Miniaturized (UWB) Band Pass Filter Using Elliptical-Ring Multi-Mode Stub-Loaded Resonator (MM-SLR)

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Abstract. *In this paper, a novel miniaturized ultra-wideband (UWB) band pass filter (BPF) with sharp slopes transition band is reported. The UWB BPF (7.45 GHz to 19.85 GHz) consists of modified elliptical-ring and multi-mode stub-loaded resonator (MM-SLR) and symmetry tight coupled resonator (STCR) via input/output (I/O) lines, achieving UWB band pass response. With adding a T-shaped to the middle resonator, two transmission zeroes are created at 6.84/23.05 GHz. The proposed filter has the ability of creating a notch band in pass band by reducing the length of two coupled lines that can be controlled based on analytical method. Moreover, the equivalent circuit and the analytical theories of each circuit element are proposed. Measured results of fabricated filter have the advantages such as ultra-wide pass band of the defined UWB pass band are 7.45 GHz and 19.85 GHz, satisfying the requirements of FCC-specified UWB limits, compact size, low insertion loss < 0.6 dB and the stop band of the proposed filter is from 19.85 to 33 GHz with attenuation of –17 to –29 dB respectively. The proposed UWB filter is realized using the substrate with dielectric constant of 2.2 and substrate height of 0.787 mm Experimental verification is provided and good agreement has been found between simulation and measurement.*

Keywords

Band Pass Filter (BPF), Ultra-Wide Band (UWB), Multi-Mode Resonator (MMR), Symmetric Tight Coupled Resonator (STCR)

1. Introduction

UWB technology with operating band (3.1 to 10.6 GHz) is an attractive technology for local area networks, positioning and tracking, and radar systems [1]. It has the characteristics of low cost, low weight, high data transmission rate and very low power consumption. The UWB filters are important elements in many RF microwave applications where they are used to separate or combine different frequencies [2], [3]. Radio frequency (RF) microwave filters can be designed as lumped element or distributed element circuits. The filters may be realized in various transmission line structures, such as waveguide, coaxial line, and microstrip. Recently, numerous surveys about UWB BPF accomplished using various resonator and analysis [3–7]. An ultra-wideband (UWB) band pass filter with a band notch was propounded [3]. In this paper, it is shown that the notch frequency could be tuned by changing the impedance ratio of the embedded SIR. A new ultra-wideband (UWB) band pass filter (BPF) using triangle-ring multi-mode stub-loaded resonator (MM-SLR) was presented [4], so that there are five resonant modes generated in the UWB pass band, including two odd modes and three even modes. Also a novel compact ultra-wideband (UWB) band pass filter (BPF) with triple sharply notched bands and good selectivity was proposed using a parallel U-shaped defected microstrip structure (UDMS) in [5]. An asymmetric dual-line coupling strip (ADLCS) could provide main two paths for the signals as propounded in [6], which makes it possible to generate multiple transmission zeroes. Lately, a novel ring resonator band pass filter (BPF) was proposed [7], that has a wide bandwidth and high selectivity and wide stop band. Various structures have been presented to implement the fixed notch bands in the pass band of the UWB band pass filters in [8–17]. As a result, the UWB BPF filters with tunable notched band become more and more important for future cognitive radio system.

In this paper, a novel miniaturized ultra-wideband band pass filter with sharp slopes transition band is reported, the UWB BPF (7.45–19.85 GHz) is realized using elliptical-ring multi-mode stub-loaded resonator (MM-SLR) and symmetric tight coupled resonator (STCR) via input/output (I/O) lines, achieving UWB band pass response. The proposed filter has the ability of creating a notch band in pass band by reducing the length of two coupled lines that can be controlled based on analytical method. Moreover, the equivalent circuit L-C and the analytical theories of each circuit element are proposed. To validate the design and analysis, a UWB BPF is designed, simulated by the ADS simulator and fabricated on a 31mil thick RT/Duorid 5880 substrate with a relative dielectric constant 2.2 and loss tangent of 0.0009. The rest of the paper contains of the filter design procedure as presented in Sec. 2. The analysis of the proposed filter is presented in Sec. 3 which is followed by results and discussion in Sec. 4. Also the software Tecplot 9.0 is used for analyzing all structures.

2. Filter Design

The layout of the proposed filter in this paper is shown in Fig. 1. The proposed filter consists of a modified elliptical-ring (MM-SLR) and symmetric coupled (I/O) lines. The dimensions of the proposed filter are shown in the figure. The proposal of the filter design is to achieve the following parameters:

- Achieves the ultra-wide band (7.45–19.85 GHz) which satisfies the requirements of FCC-specified UWB limits.
- Creates two transition zeros by adding T-shaped resonator.
- Creates 4 resonance modes in pass band frequency.
- The proposed filter has the ability of creating a notch band in the pass band by reducing the length of two coupled lines that can be controlled using an analytical method.
- Provides a very small dimensional filter (10.78 mm × 7.652 mm).

The filter design procedure is as follows: firstly, a stepped impedance resonator (SIR), certainly an initial UWB, has been reported in Fig. 2 that is used as a main structure of the present filter. Frequency response of the basic proposed filter, so a band stop response with four resonant modes at the beginning and end frequency response is presented in Fig. 2.

Secondly, by adding the symmetric interdigital coupled I/O lines in Fig. 3, UWB band pass response can be achieved. In some literatures, interdigital coupled lines have been widely used as a capacitive coupling element in band pass filters. If this SIR is properly fed with two interdigital parallel-coupled lines with an increased coupling degree, an UWB pass band can be achieved. As seen in frequency response, there are four resonant modes in band pass response, achieving an upper stop band up to more than 32.9 GHz. The proposed filter has a wide pass band from 8.63 GHz to 20.36 GHz with insertion loss which is better than 0.8 dB and return loss is less than 13.5 dB.

Finally, by adding a T-shaped to middle resonator in Fig. 4, two transmission zeroes at 6.84/23.05 GHz with sharp slopes transition band can be created, while shifting the pass band frequency of about 1 GHz to down frequencies. As shown in frequency response, there are four resonant modes generated in the UWB pass band. Also it has an upper stop band with greater than 16 dB attenuation up to more than 33 GHz. The proposed filter has a wide pass band from 7.45 GHz to 19.85 GHz with insertion loss better than 0.6 dB and return loss less than 11 dB.

Figure 5 shows the current densities of resonators at 2f(a) (stop-band frequency). It can be noticed that in Fig. 5(a) the current densities pass through the resonator with T-shaped in frequency 7.45 GHz. In Fig. 5(b) the current densities of resonators without T-shaped in frequency 7.45 GHz cannot pass through the resonator.

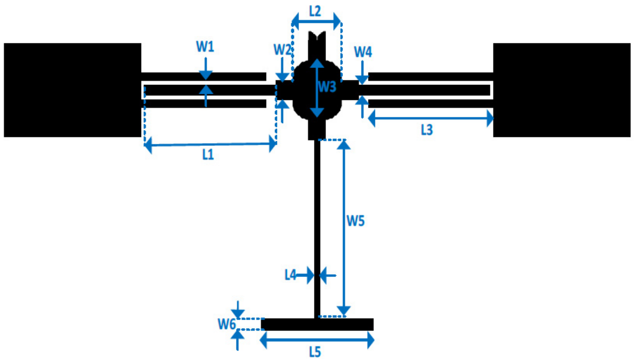


Fig. 1. The layout of the proposed UWB filter, the dimensions are $L_1 = 4$ mm, $L_2 = 1.5$ mm, $L_3 = 3.8$ mm, $L_4 = 0.2$ mm, $L_5 = 3.4$ mm, $W_1 = 0.1$ mm, $W_2 = 0.5002$ mm, $W_3 = 1.5$ mm, $W_4 = 0.3$ mm, $W_5 = 4.6$ mm, $W_6 = 0.3$ mm.

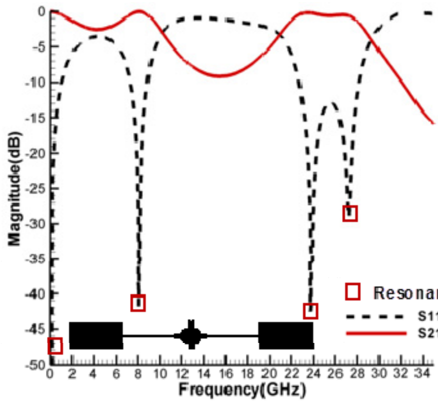


Fig. 2. Frequency dependence of the basic UWB filter magnitude.

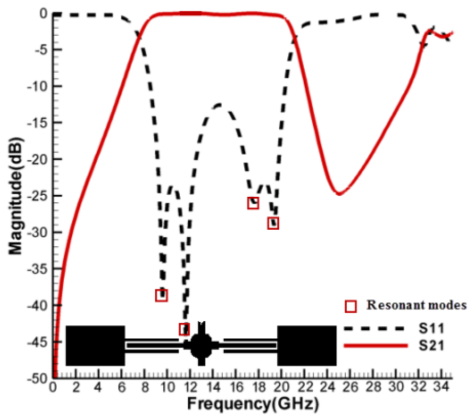


Fig. 3. Frequency dependence of added coupling lines (I/O) UWB filter magnitude.

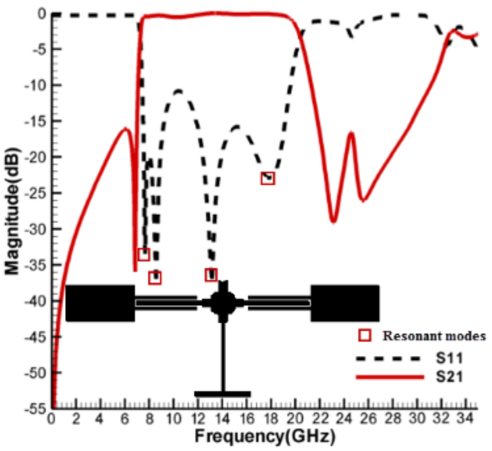


Fig. 4. Frequency dependence of added T-shape to middle resonator UWB filter magnitude.

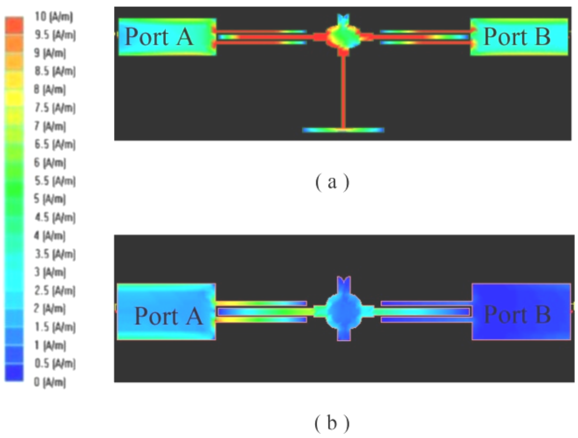


Fig. 5. Current densities of resonator: (a) With T-shaped and (b) Without T-shaped.

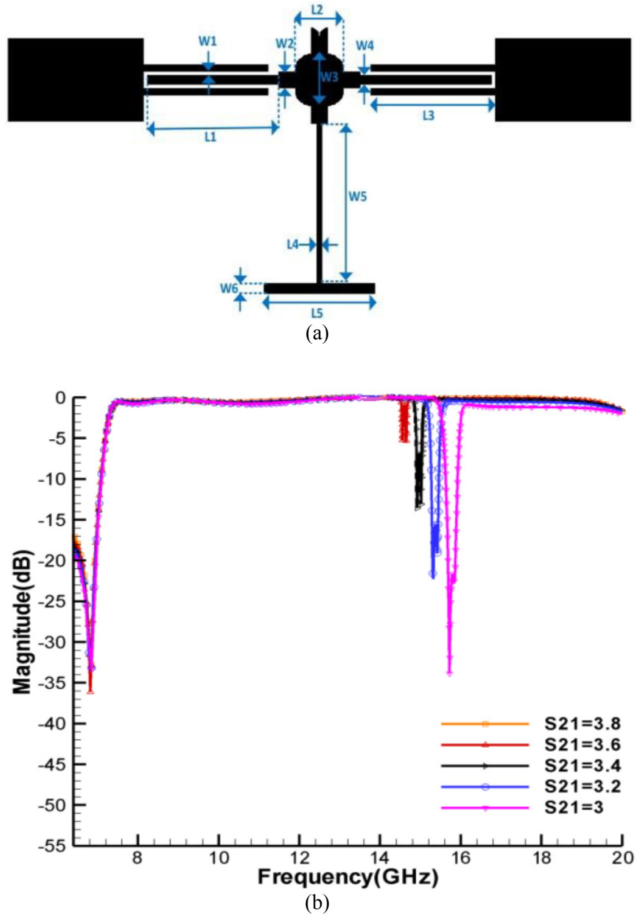


Fig. 6. (a) Configuration and (b) the frequency response of the changes notch band.

L_3 [mm]	3.6	3.4	3.2	3
Notch band frequency (GHz)	14.65	14.92	15.32	15.72

Tab. 1. Values of L_3 and notch band frequency.

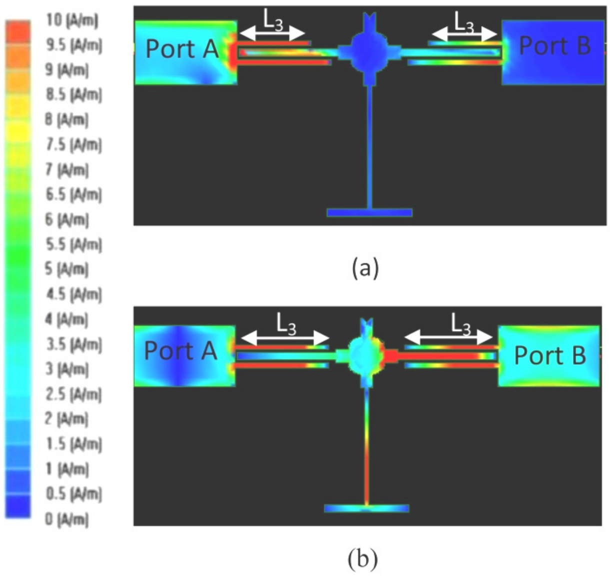


Fig. 7. Current densities of the resonator (a) with length $L_3 = 3$ mm and (b) with the length $L_3 = 3.8$ mm.

3. Proposed Filter Analysis

3.1 Control Notched Band Using Analytical Method

The exclusive use of the spectrum without causing interference to other existing services, such as wireless local – area network (WLAN), should be considered, and the FCC specification cannot provide enough protection from harmful interference from generic UWB applications for existing radio systems. For this reason, after achieving wide pass band from 6.84/23.05 GHz it is to provide notched band in order to suppress undesired signals. To control this issue, single [18–22], or multiple [22], narrow-band notched UWB filters were developed. By introducing slot line or open-circuited stubs into the filtering topologies, a notch or narrow rejection band can be generated in a certain frequency range in the UWB pass band. By emphasizing this issue, in the proposed filter, the notch band can be controlled changing the length of the symmetric coupling with formula (1), which is based on empirical method. By reducing the length L_3 from 3.8 mm to 3 mm,

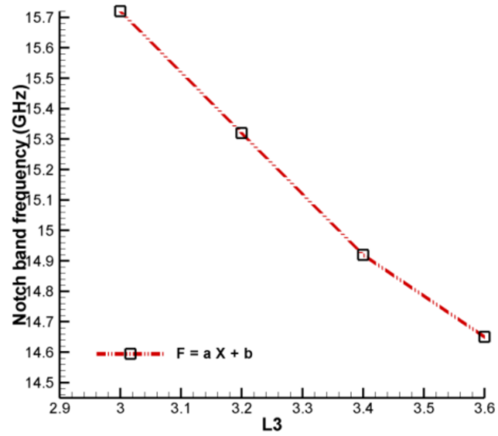


Fig. 8. Chart of the notch band frequency changes according to the length L_3 in mm.

as shown in Fig. 6(a), the notch band is created and shifts to high frequencies as depicted in Fig. 6(b). Values of L_3 and the related notch band frequency are summarized in Tab. 1. Figure 7(a) shows by selecting the length L_3 = 3.8 mm and frequency 15.72 GHz, the current densities passing through the resonator. Also Figure 7(b) shows by selecting the length L_3 = 3 mm, created notch band frequency is 15.72 GHz, the current densities cannot pass through the resonator but stop at the port B .The equation between the notch band frequency and length L_3 is approximated as a linear equation (f(GHz) = notch band frequency, $x = L_3$(mm), a and b are constants) as shown in Fig. 8. The relation between notch band frequency and L_3 can be presented as:

$$f_{\text{notch band}}[\text{GHz}] = (-1.783)\ L_3 + 21.07, \quad \text{if} \quad 3 \le L_3[\text{mm}] \le 3.6. \tag{1}$$

3.2 L-C Equivalent Circuit for the Middle Resonator

The middle resonator of the proposed filter consists of some short length of high-impedance (Z_c) lossless line which is terminated at both ends by relatively low impedance (Z_o) and is represented by a π-equivalent circuit as shown in Fig. 9. For a propagation constant $\beta = 2\pi/\lambda_g$ of the short line, the circuit parameters are given by [2]:

$$x = Z_c \sin\left(\frac{2\pi}{\lambda_g} l\right), \tag{2}$$

$$\frac{B}{2} = \frac{1}{Z_c} \tan\left(\frac{\pi}{\lambda_g} l\right), \tag{3}$$

$$\lambda_g = \frac{300}{f_c\sqrt{\varepsilon_{re}}} \tag{4}$$

where λ_g [mm] is the guided wavelength on the substrate at the center frequency, f_c is the central frequency [GHz] and ε_{re} denotes the effective dielectric constant of the microstrip line.

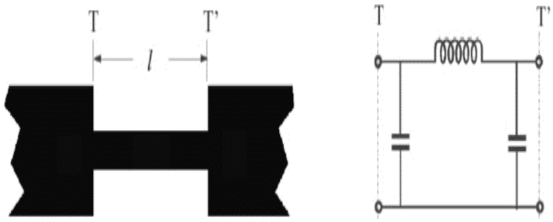
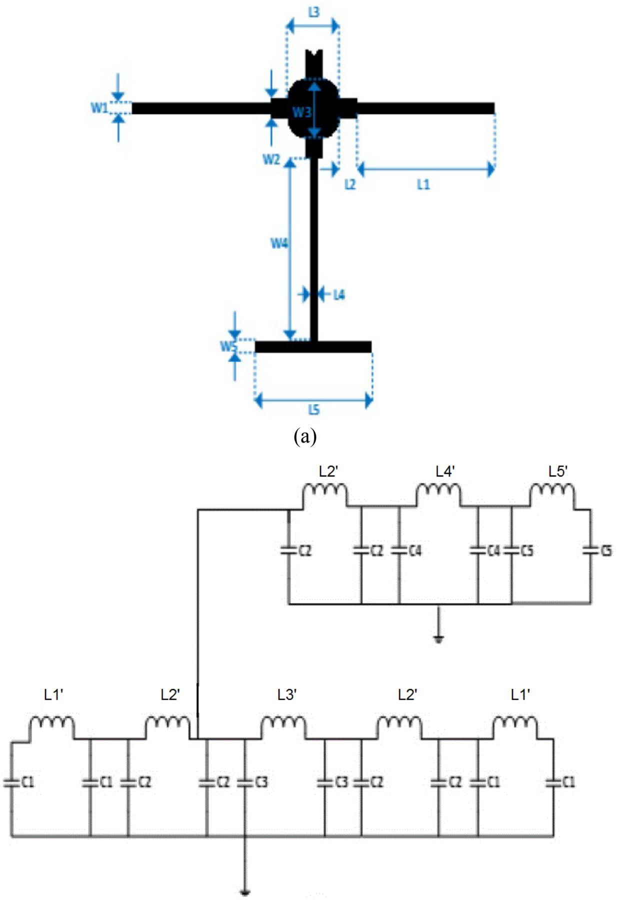


Fig. 9. High-impedance short-line element [2].



(a)

(b)

Fig. 10. (a) Middle resonator structure. (b) Equivalent circuit of the basic designed filter.

Parameters	L_1' [nH]	L_2' [nH]	L_3' [nH]	L_4' [nH]	L_5' [nH]
Calculated	2.159	0.22	0.41	2.79	1.83
Parameters	C_1 [pF]	C_2 [pF]	C_3 [pF]	C_4 [pF]	C_5 [pF]
Calculated	0.0569	0.008	0.045	0.057	0.048

Tab. 2. Element values used in the equivalent circuit of the basic designed filter.

The equivalent L-C circuit and the analytical theories of middle resonator are exhibited in Fig. 10. Furthermore, analytical theories of each circuit element are introduced and the comparison between the calculated results and the fullwave-simulated results are done to verify the proposed equivalent circuit and the analytical theories. As illustrated in Fig. 10(b), L_1', L_2', L_3', L_4', L_5', C_1, C_2, C_3, C_4, C_5 are inductances and capacitances of the open stubs. Calculated values for L-C equivalent circuit are summarized in Tab. 2.

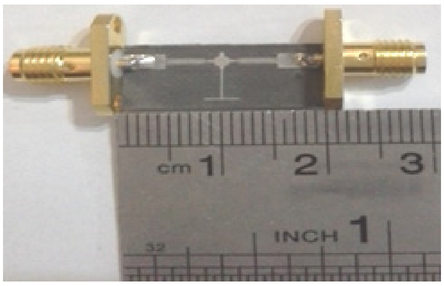
4. Simulation and Measurement Results

The proposed BPF has been fabricated on a substrate 31mil thick RT/Duorid 5880 with a relative dielectric constant 2.2 and loss tangent of 0.0009. Simulations are done by an EM-simulator (ADS Momentum). The S-parameters are measured by an Agilent network analyzer N5230A. The simulated and measured S-parameters of the designed UWB BPF filter and photograph of the fabricated filter are shown in Fig. 11. Patently, the error between simulation and measurement results is due to the SMA connector's loss and fabrication tolerance.

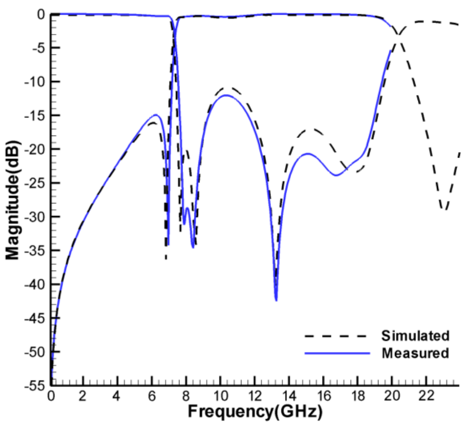
The overall size of the fabricated UWB BPF is 10.78 mm × 7.652 mm, nearly 0.71 λ_g × 0.5 λ_g, where λ_g is the guided wavelength at the center frequency (13.65 GHz). The measured results of the filter have 3dB fractional bandwidth (FBW) of 93%, with return loss less than 11 dB in 85% of pass band width and insertion loss better than 0.6 dB. The comparison of the UWB proposed filter with other designs is summarized in Tab. 3. The superior features indicate that the BPF has a potential to be utilized in the modern ultra-wideband wireless communication systems.

5. Conclusion

In this paper a compact UWB BPF (7.45–19.8 GHz) using the SIR and symmetric tight coupled resonator (STCR) via input/output (I/O) lines, achieving UWB band



(a)



(b)

Fig. 11. Fabricated proposed filters: (a) Photograph. (b) Simulated and measured results.

Ref	Circuit Size ($\lambda_g \times \lambda_g$)	3dB PBW (GHz)	Dielectric constant ε_r	Insertion loss (dB)	Return loss (dB)
[2]	0.616 × 0.5023	3.1–10.6	2.2	0.5	13
[3]	1.1 × 0.6	2.8–11	10.2	0.6	20
[4]	0.63 × 0.36	3–10.2	3.38	2.2	15
[5]	0.72 × 0.26	(3.1–4.3), (4.75–7.75), (8.65–10.8)	2.2	1	15
[6]	0.61 × 0.61	3.1–8.1	3.38	0.56	11
This work	0.71 × 0.5	7.45–19.85	2.2	0.6	11

Tab. 3. Comparisons with other proposed filters. (λ_g is the guided wavelength on the substrate at the center frequency).

pass response is proposed. By adding a T-shaped to the middle resonator, two transmission zeroes are created at 6.84/23.05 GHz with sharp slopes transition band as reported, the proposed filter has the ability of creating a notch band in the pass band by reducing the length of two coupled lines that can be controlled using an analytical method. The fabrication filter has low insertion loss and the stop band of the proposed filter is from 19.85 to 33 GHz with attenuation of –17 to –29 dB respectively. Thanks to simple structure and compact size these performances are very useful for telecommunication applications. Both measured and simulated results are in good agreement. ÃĪ'n

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