DESIGN AND SIMULATION OF A MODIFIED CIRCULAR MICROSTRIP PATCH ANTENNA WITH ENHANCED BANDWIDTH

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Abstract
In this paper, a modified circular microstrip patch antenna fed by a microstrip line feed is presented. The main aim was to improve the narrow bandwidth of microstrip patch antennas while at the same time ensuring that other important parameters of the antenna such as gain, efficiency, and impedance matching are not affected. The shape of the patch was modified by adding some parts to it and removing some parts from it with the aim of achieving a wider bandwidth. High frequency structural simulator (HFSS) was used to simulate and analyze the designed patch. Simulated results of return loss, VSWR, and Z parameters were then presented. Based on simulated results, the shape presented showed satisfactory operation in the frequency range 1647-1968 MHz which is within the L-band. The modified circular microstrip patch antenna showed remarkable improvement in bandwidth as compared to conventional microstrip patch antenna for return loss of less than -10 dB. The antenna also showed good impedance matching with the 50 Ω line that was used for simulation. The antenna is suitable for GSM 1800-1900 MHz systems.

Key words: Bandwidth enhancement, modified circular microstrip patch, antenna, simulation

1.0 Introduction

1.1 Background of the Study

An antenna is a structure for radiating or receiving radio waves. It is desired to be simple, small, lightweight and cheap. In addition it should operate over the entire frequency band of a given system. However, a single type of antenna may not possess all the desirable features. One type of antenna that possesses most of the desirable features is a microstrip patch antenna. Microstrip patch antennas are light in weight, cheap and conformable making them attractive for applications such as high performance aircraft, spacecraft, satellite and missile applications. However, they have low radiation efficiency, low power, high Q, poor polarization purity, poor scan performance, spurious feed radiation and very narrow frequency bandwidth [1].

Microstrip patch antennas are named based on the shape of the radiating patch. Thus, many configurations are in existence such as square, rectangular, dipole, circular, elliptical, triangular, disc sector, circular ring, and ring sector among others. Square, rectangular, dipole and circular microstrip patch antennas are easy to design and analyze and have desirable radiation characteristics (low cross-polarization radiation). These make them more common [1]. Circular microstrip patch antenna is more advantageous compared to rectangular one. First, it has one degree of freedom to control (radius) as compared to rectangular one which has two (length and width). Therefore, circular microstrip patch antenna is more convenient to design and its radiation can easily be controlled [2]. Secondly, the physical size of the circular patch is 16% less than that of the rectangular one at the same design frequency [3].

A microstrip patch antenna consists of a conducting metallic patch separated from the ground plane by a dielectric substrate. Figure 1 below illustrates the structure of a circular microstrip patch antenna. The thickness of the metallic patch, $t \ll \lambda_0$ (where λ_0 is free space wavelength). The height of the substrate, $h \ll \lambda_0$ (usually $0.003\,\lambda_0 \le h \le 0.05\,\lambda_0$) [1].

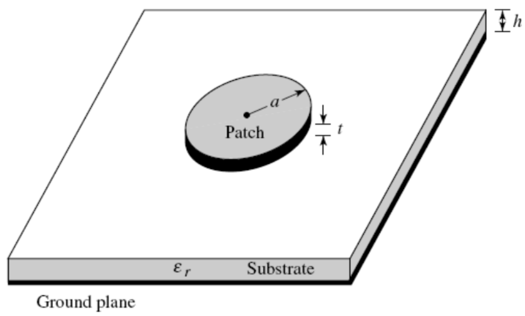

Figure 1: Circular Microstrip Patch Antenna

There are many substrates that can be used with dielectric constants ranging from 2.2 to 12 [1]. Thick substrates with low dielectric constants result in good antenna performance in terms of better efficiency, larger bandwidth and loosely bound fields that can easily be radiated into space. However, they result in larger element size. On the other hand, thin substrates with high dielectric constants are suitable for microwave circuitry because their fields are tightly bound resulting in minimal undesired radiation and coupling. Moreover, the element sizes will be smaller. However, the losses will be great making them less efficient. They also result in smaller bandwidths [4].

A number of methods can be used to feed microstrip patch antennas. The common ones are microstrip line, coaxial probe, aperture coupling and proximity coupling [1]. The methods can broadly be classified into contacting and non-contacting methods. In contacting method, there is direct feeding of RF power to the radiating patch by use of a connecting element (microsrip line). For the non-contacting case, power transfer between microstrip line and radiating patch is achieved through electromagnetic field coupling. Figure 2 illustrates the structure of a microstrip line feed for a circular microstrip patch antenna. It is a contacting method and consists of a conducting strip of a very small width compared to that of the patch. It is easy to fabricate, simple to match and simple to model. However, surface waves and spurious feed radiation increases with increase in height of the substrate. This limits the bandwidth to 2-5% [1].

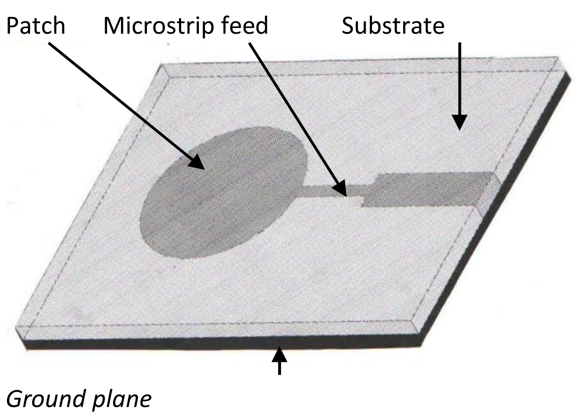

Figure 2: Microstrip Line Feed

Figure 3 illustrates the structure of a coaxial line feed (probe feed) for a circular microstrip patch antenna. It is a contacting method in which the inner conductor of the coax is connected to the radiating patch whereas the outer conductor is connected to the ground plane. It is easy to fabricate and match and has low spurious radiation. However, it has narrow bandwidth and it is more difficult to model especially when the substrates are thick ($h > 0.02 \lambda_0$) [1].

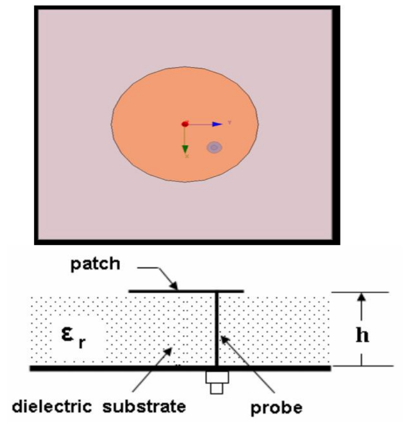

Figure 3: Probe Feed

Figure 4 illustrates the structure of an aperture coupled feed for a circular microstrip patch antenna. It is a non-contacting method that consists of two substrates separated by a ground plane. A microstrip feed line is on the bottom side of the lower substrate and is used to couple the energy to the patch through a slot on the ground plane. With this method, it is possible to optimize the feed and the radiating element independently. It is easier to model and has moderate spurious radiation. However, it is most difficult to fabricate and has narrow bandwidth [1].

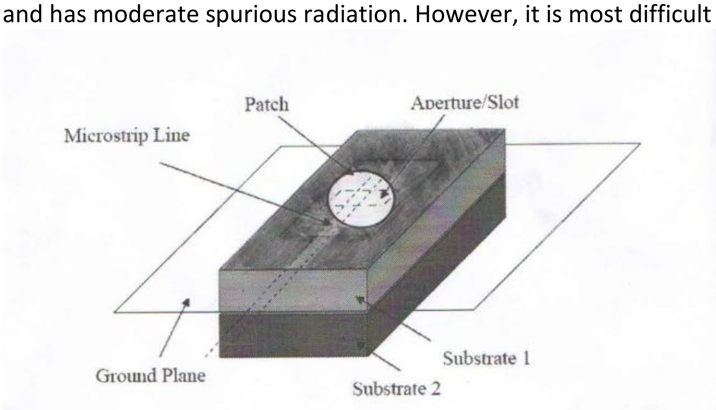

Figure 4: Aperture-Coupled Feed

Figure 5 illustrates the structure of a proximity coupled feed for a circular microstrip patch antenna. It is a non-contacting method and it is also called electromagnetic coupling scheme. It consists of two substrates with the feed line in between the substrates while the radiating patch is on top of the upper substrate. It results in the largest bandwidth (as high as 13%), is a bit easy to model, and has low spurious radiations. However, it is a bit difficult to fabricate [1].

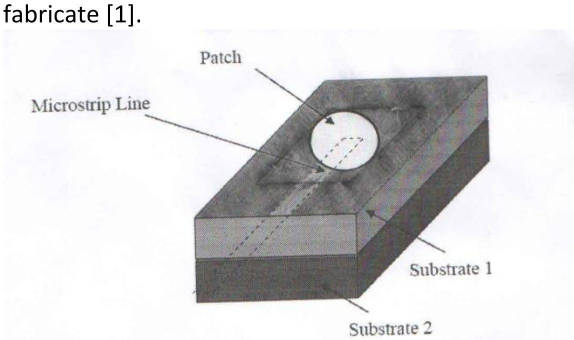

Figure 5: Proximity-Coupled Feed

In order to analyze the electromagnetic behavior of microstrip patch antennas, one can utilize transmission line model, cavity model or full wave model. The easiest of all is the transmission line model. This method also gives a good physical insight. However, it is the least accurate and it is more complicated to model coupling. Cavity model is more accurate compared to transmission line model. It also gives a good physical insight. However, it is more complex and it is a bit difficult to model coupling. Full wave models include primarily integral equations/moment methods. With proper application, full wave models are very accurate and very versatile for treating single elements, finite and infinite arrays, stacked elements, arbitrary elements and coupling. However, they are the most complicated and give less physical insight [1].

1.2 Problem Statement and Justification

Microstrip patch antennas are used in the microwave bands. These microwave bands have been assigned wider channels. Therefore, microstrip patch antennas are limited in their applications by their narrow bandwidth. There is therefore need to improve the bandwidth of conventional microstrip patch antennas for practical applications. Bandwidth describes the range of frequencies over which the antenna can radiate or receive sufficient power. Conventional microstrip patch antennas possess an impedance bandwidth of not more than 4%. Many techniques of improving the bandwidth of microstrip patch antennas have been suggested in the literature and include meandered ground plane [5], slot-loading [6], stacked shorted patch [7], feed modification [8], chip loading [9], teardrop dipole in open sleeve structure [10], using air substrate [11], using shorting posts between the patch and the ground plane [12], using thick substrates [13], using proximity coupling [1], shape modification [14] and many others.

The method of shape modification is simple and does not result in extra weight of microstrip patch antenna like some other methods such as stacking. In this study, the method of shape modification was used to enhance the bandwidth of a circular microstrip patch antenna up to 18.8%. The shape of the patch was optimized by adding some parts to and removing some parts from an initial circular patch of radius 3.587 cm with the aim of achieving an improved bandwidth. The modified circular microstrip patch antenna was designed in the L-band (1-2 GHz) with the aim of targeting the many applications in this band. Among the targeted applications were Digital Audio Broadcasting (DAB), GPS systems, Global system for mobile (GSM) mobile phones, Iridium satellite phones, INMARSAT and light squared terminals, Amateur radios and world space satellite radio broadcast. A number of researchers have enhanced the bandwidth of microstrip patch antennas within the L-band. A bandwidth of 16.2% was achieved at a center frequency of 1.31 GHz by introducing slots on a rectangular microstrip patch [15]. The bandwidth of a rectangular microstrip patch antenna was improved by 22.3 MHz at a center frequency of 1.47 GHz by use of metamaterial structure [16]. By using an aperture couple feed, a bandwidth of 17% was achieved in the frequency range 1.4 GHz-1.62 GHz [17]. Also, a bandwidth of 12% was achieved at a center frequency of 1.25 GHz by use of an aperture couple feed while a bandwidth of 19.68% was achieved at the same frequency by use of capacitive couple feed [18]. Moreover, the bandwidth of a conventional microstrip patch antenna was improved from 1.6% to 3% at a center frequency of 1.81 GHz by use of photonic band gap substrate [19]. The modified circular microstrip patch antenna developed in this research was fed by a microstrip line feed and simulated and analyzed using HFSS 13.0 which is based on full wave model.

1.3 Development of the Modified Circular Microstrip Patch Antenna

The modified circular microstrip patch antenna presented in this study was developed from an initial circular patch that was designed at a centre frequency of 1.5 GHz using RT/duroid 5880 substrate. RT duroid 5880 has a dielectric constant of 2.2. This substrate was chosen because it results in good antenna performance due to its lower dielectric constant. The height of the substrate should be within the range $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$ (where λ_0 is free space wavelength) for a microstrip patch antenna to operate satisfactorily. Therefore, the height of the substrate should be within the range 0.06cm ≤ h ≤ 1cm for a centre frequency of 1.5 GHz. For this design, the height of the substrate was taken to be 0.75 cm. Based on the design equations of circular microstrip patch antennas, (1) and (2); the corresponding radius was 3.587cm.

$$a = \frac{F}{\left\{1+\frac{2h}{\pi F \varepsilon_r}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \qquad (1)$$

Where

$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}$ (2) f_r- Resonant frequency

ε_r -Dielectric constant of substrate

h- Height of substrate

a- Radius of the patch

In the process of bandwidth enhancement, the shape of the initial circular patch was modified by adding some parts to it and removing some parts from it. As illustrated in Figure 6, two arcs each of radius 0.959 cm were added to the initial circular microstrip patch antenna to give a total radius of 4.546 cm at that point. Also, two arcs each of radius 0.635 cm were cut out from the initial circular microstrip patch antenna to give a radius of 2.952 cm at that point. The final part of the optimization process was to cut out two rectangles as also illustrated in the figure.

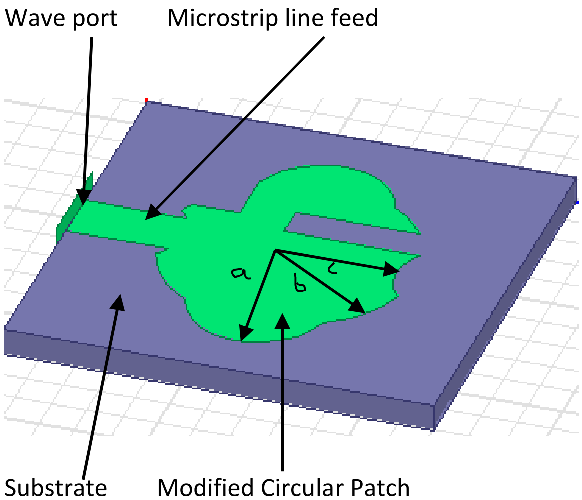

Figure 6: Modified Circular Microstrip Patch Antenna

Where

a=4.546 cm

b=3.587 cm

c=2.952 cm

The antenna was fed by a microstrip line feed of width 1.6 cm. The dimensions of the substrate were 12 cm by 12 cm. The detailed simulation procedure of the modified circular microstrip patch antenna is presented in the next section.

1.4 Simulation of the Modified Circular Microstrip Patch Antenna

The first step in the simulation process was to draw the shape of the modified circular microstrip patch antenna of figure 6 in HFSS environment. An initial circular patch of radius 3.587cm centered at 6 cm, 6 cm, 0.75cm (x, y, z) was drawn. The coordinate of the z-axis was taken to be 0.75 cm to account for the height of the substrate. Two circles each of radius 1.635 cm centered at 6 cm, 10.587 cm, 0.75 cm and at 6 cm, 1.413 cm, 0.75 cm were then cut out from the initial circular patch. This was achieved by use of the subtract command. The next step was to add two circles each of radius 1.959 cm to the resulting shape. The circles were centered at 3.413 cm, 6 cm , 0.75 cm and at 8.587 cm, 6 cm, 0.75 cm .This was done by use of unite command. Finally, two rectangles had to be cut out from the resulting patch. The first one was centered at 4 cm, 5.5 cm, 0.75 cm and had a length of 4 cm and width of 1 cm. The second one was centered at 2.9cm, 2 cm, 0.75 cm and had a length of 2.1 cm and width of 1.6 cm. This was also achieved using the subtract command. To model the microstrip line feed, a rectangle of length 3.7 cm and width 1.6 cm was drawn at 5.2 cm, 0 cm, 0.75 cm and united to the patch. Since the final structure had to be excited, a rectangle of length 3 cm and width 1 cm centered at 4.5 cm, 0 cm, 0.25 cm was drawn on the XZ plane to model the wave port. In order to draw the substrate, a box of length, 12 cm, width 12 cm and height 0.75 cm was drawn at the origin. The dimensions of the ground plane were similar to those of the substrate. However, no object was drawn to represent it as it was modeled by use of boundary condition. To model far field phenomenon, the radiations in the near field of the simulated antenna had to be absorbed. Therefore, it was necessary to draw an object to be assigned radiation boundary at a distance of at least $\frac{1}{4}\lambda$ from the patch. Therefore, a box of length 12 cm, width 12 cm and height 7.5 cm was drawn to represent it. The height in this case is equal to $\frac{1}{4}\lambda$ of 1 GHz which is the lowest frequency that was used in the simulation. The box was drawn at the origin implying that the height of the box extended from h=0 to h thus simulating radiation into the upper half-space only. After achieving the desired geometry, it was necessary to assign suitable materials to particular objects. In assigning materials, the assign material command is used. The radiation box was created to model the far field phenomenon. The material air was used in this case so as to simulate the real environment where the antenna will be utilized. The microstrip line feed and the radiating patch being perfect electric conductors were assigned the material PEC which is nothing but a lossless metal. The box representing the substrate was assigned the material RT/duroid 5880. This is the substrate that was used in the designed process. When the assignment of materials was complete, it was necessary to assign suitable boundaries to surfaces of the structure. The lower surface of the box representing the substrate was assigned the boundary PEC ground to model the ground plane as explained earlier. All the surfaces of the radiation box except the lower one were assigned radiation boundary. The lower surface was not included since the patch lies on it. Finally, it was necessary to excite the structure. Therefore, the rectangle representing the wave port was assigned wave port excitation. The modified circular microstrip patch antenna was analyzed at a center frequency of 1.7 GHz over the frequency range 1-2 GHz (L-Band).

2.0 Simulation Results, Analysis and Discussions

The performance of the antenna was determined from the simulation results based on certain criteria. First, the bandwidth of the antenna was determined from the return loss curve at -10 dB point. This point is used because it is an equivalent of a 2:1 VSWR which is allowed for practical antennas. Usually, an ideal antenna has a VSWR of 1:1. However, this ideal condition may not be achieved with practical antennas and a VSWR of up to 2:1 result in an antenna that operate satisfactorily. When the VSWR of 2:1 is converted to return loss, it gives 9.542. This value is normally taken to be 10 and since the reference point of return loss curve is zero, -10 dB point is used to determine the bandwidth of an antenna. The main aim of this study was to improve the bandwidth of a circular microstrip patch antenna by modifying its shape. However, care had to be taken so as not to sacrifice the gain of the antenna. In doing this, the gain of conventional microstrip patch antennas of 5.2 dB was used as a reference. Gain of an antenna is important since the range covered by an antenna is directly proportional to the square root of three important parameters. These parameters are gain, operating wavelength and transmitter power as depicted in the Friis transmission formula.

Impedance matching was also an important factor. Good impedance matching results in maximum power transfer. It was necessary to ensure that there was a good impedance matching with the 50 Ω line that was used in the simulation. Simulated results of return loss, VSWR, smith chart of S-parameters, and Z-parameters were as follows.

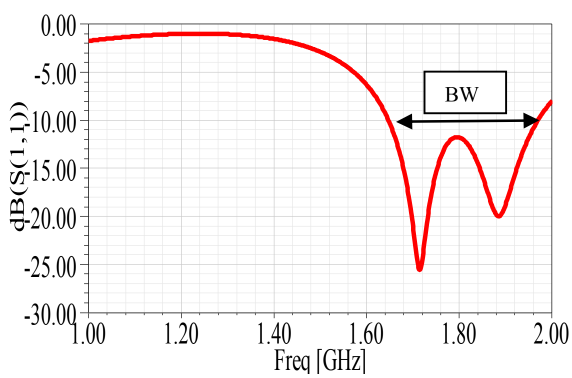

Figure 7: Return Loss Versus Frequency

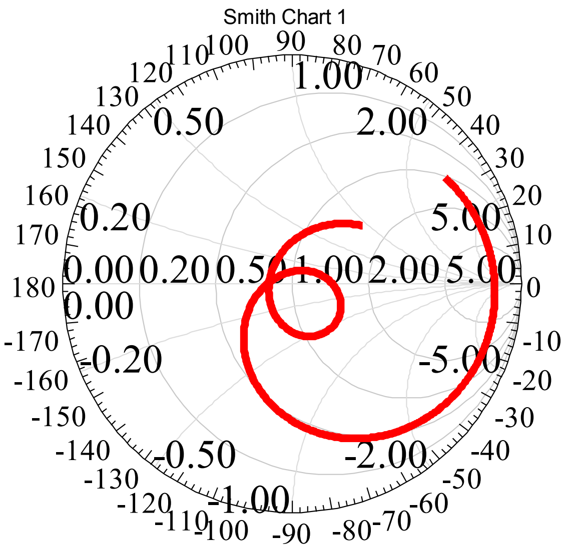

Figure 8: Smith Chart of S-Parameters

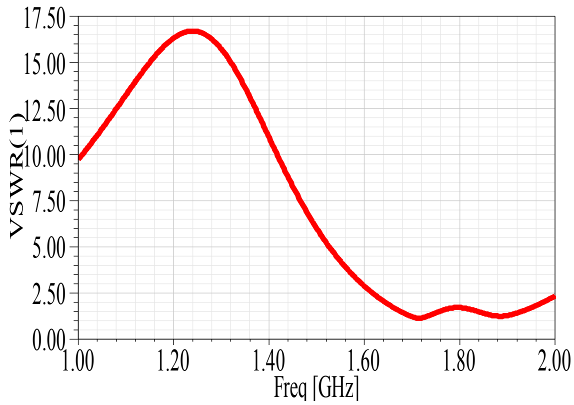

Figure 9: VSWR versus Frequency

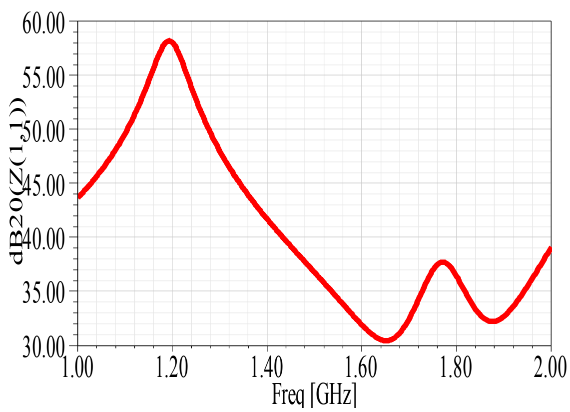

Figure 10: Z-Parameters versus Frequency

Based on -10 dB return loss, the antenna achieved an absolute bandwidth of 321 MHz. The ratio of the absolute bandwidth and centre frequency gives the percentage bandwidth. In this case, the main resonant frequency was at 1.71 GHz and therefore the bandwidth was 18.8%. This is an improvement when compared with the bandwidth of conventional microstrip patch antennas of about 4%. The gain of the modified circular microstrip patch antenna was 2.908 (4.636 dB). This shows that there was a slight decrease in gain when compared with the conventional one. The VSWR curve shows that the antenna had a VSWR of less than 2 over the bandwidth. There was also a good impedance matching with the 50 Ω line that was used for simulation. The impedance of the antenna was within the 2:1 VSWR impedance over the bandwidth. This is indicated by the smith chart of s-parameters. The same is also reflected by Z-parameters results. The antenna also recorded excellent radiation efficiency of 99.1%.

3.0 Conclusion

The modified circular microstrip patch antenna achieved improved bandwidth within the L-band. The antenna achieved return loss of less than -10 dB in the frequency range 1647-1968 MHz. The antenna resonated at two frequencies with the main resonant frequency at 1.71 GHz. The bandwidth achieved was an equivalent of 18.8% of the main resonant frequency. The bandwidth achieved is better than that achieved by Abbas and Aziz, Garg et al., Kumar et al., and Gonzalo et al. within the same band (L-Band). It is also better than the aperture couple feed case of Rathod. The antenna also showed a good impedance matching with the 50 Ω line that was used for simulation. There was only a slight decrease in gain at the expense of the bandwidth achieved. The antenna is suitable for GSM 1800-1900 MHz systems.

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