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REVISTA PERSPECTIVAS

Conjunto de antenas circulares con una línea de transmisión para formar una antena Yagi-Uda para WiFi

Circular antenna array with a transmission line to form a Yagi-Uda WiFi antenna

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Resumen— El presente trabajo describe el diseño de un conjunto de antenas apiladas Yagi-Uda para aplicaciones de 2,4 GHz. Su estructura comprende 4 capas, la primera capa contiene el elemento activo, el reflector y la línea de transmisión de alimentación. Las capas dos, tres y cuatro tienen parches circulares que funcionan como directores. La implementación de un parche en forma de "D"se incorpora en el elemento activo, en el que los resultados de la simulación muestran que la antena propuesta puede lograr un ancho de banda significativamente mayor que la antena de parche circular tradicional, dando un ancho de banda de 2,37 a 2,47 GHz. También se modificaron las dimensiones de los directores del parche circular y las distancias entre ellos para tener el mejor ancho de banda.

***Palabras Clave*— Ancho de banda, microstrip, antena yagi-Uda, antena WiFi.**

Abstract— The present paper describes the design of a Yagi-Uda stacked antenna array for 2.4 GHz applications. Its structure comprises 4 layers, the first layer contains the active element, the reflector, and the feed transmission line. Layers two, three and four have circular patches that work as directors. The implementation of a "D" shaped patch is incorporated in the active element, in which simulation results show that the proposed antenna can achieve significantly wider bandwidth than the traditional circular patch antenna, giving a bandwidth from 2.37 to 2.47 GHz. The dimensions of the circular patch directors and the distances between them were also modified to have the best bandwidth.

***Keywords*— Bandwidth, microstrip, yagi-Uda antenna, WiFi antenna.**

I. Introduction

The world is currently immersed in what is known as the "technological revolution of wireless communications", but in order to become a reality it is essential to use antennas to transmit and/or receive electromagnetic waves in free space, due to the broadcast nature of wireless communications, the information is transmitted over the air. Antennas are the components of telecommunication systems specifically designed to radiate or receipt electromagnetic waves. They can also be defined as devices that adapt guided waves, which are transmitted by conductors or wires, to waves propagated in free space. Communications systems use antennas to make point-to-point links, broadcast television, radio signals, and transmit or receive signals in portable equipment[1]. Due to the accelerated development of modern communications and in order to meet the demand for base station applications in communication systems, there is a wide variety of antenna designs.

Antenna is a subsystem which is employed in both transmitter and receiver which basically radiates electromagnetic waves (EM Waves) into free space and vice versa. It consists of conductors that convert electrical energy into EM energy at the transmitter end and vice versa at receiver end. Directional antennas such as log periodic and Yagi-Uda antennas are used in wireless communication applications that includes industrial, medical, radar communication and 4G cellular applications[2]. These antennas are classified according to their geometry. Cable antennas are, for example, dipole, monopole, spiral, helical, parabolic and panel antennas. Television antennas usually encountered on buildings consist of an array of dipoles, but there are also aperture antennas such as horn, slot and microstrip antennas that consist of a metal patch on a substrate and a ground plane underneath. Microstrip antennas are low profile, adaptable to any surface, simple and inexpensive to manufacture, and are mechanically robust when installed on rigid surfaces. Another type of antenna are reflectors, which are antennas consisting of a reflector, usually with a parabolic profile, with the antenna located at the focus of the reflector. Large space observation antennas are an excellent example of such devices. There is also antenna arrays, where more than one antenna is put together to achieve certain radiation characteristics. Antennas can also be classified according to their performance. There are broadband, miniature and multi-frequency antennas that can operate with the same characteristics for different telecommunication systems[3].

The antenna on which this project is being based is a Yagi antenna. Yagi antennas are highly directional antennas, widely used for television reception in the RF range. A Yagi antenna has either a dipole or a folded dipole as its active element. The

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director of the Yagi antenna design is made with a reduced dipole, the reflector and directors have the same length and spacing as the normal Yagi dipole antenna[4]. Afterward, the concept of Yagi-Uda antenna and microstrip patch antenna are applied together [5]. The extraordinary development of mobile communications systems, which offer a great variety of new services every day, as well as the multiplicity of standards currently operating in the world, has generated the need to design new antennas of reduced size in both base stations and mobile terminals, which must have high performance and low cost. Among the desirable features in antennas to meet current market needs, the design of antennas with more bandwidth is required [6].

Yagi-Uda stacked antenna presented in [7] provides a directivity mode, and since the three directors operate as monopole antennas, they provide pattern diversity, in which directivity mode and diversity mode can be simultaneously achieved. However, it has limited bandwidth and directivity. Knowing that one of the big problems of patch antennas is the limitation of its bandwidth. This work aims to improve the results presented in [7] based on the bandwidth parameter, and that this is within the frequencies in which WiFi technology works. The dual-mode stacked antenna array composed of four layers in vertical configuration is analyzed and designed to maintain the compact design of the antenna. Also, by reconfiguring the states of the parasitic elements on each side of the driven element, the pattern reconfiguration can be achieved. The parasitic elements can be reconfigured to serve as directors or reflectors easily by changing the electric length or by loading lumped elements[8].

The following sections describe and present some considerations in the process that was carried out to obtain the final results. First, rings are added to the directors of layers 2 and 3. Subsequently, more rings are included in layers 2, 3 and 4 in second design. Then, the final simulation of the antenna is presented, obtaining an increase in the bandwidth, performing a combination, inserting rings in the directors and changing the shape of the active element of the Yagi-Uda antenna. Finally, the results are discussed and conclusions are drawn.

II. Methodology

The Yagi-Uda antenna array construction is composed of one active element and three vertically stacked Yagi-Uda directors, operating at the frequency of 2.4 GHz. The main objective involved designing and simulating a new Yagi-Uda antenna model to increase bandwidth and directivity, based on [7]. Li studied theoretically different patch shapes (square, circular, triangle, etc.) and investigated the optimal combination to achieve a lower cross polarization or circular polarization [9]. Stacked triangular microstrip antennas were also investigated experimentally in [10] to achieve a bandwidth about 17%-5% at the centre frequency of 3.407 GHz.

For this reason, the shape of the circular patches has been retained because the antenna presents a dual polarization using circular patches in the design of one driver element and four directors. In addition for an optimization facility, since that is only required to optimize the radius of the circles.

The disadvantage of multilayer structures arises from the bonding process of the different layers, which must avoid the appearance of air bubbles and ensure dielectric homogeneity. An alternative is to use in the same layer several resonant elements within the same cell to achieve similar performance to multilayer structures, such as double or multiple concentric rings [11]. An alternative is to use several resonant elements in the same layer within the same cell in order to achieve performance similar to that of multilayer structures, such as double or multiple concentric rings [12]. These rings can be cross-shaped [13], circular [14], rectangular [15], etc. Proposals that combine rings and patches in the same layer can also be found [16]. In [17] it is also mentioned that the main purpose of implementation of ring is to enhance the gain and directivity. As compare to other investigations, in [18] and [19] mentioned that circular ring microstrip antenna has the broader bandwidth and lower resonance frequency which leads to substantial miniaturization of such antenna.

A. Stacked Yagi Antenna with ring directors (Design #1)

To modify the Yagi-Uda stacked antenna array shown in [7], a slight modification was developed in software at the directors, specifically at layer 2 and 3, this modification consists of inserting an external ring in the circular patch as shown in Fig.1.

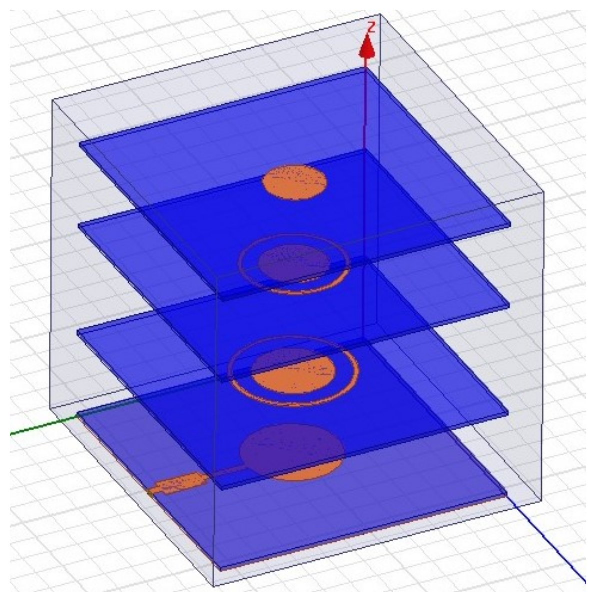

Figure 1. Proposed structure of design #1.

Fig.2 illustrates the reflection coefficient of the Yagi-Uda antenna array. The result is -46.28 dB at 2.4 GHz with a bandwidth of 60 MHz.

B. Stacked Yagi Antenna with "Bullseye" type (Design #2)

In this design, the rings in the 3 directors or parasitic elements were increased in a "bull's eye" style. In this design with the addition of the rings on the outside of the circular patch and the reduction of the radius, as shown in Fig. 3, it expected to obtain a higher bandwidth.

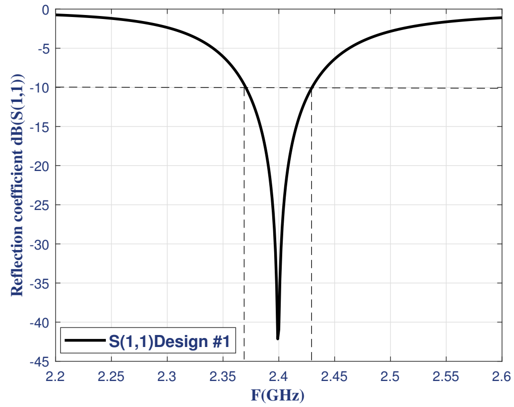

Figure 2. S(1,1)-parameter characteristic of the designed antenna #1.

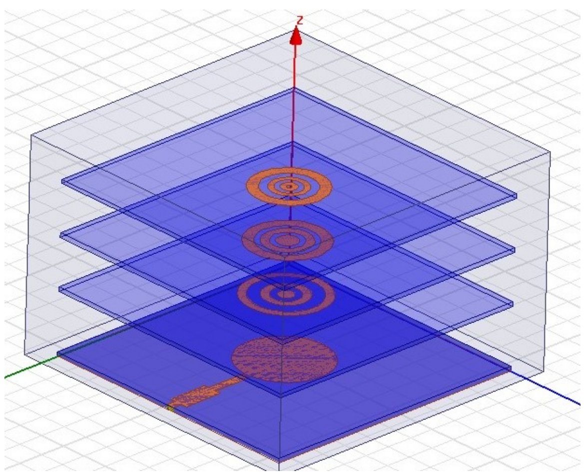

Figure 3. Proposed structure of design #2.

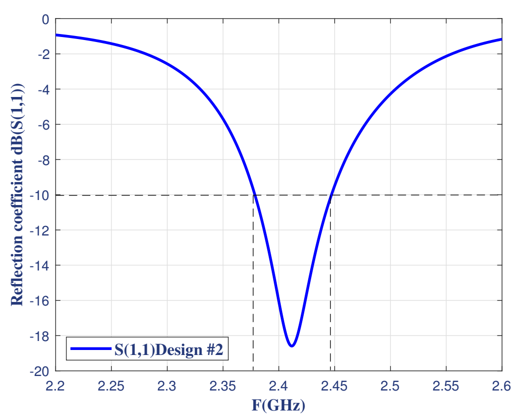

Figure 4. S(1,1)-parameter characteristic of the designed antenna #2.

Fig. 4 illustrates the reflection coefficient of the Yagi-Uda antenna array, where it can be seen that the inserted rings contributed to increase the bandwidth of the antenna array in comparison with design #1, resulting in a bandwidth of 70 MHz and S11 with -18.59 dB.

C. Stacked Yagi antenna with an adjustment in the circular patch of the active element and rings in the directors (Design #3)

Finally, it was possible to significantly increase the bandwidth in the Yagi-Uda stacked antenna array with regard to [7], the final configuration is shown in Fig. 5. This optimization was achieved, firstly, by modifying the active element, that is, the circular patch was changed by a "D" shaped patch taken from [20], where this patch was able to achieve a higher bandwidth. Secondly, the rings inserted in the conductors of design #2 were retained.

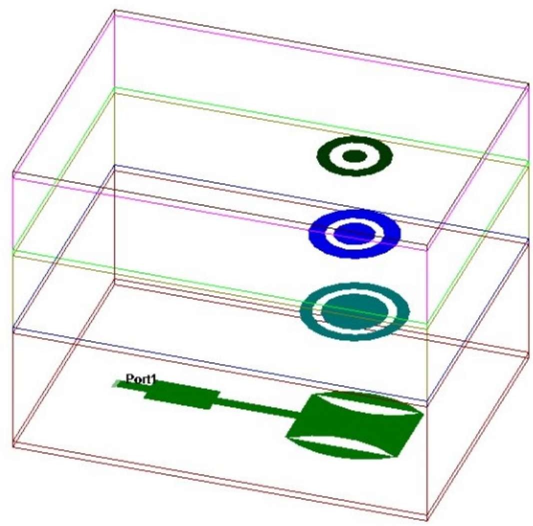

Figure 5. Geometry of the stacked Yagi–Uda antenna with straight feeding lines.

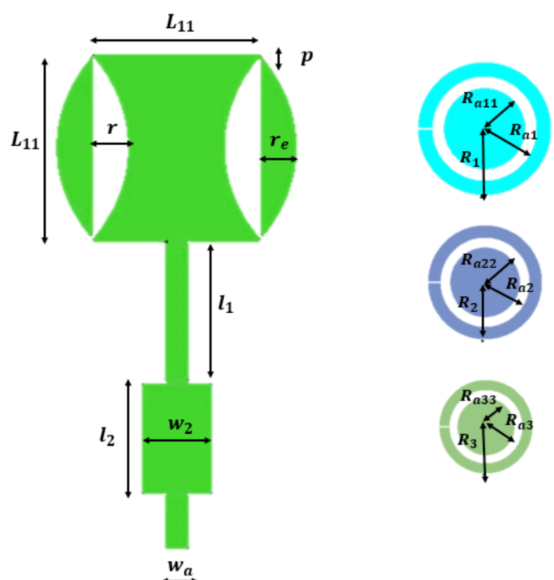

Figure 6. Illustration of the proposed antenna array layout.

Where:

W, L : Substrate dimension (FR4).

Table I
ANTENNA ARRAY DIMENSIONS.

Parameter	Dimension
W(mm)	118
L(mm)	118
R1(mm)	13
Ra1(mm)	10
Ra11(mm)	8
R2(mm)	11
Ra2(mm)	7
Ra22(mm)	5
R3(mm)	9
Ra3(mm)	6
Ra33(mm)	3
r(mm)	4.05
p(mm)	1
wa(mm)	3.051
w2(mm)	8.638
L11(mm)	27
l1(mm)	20.95
l2(mm)	16.34
l3(mm)	8
D1(mm)	30
D2(mm)	20
D3(mm)	20

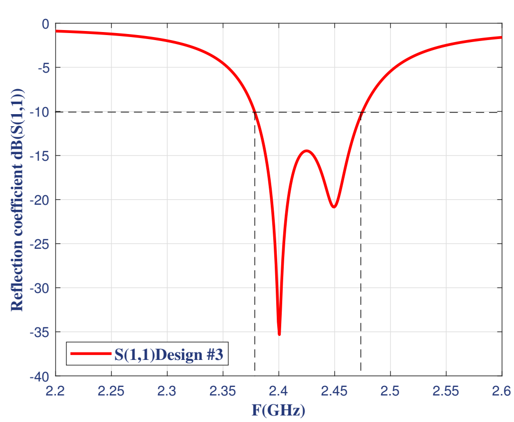

Figure 7. S(1,1)-parameter characteristic of the designed antenna #3.

$D1, D2, D3$: Distance between layers, respectively.

Fig. 7, shows the reflection coefficient of the Yagi-Uda antenna array, where it can be observed that the new active element and the insertion of the rings helped to further increase the bandwidth compared to the design of #1, #2 and the D-shaped patch, resulting in a bandwidth of 100 MHz (from 2.37 to 2.47 GHz) with a S11 of -35.8 dB. The antenna array was designed for an input impedance of 50 ohms, obtaining Zreal = 50.40 ohms and Zimg = -0.98 ohms.

D. Antenna implementation

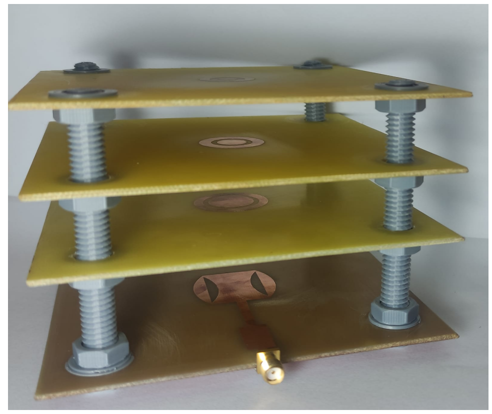

Figure 8. Photograph of the fabricated antenna array prototype design #3.

Fig. 8, shows the physical implementation of the Yagi-Uda antenna, its structure shows layer 1 of the active element and layers 2, 3 and 4 of the directors and also the screws as support at the ends of the layers, these are made of plastic so as not to interfere with the signal received by the antenna and serve to separate each layer.
The antenna is printed on a FR-4 substrate of dielectric constant 4.4, thickness 0.6 mm and with a loss tangent of 0.02. The fabricated microstrip antenna is soldered with one impedance subminiature version A (SMA) probe connector in the first layer. The array antenna has a total dimension of 76.4 mm.

III. RESULTS

A. The First Design Example

Parameter S11 show in Fig. 2 of the proposed structure over the frequency range of interest to -46,28 dB. The simulation results obtained show a antenna bandwidth (-10 dB) covers frequencies from 2.37 to 2.43 GHz or 2.5% at 2.4 GHz. Fig. 10(a) presents simulated radiation pattern. It is observed that is symmetric, the peak antenna gain is 3.49 dB. The total height of the designed configuration is 106.4 mm.

B. The Second Design Example

Simulated parameter S11 of the second design is show in Fig. 4. to -18.59 dB. The bandwidth is from 2.37 GHz to 2.44 GHz (70 MHz) or 2.92% at 2.4 GHz. The bandwidth of this antenna is narrow but sufficient for WiFi application. Fig. 10(b) presents simulated radiation pattern. It is observed that the peak antenna gain is 7.20 dB. The total height of the designed configuration is 64.4 mm compared to the designed structure described in [7], which has a dimension of 82.65mm.

C. The Third Design Example

Finally, simulated parameter S11 of the third design is show in Fig. 7. to -35.37 dB. The bandwidth is from 2.37 GHz to 2.47 GHz (100 MHz) or 4.17% at 2.4 GHz. The bandwidth of this antenna is 30 MHz wider than antenna shows in[7]. This was achieved after modifying the circular patch by a "D" shaped patch of the active element and with the rings of the second design, therefore, it was obtained values that satisfied our main objective with regard to the results reported in the reference article. Fig. 10(c) presents simulated radiation pattern. It is observed that the peak antenna gain is 6.22 dB. The total height of the designed configuration is 76.4mm compared to the designed structure described in [7], which has a dimension of 82.65mm. It is minimized the distance between directors for keeps the as compact structure as possible.

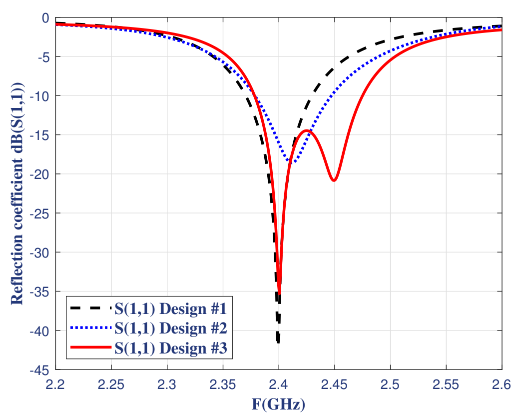

Figure 9. Comparison of the reflection parameter S11 of the designs.

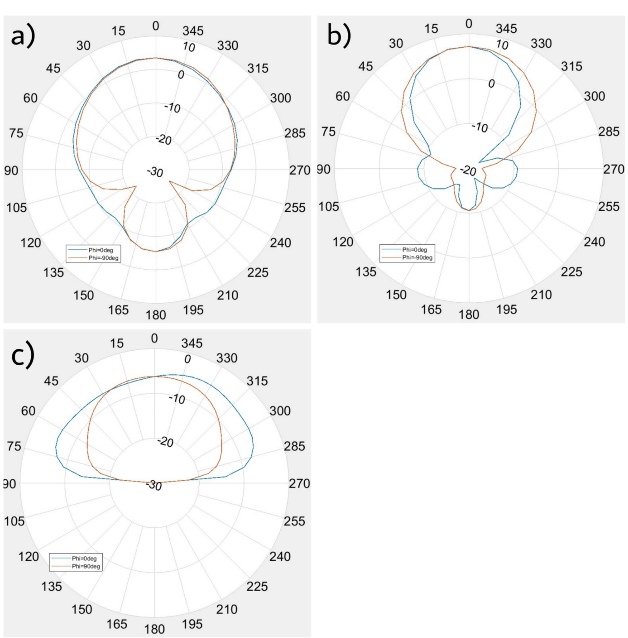

Figure 10. Simulated gain patterns on -plane at 2.4 GHz. (a) Gain pattern of design #1 (b) Gain pattern of design #2, (c) Gain pattern of design #3.

Fig. 10, shows the simulated realized-gain of each design at 2.4 GHz, when exciting port 1: (a) shows the gain pattern of the design #1. The simulated peak gain is 3.49 dBi. Fig. 10, (b) shows the gain pattern of the design #2. The simulated peak gain is 7.20 dBi. As shown in Fig. 10, (c) it can be seen that the simulated peak gain is 6.22 dBi. In addition, it is observed from Fig. 10 that the maximum radiation angle from designs #1, #2, #3 are 0.

After fabrication of Yagi-Uda antenna with modifications, the next stage was to test the designed antenna by using the vector network analyzer (VNA). The purpose of this testing was to measure some of the antenna parameters such bandwidth (170 MHz or 7.08%) and resonance frequency (2.39 GHz). Fig. 11 shows the comparison between simulation results and the measurement results obtained by using the VNA.

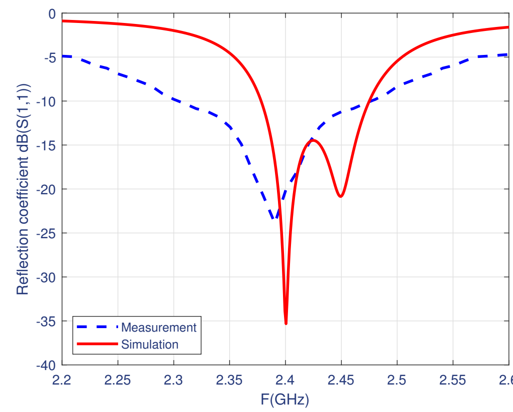

Figure 11. Comparison of simulation and measurement of designed Yagi-Uda antenna.

IV. Conclusion

The design of the Yagi-Uda antenna has allowed to detect a variety of parameters that can be modified to obtain one result or another depending on the necessity of each individual. In this paper, a class of antenna based on the classic Yagi-Uda antenna concept. By using multilayer-stacked substrates, this design allow compact size realization and achieve good performance at the demonstrated frequency of 2.4 GHz. A antenna configuration is presented and showcased with circular patches on the directors layers for dual polarization. The simulation result of S11-parameter show a reasonably good bandwidth (100 MHz or 4.17%), by joining several experimental designs of patch antennas, as it could be observed in each design, the change in the dimensions of the conducting elements and the change of the active element was reflected in the S11-parameter, where the progressive improvement of the bandwidth of this parameter can be appreciated. After the design it was possible to obtain superior bandwidth than could be obtained with a common patch antenna, this can be achieved thanks to the "D" shaped patch in the active element, the external rings, the variation of the radius of the circular patches in the directors and the variation of the distances between each layer, thereby obtaining satisfactory results. Also the entire structure is compact in size by using the vertical dimension. In this case, a large number of directors can be implemented in such multilayered geometries, can be using different planar patches in the driver layer. The performance of the stacked Yagi-Uda antenna array is significantly dependent on the active element, as its geometry can help it to achieve the desired parameters, in this case the bandwidth. This work suggests that the proposed concept provides a reasonably bandwidth for WiFi applications, is affordable, easy-to-build option and low-cost.

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