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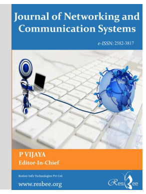

Compact Symmetrical Interdigital Filter with Vias and DGS for 802.11b/g/n Applications

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Abstract: Microstrip structures play an important role in microwave band especially the radio frequency (RF) systems which operate in 1 to 4 GHz (L and S bands). Many wireless applications are served in these such as ISM 2.4GHz, Wi-Fi, WLAN, Bluetooth, and so on. All these RF systems are designed to pick a specified range of frequencies among the received spectrum and the Band Pass Filter (BPF). This paper works in BPF of Inter Digital (ID) structure. Its unique characteristic is the second pass band will be centered at a third fundamental frequency. This ID filter is usually large in size and narrowband but the proposed filter is compact with bandwidth enhancement. The filter comprises seven quarter-wavelength resonators with a valve and DGS on the FR4 substrate. This structure offers a bandwidth of 1.2GHz pass band from 1.9GHz to 3.2GHz centerat 2.4GHz. As demonstrated by the measured results, the -20dB insertion loss is between 1.7GHz and 3.4 GHz, and its bandwidth (FBW) factor is 36.4%, which is more significant. A parametric analysis on substrate height was performed and printed on an FR4 substrate thickness of 0.4 mm and dimensions of 16.962 *17 mm2. This offers the insertion loss (IL) S12, and return losses (RL) S11, of are - 3.68dB and 13.93 dB in the pass band. The fabricated filter results are more satisfactory than the simulated results. Its pass band characteristics are helpful in the L band applications of 802.11b/g/n/ax in radio engineering, such as WLAN and Wi-Fi.

Keywords: Inter digital Filter, Dgs, Resonators, Band Pass Filter, Group Delay.

Nomenclature

Abbreviation	Expansion
RF	Radio Frequency
BPF	Band Pass Filter
ID	Inter Digital
IL	Insertion Loss
RL	Return Loss
WLAN	Wireless Local Area Network
Wi-Fi	Wireless Fidelity
UWB	Ultra Wide Band
HFSS	High-Frequency Simulation Software
DGS	Defective Ground Structures
FBW	Fractional Band Width
EM	Electro Magnetic

1. Introduction

Radiofrequency systems are compact, light in weight, are high in demand. In modern wireless communications, the most frequently used applications, such as WLAN and Wi-Fi use IEEE802.11.These operate in L and S bands. Every RF system has an antenna followed by BPF to select the required band from the received spectrum. The BPF passes only required bands by suppressing others. Microstrip lines are used to implement the BPF at frequency bands and these lines are compact, easy to fabricate, and economical. The most common types of microstrip filters are open stub type, Stepped impedance, Parallel-coupled line filter, Hairpin shaped, and Inter digital filter.

The ID configuration of the compact filter design should be below 6 GHz frequency. It is a parallel strip line which are mutually coupled and resonators are grounded at one end as shown in Fig. 1. This structure has features such as compactness, slow wave structure, and frequency response. The next pass band will appear three times the center frequency of the first pass band. However, the main

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disadvantages are poor stop-band characteristics and narrowband operation and that has been overcome in this model.

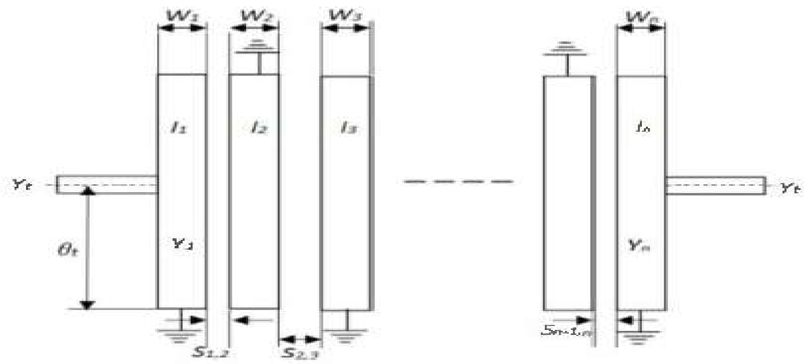


Fig1.*General schematic structure of n-pole Interdigital configuration*

The paperwork consists of 4 sections. Section 1 discusses the work's motivation and inter digital configuration's structure. In section 2, the background of IDBPF is discussed elaborately with a literature survey. Section 3 outlines the design and Modelling procedure. The comparison of simulated results with measured results and other discussions are made in Section 4; in the same section, the implemented and tested design is also shown. Section 5 mentions the advantages and disadvantages. Finally, the paper concludes in Section 6.

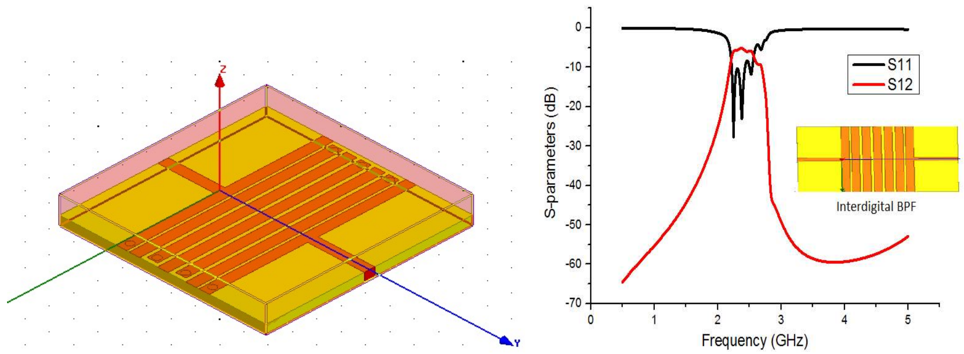
2. Literature

The inter digital filter structure consists of parallel lines between ground planes. The design metrics of the ID capacitor were elaborated by George L. Matthaei [1], and the exact theory of filter design was explained in [2] by R. J. Wenzel, in which the synthesis method was based on a calculation of the impedance matrix that provides equivalent circuits. In his paper [3], Cornelis Jan Kikkert designed different filters based on coupled resonator structures, which were the basis for other structures as in [4-6]. In [4], the author designed and simulated IDBPF on an RT-DUROID substrate with 0.5 mm height. The analysis showed that IDBPF mainly suffers from tuning. The paper [5] presented the design and implementation of a quarter wavelength UWB BPF with two shunt stubs and two squared pads. In [6] an optimum edge couple technique in IDBPF was implemented to improve the fractional bandwidth. Mukesh Kumar Khandelwal carries an interesting work in his research article [7], discreet ground structures allow wide-band operation in a wide range of applications. The filter characteristics sharpness factor and selectivity improved with dumbbell-shaped DGS [8] [9]. In [10], DGS, along with valves, can give better filter characteristics, and additional strip lines were used as a bypass to create load coupling to the source to improve filtering performance. But the size could be more compact. The effect of adding vias and stubs to get multiple and wideband operations is discussed widely in [11, 12]. Siddesh Kamat [13] worked on the seventh-order asymmetrical coupled line ID filter for the LTE -26 band. The group delay can be improved by providing L-slots, as shown in [14]. But its design complexity is high. A compact IDBPF was devised and simulated in [15] with a narrowband. The author of the paper [16] designed a 5-pole ID structure and analyzed the group delay and bandwidth factor but the design was large. By providing slots with adjustable bandwidth, improved stop band characteristics can be achieved with an ID capacitor coupled line [17, 18]. A parallel-coupled method was discussed in [20], which shows the size and poor filter characteristics. Composite right/left-handed transmission line structures were used in [21] to improve bandwidth, filter characteristics, and group delay. By proper design of the characteristic impedance of the transmission lines stop band characteristics were improved [22]. Fractal geometry was used and simulation results were listed [23].

With this knowledge, an IDBPF is proposed for this work. The filter design and its simulation were done using commercial simulation software HFSS. The filter is fabricated on an FR4 substrate of dielectric constant, $\varepsilon r = 4.4$,and the height of the substrate is 0.4 mm.

3. IDBPF Design

The design technique presented here is based on the procedure for parallel-coupled filters described in R.J. Wenzel [2]. This work contains tables for normalized coupling and normalized loaded Q values. The topology of a microstrip quarter-wavelength consists of a microstrip line with one end open and the other end shorted to the ground through a metallic via hole. The order of the filter is n=7, calculated from the filter design book [19]. The seventh-order filter obtained the Chebyshev response when the Filter's element values g0=g8=1, g1=g7=1.1811, g2=g6=1.422, g3=g5=2.0966, g4=1.573. A 0.4 mm thickness FR4 substrate is used in the filter design and the design and simulation are done using the HFSS tool. After optimization the geometry is given as: l1=l7= L=17mm, l2=l3=l4=l5=16.33 mm, W=1.118 mm, S12= S67=0.2665 mm, S23= S56=0.3686 mm, S34= S45=0.3912 mm. The input 50 Ω feed line is WP =0.866mm connected to the middle point of the resonator. The design model of the IDBPF and its simulated results are shown in Fig. 2.



(a) (b)

Fig.2. *(a) HFSS model of 7-pole IDBPF`(b) S11& S12 of IDBPF (without via)*

The pass band characteristics (S11 and S12) shown in Fig. 2 have poor stop band performance and low bandwidth. Instead of shorting at one end, a Via is provided at the short-circuited end of each resonator. It adds an inductive nature and improves the pass band characteristics. The top view and side view of the resonator with via are shown in Fig. 3

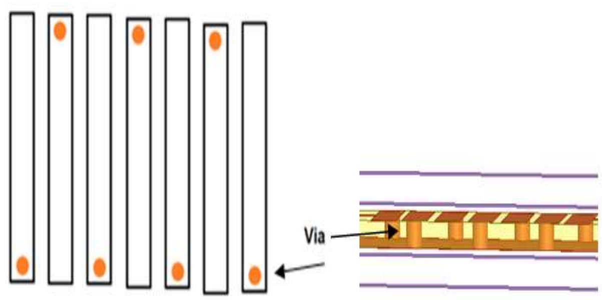
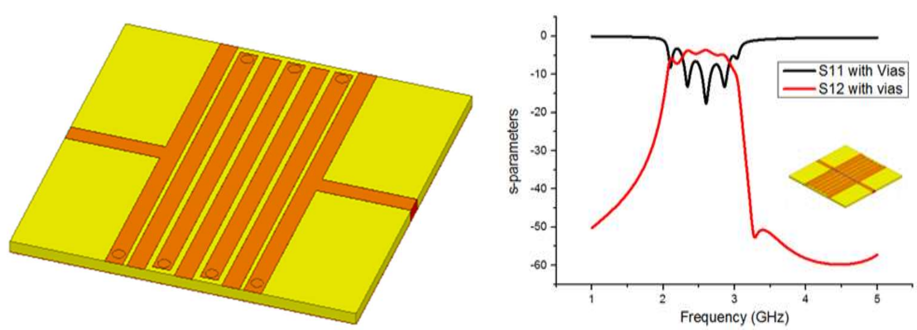


Fig.3. *Resonator with via*

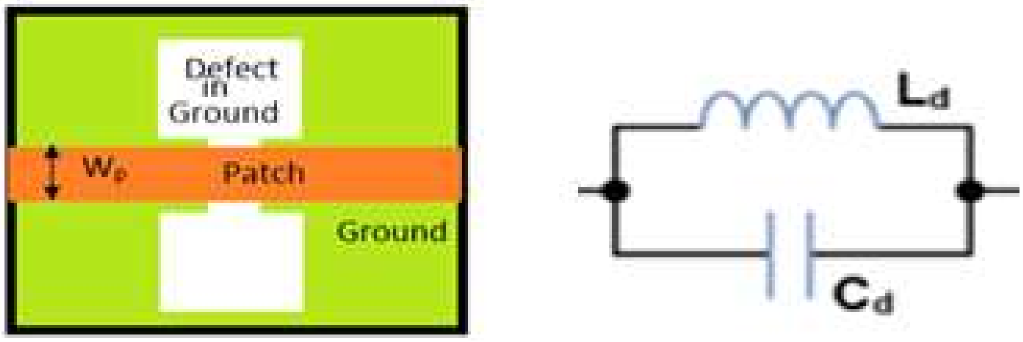
Vias provide an electrical (and thermal) connection between the patch and the ground. At the microwave range, the dimensions of via show several parasitic effects that affect the electrical performance. The HFSS design model of IDBPF with vias and its simulation result shown in Fig. 4



(a) (b)

Fig.4. *(a)IDBPF with Vias (b) S11 andnS12 of IDBPF with Vias*

The bandwidth can be improved by providing defects in the ground [20-22]. In this work, dumbbell-shaped DGS is used to improve band width. The dumbbell-shaped defect acts like an LC resonance network. Its equivalent circuit is shown in Fig. 5



(a) (b)

Fig. 5. *(a) DGS structure. (b) Equivalent of DGS structure.*

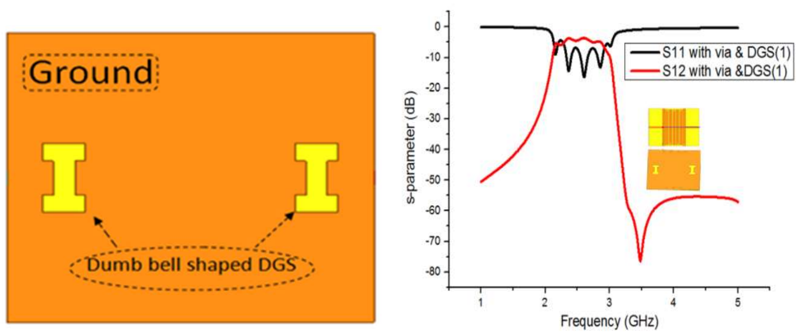
The elements L_d and C_d are calculated using the equations.

$$C_d = \frac{5 f_c}{\pi (f_0^2 - f_c^2)} \tag{1}$$

$$L_d = \frac{250}{\pi^2 f_0^2 c} \tag{2}$$

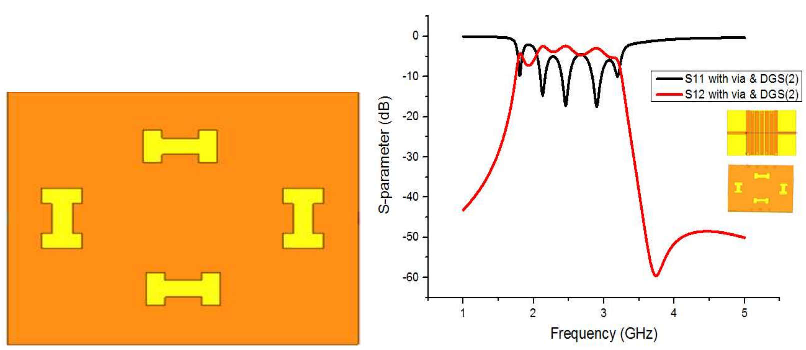
Where f_c and f_0 are the cut-off and resonant frequencies.

By doing defects in the ground, an improvement in the pass band of IDBPF with Vias is obtained. Fig. 6 and 7 show the design and its simulation with a pair of dumbbell DGS (1) and two pairs of dumbbell DGS(2). Their simulation results show an improved bandwidth from DGS (1) to DGS (2).



(a) (b)

Fig. 6.*(a) IDBPF with DGS(1) (b) S11 and S12 of IDBPF with DGS(1)*



(a) (b)

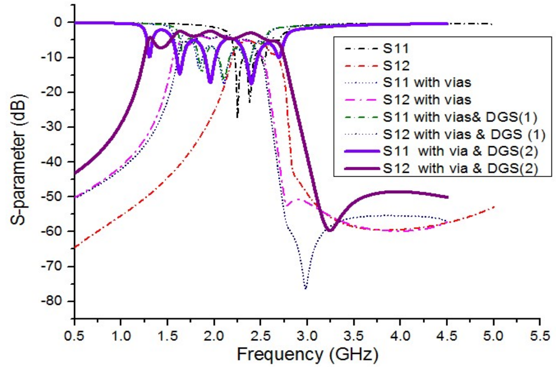
Fig. 7. *(a) IDBPF with DGS (2) (b) S11 and S12 of IDBPF with DGS (2)*

The final proposed IDBPF with via and DGS (2) is fabricated on an FR4 substrate of 0.4 mm thickness. The fabricated model and measurement setup are shown in Fig. 8.

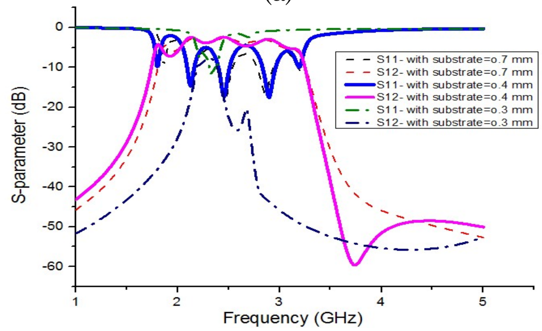
Fig.8. *Measurement setup, bottom and top view of proposed IDBPF*

4. Results and Discussion

After consolidating all simulation results, as shown in Fig. 9(a). It says that among all of the IDBPFs, via and DGS (2) offers better performance. Further parametric analysis with a thickness of the substrate is taken to support the compactness of the filter, and simulated results in Fig. 9 (b) say that the substrate with 0.4mm thicknesses gives better transmission characteristics.



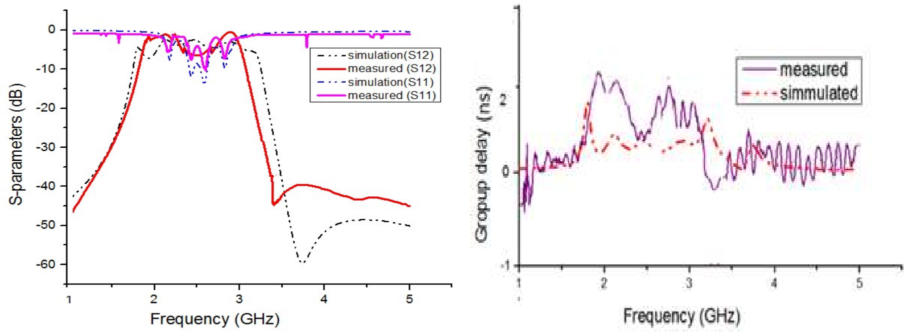
(a)



(b)

Fig.9. *(a) S11 & S12 of IDBPF with different Topologies(b) S11 & S12 of IDBPF with different Substrate heights*

The measured final model results are compared with simulated results graphically shown in Fig. 10(a) and Fig. 10(b) is the group delay graphs of simulated and measured results.



(a) (b)

Fig.10. *Measured and simulated results of IDBPF with Via and DGS(2):(a) S11 & S12(b) Group-delay*

A comparison of the size of the proposed model with other models in this frequency range is shown in Table 1. It shows the proposed work is much more compact than all other models.

Table 1. *Comparison of prospered IDBPF with other models.*

Reference	***Center frequency(GHz)***	***Relative Permittivity (ε_r)***	***Substrate***	***substrate height (mm)***	***Dimensions (Length*width) (mm²)***	***I L(dB)***	***RL(dB)***
[6]	3.2	10.2	Roger 6010	0.635	30 * 20	-3.45	-10.63
[10]	1.65	10.2	Arlon AD1000	0.762	32.22 * 18.65	-2.5	-12.5
[16]	2.4	4.4	FR4	1.6	16.53 * 46.3	-0.97	-12.2
[20]	3.2	9.2	Roger TMM(10)	0.765	56.8 * 10.3	-7.5	-14.5
[21]	2.62	3.2	Taconic RF35A2	0.76	20.6 * 12.8	-1.38	-17
[22]	2.5	4.3	FR4	1.58	26.4 * 36.4	-1.5	-12.5
[23]	2.37	10.2	Arlon AD1000	1.27	23 * 13	-0.125	-28
Proposed	**2.4**	**4.4**	**FR4**	**0.4**	**16.96 * 17**	**-3.68**	**13.93**

Table 1shows that better filter characteristics can be achieved with a 0.4 mm FR4 substrate and the filter offers better insertion and return losses.

Table 2. *Comparison of prospered IDBPF FBW with other models.*

Reference	***Center frequency(GHz)***	***Band Width (GHz)***	ε_r	***substrate height (mm)***	***FBW (%)***
[6]	3.2	0.5	10.2	0.635	12.12
[10]	1.65	0.5	10.2	0.762	15.
[16]	2.4	0.8	4.4	1.6	59.6
[21]	2.62	1.1	3.2	0.76	59
[22]	2.5	1.3	4.3	1.58	12.5
Proposed	**2.4**	**1**	**4.4**	**0.4**	**36.4**

There is also considerable growth in FBW. Usually, FBW can be improved with size. Table 2 shows the considerable growth in FBW with compactness.

Table 3. *Group delay Comparison of prospered IDBPF with other models.*

Reference	***Center frequency(GHz)***	***BW (GHz)***	***FBW (%)***	***substrate height mm)***	***Dimensions (Length*width) (mm²)***	***Group delay (nS)***
[6]	3.2	0.5	12.12	0.635	30 * 20	5.19
[16]	2.4	0.8	59.6	1.6	16.53 * 46.3	2.2
[22]	2.5	1.3	12.5	1.58	26.4 * 36.4	1.6
Proposed	**2.4**	**1**	**36.4**	**0.4**	**16.96 * 17**	**2.12**

The group delay which is another parameter in the filter is measured in the proposed model. Table 3 shows its comparison with other literature models. In this table, group delay is high because of the ID's slow wave structure.

5. Advantages and Disadvantages

Advantages: Compact, good FBW, and group delay.

Disadvantages: The complexity in the design is adding vias in the structure.

6. Conclusion

In this work, the seventh-order symmetrical coupled line ID is designed and simulated using the EM tool HFSS. The final simulated model is fabricated on the FR4 substrate, and measurements are taken and compared with the simulated results. The simulated and measured results are in good agreement. Its planar structure and compact size suit the modern microwave circuits and wireless communication systems design. However, the main focus of this work is optimizing compactness without losing filter characteristics, and the results prove the same. The resultant IDBPF model is compact and it can be used in L-band applications, especially for WLAN and Wi-Fi. It can be further extended by designing a Filtering antenna, reconfigurable antenna, and so on.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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