Miniaturized Rectangular Slotted Nameplate Antenna Design for Satellite and Radio Determination Applications

Thangavelu Shanmuganantham and Deepanshu Kaushal

A slotted rectangular nameplate antenna design with a patch bearing the name of the first author is presented. A 6.8 mm × 26 mm × 1.6 mm substrate of FR-4 epoxy material having a relative permittivity of 4.4 and a dielectric loss tangent of 0.02 is used. Additionally, the feeding technique used is a coaxial mechanism. The standard antenna design parameters, including the reflection coefficient, bandwidth, radiation pattern, gain, directivity, and voltage standing wave radio (VSWR) for the proposed prototype are analyzed using a high-frequency structure simulator (HFSS) v-15, and are compared to the measured results. The designed structure may be considered for different satellite- and radio-determination applications at the respective resonant frequencies.

Keywords: Coaxial feeding mechanism, HFSS v-15, Nameplate, Radio determination, Slotted.

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I. Introduction

The IEEE C-band of microwave frequencies ranging from 5.925 GHz to 6.7 GHz may be used for fixed satellite (earth-space) applications. Another X-band frequency range of 9.2 GHz to 9.3 GHz may be used for radio location and maritime radio navigation applications. The Ku range of frequencies between 15.7 GHz and 16.6 GHz may be utilized for radio location, whereas the K-band frequencies lying between 23.15 GHz and 23.55 GHz may be used for fixed inter-satellite applications.

The microstrip patch antennas used for the aforementioned applications are miniaturized, compact, economical, mechanically robust, conformal to most non-planar structures, compatible with most monolithic microwave integrated circuit (MMIC) designs, and diverse in terms of the offered center frequency, polarization, patterns, and impedance.

Different literature works of recent origin were studied before starting with our proposed work. In [1], Tahsin Ferdous proposed a microstrip rectangular patch antenna for X-band applications of satellite communication and radar-engineering. The designed structure yielded a single band reflection coefficient of –21.3 dB and a bandwidth of 453 MHz at 10 GHz. The gain achieved was 7.52 dBi. In [2], Shanmuganantham proposed a coaxially fed conventional microstrip rectangular patch antenna design for the study of different direct contact feeding techniques. The antenna exhibited a single band resonance of 8 GHz with a 2.3 dBi gain and a 500 MHz bandwidth. Thus, the conventional microstrip rectangular patch antenna, at most times, offered single band resonance with low gains and limited bandwidth. The use of slotted patches is often suggested for multiband operation and improvement of gain and bandwidth. In [3], Deepanshu Kaushal proposed a microstrip rectangular patch antenna that was slotted in the shape of a caterpillar. The introduction of slots in the basic rectangular patch resulted in the addition of bands with a structure offering improved gain and bandwidth characteristics. The structure had respective center frequencies of 3.12 GHz, 15.18 GHz, and 24.04 GHz, with corresponding maximum gains of 6.2 dBi, 17.1 dBi, and 16.2 dBi, respectively. The bandwidths attained at these center frequencies were 36 MHz, 4.9 GHz, and 710 MHz, respectively. This antenna had numerous applications, including radio location, around 3.12 GHz; earth exploration satellites (active) and space research, fixed mobile and space research around 15.18 GHz; and amateur satellite applications around 24.04 GHz. In [4], T. Shanmuganantham proposed a slotted rectangular patch for wideband applications. The U-shaped slot that was used in the basic rectangular patch yielded a simulated bandwidth of nearly 4.6 GHz around a center frequency of 5.6 GHz.

Based on the use of slotted patches for improved gain and bandwidth extension, it was considered that a patch bearing a long series of slots would probably result in significantly improved characteristics; the name of the first author was used as a reference for the slot design. The proposed antenna design had a compact size of 6.8 mm × 26 mm × 1.6 mm. The structure, when simulated over HFSS-15, exhibited two useful frequency bands with the first band resonating at a single center frequency of 6.07 GHz and the other resonating at 9.25 GHz, 15.79 GHz, and 23.41 GHz, respectively. The values of gain corresponding to the four different resonant frequencies included 2.9 dBi, 8.5 dBi, 26.8 dBi, and 12.6 dBi, respectively. Additionally, the first band having a single resonant frequency offered a bandwidth of 1.95 GHz, whereas the other band resonating at three different frequencies had a 21.6 GHz bandwidth. The structure was fabricated and tested using a Rhode & Schwarz ZVA 40 Vector Network Analyzer (VNA), ranging from 10 MHz to 40 GHz for its reflection coefficient and voltage standing wave radio (VSWR) parameters. It was also tested in an anechoic chamber for its radiation pattern. The measured values were plotted against the simulated values, and a comparison of both sets of values was tabulated. The proposed slotted patch antenna may be used for fixed satellite (space-earth) applications around 6.07 GHz, radio location and maritime radio navigation around 9.25 GHz, radio location around 15.79 GHz, and fixed inter-satellite applications around 23.41 GHz. Therefore, our proposed structure is novel and improved over the conventional rectangular patch and the various slotted patches discussed above, in terms of exorbitantly higher gains and bandwidths corresponding to the different resonant frequencies that encompass numerous applications.

An outline of the existing literature, proposed work, and its background is given in Section I. Section II provides a description of the geometrical aspects of the proposed antenna. Section III discusses major results wherein both the simulated and fabricated counterparts are included and compared. The final sections include the conclusion, references, and the author profiles.

II. Geometrical Aspects of the Proposed Antenna

The geometrical aspects of the proposed antenna structure are discussed in this section. The design utilizes a 6.8 mm × 26 mm × 1.6 mm FR4 epoxy substrate [5] (region in maroon) of relative permittivity of 4.4, and a dielectric loss tangent of 0.02. It is covered by a 4 mm × 25.3 mm blue rectangular patch. The feeding technique employed is a coaxial feed. The position of this feed is chosen such that the input impedance is 50 ohms. The basic equations used in the design process are listed in Table 1. To improve the gain and bandwidth parameters (compared to a conventional rectangular patch antenna) with multiband performance, the rectangular patch is slotted using a long series of alphabet characters, giving it the resemblance of the nameplate of our first author. The slots are of great significance, and result in an improved parametric performance. Exclusion of any of these slots from the patch would result in the lowering of gain and bandwidth. This alphabetical series of slots also offers significant miniaturization of the patch. The proposed antenna structure and the fabricated counterpart are shown in Figs. 1 and 2, respectively. The dimensions of the proposed antenna design are listed in Table 2.

The tabulated specifications of the proposed antenna are as follows.

Table 1. Basic design equations [6].

Parameter	Formula
Width of the patch ($W1$)	$w=\left(\frac{c}{2\times f_r}\right)\left(\sqrt{\frac{\varepsilon_r+1}{2}}\right)$
Relative permittivity $\varepsilon_{\text{reff}}$	$\varepsilon_{\text{reff}}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\times\sqrt{\left(1+\left(\frac{12h}{w}\right)\right)}$
Effective length of the patch $L1$	$L=\frac{c}{2\times f_r\times\varepsilon_{\text{reff}}}-2\Delta l$
Extension length of the patch ΔL	$\Delta l=0.412\times h\times\left[\left(\frac{\varepsilon_{\text{reff}}+0.03}{\varepsilon_{\text{reff}}-0.258}\right)\times\left(\frac{w+0.264h}{w+0.8h}\right)\right]$

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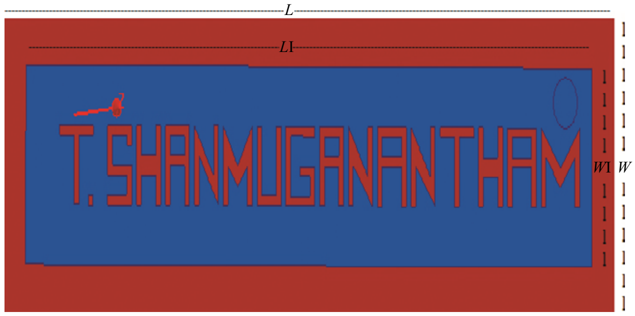

Fig. 1. Proposed antenna structure.

III. Discussion of Results

Major antenna parameters, including reflection coefficient, bandwidth, radiation pattern, gain, directivity, and VSWR, are analyzed in this section. A comparison of the simulated and fabricated results is included at the end of this section.

1. Reflection Coefficient and Bandwidth

Figure 3 shows the comparative reflection coefficient plot of the simulated and fabricated proposed prototypes. The simulations were conducted using Ansoft HFSS v-15 software [7], and the fabricated antenna was tested over a Rhode & Schwarz ZVA 40 VNA, ranging from 10 MHz to 40 GHz, for its reflection coefficient [8] plot, as shown in Fig. 3. The received set of values are used to plot the validated reflection coefficient against the simulated one.

Whereas the proposed structure exhibits a simulated dual-band quad-frequency resonance with reflection coefficients of –25.5 dB at 6.07 GHz, –16.3 dB at 9.25 GHz, –33.7 dB at 15.79 GHz, and –35 dB at 23.41 GHz, respectively, we find the fabricated structure yields reflection coefficients of –25.3 dB at 6.01 GHz, –16.3 dB at 9.22 GHz, –36.1 dB at 15.75 GHz, and –36.6 dB at 23.38 GHz, respectively. For the simulated design, the bandwidth [9] of the band covering 6.07 GHz is 1.95 GHz, and the band covering the resonant frequencies of 9.25 GHz, 15.79 GHz, and 23.41 GHz is 21.79 GHz. Similarly, for the case of fabricated design, the band covering the resonant frequency of 6.01 GHz has a bandwidth of 1.91 GHz, and the band covering the resonant frequencies of 9.22 GHz, 15.75 GHz, and 23.38 GHz is 21.76.

Table 2. Antenna specifications (mm).

Dimension	Value (mm)
L	26.0
W	6.8
*L*1	23.5
*W*1	4.0

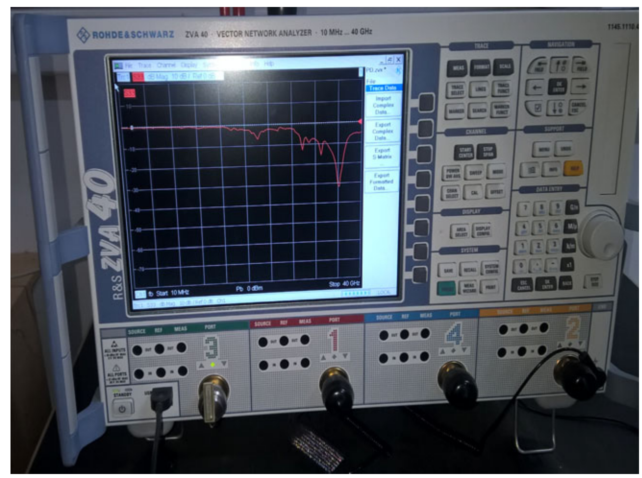

Fig. 3. Testing of reflection coefficient plot of fabricated prototype over VNA.

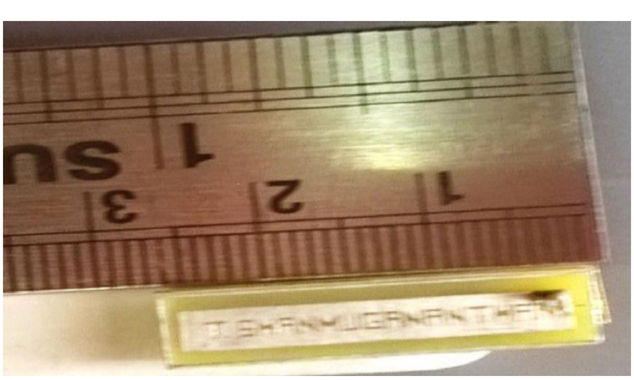

Fig. 2. Fabricated antenna.

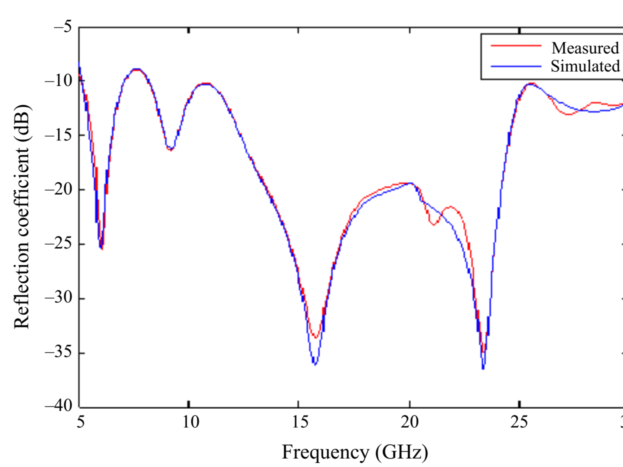

Fig. 4. Comparative plot of reflection coefficient.

The simulated and the fabricated results are very close as shown in Fig. 4.

2. Radiation Pattern and Gain

The radiation pattern [10] plots indicating the gain of an antenna for the simulated and fabricated designs are shown in Figs. 5 and 6. The design was simulated over HFSS v-15 software for its radiation pattern plot, and the fabricated design was tested in an anechoic chamber [11] (Fig. 7) for its radiation pattern (gain). The received set of values are used to plot the validated radiation pattern against the simulated one. Whereas the simulated design exhibits a peak gain [12] of 2.9 dBi at 6.07 GHz, 8.5 dBi at 9.25 GHz, 26.8 dBi at 15.79 GHz, and 12.6 dBi at 23.41 GHz, respectively, the fabricated structure reaches peak gains of 1.4 dBi at 6.01 GHz, 5.6 dBi at 9.22 GHz, 16.1 dBi at 15.75 GHz, and 11.5 dBi at 23.38 GHz, respectively.

The discrepancies between simulated and measured results of gain arise mainly owing to losses in fabrication.

3. Directivity

As shown in Figs. 8 and 9, the simulated directivity [13] values include 0.38 dB at 6.07 GHz, 0.91 dB at 9.25 GHz, 2.9 dB at 15.79 GHz, and 3.72 dB at 23.41 GHz. Similarly, for the case of fabrication, the directivity is 0.3 dB at 6.01 GHz, 0.6 dB at 9.22 GHz, 2.5 dB at 15.75, and 3.6 dB at 23.38 GHz.

Fig. 7. Anechoic chamber testing of the fabricated antenna.

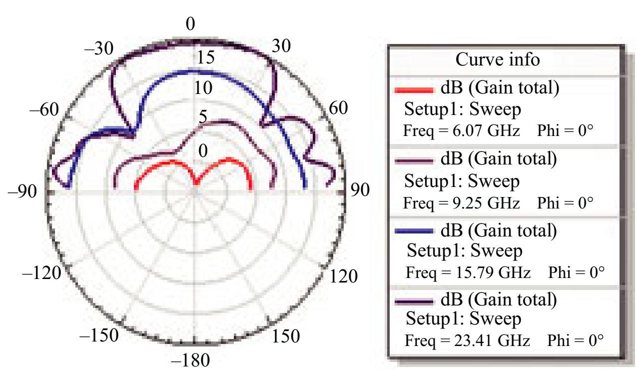

Fig. 5. Simulated radiation pattern plot.

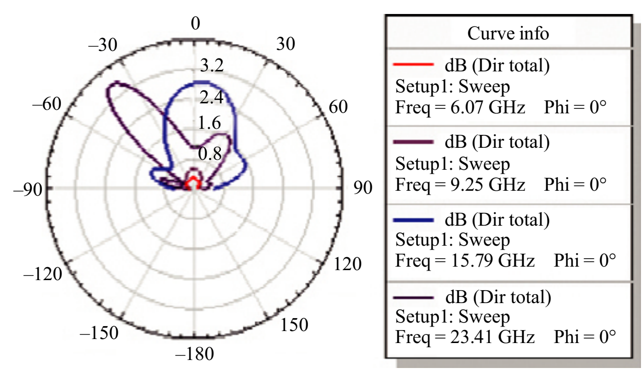

Fig. 8. Simulated directivity plot.

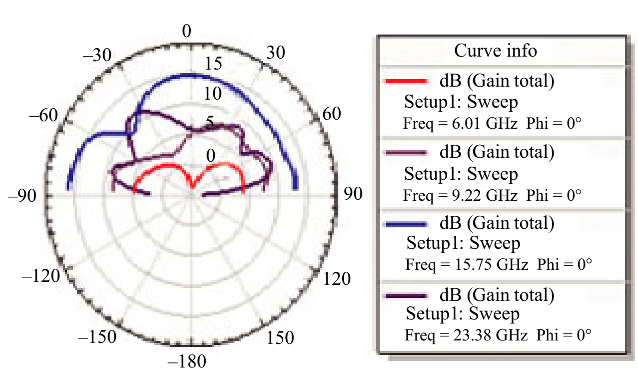

Fig. 6. Radiation pattern plot for the fabricated antenna.

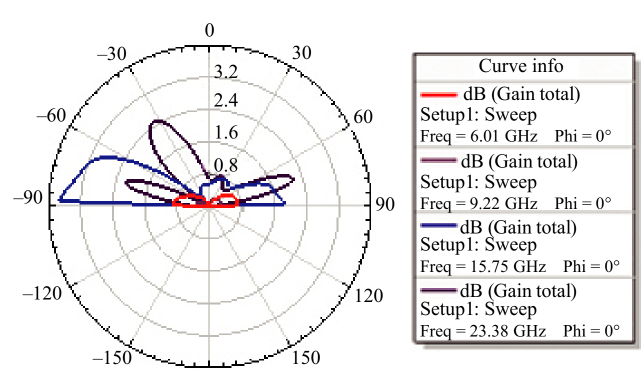

Fig. 9. Directivity plot for the fabricated antenna.

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The proposed slotted patch antenna may be used for numerous applications including the fixed satellite (space-earth) applications at 6.07 GHz (simulated design)/ 6.01 GHz (fabricated design) with a gain of 2.9 dBi and a directivity of 0.38 dB in case of simulated design and a gain of 1.4 dBi and directivity of 0.3 dB in case of fabricated design. The frequency of 9.25 GHz (simulated design) and 9.22 GHz (fabricated design) with gain of 8.5 dBi and directivity of 0.91 dB in case of simulated design and a gain of 5.6 dBi and a directivity of 0.6 dB at 9.22 GHz in case of fabricated antenna may be used for radio location and maritime radio navigation, the frequency of 15.79 GHz (simulated design)/15.75 GHz (fabricated design) with a gain of 26.8 dBi and a directivity of 2.9 dB (simulated design) and a gain of 16.1 dBi and a directivity of 2.5 dB (fabricated design) may be used for radio location purpose and the resonant frequency of 23.41 GHz (simulated design)/23.38 GHz (fabricated design) with a gain of 12.6 dBi and directivity of 3.72 dB in the case of simulated design and a gain of 11.5 dBi and directivity of 3.54 dB in case of fabricated design may be used for fixed inter-satellite applications.

4. Voltage Standing Wave Radio

Simulations were carried out using Ansoft HFSS v-15 software, and the fabricated antenna was tested using a Rhode & Schwarz ZVA 40 VNA, ranging from 10 MHz to 40 GHz for its VSWR plot, as shown in Fig. 10. The received set of values are used to plot the validated VSWR against the simulated one. The comparative VSWR [14] plot in Fig. 11 indicates a value of 1.1 at 6.07 GHz, 1.36 at 9.25 GHz, 1.04 at 15.79, and 1.03 at 23.41 GHz for the simulated design. Similarly, for the fabricated design, the values include 1.1 at 6.01 GHz, 1.4 at 9.22 GHz, 1.03 at 15.75 GHz, and 1.03 at 23.38 GHz. Both the simulated and fabricated results are nearly identical.

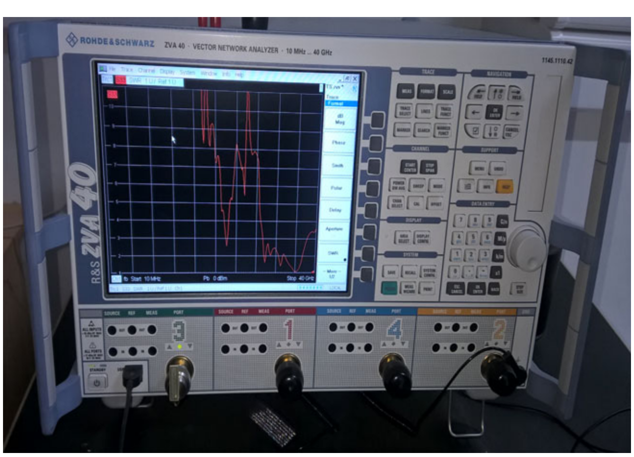

Fig. 10. Testing of VSWR plot of fabricated prototype over VNA.

A tabulated comparison of the cases of the simulated and fabricated prototype is given in Table 3.

IV. Conclusion

A miniaturized slotted rectangular nameplate patch antenna was designed using an FR4 epoxy substrate and a coaxial feeding mechanism. Based on the use of slotted

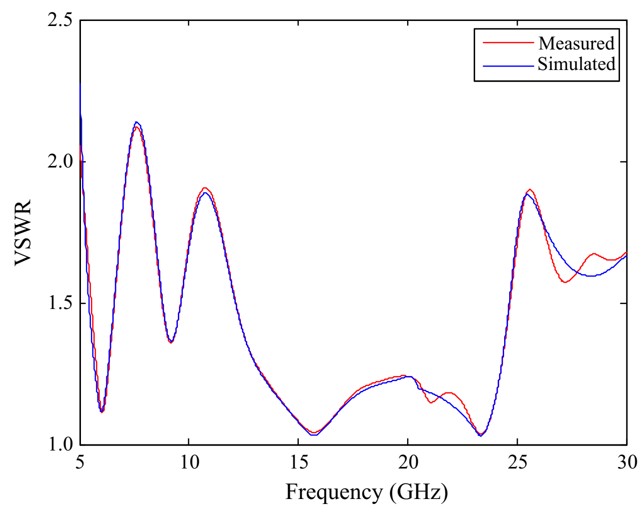

Fig. 11. Comparative VSWR plot.

Table 3. Tabulated comparison of simulated and fabricated design.

Parameters	Simulated design	Fabricated design
Number of bands	Dual	Dual
Resonant frequency (GHz)	Let fa = 6.07	Let $f1$ = 6.01
	Let fb = 9.25	Let $f2$ = 9.22
	Let fc = 15.79	Let $f3$ = 15.75
	Let fd = 23.41	Let $f4$ = 23.38
Reflection coefficient (dB)	–25.5 (at fa)	–25.3 (at $f1$)
	–16.3 (at fb)	–16.3 (at $f2$)
	–33.7 (at fc)	–36.1 (at $f3$)
	–35 (at fd)	–36.6 (at $f4$)
VSWR	1.1 (at fa)	1.1 (at $f1$)
	1.36 (at fb)	1.4 (at $f2$)
	1.04 (at fc)	1.03 (at $f3$)
	1.03 (at fd)	1.03 (at $f4$)
Bandwidth (GHz)	1.95 (for the band including the frequency fa)	1.91 (for the band including the frequency $f1$)

patches for improved gain and bandwidth extension, it was found that a patch bearing a long series of slots would result in significantly improved characteristics; the name of the first author was used as the slot model. The proposed antenna design had a compact size of 6.8 mm × 26 mm × 1.6 mm. The structure, when simulated using an HFSS-15, exhibited two useful frequency bands with the first resonating at a single center frequency of 6.07 GHz, and the second resonating at 9.25 GHz, 15.79 GHz, and 23.41 GHz, respectively. The values of gain corresponding to the four different resonant frequencies included 2.9 dBi, 8.5 dBi, 26.8 dBi, and 12.6 dBi, respectively. Moreover, the first band, having a single resonant frequency, offered a bandwidth of 1.95 GHz, whereas the other band, resonating at three different frequencies, had a 21.6 GHz bandwidth. The structure was fabricated and tested using a Rhode & Schwarz ZVA 40 VNA, ranging from 10 MHz to 40 GHz, for its reflection coefficient and VSWR parameters, and an anechoic chamber for its radiation pattern. The measured values were plotted against the simulated values and a comparison of both sets of values was also tabulated. Both the simulated and the fabricated results were found to be in close agreement. The proposed slotted patch antenna may be used for fixed satellite (space-earth) applications around 6.07 GHz, radio location and maritime radio navigation around 9.25 GHz, radio location around 15.79 GHz, and fixed inter-satellite applications around 23.41 GHz. The key findings include the exorbitantly higher gains and bandwidths for the proposed slotted patch structure when compared to conventional rectangular patch antennas.

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