A Novel Compact Tunable Bandpass Filter Loaded Varactor Diode on the DGS

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Abstract— In this paper, a novel defected ground structure (DGS) pattern with enhanced effective capacitance (varactor diode) and a hole in PCB center is presented. The increase in effective capacitance enables the new DGS pattern to achieve a lower resonance than the DGS pattern for the same etched square dimension. The hole in the center also can make resonator frequency lower with better characteristic. According to the tunable characteristic of varactor diode, the resonant frequencies can be tunable. Simulation results show that a lower resonance is achieved with active device, compared to a common DGS pattern.

Index Terms— compact size, tunable resonator, defected ground size (DGS), varactor diode, active device, hole.

I. INTRODUCTION

Resonators form the basic design elements in many circuit components including filters, oscillators, couplers and antennas. Planar resonators offer several advantages over conventional rectangular/circular waveguide resonators including size, weight and cost [1]. Bandpass filters are essential components of most microwave and mobile communication systems [2]. Such systems require compact filter structures. Additionally, such filters must have a low reflection coefficient in their stopband.

Recently, defect ground structures (DGS) etched off defected patterns from the ground planes have provided a wide rejection band in some frequency ranges [3-5]. DGSs with the characteristics of wide stopband and compact size are available to many circuits such as filters, power dividers, directional couplers and power amplifiers [6-8].

In this paper, a DGS pattern with varactor etched in the ground plane and hole is in the centre of PCB board. A bandpass filter is on the top. In order to get tunable effect in bandpass filter, active device, such as varactor, has been added to the DGS section which locates on the back side of the dielectric substrate. In order to get better characteristic than common DGS structure, via is added in the centre of PCB board. And the structure also has a very compact geometry. The DGS pattern with increased effective capacitance for the same etched area dimension

has lower frequency response without requirement to enlarge the etched ring areas for lower frequency operations. Depending on the tunable capacitance of varactor with different voltage, the resonance frequency can be tunable. At the last part, we proposed the active DGS bandpass filter with hole in PCB center. The simulation results show a better characteristic than DGS pattern without it.

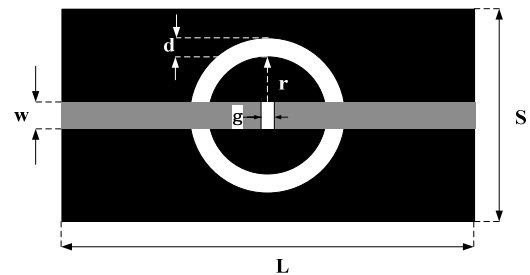## II. EFFECT OF CAPACITANCE ON Resonator

Fig. 1 Structure of the Ring DGS resonator

Fig. 1 shows a schematic view of a ring DGS resonator circuit. As shown in Fig. 1, the metal bandpass filter is located on the top surface, and the DGS structure is etched in a metal ground plane on the bottom surface of the dielectric substrate. All the dimensions are as follows: L= 30 mm, S=20 mm, w=2.3 mm, d=1 mm, r=5 mm. The line width is chosen for the characteristic impedance of 50 Ohm. The gap of bandpass filter g=0.1 mm. For the simulation, the dielectric substrate with a thickness of 1.2 mm and a dielectric constant of 4.4 has been chosen.

The characteristic of DGS simulation result is shown in Fig. 2. From the theory of DGS, there should be a resonance frequency in some frequency. It is show in Fig. 2, ω is the resonant frequency. ω_1 and ω_2 is the 3-dB cut-off frequency. The isolation of common DGS structure is about -15dB. In the equivalent circuit, the DGS cell can be modeled as a LCR resonant circuit. As shown in Fig. 3, L is effective inductance; C is effective capacitance; R is effective resistance.

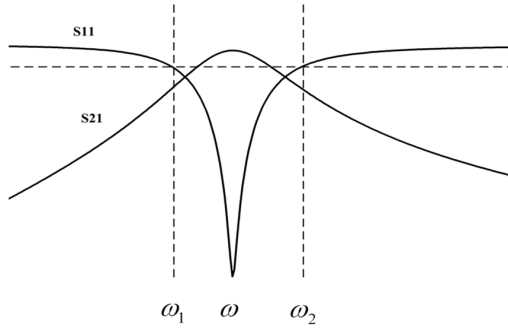$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$
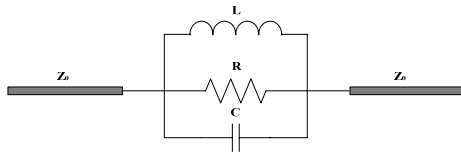
Fig.2 Characteristic of DGS Bandpass Filter

Fig. 3 Equivalent Model of DGS

In Equation (1), the resonance frequency is changed when effective capacitance and inductance are changed. The parameters affecting the characteristic of DGS include the etched defected shape, size, gap and the relative permittivity of the substrate, etc.

III. RESONATOR CAPACITANCE EFFECT

In this section, two lumped capacitors have been added parallel to the DGS, as shown in Fig. 4. In the equivalent circuit, the DGS pattern can be converted into a parallel LCR resonant circuit with parallel capacitance. As shown in Fig.5, C_a is the effective capacitance of lumped capacitor. From the equation (2), the added capacitors can influence the resonance frequency. We choose some capacitor values to simulate (1pF, 2pF, 5pF) using HFSS 10. Simulation results are shown in Fig. 6. From the group of S21, we can conclude that with the change of capacitance bigger, the resonance frequency is shifted to lower. Also from Equation (2), we can know the trend of changing. It is obviously, that the common capacitance for the DGS structure is higher than for the DGS structure without it.
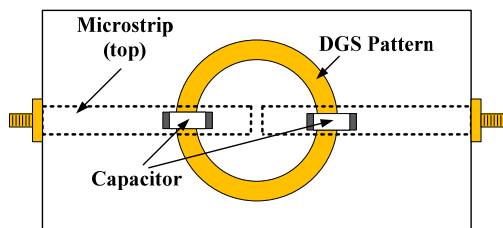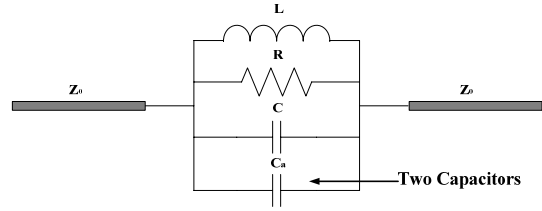

Fig. 4 DGS resonator with two lumped capacitors

Fig.5 Equivalent Model of DGS with lumped capacitor

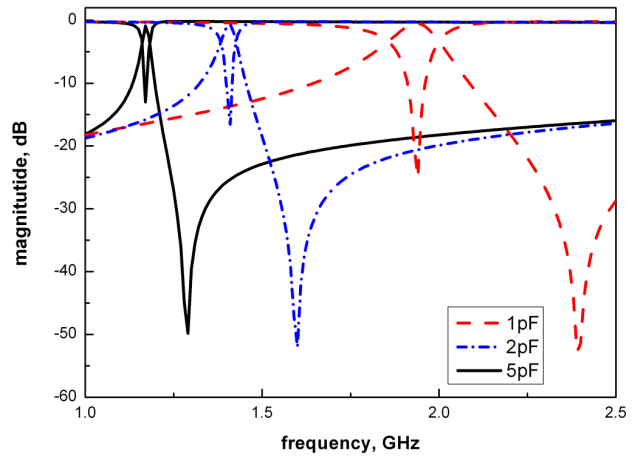$$f = \frac{1}{2\pi\sqrt{L(C+C_a)}} \qquad (2)$$

Fig. 6 Characteristic of the DGS

IV. TUNABLE DGS RESONATOR

In this section, in order to arrive a tunable resonator, a varactor has been added parallel to the DGS pattern. Fig. 7 shows the proposed resonator with DGS sections, which is located on the backside metallic ground plane. And the varactor is added in parallel to the DGS. The proposed DGS can be replaced with parallel LCR resonators, as shown in Fig. 8. The varactor has been added parallel to the DGS. SMV1233 varactor of SKYWORKS Company is chosen as proposed DGS pattern varactor. It has high capacitance ration and low series resistance for low phase noise. According to the datasheet and Fig. 9, very roughly, the capacitance of varactor diode is inversely proportional its bias voltage. We choose some defined capacitance values of varactor for simulation (1pF, 2pF, 5pF). The corresponding voltages are 7.1V, 2.7V, 0.1V. Simulation results are shown in Fig. 9. The group of S21 is changed when capacitance is changed. With the lower voltage, we can get the lower resonance frequency.

In Table 1, we can see that the resonant frequency is lower, with the bias voltage lower. And the bias voltage lower, the capacitance is higher. Table 1 has shown that the common resonator can be automatically transformed from a passive to a tunable resonator by using a varactor

instead of a capacitor. The theory is shown in Equation (3). C_{diode} is the capacitance of varactor diode. C_{diode} is a continuous value, so the resonant frequency can be changed continuously.
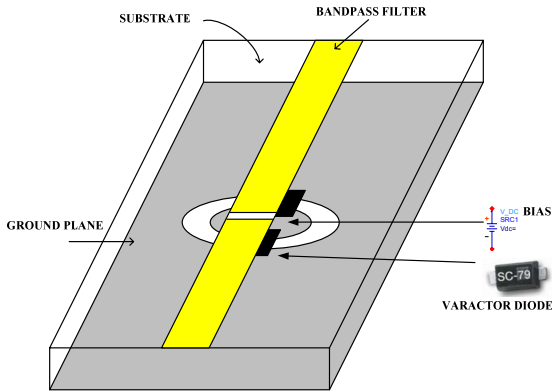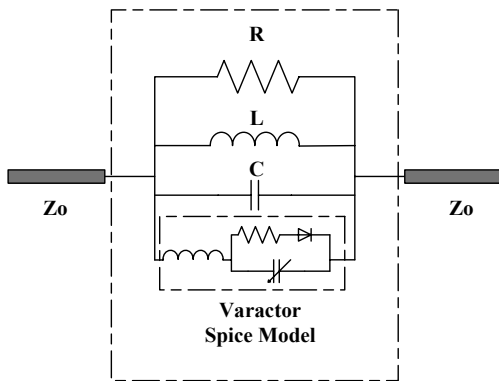

Fig. 7 3-D view of DGS resonator

Fig. 8 Equivalent circuit of the proposed DGS

The dotted box shows the DGS section
L: effective inductance; C: effective capacitance
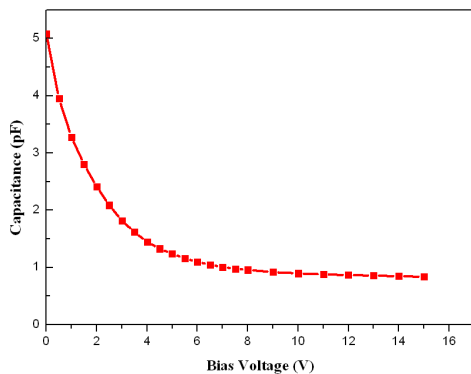Varactor Spice Model: the parallel varactor

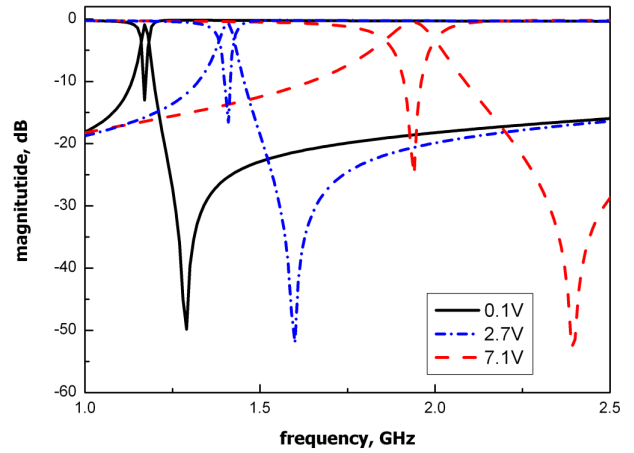Fig. 9 Relationship of bias voltage and capacitance of varactor diode

Fig. 10 Characteristic of the DGS with varactor

TABLE 1
INFLUNCE OF BIAS VOLTAGE

Bias Voltage (V)	Capacitor (pF)	Resonant Frequency (GHz)
7.1	1	1.94
2.7	2	1.41
0.1	5	1.17

$$f = \frac{1}{2\pi\sqrt{L(C + C_{diode})}} \tag{3}$$

V. TUNABLE DGS RESONATOR WITH A HOLE

In this section, we proposed another method to change the DGS resonator frequency lower with better characteristic. A hole is added in the PCB center as shown in Fig. 11. In the center of PCB, we choose the radius of hole is 0.5 mm, the depth is 1.2 mm. The equivalent circuit is shown in Fig, 12. The hole equals a capacitor.

In Fig. 13, the simulation results are shown about the hole problem. The red dotted line is shown without the hole; the black line is shown with hole. The dimension of simulation is the same with Section I.
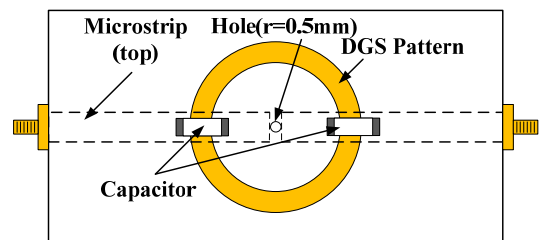

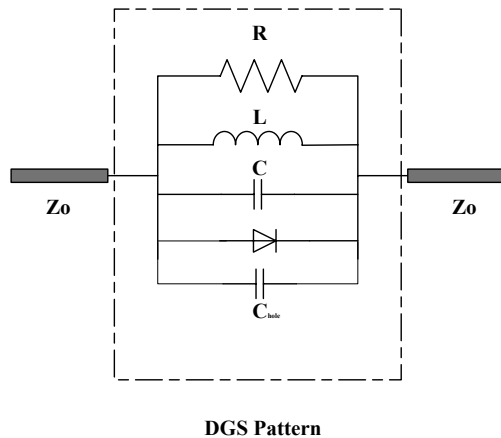Fig. 11 DGS resonator with hole in the PCB center
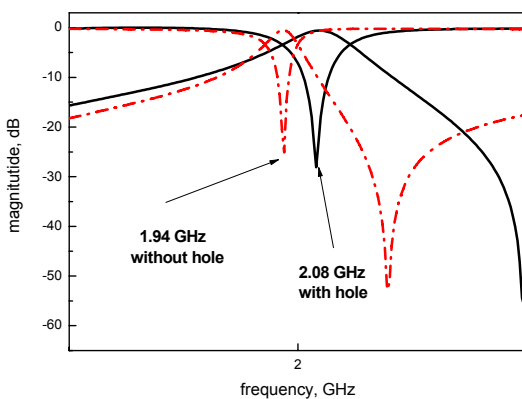
Fig.12 Equivalent Model of DGS with a hole

Fig. 13 Compare the DGS with hole

From the simulation results, we can know the PCB without the hole can get better characteristic than without the hole. The return loss is about -30dB with hole in PCB center; the return loss is about -25dB without hole in PCB center. The bandwidth of PCB with hole is bigger than without hole.

VI. CONCLUSIONS

In this paper, firstly, we proposed a novel DGS structure to solve active device's bias problem. Then we add the parallel capacitor to make the resonance frequency lower. A compact tunable DGS resonator by changing the frequency via bias voltage is proposed. At last, we proposed the PCB hole in center. It can get better characterize. By using the active device (varactor diode), the tunable resonator is achieved. Numerical simulations using 3-D HFSS show good agreement with experiment. The isolation of proposed tunable resonator S21 is above -19 dB, better than common DGS structures. The PCB with hole S21 is above -30dB. The frequency range is big enough to make many applications. This result can apply to design of VCO, Filter and PLL circuit.

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Girae Kim received the B.S., M.S. in Electronic Engineering from the Sogang University, Seoul, Korea, in 1986, 1988, respectively. He also received Ph.D. from Kyungnam University, Korea in 1999. From 1988 to 1993 he was a researcher in Communication Research Center of Samsung Electronics Co. Ltd. Since 1999, he has been on the faculty of Electronics Engineering Department at the Silla University, Busan, Korea.