Design and Analysis of Patch Antenna for C, X, Ku Band Applications

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Research Article

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DESIGN AND ANALYSIS OF PATCH ANTENNA FOR C, X, K_u BAND APPLICATIONS

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ABSTRACT

This paper presents the design and simulation of patch antenna loaded with metamaterial called Complementary Split Ring Resonator (CSRR) with increased gain and bandwidth suitable for wireless applications such as satellite, TV and radar applications. FR4 substrate with dielectric constant (ε_r) of 4.4 is used. The radiating patch consists of CSRR structure fed by microstrip line to achieve triple(C, X, K_u) band characteristics. The proposed antenna is designed and simulated using Ansys High Frequency Structural Simulator (HFSS). The proposed antenna with 4 rings having a resonant frequency of 7.662, 9.8510, 10.9455, 11.8410, 12.7365 and 13.7315GHz and the bandwidth of 230, 1090, 640, 580, 620 and 2000MHz respectively. The proposed antenna with 6 rings also having a resonant frequency of 7.7615, 9.9525, 11.0450, 11.9405 and 13.7315GHz and bandwidth of 160, 1130, 490, 1360 and 1480MHz are achieved. The proposed antenna is analyzed in terms of return loss, VSWR, gain and bandwidth. The electric field and surface current distribution were observed for the proposed antenna having 6 rings.

Keywords

Complementary Split Ring Resonator (CSRR), Microstrip line feed, Metamaterial, Voltage Standing Wave ratio (VSWR).

1. INTRODUCTION

The microstrip patch antennas are comes under the class of planar antennas and it is widely used for many wireless applications because of having compact in size, light weight, reliable and mobile. Because of these reasons the microstrip patch antennas become popular in the last four decades. The metamaterial structure like CSRR are imposed on the microstrip patch antenna to improve the antenna performance in terms of return loss, Voltage standing wave ratio, Bandwidth, Gain and Directivity. The two meta-resonators having an inductive feeding and it are considered as an inductive capacitive (LC) resonant tank. The metamaterial unit cells are rotated to form a ring like structure which exhibits omnidirectional radiation pattern. Their measured bandwidth ranges from 2.4 to 2.48 GHz having a peak gain of 1.17 dBi and radiation efficiency of greater than 80% was achieved [1]. The novel resonator consisting of metal-insulator-metal capacitors that is impressed from the split-ring resonator. The circularly polarised antennas are mostly used in wireless communication systems, such as global positioning system (GPS), radio frequency identification (RFID), wireless local area network (WLAN) etc., the split ring resonator inspired circularly polarised antenna having peak gain of 5.51dBi, bandwidth ranges from 900 to 928 MHz and the radiation efficiency of 86.5% was obtained [2].

CSRR based compact antenna with coplanar waveguide fed. The results obtained with patch and patch loaded with CSRR are compared. First the basic patch is simulated and the return loss obtained was -30 dB at 3.01 GHz. Then the patch loaded with CSRR is simulated and the obtained return loss of -35.425 dB at a frequency of 2.4 GHz having the peak gain and directivity of -6.0892 dBi and -5.9377 [3]. The triangular patch antenna is loaded with triangular split ring resonator [4] having four operating bands they are 3.5, 4.1, 5.6 and 9.1 GHz. The S11 obtained are -12.01, -11.7, -19.54 and -14.16 dB for the four operating bands 3.5, 4.1, 5.6 and 9.7 GHz. The measured gains are 1.24, 0.6, 0.7 and 2.09 dBi for the corresponding operating bands. Then double H shaped complementary split ring resonator [5] using FR4 substrate is designed. The antenna operates in a bandwidth ranges from 2.59 to 3.26 GHz, 9.39 to 10.12GHz, 10.6 to 12.2 GHz and 12.3 to 12.8GHz. The above resonant frequencies were located at S, X, K_u bands.

The coupled ring split ring resonator is designed for microwave applications. The antenna is fabricated using FR4 substrate. The antenna operates in a bandwidth ranges from 2.15 to 2.3GHz, 4.45 to 4.95GHz, 5.7-6.1GHz and 8.46 to 9.2GHz. The proposed metamaterial structure is suitable for S, C, X band applications [6]. The symmetrical meandered monopole radiators and Y shaped element. The split ring resonator is used to reduce the interference signal coupled to the antenna system which in turn reduces the mutual coupling effect. The proposed MIMO antenna having bandwidth ranges from 3.3 to 3.6 GHz and 4.8 to 5 GHz and after the addition of split ring resonator the experimental results showing that the mutual coupling between the two elements is below -25dB in the operating band [7].

The microstrip rectangular patch antenna is loaded with complementary split ring resonator was designed. The proposed antenna operates in three bands. The obtained return loss are -15.6, -14.6 and -21dB for 4.3, 7.4, 9.3 GHz and having bandwidth of 80, 300, and 410 MHz respectively. The measured gain of 3.88, 3.72 and 3.6dBi is obtained for the central frequency of 4.3, 7.4, 9.3 GHz [8]. The dual band two sided beam generation is produced by periodically modulated metasurface (MTS) and it is formed by array of split ring resonator [9]. The omnidirectional circularly polarised antenna is loaded with complementary V shaped slot is proposed. The antenna operates at 5.8GHz having bandwidth ranges from 5.65-5.75GHz and a peak gain of 1.26dBi [10]. A compact asymmetric coplanar waveguide (CPW) feed with split ring resonator is proposed to resonate at dual band for WLAN and WiMAX applications [11]. Different types of efficiencies for metasurface is introduced using single point source excitation [12].

A compact semi-circular monopole antenna loaded with complementary split ring resonator (CSRR) and two C-shaped slots [13] are introduced for GSM, WiMAX and C-band applications. A multiband monopole antenna based rectangular shaped complementary split ring resonator with offset-fed microstrip [14] is proposed for GSM and WLAN applications. In this paper [15] the design of compact penta band triangular patch antenna backed by hexagonal complementary split ring resonator for GPS, GSM, WLAN and WiMAX applications. For the gain improvement the microstrip patch antenna [16] with split ring resonator loaded ground plane is proposed for ISM band applications. The radiation pattern obtained in H-Plane is omnidirectional and in E-Plane is bidirectional.

The transmission lines loaded with split ring resonator (SRR) and complementary split ring resonator (CSRR) are arbitrarily oriented. The cross polarisation effect arises due to nonorthogonal alignment of the silt of the resonators [17]. A compact patch antenna is loaded with complementary split ring resonator (CSRR) and reactive impedance surface (RIS) and it provides multiband operations [18]. Patch antenna using split ring resonator at a resonant frequency of 4.67GHz and a size reduction of 29.3% is achieved with gain of 4.84dBi [19]. The microstrip patch antenna is loaded with complementary split ring resonator on the ground plane altering the effective medium parameters of the substrate [20]. The proposed antenna is discussed in section 2, simulated and measured results are discussed in section 3 and section 4 presents the conclusion.

2. PROPOSED ANTENNA

The microstrip patch antenna loaded with CSRR produce triple (C, X, K_u) band characteristics for wireless applications. The proposed antenna design is simulated using Ansys HFSS and designed on FR4 epoxy glass substrate is suitable for PCB applications. The material is very low cost and has good mechanical properties. The proposed antenna having patch length and width of 38mm and 38mm and the height of the substrate is 1.6mm.

2.1 DESIGN EQUATION FOR PATCH

The width of the patch will be calculated from the following equation(1)

$$W = \frac{C}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad \ldots \quad (1)$$

where W is the width of the patch, ε_r is the dielectric constant, C is the velocity of light, f_0 is the resonant frequency

2.2 DESIGN EQUATION SOLUTION FOR SQUARE SPLIT RING RESONATOR

Fig1a shows the structure of split ring resonator. Fig1b and 1c shows the proposed patch antenna loaded with 4 rings and 4 rings.

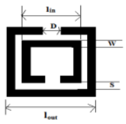


Fig. 1a Structure of split ring resonator

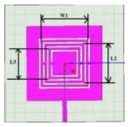


Fig. 1b Proposed antenna loaded with 4rings

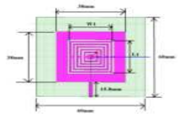


Fig. 1c Proposed antenna loaded with 6rings

Where L_{in} and L_{out} are the lengths of the outer and inner ring, W is the width of the metal ring, S is the space between the two rings and D is the opening of the rings or gap. The inductance L_m of each ring can obtained as,

$$L_m = \frac{\mu_0 S[l_{out}+l_{in}]}{W} \quad \ldots \quad (2)$$

The value for L_m= 60nH then find the value for C_m from the equation. After substituting all these values we get the value for C_m=75Ff.Assume the value for $S = W$ =1mm for simplifying the calculation

$$l_{in} + l_{out} = \frac{W L_m}{\mu_0 S} \qquad \ldots \quad (3)$$

Then substituting the values for S, W, L_m and $\mu_0$we get $l_{out} + l_{in} = 47.77mm$.The Equilibrium constant (A) is found by using the following equation (4)

$$A = \frac{C^2}{4\pi^2[l_{out}+l_{in}]^2 f_0^2 \varepsilon_r} \quad \ldots \quad (4)$$

The value for A= 0.03942.The dimension of the opening gap (D) is calculated by using the following formula (5)

$$D = 2\{[l_{out} + l_{in}] - \frac{C_m}{A\varepsilon_0\varepsilon_r}\} \quad \ldots \quad (5)$$

The value for D =1.14mm. Since it is a square patch the length and width are same. Table 1 shows the parameters of the proposed antenna with 4rings and 6 rings.

Table 1 Parameters of the proposed antenna having 4 rings and 6 rings

Parameters	Dimension(mm)
Length of the patch	38
Width of the patch	38
Length of the feed line	15.8
Width of the feed line	2.056
L1	21.885
W1	21.885
L2	17.885

Parameters	Dimension(mm)
W2	17.885
L3	13.885
W3	13.885
L4	9.885
W4	9.885
L5	5.885
W5	5.885

3. RESULTS AND DISCUSSION

Fig 2a shows the simulation results of the reflection coefficients for the proposed antenna having 4 rings. The first outer slot creates the resonant frequency of 7.6620, 9.8510, 11.8410 GHz, the second outer slot creating a resonant frequency 12.7365GHz, the third outer cut creating a resonant frequency of 10.9455GHz and the fourth slot creating a resonant frequency 13.7315GHz for the proposed antenna with 4rings. The proposed antenna with 4 rings having a triple (C, X, K_u)

band of frequency 7.6620, 9.8510, 10.9455, 11.8410, 12.7365 and 13.7315GHz are achieved with return loss of -14.7001, -32.1488, -15.6399, -19.0459, -16.3600 and -16.0422dB respectively. It is observed from fig 2a good return loss is achieved at 9.8510GHz.

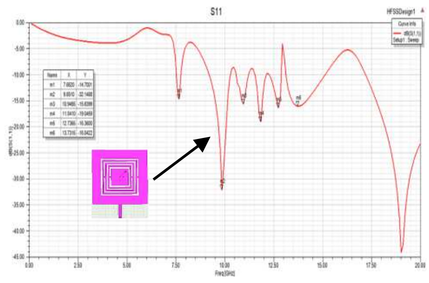


Fig. 2a Simulation result of the reflection coefficients for the proposed antenna having 4 rings

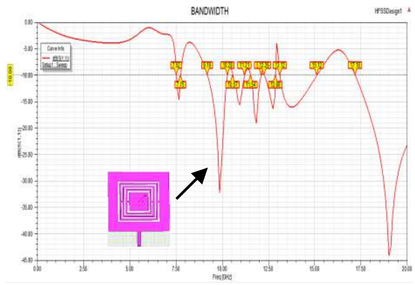


Fig. 2b Simulation results of the bandwidth for the proposed antenna having 4 rings

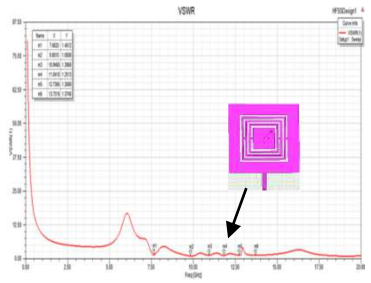


Fig. 2c Simulation result of the VSWR of the proposed antenna having 4 rings

Fig 2b shows the bandwidth for the proposed antenna having 4 rings. For the proposed antenna with 4 rings -10dB impedance bandwidth of 230MHz (7.52-7.75GHz), 1090MHz (9.19-10.28GHz), 640MHz (10.57-11.21GHz), 580MHz (11.54-12.12GHz), 620MHz (12.26-12.88GHz) and 2000MHz (13.12-15.12GHz). The gain of 4.0306, 2.5214, 2.0148, 4.4971, 4.0643 and 0.9781dBi is obtained for corresponding resonant frequencies. From fig 2b it is inferred that the highest bandwidth is achieved at 13.7315GHz respectively. Fig 2c shows the VSWR of the proposed antenna having 4 rings. For the proposed antenna with 4 rings having Voltage Standing Wave Ratio (VSWR) of <1.4 is achieved at all resonant frequencies respectively. Fig 3a shows the simulation results of the reflection coefficients for the proposed antenna having 6 rings.

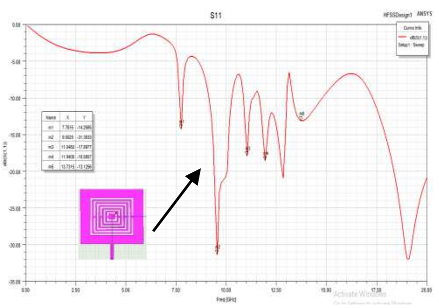


Fig. 3a Simulation result of the reflection coefficients for the proposed antenna having 6 rings

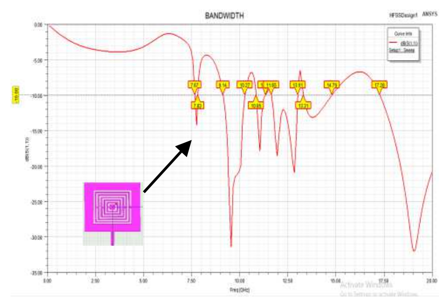


Fig.3b Simulation results of the bandwidth for the proposed antenna having 6 rings

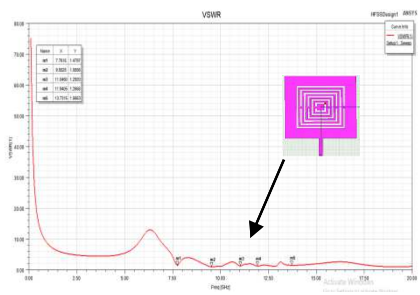


Fig. 3c Simulation result of the VSWR of the proposed antenna having 6 rings

The first outer slot creates the resonant frequency of 7.7615GHz, the second outer slot creating a resonant frequency 11.0450GHz, the third outer cut creating a resonant frequency of 9.5525GHz, the fourth slot creating a resonant frequency 11.9405GHz and sixth slot creating a resonant frequency of 13.7315GHz for the proposed antenna with 6rings.The proposed antenna with 6 rings having a triple (C, X, K_u) band of frequency 7.7615, 9.5525, 11.0450, 11.9405 and 13.7315GHz are achieved with return loss of -14.2685, -31.3533,-17.8977, -18.5857 and -13.1256dB respectively. It is observed from fig 3a good return loss is achieved at 9.5525GHz.

Fig 3b shows the bandwidth for the proposed antenna having 6 rings. For the proposed antenna with 6rings -10dB impedance bandwidth of 160MHz (7.67-7.83 GHz), 1130MHz (9.14-10.27 GHz), 490MHz (10.85-11.34 GHz), 1360MHz (11.65-13.01 GHz) and 1480MHz (13.31-14.79 GHz). From fig 3b it is inferred that the highest bandwidth is achieved at 13.7315GHz respectively. The gain of 9.2, 7.06, 7.6, 6.8, and 5.7dBi is obtained at corresponding resonant frequencies. Fig 3c shows the VSWR of the proposed antenna having 6 rings. For the proposed antenna with 6 rings having Voltage Standing Wave Ratio (VSWR) of <1.5 is achieved for all operating bands respectively. Fig 4 shows the photograph of the fabricated antenna having 6 rings. Fig 5 shows the observation of reflection coefficient in Vector network Analyzer.

(a) **Top view** (b) **Bottom view**

Fig. 4 Photograph of the fabricated antenna having 6 rings

Fig 5 shows the observation of reflection coefficient in Vector Network Analyzer for the proposed antenna having 6 rings.

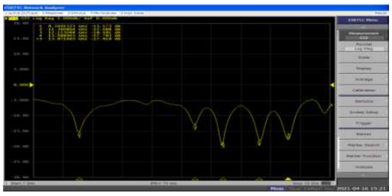
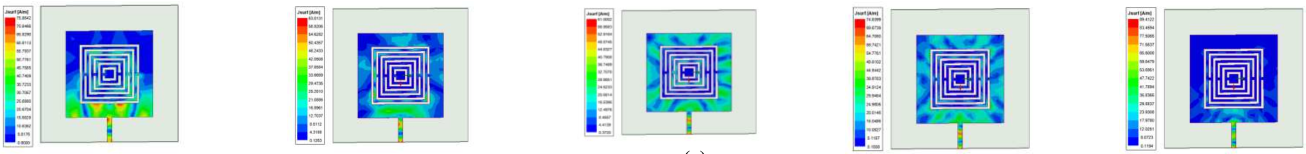


Fig. 5 Observation of Reflection Coefficient in Vector Network Analyzer

Fig 6 shows the Surface current distribution at five resonant frequencies. From this fig 7 it is observed that the maximum surface current is obtained at 13.7315 GHz.



(a) **(b)** **(c)** **(d)** **(e)**

Fig. 6 Surface Current distribution for the proposed antenna having 6 rings (a)7.7615GHz (b)9.5525GHz (c)11.0450GHz (d)11.9405 GHz (e) 13.7315 GHz

Fig 7 and 8 shows the radiation pattern of the proposed antenna having 6 rings. The radiation pattern of the proposed antenna having 6 rings exhibits omnidirectional radiation pattern in E Plane (Elevation plane) and H Plane (Azimuthal plane).

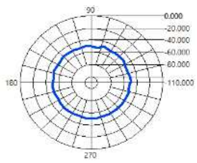


Fig. 7 Radiation pattern in E Plane

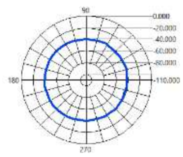


Fig. 8 Radiation pattern in H Plane

Table 2 and 3 shows the simulation results of the proposed antenna having 4rings and 6 rings. Table 4 shows the comparison with the previous work.

Table 2 Results for the proposed antenna having 4 rings

S.No	Band	Frequency (in GHz)	S11(in dB)	VSWR	BANDWIDTH (in GHz)	GAIN (in dBi)
1	C	7.6620	-14.7001	1.4512	7.52-7.75 (230MHz)	4.0306
2	X	9.8510	-32.1488	1.0506	9.19-10.28 (1090MHz)	2.5214
3	X	10.9455	-15.6399	1.3958	10.57-11.21 (640MHz)	2.0148
4	X	11.8410	-19.0459	1.2513	11.54-12.12 (580MHz)	4.4971
5	K_u	12.7365	-16.3600	1.3586	12.26-12.88 (620MHz)	4.0643
6	K_u	13.7315	-16.0422	1.3745	13.12-15.12 (2000MHz)	0.9781

Table 3 Results for the proposed antenna having 6 rings

S.No	Band	Frequency (in GHz)	S11(in dB)	VSWR	BANDWIDTH (in GHz)	GAIN (in dBi)
1	C	7.7615	-14.2685	1.4797	7.67-7.83 (160MHz)	9.2
2	X	9.5525	-31.3533	1.0556	9.14-10.27 (1130MHz)	7.06
3	X	11.0450	-17.8977	1.2920	10.85-11.34 (490MHz)	7.6
4	X	11.9405	-18.5857	1.2668	11.65-13.01 (1360MHz)	6.8
5	K_u	13.7315	-13.1256	1.5663	13.31-14.79 (1480MHz)	5.7

Table 4 Comparison with the previous work

References		Substrate	Frequency (in GHz)	Bandwidth (in GHz)	Gain (in dBi)	Applications
Mahendran K et al. (2020) [4]		FR_4	3.5, 4.1, 5.6, 9.1	0.3, 0.2, 0.3, 0.4	1.2, 0.60, 0.7, 2.09	S, C, X band
Air Mohammad Siddiky et al. (2020) [5]		FR_4	3.1, 10.1, 11.8, 12.44	0.41, 0.73, 1.6, 0.5	-41.78, -33.1, -47.2, -35.7	S, X, K_u band
Proposed antenna loaded with 4 rings		FR_4	7.7620, 9.8510, 10.9455,11.8410, 12.7365, 13.7315	0.23, 1.090, 0.64, 0.58, 0.62, 2.0	4.0306, 2.5214, 2.0148, 4.4971, 4.0643, 0.9781	C, X, K_u band
Proposed antenna loaded with 6 rings	Simulated	FR_4	7.7615, 9.5525, 11.0450, 11.9405. 13.7315	0.16, 1.13, 0.49, 1.36, 1.48	9.2, 7.06, 7.6, 6.8, 5.7	C, X, K_u band
	Measured	FR_4	8.2, 11.3, 12.12, 13.06, 13.86	0.45, 0.25, 0.4, 0.4, 0.5	2.52, 1.78, 6.47, 11.9, 0.05	X, K_u band

From table 4 it is inferred that the proposed antenna with 4 rings having six resonant frequencies. For C band at resonant frequency of 7.7620GHz the gain (in dBi) is improved by 5.8times than [4]. For X band at resonant frequency of 9.8510GHz the gain (in dBi) is improved and bandwidth is also improved by 2.73times compared to [4]. For K_u band having a resonant frequency of 13.7315GHz, bandwidth is improved by 4times compared to [5].

From table 4 it is inferred that the proposed antenna with 6 rings having five resonant frequencies. For C band having resonant frequency of 7.7615GHz the gain (in dBi) is improved by 7.7times than [4]. For X band having resonant frequency of 9.5525GHz the gain is improved by 3.38times and bandwidth is improved by 2.83times than [4] and improvement in gain is achieved compared to [5]. For K_u band at a resonant frequency of 13.7315GHz, bandwidth is improved by 2.96 times than [5].

4. CONCLUSION

The triple (C, X, K_u) band microstrip patch antenna is designed and simulated. The antenna with 4 rings having a triple band of frequency 7.6620, 9.8510, 10.9455, 11.8410, 12.7365 and 13.7315GHz are achieved with return loss of -14.7001, -32.1488, -15.6399, -19.0459, -16.3600 and -16.0422dB respectively and achieve -10dB impedance bandwidth of 230MHz (7.52-7.75GHz) for fixed satellite service (FSS) applications, 1090MHz (9.19-10.28GHz), 640MHz (10.57-11.21GHz), 580MHz (11.54-12.12GHz) for military FSS, terrestrial earth exploration, meteorological satellite and radar applications, 620MHz (12.26-12.88GHz) and 2000MHz (13.12-15.12GHz) for broadcast satellite service (BSS). The gain of 4.0306, 2.5214, 2.0148, 4.4971, 4.0643 and 0.9781dBi is obtained at center frequency of 7.6620, 9.8510, 10.9455, 11.8410, 12.7365 and 13.7315GHz, respectively. And the antenna with 6 rings also having a triple band of frequency 7.7615, 9.9525, 11.0450, 11.9405 and 13.7315GHz are achieved with return loss of -14.2685, -31.3533, -17.8977, -18.5857 and -25.4562dB respectively and achieve -10dB impedance bandwidth of 160MHz (7.67-7.83 GHz) for fixed satellite service (FSS) applications, 1130MHz (9.14-10.27 GHz), 490MHz (10.85-11.34 GHz), 1360MHz(11.65-13.01 GHz) for military FSS, terrestrial earth exploration, meteorological satellite and radar applications and 1480MHz (13.31-14.79 GHz) for broadcast satellite service (BSS). The gain of 9.2, 7.06, 7.6, 6.8 and 5.7 dBi is obtained at center frequency of 7.7615, 9.9525, 11.0450, 11.9405 and 13.7315GHz, respectively.

Declaration

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Conflicts of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Availability of data and material

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Code availability

Code availability not applicable to this article as no codes were generated or analyzed during the current study.

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