Design of Dielectric Resonator Band Stop/Band Pass Filters

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Abstract ─ A square dielectric resonator element (SDR) with a defected ground structure (DGS) is investigated. The proposed DGS is composed of two rectangular slots connected by two transverse slots and is placed in the ground plane. It is fed by a strip line through the substrate layer. The objective of this structure is to design dielectric resonator band-stop filter (DRF) and enhance the performance in terms of better insertion loss and increased bandwidth. The DRF has been fabricated and some measurements are taken. The cut-off frequency of the band- stop filter is 2.25 GHz, with transmission loss of 2-dB. The 3-dB of the band-stop filter is 1.24 GHz. The effect of the transverse slot width on the filter response curve is studied. The same structure is modulated to be frequency reconfigurable DRF to achieve frequency agility by using ideal metallic switches. The cut-off frequency is moved to 1GHz, and the 3-dB bandwidth in 1.5 GHz, while the transmission loss is decreased by 0.75 dB. Finally, the effect of loading SDR with metal plate is investigated. This structure combines the dielectric resonator antenna (DRA) and the DRF to propose dielectric resonator antenna filter (DRAF), this structure is used to miniaturize the global-positioning-system receivers that contain both the antenna and filter. The DRAF has been fabricated and measured, it has 3-dB pass bandwidth in 1GHz. Factors such as return loss, insertion loss, radiation pattern and mutual coupling of DRAF are calculated using finite element method (FEM). Comparison of calculation and measurement factors of DRAF shows a good agreement.

Index Terms ─ DGS, DRA, DRAF, DRF, FEM.

I. INTRODUCTION

The filter and the antenna are playing an important role in wireless communication, satellite communication, radar systems, telecommunication, and other military and commercial applications. The antenna is a necessary component for transmitting and receiving microwave signals. Filters are used to pass or eliminate specific frequency and are classified to low-pass (LP), high-pass (HP), band-pass (BP), and band-stop (BS) filters. The band-pass filter (BPF) passes a desired range of signal frequencies while blocking others; however, the band-stop filter suppresses a desired range of signal frequencies and allows all other frequencies. Many researches seek to combine both filtering and radiating functions with simplicity and miniaturization through integrating the filter and the antenna into a single component, known as filtering antenna, or "filtenna" [1]. The filtenna improves both the noise performance of the system and the impedance bandwidth. It reduces the requirement of pre-filtering and enhances the overall performance of the system. The filtenna has been implemented in different forms, Yagi antenna [2], monopole antenna [3], slot dipole [4], rectangular patch [5], circular patch [6], patch array [7], r-shaped antenna [8], and dielectric resonator antennas (DRA) [9]. The filtering antenna is composed by a feed line, two hairpin resonators, and rectangular patch. Defected ground structures (DGS) have been attracting researches in recent years because of their use in radar, microwave oscillators, microwave filters, microwave amplifiers, and mobile communication systems. The DGS can provide size reduction, cross polarization reduction and harmonic suppressions for different applications. In addition, DGS can be used to improve the performance of power dividers and couplers, reduce the side lobes in phased arrays and provide beam steering in antennas [10]. The resonant gap or slot in the ground metal is the basic element of DGS. It is aligned directly under a transmission line for efficient coupling to the line [11] and has different shapes for filter applications, such as dumbbell DGS [12], arrowhead dumbbell DGS [13], H-shaped DGS [14], spiral DGS [15], and U-slot DGS [16]. Each of these shapes differs in occupied area, coupling coefficient, equivalent L-C ratio and other electrical parameters. The equivalent circuit for a DGS is parallel-tuned circuits in series with its coupled transmission line. The equivalent values of L, C and R are determined by the

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dimensions of the DGS structure and its position relative to the transmission line [10] as shown in Fig. 1. This defect in the ground plane disturbs the shielding current distribution due to its natural resonant characteristics. The shielding current distribution depends on the shape and the dimensions of the defect.

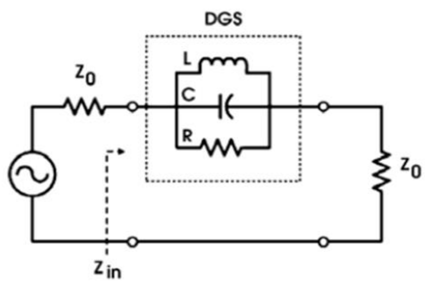


Fig. 1. The equivalent circuit of DGS.

The proposed structure gives some advantages of using the DR element to achieve several purposes. Among these advantages we can cite; high radiation efficiency, high temperature tolerance, low loss, wide bandwidth, small size, low cost, light weight, high power-handling capability and flexible excitation techniques [17-21]. The first purpose of using DR is designing band stop filter with wide rejection bandwidth from 1.25 GHz to 2.82 GHz. This can be implemented by using a single piece of DR element through employing DGS in the ground plane. The second purpose is to achieve frequency agility by modulating the first structure to obtain frequency reconfigurable DRF [22]. This can be satisfied by varying the rectangular slots effective area using ideal metallic switches. These ideal metallic switches vary the rejection bandwidth for the first design “band-stop filter” from 2.3 GHz to 4 GHz. The last purpose is to integrate the dielectric resonator antenna (DRA) and the dielectric resonator filter (DRF) into one element known as filtering antenna (DRAF). A square DR of the first design loaded with a square metallic plat is used as the resonator for the antenna as well as for the band-pass filter. A square metallic plat has been loaded to the top surface of the DRA (known as SDRA) to achieve reduction in the resonant frequency of the antenna [23]. The DRF and DRAF have been fabricated and measured. The return loss, insertion loss, radiation pattern and mutual coupling of the DRAF are investigated. The measured and simulated results show a good agreement.

This paper is arranged as follows. Introduction in the first Section I, the second Section II discusses the methods used for finding the solution of the proposed antenna and is divided into two sub sections: the first finite element methods and the second finite integration methods. Section III discusses the simulations and numerical results of defected ground structure filters, in three subsections A, B and C. A summary is presented in Section IV.

II. METHODS OF SOLUTION

A. Finite element method

The finite element method (FEM) is used for finding approximate solution of partial differential equations (PDE) and integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an equivalent ordinary differential equation, which is then solved using standard techniques such as finite differences. In solving partial differential equations, the primary challenge is to create an equation which approximates the equation to be studied, but which is numerically stable, meaning that errors in the input data and intermediate calculations do not accumulate and cause the resulting output to be meaningless. There are many ways of doing this, all with advantages and disadvantages. The finite element method is a good choice for solving partial differential equations over complex domains or when desired precision varies over the entire domain. More details about FEM can be found in [24, 25].

B. Finite integration technique

The finite integration technique (FIT) is a spatial discretization scheme to solve electromagnetic field problems in time and frequency domain numerically. FIT was proposed in 1977 by Thomas Weiland [24, 25] and has been enhanced continually over the years. This method covers the full range of electromagnetics, from static up to high frequency and optic applications. The basic idea of this approach is to apply the Maxwell’s equations in integral form to a set of staggered grids. This method stands out due to high flexibility in geometric modeling and boundary handling as well as incorporation of arbitrary material distributions and material properties such as anisotropy, non-linearity and dispersion. Furthermore, the use of a consistent dual orthogonal grid (e.g., Cartesian grid) in conjunction with an explicit time integration scheme (e.g., leap-frog-scheme) leads to extremely high efficient algorithms referred to both computation time and memory requirements which are especially adapted for transient field analysis in RF applications. More details about FIT can be found in [25].

III. DEFECTED GROUND STRUCTURE FILTERS

Figure 2 shown the square design of dielectric resonator filter (SDRF). The square dielectric resonator element (SDR) of FR-4 material has side length l_r=44mm, height h=1.524mm, and dielectric constant εr=4.5, and loss tangent 0.002. It is mounted on the DGS perfect conductor ground plane of $l_g \times l_g$ dimensions equal to 70mm ×70mm. The DGS section is etched on the ground plane. The DGS is composed of two rectangles, Ws×Ls, Ws=8mm, Ls=16mm, connected with two transverse slots of width t=1mm, and length tt=14mm. The distance between the two slots, k, is 7mm. The substrate material is FR-4 of dielectric constant 4.5, loss tangent 0.002 and has thickness of 1.5mm.

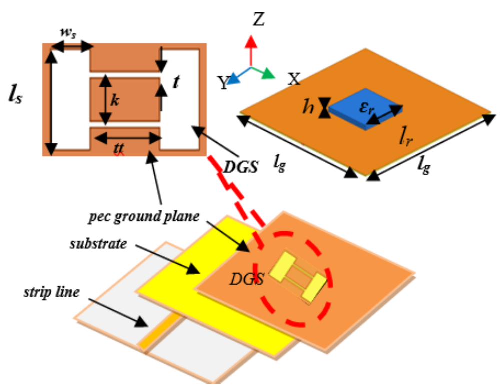
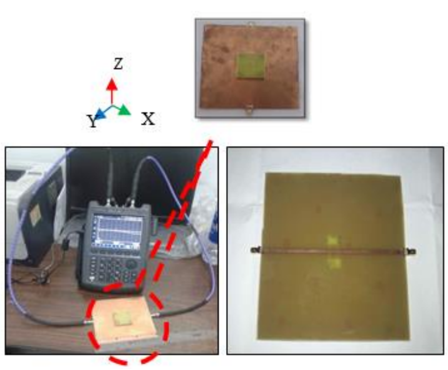


Fig. 2. The structure of the SDR filter antenna.

A. Frequency characteristics of SDRF on DGS unit section

The DGS unit section can provide cut-off frequency and attenuation pole at some specific frequency without any periodicity of DGS. In order to investigate the frequency characteristics of the DGS section, the DGS unit section has been measured and their parameters are calculated using FEM to verify the measured results. Pictures of the fabricated band stop filter system are shown in Fig. 3. The results shown in Fig. 4 indicate a rejection of wide bandwidth of 3dB equal to 1.57 GHz (from1.25 GHz to 2.82 GHz).



(a) Top view (b) Bottom view

Fig. 3. The photograph of the fabricated BSF.

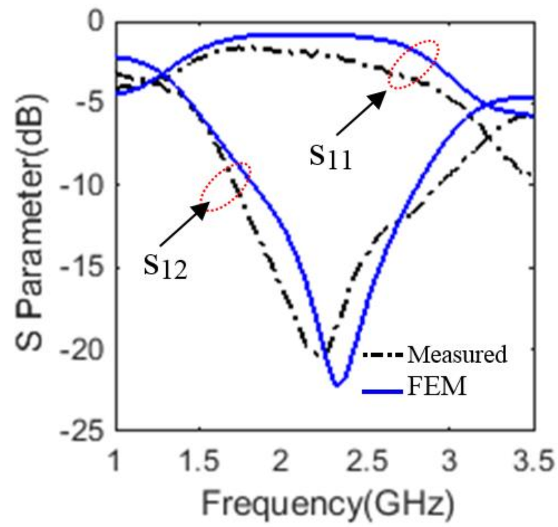


Fig. 4. Measured and calculated return losses, insertion losses.

The cut-off frequency of the slot band-reject response at 3dB is f_c and its pole frequency is f_0. Both are in GHz. Results show that f_c of the unit-slot *is* 1.2 GHz and f_0 *is* 1.98 GHz. The experimental response curves match with the calculated results to a great extent. The characteristics of Fig. 4 shows a band-reject filter response with low transmission loss and wide band-stop features. Tuning the band-stop filter (BSF) is achieved by varying the transverse slot width.

The transverse slot width t of the DGS is varied from 3 mm to 4 mm. Return losses S_{11} and insertion losses S_{21} are calculated and given by Fig. 5. It can be shown from results that the band-stop central frequency f_0 increases, rejection level decrease*s* and transmission loss increases with increasing the transverse slot width.

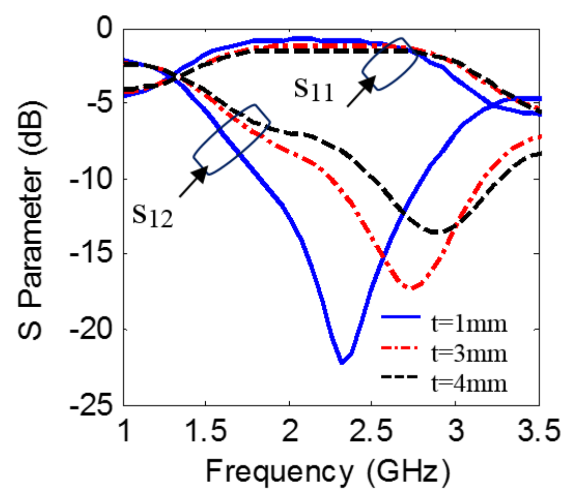


Fig. 5. Calculated return losses, insertion losses for varying the transverse slot width, t.

B. Frequency characteristics of reconfigurable DRF on DGS unit section

In this design, three ideal metal switches are integrated on each rectangular slot of the DGS to split it into four narrow strips to change the resonance frequency due to change in the current distribution. Return losses S11 and insertion losses S21 are calculated and given by Fig. 6. Results show that the band-stop central frequency f_o is moved to 3GHz and f_c is moved to 2.3GHz. A rejection of wide bandwidth of 3dB is equal to 1.7 GHz (from 2.3 GHz to 4 GHz), and the transmission loss is about 1.24dB.

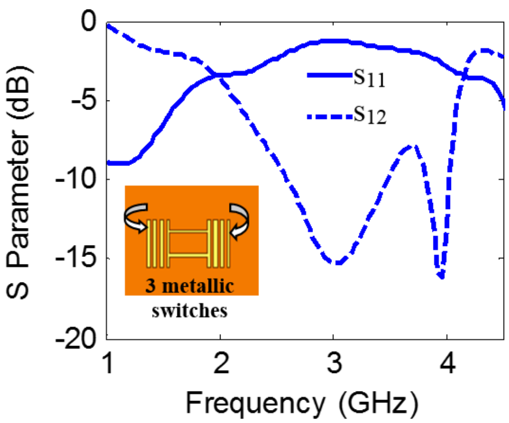


Fig. 6. Calculated return losses, insertion losses for reconfigurable filter.

C. Frequency characteristics of DRAF "filtenna" on DGS unit section

In this section the dielectric resonator antenna filter (DRAF), “filtenna”, that combines the DRA and DRF is fabricated as shown in Fig. 7. This structure integrates two types of filters, band-stop filter and band-pass filter. The unit cell in this structure is designed with the same dimensions for the first structure. However, the SDR is loaded with a metallic plate square of length, l_p=22mm, which is then used as the resonator for the antenna as well as for the band-pass filter. The SDRA is characterized by height h, side length l_r, as shown in Fig. 1 and is made of material with dielectric constant ε_r. This geometry is equivalent to a square DRA of the same material placed over a ground plane with the same dimensions, but the height is equal to h/2. The added metallic plate acts as an electric wall, which will reduce the DRA size by half, also it acts as a shorting post for the electric field and the removed part from DRA [23, 26]. The equations for calculating the resonant frequency approximately are given by [26]:

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_o^2, \qquad k_o = \frac{2\pi}{\lambda_o}, \tag{1}$$

$$f_o = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2}, \tag{2}$$

$$k_y = k_x,\; k_z = \frac{\pi}{h}, \tag{3}$$

$$k_x \tan\left(\frac{k_x l_r}{2}\right) = \sqrt{((\varepsilon_r - 1)k_o^2 - k_x^2)}, \tag{4}$$

where k_x, k_y, and k_z denote the wave numbers along the x, y, and z directions inside the DR, respectively, and k_o is a free space wave number.

This structure can be used as the resonator for the antenna as well as for the band-pass filter. The DRAF has been fabricated and measured. Figure 8 shows the photograph of the fabricated DRAF "filtenna".

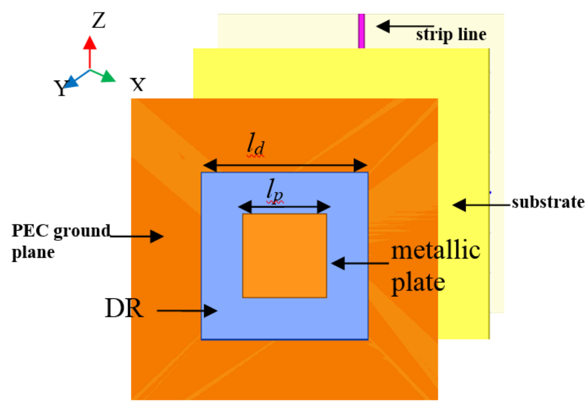
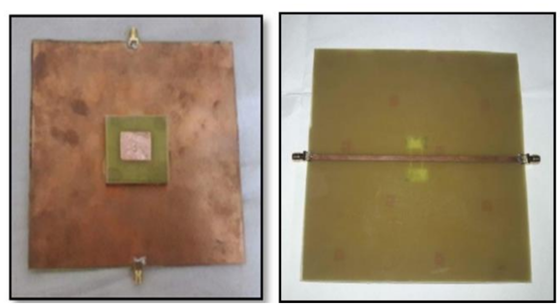


Fig. 7. The structure of the filter antenna with top metallic plate.



(a) Top view (b) Bottom view

Fig. 8. The photograph of the fabricated DRAF “filtenna”.

The measured and simulated results show a good agreement as shown in Fig. 9. Results show that the DRAF has two band-stop filter with bandwidths of 800 MHz and 650 MHz.The return losses of the filters are 0.52 dB for a central frequency f_0 =1.78 GHz and 2 dB for a central frequency f_0 = 3.88 GHz. It can be shown from Fig. 9 that the band-pass filter has central frequency f_0 at 2.78 GHz, the 3-dB cut-off frequency f_c at 2.1 GHz, the 3-dB pass bandwidth is about 1.3G*Hz*, the rejection level 22dB and insertion loss about 0.89

dB. The total loss of the filtering antenna is almost the same as the filter insertion loss. The calculated radiation patterns at 2.78GHz, for the designed filtering antenna system in the x-y, y-z, and x-z planes are shown in Fig. 10.

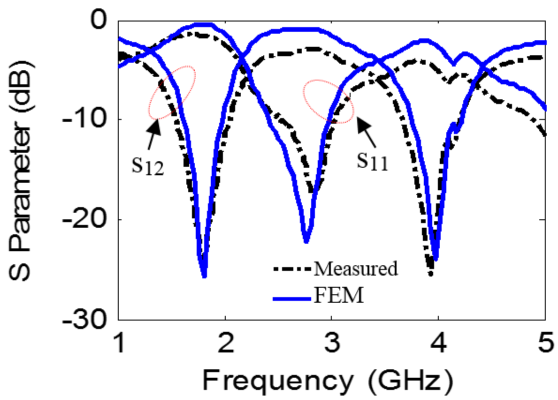


Fig. 9. Measured and calculated return losses, insertion losses for filter antenna with top metallic plate.

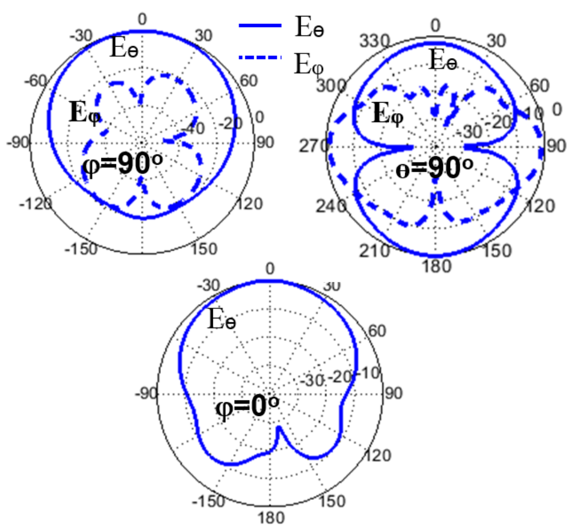


Fig. 10. Calculated radiation patterns for filter antenna with top metallic plate at f = 2.78GHz.

The band-stop and band-pass filters are tuned with varying metallic plate length. The metallic plate length l_p is given for 3 values 11mm, 33 mm and 44 mm and then the return losses S_{11}, insertion losses S_{21} are calculated as shown in Fig. 11. It is noted that the central frequencies f_0, the rejection levels and an insertion loss of the two filters are affected as shown in figure.

IV. CONCLUSION

This article proposes the square dielectric resonator element with a defected ground structure (DGS) and investigates different geometrical structures. Two structures of filter (band-stop filter, band-pass filter) have been successfully designed and investigated. The first structure is a dielectric resonator band-stop filter (DRF). The filter has bandwidth of 1.57GHz and transmission losses of 0.6dB at 2GHz. The second structure is a dielectric resonator filter antenna (DRFA). Results show that the DRFA has two band-stop filters with bandwidths of 800MHz and 650MHz. The band-pass filter has an insertion loss about 0.89 dB at 2.78 GHz with bandwidth about 1GHz. To verify the performance, the filters are fabricated, calculated and measured. The measurements show a good consistency with the calculations.

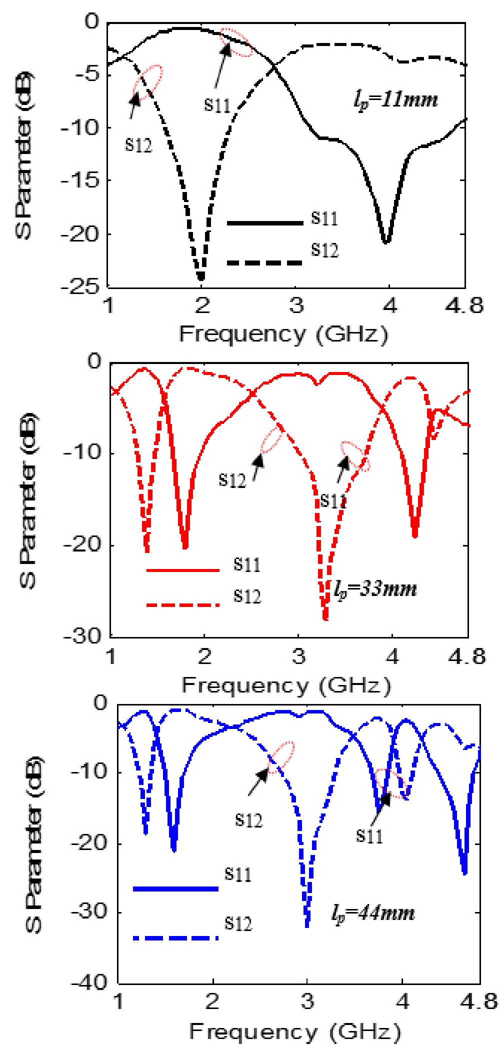


Fig. 11. Calculated return losses, insertion losses for varying l_p.

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