Design and optimization of a new compact 2.4 GHz-bandpass filter using DGS technique and U-shaped resonators for WLAN applications

A. Belmajdoub[1], A. Boutejdar*[2], A. El Alami[3], S. D. Bennani[4], M. Jorio[5]
[1,4,5]Sidi Mohamed Ben Abdellah University, Faculty of Sciences and Technics, Fez, Morocco
[2]Microwave and Communication Engineering, German Research Foundation (DFG), Germany
[3]Moulay Ismail University, Faculty of Sciences and Technics, Errachidia, Morocco
*Corresponding author, e-mail: boutejdar69@gmail.com

Abstract

The objective of this work is the study, the design and the optimization of an innovative structure of a network of coupled copper metal lines deposited on the upper surface of a R04003 type substrate of height 0.813 with a ground deformed by slots (DGS). This structure is designed in an optimal configuration for use in the design of narrowband bandpass filter for wireless communication systems (WLAN), the aim of use the defected ground structure is to remove the unwanted harmonics in the rejection band, the simulation results obtained from this structure using CST software show a very high selectivity of the designed filter, a very low level of losses (less than-0.45 dB) with a size overall size of 43.5x34.3 mm.

Keywords*: bandpass filter, coupled line, DGS slots, WLAN*

1. Introduction

The evolution of electronic systems for the new generations of mobile and wireless communication applications (GSM, UMTS, LTE, WLAN, WIMAX and RFID) is driving the designers of RF and microwave circuits to design new compact and high performance narrow-band microwave filters to increase their degree of integration into the transmission chains related to these applications [1, 2]. The design of these microwave filters is directly related to the properties of the technology used. The choice of technology depends on the performance and type of application envisaged, the weight, the size, the consumption and the cost which are the main criteria guiding the choice. Microstrip technology remains an attractive solution to design microwave filter circuits because it is the most used industrially to realize compact and efficient microwave integrated circuits because of the existence of accurate simulation models that allow good circuit design. Coupled line techniques [3-11] have often been used since 1958 to design narrow-band filtering circuits because of their ease of initial design and technological realization for integrated circuits, but their disadvantage lies in their large size, which limits their integration in the new generations of intelligent electronic systems. To remedy this problem we will propose two more efficient methods that will have given us a compact size, the first method touches the shape of the line we will bend the line on itself in order to gain a little surface [12-21]. In the second method we will integrate slots (DGS) at ground level to decrease the dimensions of these lines and improve the performance of the filter [22-26].

In this research, a new type of compact microstrip bandpass filter using slow wave effect and defected ground technique has been presented. The first step was to design a conventional parallel coupled band pass filter basing on the filter theory. The second step was the U-transformation of the topology in order to minimize the size of the filter without any additional devices. In order to improve the other features like losses in the passband, the rol-off in transition domain and the repression of the undesired harmonics in stopband, a new quasi fractal-inverse-arrowhead DGS resonators have been etched in the ground plane and placed in the center and on the both corners of the structure. The proposed compact BPF structure has been designed and optimized. The comparison between the final S-scattering results shows

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clairly the effectiveness of the used U-transformation and DGS techniques and thus confirm the validity of the proposed design approach. The proposed 2.4 GHz-band-pass filter has been developed to meet the requirements of high HF performance for the WLAN applications.

2. Design of Parallel Coupled Lines Bandpass Filter

The filter design is based on the constraints imposed by a set of specifications based on the intended application. That's why, as an application, we chose to create a band pass filter for a WLAN application. The filter specifications are summarized in the following Table 1.

Table 1. The Filter Specifications of the Proposed Bandpass Filter

Spesifications	Value
Center frequency	2.4 GHz
bandwidth	300 MHz
Relative bandwidth	0.125
Loss of reflection	-15 dB

The filter design based on coupled lines is generally divided into two parts: theoretical synthesis and technological implementation. The theoretical synthesis of the filter allows us to identify the topology of the filtering circuit and to define the values (impedances, electrical lengths) of the constituent elements of the filter in relation to the electrical characteristics to be achieved (bandwidth, central frequency and rejection level). The technological implementation of the filter allows us to identify the topology of the mass pattern in a given substrate.

2.1. Theoretical Synthesis of the Filter

The use of Parallel coupled line technique is very common for implementation of bandpass filter with required narrow-band. Due to their relatively weak coupling, this type of filter has narrow fractional bandwidth but instead has desired advantages such as low-cost fabrication, easy integration and simple designing procedure. The coupled line structure supports two qasi-TEM odes: odd mode and even mode as shown in Figure 1.

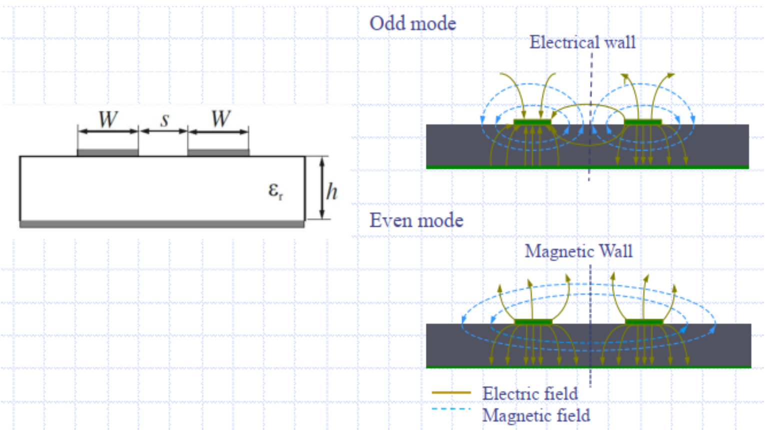

Figure 1. The coupled line structure supports two qasi-TEM odes: odd mode and even mode

To calculate the essential parameters of this parallel coupled line filter we can use the following (1) and (2):

$$\frac{J_{0,1}}{Y_0} = \sqrt{\frac{\pi.B}{2g_0g_1}} \quad (1)$$

for intermediate structure

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi.B}{2\sqrt{g_j g_{j+1}}} \quad (2)$$

for final coupling

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi.B}{2g_n g_{n+1}}} \quad (3)$$

g_0, g_1 g_n can be taken be taken from above, B is the relative bandwidth, J_n, J_{n+1} is the characteristic admittance of J inverter and Z_0 is the characteristic impedance of the connecting transmission line. With the data of characteristic admittance of the inverter, we can calculate the characteristic impedances of even-mode and odd-mode of the parallel-coupled microstrip transmission line. The odd and even impedances are calculated by the following (4) and (5):

$$(Z_{0e})_{j,j+1} = Z_0\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad (4)$$

$$(Z_{0o})_{j,j+1} = Z_0\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad (5)$$

In order to find the desired electrical performance we have used the ADS tuning tools to optimize the values of even and odd mode impedances. Even and odd impedances has been calculated for four sections and shown in Table 2. Figure 2 illustrates frequency spectrum for BPF using CLIN. The simulated results obtained as center frequency at 2.4 GHz and cutoff frequencies as 2.25 GHz and 2.55 GHz.

Table 2. The Values of Even and Odd Impedances

	J/Y0	Before optimization		After optimization	
		Even mode	Odd mode	Even mode	Odd mode
0 , 3	0.4363	81.3324	37.7029	85.3324	39.8029
1 , 2	0.1805	60.6529	42.6045	72.52232	56.0836

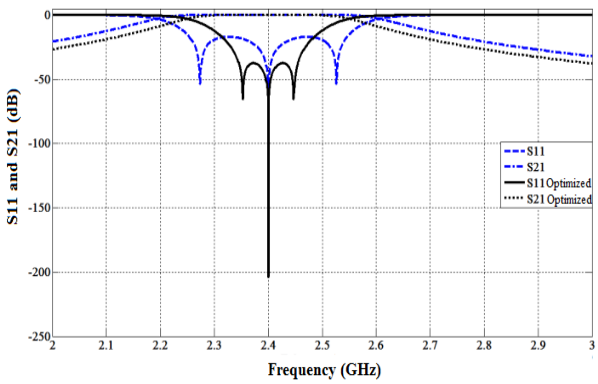

Figure 2. Frequency response for BPF using CLIN

2.2. Technological Implementation of the Filter

Figure 3 gives the layout of the parallel coupled band pass filter has two ports and coupling sections, it shows the physical structure of parallel coupled micro strip filter. This filter is simulated using Computer Simulation Technology Software (CST) and the substrate used for this filter was RO4003 substrate which has dielectric constant of 3.38 throughout the frequency range. To calculate the dimensioning of this filter we use the calculator "LineCalc" of ADS. All dimensions of the conventional filter are depicted in Table 3.

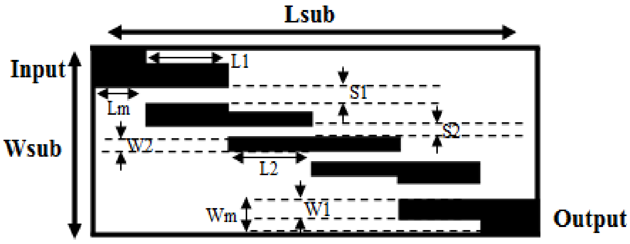

Figure 3. Basic layout of designed parallel coupled band pass filter

Table 3. Computed Dimensions in mm of Basic Layout Structure

Computed dimensions	Value
W_m	1.84043
L_m	1.42
L_1	18.93
W_1	1.1417
L_2	18
W_2	1.19276
S_1	0.45
S_2	1.37

The BPF is simulated by using CST software. The S-parameters of the filter are shown in Figure 4. We observe that the 3dB filter bandwidth is approximately 12.5% and the center frequency is around 2.4 GHz. The insertion loss less than -0.34947 dB has been obtained, but with dimensions of (76.7x12.84) mm^2.

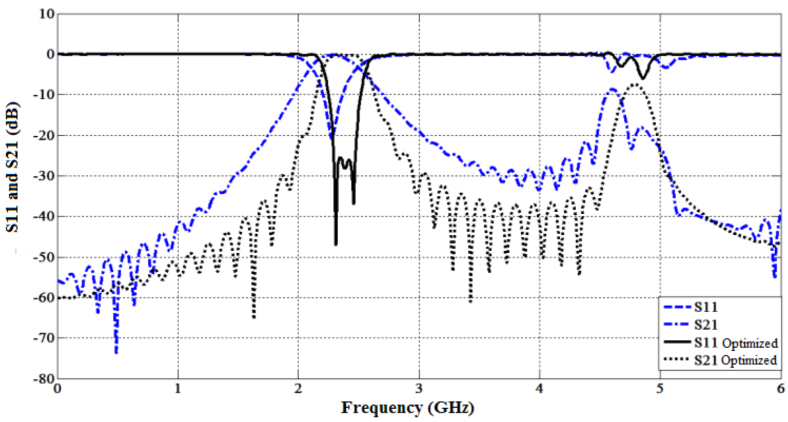

Figure 4. Simulation response of three poles coupled line BPF

Since new generations of electronic systems require compact devices. Our idea is to fold the second and third line coupled on it self to build a U-shaped structure in order to gain a more compact size of the filter. The new dimensions are presented in the Table 4. The input and output feeding lines are connected to the coupled lines on one side of while the U-resonator is the coupled lines as shown in Figure 5.

The simulated results obtained as center frequency at 2.4 GHz and 3dB bandwidth of 351 MHz with insertion loss of -0.4435 dB with dimensions of 40.07x17.7 mm^2 shows second passband around 5 GHz. To remedy the problem of the undesired second passband, the next step will be to remove these armonies by integrating slots at the mass plane level (DGS). Simulated S-parameters of proposed structure as shown in Figure 6.

Table 4. The New Dimensions in mm of Compact Layout Structure

Computed dimensions	Value
W_m	1.84043
L_m	1.42
L_1	17.25
W_1	1.1417
L_2	19.4
W_2	1.19276
S_1	0.3
S_2	1.3
a	1
b	14.93
c	8.924

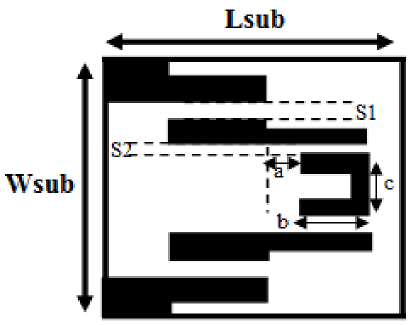

Figure 5. Dimensions of proposed compact bandpass filter

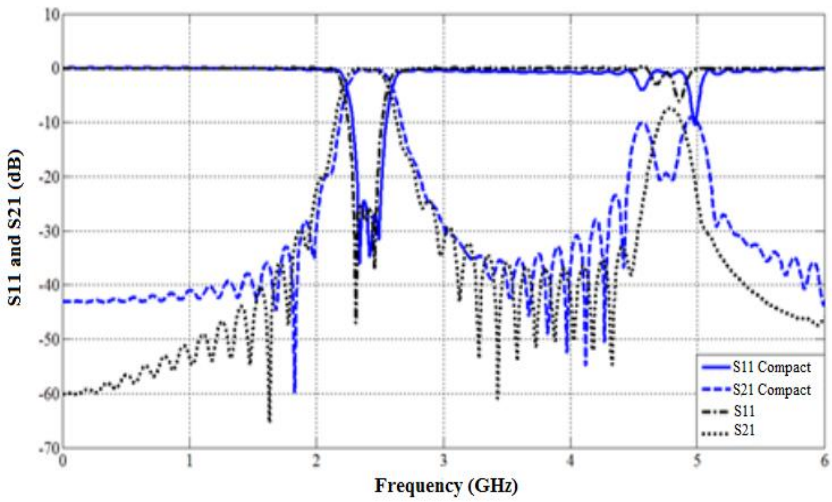

Figure 6. Simulated S-parameters of proposed structure

3. Filter Incorporating Defected Ground Structure
3.1. DGS Design

Several Compact and high performance components have been reported by using the generic structure called the defected ground structure (DGS) for the micro strip line. DGS has been attractive to obtain the function of unwanted frequency rejection and circuit size reduction. The structure of DGS can provide cutoff frequency and attenuation pole in some frequencies without any periodic array of DGS. The defected areas can be realized by dumbbell slot, rectangular, circular slot, and arrow slot shape and slot variation as shown in Figure 7. The structure of DGS and its equivalent circuit as shown in Figure 8

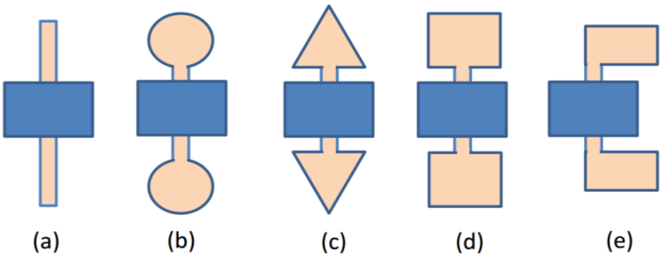

Figure 7. Example of DGS shapes (a) rectangular (b) circular (c) arrow and (d) dumbbell (e) slot variation

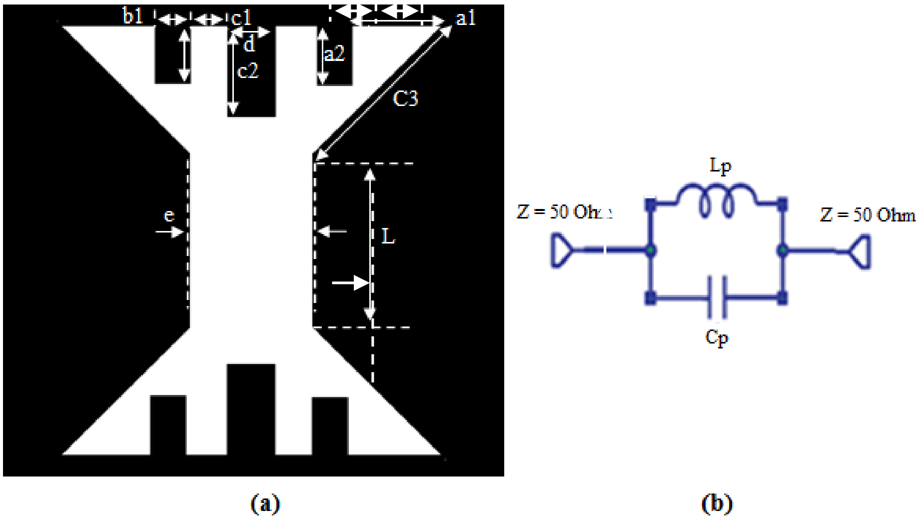

Figure 8. (a) Three dimensional view of micro strip line with DGS slot variation (b) Equivalent circuit of DGS

His capacitance in Pico-farads and the inductance in Nano-henrys are computed by:

$$C_p = \frac{\omega_c}{R_0 g_1} \frac{1}{\omega_0{}^2 - \omega_c{}^2} \quad (6)$$

$$L_p = \frac{1}{4\pi^2 f_0{}^2 C_p} \quad (7)$$

where f_c, in gigahertz, is the cutoff frequency of the band-reject response of the slot at 3 dB and f_0, in gigahertz, is its pole frequency. The dimensions of the new DGS topology are seen in the Table 5.

A DGS has two design parameters (L and e). In order to investigate the frequency characteristics of the DGS section, we simulated the DGS unit section and considered the effect of parameter that affect to $|S_{21}|$. Figures 9 and 10 show the response of $|S_{21}|$, when increase L by e=0.01 mm and L=5 mm per one step the result is attenuation pole decreased. So the greatest response used for suppression second pass band which occurs from three poles coupled line BPF and is able to cover the pass band has dimension of the DGS at L=5 mm, e=0.01 mm. as shown in Table 6.

Table 5. Calculated Dimension of DGS Resonator in mm

Parameter	Value
a_1	1.25
a_2	0.4
c_1	1.5
c_2	0.9
c_3	1.5
b_1	0.125
d	0.125
e	var
L	var

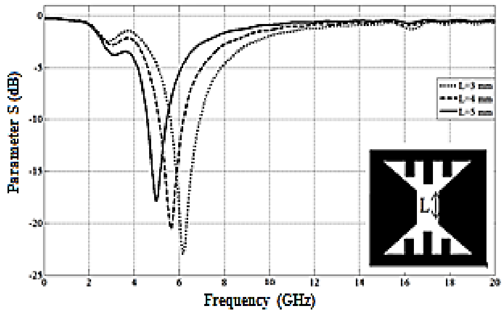

Figure 9. Investigate parameter L

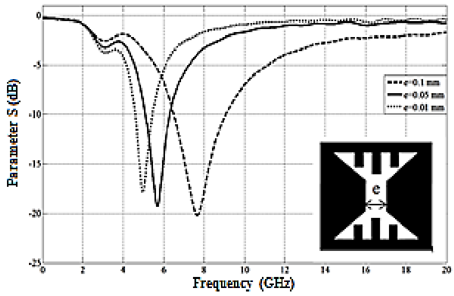

Figure 10. Investigate parameter e

Table 6. Characteristics of the Proposed DGS with Different L and e

	F_0(GHz)	S_{21} (dB)
L=3 mm	6.18	-22.92
L=4 mm	5.62	-20.483
L=5 mm	5	-17.847
e=0.1 mm	7.657	-20.213
e=0.05 mm	5.74	-19.028
e=0.01 mm	5	-17.847

3.2. Design of Band Pass Filter with DGS

The structure of the BPF which significantly suppresses unwanted passband is shown in Figure 11. The simulation results of this new Compact BPF DGS using CST Studio are shown in Figure 12. And the simulation results of the proposed filter structure with and without DGS are summarized in the Table 7.

From the analysis of this table we can see that the integration of the slits at the level of the ground plane has an effect on the performance of the designed filter, we notice a minimization at the level of insertion loss with an improvement of the bandwidth. The electrical performances of the filter in comparison with other research works are presented in the Table 8.

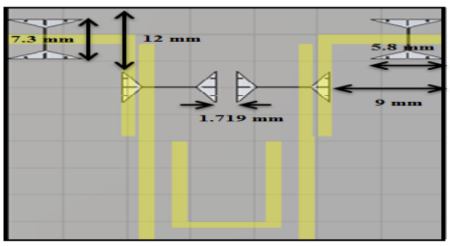

Figure 11. Layout of three poles compact BPF with defected ground structure

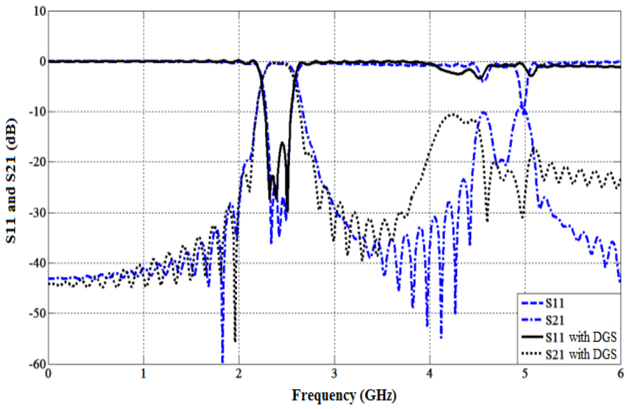

Figure 12. Simulation response of three poles compact BPF without and with DGS

Table 7. Performance Compact BPF-DGS

	BPF without DGS	BPF with DGS
Réponse S_{11} à F_0	-34.79 dB	-27.322 dB
bandwidth	355 MHz	344 MHz
Insertion loss	-0.468 dB	-0.429 dB
Loss of reflection	-24.492 dB	-22.658 dB
	-26.922 dB	-16.165 dB
Over all Size	40.07*17.7 mm	43.49*34.319 mm

Table 8. Comparison of the Proposed DGS BPF with Other Related BPFs

Research work	f_0 (GHz)	BW (GHz)	Loss of insertion (dB)	Overall size mm²
[3]	2.4	1	———	18.4x30
[4]	2.5	0.08	3.144	———
[5]	2.3	0.360	3.74	———
[6]	6	2	2	———
Our work	2.4	0.344	0.429	43.49x34.319

4. Conclusion

In this paper, a new microstrip elliptic function filter with miniaturized coupled hairpin resonators is presented. Investigations of its geometrical dimensions and its effect have been carried out. The quasi-elliptic filter was designed using a chebyshev approximation and DGS method. The cutoff and resonance frequencies bounding the stopband can be easily controllable by changing the length or the width of the investigated structure without changing the area occupied by the filter. The filter was simulated using Microwave Studio Software CST and Agilent Advanced Design System ADS. The proposed BPF had a wide stop band and sharp transition regions due to the use of the DGS elements. The response is sharp in transition domain and the passband is almost lossless. Moreover, this filter can also provide a 20 dB wide upper stopband up to 2 times the center frequency. The total size of the used topology is 43.5x34.3 mm^2. The optimized results have shown the effectivity of the proposed deformation idea. Finally, the proposed compact and high-performance DGS filter can be usefull in several technologies for WLAN and medical applications.

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