Design of a New Ultra-Wideband Bandpass Filter using Multiple-Mode-Resonator for Medical Sensor Networks

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Abstract. This paper is intended to provide a new design of an innovative Ultra-wideband (UWB) bandpass filter with the use of multiple-mode-resonator (MMR) based for Medical Sensor Networks (MSN) applications. The design work was initiated through theory examination of the MMR to calculate the dimensions values of their lines. Then, the study was simulated and optimized using Advanced design system to obtain a wideband response from 3.4 GHz to 10.6 GHz. When successful design validation was verified by the use of CST Microwave software, the filter structure was further developed to attain compact topology by inclining the central resonator in inverted U-shaped line. Its compact size and the good key performance such as low insertion loss and high return loss in the UWB range make it a potential candidate for UWB wireless communication in medical applications.

1 Introduction

Medical Sensor Networks (MSNs) are a set of communicating sensors that monitor patients' physique, especially in a permanent and/or periodic way. These sensors could be wear or implantable to collect important information such as blood pressure, heart rate, body temperature and glucose levels. The data signals are wirelessly transmitted to a central hub (such as a smartphone or medical monitoring system) for analysis, diagnosis, and potentially real-time medical intervention [1–4].
MSNs are widely employed in health care for long-distance patient monitoring, telemedicine and chronic disease supervision, providing a non-intrusive, simple and convenient way to monitor patient health. MSN is of great importance to the health care, since it achieves the monitoring of the human health continually without the need of visiting the hospital regularly [2].

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In this context, microstrip filters are the keys to guarantee the reliability and effi-ciency of the wireless communication from the sensors to the monitoring units [5]. Microstrip bandpass filters (BPFs) are used to select a specific frequency band [6–10]. Moreover, BPFs are commonly examinated for designing multiplexers and di-plexers [11–16]. Several techniques are utilized to enhance their performance or miniaturize the topology of the filters. Some filters are developed using meander lines [9,16,17], hairpin resonators [5,15,18,19], new shaped-resonator to guarantee both miniaturization and high performances [6,7,20]. Plus, defetcted ground structure (DGS) is used in the design of BPFs to ameliorate selectivity and suppress the undesired harmonics [20]. In addition, to attain UWB bandpass filters, researchers are used multiple mode resonators (MMRs), which are included short-circuited stubs and separated by quarter wavelength and a semicircle [21].

This letter introduces the analysis of a compact Ultra-Wideband (UWB) filter for Medical Sensor Networks (MSN). The work starts with a theoretic study of a multiple-mode resonator, followed by its simulation and optimization steps using advanced design system. Then, the basic BPF is developed by inclining the central resonator into an inverted U-shaped line to obtain the more compact configuration of the filter. The results, obtained between both Advanced Design System and CST Microwave Studio, show excellent responses exhibiting low insertion loss and good return loss over the UWB range (3.4-10.6 GHz), which makes this filter a suitable one for effective and reliable communication in MSNs.

2 Design of basic multiple-mode-resonator

2.1 Theory of multiple-mode resonator

Muliple-mode resonator (MMR) is a topology of resonator, which is used and designed to resonate at several distinct frequencies, allowing the creation of a compact and efficient UWB bandpass filter [21,22].

Fig. 1 illustrates the configuration of the suggested microstrip MMR UWB bandpass filter. As shown, MMR includes, there is a half-wavelength (λg/2) low impedance line part in the middle of the ultra-wideband, and two identical (λg/4) high impedance line sections on both sides. This suggested topology may be classified as a stepped-impedance resonator (SIR).

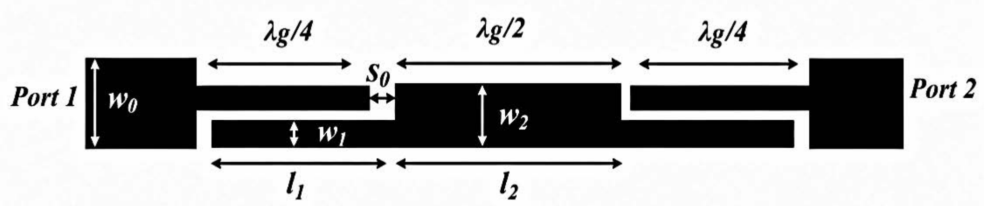

Fig. 1. Structure of basic MMR.

The following equations are employed to calculate the lengths l_1 and l_2 of the lines based on the guided wavelength [23]:

$$l_1 = \frac{\lambda_g}{4} \quad (1)$$

$$l_2 = \frac{\lambda_g}{2} \quad (2)$$

Where: $\lambda_g = \frac{C}{f\sqrt{\varepsilon_{eff}}}$

C is the velocity of electromagnetic waves in free space.

f is the frequency.

ε_{eff} is the effective dielectric constant.

f_0 is resonance frequency.

The widths of the two lines are calculated using the approximate expressions for W/h [23]:

For W/h ≥ 2 :

$$\frac{W}{h} = \frac{2}{\pi}\left[(B-1) - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right] \quad (3)$$

With: $B = \frac{60\pi^2}{Z_c\sqrt{\varepsilon_r}}$

$$L_r = \frac{\lambda}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon_r}}$$

$$\lambda_0 = \frac{C}{f_0}$$

For W/h ≥ 2 :

$$\frac{W}{h} = \frac{8\exp(A)}{\exp(2A) - 2}$$

With :

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \quad (4)$$

Z_c is characteristic impedance.

ε_r is permittivity of substrate.

Noted that the lengths and widths can be calculated using the tool LinCalc that is integrated on advanced design system software.

2.2 Simulation of the basic topology of MMR

A microstrip bandpass filter based on MMR was simulated and optimized using advanced design system and based on the analysis discussed above. This filter is designed to operate at ultra-wide band from 3.1GHz to 10.6GHz. The optimized parameters, including the lengths l_i, widths w_i, and gap S_i of the structure in question, are illustrated in Table 1.

Table 1. Optimized parameters of MMR.

Parameters	l_1	l_2	W_0	W_1	W_2	S_0
Values (mm)	4.15	7.34	1.2	0.4	3	0.05

The performance of the designed topology was evaluated through the electromagnetic (EM) simulations using the Advanced Design System (ADS). The substrate used is Rogers RO 3210, having a permittivity of 10.8, thickness of 1.27mm and TanD of 0.0027. Fig. 2 depicts the UWB MMR's frequency responses.

According to the simulated results shown in Fig. 2, the basic MMR UWB BPF exhibits acceptable performance from 3.5GHz to 10.6GHz, with the transmission coefficient S_{21} being approximately -0.3 dB at the center frequency 6.85 GHz and the reflection coefficient S_{11} measuring around -11 dB at the UWB. Moreover, the conventional BPF is around 19✕3mm^2, making it more large for the demanded application. To attain an increasingly compact topology, the central resonator should be developed.

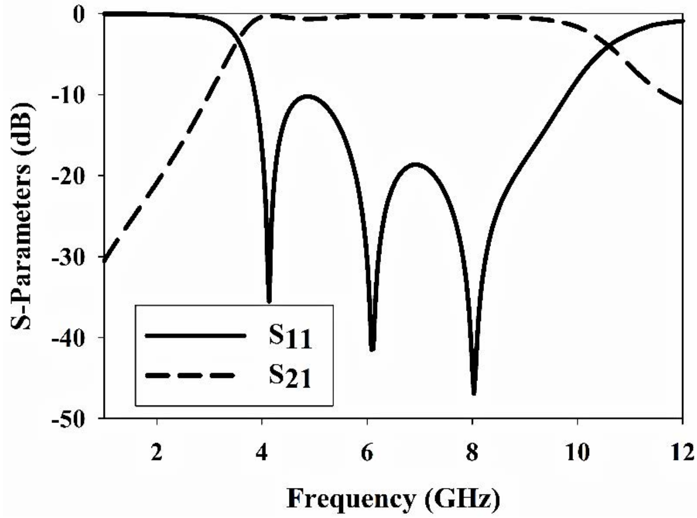

Fig. 2. Frequency response of the basic BPF.

3 Design of innovative multiple-mode-resonator

To obtain a more compact structure of the BPF, the filter structure was developed by inclining the central resonator in inverted U-shaped line, as presented in Fig. 3. The development of a MMR BPF using inverted U-shaped line can effectively optimize the frequency band to keep UWB response. U-shaped, with their compact structure, not only reduce the filter's overall size but also allow of a low insertion loss and good return loss in the UWB. Plus, the U-shaped line keep the some length of the basic line except the width, which is intended for a parametric analysis.

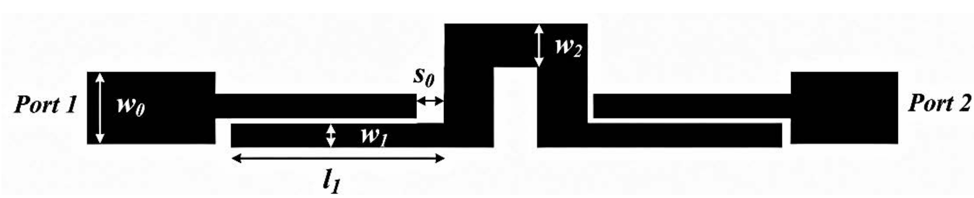

Fig. 3. Structure of the developed MMR based on inverted U-shaped line.

The innovative BPF using MMR and inverted U-shaped line was simulated and optimized by ADS using the same substrate. As shown in Fig. 4, the decrease in width w_2 to 0.5mm shows the enlargement of the band from 3.5GHz to 11GHz; as well, the value of the return loss decreases to 10dB. Whereas increasing this parameter implies a drop in bandwidth from 3.5 to 10.4GHz and a decrease in the value of the return loss to 9.1dB. The optimum value of 0.7 provides an acceptable value of the return loss 14dB in the examined range from 3.4GHz to 10.6GHz.

Once the dimensions of the proposed topology of the BPF has been optimized, the EM simulation using (ADS) and CST Microwave Studio has been plotted in Fig. 5. The return loss is 14 dB, indicating low reflection inside the desired UWB. The insertion loss is also found to be 0.3 dB which implies the high signal transferring capability over the ultra-wideband. Furthermore, this new topology is based on a compact topology down to just

14x3mm^2 area. These advantages demonstrate the potential for the proposed BPF in UWB wireless communication for medical applications, especially a medical sensor application as UWB filters provide a real-time transmission of the imaging data which are essential in emergency care, remotely diagnosis and patient monitoring systems.

The current distribution of the UWB filter varies wildly across different frequencies. The stopband has a low current concentration, indicating that the filter is successful in rejecting undesired signals (Fig 6–b). Contrariwise, in the passband, the current is highly concentrated, particularly in the structure's center, indicating significant signal transmission from the input to the output ports, as seen in Fig. 6-a.

The UWB filter's performance comparison with the designs reported in the literature is summarized in Table 2. The designed filter shows good S11 and lower S21 than the above references in Table 2 [21,24-26]. Notably, with dimensions of just 14$\times$3mm^2, it offers the smallest size among the filters listed in the Table 2 [21,24-26]. Thus, this demonstrates that the inverted U-shaped line is very efficient for compactness and high performance in UWB BPF design.

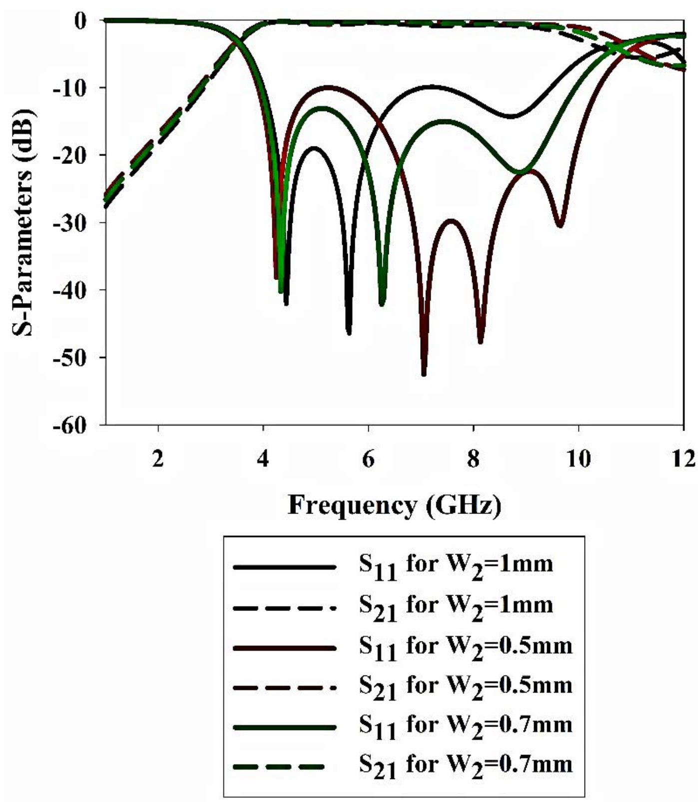

Fig. 4. Simulated S-Parameters of innovative BPF with varied W_2.

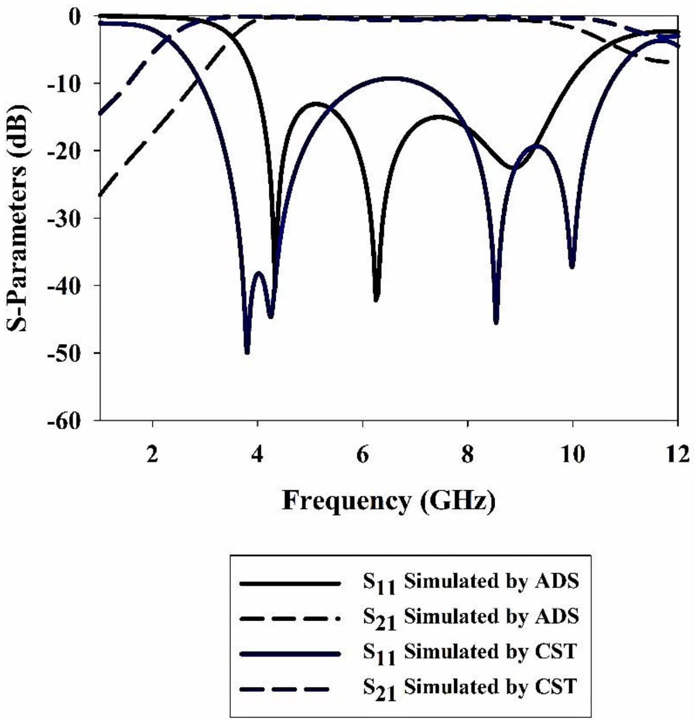

Fig. 5. Results of the creative BPF obtained by ADS and CST.

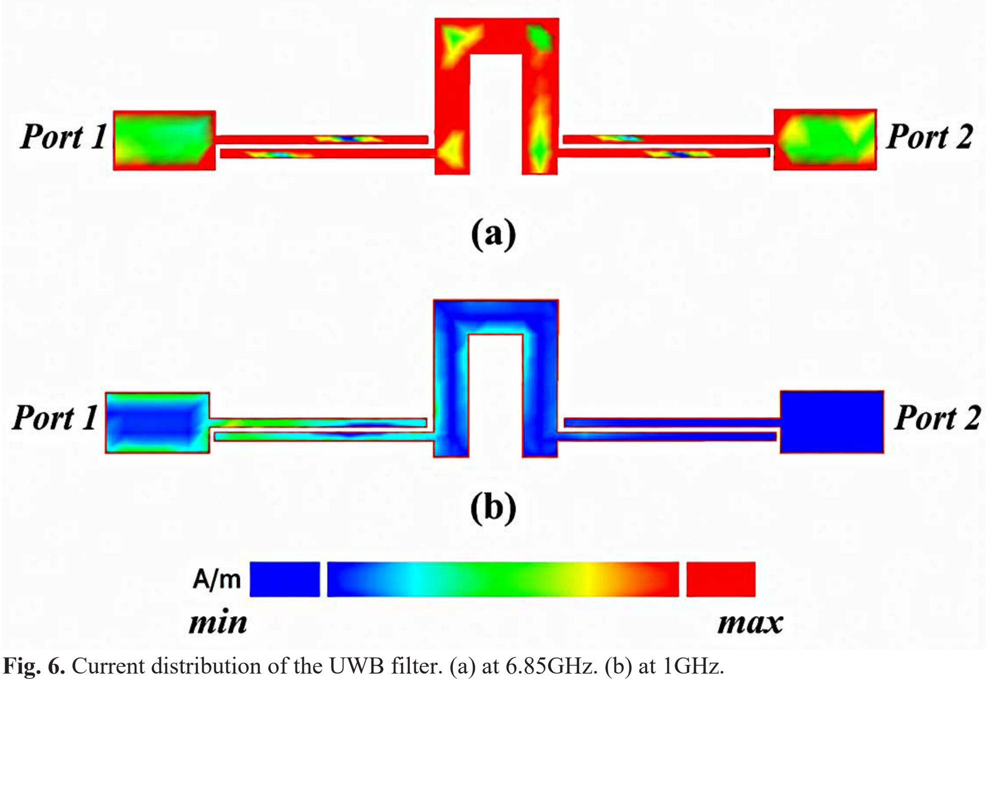

Fig. 6. Current distribution of the UWB filter. (a) at 6.85GHz. (b) at 1GHz.

Table 2: Performance comparison of the intended BPF and others works in literature.

References	Return loss (dB)	Insertion loss (dB)	Size (mm^2)
[21]	10	2	60
[24]	11	1.1	127.4
[25]	15	1.75	≃100
[26]	12	1.6	232
[This work]	14	0.3	42

4 Conclusion

This letter emphasizes the development of an innovative bandpass filter based on the multiple-mode resonator. The proposed innovative bandpass filter provides significant advantages for operating in the UWB from 3.4GHz to 10.6GHz by involving inverted-U shaped line into its design. It has been shown from the obtained results that a high return loss with a low insertion loss the proposed filter is well suited for the UWB applications. This thus serves as an efficient solution for the contemporary MSN applications that require dependable signal quality.

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