High Band Rejection Improvement for Coupled Line Using Defected Ground Structure Technology

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Abstract. In this article a high band rejection has been achieved by using Defected Ground Structure (DGS) technology depending on adding couple poles to improve the inverter and resonator, it will get a high rejection characteristic with good return loss by using this technology. The proposed coupling filter applied to a bandpass diplexer filter with two bands of 2.6 GHz and 6 GHz implemented on RO4350 substrate has a dielectric constant of 3.67 with 14×75 mm overall dimensions. The design technique for the suggested coupled - line filter is implemented based on the theory of coupled - line filters and the DGS equivalent circuit. The simulation results after using DGS show better agreements with theoretical results.

1. Introduction

In Radio Frequency (RF) and other frequency-band implementations, a photonic bandgap (PBG), that has a regular array of the defects, was recorded with several configurations (DGS)[1][2]. The DGS provides a reject band for a certain frequency range with periodic or nonperiodic arrays due to the increasing efficiency of the transmission line induction [3][4]. Several modules like the power amplifier, panel, power separators, and filters are included in this rejection feature of the DGS. To add different features, though, the modelling process for a DGS to a practical circuit a DGS is expected to be preceded. Different efforts to find the DGS parameters and corresponding circuits are important[5].

An engraved fault disturbs shield current distribution in the ground plane. This disorder can alter transmission line features such as the capacitance of the line and the inductance. The suggested DGS depends on a narrow and wide etched excavate in the metallic rear ground panel, resulting in a raise in the operative capacitance and induction of a transmission line, correspondingly. Thus the proposed unit DGS circuit could be expressed with an identical LC circuit[6][7]. To obtain the equivalent circuit parameters for segment DGS, -parameters for the new portion Part of the DGS units were measured using a 3-dimension finite element simulator Method (FEM). Three-pole bandpass coupling filter with DGS parts seen in Figure (1). The coupled-line filter has a microstrip resonator at the in-out outlet and two DGS parts. Groups of DGS in suggested segment Coupled-line bandpass filter may be used at the same time as inverter and resonator. So, a bandpass filter with three poles the suggested filter design can be realized with just a one single resonator.
Compared with a traditional coupled-line bandpass filter, the new coupled-line of bandpass filter has a more consolidated scale and outstanding insertion, return loss feature. Furthermore, DGS has a level of self-resonance. Any of this self resonant element of the segment DGS, hence the suggested bandpass filter framework may include a damping pole within the upper front stop. Because of this reduction pole, the stopband is broad than the traditional coupled-line filters [5].

2. Filter Fundamentals

2.1. Parallel-Coupled, Half-Wavelength Resonator Filters

The general layout of the parallel-coupled of microstrip bandpass filters demonstrates in Figure 2 that utilizes resonators with half-wavelength axes. They are positioned in such a way that adjacent resonators along half their length are parallel to each other. This parallel system offers fairly broad interconnections for a defined spacing [8].

![Figure 1. Three-pole bandpass coupling filter with DGS parts](image)

This filter structure is especially handy between resonators to create filters with a broader bandwidth compared with the end-coupling microstrip filter structure. The design expressions for this filtering kind are indicated in [9].

\[
\frac{J_{01}}{Y_0} = \frac{\pi FBW}{2\gamma_0} \tag{1}
\]

\[
\frac{J_{n,n+1}}{Y_0} = \frac{\pi FBW}{2\gamma_n}\gamma_{n+1} \tag{2}
\]

\[
\frac{J_{j+1}}{Y_0} = \frac{\pi FBW}{2\sqrt{\gamma_j}\gamma_{j+1}} \quad j = 1 \text{ to } n - 1 \tag{3}
\]
where \( g_0, g_1 \ldots g_n \) are part of a ladder-kind lowpass prototype development with a normalized \( \Omega_c \) equal one, \( FBW \) is the fractional bandwidth of the bandpass filter. \( J_{j,j+1} \) is the distinctive feature admittance of \( J \)-inverters and \( Y_0 \) is the characteristic admittance of the terminating lines.

The distinctive feature impedances of coupled line microstrip resonators are calculated to realize the \( J \)-inverters obtained above[10].

\[
(Z_{oe})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 \text{ to } n \quad (4)
\]

\[
(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 \text{ to } n \quad (5)
\]

The existing lengths of any coupled line part are then defined with:

\[
l_j = \frac{\lambda_0}{4(\sqrt{\varepsilon_{re}j\kappa(\varepsilon_{ro})})^{1/2}} - \Delta l_j \quad (6)
\]

where \( \Delta l_j \) is the tantamount length of microstrip open end

2.2. Theoretical Background

The adopted coupling design of the bandpass filter with double DGS parts situated on the metallic ground level, the parallel LC resonators can replace the DGS sections and the concatenation susceptance for a resonator with parallel \( L \) and \( C \) are shown in Figure (3), which corresponds to the section DGS, can be switched to a -inverter parallel resonator, as demonstrated in Figure (4).

![Figure 3. The suggested coupling design of the bandpass filter with two DGS parts](image)

![Figure 4. An inverter parallel resonator.](image)
So, the suggested bandpass filter has characteristics of a 3-pole bandpass filter. Interactions among these circuits demonstrated in Figure (3), could be drawn from $Y_a$ and $Y_a'$ equivalence, as demonstrated in Figure (4), the source viewed input admittances. The formulation of inverter and resonator susceptance are written as:

\[ J_{01} = \frac{B_a^2}{1 + \left(\frac{B_a}{Y_a'}\right)^2} \]  
\[ B_1 = \frac{B_a}{1 + \left(\frac{B_a}{Y_a'}\right)^2} \]  

where $B_a = \omega c_1 C_1 \left(\frac{\omega}{\omega c_1} - \frac{\omega c_1}{\omega}\right)$ that Susceptance of the DGS part. $B_1$ is the susceptance of the equivalent to the resonator for the DGS section. $\omega c_1$ then denotes the angular resonant frequency of the parallel $L$ and $C$ resonators, demonstrate in Figure (3), and $C_1$ indicate the extracted capacitance amount of a DGS. At this resonant frequency of the DGS proposed circuits, the $J$-inverter amount will be zero. This implies that at this frequency there is no such thing as correlation, like dc. So, the suggested bandpass-filter design at the resonant frequency of the DGS equivalent circuit could supply a reduction pole. Additionally, as seen in Figure (5), the coupled-line part could be converted into the $J$-inverter and transmission lines at both ends. The corresponding relationship between a coupling circuit and the transmission lines $J$-inverter circuit is given as follows:

\[ Z_{oe} = \frac{Z_0 \sin \theta (\sin \theta + jZ_0 + j^2Z_0 \sin \theta)}{\sin \theta^2 - j^2Z_0^2 \cos \theta} \]  
\[ Z_{oo} = \frac{Z_0 \sin \theta (\sin \theta - jZ_0 + j^2Z_0 \sin \theta)}{\sin \theta^2 - j^2Z_0^2 \cos \theta} \]  

The corresponding circuit of the current DGS coupler bandpass filter can be represented in Figure (6).
The conditions issued, the susceptibilities for each corresponding resonator displayed in figures are to be extracted from the design formula, which implies the -inverter formula. Both would be taken from 6 and 7. For the first resonator, susceptions are given as follows for each direction:

\begin{align*}
    jB_{r1} &= j(B_1 + Y_1 \tan \theta_1) \quad (11) \\
    jB'_{r1} &= jY_1 \tan(\theta_1 + \alpha) \quad (12)
\end{align*}

\text{when } \alpha = \tan^{-1}(B_1/Y_1)

The 2\textsuperscript{nd} resonator, appropriations are as described out below:

\begin{align*}
    jB_{r2} &= jY_1 \tan(\theta_1 + \phi') \quad (13) \\
    jB'_{r2} &= jY_2 \tan(\theta_2 + \phi'') \quad (14)
\end{align*}

\textit{Where } \phi' = \tan^{-1}\left(\frac{Y_3}{Y_1}\tan(\theta_3 + \phi')\right)

\begin{align*}
    \theta' &= \tan^{-1}\left(\frac{Y_2}{Y_3}\tan \theta_2\right) \\
    \phi'' &= \tan^{-1}\left(\frac{Y_3}{Y_2}\tan(\theta_3 + \phi'')\right) \\
    \theta'' &= \tan^{-1}\left(\frac{Y_1}{Y_3}\tan \theta_1\right)
\end{align*}

For the 3\textsuperscript{rd} resonator, appropriations are as described out below:

\begin{align*}
    jB_{r3} &= jY_2 \tan(\theta_2 + \beta) \quad (15) \\
    jB'_{r3} &= j(B_2 + Y_2 \tan \theta_2) \quad (16)
\end{align*}

\textit{Where } \beta = \tan^{-1}\left(\frac{B_2}{Y_2}\right), \text{ } B_2 \text{ is suscepion of the second DGS segment of the corresponding resonator. Additionally, the electrical dimensions of any coupled segment could be determined as below by using the first and second resonator resonance conditions:}
\[ \theta_1 = \tan^{-1} \left( \frac{\omega_1 C_1 \left( \frac{\omega_1}{\omega_0} - \frac{\omega_0}{\omega_1} \right)}{\frac{1}{Y_1} \left( 1 + \frac{B_2^2}{Y_0^2} \right)_{\omega=\omega_0}} \right) \left( \frac{\omega}{\omega_0} \right) \] (17)

\[ \theta_2 = \tan^{-1} \left( \frac{\omega_2 C_2 \left( \frac{\omega_2}{\omega_0} - \frac{\omega_0}{\omega_2} \right)}{\frac{1}{Y_2} \left( 1 + \frac{B_2^2}{Y_0^2} \right)_{\omega=\omega_0}} \right) \left( \frac{\omega}{\omega_0} \right) \] (18)

Where \( B_p \) is the second segment of DGS susceptance. \( \omega_{c2} \) Denotes the parallel LC resonator angular resonant frequency, and \( C_2 \) indicate the measured capacitance amount for the 2nd DGS.

The developed design approach for the coupling line suggested by the DGS may be applied directly to construct a functional filter. Besides, it has been shown from derived design calculations the DGS segment in the suggest coupled-line bandpass filter is worked concurrently like both a resonator, inverter. Following is the segment, it will be presenting the illustration with the announced filter equivalent to the circuit and expressions for bandpass filter structure [5].

3. The proposed filter design

3.1 Introduction

An iterative design process that starts with the design constraints and initial values that refer to the expressions in the closed-form described above. The centre frequencies of the passband are 2.6 GHz for the first passband and 6 GHz for the second passband, can be used in a wide variety of wireless communication applications such as WiMax and 802 IEEE Standard application.

3.2. Design specification

The proposed diplexer filters have several specifications such as thickness, dielectric constant … etc as shown in Table 1.

| Specifications                  | proposed design |
|--------------------------------|-----------------|
| Materials (Substrate)          | Roger (RO4350)  |
| TanD (Tangent loss)             | 0.0037          |
| Dielectric constant             | 3.7             |
| Thickness (mm)                  | 1.524           |

By using the prototype calculations and expressions from 1 to 6, in section one, the even and odd impedance of each coupled line of 3 order filter are obtained as listed in Table 2. The coupling coefficient for 0.1 dB ripple also calculated to get the parameters of the circuits.
Table 2. The impedance calculation

| N | For 2.6 GHz | For 6 GHz |
|---|-------------|-----------|
|   | $Z_{0n}$ | $Z_{oe}$ | $Z_{oo}$ | $Z_{0n}$ | $Z_{oe}$ | $Z_{oo}$ |
| 1 | 0.59 | 97.1 | 37.9 | 0.39 | 77.1 | 38.5 |
| 2 | 0.87 | 132.5 | 44.6 | 0.38 | 76.3 | 38.1 |
| 3 | 0.39 | 97.1 | 37.9 | 0.39 | 77.1 | 38.5 |

Both even and odd mode transmission line impedance are submitted in ADS (Advanced Design System) specifically to the instruction LineCalc (Line Calculator) package along with the values of the parameters. The length, width, and spacing value between the resonators are then modified, the values are given in Table 3.

It could be attention that the design of dual bandpass filter using the coupled line technology is used a half-wavelength line resonator. They are arranged to get the best resonator along half of their wavelength this parallel arrangement provides a relatively large coupling for a given spacing.

This filter structure is particularly convenient between the resonators and thus for the construction of filters with a wider bandwidth compared to the structure for the final coupled microstrip filters described in the previous.

Table 3. The length, width, and spacing value between the resonators

| N | For 2.6 GHz | For 6 GHz |
|---|-------------|-----------|
|   | Width (mm) | Space (mm) | Length (mm) | Width (mm) | Space (mm) | Length (mm) |
| 1 | 1.8 | 0.13 | 17 | 2.5 | 0.3 | 7 |
| 2 | 2.5 | 0.3 | 15 | 3.5 | 1.3 | 6.2 |
| 3 | 1.8 | 0.13 | 17 | 2.5 | 0.3 | 7 |

Fabricated PSCs are carefully connected to Anritsu Wiltron MS4642B Vector Network Analyzer - 10 MHz to 20 GHz for the measurement, After the preparation of all the requirements for experimental testing. The prototype filter of (RO4350) is connected with the MS4642B network analyser to measure the four parameters S11, S21, S31, and S23. After complete the measurement, a comparison between the simulation and the experimental results is done as shown in Figure 7.
3.3. Improvement of High Band Rejection using DGS

To improve the result by providing high selectivity and very good rejection band, this technique will solve some problem have been faced in the prototype filter designed previously.

To show the validity of the proposed coupling bandpass-filter structure and design process, it can add a pole to an approved bandpass filter with the centre frequency of 2.6 and 6 GHz and the attenuation pole in the upper stop and which is improved by the DGS, the design is done with a ripple of 0.1 and 10% bandwidth, place of attenuation-pole was can be chosen at 3.9 and 6.8 GHz for 2.6 and 6 GHz centre frequency respectively, Which corresponds to DGS circuit self-resonant frequency. The DGS circuit will introduce the parallel LC resonator circuit for the realization of the planned bandpass filter as mentioned previously in chapter two.

DGS section has been calculated and implemented by using ADS EM simulator, the used substrate is roger RO4350 with the thickness of 1.524 mm and dielectric constant of 3.9, and conductor thickness of 35 um for both side of the copper conductor. Figure (8) shows the layout design of DGS for both sides top and bottom. By using ADS EM simulator and using a range of frequency from 0 to 15 GHz to show the response of band rejection, it has shown and confirmed the suggested DGS coupled-line filter helps us to produce clear with compact lengths, better stopband. Figure (9) shows the difference between the prototype of the diplexer filter and the DGS style for the second improved filter. A demonstration of a pole bandpass filter has been obtained to demonstrate the feasibility of the suggested coupled line bandpass filter configuration and designing process. Experimental effects on a developed bandpass filter indicate outstanding loss features and position of the attenuation pole at 2.6 and 6 GHz besides, a high band rejection has been improved as shown previously.
Figure 8. The layout of proposed design (a) Top (b) bottom

Figure 9. Comparison between two response (a) first layout (b) DGS layout
The presented study in this thesis is contrasted with related activities in this field as outlined in Table 4, it can be noticed that there is the high response of this prototype filter compared with the previous study. The response obtained in this study indicates there is an improvement of several parameters such as the return loss, insertion loss, and isolation as shown in the table above, the high band rejection.

### Table 4: Comparison of results with previously published researches

| Ref. | FC1 GHz | FC2 GHz | IL1 | IL2 | RL1 | RL2 | Isolation | Size (mm*mm) |
|------|---------|---------|-----|-----|-----|-----|-----------|--------------|
| [11] | 2.6     | 6.0     | 0.6 | 0.9 | >10 | >10 | 13        | 25.7×22.3    |
| [12] | 1.8     | 2.45    | 2.2 | 1.8 | 17  | 16  | 21        | 20.0×52.0    |
| [13] | 2.95    | 4.92    | 1.43| 1.47| 16  | 18  | >40       | 17.7×11.0    |
| [14] | 8.3     | 10      | 1.8 | 1.9 | 10  | 10  | 26.6      | 15.1×2.6     |
| [15] | 2.4     | 5.2     | 1.94| 2.55| 10.8| 12  | 25        | 35×23.16     |
| [16] | 2.4     | 2.6     | 2.24| 3.17| 12.4| 17.86| 15       | 134×68.47    |
| [17] | 1.8     | 2.45    | 2.05| 2.15| 15  | 15  | 25        | 50×53        |
| [9]  | 2.36    | 5.17    | 2.3 | 2.8 | -   | -   | 18        | 61.8×34.7    |

**This work**  
2.6  6  0.5  2  25  27  23  14×75

#### 4. Conclusion

To achieve a high rejection band with acceptance insertion and return losses the DGS technology applied on a coupled line microstrip diplexer filter. The design technique for the proposed coupling-line filter is applied using the coupling principle-line filters and the related DGS circuit. The bandpass filter simulation results are presented good loss features at the attenuation-pole position at 3.9 and 6.8 GHz. The suggested DGS coupling-line filter and the corresponding design process are readily compatible with monolithic integrated microwave circuit (MMIC) or multilayer processing and can see a broad variety of applications.
5. Reference

[1] T. J. Ellis and G. M. Rebeiz, “MM-wave tapered slot antennas on micromachined photonic bandgap dielectrics,” in 1996 IEEE MTT-S International Microwave Symposium Digest, 1996, vol. 2, pp. 1157–1160.

[2] M. P. Kesler, J. G. Maloney, B. L. Shirley, and G. S. Smith, “Antenna design with the use of photonic band-gap materials as all-dielectric planar reflectors,” Microw. Opt. Technol. Lett., vol. 11, no. 4, pp. 169–174, 1996.

[3] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, “Novel 2-D photonic bandgap structure for microstrip lines,” IEEE Microw. Guid. wave Lett., vol. 8, no. 2, pp. 69–71, 1998.

[4] C.-S. Kim, J.-S. Park, D. Ahn, and J.-B. Lim, “A novel 1-D periodic defected ground structure for planar circuits,” IEEE Microw. Guid. wave Lett., vol. 10, no. 4, pp. 131–133, 2000.

[5] J. S. Park, J. S. Yun, and D. Ahn, “A design of the novel coupled-line bandpass filter using defected ground structure with wide stopband performance,” IEEE Trans. Microw. Theory Tech., vol. 50, no. 9, pp. 2037–2043, 2002, doi: 10.1109/TMTT.2002.802313.

[6] J.-I. Park et al., “Modeling of a photonic bandgap and its application for the low-pass filter design,” in 1999 Asia Pacific Microwave Conference. APMC’99. Microwaves Enter the 21st Century. Conference Proceedings (Cat. No. 99TH8473), 1999, vol. 2, pp. 331–334.

[7] D. Ahn, J.-S. Park, C.-S. Kim, J. Kim, Y. Qian, and T. Itoh, “A design of the low-pass filter using the novel microstrip defected ground structure,” IEEE Trans. Microw. Theory Tech., vol. 49, no. 1, pp. 86–93, 2001.

[8] D. M. Pozar, Microwave engineering. John Wiley & Sons, 2009.

[9] P. H. Deng, C. H. Wang, and C. H. Chen, “Compact microstrip diplexers based on a dual-passband filter,” Asia-Pacific Microw. Conf. Proceedings, APMC, vol. 2, pp. 1228–1232, 2006, doi: 10.1109/APMC.2006.4429629.

[10] J.-S. G. Hong and M. J. Lancaster, Microstrip filters for RF/microwave applications, vol. 167. John Wiley & Sons, 2004.

[11] L. Noori and A. Rezaei, “Design of a microstrip diplexer with a novel structure for WiMAX and wireless applications,” AEU - Int. J. Electron. Commun., vol. 77, pp. 18–22, 2017, doi: 10.1016/j.aeue.2017.04.019.

[12] A. Chinig et al., “Microstrip Diplexer Using Stepped Impedance Resonators,” Wirel. Pers. Commun., vol. 84, no. 4, pp. 2537–2548, 2015, doi: 10.1007/s11277-015-2718-2.

[13] A. Chinig, “A Novel Design of Microstrip Diplexer Using Meander-Line Resonators,” vol. 2, no. 5, pp. 10, 2017.

[14] S. N. Dembele, J. Bao, T. Zhang, and D. Bukuru, “Compact microstrip diplexer based on dual closed loop stepped impedance resonator,” Prog. Electromagn. Res. C, vol. 89, no. December 2018, pp. 233–241, 2019, doi: 10.2528/PIERC18110608.

[15] C.-M. Chen, S.-J. Chang, and C.-F. Yang, “Fabrication of a Novel Diplexer Using Folded Open-Loop Ring Resonators and Microstrip Lines,” Appl. Comput. Electromagn. Soc. J., vol. 29, no. 11, 2014.

[16] N. H. Baba, A. H. Awang, M. T. Ali, M. A. Aris, and H. M. Hizan, “Design of a SIW-based microstrip diplexer using TM 010 circular cavity,” in Theory and Applications of Applied Electromagnetics, Springer, 2016, pp. 71–79.

[17] H. Liu, W. Xu, Z. Zhang, and X. Guan, “Compact diplexer using slotline stepped impedance resonator,” IEEE Microw. Wirel. Components Lett., vol. 23, no. 2, pp. 75–77, 2013.