ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014

Study for Realization of Low Pass Filter Using Triangular DGS Element

Chirag Garg[1], Nishant Kumar Tomar[2], Magandeep Kaur[3]

M.Tech Student, ECE Department, Lingaya's University, India[1]

Software Engineer, Suparna System, India[2]

Assistant Professor, ECE, Lingaya's University, Faridabad, India[3]

Abstract: Electromagnetic band gap (EBG) or alternatively called photonic band gap (PBG) structures have been the bases of designing microwave and millimeter wave devices, they called photonic band gap (PBG) structures have been attractive to obtain the function of unwanted frequency rejection and circuit size reduction. But, recent advancements has evolved Defected Ground Structure (DGS) that is having several advantages than EBG and PBG. This paper presents concept behind filter designing with DGS, as well as design methodology of Low Pass Filter (LPF) using DGS with the application of DGS in microwave technology field.

Keywords: DGS, EBG, PBG, LPF

I. INTRODUCTION

High performance, low cost and compact sizes often meet the stringent requirements of modern microwave communication systems. New technologies such as (LTCC) Low-temperature co-fire ceramic technology, (LTCF) Low-temperature co-fire ferrite and structures such as Photonic band gap (PBG), DGS, (SIW) Substrate integrate wave-guide has been evolved to enhance the whole quality of system. In 1987 Photonic band gap (PBG) was proposed by Yablonovitch and John [1, 2] which implodes and utilizes metallic ground plane that breaks traditional microwave circuit design to surface components and distributions of the medium circuit plane. Photonic band gap (PBG) is a periodic structure known for providing rejection of certain frequency band but, it's difficult to design the microwave or millimeter-wave components. GPA or ground plane aperture is another technique that incorporates microstrip line with a centered slot at the ground plane and it has attractive applications in 3 dB edge coupler for tight coupling and band pass filters for spurious band suppression and enhanced coupling [3, 4]. Due to introduction of GPA below the strip, as characteristic impedance varies with the width of the GPA there can be change in line properties. Several high performance and compact components like EBG and PBG have been reported earlier, Electromagnetic band gap (EBG) or alternatively called photonic band gap (PBG) structures have periodic structure.

These structures have been attractive to obtain the function of unwanted frequency rejection and circuit size reduction. Recently, there has been considerable research effort in the areas of photonic band gap (PBG), electromagnetic band gap (EBG) various shapes of DGS and DMS structures have been appeared. All these are applicable etching geometries uniformly or no uniformly in planar structure (periodically or non-periodically pattern) to suppressed harmonics, noise, to enhance stop band characteristics and delay line. However, it is difficult to use a PBG structure for the design of the microwave or millimeter wave components due to the difficulties of the modeling Hence DGS structures are used in RF/microwave components (filters, dividers, amplifiers and high-speed digital designs) and direct application of such frequency selective characteristics is found in microwave filters. Many passive and active microwave circuits have been developed by using DGS or PBG (Photonic band-gap) patterns to suppress harmonics and realize the compact size [5-7]. Furthermore, to improve circuit performance more investigation is carried out. Park et al. [8] proposed DGS designed by connecting two square PBG cells with a thin slot. DGS adds an extra degree of freedom in microwave circuit design and opens the door to a wide range of application. This paper presents a new approach that leads to the designing of LPF emphasizing on Triangular DGS element due to its sharpest response. The basic notion and main applications of DGS in microwave technology field have been described.

II. PHOTONIC BAND GAP

Filtering of undesired frequencies elements can be implemented with shunt stubs or stepped-impedance lines, but these technique gives out typically narrowband and spurious pass-band in the stop-band occupy valuable circuit layout area. Photonic band-gap (PBG) structures have been considered as an alternate to solve this problem in microwave and millimeter-wave circuit applications recently. PBG's are periodic structures with ability to control the propagation of electromagnetic waves. PBG improves directivity of antennas and mainly incorporates: suppression of the surface waves, reflectors and Harmonics [9]. The PBG also have the specific property of defects (defined as distributing of the periodicity of the structure). Defects can be treated as a resonant cavity, in aspect of propagation of the electromagnetic waves. So, it forms free mode inside the forbidden band-gap (in time response) and this can be used to obtain structures with specific response, and So PBG is a periodic structure known for providing rejection of certain frequency band.

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

The low pass filter (LPF) using PBG with stubs has a number of attractive features, which include the following:

1. Simple structure that easy to design and fabricate.
2. Wide and deeper stop band than that of conventional low pass filter (LPF).
3. Very low insertion loss.

III. DEFECTED GROUND STRUCTURE

A. Transmission Characteristic & Basic Structure

PBGSs follow Bragg's condition that provides cell-separation (inter-element spacing) to generate the stop-band. On the other hand, the behaviors of DGSs in controlled by current path around DGS element. To achieve compact size and controlled behavior reasons Uni-planar Compact PBGS (UC-PBGS) has been proposed. But due to their complex nature DGS was given preference.

Both DGSs and PBGSs are termed as EBGSs. The conventional DGS is realized by connecting regular PBGS with narrower slots in the ground plane. The frequency of operation can be changed with the dimensions of DGS. DGS is realized by etching defected shapes in Metallic ground [10, 11]. This process modifies the characteristics of the transmission line such as the line capacitance and inductance. Several improvements are obtained using DGS in the metallic ground plane for the response of LPF. These improvements summarize as follow:

1. More transition sharpness.
2. Suppressing higher harmonic.
3. Achieving broader stopband responses.
4. Improving the stop and pass band characteristics.

The first and the basic DGS is the dumbbell DGS that composes of two $a \times b$ rectangular defected areas, $g \times w$ gaps and a narrow connecting slot wide etched areas in backside metallic ground plane as shown in Fig. 1(b). [8]. As compared with PBG, DGS are easy to design, implement and have a higher precision with regular defect structures.

Therefore, it is being very extensively used to extend applications of microwave circuits. DGS has more competition than PBG in the microwave circuit with high requirement of dimension under certain craftwork condition.

B. Unit DGS

For adequately utilizing the unique performance of DGS, there have been two research aspects:

1. DGS unit
2. Periodic DGS.

Different types of geometries etched in the microstrip line ground plane is shown In Fig. 2, including arrowhead-slot, spiral head and "H" shape slots and more complex DGSs to improve the circuit performance are square open-loop with middle section slot, open-loop dumbbell. The newly evolved DGS unit can control the two transmission zeros near the passband edges and easily control the frequency of the slot by changing the length of the metal fingers [12, 13].

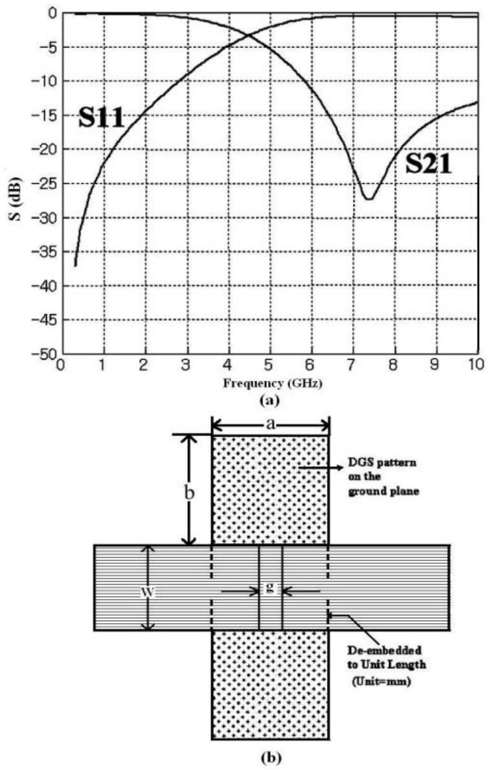

Fig. 1. The first DGS unit: (a) Simulated *S*-parameters for dumbbell DGS unit, (b) Dumbbell DGS unit.

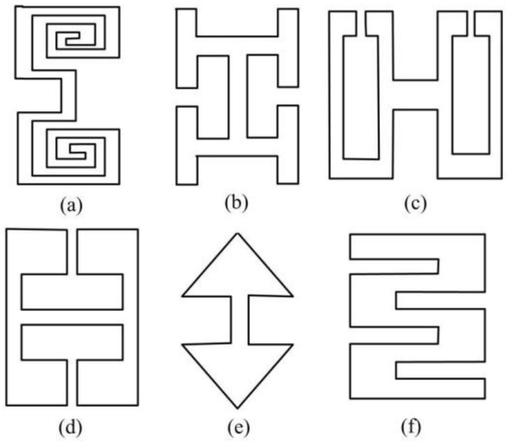

Fig. 2. Various DGSs: (a) Spiral head, (b) "H" shape slots, (c) Open-loop dumbbell, (d) A square open-loop with a slot in middle section, (e) Arrowhead-slot and (f) Interdigital DGS

There are two main methods for the design and analysis of DGS [14]. The commercially EM software is the main simulate software to design and analyze DGS, which is relatively slow and does not give any physical insight of the operating principle of DGS. On the contrary, the equivalent circuit method can quickly give the frequency responses of DGS by exacting equivalent circuit parameters.

In order to derive the equivalent circuit parameters of DGS unit at the reference plane, the *S*-parameters vs. frequency should be calculated by full-wave electromagnetic (EM)-simulation. Presently, DGS can be equivalent by three types of equivalent circuits [15-17]:

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014

1. *LC* and *RLC* equivalent circuits,
2. *Π* shaped equivalent circuit,
3. Quasi-static equivalent circuit.

The LC and LCR equivalent circuit are simple and most widely used [19]. However, the LCR equivalent circuit model cannot provide the exact response curve, which should be in line with the measured or simulated results [18, 20, 21].

The newly proposed DGS unit is having more advantages than dumbbell DGS:

1. Deeper rejection and a narrow stopband width.
2. A more compact circuit with a higher slow wave factor, like filters using "H" shape slots are much smaller about 26.3% than using dumbbell DGS [22].
3. Having external Q slightly larger. We can compare the transfer characteristics of the U-slot DGS with the conventional DGS, spiral-shaped and U-slot DGS are designed to provide same resonance frequency. The Q factor of the spiral DGS is 7.478, while U-slot DGS is having a high-Q factor of 36.05 [23].

These proposed DGSs can bring great convenience to design the microwave circuits for realizing various active and passive devices, compact structures and to suppress the harmonics.

C. Periodic DGS

A periodic DGS is the repeated model fixed with DGS's. Periodic means repetition of the structure. By cascading DGS resonant cells in the ground plane the bandwidth and depth of the stopband for proposed DGS circuit are inclined to depend on the number of period.

Period DGSs care about parameters like shape of unit DGS, distribution of the different DGSs and distance between two DGS units As shown in Fig. 3, there are two types of periodic DGS: one is (a) Vertically periodic DGS (VPDGS), the other is (b) Horizontally periodic DGS (HPDGS) [24, 25]. The features of the above structure include organizing the periodicity along the vertical direction as well as the horizontal direction and it is termed as VPDGS.

Whereas, HPDGS with serially cascading structure along the direction of transmission are for conventional DGS for planar transmission lines. HPDGS was initially produced for enlarging the stopband of frequency response curve. A periodic DGS for planar circuit is formed by the uniform square-patterned defects, that provides excellent stopband and slowwave characteristics that are being used in oscillators and amplifiers [25-28].

DGSs have been able to compensate microstrip line and the dimensions of square defects that vary in proportion to relative amplitudes distribution of the exponential function *e*1/*n* distribution (where, *n* denotes the positive integer).

The VPDGS produces much higher slow wave factor than HPDGS which means the longer electrical length for the same physical length.

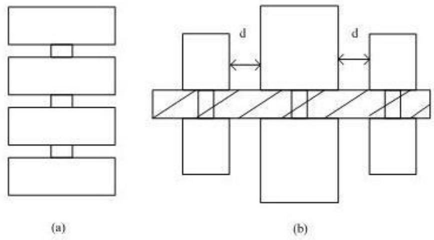

Fig. 3. Periodic DGS: (a) VPDGS, (b) HPDGS.

IV. LOW PASS FILTER DESIGNING

A. General Theory of Low Pass Filter Design

A low-pass filter (LPF) may be constructed from a tandem connection of alternating high and low impedance transmission line sections. The low pass filter prototype element values are calculated for Chebyshev response. The as extreme as possible characteristic impedance values lead to the best approximation to lumped inductive and capacitive element. However, because of transmission line nature of the elements, the lumped component approximations for a particular length of line are not possible when the frequency increases and there will be a degradation of the stop band performance. These lumped element values are translated into distributed element values using standard formulas. Considering practical Low-pass filter (LPF) with alternating high and low impedance section there will be fringing field from the end of low impedance line. Filter lengths of line further require that the short line approximation is modified by the inclusion of the full Π and T equivalent circuit.

B. Method of Designing Low Pass Filter

Filters can be designed by using image parameter or insertion loss methods. Filters designed using the image parameter method consist of a cascade of simpler two-port filter sections to provide the desired cutoff frequencies and attenuation characteristics and this design is simpler that insertion loss method. Being simpler it does not allow the specification of a frequency response over the complete operating range. Thus, achievement of desired results takes time in case of image parameter. It is useful for low-frequency filters in radio and telegraph.

In case of insertion loss method, the design starts with a low-pass prototype based on maximally flat or Chebyshev response and can be defined in both the pass band and in the stop band. The design is simplified by beginning with low-pass filter prototype that is normalized in terms of impedance and frequency. Transformations are applied to convert prototype to desired frequency range and impedance level. Both the image parameter and insertion loss method of filter design provide lumped element circuits. For microwave applications such designs usually must be modified to use distributed elements consisting of transmission line sections.

C. Designing of Low Pass Filter with DGS

DGS components are the dominant technology which can provide size reduction and has capability of harmonics. The DGS can be applied to various kinds of components such as lowpass filters (LPFs) and bandpass filters (BPFs)

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

as well as RF phase shifters. There have two types of filter design using DGS: one is directly using the frequency-selectivity chrematistic of DGS to design filters [29-32], the other is using DGS on the conventional microstrip filters so as to improve performance [33-36] [19]. After using DGS in metallic ground plane for the response of filter there have been a lot of improvements such as: (1) Higher harmonic suppression, (2) Broader stopband responses, (3) More transition sharpness, (4) Improvement of stopband and passband characteristics. An LPF is achieved by cascading at least two DGS units on the ground plane so in order to evolve an LFP using DGS element all the factors should be examined to improve performance of filters. The basic microwave lowpass filter (LPF) is implemented either by all stunt stubs or by series connected high-low (Hi-Lo) stepped-impedance microstrip line sections. However, these designs suffer from some disadvantages such as the fabrication difficulties associated with the high impedance lines and the appearance of spurious bands. In order to overcome these disadvantages, a method has been proposed in [37, 38], which uses both DGS resonators and a compensated microstrip line to design the desired LPF.

D. LPF designing using Triangular DGS element

After studying all the DGS elements it has been seen that triangular DGS elements have the sharpest responses among several DGS shapes. Hence, in order to propose an optimized filter with array of DGS with DMS over it, we start our design process with design and simulation for a basic triangular shaped DGS without DMS structure. Since, An LPF is achieved by cascading at least two DGS units on the ground plane. For that lets consider a basic Single Triangular shape DGS shown in Fig. 4 with its frequency response in Fig. 5. On analyzing the conventional low pass filter undesired harmonics can be seen which states that this Single Triangular shape DGS element is not having good power-handling capability.

The Field analysis of Single Triangular shape DGS element at ground surface shows **that** it has high electric field intensity along length of rectangular etching and high magnetic field intensity along sides of triangular etching. Hence it reveals that rectangular etching produces capacitive effect and triangular etching produces inductive effect. The value and combination of produce capacitance and inductance are in such a way that considered Single Triangular shape DGS element is said to be behaving as a low pass filter.

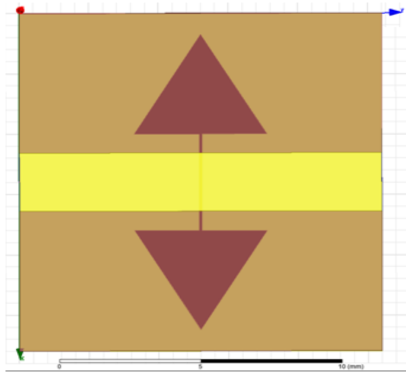

Fig 4. Single triangular DGS without DMS

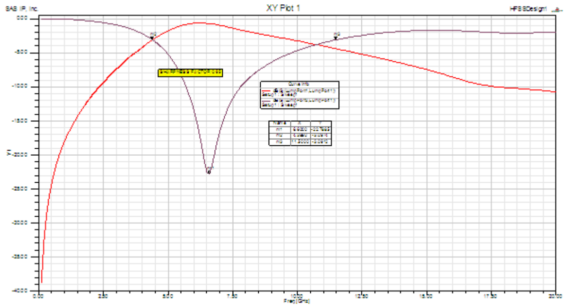

Fig 5. Frequency response of traditional LPF having triangular DGS

V. APPLICATION IN MICROWAVE CIRCUIT

Every DGS element has its own distinct characteristics depending on the geometries. So by placing the required DGS patterns corresponding to the desired circuit operations without increasing circuit complexity, circuit functionalities such as filtering unwanted signals and tuning high-order harmonics can easily be accomplished. This leads to a wide variety of applications in active and passive devices useful for compact design.

A. Stopband Effects

A Defective Ground Structure (DGS) provides bandgap effects i.e. rejection of certain frequency band; the stopband is useful to suppress unwanted surface waves, spurious and leakage transmission. Consider, Hilbert curve ring (HCR) DGS-LPF that achieves quite steep rejection property, low in-band insertion loss and high outband suppression [32][37]. DGS provides excellent performance in terms of ripples in passband, sharp-selectivity at the cut-off frequency and spurious free wide stopband.

B. Slow-Wave Effect

Slow-wave effect caused by the equivalent *LC* components is one of the advantages of DGS: due to the help of which the circuit size can be reduced such as microwave amplifiers and Rat-race hybrid couplers [39]. Comparing DGS Doherty power amplifier (DDA) with conventional Doherty power amplifier (CDA) we can conclude that DGS Doherty power amplifier (DDA) could reduce the circuit size effectively by the negligible insertion loss, excellent harmonic termination characteristic and slow-wave effect [40].

C. High Characteristic Impedance

It is possible to increase the equivalent inductance *L* highly and to decrease the equivalent *C* at the same time by designing DGS on ground plane; this will also raise the impedance of the microstrip line more than 200 Ω. The high characteristic impedance of DGS may also be used in digital systems [37].

D. Additional Applications of DGS

Delay lines— Changes in propagation of wave along the line can be introduced by placing DGS resonators along a transmission line. In this DGS elements don't affect the odd mode transmission, but it slows down the even mode. With this change in the phase velocity of the wave and the effective dielectric constant is effectively altered [41].

Antennas—The filtering characteristics of DGS can be applied to antennas, reducing unwanted responses and mutual coupling between antenna array elements. This is the most common application of DGS for antennas, as it reduces sidelobes in phased arrays, improves performance of coupler and power dividers, reduces response to out-of-band signals for both transmit and receive. An interesting application combines the slot antenna and phase shift behaviors of DGS [41].

V. CONCLUSIONS

The study of DGS and designing of an LPF with DGS element has been done. After this it is found that triangular DGS elements have sharpest responses among several DGS shapes. DGS adds an extra degree of freedom in microwave design and application. Hence, in order to propose an optimized filter with array of DGS with DMS over it, we considered basic Single Triangular shape DGS which stated that it can be an LFP but it won't be having good power-handling capability. So, in order to improve and enhance the LPF, an array of triangular DGS pattern for low pass filter is consider which will be realized in order to propose a high performance LPF using Triangular DGS elements that will have compact size, control of the cutoff frequency and transmission zero, simple circuitry, low cost, broader stopband responses, Fewer loss, sharp transition response and good power-handling capability that would be better than conventional low pass filter.

ACKNOWLEDGEMENT

No task is said to be completed without the expression of appreciation to the people who made it possible. So, we would like to express our gratitude to almighty GOD and our PARENTS without their blessings, we would not been able to complete this paper. With pride, veneration and honour we acknowledge all those whose guidance and encouragement has made successful completion of our paper. It is our profound privilege to express our sincere thanks to Mr. Prakash Ranjan (Assistant Professor, Lingaya's G.V.K.S. Institute of Mgmt. & Tech., Faridabad) for providing his valuable guidance, support and time.

REFERENCES

[1] John, S., "Strong localization of photons in certain disordered dielectric superlattices," Physical Review Letters, (Vol. 58, No. 23), (2486–2489), 1987.
[2] Yablonovitch, E., "Inhibited spontaneous emission in solid-state physics and electronics," Physical Review Letters, (Vol. 58, No. 20), (2059–2062), 1987.
[3] Daeyoung, O. and P. Ikmo, "Two-arm microstrip spiral antenna with a circular aperture on the ground plane for generating circularly polarized conical beam," IEEE Antennas Propag. Soc. Int. Symp., (Vol. 3),(866–869), 2003.
[4] Sharma, R., T. Chakravarty, S. Bhooshan, et al., "Characteristic impedance of a microstrip-like interconnect line in presence of ground plane aperture," International Journal of Microwave Science and Technology ,Vol. 1,1–5, 2007.
[5] X. S. Rao, L. F. Chen, C. Y. Tan, J. Liu and C. K. Ong, "Design of one-dimensional microstrip bandstop filters with continuous patterns based on Fourier transform," Electronics Letters, vol. 39, no. 1, pp. 64-65, January 2003.
[6] J.-S. Lim, Y.-T. Lee, C.-S. Kim, D. Ahn and S. Nam, "A vertically periodic defected ground structure and its application in reducing the size of microwave circuits," IEEE microwave and Wireless Component Letters, vol. 12, no. 12, pp. 479-481, December 2002.
[7] K. M. Shum, Q. Xue and C. H. Chan, "A novel microstrip ring hybrid incorporating a PBG cell," IEEE microwave and Wireless Component Letters, vol. 11, no. 6, pp. 258-260, June 2001.
[8] Park, J.-I., C.-S. Kim, et al., "Modeling of a photonic bandgap and its application for the low-pass filter design," Asia Pacific Microwave Conf. Proc. APMC, Vol. 2, 331–334, 1999.
[9] Dusan Nesic, "A breif review of microwave photonic band-gap (PBG) structures, "Microwave Review, 18-24, july 2001.
[10] A. Boutejdar, A. Ramadan, M. Makkey and A. S. Omar. "Design of Compact Microstrip Lowpass Filters Using a U-Shaped Defected Ground Structure and Compensated Microstrip Line". Microwave Conference, 2006. 36th European ,267-270, 10-15 Sept. 2006
[11] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "Novel 2-D photonic bandgap structure for microstrip lines,"IEEE Microw. Guided Wave Lett., vol. 8, no. 2, pp. 69–71, Feb. 1998.
[12] Liu, H., Z. Li, and X. Sun, "Compact defected ground structure in microstrip technology," Electron. Lett., Vol. 41, No. 3, 132–134, 2005.
[13] Ting, S.-W., K.-W. Tam, and R. P. Martins, "Compact microstrip quasi-elliptic bandpass filter using open-loop dumbbell shaped defected ground structure," IEEE MTT-S Int. Microwave Symp. Digest, 527–530, 2006
[14] Yuchun Guo, Qing Wang, "An Improved Parameters Extraction Method for Dumbbell-Shaped Defected Ground Structure," Scientific Research, Engineering Journal, Vol.2 No.3, April 13, 2010
[15] G. Xue, D. X. Qu, J. Li, et al., "Design of a novel DGS unit," International Conference of Microwave and Milli- meter Wave Technology, pp. 354-356, 2008.
[16] N. C. Karmakar, S. M. Roy and I. Balbin, "Quasi-static modeling of defected ground structure," IEEE Transa- ctions on Microwave Theory and Techniques, Vol. 54, pp. 2160-2168, 2006.
[17] H. W. Liu, X. W. Sun and Z. F. Li, "A new parameter- extraction method for DGS and its application to the low- pass filter," Active and Passive Electronic Components, Vol. 27, pp. 119-123, 2004.
[18] J. I. Park, C. S. Kim, J. Kim, et al., "Modeling of a photonic bandgap and its application for the low-pass filter design," Asia Pacific Microwave Conference, Vol. 2, pp. 331-334, 1999.
[19] L. H. Weng, Y. C. Guo, X. W. Shi, et al., "An overview on defencted ground structure," Progress in Electromag- netics Research B, Vol. 7, pp. 173-189, 2008.
[20] I. Garde, M. J. Yabar and C. Del Rio, "Simple modeling of DGS to design 1D-PBG low-pass filters," Microwave and Optical Technology Letters, Vol. 37, pp. 228-232, 2003.
[21] A. Balalem, A. R. Ali, J. Machac, et al., "Quasi-elliptic microstrip low-pass filters using an interdigital DGS slot," IEEE Microwave and Wireless Components Letters, Vol. 17, pp. 586-588, 2007.
[22] Insik, C. and L. Bomson, "Design of defected ground structures for harmonic control of active microstrip antenna," IEEE Antennas Propag. Soc. Int. Symp., Vol. 2, 852–855, 2002.
[23] Woo, D.-J., T.-K. Lee, J.-W. Lee, et al., "Novel u-slot and v-slot dgss for bandstop filter with improved Q factor," IEEE Trans. Microwave Theory Tech., Vol. 54, No. 6, 2840–2846, 2006.
[24] Lim, J.-S., Y.-T. Lee, C.-S. Kim, et al., "A vertically periodic defected ground structure and its application in reducing the size of microwave circuits," IEEE Microwave Compon. Lett., Vol. 12, No. 12, 479–481, 2002.
[25] Oskouei, H. D., K. Forooraghi, and M. Hakkak, "Guided and leaky wave characteristics of periodic defected ground structures," Progress In Electromagnetics Research, PIER 73, 15–27, 2007.
[26] Xue, Q., K. M. Shum, and C. H. Chan, "Novel 1-d microstrip PBG cells," IEEE Microwave Guided Wave Lett., Vol. 10, No. 10, 403–405, 2000.
[27] Liu, H.-W., Z.-F. Li, X.-W. Sun, et al., "An improved 1d periodic defected ground structure for microstrip line," IEEE Microwave Compon. Lett., Vol. 14, No. 4, 180–182, 2004.
[28] Mollah, M. N. and N. C. Karmakar, "A novel hybrid defected ground structure as low pass filter," IEEE Antennas Propag. Soc. Int. Symp., Vol. 4, 3581–3584, 2004.
[29] Balalem, A., A. R. Ali, J. Machac, et al., "Quasi-elliptic microstrip low-pass filters using an interdigital DGS slot," IEEE Microwave Compon. Lett., Vol. 17, No. 8, 586–588, 2007

[30] Xiao, J. K. and Y. Li, "Novel compact microstrip square ring bandpass filters," Journal of Electromagnetic Waves and Applications, Vol. 20, 1817–1826, 2006.

[31] Chen, J., Z.-B. Weng, Y.-C. Jiao, et al., "Lowpass filter design of hilbert curve ring defected ground structure," Progress In Electromagnetics Research, PIER 70, 269–280, 2007.

[32] Xiao, J. K., S. W. Ma, and S. L. Zhang, "Novel compact split ring stepped-impedance resonator (SIR) bandpass filters with transmission zeros," Progress In Electromagnetics Research, PIER 21, 329–339, 2007

[33] Yang, G. M., R. Jin, et al., "Ultra-wideband bandpass filter with hybrid quasi-lumped elements and defected ground structure," IET Microwaves Antennas Propag., Vol. 1, No. 3, 733–736, 2007.

[34] Wang, C.-J., S.-Y. Chen, and Y.-C. Lin, "Improvements of microstrip loop filters," IEEE Int. Workshop Anti-counterfeiting Secur. Identif., 40–43, 2007.

[35] Wu, G.-L., W. M., X.-W. Dai, et al., "Design of novel dual-band bandpass filter with microstrip meander-loop resonator and csrr DGS," Progress In Electromagnetics Research, PIER 78, 17–24, 2008.

[36] Naghshvarian-Jahromi, M. and M. Tayarani, "Miniature planar uwb bandpass filters with circular slots in ground," Progress In Electromagnetics Research Letters, Vol. 3, 87–93, 2008.

[37] Weng L. H., Guo Y. C. , Shi X. W. , and Chen X. Q. "AN OVERVIEW ON DEFECTED GROUND STRUCTURE" Progress In Electromagnetics Research B, 2008; 7: 173–189.

[38] Dal Ahn, , Jun-Seok Park, Chul-Soo Kim, Juno Kim, Yongxi Qian, and Tatsuo Itoh, "A Design of the Low-Pass Filter Using the Novel Microstrip Defected Ground Structure" IEEE Transactions On Microwave Theory And Techniques, 2001; 49(1).

[39] Sharma, R., T. Chakravarty, S. Bhooshan, and A. B. Bhattacharyya, "Design of a novel 3 db microstrip backward wave coupler using defected ground structure," Progress In Electromagnetics Research, PIER 65, 261–273, 2006.

[40] Choi, H.-J., J.-S. Lim, Y.-C. Jeong, et al., "Doherty amplifier using load modulation and phase compensation DGS microstrip line," 36th European Microwave Conf., 352–355, 2006.

[41] Gary Breed," An Introduction to Defected Ground Structures in Microstrip Circuits," High Frequency Electronics, 50-54, November 2008.