1-15 GHz. the reflection coefficient of antenna is found to be -14.63 dB at the frequency of 3.675 GHz and - 11.91 dB at the frequency of 10.35 GHz. gain of antenna is obtained to be as 7.76 dB and 11.04 dB respectively. Antenna has been tested for different parameter variation like dimension of defect, Air thickness, Insulator thickness. Simulated and fabricated antenna have a good agreement on the results obtained.

In the year 2018, Woncheol Lee et al. [112], in their research article, *Ferrite- cored patch antenna with suppressed harmonics radiation*, multiple-ferrite cored patch antenna was investigated and developed to suppress the harmonics radiation above the range of frequency of 1 to 10 GHz and have obtained a wide suppressing bandwidth. The comparative study was done with respect to conventional, defected ground, photonic band gap methods among which this ferrite cored method shows effectively suppression of harmonics up to 5.6 $f_o$ is 0.9 GHz, while other gave 3$f_o$. it is obtained by disintegrating the ferrite material for the unwanted signals, where as other method suppress by reflecting or forwarding the unwanted signals, it's found that ferrite core method is found to be unique method for the suppression of any harmonic radiation. It was found that any radiation harmonic by a patch antenna can be reduced by loading ferrites, which possess appropriate complex permeability and magnetic loss.

In the year 2018, Karishma D. Girase., and Mandar P. Joshi [113], in their research article, *Design of Wideband Monopole Square microstrip patch antenna*, square patch antenna for the application of wideband is presented in the article. The antenna that is proposed was designed such that it can operate at 3GHz. Overall dimensions of antenna are 45×30 $mm^2$. FR4 substrate with dielectric constant 4.4 is used. Bandwidth enhancement is achieved by introducing DGS, offset feed and modified patch technique. CAD FEKO simulation software is used for simulation. Fractional bandwidth of 229% with gain of 2.36 dBi is achieved.

## IV. FORMULATION OF RESEARCH PROBLEM

From the above extensive review of literature, it's clear that the topic of DGS on integrated printed antennas remains an open book for researchers. Moreover, the study on DGS in chronological order is rarely found in literature.

As DGS is a new face of microstrip antennas, efforts to understand the change in the behaviour of antenna parameters with particular shape on different frequency is hardly conducted. Moreover, it was planned to take up the study as research problems due to the following drawbacks:

1. In the past work, defected ground structures had been proved to be more effective in various filter design applications. However, this study is to be more explored in microstrip patch antennas for its extensive advantages.
2. In the literature, it is seldom found that defected ground structures is used for the compactness or the lessening in size of MSA patch.
3. Different shapes of defects are rarely implemented on the same patch antenna for understanding the effect of the shape on the antenna is rarely found.
4. In the literature, it's rarely found to identify the effective shape of defect on different conventional antennas.
5. Idendification of change in resonating frequency of designed single antenna with respect to change in dimension of ground plane defect is hardly ever found.

Thus, a small contribution to the improvement and development of parameters is done by using DGS on patch of MSA in this thesis.

Study has started initially by embedding simple DGS designed on ground plane based on frequency of 2.4 GHz. The designed antenna are as follows:

- H shaped-DGS
- Regular Shaped -DGS
- Modified Square shaped-DGS
- Concentric Ring shaped-DGS

Further work is continued after achieving some satisfactory results in enhancement of parameters of 2.4 GHz antenna. Extended work is conducted on 5 GHz conventional antenna to obtain the following parameters.

- Physical Size Reduction in the antenna without disturbing the patch dimension.
- Multiband of frequencies for proposed single antenna.
- To obtain higher gain, better efficiency and broadside radiation pattern.

Designs are classified in the following categories:

- Multi slot-DGS
- H-Shaped DGS

- Grid Shaped-DGS
- Interconnected Slots-DGS
- Triangular Shaped-DGS
- Chess Board Structured-DGS

Expanding the study of DGS is carried out from lowest possible size of defect to the maximum possible size of defect that can be embedded on ground plane was investigated, thus understanding the behaviour of defect variation on resonating frequency with return loss. To perform the above experiment, a single 5 GHz conventional antenna is embedded with a square defect and its variation in size is conducted and the results are tabulated.

The above comprehensive study was made by designing and fabricating the antenna with fore-mentioned configurations. Later, these fabricated antennae were experimentally tested with Vector Network Analyzer (VNA). The measured experimental data is analysed. Moreover, some of these designs are also simulated using ANSYS-HFSS simulation software. Preceding chapter highlights the methodology and experimental setups tailored to measure and evaluate the various above said DGS's.

 