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Miniature Triple-Mode Diplexer with Good Selectivity

Sugchai Tantiviwat*, Siti Z. Ibrahim, and Mohammad S. Razalli

Abstract—This paper presents a compact diplexer with high selectivity. The proposed diplexer employs two sets of triple-mode bandpass filters. Using this approach, the pair of even-mode resonant frequencies can be flexibly controlled by adjusting the characteristic impedance or electrical lengths of the two open-circuited stubs while the odd-mode resonant frequency remains at the fundamental resonant frequency. For a demonstration, a diplexer with two passbands centred at 1.50 and 1.70 GHz and the transmission zeros are created close to the passband edges which extremely improve the skirt selectivity. As a result, the proposed diplexer occupies an extremely small area, i.e., approximately $0.30\lambda_g \times 0.35\lambda_g$. The measured results are in good agreement with the simulated predictions.

1. INTRODUCTION

A diplexer is one of the significant devices used to separate one signal into two output channels or combine two signals into one output channel. Diplexers with compact size and high-selectivity are highly demanded nowadays to meet recent growing trend in the modern wireless communication systems [1–3]. The most common approach to realize a diplexer is using two bandpass filters with parallel/cross coupling of single-mode resonators. The notable resonators are open loop resonators, hairpin line resonators, stepped impedance resonators, quarter-wavelength resonators, and hybrid resonators respectively [4–9]. Using such resonators, each of the passbands is designed at its fundamental frequency. In turn, higher order mode of the filters is required to provide sharp passband skirts; however, this will lead to the whole larger dimension. In [8, 9], the defected ground structures are utilized to design diplexers. Conversely, this method is not appropriate since they always have top and bottom circuits, which is an inflexible and complicated circuit.

Another well-known method is the multi-mode resonators. Such resonators are dual-mode resonators [10–12], triple-mode resonators [13] and quadruple-mode resonators [14]. Those filters, which are realized by multi-mode resonators, have the ability to reduce the circuit size and improve the selectivity of bandpass filters, triggering the multi-mode resonators as the common method for achieving compact size diplexers. Additionally, the multi-mode structures allow more freedom to control the coupling coefficients, and they are also widely utilized to design various filters.

In this paper, a compact diplexer using a triple-mode stub loaded resonator is presented. The diplexer is basically composed of two bandpass filter channels, and each channel can be designed individually. Therefore, the even-mode resonant frequencies are easily tuned without affecting the odd-mode frequency. The passband frequencies can be appropriately adjusted to the desired values by controlling the corresponding different physical impedances and length ratios of the resonators. Moreover, the coupling structure is introduced to produce transmission zeros at the adjacent passbands, and sharp passband skirts of the two bandpass filters are observed.

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* Corresponding author: Sugchai Tantiviwat (sugchai.t@rmutsv.ac.th).
The authors are with the School of Computer and Communication Engineering (SCCE), Universiti Malaysia Perlis (UniMAP) Arau, Perlis, Malaysia.

2. CHARACTERISTICS OF TRIPLE-MODE RESONATOR

As shown in Fig. 1(a), the proposed triple-mode stub-loaded resonator is formed by appropriately attaching parallel two open-circuited stubs loaded in the middle symmetrical plane of the resonator. As can be seen in Fig. 1(a), this resonator configuration can be investigated in terms of even and odd resonance mode frequencies. Since the resonator is symmetrical to the T-T' plane, it behaves as electric and magnetic walls for odd-mode and even-mode excitation, leading to the estimated transmission line circuit models which are illustrated in Fig. 1(b), Fig. 1(c) and Fig. 1(d), respectively. In addition, Z_1, Z_2, Z_3, Z_4, Z_5, and Z_6 are the characteristic impedances respect to the width (W) of stepped impedance transmission line. L_1, L_2, L_3, L_4, L_5, and L_6 denote the lengths of microstrip line where $\theta_i = \beta L_i$; $i = 1, 2, 3, \ldots$ denotes the electrical lengths of resonator, and β is the propagation constant. From the resonance condition derived by setting $Z_{in} = \infty$, under the odd-mode excitation, the resonance frequency condition can be extracted as follow:

$$\tan\theta_1 \tan\theta_2 = \frac{Z_1}{Z_2} \tag{1}$$

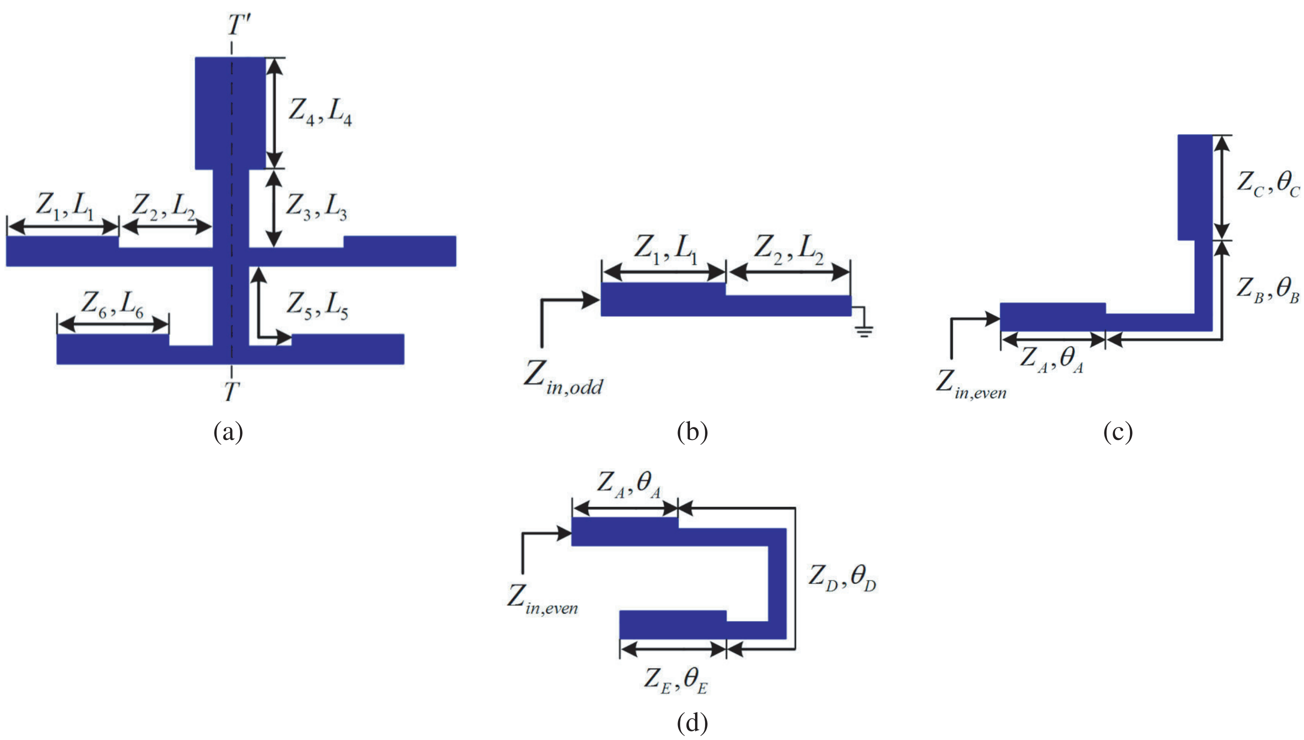

Figure 1. Schematic of the proposed stub loaded resonator. (a) Structure of the triple-mode stub loaded resonator. (b) Odd-mode. (c) Higher even-mode. (d) Lower even-mode.

To simplify the special case $2Z_2 = Z_3$, namely Z_B, $\theta_2 + \theta_3 = \theta_B$ while $Z_1 = Z_A$, $Z_4 = Z_B$ are assumed. For higher even-mode resonance, the resonance condition is expressed by

$$\frac{Z_A}{Z_B}\tan(\theta_A/2)\tan(\theta_B/2) + \frac{Z_A}{Z_C}\tan(\theta_A/2)\tan(\theta_B/2) + \frac{Z_B}{Z_C}\tan(\theta_B/2)\tan(\theta_C/2) = 1 \tag{2}$$

For lower even-mode resonance, similarly calculated to the higher even mode resonator, we can assume $2Z_2 = Z_5$, namely Z_D, $\theta_2 + \theta_5 = \theta_D$ while $Z_1 = Z_A, Z_6 = Z_E$ can be calculated approximately as follows:

$$\frac{Z_A}{Z_D}\tan(\theta_A/2)\tan(\theta_D/2) + \frac{Z_A}{Z_E}\tan(\theta_A/2)\tan(\theta_D/2) + \frac{Z_D}{Z_E}\tan(\theta_D/2)\tan(\theta_E/2) = 1 \tag{3}$$

For example, the identical open-circuited stubs can be applied to push one resonant mode to the desired passband. According to expressions (1) to (3), the triple-mode resonator is designed to achieve the desired resonant frequencies. Two microstrip lines with 50 Ω characteristic impedance are used to feed the suggested triple-mode stub loaded resonator by using loose coupling. The fundamental odd-mode frequency is fixed by the lengths of L_1 and L_2, and the dimensions of the odd-mode resonator are chosen as: $Z_1 = 51.90\,\Omega$, $Z_2 = 83.82\,\Omega$, $\theta_1 = 41.10°$, $\theta_2 = 33.80°$; the fundamental frequency is 1.50 GHz as specific effect of open-ended stub; the parameters $W_4 = 83.82$ mm, $W_3 = 2.00$ mm, $L_4 = 16.90$ mm, which are preliminary designed and not varied. The length L_3 is adjusted from 9.30 mm to 10.30 mm, and the resonant mode frequencies of higher even modes are shifted while the odd-mode resonant frequency is reserved. In addition, the length L_5 is varied between 16.55 mm and 17.55 mm while $W_6 = 3.20$ mm, $L_6 = 10.85$ mm, and other parameters are fixed to demonstrate the variation in lower even-mode resonance as shown in Fig. 2(a) and Fig. 2(b), respectively. As can be seen, these two fundamental even modes and odd mode are designed based on the approved fundamental frequencies and bandwidth. Additionally, two transmission zeros appear due to the virtual ground created by the shunt stub. The resonant frequencies can be flexibly distributed at either lower or higher side of the desired passband.

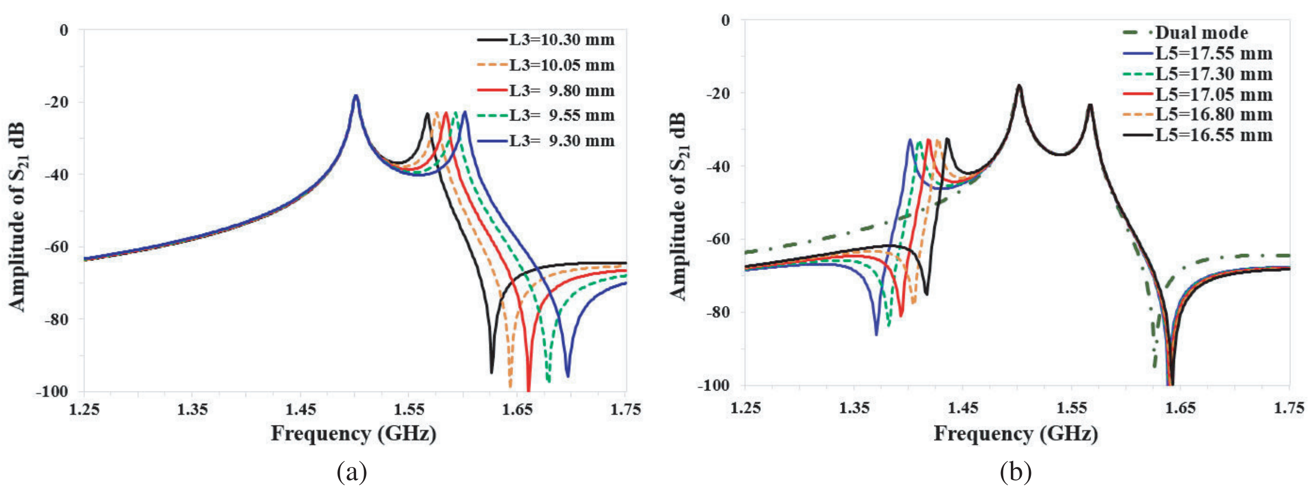

Figure 2. Simulated response with different length of stub loaded resonator. (a) Resonant properties of the dual-mode with different length L_3. (b) Resonant properties of the triple-mode with different length L_5.

3. TRIPLE-MODE DIPLEXER DESIGN

The three-pole diplexer is also designed to demonstrate this concept. The configuration and coupling scheme of the compact diplexer are shown in Fig. 3(a) and 3(b) which are composed of two triple-mode resonators of two difference bandpass filters. To achieve a small size area, only two triple-mode resonators are used. For each passband of diplexer based on tri-mode resonator filter design, the passband bandwidths can be decided by properly adjusting the three resonant modes of each resonator. In this case, we can determine the desired values of coupling coefficient M_{ij} of the first and second passbands according to the specifications. M_{ij} represents the coupling coefficient between odd-mode and even-mode, thus Q_e denote the external quality factors of the input and output of the first and second passbands which can be determined by solving the following equations, respectively.

$$M_{ij} = \frac{2|f_{odd} - f_{even}|}{f_{odd} + f_{even}}, Q_e = \frac{f_0}{\delta f_{3-dB}} \quad (4)$$

Generally, a stronger coupling can be obtained with a smaller gap, high impedance and longer coupled-line where the gap or length of feed line is varied, and Q_e of the input and output coupled lines are adjusted to achieve the given bandwidth specification.

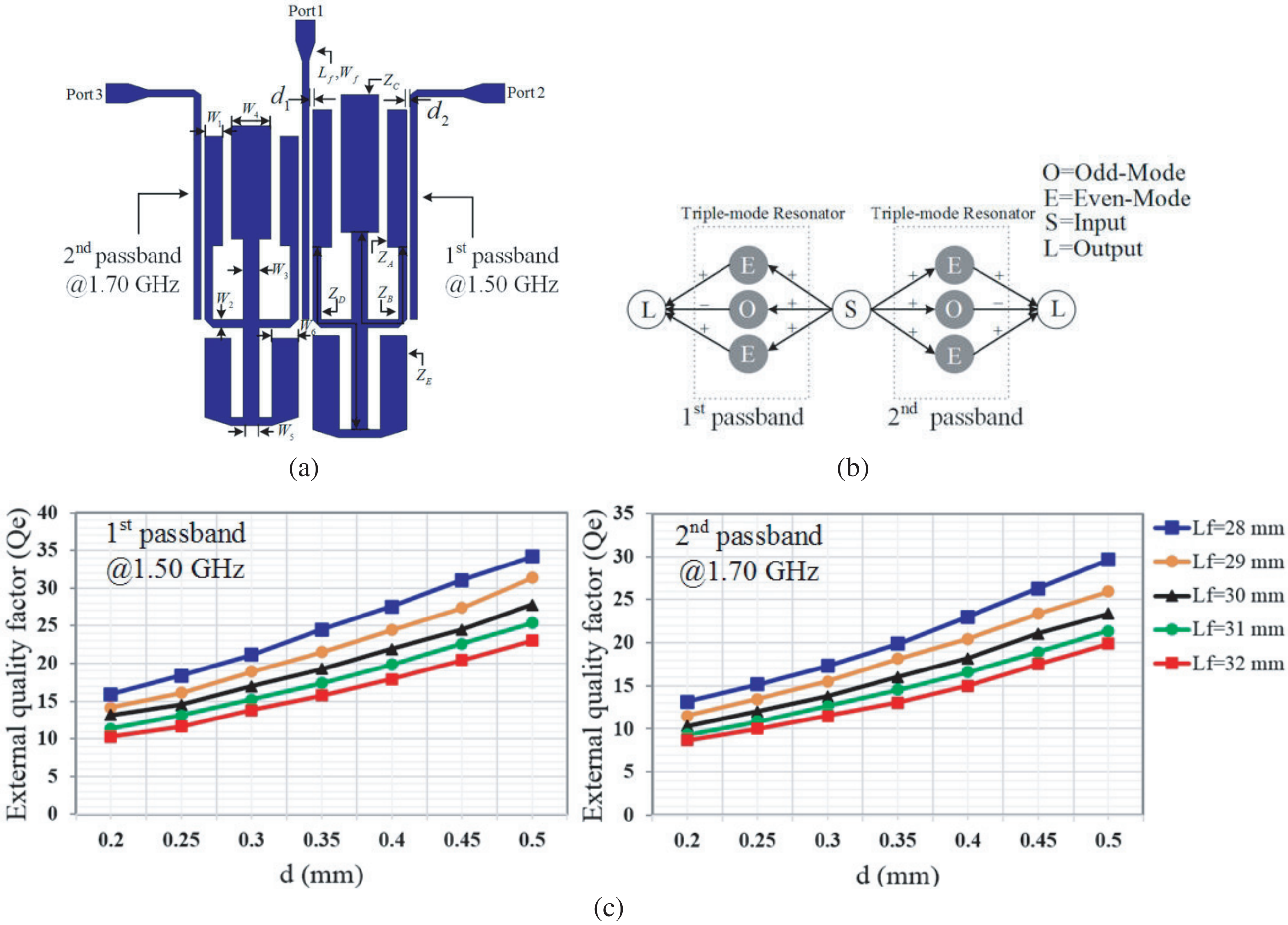

Figure 3. (a) Configuration of three pole diplexer, (b) coupling scheme of the proposed diplexer, and (c) external quality factor versus the dimension of gaps with different L_f.

For the demonstration, a diplexer is designed on a Diclade Arlon 880 substrate with a relative dielectric constant of 2.20, thickness of 0.80 mm, and loss tangent of 0.009. The specification of third-order bandpass diplexer is designed to operate at 1.50 GHz and 1.70 GHz, and the fractional bandwidths are 5.33% and 4.70%, respectively. The proposed diplexer is designed with parameters listed in Table 1. The odd-mode resonant frequency f_{odd} and even mode resonant frequency f_{even} of resonators are determined in Equations (1)–(3). In order to achieve the physical dimensions of the two

Table 1. Design parameters of triple-mode stub loaded resonators.

	1st Passband	2nd Passband
f_{odd} (GHz)	1.50	1.70
Lower f_{even} (GHz)	1.46	1.66
Higher f_{even} (GHz)	1.54	1.74
$Z_A, Z_B, Z_C, Z_D, Z_E (\Omega)$	51.90, 83.82, 51.90, 83.82, 41.46	53.42, 83.82, 50.48, 83.82, 41.46
Width of $W_1, W_2, W_3, W_4, W_5, W_6$ (mm)	2.30, 1.00,2.00,4.60, 2.00, 3.20	2.20, 1.00, 2.00,4.80, 2.00, 3.20
Length of $L_1, L_2, L_3, L_4, L_5, L_6$ (mm)	16.82, 13.58, 10.63, 16.88, 13.93, 12.58	13.37, 12.72, 9.82, 13.87, 12.42, 9.72
Dimension of d_1, d_2 (mm)	0.45, 0.45	0.45, 0.45

bandpass filters, the coupling coefficients (M_{ij}) and external quality factors (Q_e) can then be found as (first passband @1.50 GHz) $M_{12}^I = M_{23}^I = 0.049$ and $Q_{ei}^I = Q_{eo}^I = 18.76$, (second passband @1.70 GHz) $M_{12}^{II} = M_{23}^{II} = 0.043$ and $Q_{ei}^{II} = Q_{eo}^{II} = 21.25$. A full-wave simulator is used to extract Q_e as shown in Fig. 3(c), where the width of feed port input (W_f) is fixed at 0.90 mm. The geometric parameters are approximately obtained as $L_f^I = 32.00$ mm, $d_1^I = d_2^I = 0.45$ mm, $L_f^{II} = 31.00$ mm, $d_1^{II} = d_2^{II} = 0.45$ mm, where the superscripts I and II denote the first and second passbands, respectively.

4. SIMULATED AND MEASURED RESULTS

Figure 4 shows a photograph of the fabricated diplexer. The overall size of the fabricated circuit is 42.95 mm × 52.25 mm, i.e., about $0.30\lambda_g \times 0.35\lambda_g$, where λ_g is the guided wavelength of 50 Ω line on

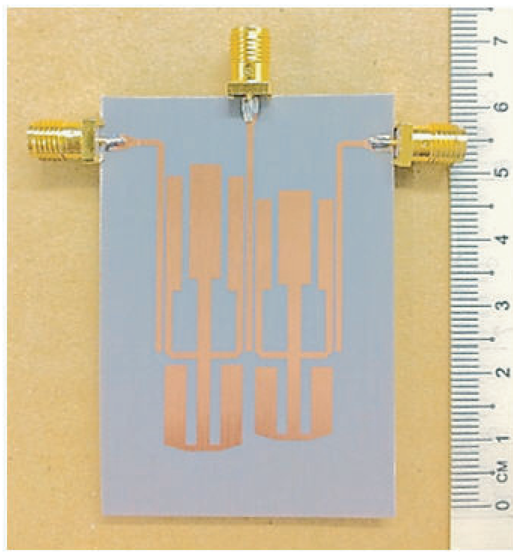

Figure 4. Photograph of the fabricated diplexer.

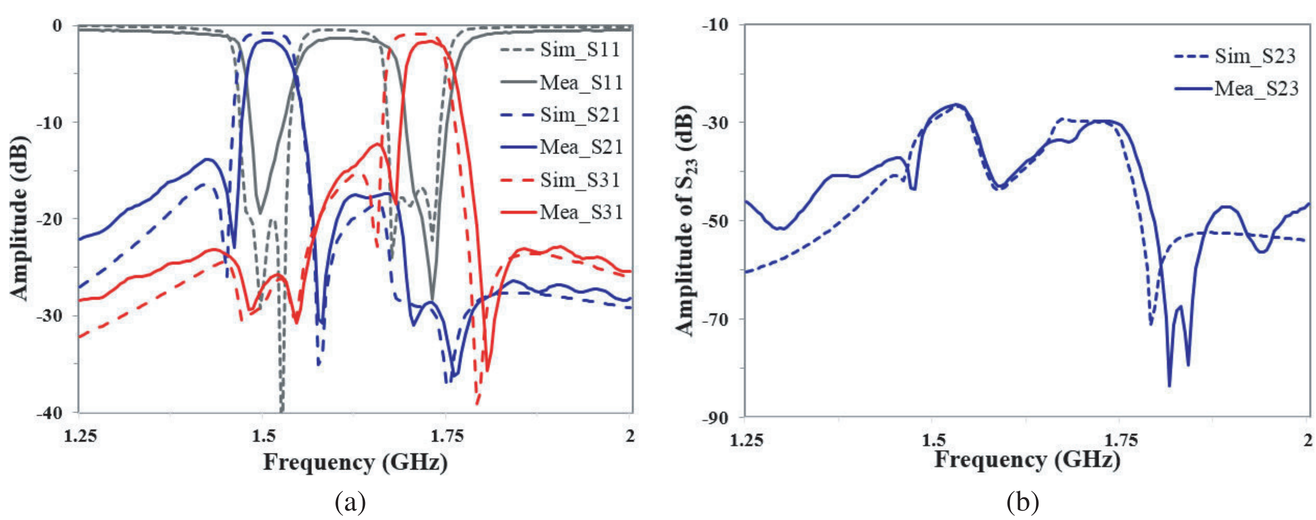

Figure 5. Comparison between the simulated and the measured response of the proposed diplexer. (a) Measured and EM simulated S-parameters of the diplexer. (b) Comparison of isolation (S_{23}) response of the diplexer.

the substrate at center frequency of first passband (1.50 GHz). The simulated and measured results of the proposed diplexer are illustrated in Fig. 5(a). The measured passband return losses (S_{11}) are better than 15 dB for two channels, while the insertion losses (S_{21}) in the lower and upper passbands are approximately 1.52 dB and 1.68 dB, respectively. The insertion losses are mainly attributed to the conductor loss of copper. The measured isolation between the channels in Fig. 5(b) better than 25 dB is achieved. The suppression of each bandpass filter at the other filter passbands is larger than 25 dB. Overall, measured and simulated results are in good agreement.

5. CONCLUSION

In this paper, a miniaturized diplexer using triple mode stub-loaded resonators is proposed. The diplexer is formed by two third-order BPFs that employed a simple structure. It has the properties of compact size, high selectivity, and good in-band isolation. Its resonant frequencies of two lower and higher resonant frequencies of even-mode can be flexibly controlled, while the odd-mode remains, with no effect on the resonant frequency. Moreover, the triple-mode resonator is folded to be compact to satisfy a significant size reduction. Measured results of the fabricated diplexer agree well with the simulations.

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