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Miniaturized Minkowski-Island Fractal Microstrip Antenna Fed by Proximity Coupling for Wireless Fidelity Application

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Abstract

This paper proposed a new design of Minkowski Island microstrip antenna fed by proximity coupling with partial ground plane. The design was consisted of two layers of substrate, on the top substrate was the antenna patch and on the bottom substrate was the proximity feed line and the partial ground. At the first stage, the normal square patch antenna was mainly designed. Then, the Minkowski patch antenna was designed using 1st iteration technique and 2nd iteration technique. The Minkowski fractal shape slot was embedded in the center of the patch to form a Minkowski Island patch antenna. Using the Minkowski Island fractal technique, the dimension of the patch can be reduced up to 58.7%. The proximity feed line in this design was used to increase the impedance bandwidth, and from the measurement the impedance bandwidth of the proposed antenna was 240 MHz with return loss of -24.54 dB and VSWR of 1.126.

Keywords*: Minkowski Island, fractal, proximity feed, microstrip antenna, Wi-Fi*

1. Introduction

Demands of devices with small sizes are more and more increasing and therefore corresponding antennas must be designed on small size and light weight structures. The microstrip patch antenna is the best selection for the researcher because it is a low cost material, lightweight and also easy to fabricate [1]. Several new techniques are combined to enhance the performance of the antenna and to save space. These techniques include reconfigurable antenna arrays [2, 3], peripheral slits, and fractal geometries. This is to cater the high demand of high end user nowadays, especially on the Wireless Local Area Network (WLAN) or Wi-Fi application.

One of the best ways to miniaturize antennas and improve their properties is to shape their basic structures in the form of fractal geometries, which are based on self-similar configurations. Consequently, fractal antennas can benefit from their space-filling properties to occupy a small volume by quite a long electrical length, so that the operating frequency decreases and effective antenna miniaturization is achieved [4]. Fractal geometry shape can be composed of multiple copies of the similarity structure with different size and scale. Minkowski shape is one of the fractal geometry that can be applied for this purpose. At [5] Minkowski-like pre-fractal curve is deployed to achieve size reduction up to 57.15%, but this design uses a direct coupling technique that is relatively difficult to fabricate. The other example of fractal shape is Koch [6], resulting in patch reduction up to 73.5%, but this design is limited to simulation and not fabricated. Minkowski Island is the improvement technique of the Minkowski fractal by embedding the Minkowski slot in the center of the antenna patch. Minkowski Island in combination with partial ground techniques are applied at [7, 8] to achieve substrate reduction up to 22.45%, but no patch size reduction is obtained.

However, these microstrip antennas also have some basic disadvantages, namely, limited gain, low power, and narrow bandwidth of only about 2% - 5%. To overcome the narrow

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bandwidth, has been introduced the indirect or electromagnetic coupling. The advantage of this technique is that it can widen the bandwidth and can reduce the soldering process [9]. Research conducted by [10] using the electromagnetic coupling in the form of microstrip feed line, and the resulting bandwidth of this fractal antenna is up to 7%. Another research done by [11] using fractal antenna fed with coplanar waveguide (CPW), a type of electromagnetic coupling with the bandwidth generated up to 8%. The research done by [12] using fractal antenna fed with proximity coupling and the resulting bandwidth is up to 9%. Proximity feed technique itself has another advantage that when it is manufactured, the antenna is easy to optimize by shifting the position of the feed line.

Based on previous study results, it can be inferred that the fractal geometry method can reduce the antenna size. Therefore this paper proposed a new design of miniature Minkowski Island fractal microstrip antenna fed by proximity feed line to increase the impedance bandwidth.

2. Antenna Design

The design of the proposed antenna is made based on two layers of FR4 substrate with relative permittivity (***εr***) of 4.3, substrate thickness (***h***) of 1.6 mm each, and loss tangent (***tan δ***) of 0.0265. Patch will be positioned on the top layer substrate, while the proximity feed line and partial ground will be on the bottom layer substrate.

The dimensions of the square patch antenna can be obtained from the equations below. With ***a*** is the side length of the square, f_r is the resonance frequency of Wi-Fi (2400 MHz) and ***c*** is the speed of light (3×10^8 m/s).

$$\boldsymbol{\varepsilon_{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{10h}{a}\right)^{-\frac{1}{2}} \quad (1)$$

$$\boldsymbol{a_{eff}} = a\left[1 + 0.824\frac{h(\varepsilon_{eff}+0.3)(\left(\frac{a}{h}+0.262\right)}{a(\varepsilon_{eff}-0.258)(\left(\frac{a}{h}+0.813\right)}\right] \quad (2)$$

$$\boldsymbol{f_r} = \frac{c}{2a_{eff}\sqrt{\varepsilon_{eff}}} \quad (3)$$

Side length of the square patch (***a***) = 35 mm is obtained from the equations. Then the Minkowski curve can be characterized by the iteration factor, shown in Figure 1. Zero iteration (N_0) is represented by the normal patch without any scraped out of copper. First iteration (N_1) shows that four rectangular shapes of copper had been cut from the patch. Second iteration (N_2) shows another eight rectangular had been cut from the patch. Minkowski Island is the improvement technique of the Minkowski fractal of embedding the Minkowski slot in the center of the antenna patch (P_0). Finally, the overall patch size reduction is achieved in P_1. The dimension of the Minkowski Island fractal antenna generation are given in Table 1 with the same size was use for both substrates.

Table 1. Dimension of Minkowski Island Fractal Antenna Generation

Part	Symbol	Dimension (mm)				
		N_0	N_1	N_2	P_0	P_1
Substrate width	W_s	37	37	37	37	30
Substrate length	L_s	48	48	48	48	38
Patch side	a	35	35	35	35	22.5
Feed width	W_f	2.6	2.6	2.6	2.6	2.6
Feed length	L_f	17	17	17	17	17
Ground width	W_g	30	30	30	30	30
Ground length	L_g	7	7	7	7	7
Stub length	L_{stub}	5	5	5	5	6

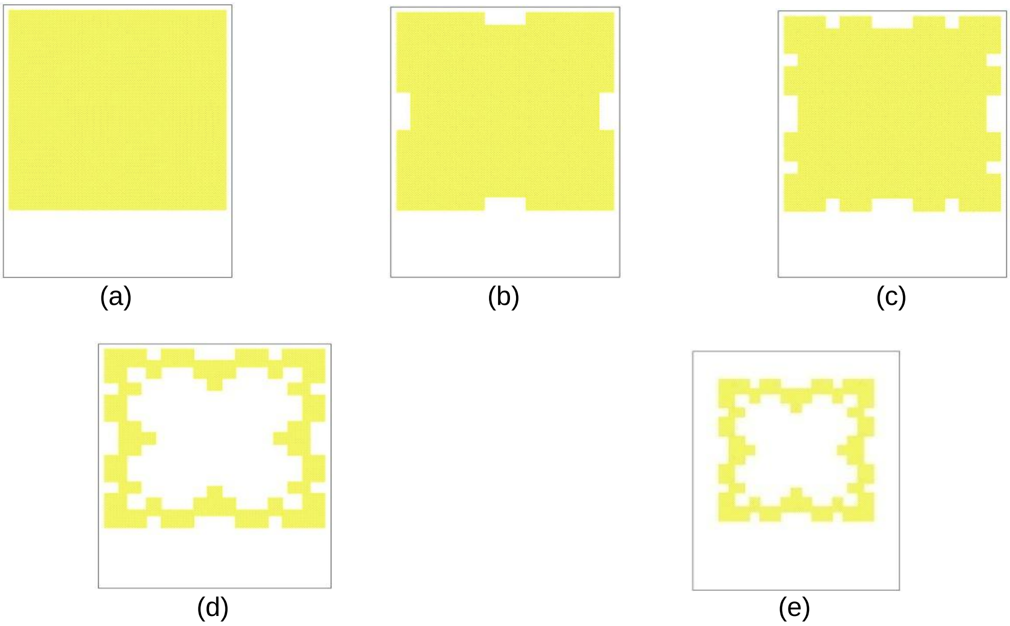


Figure 1. Generation procedure of Minkowski Island patch antenna, (a) Basic square patch microstrip antenna (***N₀***), (b) 1st iteration (***N₁***), (c) 2nd iteration (***N₂***), (d) Minkowski Island patch (***P₀***), (e) Miniaturized Minkowski Island patch (***P₁***)

Figure 2 exhibits the configuration of final design (***P₁***) of the proposed antenna. The Minkowski patch part dimension is 22.5 mm width x 22.5 mm length, located at the top layer substrate. The antenna fed by proximity coupling using a 50 Ohm connector to enlarge the impedance bandwidth. The feed line is located at the bottom substrate with 17 mm in length and 2.6 mm width. The stub length of the feed line is 6 mm. The bottom substrate also consists of partial ground with the dimension of 30 mm width x 7 mm length, which is used to optimize the return loss of the antenna.

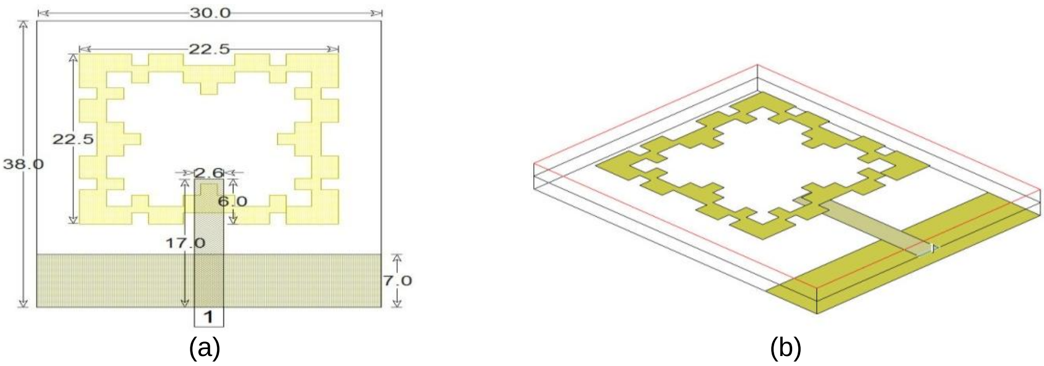
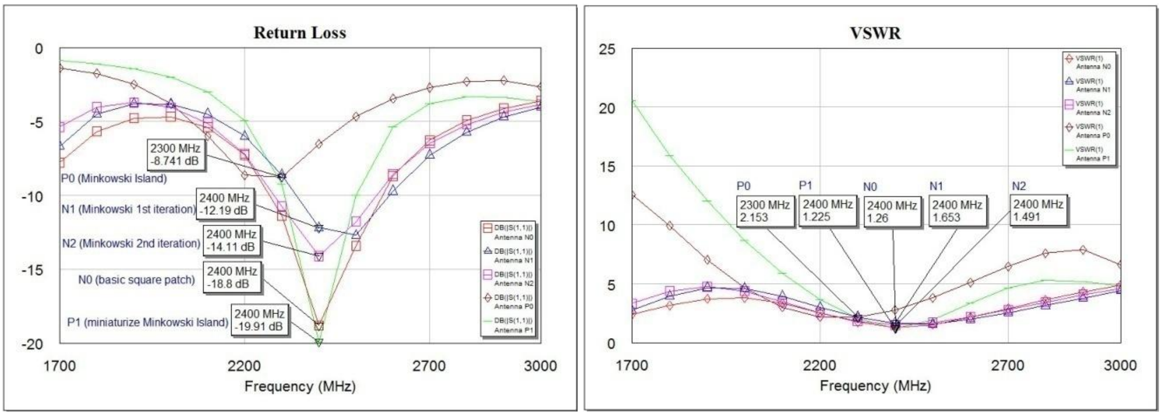


Figure 2. Configuration of the final design (***P₁***), (a) Dimension of the proposed antenna, (b) 3D layout of the proposed antenna

3. Results and Analysis

The simulation results of return loss and VSWR from different generation of Minkowski Island patch antenna are shown in Figure 3.



(a) (b)

Figure 3. Simulation results of (a) Return Loss value and (b) VSWR value

The resonant frequency of design $\boldsymbol{N_0}$ was at 2400 MHz with return loss of -18.80 dB and VSWR of 1.260 and bandwidth of this design was 305 MHz at the range frequency of 2267 MHz until 2572 MHz. The resonant frequency of 1st iteration design $\boldsymbol{N_1}$ was at 2400 MHz with return loss of -12.19 dB, VSWR of 1.653 and bandwidth of 251 MHz at the range frequency between 2339 MHz to 2590 MHz. The resonant frequency of 2nd iteration design $\boldsymbol{N_2}$ was at 2400 MHz with return loss of -14.11 dB, VSWR of 1.491 and bandwidth of 276 MHz at the frequency between 2279 MHz and 2555 MHz. According to the theory, the resonant frequency of design $\boldsymbol{P_0}$ should be lower than basic square geometry because of the longer electrical length of fractal geometry, and indeed it was decrease to 2300 MHz but could not achieve matching condition with only -8.741 dB of return loss and VSWR of 2.153. The design then optimized in $\boldsymbol{P_1}$ by reducing the size of fractal patch and then the resonant frequency was return to 2400 MHz with return loss of -19.91 dB and VSWR of 1.225 and bandwidth of 193 MHz at the range frequency of 2307 MHz until 2500 MHz. The overall simulation results of all antenna generation are summarized in Table 2. Clearly from Table 1 and Table 2 results, $\boldsymbol{P_1}$ was chosen as the final design by achieving the best overall parameter including size, resonant frequency, return loss, VSWR, bandwidth, and input impedance.

Table 2. Simulation Results of Minkowski Island Fractal Antenna Generation

Design	Resonant Frequency f_r (MHz)	Return Loss (dB)	VSWR	Bandwidth (MHz) f_1-f_2 (MHz)	Input impedance at f_r (Ω)
N_0	2400	-18.80	1.260	305 2267-2572	47.439
N_1	2400	-12.19	1.653	251 2339-2590	39.866
N_2	2400	-14.11	1.491	276 2279-2555	52.356
P_0	2300	-8.741	2.153	-	85.690
P_1	2400	-19.91	1.225	193 2307-2500	41.562

A laboratory prototype structure of design $\boldsymbol{P_1}$ was fabricated to validate the simulated results. The antenna was fitted with the standard 50 Ohm connector having a center pin diameter of 1.2 mm as seen in Figure 4. The return loss (S_{11}) was measured using 300 kHz - 20 GHz Vector Network Analyzer (VNA). An anechoic chamber was used to measure the radiation properties of the fabricated antenna. The measurement setup to measure return loss and radiation pattern are shown in Figure 5(a) and 5(b) respectively.

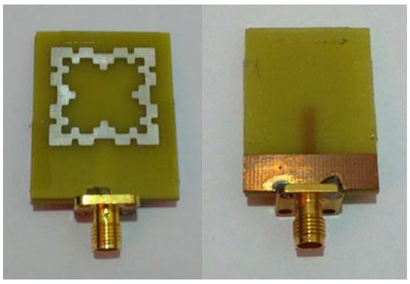
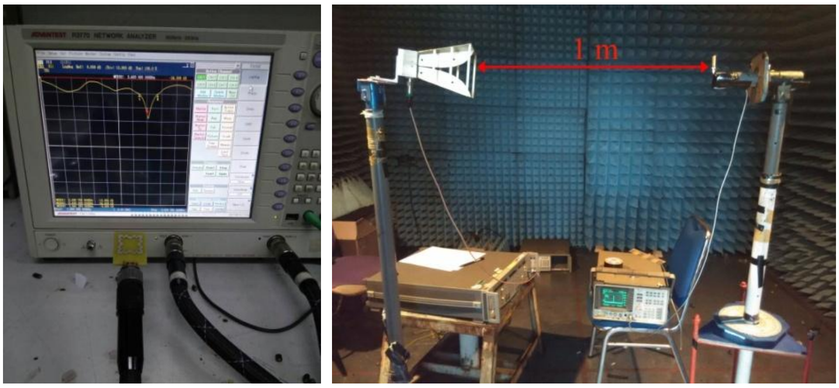


Figure 4. Photograph of the fabricated antenna prototype from design $\boldsymbol{P_1}$



(a) (b)

Figure 5. Measurement setup (a) Return loss measurement with VNA, (b) Radiation pattern measurement in the anechoic chamber

The measurements result of return loss and VSWR that have been done in the laboratory can be seen in Figure 6 and Figure 7. The comparison between simulated and measured parameter characteristics of proposed antenna is shown in Table 3 and the graphic comparison of Return Loss and VSWR are shown in Figure 8 and Figure 9 respectively. It is evident from these results that the measured results are different (actually better) from the simulation. This can be caused by antenna fabrication which is not 100% equal to the dimensions of the simulation, the imperfection of SMA connector soldering process, the imperfection process of joining the two substrates so there is an air gap between them, as well as the loss of the connectors and coaxial cable. The measurement results indicate that the proposed antenna can be a suitable design for Wi-Fi application.

Table 3. Comparison between Simulated and Measured Parameter of the Proposed Antenna

Parameter	Simulation	Measurement
Resonant Frequency (f_r)	2400 MHz	2400 MHz
Return Loss	-19.91 dB	-24.54 dB
VSWR	1.225	1.126
Bandwidth	193 MHz	240 MHz
f_1-f_2	2307 MHz – 2500 MHz	2300 MHz – 2540 MHz
Input impedance	41.562 Ω	45.854 Ω

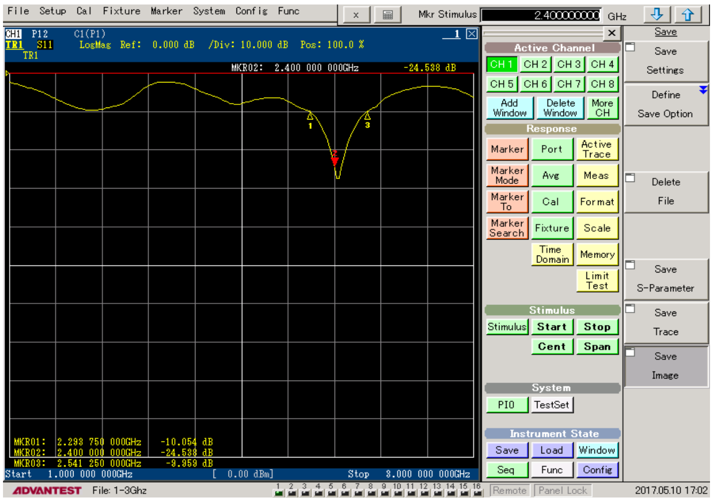


Figure 6. Measurement of return loss

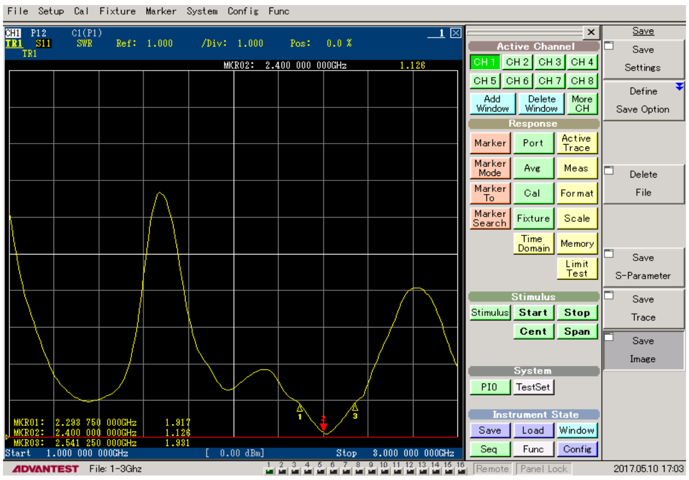


Figure 7. Measurement of VSWR

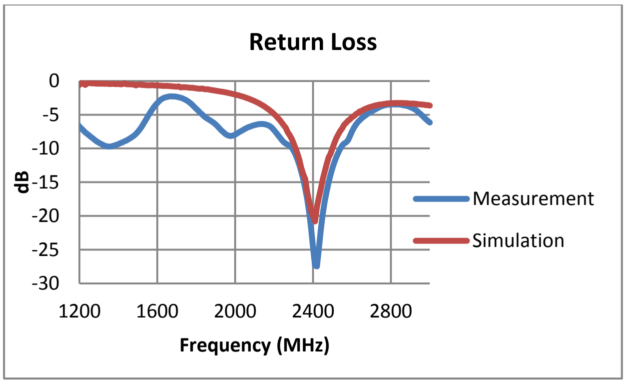


Figure 8. Comparison between measurement and simulation results of return loss

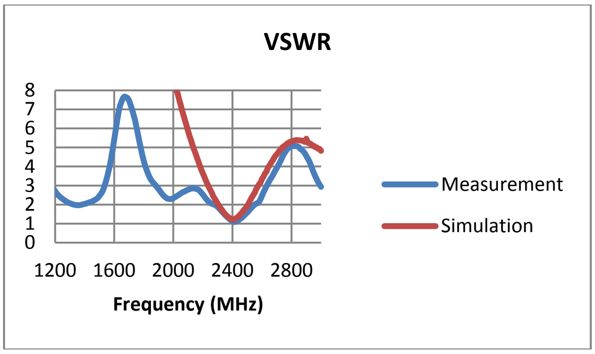


Figure 9. Comparison between measurement and simulation results of VSWR

The radiation pattern measurement was conducted in the anechoic chamber by using a horn antenna (model SAS-200/571 frequency 700 MHz – 18 GHz) as the reference antenna. The RF generator and spectrum analyzer were set to 2400 MHz. The far field distance between the reference antenna and measured microstrip antenna has been calculated as 1 meter. The measured microstrip antenna was rotated with a 10^0 increment from 0^0 to 350^0. Figure 10 shows the radiation pattern measurement result from the proposed antenna design with Half Power Beamwidth (HPBW) of 30^0.

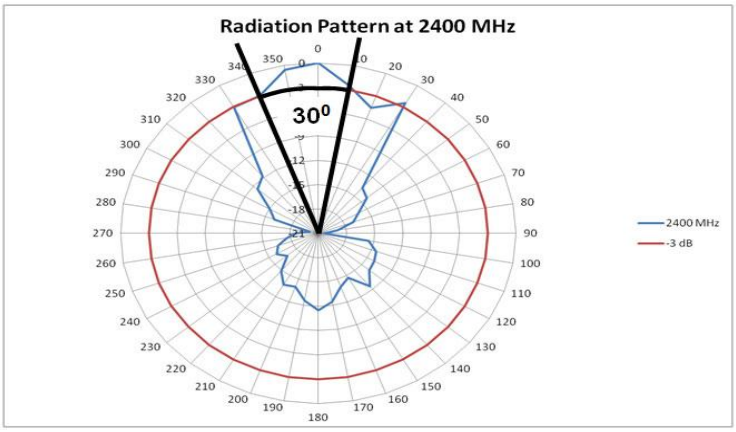


Figure 10. Radiation pattern of the proposed antenna

The gain of the proposed Minkowski Island fractal antenna ($\boldsymbol{G_T}$) was calculated by using the following formula.

$$G_T[dBi] = G_0[dBi] + P_T[dBi] - P_0[dBi] \quad (4)$$

With $\boldsymbol{P_T}$ is the power received by the measured antenna, $\boldsymbol{P_0}$ is the power received by the reference antenna, and $\boldsymbol{G_0}$ is the gain of the reference antenna. Given the measurement value of $\boldsymbol{P_T}$ = -22.77 dBi, $\boldsymbol{P_0}$ = -14.24 dBi and $\boldsymbol{G_0}$ = 12 dBi, the calculated gain of the proposed antenna at 2400 MHz is 3.47 dBi.

4. Conclusion

By using the 1^{st} iteration technique and 2^{nd} iteration technique of Minkowski fractal to the basic square patch then embedding Minkowski fractal slot to form the Minkowski Island shape, the size of patch area and substrate area can be reduced up to 58.7% and 35.8% respectively to produce a compact antenna that is suitable for Wi-Fi application. The proposed microstrip antenna is also optimized for bandwidth and return loss by applying proximity feed in combination with partial ground technique. The fabricated prototype of Minkowski Island fractal antenna has been measured and it is observed that the result from the measurement are better than the simulation with resonant frequency of 2400 MHz, return loss of -24.54 dB, VSWR of 1.126, impedance bandwidth of 240 MHz, and gain of 3.47 dB. From the simulation and measurement results, they show that the application of Minkowski Island fractal to the patch of basic microstrip antenna can be used to reduce the size of the overall antenna significantly without sacrificing the performance of the antenna.

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