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Low Cost Tunable Bandstop Filter Design of Defected Ground Structure using FR4 Substrate

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Abstract- This paper presents a tunable bandstop filter design using defected ground structure (DGS) where FR4 substrate is used as a low cost solution compared to others substrate such as Teflon and Rogers RT/Duroid. Thus, the performance of the tunable DGS bandstop filter using FR4 substrate is analyzed in this paper. Besides, analytical modeling of the tunable bandstop filter is derived and discussed as well where the tunable element of varactor diodes are used in the design. As result, tuning range in simulation is achieved from center frequency of 0.445 to 1.99GHz while the tuning range of fabricated filteris from 0.495 to 1.88GHz. The range of bandstop attenuation is between 9 to 46 dB for tuning voltage between 0 to 8 V.

Keywords –Tunable filter, bandstop filter, defected ground structure (DGS), FR4

I. INTRODUCTION

Most of the Radio Frequency (RF) application such as telecommunication, military and instrumentation deals with signal handling where this devices need a component to suppress unwanted signals especially in RF receiver front-end system [1]-[2]. Conventionally, RF filters are replaced manually in a device or system because each filter is designed to operate only at certain specified frequency. The best solution to overcome this manual process is to design a tunable RF filter which can operate in a wider frequency range without making component replacements.

There are several possible technique and technology in tunable or reconfigurable filter using microstrip technology as reported in [3]. These filters can be tuned or configured using varactor diode, PIN diode and MEMS. Other possible technique of tuning is current conveyer [4]. As reported in [5]-[9], Defected Ground Structure (DGS) has been one of the options used for microwave circuit applications that can be used astunable bandstop filter because of simple structure and havingcharacteristic of slow-wave propagation and compact filter design.

Generally, DGS can be easily obtained by etching ground plane pattern and it can be fabricated on a printed circuit board with low cost substratewhere bandstop attenuation can be easily achieved. However, papers in [6]-[9] used either Teflon or Rogers RT/Duroid which are quite expensive in term of substratecost.However, there is an option to use FR4 substrate in DGS design which is low cost and widely used at low frequency between 1 to 3 GHz as reported in [5], [10] and [11]. It is a composite substrate composed of woven fiberglass cloth with an epoxy resin binder.

In this paper, a tunable bandstop filter of DGS using FR4 substrate is presented. The DGS is based on the structure proposed in [6]. Two varactor diode are used to tune the DGS filter by changing the biasing voltage of the varactor diodes. This paper is organized as follows. The circuit theory and the design of the tunable bandstop filter of DGS is presented in section II. The circuit theory focuses on the analytical analysis of the circuit modeling where the tunable element is discussed in details. Simulation and measurement result of the tunable bandstop filter of DGS is discussed in section III. The performance of the tunable bandstop filter is investigated and discussedas well. Concluding remarks are given in section IV.

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II.CIRCUIT THEORY AND TUNABLE FILTER DESIGN

Tunable bandstop filter of DGS can be modeled as a parallel inductor and capacitor [12] as shown in Figure 1 which is connected with the same input and output impedance of Z_0. The tunable element in this filter is the tunable capacitor (C_{tune}).

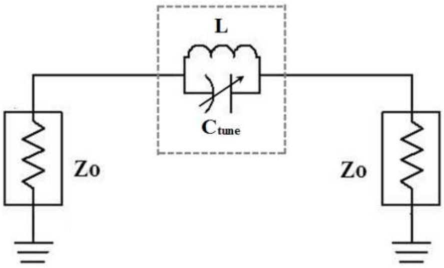

Figure 1. Equivalent circuit of tunable bandstop filter of DGS

The impedance of the equivalent circuit in Figure 1 can be calculated as follows,

$$Z = \frac{Z_{C_{tune}} Z_L}{Z_{C_{tune}} + Z_L} \quad \text{……………………………………………………} \quad (1)$$

Then, by substituting (1) with $Z_{C_{tune}} = \frac{1}{j\omega C}$ and $Z_L = j\omega L$; it can be simplified as

$$Z = \frac{-j\omega L}{\omega^2 LC_{tune} - 1} \quad \text{…………………………………………………} \quad (2)$$

where $\omega = 2\pi f$. If $\omega^2 LC_{tune} = 1$, the impedance is ideally will be infinite. Hence, the DGS acts as a bandstop filter having infinite impedance at resonant of the parallel inductor and capacitor.

The equivalent circuit of the filter also can be modeled as transmission matrix (ABCD matrix)

$$[T] = \begin{bmatrix} 1 & \frac{-j\omega L}{\omega^2 LC_{tune} - 1} \\ 0 & 1 \end{bmatrix} \quad \text{…………………………………………………} \quad (3)$$

From (3), by converting the transmission matrix to S-parameter, we get

$$S_{21} = \frac{2}{2 - \frac{-j\omega L}{(\omega^2 LC_{tune} - 1)Z_0}} \quad \text{…………………………………………………} \quad (4)$$

Equation in (4) is very useful to analyze the bandstop response of DGS where magnitude (ordecibel) versus frequency can be plotted.

The resonantfrequency of DGS can be calculated using

$$f = \frac{1}{2\pi\sqrt{LC_{tune}}} Hz \quad \text{…………………………………………………} \quad (5)$$

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whereC_{tune}plays a key element to tune the resonant frequency to upper or lower frequency.

To realize the tunable bandstop filter of DGS, Figure 2 shows the dimension of the DGS using FR4 substrateof substrate. First, the design of microstrip transmission line at top layeris based on calculation in [13]and the FR4 substrate properties where the value of the substrate thickness of 1.6mm and dielectric constant ε_r= 4.7are taken into the calculation.Then, the width of transmission line obtained as 4.84mm.

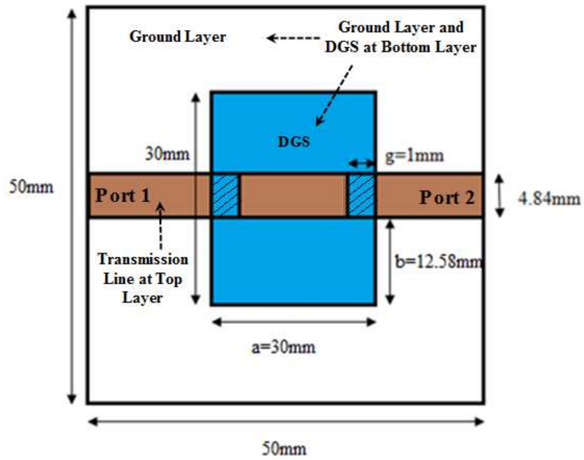
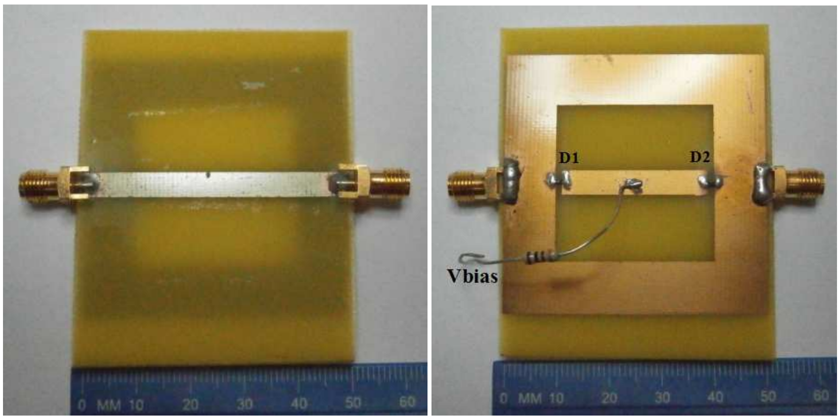


Figure 2. Dimension of tunable bandstop filter of DGS.

Second,the construction of the defected ground structure is designed on the bottom layer which is parallel to the position on the microstrip transmission line on the top layer. This has been done in Advanced Design Software (ADS). The DGS layer is designed exactly on the lines constructed as shown in Figure 2 in order to obtain accurate simulated results based on the specified parameters. The DGS design is completed by placing input and output port (Port 1 and Port 2) on the transmission line on the top layer and four ground reference ports were added on both left and right side of the layout to obtain perfect grounding in order to observe the characteristic of DGS clearly.

The final dimension of the DGS structure is obtained through parametric study as reported in [14] - [17] since there is no any specific formula to obtain the parameter of DGS design. These parametric study has been performed in Momentum of ADS using 2D EM simulation.It is well known that the effective inductance of the dumb-bell shaped DGS pattern increases with larger square areas (*a* and*b*), while its effective capacitance increases with a narrower gap width in the middle (*g*) [12].Therefore, as shown in Figure 2 the response of the bandstop filter of the DGS can be tuned by changing this square areas (*a* and *b*) and gap (*g*). Thus, the final dimension of lattice square of a=30mm, b=12.58mm and two gaps, g=1mm are chosen to be resonated at 2.8 GHz.Figure 3 shows the fabricated tunable bandstop filter of DGS with picture of top view and bottom view.



(a)(b)

Figure 3. Prototype of tunable bandstop filter of DGS. (a) top view (b) bottom view.

Figure 4 is a circuit configuration of electrical tuning of C_{tune}using two varactor diodes. The varactor diodes are SMV1247-079LF packaged in SC-79 standard package from Skyworks. The characteristics of the varactor diode is shown in Table I where the tuning voltage is between 0 to 8 V to varies the capacitance between 0.64 to 8.86 pF.

Table - 1 Characteristics of varactor diode (SMV-1247-079).

Inner series resistance, R_S	4.9 Ω
Inner series inductance, L_S	0.7nH
Parallel packaging capacitance	0.54pF
VVC diode capacitance range	0.64pF – 8.86 pF
Reverse bias voltage	0V – 8V

The two varactor diodes are placed exactly on the two gaps to vary the capacitance of the DGS and the biasing line (Vbias) is connected with the biasing wire at the centre of DGS by using copper wire. Therefore, from (5), we know that the total $C_{tune}$is parallel of these two varactor diode where

$$C_{tune} = C_{D1} + C_{D2} \qquad (6)$$

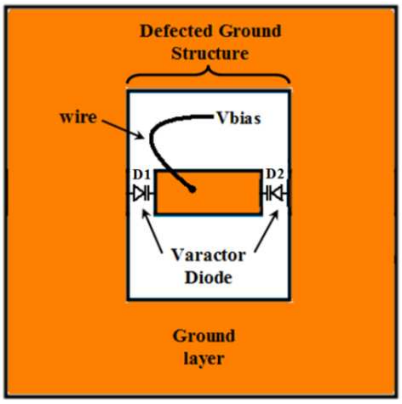
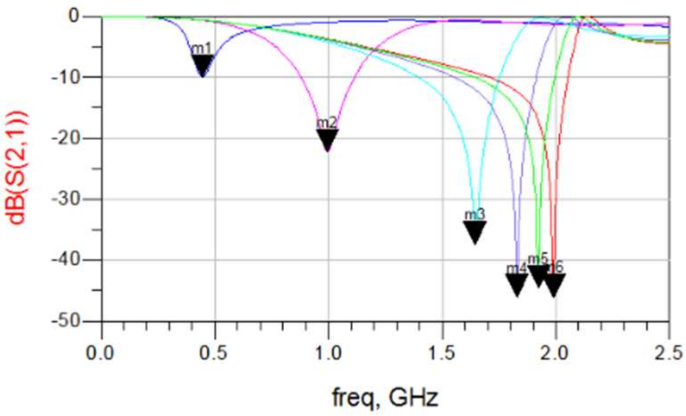


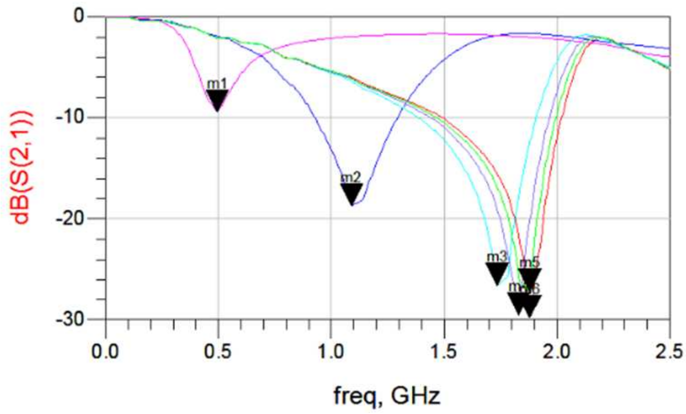
Figure 4. Tunable circuit configuration on the DGS at bottom layer.

III. SIMULATION & MEASUREMENT RESULT

Figure 5 shows the simulated and measured of tunable bandstop filter of DGS. The filter prototype are measured using Network Analyzer equipment. Five different value of voltages (0V, 2V, 4V, 6V, and 8V) are supplied in order to observe the tuning characteristics of DGS.



(a)



(b)

Figure 5. Bandstop attenuation of S21with different resonant frequency (a) simulation result (b) measurement result.

Based on Figure 5, the tuning range for simulation results is achieved from center frequency of 0.445to 1.99GHz while the tuning range of fabricated tunable filter of DGS is from 0.495to 1.88GHz. Both measurement and simulation results have achieved the specifications of design target which is to reach almost 2GHz with bandstop attenuation higher than 10 dB. As the reverse bias voltage increases, the bandstop attenuation value of both simulation and measurement results moves much lower where for simulation, it varies from the value of -9.926 to-45.984dB whereby for measurement is varied from -9.469 to -29.814dB. This tunable filter indicates a small reflected signal which means that this filter is well matched at input port and transmitting more than 90% of signal power. The response of the tuning characteristics at higher frequency is narrow because of maximum threshold frequency

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isreached at maximum tuning voltage. It is also observed that the bandwidth of the measured results is slightly wider compared to simulation results. All the simulated and measured results in Figure 4 are summarized in Table 2 for comparison.

Table - 2Comparison between simulated and measured results.

Marker	Tuning Voltages (V)	Simulation		Measurement	
		Bandstop Attenuation (dB)	Resonant Frequency (GHz)	Bandstop Attenuation (dB)	Resonant Frequency (GHz)
m1	0	-9.926	0.445	-9.469	0.495
m2	2	-22.251	0.995	-18.727	1.090
m3	4	-37.390	1.645	-26.615	1.735
m4	5	-46.025	1.830	-29.517	1.830
m5	6	-44.563	1.925	-27.190	1.880
m6	8	-45.984	1.990	-29.814	1.880

IV. CONCLUSION

Tunable DGS bandstop filter using FR4 substrate has been designed and developed for investigation of its attenuation and tuning range performance. The equations of the tunable filter has been derived using ABCD matrix& S-parameter equation. It is found that the capacitance of the DGS is theoretically can be tuned using varactor diode. Investigation of the filter performance has been done in simulation software and verified bymeasurement. It is found that the tuning range of the filter is mainly due to varactor diode performance and the bandstop attenuation is depend on the combination of DGS and varactor diode. As a conclusion, the tunable bandstop filter of DGS can be developed using FR4 substrate for low cost solution without sacrificing the bandstop attenuation performance. The tuning range of the filter can be further improved if using varactor diode with wider tuning range.

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