Journal of Engineering Research

Volume 2
Issue 2 *(December)*

Article 8

2018

Design of Integrated Millimeter Wave Microstrip Pseudo-Interdigital Band pass Filter Using 0.18µm CMOS Technology

Nessim Mahmoud

Design of Integrated Millimeter Wave Microstrip Pseudo-Interdigital Band pass Filter Using 0.18µm CMOS Technology

Nessim Mahmoud, Mahmoud.A.A.Ali, and Mohamed E. Nasr, *Member, IEEE*

Abstract— High selectivity design of an improved on-chip band pass filter for 60 GHz millimeter-wave applications using 0.18 µm CMOS technology is presented. A new type of miniaturized microstrip bandpass filters with pseudo-interdigital structure without via holes grounded resonators is described. A very compact filter of this type, having a size less than quarter-wavelength by quarter-wavelength at a mid-band frequency of 60 GHz was designed. The adoption of a pseudo-interdigital BPF and utilization of two transmissions zero permits a compact size and high selectivity for the BPF. Besides, two defected ground structure cells are etched under the coupled lines to improve the filter insertion loss. The proposed BPF has the center frequency of 60 GHz, insertion loss of -3.6. dB, a 3dB band width of 8 GHz, and core size 200×500 µm^2 with total chip size 500×300 µm^2 (including bonding pads

Index Terms— Millimeter wave; Bandpass; CMOS; pseudo-interdigital filter.

I. INTRODUCTION

Filters designed with CMOS technology in modern RF wireless communication systems process become great importance for enabling the integration of the millimeter - wave system on a single chip. The widespread use of the passive microstrip band pass filters (BPFs) makes it necessary for improving the performance of the front-end circuits in radio communication system. Designing a band pass filter (BPF) with easy integration and high performance is currently of great interest. Although several related studies [1-7] have focused on continuous improvements of on-chip passive microstrip band pass filters in the free frequency band, these filters have various disadvantages, e.g. high insertion loss, poor selectivity, too wide band pass and large chip size [2, 8, 9] makes it difficult to be employed in real implementation. For example, the lumped component BPF in [1] showed excellent selectivity response and small size, however, the 6.9 dB insertion loss is too high to be utilized in real implementation. In [2], the dual-mode loop resonator BPF presented good selectivity response, nevertheless, the 4.9 dB insertion loss was still high, and moreover, the special input position and the large chip size restricted its application. The folded microstrip line BPF [3] is successfully fabricated at 60 GHz with insertion loss of 2.7 dB, however, it is difficult to be used in the 60 GHz waveband wireless internet standard because it has more than 30 GHz bandwidth. Many techniques were proposed to enhance the passband insertion loss. In [7] , a Defected Ground structures (DGS) H-shape was used under the coupled area to increase the slow wave factor which improve the insertion loss, on the other hand the filter design consumes large size and large bandwidth . In [8], a folded open loop structure was used on patterned ground shields in the first two stages open loop resonator, however, it stills suffer from large bandwidth. The mixed coupled BPF in [10] presents very compact size and low insertion loss but it still suffers from wide bandwidth and poor characteristic at the lower stop band.

In this paper, a compact size, low insertion loss and sharp-rejection on-chip band pass filter is proposed and simulated in 0.18µm CMOS technology. The proposed BPF employs a technique to further reduce the size of interdigital band pass filters known as microstrip pseudo-interdigital band pass filters without the complication of vias connections to the ground. The proposed BPF employs I-shaped DGS cells etched under the coupled arms to reduce the size and enhance the insertion loss significantly.

II. DEVELOPMENT OF PSEUDO-INTERDIGITAL FILTERS

The pseudo-interdigital filter may be similar to the conventional interdigital band pass filter structure shown in Fig.l (a). The Interdigital filter contains quasi-TEM mode transmission line resonators. Each resonator element is a quarter-wavelength long at the mid-band frequency, and is short-circuited at one end and open-circuited at the other end with alternative orientation [1]. Interdigital filters are compact in size but require grounding microstrip ends through vias. Since the grounded ends are at the same potential, they may be so connected, without severe distortion of the band pass frequency response, to yield the modified interdigital filter given in Fig. l (b). At the mid band frequency there is an electrical short-circuit at the position where the two grounded ends are jointed, even without the via hole grounding. Thus, it would seem that the current and voltage distributions would not change much in the area of the mid-band frequency, even though via holes are removed. This operation results in the so-called pseudo interdigital filter structure shown in Fig.1(c).

Nessim Mahmoud ,Mahmoud.A.A.Ali and M. E. Nasr are with Electronics and Electrical Communications Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt (emails: eng.nessim@gmail.com, mahmoudahmedattia@yahoo.com and menasr2001@yahoo.com)

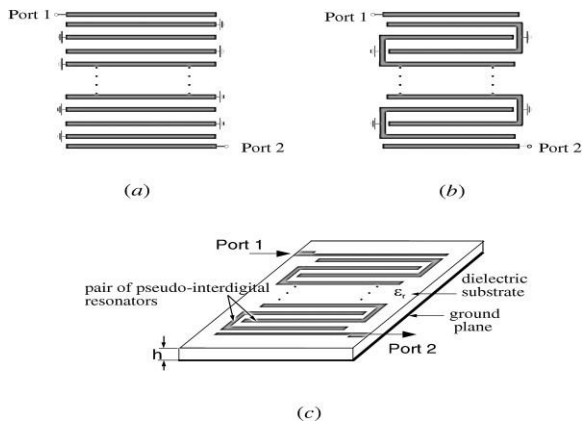

Fig. 1. Conceptualized development of the pseudo-interdigital filter. (a) Conventional interdigital filter. (b) Modified interdigital filter. (c) Microstrip pseudo-interdigital bandpass filter [1].

This filtering structure acquires its compactness from the fact that it has a size similar to that of the conventional interdigital band pass filter and attains simplicity because of no grounding of short circuit ends with via holes . So these filters are compact and simple to be fabricated using planar fabrication techniques.

III. FILTER GEOMETRY AND DESIGN

Fig.2 shows the geometry and dimensions of the pseudo-interdigital filter BPF which designed using 0.18µm CMOS technology. Instead of using conventional coupled-line, a direct tapped feeding lines were used to reduce the size of the filter and to increase the power coupled to the resonators. All the quarter wavelength resonators are of same size with thickness W_1 of 35µm and length L_1 of 550 µm. Short circuit connections are of thickness 5 µm and length L_2 of 130 µm . Table 1 lists the optimized dimensions of the proposed BPF. The filter structure is constructed on the top metal layer (M_6) while the ground plane is constructed on the bottom layer (M_1) with a total filter area of 0.2 mm^2 including measurement pads.

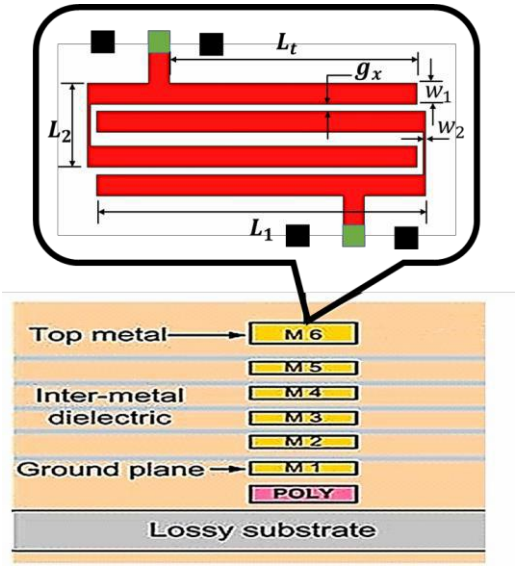

Fig. 2. The layout of the pseudo-interdigital BPF.

TABLE I. DIMENSIONS OF THE PSEUDO-INTERDIGITAL BPF (µm)

L_1	L_2	W_1	W_2	g_x	L_t
550	130	35	5	12	455

To investigate the performance of the proposed BPF in terms of achieving good operations, the commercially available simulation software ANSFT HFSS® was used for numerical analysis. Fig. 3 shows the simulated results of S11 and S21 versus frequency of the BPF which illustrates that the insertion loss of the BPF is more than 5 dB with a 3dB bandwidth of 7 GHz and two transmission zeros less than 35dB are obtained at 50 GHz and 90GHz respectively.

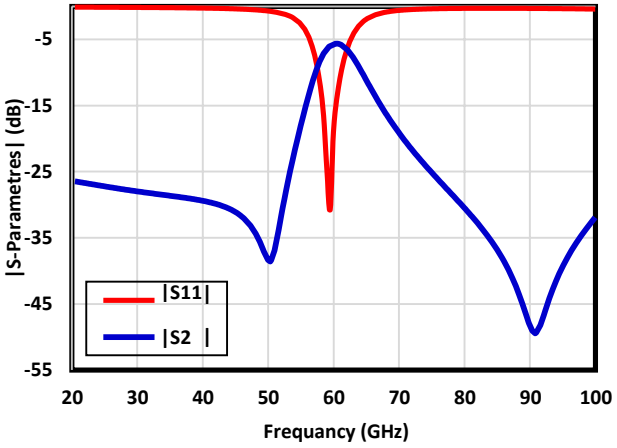

Fig. 3. Simulated S-Parameters of the pseudo-interdigital BPF.

To examine the effect of the position of the tapped feed line L_t on the filter performance, a parametric study of L_t is conducted. As shown in Fig.4 and Fig.5. Four values of L_t, were simulated with the same filter dimensions. It should be noticed that as L_t increases, the transmission zeros move toward the resonance frequency which leads to a smaller bandwidth and an improvement in filter selectivity and better filter performance.

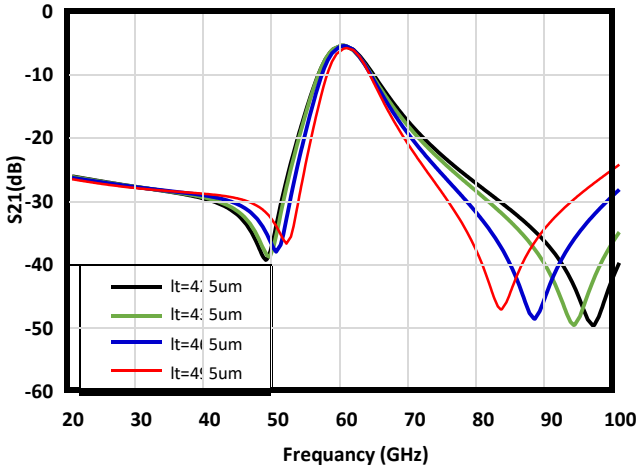

Fig. 4. Simulated $|S_{21}|$ versus frequency at different feeding position lt.

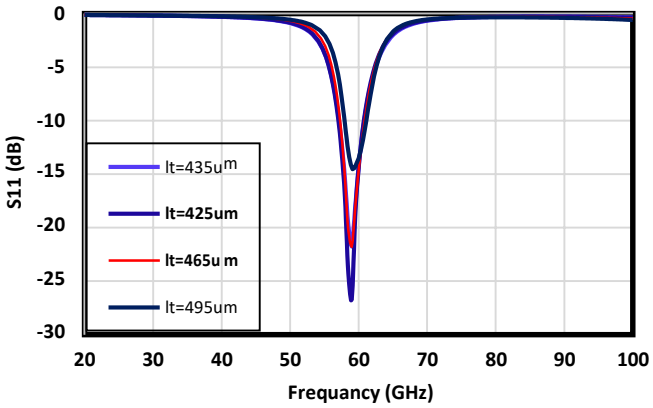

Fig. 5. Simulated |S11| versus frequency at different feeding position *lt*.

IV. INSERTION LOSS IMPROVEMENT USING I-SHAPED DGS

To improve the performance of the pseudo-interdigital BPF mentioned above, two I-shaped DGSs were etched under the coupled arms as shown in Fig.6 (a). Fig.6 (b) presents the I-shaped DGSs as a parallel LC circuit where C_{dgs} is the gap lumped capacitance, L_{dgs} inductance L is related with the extra magnetic flux passing through the apertures on the ground plane and the radiation effect is explained by resistance R_{dgs}[2].

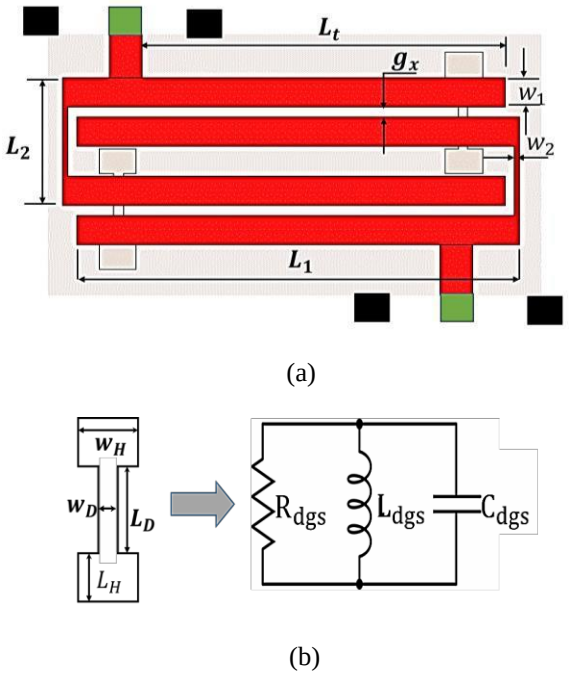

Fig. 6. (a) Layout he pseudo-interdigital BPF with I shaped DGS.
(b) I-shaped DGS and its equivalent circuit.

The equivalent values of L_{dgs}, C_{dgs} and R_{dgs} are determined by the dimensions of the DGS structure and its position relative to the transmission line and calculated using:

$$C_{dgs} = \frac{\omega_c}{2Z_o(\omega_o^2 - \omega_c^2)} \quad (1)$$

$$L_{dgs} = \frac{1}{4\pi^2 f_o^2 C} \quad (2)$$

$$R_{dgs} = \frac{2Z_o}{\sqrt{\frac{1}{|S_{11}(\omega)|^2} - (2Z_o(\omega C - \frac{1}{\omega L}))^2} - 1} \quad (3)$$

Where ω_o is the center angular frequency and ω_c is the 3dB cutoff angular frequency taken from the S21, curve.

TABLE II. DIMENSIONS OF THE PSEUDO-INTERDIGITAL BPF WITH DGS (μm)

L_1	L_2	W_1	W_2	g_x	L_t	L_D	W_D	L_H
475	128	35	5	12	432	125	10	30

Table 2 lists the I shaped DGS-BPF's optimized dimensions. Comparing the new dimensions with the original shape dimension; it can be observed that, the size of the DGS filter is reduced from 0.2mm^2 to 0.15mm^2. More than 20% reduction in filter size was achieved.

Fig.7 shows a comparison of the total filter performance of the proposed BPF with/without the DGS. It illustrates that the I shaped DGS-BPF has increased coupling compared with that of the original BPF. Therefore, a smaller IL is produced. By etching two DGS cells under the coupled arms the performance of the proposed filter was improved significantly, the insertion loss was improved from 5.63 dB to 3.6dB, more than 2 dB improvement in the insertion loss was achieved with a slight increase in the filter bandwidth from 7 GHz to 8 GHz

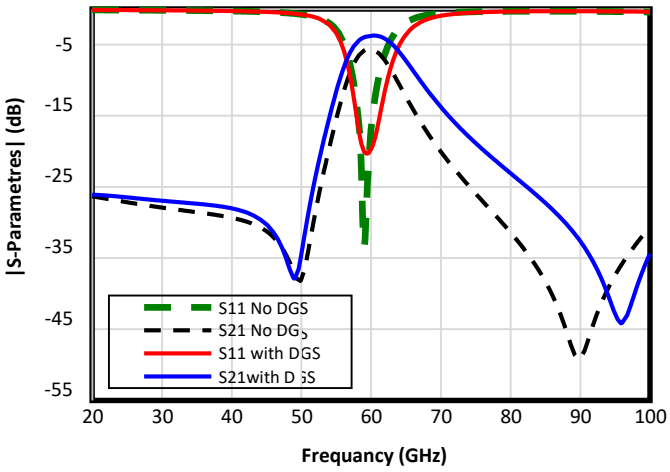

Fig. 7. Simulated performance of the proposed BPF with and without DGS

V. PERFORMANCE EVALUATION

The overall performance of the proposed BPF was summarized and compared with other recent publications in Table III. For fair size comparison, each chip area is divided by its corresponding squared guided wavelength such that

$$chip\ area(\lambda g^{2}) = \frac{chip\ area\ (\mathrm{mm}^2)}{\lambda g^2} \qquad (4)$$

According to the bandwidth, it can be observed that the 60-GHz 0.13 CMOS band pass filter in [3] exhibits the characteristics of high selectivity with 17% fractional bandwidth which is much higher than the fractional bandwidth of our proposed filter. Moreover, the insertion loss of 4.1dB is much high and consume twice the chip area compared to our proposed filter which has a fractional bandwidth of 13.3% and an insertion loss of 3.6dB. According to area, the filter in [4] consumes a small chip area 0.018 λg^2,on the other hand, it occupies more fractional bandwidth of 27% compared to our filter bandwidth. The filter designs in [5] show very small insertion loss of 2.1 dB, however it have boor selectivity with 34% fraction bandwidth. Finally, the filter designed in[6] has a low insertion loss of 2.6dB however it still suffer from large chip area of 0.09 λg^2 which is very large and approximately four times of our proposed filter area in this paper. Finally, the proposed filter in [7] has a very compact size and low insertion loss, on the other hand, it has poor selectivity and higher fractional bandwidth than our proposed filter.

TABLE III. PERFORMANCE COMPARISON WITH LITERATURE DESIGNS

Reference	Technology	f_0 (GHz)	Chip Area (λg^2)	Max S21 (dB)	FBW (%)
[3](2012)	0.13 µm	60	0.04	4.1	17
[8](2013)	0.18µm	60	0.028	4	38
[4](2014)	0.18 µm	77	0.018	2.9	27
[5](2017)	0.18 µm	60	0.025	2.1	34
[6](2015)	0.18 µm	56	0.09	2.682	19
[7](2016)	0.18 µm	59	0.015	2.85	26
This work	**0.18 µm**	**60**	**0.024**	**3.6**	**13.3**

VI. CONCLUSION

In this paper, a pseudo-interdigital band pass filter is designed at 60 GHz on 0.18µm CMOS technology for millimeter-wave applications with insertion loss of -3.6dB, a bandwidth of 8GHz and a chip area of 0.15mm^2. The pseudo interdigital bandpass filter achieves the simplicity without short circuit connections in the band pass filter unlike the conventional interdigital band pass filters. Moreover, the two DGS cells etched in the ground plane further improve the insertion loss and reduce the filter size significantly.

REFERENCES

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

[2] I. Chang and B. Lee, "Design of defected ground structures for harmonic control of active microstrip antenna," in *Antennas and Propagation Society International Symposium, 2002. IEEE*, 2002, pp. 852-855.

[3] A. L. Franc, E. Pistono, D. Gloria, and P. Ferrari, "High-Performance Shielded Coplanar Waveguides for the Design of CMOS 60-GHz Bandpass Filters," *IEEE Transactions on Electron Devices*, vol. 59, pp. 1219-1226, 2012.

[4] Y.-M. Chen and S.-F. Chang, "A ultra-compact 77-GHz CMOS bandpass filter using grounded pedestal stepped-impedance stubs," in *Microwave Conference (EuMC), 2011 41st European*, 2011, pp. 194-197.

[5] A. Barakat, N. Mahmoud, and a. R. K. Pokharel, " Low Insertion Loss 60 GHz CMOS H-shaped Resonator BPF " presented at the RWW2017, 2017.

[6] D. Mat, R. Pokharel, K. Yoshida, and H. Kanaya, "Comparison of 60GHz CSRRs Ground Shield and Patterned Ground Shield On-chip Bandpass Filters Designed for 0.18 µm CMOS Technology."

[7] A. Barakat, R. Pokharel, and T. Kaho, "60 GHz on-chip mixed coupled BPF with H-shaped defected ground structures," *Electronics Letters*, vol. 52, pp. 533-535, 2016.

[8] K. Ma, S. Mou, and K. S. Yeo, "Miniaturized 60-GHz on-chip multimode quasi-elliptical bandpass filter," *Electron Device Letters, IEEE*, vol. 34, pp. 945-947, 2013.