Design of a compact and miniature band-pass filter for global positioning system applications

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ABSTRACT

In this paper, a novel compact band pass filter (BPF) is proposed for global positioning system (GPS) applications. The proposed filter which is based on a microstrip resonator is mounted on a low cost RO4000 substrate with a dielectric constant εr=3.5, a thickness h=1.542 mm, a loss tangent tan (δ)=0.0027. It has a bandwidth from 1.55 GHz to 1.72 GHz. This filter is optimized and validated by using two electromagnetic solvers. The area occupied by this BPF is 33.6×41.24 mm^2. The final circuit is a low cost BPF and can be associated with passive and active circuits due to the miniature dimensions.

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1. INTRODUCTION

The development of multi-service mobile wireless communication systems have attracted commercial interest, particularly in the context of combining global positioning systems (GPS). This development has led to an ever-increasing demand for various wireless systems and devices which are compact in size and energy efficient. Filters are critical components in a wide range of electrical systems. These filters are devices that filter, eliminate, or separate signals in distinct frequency ranges. They can be passive or active. Planar filters are made up of metallized lines that act as resonators and have a length proportional to the wavelength of the operating frequency [1]-[10]. Band pass filter (BPF) is an important component in microwave circuits. Recently, there has been a surge of interest in planar BPFs because of their ease of fabrication [11]-[15]. Researchers are now up against a serious difficulty in developing bandpass filters with high matching levels, low insertion losses, small sizes, and ease of manufacture.

Single-mode resonators are commonly used in traditional microstrip BPF. Dual-mode resonators have lately become popular in microwave and radio frequency (RF) wireless communication applications due to their high performance and low loss characteristics [16]-[20]. A dual-mode bandpass filter of a given order requires half as many resonators as a typical configuration due to its double resonant nature [1]. The dual-mode standard for planar resonators is noteworthy, and it has been the focus of extensive research for almost four decades [2].

2. RESEARCH METHOD

The relatively large dimension of planar filters has a considerable impact on their wide application. The widely used dual-mode resonators can be used to make small planar filters. Figure 1 shows the two-dimensional (2D) symmetry of a microstrip dual-mode resonator:

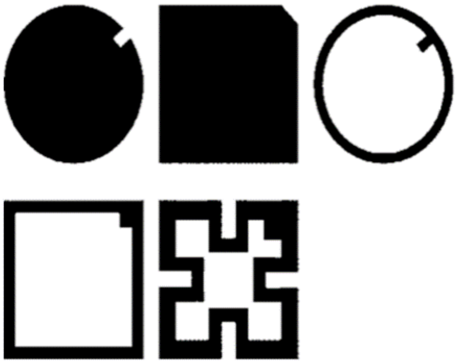


Figure 1. Some microstrip dual-mode resonators [2]

Many RF/microwave filters have been constructed by using dual-mode resonators. The fact that each dual-mode resonator can be utilized as a double tuned resonant circuit reduces the number of resonators required for an n-degree filter by half. This results in a compact filter configuration which is a key characteristic and advantage of these types of resonators [21]-[26]. This filter operates as the shunt-resonator whose design is described by (1)-(3) [2]:

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\left(\frac{FBW}{g_0 g_1}\right)} \quad (1)$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2\sqrt{g_j g_{j+1}}} \; j=1 \text{ to } n-1 \quad (2)$$

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

where g_o, g_1 . . . g_n are the element of a ladder-type lowpass prototype with a normalized cutoff Ω_c=1, the $J_{j,j+1}$ are the characteristic admittances of J-inverters and Y_0 is the characteristic admittance of the microstrip line and is the fractional bandwidth (FBW) [2].

3. DESIGN PROCEDURE

The performance evaluation served as the foundation for this paper. The proposed BPF's configuration is shown in Figure 2, the design approach starts with the creation of a double resonator microstrip BPF with two resonators having slots. Two electromagnetic solvers were used to simulate the proposed filter. One is based on the moments method, while the other is based on Finite Integration. The proposed filter is engraved on a low-cost RO4000 substrate. The dimensions of the upgraded and reduced filter are shown in Table 1. The suggested BPF shows a passband from 1.55 GHz to 1.72 GHz. The size of the proposed BPF is 33.6×44.24 mm^2 which is miniature in comparison with conventional microstrip filters.

A parametric examination into the impact of crucial side length's' has revealed the impact of gap width on the BPF in terms of electrical properties. After this parametric study we have conducted many series of optimization based on random method in order to obtain the fixed goal. Table 2 summarizes the results obtained. Figure 3 illustrates the variation outcome of transmission coefficient S21 filter responses with respect to different 's' values, we can remark that the decrease in 's' value permits to adjust the bandwidth at the GPS band which corresponds to s=0.15 mm.

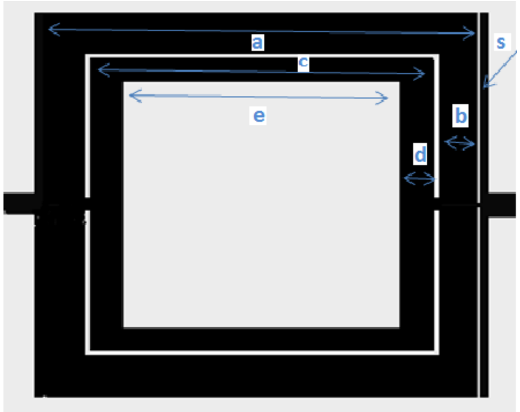


Figure 2. The proposed structure of the microstrip bandpass filter

Table 1. Summary of the dimensions of the proposed bandpass filter

Variable	Value (mm)
a	33.6
b	3
c	26.75
d	2.63
e	21.55
s	0.15

Table 2. The different values of the parameter 's'

Variable	Value (mm)
S_1	0.45
S_2	0.30
S_3	0.15

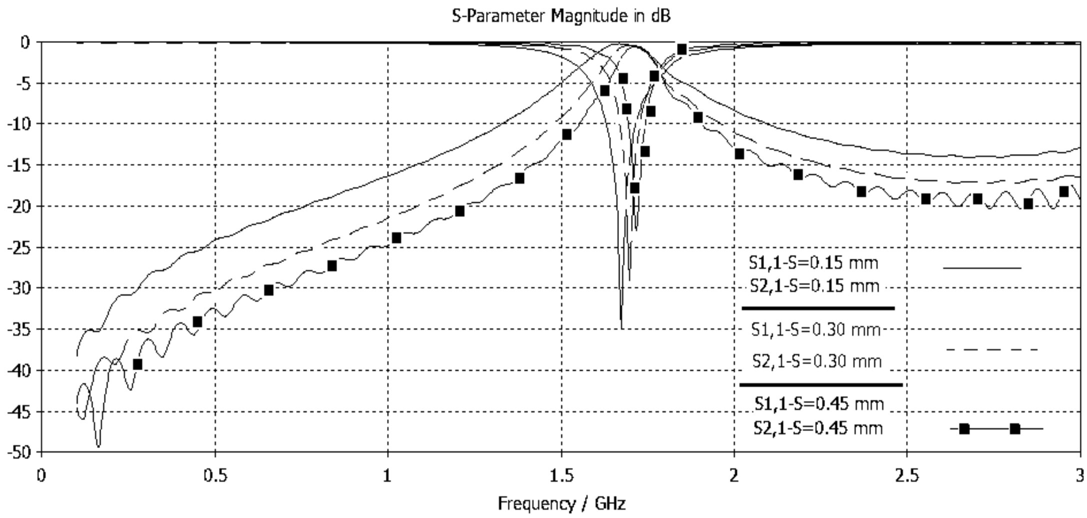


Figure 3. S-parameters of the bandpass filter versus the value of 's'

4. RESULTS AND DISCUSSION

Figure 4 shows the proposed filter's final response versus frequency in terms of input reflection coefficient (S11) and insertion loss (S21). The simulation findings show a good pass band from 1.55 to 1.72 GHz, as well as high return and insertion losses, implying excellent transmission quality in this frequency range. To ensure that the simulation findings are accurate, by using moments method, we both did the same research by using another electromagnetic solver using finite integration technique (FIT) which is 3D design.

For the second solver we have taken into account the dimensions of the ground plane in comparaison with the first solver where the ground plane is infinite. The whole circuitwere simulated taking a high meshing density. The three-dimensional (3D) view of the proposed filter is shown in Figure 5. As seen in Figure 6, the two solvers are in good agreement, with a little difference due to the fact that both electromagnetic solvers employ different numerical approaches.

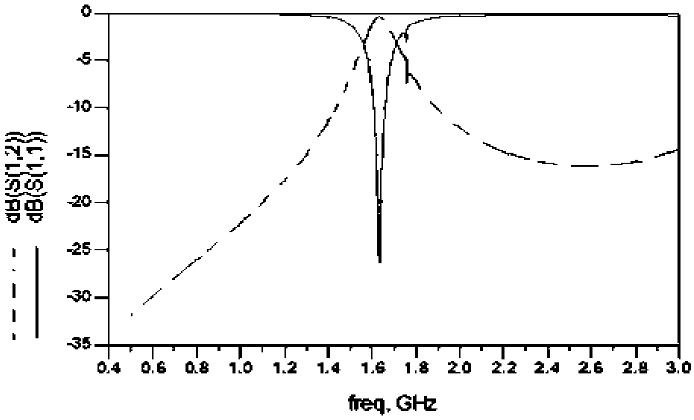


Figure 4. S-parameters of the bandpass filter versus frequency

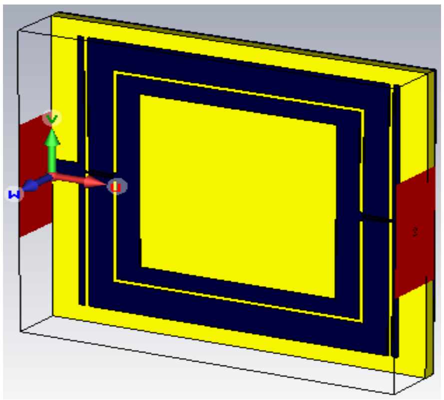


Figure 5. Three-dimensional view of the proposed filter

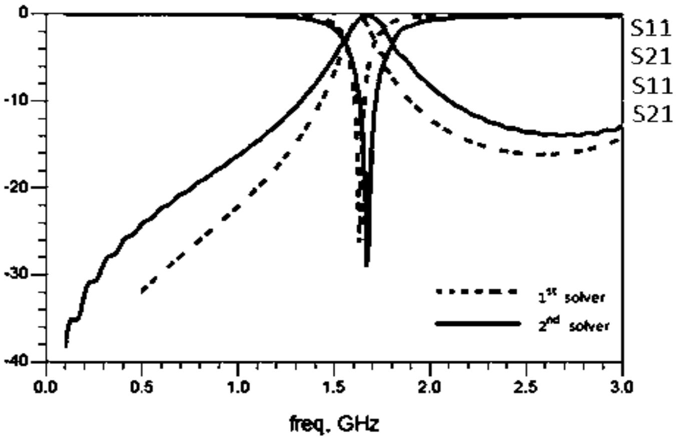


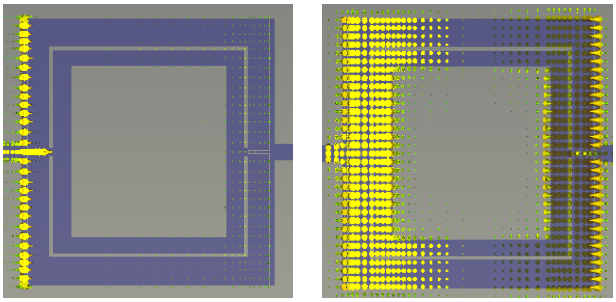
Figure 6. Comparison of the results obtained through the two electromagnetic solvers

The proposed bandpass filter is compared to previous works published in the literature. Table 3 demonstrates that the proposed circuit has a area of 33.6×40 mm^2 and outstanding electrical performance bandwidth. Compared to other works included in the Table 3, the proposed bandpass filter is miniature and compact.

Table 3. Performance comparison with published studies

Parameters/Ref	Pass Band (GHz)	Size (mm^2)
[16]	[1.2-1.75]	1616.24
[17]	[1.1-1.7]	1800
This Work	[1.55-1.72]	1385.66

The surface current distributions at frequencies of 1 GHz and 1.6 GHz are presented in Figure 7 which confirm the behavior of the suggested BPF. It's evident that the surface current distributions at these two frequencies aren't the same. When the first resonant frequency is at 1 GHz, most of the surface current is concentrated on the left part of the supply line Figure 7(a) where the signal is attenuated and dosen't reach the port 2. As indicated in Figure 7(b), the surface current distribution becomes more concentrated along the filter at 1.6 GHz and permitting the RF signal to pass from port1 to port 2.



(a) (b)

Figure 7. Current distributions of the proposed filter at (a) at 1 GHz and (b) at 1.6 GHz

5. CONCLUSION

This study presents and discusses a new filter topology that allows for the creation of a small band-pass filter for GPS applications. When compared to typical bandpass filter topologies, the proposed filter is a new construction with a small dimension. Also the final proposed circuit has good insertion loss and return loss performances. Two electromagnetic simulators were used to analyze the frequency response of the proposed circuit which permit to validate the final circuit. As perspectives we propose to associate metamaterials with the proposed BPF circuit in order to enhance the performances and to make it agile in term of frequency band we propose to integrate with this filter structure active components like varactor diodes permitting to tune and to make the frequency band reconfigurable.

REFERENCES

[1] D. M. Pozar, *Microwave engineering*, 4th ed. JohnWiley & Sons, Inc, 2012.

[2] J.-S. Hong and M. J. Lancaster, *Microstrip filters for RF/microwave applications*. New York, USA: John Wiley & Sons, Inc., 2001.

[3] Y. S. Makimoto M., *Microwave resonators and filters for wireless communication*, vol. 4. Berlin, Heidelberg: Springer Berlin Heidelberg, 2001.

[4] F. Furqan, S. Attamimi, A. Adriansyah, and M. Alaydrus, "Bandpass filter based on complementary split ring resonators at X-Band," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 13, no. 1, pp. 243–248, Jan. 2019, doi: 10.11591/ijeecs.v13.i1.pp243-248.

[5] A. Kadiri, A. Tajmouati, I. Zahraoui, A. R. A. Laaraibi, and M. Latrach, "A planar high pass filter with quasilumped elements for ISM, Wimax and Wlan applications," in *2020 IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science, ICECOCS 2020*, Dec. 2020, pp. 1–4, doi: 10.1109/ICECOCS50124.2020.9314620.

[6] P. H. Mukti, W. Waskito, and E. Setijadi, "Design of Ultra-wide Band band-pass filter with notched band at 802.11a Frequency Spectrum using multi-mode ring resonator," in *ICAMIMIA 2015-International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation, Proceeding - In conjunction with Industrial Mechatronics and Automation Exhibition, IMAE*, Oct. 2016, pp. 81–85, doi: 10.1109/ICAMIMIA.2015.7508007.

[7] A. M. Zobilah, A. Othman, N. A. Shairi, and Z. Zakaria, "Parametric studies of ring and parallel coupled line resonators for matched bandstop filter design," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 1, pp. 29–37, Apr. 2019, doi: 10.11591/ijeecs.v14.i1.pp29-37.

[8] A. Namsang and P. Akkaraekthalin, "Microstrip bandpass filters using end-coupled asymmetrical step-impedance resonators for wide-spurious response," *Progress In Electromagnetics Research C*, vol. 14, pp. 53–65, 2010, doi: 10.2528/PIERC10012704.

[9] H. Saghlatoon and M. H. Neshati, "Design investigation of a novel bandpass filter using trisection open loop resonator," in *Progress in Electromagnetics Research Symposium*, 2012, pp. 1203–1206.

[10] M. Mustapa, Z. A. Zakaria, and N. A. Shairi, "Design of quasi-elliptic bandpass filter for substrate integrated waveguide (SIW) using cross coupling technique," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 12, no. 3, pp. 1366–1372, Dec. 2018, doi: 10.11591/ijeecs.v12.i3.pp1366-1372.

[11] V. M. Dabhi and V. V. Dwivedi, "Parallel coupled microstrip bandpass filter designed and modeled at 2 GHz," in *International Conference on Signal Processing, Communication, Power and Embedded System, SCOPES 2016 - Proceedings*, Oct. 2017, pp. 461–466, doi: 10.1109/SCOPES.2016.7955873.

[12] Y. S. Mezaal and A. S. Al-Zayed, "Design of microstrip bandpass filters based on stair-step patch resonator," *International Journal of Electronics*, vol. 106, no. 3, pp. 477–490, Mar. 2019, doi: 10.1080/00207217.2018.1545144.

[13] P. Vélez, J. Naqui, M. Durán-Sindreu, J. Bonache, and F. Martín, "Broadband microstrip bandpass filter based on open complementary split ring resonators," *International Journal of Antennas and Propagation*, vol. 2012, pp. 1–6, 2012, doi: 10.1155/2012/174023.

[14] Y. S. Mezaal and H. T. Eyyuboglu, "Investigation of new microstrip bandpass filter based on patch resonator with geometrical fractal slot," *PLoS ONE*, vol. 11, no. 4, p. e0152615, Apr. 2016, doi: 10.1371/journal.pone.0152615.

[15] A. J. Salim, A. N. Alkhafaji, M. S. Taha, and J. K. Ali, "A polygonal open-loop resonator compact bandpass filter for Bluetooth and WLAN applications," *IOP Conference Series: Materials Science and Engineering*, vol. 433, no. 1, p. 012083, Nov. 2018, doi: 10.1088/1757-899X/433/1/012083.

[16] T. J. Zeng and C. J. Wang, "Design of a compact wideband microstrip bandpass filter using multiple-mode resonator," in *2016 Progress In Electromagnetics Research Symposium, PIERS 2016 - Proceedings*, Aug. 2016, pp. 2951–2953, doi: 10.1109/PIERS.2016.7735164.

[17] L. Wang, G. Wang, Y. He, and R. Zhang, "Design of microstrip bandpass filters using fragment-type coupling structure based on multi-objective optimization," in *IEEE MTT-S International Microwave Symposium Digest*, Jun. 2017, pp. 1620–1623, doi: 10.1109/MWSYM.2017.8058946.

[18] S. El Kilani, L. El Abdellaoui, J. Zbitou, A. Errkik, and M. Latrach, "A compact dual band PIFA antenna for GPS and ISM BAND applications," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 3, pp. 1266–1271, Jun. 2019, doi: 10.11591/ijeecs.v14.i3.pp1266-1271.

[19] P. Marraccini and N. Behdad, "Design of Compact and miniaturized band-pass filters in coplanar waveguide (CPW) technology 2. Filter design and principles of operation 3. Filter implementation and measurement results," in *URSI XXIX General Assembly conference*, 2008, vol. 1, pp. 2–5.

[20] N. Rosli, S. A. M. Akhir, S. Z. Ibrahim, N. B. M. Hashim, and N. Khalid, "Design of compact multi-mode microstrip resonator filters for dual-band application," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 13, no. 2, pp. 696–701, Feb. 2019, doi: 10.11591/ijeecs.v13.i2.pp696-701.

[21] P. H. Deng and J. T. Tsai, "Design of microstrip cross-coupled bandpass filter with multiple independent designable transmission zeros using branch-line resonators," *IEEE Microwave and Wireless Components Letters*, vol. 23, no. 5, pp. 249–251, May 2013, doi: 10.1109/LMWC.2013.2253601.

[22] N. A. Wahab, M. N. Md Tan, and M. N. Hushim, "Closed-loop ring resonator topology for bandpass filter applications," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 3, pp. 1422–1426, Mar. 2019, doi: 10.11591/ijeecs.v17.i3.pp1422-1426.

[23] L. Huang, I. D. Robertson, W. Wu, and N. Yuan, "Substrate integrated waveguide filters with broadside-coupled complementary split ring resonators," *IET Microwaves, Antennas and Propagation*, vol. 7, no. 10, pp. 795–801, Jul. 2013, doi: 10.1049/iet-map.2013.0117.

[24] R. L. La Valle, J. G. Garcia, and P. A. Roncagliolo, "Dual-band bandpass filter with wide stopband and low insertion loss for GNSS signals," in *LAMC 2016-IEEE MTT-S Latin America Microwave Conference*, Dec. 2017, pp. 1–3, doi: 10.1109/LAMC.2016.7851257.

[25] N. Ab. Wahab *et al.*, "Bandpass filter based on ring resonator at RF frequency above 20 GHz," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 9, no. 3, pp. 680–684, Mar. 2018, doi: 10.11591/ijeecs.v9.i3.pp680-684.

[26] E. Sghir, E. Ahmed, J. Zbitou, A. Tajmouati, and L. El Abdellaoui, "A novel compact CPW multi-stopband filter with DGS integrating circular ring resonator," *Transactions on Machine Learning and Artificial Intelligence*, vol. 5, no. 4, Aug. 2017, doi: 10.14738/tmlai.54.3331.

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