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Design of Multiband Microstrip Antenna Using Stepped Cut Method for WLAN/WiMAX and C/Ku-Band Applications

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Abstract**—**In this paper, a planar monopole antenna for multi band applications is proposed. The antenna structure operates at three operating frequencies at 3.7, 6.2, and 13.5 GHz which cover different communication frequency ranges. The antenna consists of a quasi-modified rectangular radiating patch with a partial ground plane and two parasitic elements (open-loop-ring resonators) to serve as coupling-bridges. A stepped cut at lower corners of the radiating patch and the partial ground plane are used, to achieve the multiband features. The proposed antenna is manufactured on the FR4 substrate and is simulated and optimized using High Frequency Simulation System (HFSS). The antenna topology possesses an area of 30.5 x 30 x 1.6 mm^3. The measured results demonstrate that the candidate antenna has impedance bandwidths for 10 dB return loss and operates from 3.80 – 3.90 GHz, 4.10 – 5.20 GHz, 11.2 – 11.5 GHz and from 12.5 – 14.0 GHz, which meet the requirements of the wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX), C- (Uplink) and Ku- (Uplink) band applications. Acceptable agreement is obtained between measurement and simulation results. Experimental results show that the antenna is successfully simulated and measured, and the tri-band antenna can be achieved by adjusting the lengths of the three elements and it gives good gains across all the operation bands.

Keywords**—**Planar monopole antenna, FR4 substrate, HFSS, WLAN, WiMAX, C & Ku.

I. Introduction

WITH rapid development of wireless communication systems, one of the key issues is the design of compact multi-band antenna while providing wideband characteristic over the whole operating band, especially for WLAN (2.4-2.48, 5.15-5.35, 5.725-5.85 GHz) and WiMAX (2.5-2.69, 3.4-3.69 GHz), where it plays a major importance. Consequently, a number of planar antennas using several topologies have been experimentally characterized. In addition, other methods to progress the impedance bandwidth which do not include adjustment of the geometry of the planar antenna have been examined [1]-[4]. It is a well-known fact that commercial UWB systems demand compact and low-cost antennas with omnidirectional radiation patterns and large bandwidth [1].

Microstrip monopole antennas illustrate truly appealing physical characteristics features, such as uncomplicated structure, compactness and low-cost of fabrication process, low profile of antenna, light in weight, ease of installation process and integration with numerous feed types. Because of all these important features, planar monopole antennas are highly attractive to be employed in advanced UWB technologies, and recent research activity is being focused on them. Measuring the decrease of the planar patch antenna has been carried out utilizing a few strategies such as the utilization of high dielectric constant substrates, adjustment of the conventional patch shapes, use of short circuits, shorting-pins technique [7], [8]. Employing high dielectric constant substrates is a simple solution, but it shows narrow bandwidth, high loss and poor ability due to surface wave excitation [9]. In order to generate the single and multiple band-notched functions, respectively, single and multiple half- wavelength ring resonators [6] are incorporated in the radiation patch topology. In [7], band-notch function is reached by using a T-shaped coupled-parasitic element in the ground plane. Also, different planar inverted-F antennas (PIFA) designs have been proposed for several bands in newest researchers. Minimized dual band (PIFA) has been reported in [10], [11], and is reached using etched slotted radiated element. In [12]-[17], triple band small size composite-resonator monopole antenna designs for wireless communications were presented. These antennas consist of three resonant topologies. Two types of compact short-circuited resonators were used; stepped impedance and quarter-wave resonators. The narrowband services such WLAN, WiMAX, and ITU may generate undesired interference with the UWB band. In order to avoid this problem, it is preferable to use antenna-topologies with noch-band features. However, there are some other existing narrowband services that may cause interference with the UWB band, such as WLAN, WiMAX, and ITU. To solve this problem, it is desirable to design antennas with band-notched characteristic to reduce potential interference [2], [3]. To avoid these interferences, there are several researchers who proposed multiple antenna design methods to produce the band-notched characteristic in the UWB band, such as photonic band-gap (PBG) structure, defected ground structure (DGS), defected microstrip structure (DMS) and using slotted the patch or ground through different slots [5].

In this work, a simple method for designing a quad-band small size monopole microstrip antenna with width band

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features has been presented. The proposed antenna consists of quasi U-Shaped patch element which contains multiple stepped cuts at lower corners of the radiated patch. The added stepped cuts lead to generation of some resonances at high frequency ranges, while an enhancement will be achieved using partial ground plane. The proposed topology is simulated and optimized and manufactured on the 30.5 x 30 x 1.6 mm^3 Rogers duroid 6010 substrate of permittivity 10.2. The simulation investigations are carried out using the Ansoft HFSS commercial software [12]. Details of the antenna design are described, and fabricated and simulated. Return loss, radiation pattern and antenna gain results are represented and discussed in the following section. The acceptable agreement between the experimental and the simulation results is observed. The slight deviation between the simulated and fabricated results is due to the mismatching losses and the inexactitude of the manufacturing process. The parametric investigation is accomplished to understand the characteristics of the proposed antenna.

II. Antenna Design

The topology of the proposed monopole microstrip multiband antenna, fed by 50 Ω microstrip feed line, is shown in Fig. 1. The design consists of modified structure of a conventional rectangular patch antenna with stepped cuts added at lower corners of the radiating patch and two loaded parasitic ring resonators around of the 50 Ω feed line. The radiating patch has a length L and a width W. The W and L are the width and length of the feed line, which connect the patch with SMA connector. On the other side of the substrate, a conducting partial ground plane is placed. The dimensions of the partial ground plane are width W_{gnd} and length L_{gnd} (see Fig. 1). The width of the microstrip feed line is fixed at 2 mm. The antenna is printed on a 30.5 x 30 x 1.6 mm^3 or about 0.924 λ_g x 0.910 λ_g x 0.048 λ_g with λ_g = 33 mm at 3.7 GHz (the first resonance frequency) and a Rogers duroid 6010 substrate of thickness 1.27 mm, permittivity 10.2, and loss tangent tanδ = 0.003. The design processes to reach the proposed antenna are depicted in Fig. 4. The investigated antenna is connected to a 50 Ω-SMA connector for signal transmission. The parameter values of the proposed design are illustrated in Fig. 1.

III. Results and Discussions

The investigated microstrip monopole DGS antenna with different design parameters, which can influence the bandwidth, were constructed, and the scattering results of the input impedance and radiation characteristics are demonstrated and discussed.

From Fig. 2, it is clear that, the proposed DGS antenna structure with partial ground has been achieved multiband operational frequencies. Fig. 4 illustrates the reflection coefficient characteristics of the proposed tri-band antenna. It can be seen that, in the proposed antenna, the three resonant modes are excited around the 3.7, 6.2GHz and 13.5 GHz WLAN/WiMAX and C/Ku-Band Applications for a S_{11} ≤−10dB.

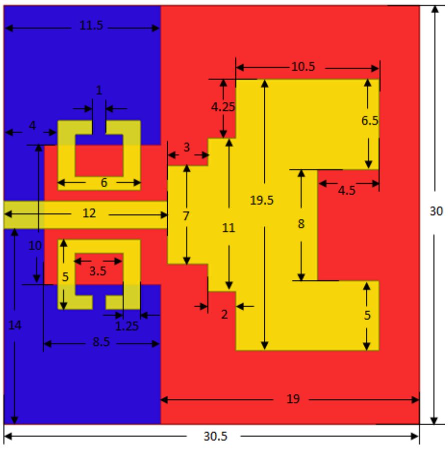


Fig. 1 Geometry of the proposed antenna structure

In order to carry out different behaviors of this structure, several parameters of this antenna candidate are studied by varying one parameter, while others are kept constant. Fig. 3 shows the steps process of the monopole antenna, the conventional square antenna (Fig. 3 (a)), geometry with two ring resonators located along of the microstrip feed line (Fig. 3 (b)), antenna with incorporated stepped cuts in the under corners of the patch (Fig. 3 (c)).

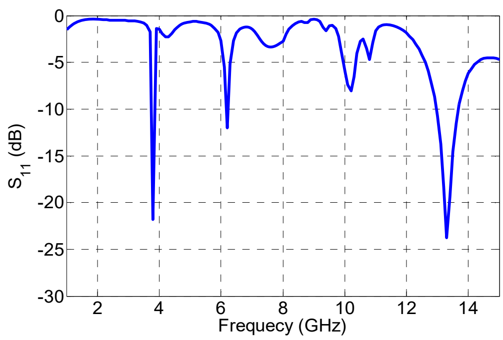
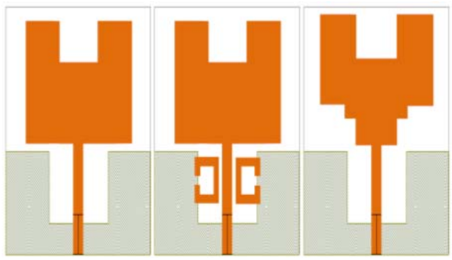


Fig. 2 The simulated S_{11} [dB] of the proposed DGS antenna



(a) (b) (c)

Fig. 3 Design evolution of the proposed antenna; (a) antenna I, (b) antenna II, and (c) antenna III

The achieved simulation results are computed using the high-frequency structure simulator (HFSS). Fig. 4 depicted the optimized multiband antenna.

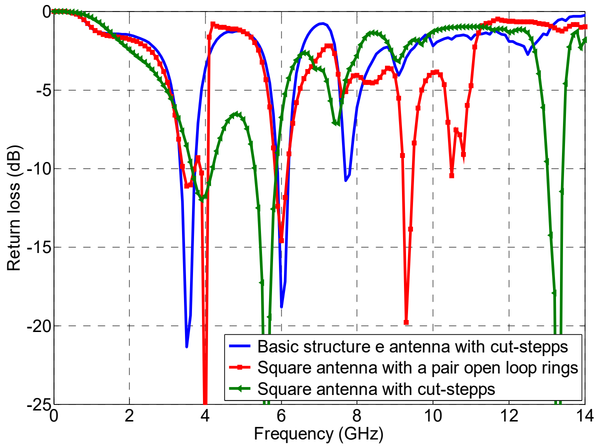


Fig. 4 Simulated reflection coefficients of various antenna designs

As shown in Fig. 4, for the proposed antenna configuration, the conventional quasi square monopole can provide the fundamental and the two next higher resonant radiation bands at 3.8 GHz, 6 GHz and 7.8 GHz, respectively. As illustrated in Fig. 3, the ring resonators leads to an improvement in the broadband features and play a role in determining the sensitivity of impedance matching of such antenna. This is because it can influence the effects of electromagnetic coupling between the patch and the ground plane, hence the improvement its impedance bandwidth without any cost of size or expense. Depending on the above regenerated high frequencies at 9.5 GHz and 11.5 GHz can be observed. It is found that by incorporating of the cutting steps at lower edges of the radiator patch, additional resonance frequency at 13.5 GHz is excited and hence much wider impedance bandwidth with multi-resonance characteristics can be achieved, especially at the higher band. In the other words, it can be concluded that the resonance frequencies, therefore impedance bandwidth can be controlled separately by controlling the measurements and location of the added parasitic shapes. To describe the relations between the resonant frequencies and certain parts of the patch and operational principle,

We present current distributions of the proposed antenna structure in Fig. 5. Figs. 5 (a)-(c) demonstrates the current distributions at 3.7, 6.2, and 13.5 GHz, respectively. As we can see, the currents at 3.7 GHz mostly concentrate on the added parasitic rings which clearly indicates that the two parasitic elements generate the first resonant frequency at 2.5 GHz together, and at 6.2 GHz it turns to the longer feed line and edges of the patch which means that the microstrip feed line is responsible for the generation of the resonance at 6.2 GHz and also endorses the radiation characteristics at this frequency band, while from Fig. 5 (c) the current is mainly distributed at the pair of symmetrical stepped cuts for the third resonant frequency 13.5 GHz, this is generally caused by the higher order mode generated by the antenna. This implies that good radiation patterns with low cross polarization will be obtained. The radiation characteristics of the proposed design are studied with HFSS. The azimuth and altitude plane patterns are derived by simply cutting through the 3D radiation pattern shown in Fig. 6 (d) where one can observe that there is an individual major lobe with a completely wide beam-width with shallow nulls indicating up and down from the antenna. Otherwise, there are not plentiful merits to the pattern. X. In this case, the azimuth plane pattern is obtained by cutting through the x-z plane (E-plane), and the elevation plane pattern is shaped by portioning the y-z plane (H-plane). The radiation patterns are given at the central operating frequency in each band. Nearly omni-directional patterns are achieved in (YOZ) and the radiation patterns in the (XOZ) are almost bidirectional at central frequencies of 3.7 GHz, 6.2 GHz and 13.3 GHz, respectively (Figs. 6 (a)-(c)).

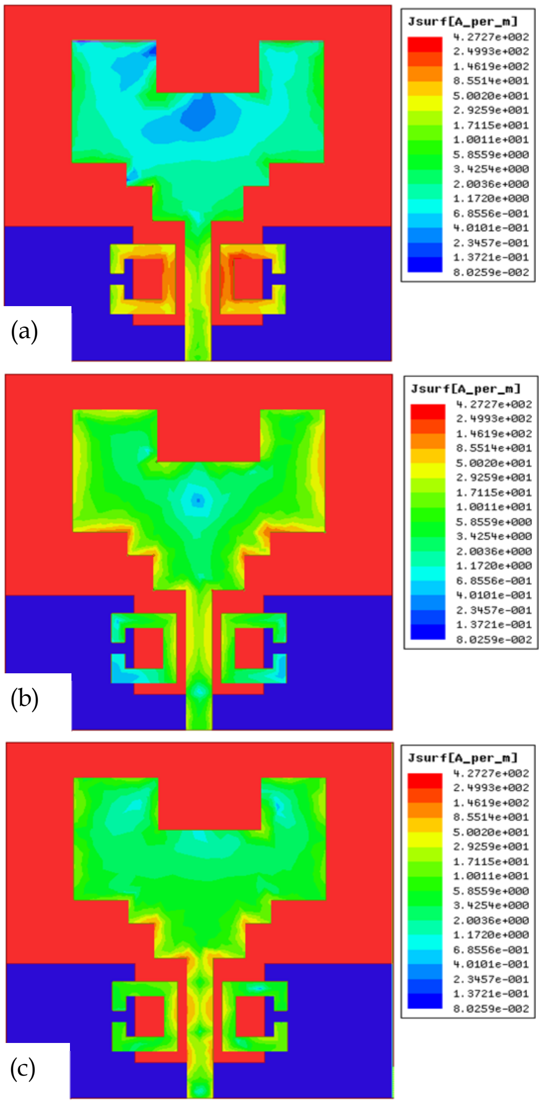
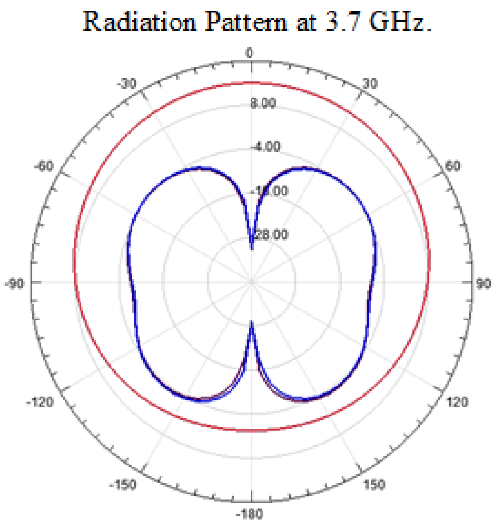
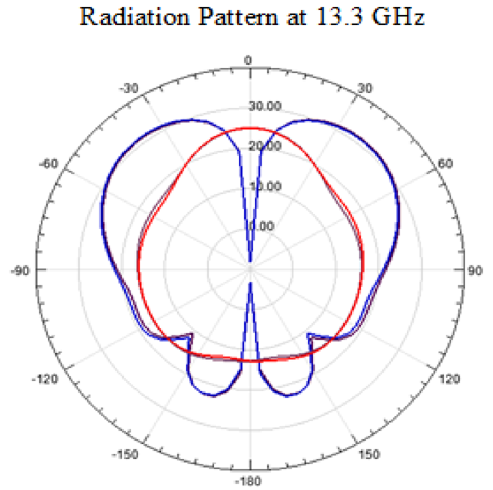


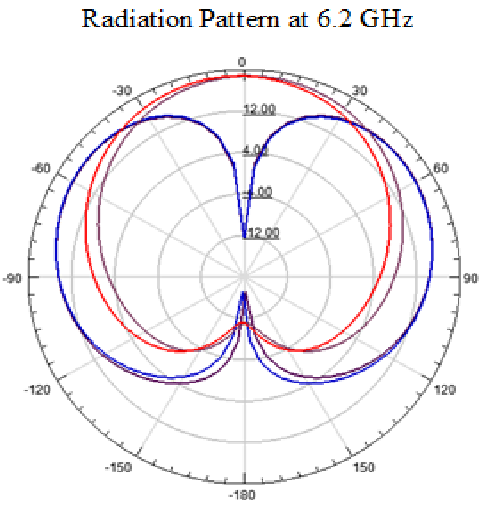
Fig. 5 Simulated surface current distribution of the proposed antenna at (a) 3.7 GHz, (b) 6.2 GHz, (c) 13.5 GHz



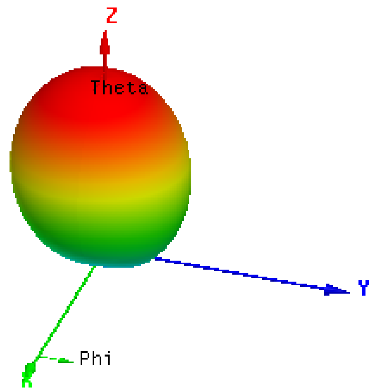
(a)



(b)



(c)



(d)

Fig. 6 Simulated 2D radiation patterns of proposed antenna at respectively (a) 3.7 GHz, (b) 6.2 GHz, (c) 13.5 GHz, 3D radiation pattern

IV. The Investigation and Experimental Measurements

After the optimizing of the proposed triple-band antenna parameters, an experimental prototype of the final design was fabricated using printed circuit technology and tested. A photograph of the fabricated antenna is shown in Fig. 7. The measurements on the fabricated antenna were carried out using a vector network analyser (VNA), over a relatively wide frequency range from 1- 15 GHz (Fig. 8).

Fig. 9 illustrates the comparison between the simulated and measured reflection coefficient S11 of the proposed antenna. The measured results clearly indicate that the proposed antenna provides at least three resonance bands. From this figure, it is clear that the simulated and measured results show a reasonable agreement. The small discrepancy is due to the fabrication tolerance which cannot be totally avoided. Concurrently, with these performances, the proposed antenna satisfies the requirements of WLAN/ WiMAX and C/Ku-Band applications.

Fig. 7 Fabricated prototype of the proposed antenna

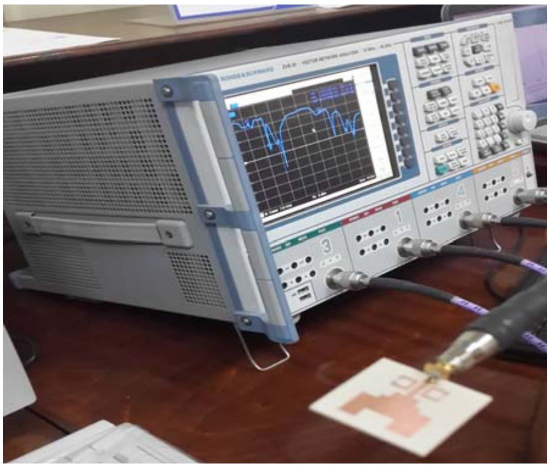


Fig. 8 Return loss of the proposed antenna using VNA

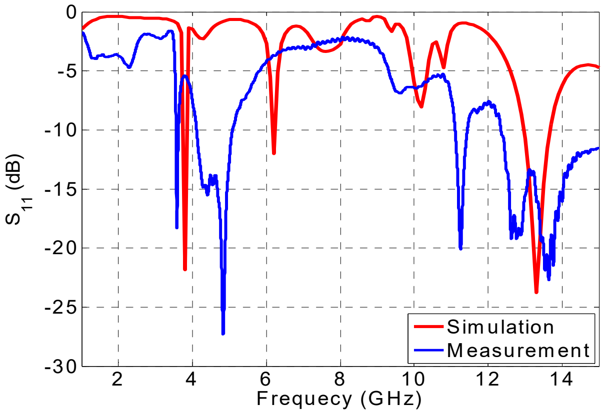


Fig. 9 Simulated and measured reflection coefficient of proposed tri-band antenna

V. Comparative Study

Diverse antennas such as fork type grounded antenna [18], dual/triple-band microstrip antenna are proposed with an M-shaped patch [19]. Recently, a dual broadband antenna is proposed for WLAN application. In this design, principle of capacitive and inductive coupling of two open-ended ring resonators is used for generating dual bands and enhances the impedance bandwidth due to the effect of capacitive and inductive resonator loading [20], [21]. Considerable approaches with novel F shaped slot antenna have been proposed in [8]. MTM inspired reactive loading and metamaterial transmission lines (SMTLs) are used in [22]. As compared to proposed design, it has many limitations such as complex configuration, larger size although all the reported antennas destined to the appropriate applications but are somewhat complicated in structure and have large physical size as shown in Fig. 10. From the figure, it can be observed that the proposed tri-band antenna realizes tri-band performance capable of WLAN/WiMAX and C/Ku-Band applications on a low-cost substrate with a compact circuit size as well as sufficient impedance bandwidths.

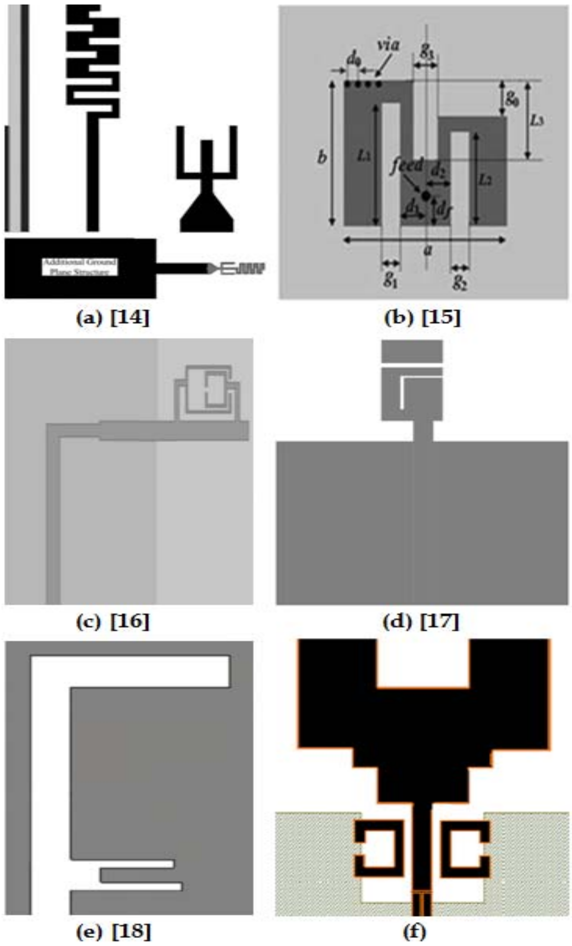


Fig. 10 Comparison of size of the proposed antenna with other references, (a) 60x40 mm^2, (b) 64x62 mm^2, (c) 60x90 mm^2, (d) 33x90 mm^2, (e) 40x45 mm^2, and (f) the proposed miniaturized structure 30x30.5 mm^2

VI. Conclusion

A compact monopole antenna with multi band features for wideband applications is presented in this work. The investigated topology operates at three different frequencies at 3.7, 6.2GHz and 13.5 GHz. In order to improve the impedance bandwidth and radiation characteristics and to minimize the size of conventional rectangular antenna, stepped cuts at lower corners are added to the radiating patch and a partial ground plane has been etched on the metallic ground plane. The proposed antenna is simulated and manufactured on the FR4 substrate with an area of 30.5 x 30 x 1.6 mm^3. The measured results show, that the proposed topology operates at WLAN, WiMAX, C- (Uplink) and Ku- (Uplink) band applications. Simulation and measurement results show that the compact antenna due to its good characteristics can be a good candidate to be used in personal and mobile UWB applications. The appeared deviation between the simulation and measurement is assumed to be related to the mismatching at the SMA port and to the inaccurate of the fabrication.

Taking into account the topic, comparisons between other similar antennas in aspects of size and design complexity have been made.

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