Hybrid Microstrip/Slotline Ultra-Wideband Bandpass Filter with a Controllable Notch Band

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Abstract— An ultra-wideband (UWB) bandpass filter (BPF) with a controllable notch band is presented by using hybrid microstrip/slot line structure. Firstly, a slot line resonator with symmetrically loaded stubs is fed by two microstrip lines to produce a UWB bandpass filtering response. Secondly, a microstrip triangular loop resonator is externally loaded over the slot line, and a notch band is introduced in the UWB passband. The notch band is determined by the perimeter of the loop resonator. Thirdly, two patches are added as the perturbation element to the corners of the microstrip resonator to excite a pair of degenerate modes. Bandwidth of the notch band can be tuned by properly selecting the patch size. Circuit model for the microstrip resonator loaded slot line is given and studied. Finally, the filter is designed, simulated, and measured. Measured results have agreed well with the simulated ones, demonstrating that a UWB filter with a controllable notch band has been realized.

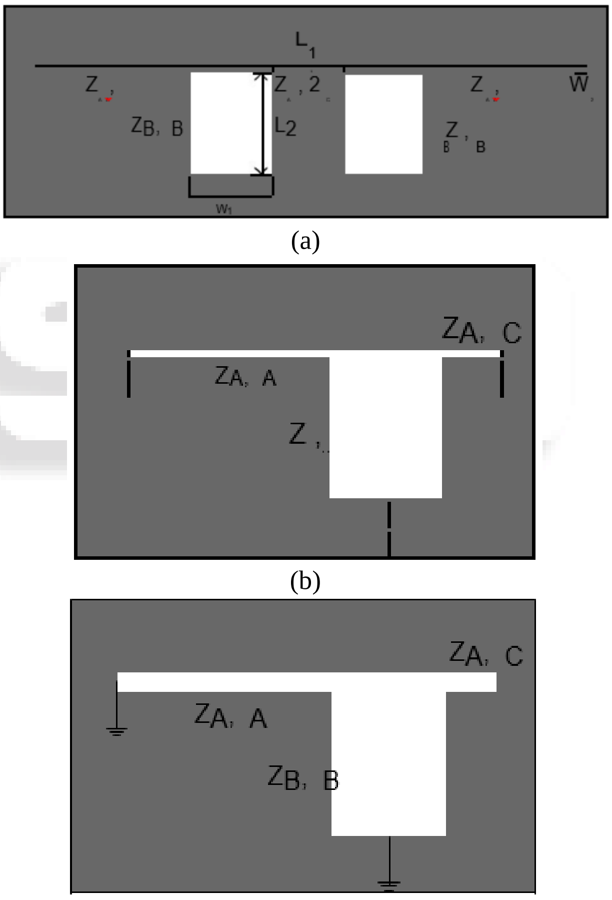
Key words: Ultra-Wideband (UWB), Bandpass Filter (BPF)

I. INTRODUCTION

Continuous progress in wireless systems requires advanced RF/microwave components, like well-designed filters. Ultra-wideband (UWB) characteristics are in order to meet the subscribers' demands. Many methods have been proposed to design various UWB bandpass filters (BPFs) by using multimode resonators (MMRs) [1, 2], multilayer stepped-impedance resonators (SIRs) [3], and stub-loaded resonators.

To acquire the desired strong coupling between resonator and feed lines while keeping the gap width between straplines in a moderate scale that can be achieved easily by using PCB process, an aperture-backed parallel-coupled microstrip line with enhanced coupling degree is constructed to allocate the coupling peak [5, 6]. For some practical applications, there is a need to avoid the interference from existing wireless communication systems such as wireless local area network in 5.0 GHz band. Generating a notch band in a UWB BPF is an effective and feasible method to solve this problem. As usual, an external resonator is used to create a notch band in the core of the UWB BPF at the cost of enlarged size [7]. In [8, 9], a SIR is embedded to achieve a band notch characteristic without increasing the circuit size. Band-notched filtering effect was achieved by adding a meander line slot to reject the undesired WLAN radio signal [10]. In [11], two spur line sections are employed to create a sharp notched-band filter for suppressing the signals of 5 GHz WLAN devices. In [12], a dual-mode fractal defected ground structure (DGS) band stop filter is realized and connected with MMR; band-notched characteristics are realized. To avoid the interference of the wireless local area network (WLAN) at 5.25 and 5.775 GHz, two different quarter-wavelength lines are arranged on the ground of UWB BPF to generate dual narrow stop band [13]. Obviously, combined bottom layer and top layer can make full use of the circuit board, without increasing the circuit size [14].

In this article, a hybrid microstrip/slot line structure is adopted to develop a novel UWB BPF with a controllable notch band. UWB bandpass characteristics have been achieved by using a microstrip-fed multimode slot line resonator. Desired strong coupling is simply realized by changing the position between microstrip and slot line portions. When a microstrip dual-mode triangular loop resonator is loaded to the slot line, a notch band is created in the UWB passband. Circuit model for this structure is provided and



(a)

(b)

(c)

Fig. 1: (a) Slotline MMR and its equivalent circuits (b) odd-mode and (c) even-mode studied, indicating the notch band can be fully controlled.

Finally, a prototype filter is fabricated to verify the predicted dual-wideband performance in experiment.

II. DESIGN APPROACH FOR PROPOSED FILTER

A. Dual-Stub-Loaded MMR.

Two stubs are symmetrically loaded to slotline, which forms a dual-stub-loaded MMR, as shown in Figure 1(a). Because the proposed slotline MMR is a symmetrical structure, evenodd theory can be applied to analyze its resonant characteristics. Figures 1(b) and 1(c) give equivalent circuits of the slotline MMR.

Under odd-mode excitation, the symmetrical plane can seem as short-circuited, and its resonant condition can be derived as

$$\tan \tan + \tan \tan + \tan \tan = 0 \qquad (1)$$

where , and , , are the characteristic impedances and electrical lengths of the dual-stubs loaded MMR, respectively.

Under even-mode excitation, the symmetrical plane can seem as open-circuited, and its resonant condition can be summarized as

$$\tan + \tan = \tan \tan \tan \qquad (2)$$

and third resonant modes of resonator, respectively. When increases from 0.2 mm to 2.2 mm, 3 decreases from 9.6 GHz to 8.2 GHz, while 1 and 2 shift slightly. When 1 increases from 23 mm to 25 mm, both 1 and 2, together with 3, decrease steadily. When 2 increases from 1 mm to 6 mm, 2 drops from 8.2 GHz to 6.5 GHz and 3 drops from 13.5 GHz to 8 GHz, while 1 keeps unchanged. Though this method, three resonant modes of the resonator can be designed intuitively and well set in the UWB passband.

B. Ultra-Wideband BPF

Layout of a proposed UWB BPF is depicted in Figure 3, which is constructed by a slot line resonator and two microstrip feedlines. On the bottom layer, a dual-stub-loaded slot line resonator is formed firstly, where two identical stubs are symmetrically loaded to a uniform slot line resonator. Figure 4 illustrates the frequency responses of the slot line UWB BPF with different lengths of feed line (4) under all the other sizes fixed. When the slot line resonator is fed under weak coupling case with 4 = 4.8mm, three resonant modes with peak 21-magnitudes are observed at about 4.08, 6.41, and 9.5 GHz, respectively. As 4 increases to 10 mm, the 21-magnitude realizes an almost flat frequency response over a UWB passband. After its sizes are slightly adjusted, an UWB frequency response is satisfactorily realized. Under the use of this hybrid microstrip/slot line structure, the desired strong coupling between feed lines and MMR can be easily achieved by properly selecting the relative position between them.

Resonant modes of the resonator can be controlled and allocated according to the requirements by changing the parameters of the resonator.

To have a clear knowledge of slot line resonator, resonant characteristics of the dual-stub-loaded slot line resonator are performed by invoking the 3D EM simulator. Resonant modes of slot line resonator against, 1, and 2 are plotted in Figure 2, where 1, 2, and 3 indicate the first, second,

C. Realization of Notch Band

Considering the fact that the above-achieved UWB passband range may interfere with the existing wireless systems such as wireless local area network (WLAN), a notch band may be highly demanded in various practical applications. For this purpose, a microstrip dual-mode triangular loop resonator is formed on the top layer of a dielectric substrate and loaded to the slot line MM.

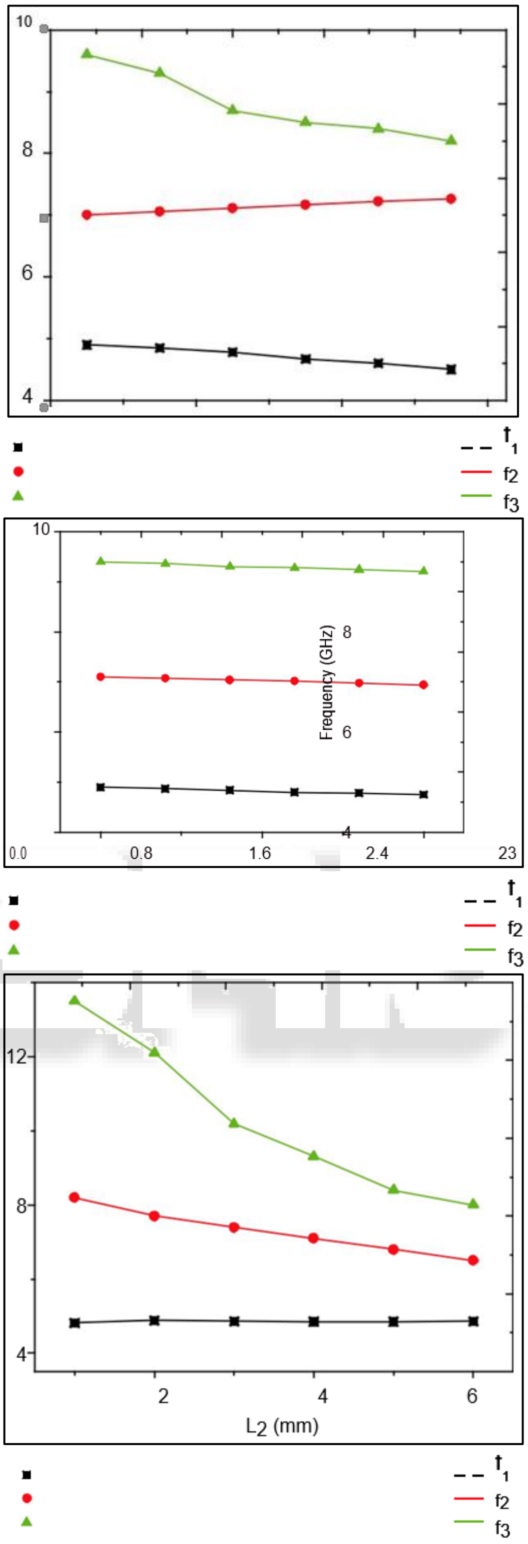
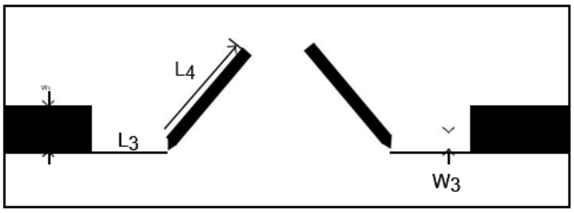
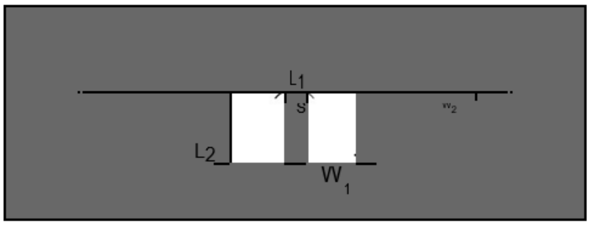


Fig. 2: Resonant Modes of Slotline Resonator with Fixed $_1$ = 2.0mm, $_2$ = 0.3mm, and varied (a) ($_1$ = 23mm, $_2$ = 3mm), (b) $_1$ (= 0.6mm, $_2$ = 3mm), and (c) $_2$ (= 0.6mm, $_1$ = 23mm)



(a)



(b)

Fig. 3: Schematic of the UWB filter. (a) Top layer and (b) Bottom Layer

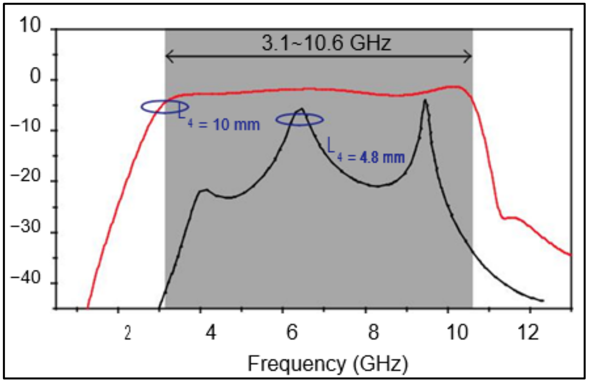
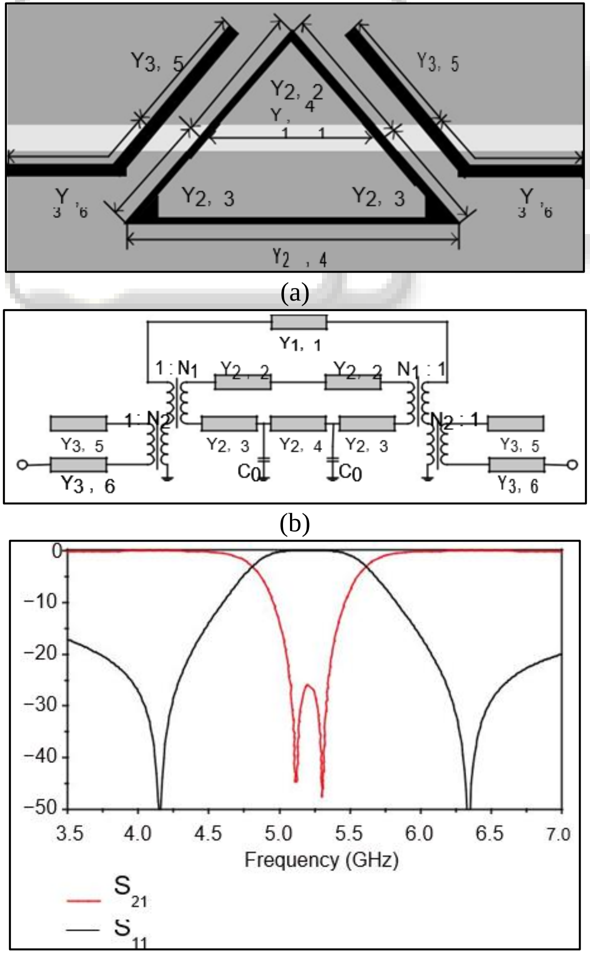


Fig. 4: Frequency Responses of Transmission Coefficient of the Proposed Wideband BPF with different Feeding Line Lengths ($_4$)



(a)

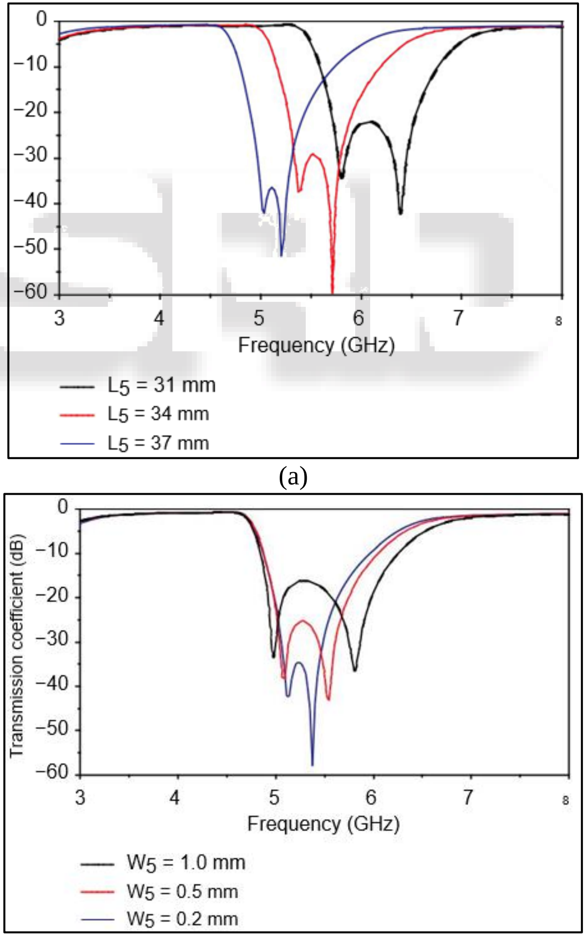
(b)

(c)

Fig. 5: A microstrip Triangular Loop Resonator loaded with Backside Slot line Portion. (a) Diagram, (b) Equivalent Circuit model, & (c) simulated results

Figure 5 depicts the geometry, equivalent circuit model, and simulated frequency response of a slotline loaded with back sided microstrip triangular loop resonator, respectively. Figure 5(a) shows a simplified circuit geometry of the structure, where the white portion indicates the slotline and the black ones are microstrip feed lines and a dual-mode triangular loop resonator with perturbations. Its equivalent circuit model is given in Figure 5(b). Coupling between dual-mode resonator and source/load can be intuitively neglected because its value is quite small. Figure 5(c) plots the simulated result derived from the equivalent circuit model, where the solid and dashed lines indicate the simulated reflection and transmission coefficients, respectively. Two transmission zeros in the notch band are created by the resonant modes of the microstrip resonator.

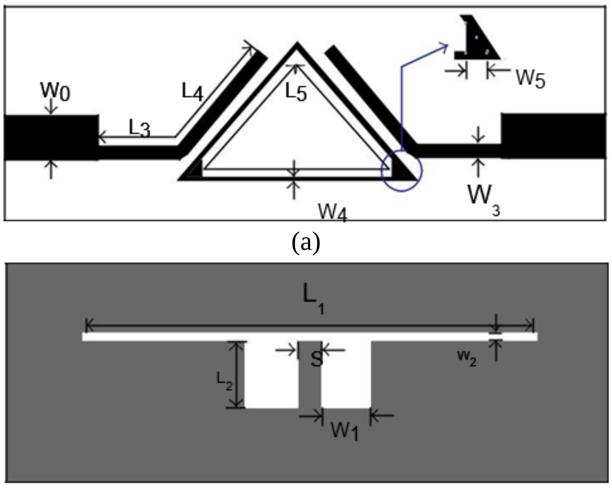
Next, two small patches are symmetrically added as the perturbation element to the lower angles of the triangular loop resonator. These perturbations can accomplish the further separation of the two degenerate modes, creating the dual-mode behavior of the resonator. Resonant modes of the triangular loop resonator are coupled to the slotline, providing a bypass for the adjacent signal of its resonance,



(a)

(b)

Fig. 6: Frequency-Dependent Transmission Coefficient of the Proposed Dual-Mode Triangular Loop Resonator Loaded Slotline Against (a) $_5$ and (b) $_5$



(a)

(b)

Fig. 7: Schematic of the Proposed Filter. (a) Top Layer and (b) Bottom Layer

A notch band is thus created. Figure 6(a) shows the trans-mission characteristics of the resonator versus 5, that is, the perimeter of a triangular loop resonator. As 5 increases from 31 to 37 mm, the central frequency of notch band falls off from 6.25 to 5.39 GHz and its absolute bandwidth decreases from 1.49 to 1.37 GHz. Obviously, the perimeter of triangular loop resonator can directly determine the position of the notch band. Figure 6(b) illustrates the influence on the frequency response from varied 5 and width of two patches. As 5 increases from 0.2 to 1.0 mm, the notch bandwidth goes up from 1.52 to 1.79 GHz. These exhibited characteristics can be used to determine the central frequency and bandwidth of the created notch band; thus, the notch band of the UWB BPF can be fully controlled.

III. FILTER IMPLEMENTATION & RESULTS

Based on the filter structure and analysis approach described above, a UWB BPF with a controllable notch band is designed and fabricated on a substrate with a dielectric constant of = 3.5, loss tangent of 0.0018, and thickness of h = 0.8mm. The layout of proposed UWB BPF with a notch band is depicted in Figure 7. As mentioned above, a dual-stub-loaded slot line resonator is etched on the ground plane, and on the top layer, two folded microstrip feedlines and a microstrip triangular loop resonator are constructed. All the dimensions of the filter shown in Figure 7 are as follows: 0 = 1.8mm, 1 = 23.0mm, 1 = 2.0mm, 2 = 3.0mm, 2 = 0.3mm, 3 = 2.0mm, 3 = 0.8mm, 4 = 11.5mm, 4 = 0.6mm, 5 = 36mm, 5 = 0.3mm, and = 0.6mm.

Simulated & measured transmission and reflection coefficients of the constructed filter are plotted in Figure 8. Simulated results show that the 3-dB passband of the filter covers the ranges of 2.83–4.78 GHz and 6.29–10.33 GHz, respectively, while measured ones show that the 3-dB pass-band cover the ranges of 2.49–4.91 GHz and 6.29–9.2 GHz. Measured minimum insertion losses of the first and second passbands are 1.1 dB and 1.5 dB, respectively. Measured maximum return losses in the first and second passbands are 13.2 dB and 13.5 dB, respectively. Simulated and measured maximum insertion loss in the notch band is 25 dB and 35 dB, respectively. In general, the measured results agree well with the simulated results except the loss in the high frequency band that may be caused by the dielectric loss and fabrication tolerance. Meanwhile, simulated and measured results indi-cate that the group delay within the passbands is varied within 0.3~0.7 ns. The photographs of the fabricated filter are shown in Figure 9, and its overall size is about 28 mm × 25 mm.

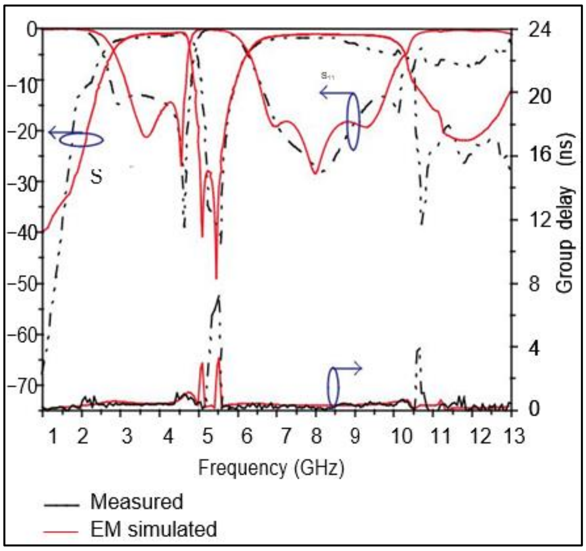
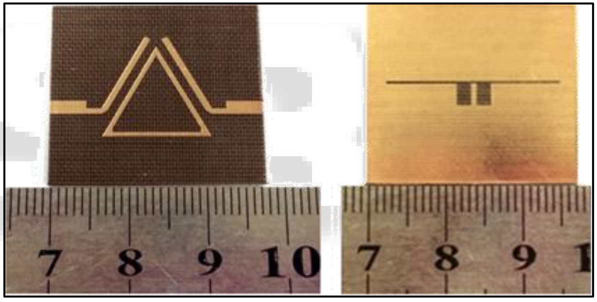


Figure 8: Simulated & Measured Frequency Responses of the Designed Filter



(a) (b)

Fig. 9: Photograph of the Fabricated Filter. (a) Top View and (b) Bottom View

Ref. number	CFs (GHz)/FBW (%)	Notch band (GHz)/| 21|(dB)	In-band return loss (dB)	Circuit size (∠0)
[8]	3.65/63, 5.8/69	5.22/20	>14/>12	0.309
[10]	3.96/59, 8.31/60	5.47/25	>12/>11	0.272
[12]	4.4/32, 8.2/65	5.3/37, 5.4/35	>15/>12	0.187
This work	*3.8/52,* *8.31/49*	*5.1/39,* *5.5/45*	*>14/>18*	*0.181*

Table 1: Comparisons between Referenced Works & our Work

IV. CONCLUSION

In this article, a novel UWB BPF with a controllable notch band using the hybrid microstrip/slotline structure is pro-posed. UWB BPF is at first designed by using the microstrip-fed stub-loaded slotline MMR. And then the notch band of 4.78–6.29 GHz is achieved by loading a dual-mode microstrip triangular loop resonator to the slotline MMR. A prototype UWB BPF is finally fabricated and good agreement between simulated and measured results is gained over a wide frequency range.

V. CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ACKNOWLEDGMENTS

The comparison with other reported UWB BPFs is shown in Table 1, which depicts that the proposed filter has excellent notch band characteristics with compact size.

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