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Analysis of Circular and Rectangular Slots on Printed Patch Antenna for Multiband Application

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***Abstract*—This article gives a brief comparative study on circular and ISI-shaped rectangular slots loaded antenna for satellite, WLAN application. The printed patch antenna is designed for 3.5 GHz and simulation is performed by Ansoft high frequency structure simulator software. Embedding circular slots show an increase in multiband with improvement in the fraction bandwidth as collating to the ISI-shaped rectangular slots. The simulated antennas are designed on flame retardant substrate FR4. The proposed antenna parameters are measured using Vector Analyzer and it is manifest seven working frequencies with good return loss and also shows overall bandwidth of 30.33%.**

***Index Terms*—Circular slots, ISI shaped slot, FR4, Multiband**

I. INTRODUCTION

Telecasting information from one place to another place is a pivotal function in wireless communication. he data imparting is done by the antenna, if multiple antennas have to include in the systems meanwhile it increases the system size. Hence adapting a multiband antenna is a convenient way. Using flame-retardant substrate, low-cost simple microstrip printed antennas will emerge, hence in this scenario, many researchers are attracting to the study of multiband antennas. Additionally, the microstrip antenna is unique from traditional antennas because of its low profile, easy fabrication at an affordable price. [1]- [3]. Multiband application can be obtained by different techniques by mbedding slots, defective ground structures, EBG structure, metamaterials, slits and shorting pins, and so on. A multiband antenna with magnetron slot-loaded gives four resonant frequencies with a gain of 5.96 [4]. An octagonal patch antenna with a slot showing six resonant frequencies with considerable return loss and gain [5]. A triple-band antenna has been fabricated on the FR4 for LTE application with a slot-loading technique [6]. Not only with the slot embedding but a novel ensemble algorithm has also been used to analyse the multiband using textile which shows the application in the field of LTE and 5G application [7]. A Vivaldi antenna with a fan-shaped antenna is designed for dual-band application and is analysed using CST microwave studio, where the antenna is showing wideband with a good radiation pattern [8]. Later a fan stub-shaped slot is introduced for the microstrip antenna to analyse the multiband operation for LTE band application [9]. Further, an H shaped slot has been designed for GSM band application [10]. A novel multi-band antenna for body application has been studied for the bending effect using a cylindrical rectangular cavity model and it is deemed that the antenna is adequate for patient supervision [11]. Different multiband antenna design using different methods has been discussed, where multiband with higher bandwidth and virtual size reduction has not been observed much from the literature.

In this work effect of circular and rectangular slots on the microstrip antenna with low cost flame-retardant substrate are analysed for multiband applications.

A. Antenna Design

The basic printed antenna is designed using a flame retardant substrate with dimensions 8x4x0.16 cm and simulated using HFSS software. Simulated antenna with dimensions and the fabricated antenna are shown in figure 1 and 2 respectively. The simulated antenna is resonating at 3.39 GHz frequency with return loss -15.83 dB and the measured antenna is resonating at frequencies 3.29 GHz with return loss -14.88 dB as shown in Fig. 3. Table I gives the detailed dimensions to design a rectangular microstrip antenna for 3.5 GHz.

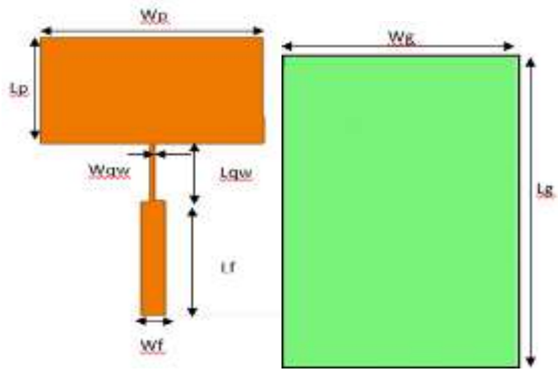


Fig. 1. Simulated Conventional microstrip antenna.

Top view Bottom view

Fig. 2. Fabricated prototype of conventional microstrip antenna.

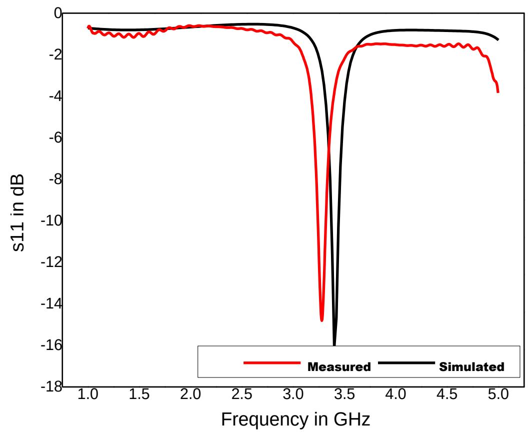


Fig.3. Measured and Simulated return loss graph

TABLE I: DIMENSIONS OF CONVENTIONAL ANTENNA

Sl. no	Conventional Antenna	
	Parameters	Value in cm
1	Width of the patch *Wp*	2.04
2	Length of the patch *Lp*	2.68
3	Width of the Quarter wave feed *Wqw*	0.05
4	Length of the Quarter wave feed *Lqw*	1.09
5	Width of the Feedline *Wf*	0.31
6	Length of the Feedline *Lf*	2.18
7	Thickness of the substrate	0.16

From Fig.3, it is evident that conventional microstrip antenna is resonating at single bandwidth narrow impedance bandwidth of 2.439 %. To overcome this limitation a proposed antenna has been designed by adapting simple slot loading technique.

II. PROPOSED ANTENNA DESIGN

A. Antenna with Circular Slots

According to Babinets principle when a slot is loaded with air and surrounded by the conducting plane, then the antenna will radiate electromagnetic waves. Hence the proposed antenna has been designed by embedding circular and rectangular slots on the radiating patch. When the slots are loaded a new resonance has created and also increases the bandwidth as compared with the conventional antenna.

The proposed antenna analysis has been carried out in three stages. The microstrip antenna is loaded with five circular slots with two slits on opposite sides of the radiating edges of the patch. The circular slots with radius C_1 = 0.4 cm, C_2=C_3=C_4=C_5=0.09 cm and slits with length L_1 =0.3, L_2 = 0.35, and width W_1=W_2=0.1 cms are loaded as shown in the Fig. 4.

From Fig. 4, it is observed that CSSLRMSA- Circular Slotted with Slits Loaded Rectangular Microstrip Antenna is designed for 3 iterations. In iteration I the effect of circular slots results in five working frequencies with a gain of 1.205 dB. For the second iteration circular slots with a smaller radius than C_1 had embedded and it is observed that the antenna is resonating at six resonance frequencies with a gain of 1.99 dB. Further two silts are added on the opposite sides of the radiating patch, exhibits seven different frequencies with the gain of 2.60 dB.

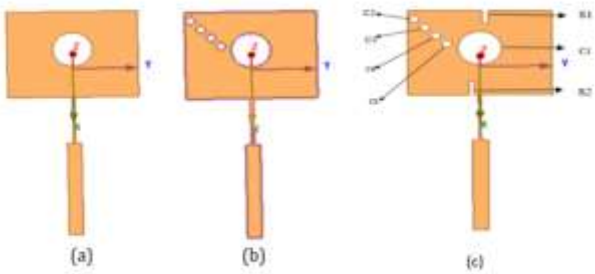


Fig. 4. Proposed Antenna 1: (a) Iteration I, (b) Iteration II, and (c) Iteration III.

B. Antenna with Rectangular Slots

Rectangular lots whose length equal to the quarter the wavelength is embedded on the microstrip radiating patch in the form of ISI structure. The Rectangular slots with length $L_1 = L_7$ =0.5 cm L_2 =1cm, $L_3 = 0.8$ cm, $L_4 = 0.6$, L_5 = 0.9 cm, L_6= 1.15 cm, L_7 = 0.5 cm, $L_8 = L_9 = 1.3$ cm and width $W_1 = W_3 = W_5 = W_7 = W_8 = W_9$=0.05 cm, $W_2 = W_4 = W_6$= 0.1 cm are embedded on the radiating patch as shown in the Fig. 5

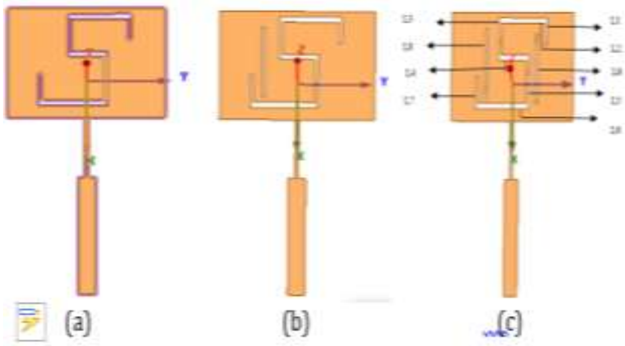


Fig. 5. Proposed Antenna 2: (a) Iteration I, (b) Iteration II, and (c) Iteration III

Proposed Antenna 2 ISI-shaped Rectangular Microstrip Antenna[ISISRMA] shows a triple band with a gain of 4.6 for iteration I. By adding a rectangular slot as in iteration II ISISRMA exhibits two more new resonance with five bands and also increases its gain up to 8.5 dB. Further to optimize ISISRMA iteration III has been analyzed which results in adding two more new resonance showing seven different bands with a good gain of 8.86 dB for a considerable return loss by shifting the frequency to 3.05 from 3.5 *GHz*. Hence ISISRMA has a virtual size reduction of 11.5 % and is calculated by

$$\text{Virtual size reduction (VSR)} = \frac{f_{con} - f_{aut}}{f_{con}} \qquad (1)$$

where f_{con} is the frequency of conventional antenna and f_{aut} is the frequency of antenna under test.

TABLE II: COMPARISON OF THE CONVENTIONAL ANTENNA WITH PROPOSED ANTENNA

Antenna	Parameters			
	Frequency (GHz)	Return Loss (dB)	Fractional BW in GHz	VSWR
Conventional Antenna	3.28	-14.81	2.43	1.24
Proposed Antenna 1 [CSSLRMS]	3.09 5.19 6.11 6.65 8.02 9.11 11.17	-24.98 -24.05 -15.61 -20.55 -11.29 -26.01 -33.11	2.39 2.38 3.84 7.32 1.40 3.42 9.56	1.17 1.11 1.39 1.23 1.80 1.09 1.07
Proposed Antenna 2 [ISISRMA]	2.79 2.96 4.83 5.90 7.17 11.35	-15.56 -16.95 -16.25 -16.86 -30.72 -22.31	1.96 2.05 1.96 1.72 6.32 6.94	1.35 1.29 1.37 1.33 1.05 1.15

From the table II it is summarizing that conventional antenna has narrow bandwidth with single frequency. when the circular slots are loaded on the radiating patch seven working frequencies are observed and also shows virtual size reduction of 11.71% with impedance bandwidth of 30.31 %. Similarly, when the radiating patch is embedded with the rectangular slots it shows six resonance frequencies with virtual size reduction of 20.28 % but the impedance bandwidth is about 20.96 % has observed.

III. RESULT AND DISCUSSION

The optimized CSSLRMSA prototype is shown in Fig. 6. By step by step analysis using HFSS simulator software antenna is fabricated using the photolithography process and the parameters are measure using a vector analyser. In the iteration one the antenna is working at five different frequencies f_1 = *5.96* GHz, f_2 = 6.435 GHz, $f3$ = 8.93 GHz $f4$ = 9.56 GHz and $f5$ = 11.34 GHz with good return loss *-29.9* dB, -11.93dB, -20.82 dB, -11.27dB and -15.40 dB. Similarly, for the iteration II the antenna exhibits new resonance by total six working frequencies bands, f_1= 3.21 GHz, f_2 = *5.33* GHz, f_3 = 6.18 GHz, f_4 = *6.59* GHz, f_5 = 9.18 GHz and f_6 = 11.45 GHz with reflection coefficient values –10.17 dB, -10.42 dB, -23.42 dB, -14.51 dB, -31.09 dB, and -18.21 dB respectively. For the third iteration, the antenna with slits loaded shows seven bands with good return loss as shown in Figure 7. This optimized antenna is fabricated and measured using vector analyser and compared with the simulated results as shown in the figure 8. The [CSSLRMSA] antenna working frequencies along with the impedance bandwidth are listed in Table II.

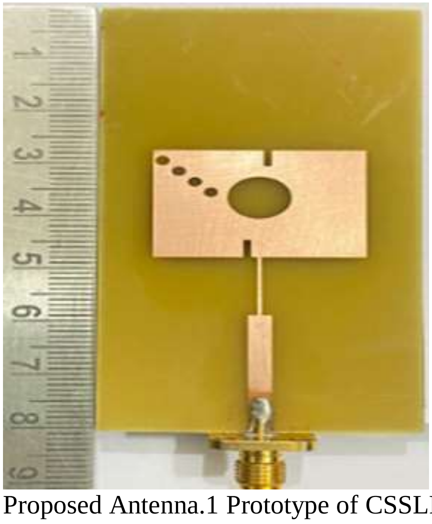


Fig. 6. Proposed Antenna.1 Prototype of CSSLRMSA

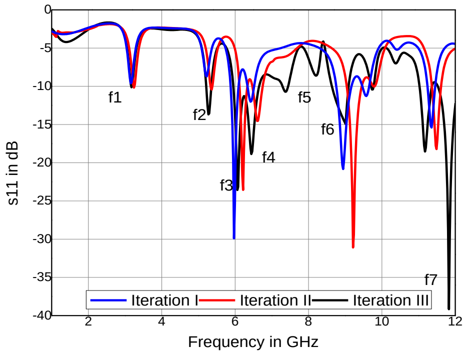


Figure 7. Simulated return loss versus frequency plot for Iteration I, II and III of CSSLRMSA

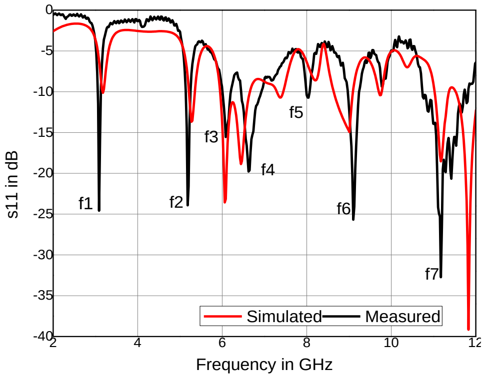


Fig 8. Measured and simulated return loss versus frequency plot of CSSLRMSA.

Fabricated prototype of Antenna 2 with the return loss versus frequency graph represented by Fig. 9. The design procedure of this antenna tells us regarding the effect of the rectangular slot on the patch which gives rise to new resonance with the improvement in the antenna parameters. In ISISRMA design iteration I shows resonating frequencies at f_1 = 5.34 GHz , f_2 = 6.07GHz and 8.28 GHz with return loss -11.98 dB, -30.03 dB and -12.92 dB. For the second iteration ISISRMA exhibits new resonance by resonating at five different frequencies f_1 = 3.12 GHz, f_2 = 5.26 GHz , f_3 = 6.21 GHz , f_4 = 8.12 GHz and f_5 = 11.29 GHz with the acceptable return loss -13.24 dB, -27.81 dB, -28.45 dB,-13.74 dB and-12.27 dB. In the third iteration, ISISRMA shows improvement in the number of frequency bands to six as shown in Figure 10 return loss versus frequency plot. The optimized antenna for third iteration is fabricated and the experimental results are carried out using vector analyser and is compared with the simulated results as shown in the figure 11. The resonating frequency bands with return loss values are tabulated in Table II of the proposed antenna.2 [ISISRMA].

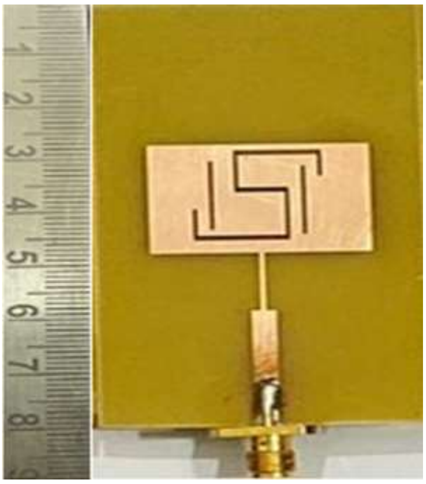


Fig. 9. Proposed Antenna.2 Prototype of ISISRMA.

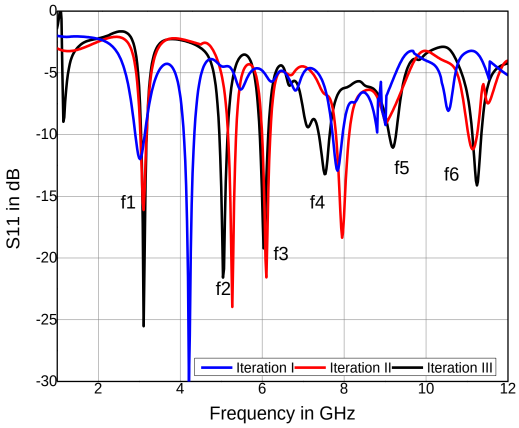


Figure 10. Simulated return loss versus frequency plot for Iteration I, II and III of ISISRMA

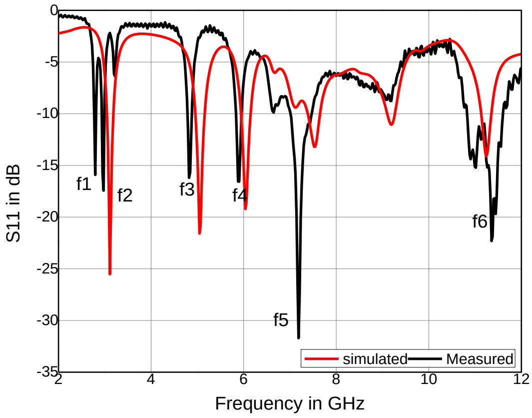


Fig. 11. Measured and simulated return loss versus frequency plot of ISISRMA

A. Voltage Standing Wave Ratio

For an ideal antenna the Voltage standing wave ratio has to be achieved less than 2. The proposed antenna CSSLRMSAI and SISRMA for iteration I, II, and III resonating frequencies are showing vswr vlaues less than 2 for better performance of the antenna, and the proposed antenna's VSWR values are tabulated in Table 2. The VSWR values for all three iterations for both the proposed antenna are shown in Fig. 12 and Fig. 13.

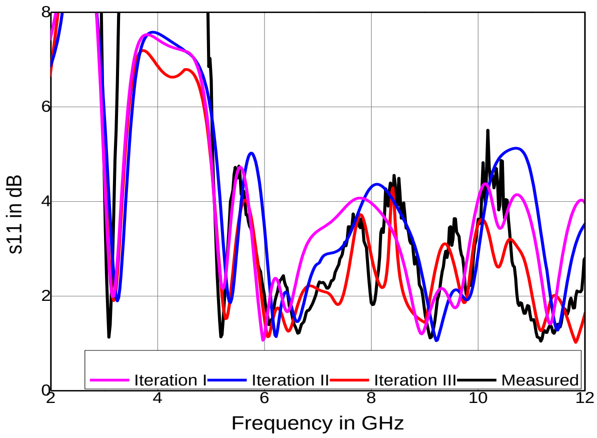


Fig. 12. VSWR versus frequency plot for Proposed Antenna1: CSSLRMSA

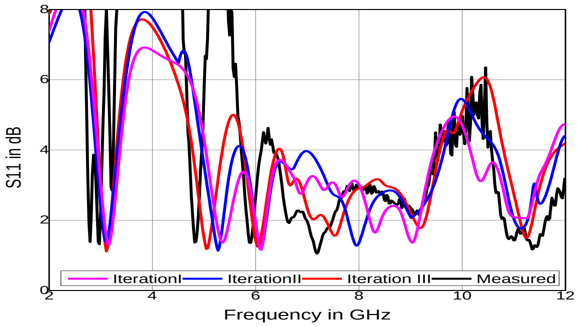
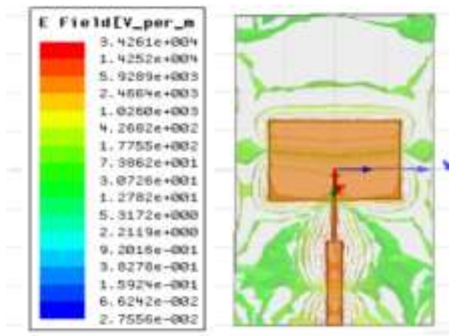


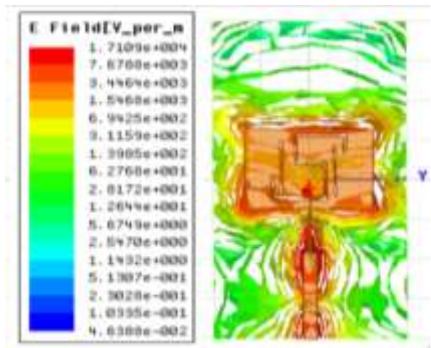
Fig. 13. VSWR versus frequency plot for Proposed antenna 2 ISISRMA

B. E Field Patterns

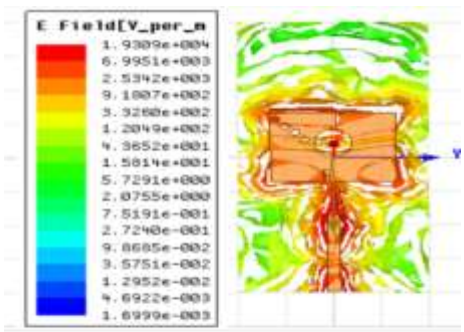
The E field distribution plot as shown in Fig. 14 (a), (b), and (c) briefly explains how the path of the currents are dividing in the substrate of the antenna to radiate the electromagnetic waves. The current distribution in the figure 14 (a) shows very little near feed line and the radiating edge of the antenna. When the rectangular slots are loaded the current paths increases near the slots and is shown in the figure 14 (b). Futher introducing the circular slots on the radiating patch results in highest electric field distribution as shown in the figure 14 (c). It is observed that inserting the slot the path and current desity has changed and more current distribution is observed in case of circular slot loaded antenna.



(a)



(b)



(c)

Fig. 14. Electric field distibution: (a) Conventional Antenna, (b) ISISRMA and (c) CSSLRMSA.

TABLE III: SUMMARIZING OF PROPOSED WORK WITH PAST WORK

Reference	Parameters			
	Frequency (GHz)	Return Loss (dB)	Fractional BW in %	Size in cm
[12]	8.78 12.86 15.35 18.50	-20.47 -26.47 -20.91 -15.44	3.41, 3.49, 6.84, 3.78	7x3.5x 0.16
[13]	1.65 3.14 4.44 5.24	-23 -12 -24 -37	35,14,12,9	5.3x5.3 x 0.16
[14]	6.46 8.54 9.65	-16.93 -13.2 -11.31	11.62,2.93,1.8 6	8x4x 0.16
[15]	4.94 9.7 16.9	-42.63 -35.95 -32.30	5.06,5.15,10.0 5	1.9x1.7 x0.16
[16]	1.81 3.60 4.53 5.73	23.33 -28.11 -18.86 -18.07	-	6.0x7.0 x 0.16
Proposed Antenna 1 [CSSLR MS]	3.09 5.19 6.11 6.65 8.02 9.11 11.17	-24.98 -24.05 -15.61 -20.55 -11.29 -26.01 -33.11	2.39 2.38 3.84 7.32 1.40 3.42 9.56	8x4x0. 16

From the table III the proposed work and athe exhisting work has compared. The proposed work shows multiband performance with better bandwidth than the previous prototypes. In the proposed work, the seven working frequency with high impedance bandwidth is considered novel.

IV. CONCLUSION

A Circular and ISI-shaped rectangular slots on the microstrip antenna are loaded and the performance is studied by comparing the two multiband antennas. The simulated and measured results concluded that the circular slot-loaded antenna CSSLRMSA shows seven working frequencies with good return loss, gain 2.60 dB, and total impedance bandwidth of 30.33 %. For ISI-shaped rectangular slots loaded, ISISRMA resonates at six frequencies with impedance bandwidth of 20.976 % and has a gain of 8.83 dB. The proposed antenna is a simple slot loading technique for enhancing the gain and bandwidth of the antenna. The VSWR, gain and return loss values of simulated and measured results are acceptable. The proposed antennas 2 cover frequencies from 2.792 to 11.35 GHz, hence it can be used in IMT, WLAN, Satellite, and C band application.

CONFLICT OF INTEREST

"The authors declare no conflict of interest".

AUTHOR CONTRIBUTIONS

Mamatha A G conducted the research and analyzed the data. Prof. Dr. Pradeep M Hadalgi reviewed and approved the final version.

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