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Research Article

An Overview of Defected Ground Structure with Practical Application of Defected Ground Structure Bandpass Filter in Energy Harvester Circuit

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Abstract: The aim of the study is to practically implement the Defected Ground Structure (DGS) based microstrip bandpass filter in an energy harvester circuit. DGS is widely used to bring about an enhancement in the characteristics of microwave circuits. The study of DGS is derived from the concept of Photonic/electromagnetic Band Gap (PBG) structures but it is easier to design and fabricate and has an easier equivalent LC resonator circuit. In this study, DGS has been reviewed from all aspects such as comparing it with PBG, discussing in detail its unit, its structure and property according to various shapes and designs and its several advantages in microstrip filters. Although DGS has various advantages in the area of microwave power amplifier, Wilkinson power divider, microwave antennas, couplers, etc., it is extensively used in the design of microwave filter to achieve stopband effects, slow-wave effects, frequency adjustment etc. Finally a DGS based bandpass filter working at 900 MHz has been designed, fabricated and tested for implementation in an Energy Harvester circuit.

Keywords: Bandpass filter, DGS, energy harvester

INTRODUCTION

Microwave components are used in spacecraft, satellite, aircraft and missiles where different parameters such as size, weight, cost, performance parameters and easiness in installation are constraints. In modern era, there are many commercial and government applications, such as; radio and mobile communication, microwave communication and millimeter wave communication where filters, couplers, antennas etc., are deployed (Arya *et al*., 2011).

Ideally, two different types of structures are used to achieve miniaturization and better performance in microwave circuits, namely, Defected Ground Structure (DGS) and the Electromagnetic/Photonic Band Gap (EBG/PBG) (Yang and Rahmat-Samii, 2009). However, a PBG structure is difficult to model and that’s why not it’s not a preferred method for the design of millimeter and microwave components. Moreover, PBG structures radiate more than the DGS structures and its radiation effects are difficult to realize.

DGS is an intentionally produced defect in ground plane of a transmission line. It can be a periodic or a non periodic configuration depending on the requirement. The effect of defect on a transmission line is that it disturbs the current distribution in the ground plane. Therefore, it changes the effective capacitance and inductance of the transmission line. In other words, effective capacitance and inductance can be altered by producing a specified defected shape in the ground plane of the microstrip (Weng *et al*., 2008).

DGS structures can be designed in different shapes such as square (Sharma *et al*., 2006), rectangular (Kim and Park, 2001), circular (Dalili Oskouei and Atlasbaf, 2005), dumbbell shaped, spiral, L-shaped, concentric ring, U-shaped, V-shaped, hairpin DGS, hexagonal DGS and cross shaped DGS have been reported in the literature. Each shape has its own distinct characteristics that helps improve the performance of a microwave device (Lim *et al*., 2002a).

DGS is widely used for various applications in microwave devices. These include efficiency improvement of power amplifier, frequency control of microstrip antenna and improving working performance of filters and power dividers (Arya *et al*., 2011). DGS has been used to provide frequency selectivity and effective parallel feedback path for an oscillator configuration in (Jung *et al*., 2003). Meanwhile, DGS reduces the mutual coupling between the antenna array elements (Arya *et al*., 2011). It has effectively been used to reduce side lobes in phased arrays (Breed, 2008). DGS resonators are also applied in a few number of microstrip circuits to reduce the complexity and improve the performance by a frequency notch (Oskouei *et al*., 2007).

In this study, recent advances and applications in the field of microwave communications with respect to

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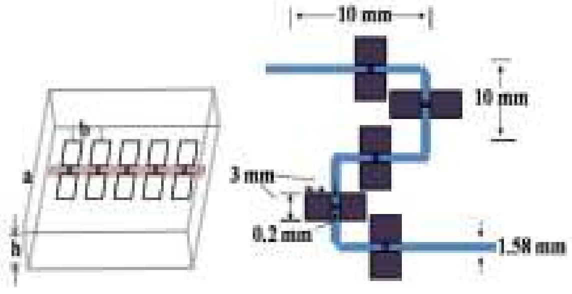
defected ground structure has been discussed. First DGS and PBG structures are compared according to their structures, complexity and applications. Then unit of DGS structure is fully explained accompanied by its main properties. Some of the classifications of DGS according to shapes are also discussed. Bandpass filters are mainly focused with special emphasis on their performance improvement and application in microwave circuits. An application of DGS based end-coupled bandpass filter in an energy harvester circuit is designed, developed and discussed.

METHODOLOGY

Differences between photonic bandgap structures and defected ground structures: PBG is a structure which provides a rejection of certain frequency band. The characteristic impedance and propagation constant of a microstrip line is modified by PBG. Its disadvantage is that it has modeling complexity and that's why not preferable to use in microwave components. Whereas, the radiation emitted from the periodic etched defects make it difficult to realize on a thin substrate. The narrow width of a microstrip line is not ideal for a PBG cell. Moreover, it is not suitable for high power applications as it possesses extensive discontinuities (Lim *et al*., 2002b).

In order to diminish these problems, Park *et al.* (1999) proposed a DGS which is designed by connecting two PBG cells with a thin slot. DGS opens the door for a wide range of applications in microwave circuit design. DGS is located on the ground plane, as an etched lattice shape. This idea of DGS is motivated by the property of PBG to change guided way properties. The DGS structure may be found in both One-Dimensional (1-D) (Kim *et al*., 2000) and Two Dimensional (2-D) forms (Radisic *et al*., 1998; Liu *et al*., 2005), as shown in Fig. 1a and b, respectively.

The DGS structure has few advantages over PBG such as it needs less circuit size for same unit or few periodic structures. It is easier to implement, design and the precision of defected structures is very high (Ghorbaninejad and Khalaj-Amirhosseini, 2008; Zhao *et al*., 2008; Weng *et al*., 2008; Lum and Lum, 2012). The insertion loss of DGS based structures is much lower than the other counterparts and has lower insertion loss (Choi *et al*., 2006; Xiao, 2008). It is able to shorten the length of microstrip line (Choi *et al*., 2006). DGS can remove the spurious and higher order frequency component using its ability of impeding fixed frequency band. Moreover, for the same impedance length, the microstrip length can be widen using DGS slots (Yoo *et al*., 2009). DGS microstrip line has characteristics of frequency band rejection, due to which passband and stopband can be controlled with size and physical shape of DGS (Choi *et al*., 2009). Due to these advantages, it is largely used in the design of microwave filters (Bhabani *et al*., 2012).



(a) (b)

Fig. 1: (a) 1-D DGS (Kim *et al*., 2000) (b) 2-D DGS (Radisic *et al*., 1998)

The DGS unit: The first ever thoroughly investigated structure was the circular head dumbbell defected ground structure that was proposed by Parui and Das (2007) and Chalal *et al.* (2011). It is designed using a combination of two rectangular slots that is connected by a single slot in the ground plane (Arya *et al*., 2008, 2009) as shown in Fig. 2.

An equivalent LC element can be derived from these combinations of defect and thus a parallel LC resonant circuit in series with a transmission line makes up the equivalent circuit of DGS structure (Yoon *et al*., 2004). The square area of the etched slot is responsible for giving cutoff frequency whereas the gap of the defect adjusts the location of the attenuation pole (Arya *et al*., 2011). The attenuation pole thus generated is due to the blend of the inductance and capacitance elements. The parallel capacitance with the effective line inductance is provided by the area of the etched gap (Parui and Das, 2007). The reactance of the microstrip increases with the increase of frequency due to the series inductance provided by the DGS slot. However, due an increase in operating frequency, decreases the capacitive reactance and results in producing a band gap between the propagating frequencies (Bhabani *et al*., 2012). Thus, a conventional DGS section as depicted in Fig. 3a is modeled by an equivalent LC circuit as shown in Fig. 3b (Liu *et al*., 2007).

The equivalent L and C values can be found out by using the following equations:

$$L = \frac{1}{4\pi^2 f_0{}^2 C} \tag{1}$$

$$C = \frac{f_c}{2Z_0} \cdot \frac{1}{2\pi(f_0^2 - f_c^2)} \tag{2}$$

where, f_0 and f_c are attenuation pole frequency and center frequency, respectively.

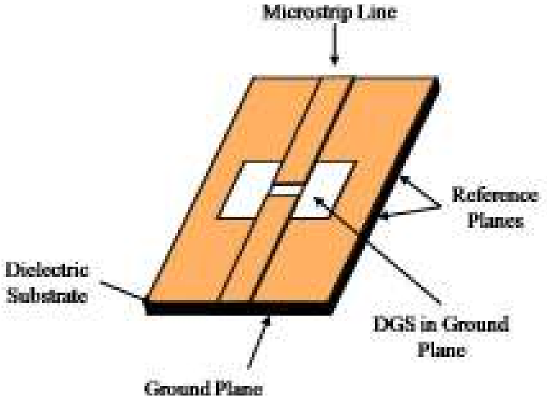
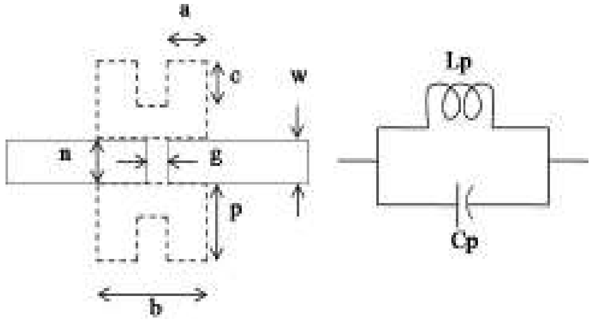


Fig. 2: Microstrip line with dumbbell shaped DGS in the ground plane



(a) (b)

Fig. 3: Microstrip line with dumbbell defected ground structure (a) layout, (b) the equivalent circuit (Parui and Das, 2007)

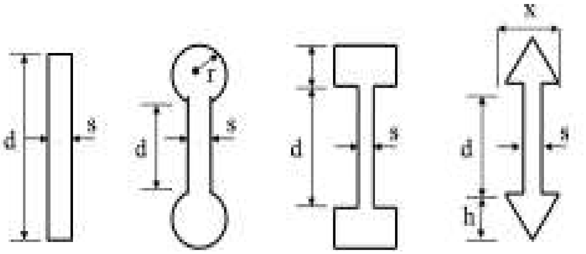
DEFECTED GROUND STRUCTURES AND ITS VARIOUS SHAPES

DGS unit has the property that its response can be changed by using the shape of the slot. It is divided into following two categories for this purpose:

- Rectangular slot without head
- Rectangular slot with different heads (like circular, square, arrow)

Different slot configurations (rectangular slot, with circular head, square head, arrow head, respectively) for the DGS are shown in Fig. 4 (Abdel-Rahman *et al*., 2005).

Three different shapes, i.e., Rectangular Head (RH) DGS, Triangular Head (TH) DGS and U-shape DGS are considered in Arya *et al*. (2009). The DGS is placed on the ground plane of 50 Ω microstip line having a width of 0.52 mm. It was observed that a low pass filter based on RH-DGS offers the widest rejection band of 5.87 GHz, the smallest sharpness transition region of 0.48 and the smallest sharpness of the cutoff. Similarly for bandpass filter, the RH-DGS gives the best characteristics (Chalal *et al*., 2011). The comparison is shown in Table 1.



(a) (b)

Fig. 4: Different slots for DGS (a) rectangular slot without head and with circular head, (b) with rectangular and triangular slot (Abdel-Rahman *et al*., 2005)

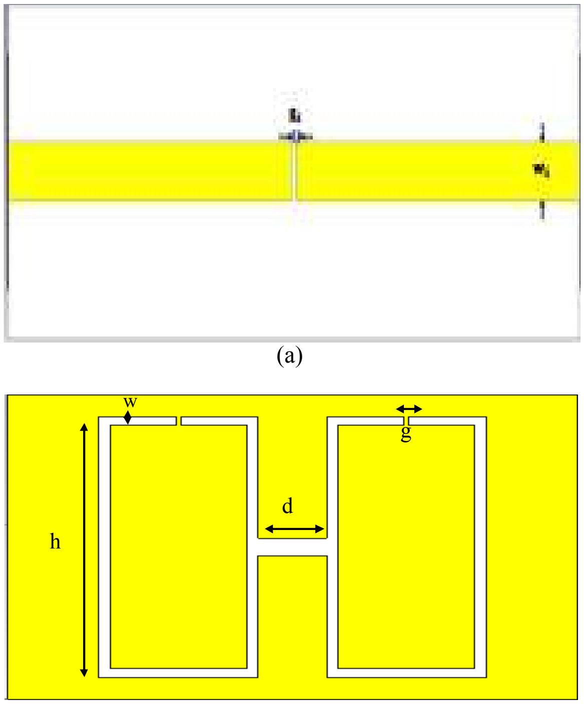
Table 1: Characteristics of different DGS bandpass filters (Liu and Li, 2005)

Characteristics/DGS BPF's	TH-DGS BPF	RH-DGS BPF	US-DGS BPF
Center frequency (GHz)	4.07	3.24	4.98
Return loss (dB)	-8.23	-26.56	-9.63
Insertion loss (dB)	-2.10	-0.50	-1.60
3-dB bandwidth (GHz)	0.52	0.74	0.38

In the past various types of DGS with different applications have been proposed (Kim *et al*., 2000; Lim *et al*., 2002c; Abdel-Rahman *et al*., 2004; Liu and Li, 2005; Liu *et al*., 2005). Harmonic suppression in ring bandpass filter has been proposed by using DGS in (Kim *et al*., 2005). In the field of bandpass filters, DGS slots are implemented to achieve compact size and enhance the performance. A DGS etched in ground plane that is excited by a microstrip line can be characterized as an evanescent mode waveguide section. A band reject response can be attained by utilizing the combined effect of the slot and coupling capacitor between the microstrip lines. Meanwhile, around 50% of size reduction is achieved by replacing the top-resonators with the DGS resonators (Abdel-Rahman *et al*., 2005).

Implementation of DGS-bandpass filter for rectifier circuit: In this section a practical application of a DGS based bandpass filter is developed and verified. A Bandpass filter has been tuned and designed to work on 900 MHz. The main purpose of designing this filter is to implement it in a rectifier circuit of an Energy Harvester. The design purposed here, has been tuned to 900 MHz from 2.4 GHz using the tuning parameters of dumbbell DGS structure.

Design parameters for 900 MHz: An open-loop dumbbell-shaped DGS unit is implemented in the design. Figure 5a and b shows front view of the design.



(a)

(b)

Fig. 5: (a) Front view of the design (b) back view of the design

It has a pair of end-coupled microstrip lines with equal-length on the top and a dumbbell-shaped outline symmetrically etched in the ground plane. The etched pattern depicted in Fig. 5b consists of two identical square-loops having open-loop edge length "L" together with open-ends "g" and a slot-line "d" which forms connection between them. In this configuration, the dumbbell-arm is aligned with the microstrip line on the top. The design configuration depicted here (Ting *et al*., 2006) is made on Rogers RT 5880 substrate with a dielectric constant of 2.2 and a thickness of 0.747 mm.

RESULTS AND DISCUSSION

The results that can be deduced from the simulation are that the center frequency has been tuned to 900 MHz by changing the DGS parameters as depicted in Fig. 6. As far as simulations is concerned the location of transmission zeros are a zero at DC, the passband is further bounded by two finite transmission-zero at frequency f_1 = 0.52 GHz and f_2 = 1.8 GHz. The filter gives an insertion loss of -0.965 dB, a return loss of -42 and -3 dB bandwidth of 350 MHz.

Moreover, according to measured results the location of transmission zeros are a zero at DC, the passband is further bounded by a finite transmission-zero at frequency f_1 = 0.54 GHz. Whereas, using the measured value, the filter gives an insertion loss of -1.583 dB, a return loss of -35 and-3 dB bandwidth of 270 MHz.

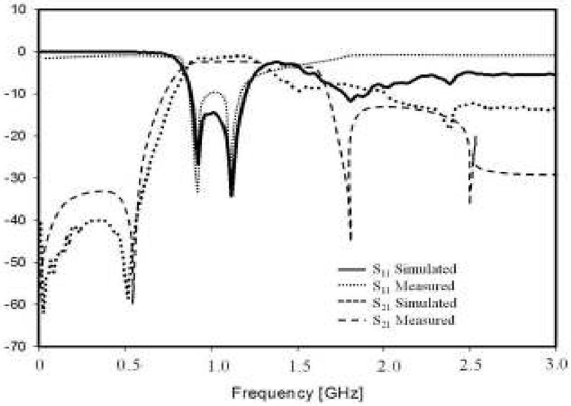


Fig. 6: Simulated and measured result of design rectifier circuit BPF showing S_{11} and S_{21}

(a)

(b)

Fig. 7: (a) Fabricated front view of the design, (b) fabricated back view of the design

The degradation between the measured and simulated result is due to fabrication error and resonator and DGS alignment error. The filter has been fabricated on Rogers R5880 board and is the practical structure's front and back sides are depicted in Fig. 7a and b, respectively.

Rectenna (energy harvester) architecture: A rectanna or an energy harvester is system comprising of a receiving antenna and a rectifying circuit which converts microwave energy to DC power. A block diagram of a conventional rectanna system is depicted in Fig. 8 consisting of an antenna, a matching circuit, a bandpass filter, rectifying circuit, post-rectification filter for DC path and a resistive load (Breed, 2008). To keep within the scope of our research, antenna design and matching network will not be discussed in ensuing sections.

Measurement of filter with energy harvester circuit: The energy harvester circuit was connected with an antenna of 915 MHz and 6.1 dBi. A Transmitter (Tx) is used to transmit frequency with a range from 915 to 1000 MHz.

The first setup was without DGS-BPF as showed in Fig. 9. The output voltage was measured by changing the distance of transmitter and the energy harvester circuit. The same procedures were repeated with the integration of DGS-BPF and energy harvester circuit.

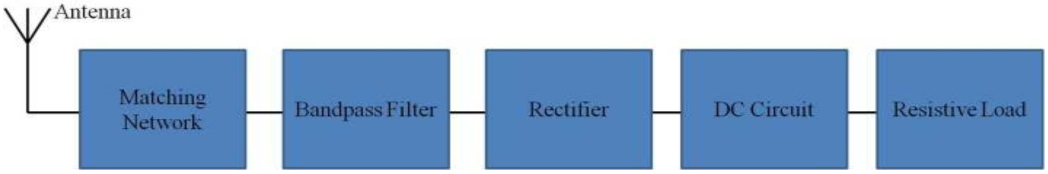


Fig. 8: Energy harvest architecture (rectenna)

Fig. 9: The setup of transmitter and energy harvester circuit with DGS-BPF

Fig. 10: The setup of transmitter and energy harvester circuit with DGS-BPF

Table 2: Energy harvester circuit without DGS-BPF

Distance from Tx (m)	Output voltage (v)
0.15	3.49
0.30	3.36
0.45	3.21
0.60	3.07
0.75	2.95
0.90	2.76
1.00	2.59

Table 3: Energy harvester circuit with DGS-BPF

Distance from Tx (m)	Output voltage (v)
0.15	3.49
0.30	3.36
0.45	3.27
0.60	3.15
0.75	3.01
0.90	2.96
1.00	2.83

The setup of the system and the results obtained are recorded and tabulated in Table 2.

The results obtained from the experiment are summarized in Table 3. It is observed that the output voltage for both the setups decrease as the distance from the transmitter increases. The reason is that once the distance increases, the antenna has difficulty to capture the signals from the transmitter which will cause a decrease in output voltage of the circuit. The DGS-BPF shows better trend in case of voltage levels as the decrease in voltage is not abrupt. It can be thus summarized that the designed DGS-BPF gives better results compared with the traditional BPF in an energy harvester circuit. The complete setup is depicted in Fig. 10.

CONCLUSION

It is obvious that there is a great potential in utilizing the defected ground structure technique for bandpass filter design. The investigation carried out by researchers in this area suggests that by applying DGS in the microwave circuits, the efficiency is improved and performance is enhanced. A bandpass filter tuned to 900 MHz using DGS tuning slots is presented here and discussed. The filter is then utilized in an energy harvester circuit to validate its application. The filter shows better results in term of voltage drop per distance from the transmitter. Thus, it shows that DGS based bandpass filter is able to solve the long term wireless communication problem of miniaturization yet effective components.

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