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Miniaturized Ultra-wide Stopband Bandpass Filter for WiMAX Applications

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Abstract
In this research, a miniaturized narrow-band bandpass filter is presented. The design procedure has been started using a coupled structure and the final circuit has been bent to reduce the circuit size. The operational frequency is located at 3.6 GHz with an acceptable sharpness in the transition bands. In the passband, both the insertion and return loss are 0.6 and 27 dB, respectively. The obtained fractional bandwidth of the filter is about 2%, which is highly appropriate for a special-purpose narrow-band BPF. The presented BPF has been fabricated on an RT/Dourid5880 substrate. The obtained results of the fabricated circuit are consistent with the simulation one.

Keywords: Bandpass Filter, Microstrip, Miniaturized, Narrow-Band.

1. INTRODUCTION

The invention and development of new applications in wireless are the results of advances in telecommunications technology along with governmental regulations and market needs. These new applications provide definite features in telecommunications services, which propose three substantial items to customers. Coverage is the first one, which means that a minimum signal level should support each customer; the second one is capacity, which means that the customer can upload and download data by having enough data rate,

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and finally, ensure the quality of data transfer from the sender to the recipient, which is called a service quality.

Undoubtedly, WiMAX (Worldwide Interoperability Microwave Access) can be considered an appropriate solution to many problems in wireless networks. We need a completely new receiver and a transmitter for the realization of such a system as WiMAX.

The design of bandpass filters (BPFs) with compact size is essential for filtering applications in modern electronics and communication systems. A bandpass filter can select signals within a specified bandwidth at a certain center frequency and reject signals at different frequencies, especially in frequency regions which can interfere with information. There are many types of microwave BPFs such as narrow-band, wide-band, dual-band, forth-band, etc [1-27].

Narrow-band bandpass filters are more important in WLAN and WiMAX than the other. They are used in communication and microwave systems. In mobile communication systems, the compactness of the devices has been greatly important. Various techniques have been proposed for this purpose, such as microstrip ground structure (DMS) [1, 2], step impedance resonators (SIRs) [3], defected ground structures (DGS) [4, 6], photonic bandgap (PBG) structure [7], and cascaded resonators [8, 9]. One of the usual techniques is implementing microstrip filters with cascaded low-high impedance elements or an open stub [10, 11].

Using coupled lines and two short-circuited stubs, a BPF was reported in [12]; it suffers from large size and narrow stopband. The investigated BPF in [13], were fabricated with an inductive-coupled stepped-impedance quarter-wavelength resonator. The filter has good characteristics like high return loss in the passband. Nonetheless, it has a narrow stopband. In [14], a wide stopband hairpin BPF was designed for millimeter-wave applications. This topology suffers from bad characteristics in the passband. Also, complex topology and enormous size are undesirable characteristics of this circuit. A narrow-band bandpass filter was reported in [15] with complex topology and incompetent stopband region. The compact dual-mode BPFs were studied in [16-18]. They suffer from significant fluctuations in the passband, large circuit size, and narrow stopband. These works include a miniaturized narrow-band passband filter with a central frequency of 3.6 GHz and an appropriate group delay in the passband. The 3.6 GHz frequency is located in the WiMax frequency range and is a common telecommunication protocol. Also, it can be used to keep the second and third harmonics in different GSM applications.

2. DESIGN PROCESS

The proposed BPF is designed in 4 steps: the gapped resonator, coupled resonator, bent coupled- resonator, and final BPF design. The proposed gapped resonator is illustrated in Fig.1.

The gapped resonator is made of a weakly coupled structure, which can produce a pole in its frequency response. This pole can be improved and used to produce a narrow passband. *LC* equivalent circuit of this resonator is shown in Fig.2.

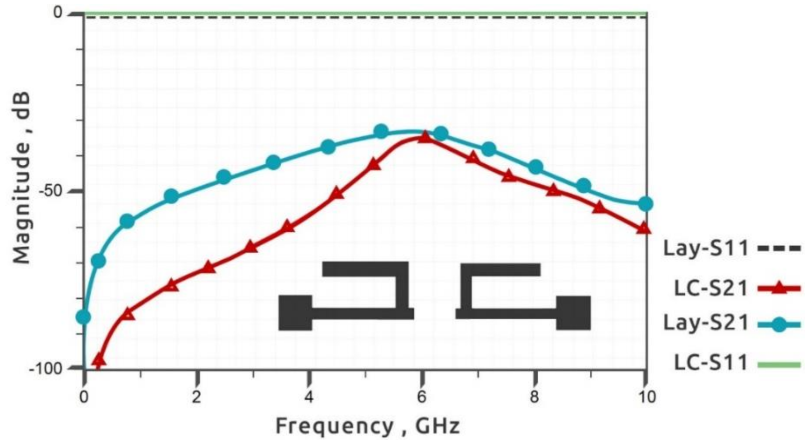

Fig.1. Microstrip layout and simulated S-parameters of the gapped resonator.

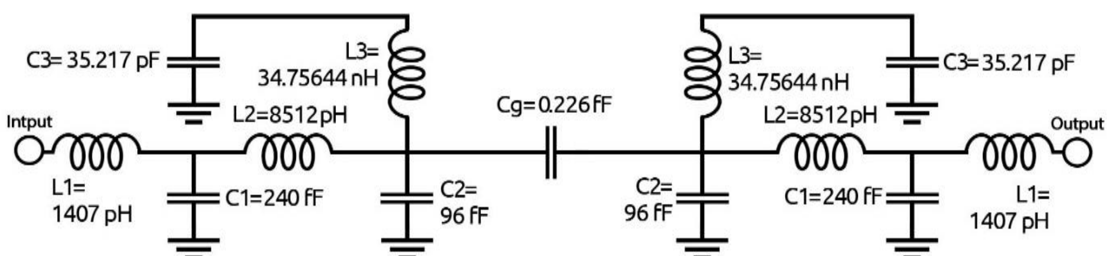

Fig. 2. LC equivalent circuit of the gapped resonator.

Considering the proposed *LC* model, the ABCD matrix for the gapped resonator can be obtained from:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & L_1 S \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ C_1 S & 1 \end{bmatrix} \times \begin{bmatrix} 1 & L_2 S \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ C_2 S + \frac{1}{L_3 S + \frac{1}{C_3 S}} & 1 \end{bmatrix} \times \begin{bmatrix} 1 & \frac{1}{C_g S} \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & L_1 S \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ C_1 S & 1 \end{bmatrix} \times \begin{bmatrix} 1 & L_2 S \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ C_2 S + \frac{1}{L_3 S + \frac{1}{C_3 S}} & 1 \end{bmatrix} \quad (1)$$

For simplifying Eq. 1, two auxiliary parameters of P and the matrix of M are defined below:

$$P = C_2 S + \frac{1}{L_3 S + \frac{1}{C_3 S}} \quad (2)$$

$$M = \begin{bmatrix} Q & R \\ W & 1 \end{bmatrix} = \begin{bmatrix} 1 & L_1 S \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ C_1 S & 1 \end{bmatrix} \times \begin{bmatrix} 1 & L_2 S \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ C_2 S + \frac{1}{L_3 S + \frac{1}{C_3 S}} & 1 \end{bmatrix} = \begin{bmatrix} Q & (L_1 S + L_2 S) \\ C_1 S + P & 1 \end{bmatrix} \quad (3)$$

where $Q = 1 + C_1 S(L_1 S + L_2 S) + P(L_1 S + L_2 S)$.

So, Eq. 1 can be simplified as follows:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = M \times \begin{bmatrix} 1 & \frac{1}{C_g S} \\ 0 & 1 \end{bmatrix} \times M \quad (4)$$

By applying Eq. (3) to Eq. (4), the following one is obtained.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} Q^2 + RW & \frac{1}{C_g S}(Q^2 + RW) + R(Q+1) \\ W(Q+1) & \frac{W}{C_g S}(Q+1) + WR + 1 \end{bmatrix} \quad (5)$$

Obviously, the gapped resonator has a symmetric topology. So, the resonator should have a reciprocal response. Therefore, the ABCD matrix determinant should be equal to the unit:

$$\Delta \begin{bmatrix} A & B \\ C & D \end{bmatrix} = (Q^2 + RW) \times \left(\frac{W}{C_g S}(Q+1) + WR + 1\right) - (W(Q+1)) \times \left(\frac{1}{C_g S}(Q^2 + RW) + R(Q+1)\right) = 1 \quad (6)$$

As indicated in Fig. 2, the *LC* values are extracted using Eq. (6). The relationship between dimensions of line and the equivalent *L* and *C* are formalized in [28]. In the next step, as shown in Fig.3, the proposed resonator has been coupled with a stub, and then, it has been bent.

As illustrated in Fig. 4, the coupled stub added a zero to the frequency response at frequency 11GHz.

Not only is there no significant difference between the S-parameters of the coupled resonator and the bent coupled one, but also good miniaturization has accrued in the bent structure. The corresponding dimensions are indicated in Fig. 3, and the widths of the bent lines are 0.2 mm. Finally, the proposed BPF has been designed by adding a meandered T-shaped resonator to the bent coupled-resonator as in Fig. 5.

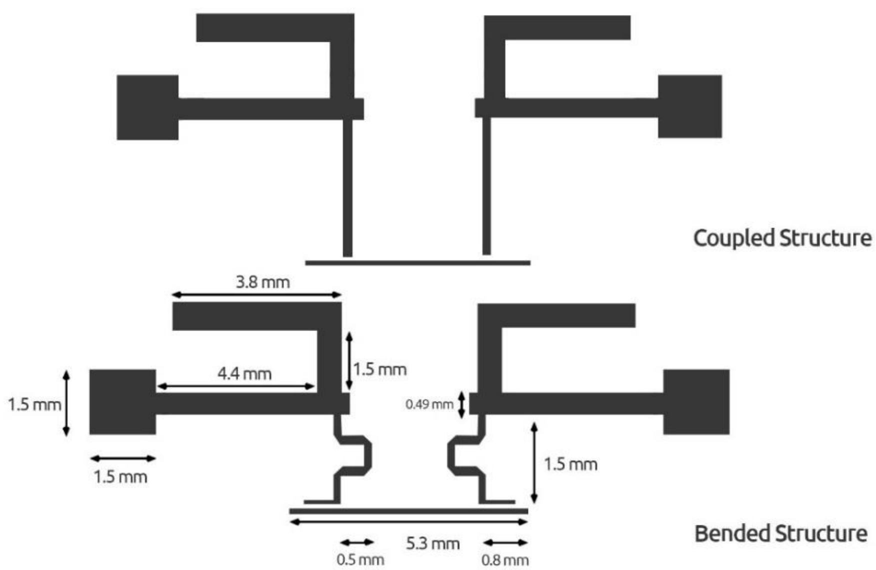

Fig. 3. Coupled and the bent coupled-resonator.

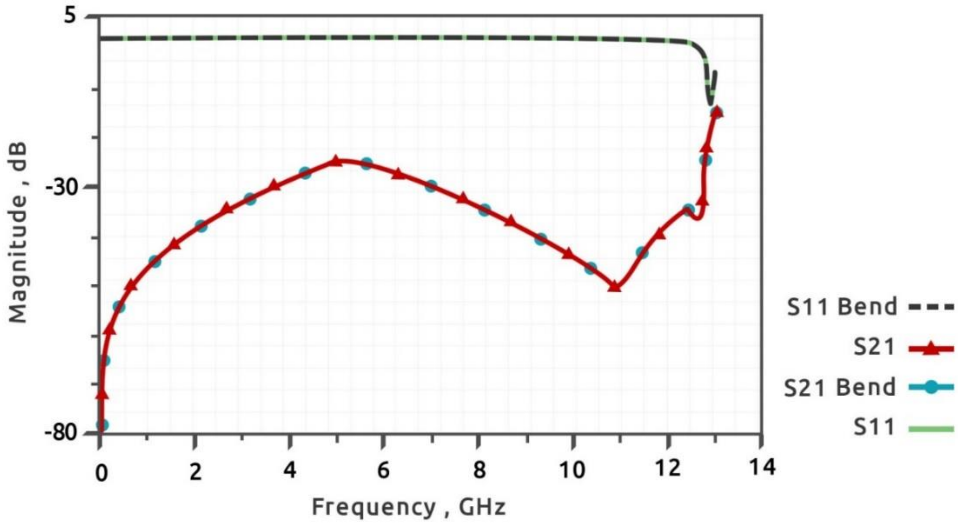

Fig. 4. S-parameters of the Coupled and the bent coupled-resonator.

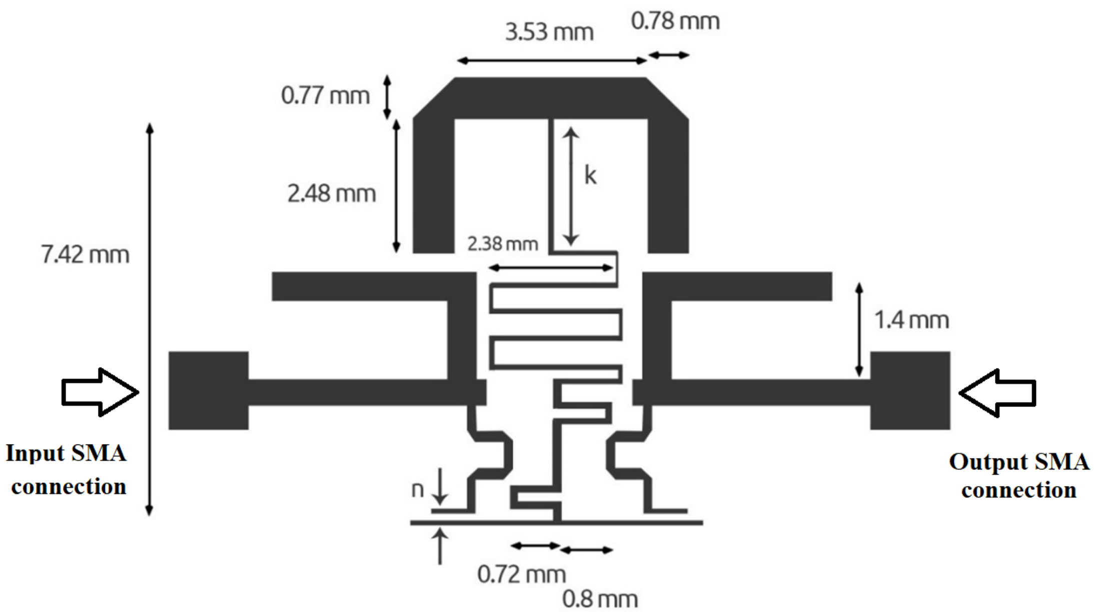

Fig. 5. The structure of the proposed BPF.

As depicted in Figs. 6 and 7, it can be adjusted to a very applicative and standard frequency of 3.6 GHz using a tuning procedure.

The magnitude of the S_{12}-parameter of the BPF as a function of *n* is illustrated in Fig. 6. Considerably, the passband is dependent on this parameter and can be adjusted by tuning this gap distance. Besides, the magnitude of the S_{12}-parameter is illustrated in Fig. 7 for the suggested BPF as a function of *K*. As regarded, the passband is also dependent on this parameter and can be adjusted by tuning this high-impedance line.

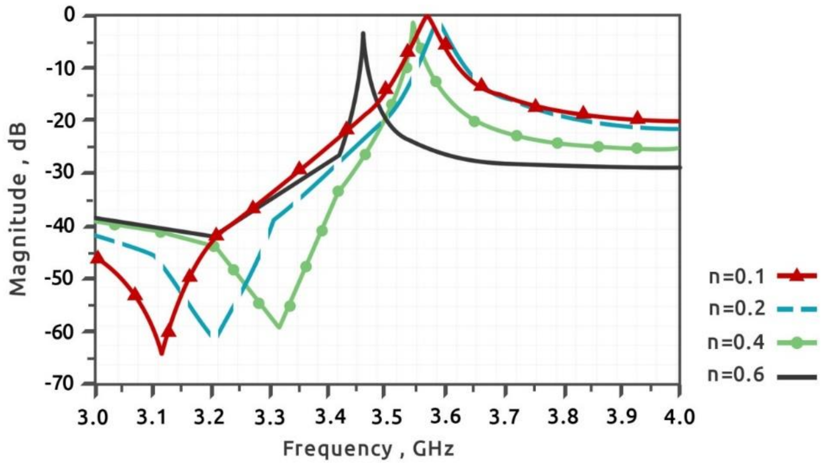

Fig. 6. The magnitude of the S_{12}-parameter as a function of n.

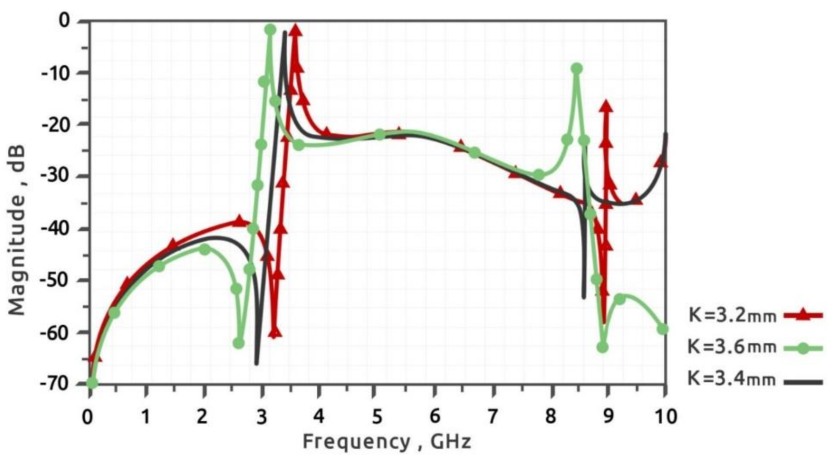

Fig. 7. The magnitude of the S_{12}-parameter as a function of K.

3. RESULTS AND DISCUSSION

As shown in Fig. 8, the designed filter has been fabricated on an RT/Duroid 5880 substrate with a relative dielectric constant ε_r = 2.2, thickness h = 20 mil, and loss tangent 0.0009.

The measurement response and simulation of this filter are compared in Fig. 9, which displays the measured results have suitable matching with the simulation results.

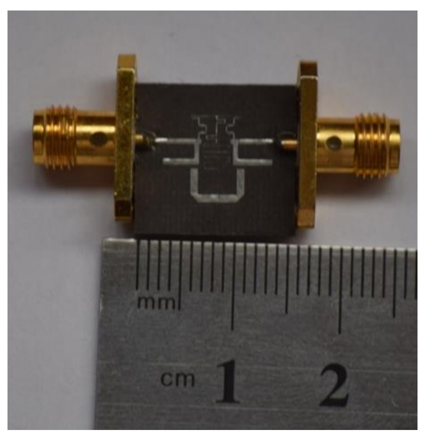

Fig. 8. Fabricated filter.

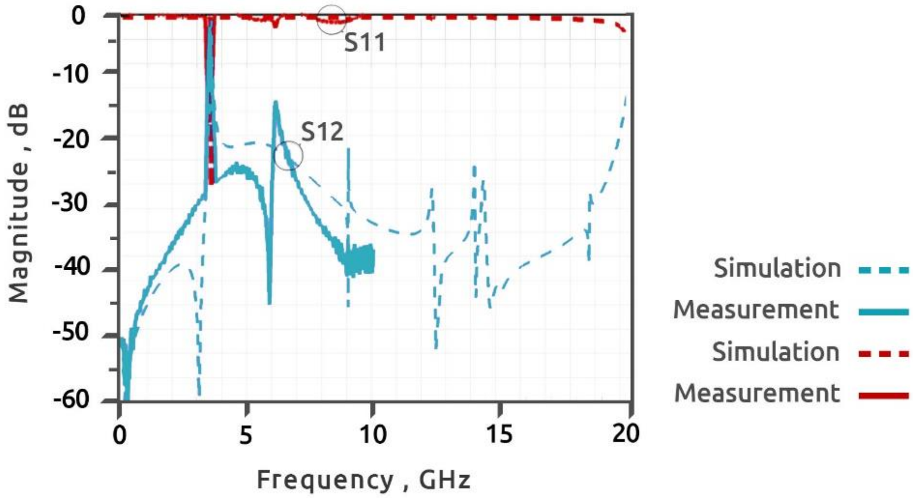

Fig. 9. Comparison of measured results with simulated results.

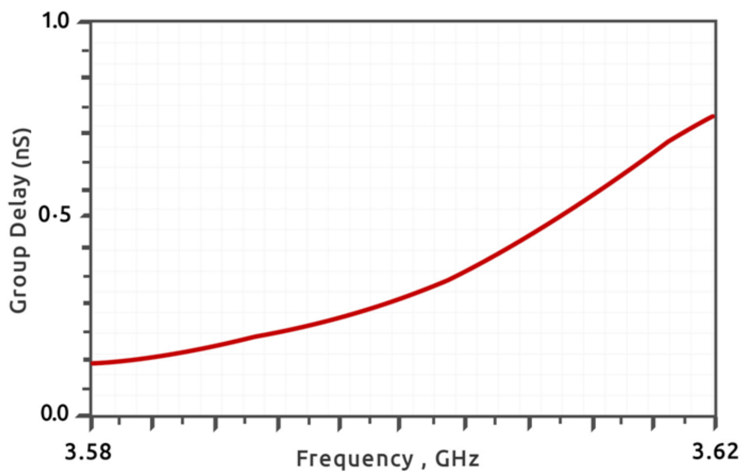

Fig. 10. The group delay of the designed bandpass filter.

The filter has sharp transition bands. The first transition band is 100MHz and the second transition band is 270 MHz (from -3 to -20 dB). The measured bandwidth is too narrow (from 3.58 to 3.62 GHz). The measured insertion loss is 0.6 dB at 3.6 GHz and the return loss is 27 dB. The fractional bandwidth of the proposed filter is about 2%. Concluded from the simulation results, the upper stopband region has been extended to 19.1 GHz with respect to the rejection level of -20 dB. Also, the size of the filter is only 11.9 mm × 8.2 mm equal to $0.19\lambda g \times 0.13\lambda g$. Having a flat group delay in the passband is one of the suitable parameters of a filter [5]. The group delay can be obtained using the equation given below:

$$\text{Group delay (s)} = -\frac{d\varphi}{d\omega} \qquad (7)$$

where ω is the angular frequency in radians per unit time, equal to $2\pi f$, f is the frequency in Hertz, and φ is an overall phase shift in radians. The obtained measured S-parameters from the network analyzer contain both the magnitude and phase of the S-parameters. Fig. 10 has been sketched by extracting the phase of the measured S21 parameter and using Equation (7) in Matlab software. The utmost measured variation group delay is just 0.6 *n*s in the passband area.

The comparison between the proposed BPF and some related studies is listed in Table 1.

As indicated in Table 1, the proposed study demonstrates the least Insertion loss. It is essential to acknowledge the inherent trade-offs in configuring filter parameters. Consequently, the proposed BPF not only exhibits a narrow-band bandwidth but also showcases favorable characteristics like good return and insertion losses. Moreover, observation reveals that the suggested filter stands out as one of the most compact among the references cited.

Table 1. ***A comparison with some published BPF*.**

ref	F(GHz)	Return loss	Insertion loss (dB)	NCS	FBW
[13]	2.35	27.7	1.4	0.2 λg×0.16 λg	16%
[14]	34	12	3.5	0.47 λg×0.28 λg	5%
[15]	2.45	22.7	0.8	0.92 λg×0.345 λg	10%
[18]	2.45	15	0.8	0.92 λg×00.34 λg	10%
[20]	2.6	14	5.8	0.3 λg×0.55 λg	31%
[21]	0.9	15	3	0.28 λg×0.13 λg	20%
[22]	1	14	5.8	0.589 λg×0.317 λg	30%
[23]	2	25	1.7	0.49 λg×0.34 λg	11%
[24]	2.5	19	0.8	0.35 λg×0.35 λg	54%
[25]	3.03	15	0.9	0.77 λg×0.39 λg	105%
[26]	91.5	10	4	-	5%
[27]	16.21	22.5	2.42	0.725 λg×0.598 λg	1.2%
[29]	1.25	24.34	1	0.34λg×0.34λg	22.9%
[30]	30	20	1.5	0.70 λg ×0.38 λg	3%
[31]	0.37-0.8	35	3.4	0.05 λg ×0.06 λg	6%
[32]	3.1	10	1	-	111%
[33]	3.1	13.3	2.9	0.15 λg ×0.12 λg	5%
This work	3.6	27	0.6	0.19λg×0.13λg	2%

4. CONCLUSIONS

In this paper, a single-frequency bandpass filter using a modified coupled structure has been designed. The operational frequency has been adjusted to 3.6 GHz, which is applicable in WiMAX systems. The measure data validated the design results. The proposed BPF has very appropriate passband characteristics with a wide stopband region and too small fabricated circuit size. The insertion and return losses are 0.6 and 27 dB, respectively. To reduce the size, the structure has been bent. The overall size of the designed circuit is just $0.19\lambda g \times 0.13\lambda g$. Due to these excellent features, this filter is suitable for WiMAX applications.

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