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Compact Double Layer Two Via Electromagnetic Band Gap Structure for RCS Reduction

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ABSTRACT: In this paper, a multi-layered mushroom-type electromagnetic band gap (EBG) structure is proposed. A double layer two via EBG (DLTV EBG) structure is designed at 1.65 GHz. The proposed DLTV-EBG structure consists of a two-layer dielectric substrate, which reduces the lateral sizes due to a multilayer topology. By adjusting the patch dimensions and positions of the vias, the center frequency, and equivalent L and C parameters meet design requirements. In a DLTV-EBG, layer-1 has a square ring patch; layer-2 has a circular ring; outer square ring patch with 2 edged located vias gives the additional capacitance and inductance to achieve compactness. The simulation of the DLTV-EBG structure is carried out using the Ansys high-frequency structure simulator (HFSS) and experimentally validated. The band gap of the DLTV-EBG structure is measured using suspended microstrip line (SML) method. The Experimental results agree well with simulation one. The periodic size of the proposed DLTV-EBG structure is $0.05\lambda_{1.65\,\mathrm{GHz}}$, which is a good candidate where compact size is highly desired.

1. INTRODUCTION

Electromagnetic band gap structure is a periodic structure with a general size less than $\lambda/4$, which possesses unique characteristics like zero reflection phase at operating frequency. This unique property of EBG plays an important role in different applications like reduction in radar cross section (RCS), performance improvement of the printed antenna, etc. In literature, various methods have been reported to reduce the RCS like changing shape technique [1–3], radar absorption material (RAM) [4–6] and EBG based methods [7–9]. In [10], the authors investigate using Positive-Intrinsic-Negative (PIN) attenuator diodes to reduce the RCS of a microstrip patch antenna, another circuit loading method for RCS reduction. Compared to these methods, the EBG-based method works well at lower frequency [7]; therefore, it is essential to design a compact EBG structure at a lower frequency for such applications. A multilayer EBG structure (ML-EBG) is proposed in [11] operating at 2.55 GHz with a patch size of $0.119\lambda_{2.55\,\mathrm{GHz}}$. In [12], a compact low-permittivity dual-layer (LPDL) EBG structure is proposed with a patch size of $0.26\lambda_{5\,\mathrm{GHz}}$. [13] proposes a dual-layer dual-patch EBG (DLDP-EBG) with patch size of $0.23\lambda_{5.39\,\mathrm{GHz}}$. A rectangular polarization-dependent EBG (PDEBG) structure is proposed in [14] with a patch size of $0.16\lambda_{3\,\mathrm{GHz}}$. An artificial ground EBG (AG-EBG) with a patch size of $0.13\lambda_{6\,\mathrm{GHz}}$ is proposed [15]. In [16], an Improved Dual-Layer Mushroom type EBG (IDL-EBG) structure is proposed with a periodic patch size of $0.083\lambda_{2.45\,\mathrm{GHz}}$. Reported EBG structures may not be suitable for low-frequency applications due to the patch size. Therefore in this paper, a compact single-band mushroom-type double-layer two-via electromagnetic band gap (DLTV-EBG) is proposed. The paper is organized as follows. Section 2 presents the design, equivalent circuit, and analysis of the reflection phase diagram. In Section 3, fabricated prototype and analysis of measurement results are presented. In Section 4, the application of DLTV-EBG is presented to reduce RCS. Finally, the conclusion is presented by comparing the proposed structure with reported EBG structures.

2. DESIGN OF DOUBLE LAYER TWO VIA EBG

The unit cell design and the reflection phase results of DLTV-EBG are discussed in this section. The evolution of the proposed DLTV EBG, a detailed design of unit cell, and equivalent circuit are shown in Figures 1 and 2, respectively. The proposed EBG unit cell geometry consists of layer-1 with an edge located via at the right side with a square ring patch, and layer-2 consists of an edge located via at the left side with a square ring and circular ring patch as shown in Figures 2(b) and (c). The compactness of the structure is achieved due to the arrangement of two extreme ends via structure. A suspended microstrip line (SML) method [24, 25] is used for the equivalent circuit modeling to define the characteristics of the unit cell DLTV-EBG. Layer-1 square ring patch gives the current path between via-1 and via-2 as shown in Figure 1(d). The top views of layer-1 and layer-2 of the proposed DLTV EBG are shown in Figures 2(b) and (c), respectively. As shown in Figure 2(d), the capacitance C1 is formed between the 50 Ohm microstrip line and layer-2 EBG patch. Capacitance C2 and C3 are formed due to layer-1, layer-2 EBG patch, and ground plane, respectively. The equivalent inductance is formed due to the current path provided by

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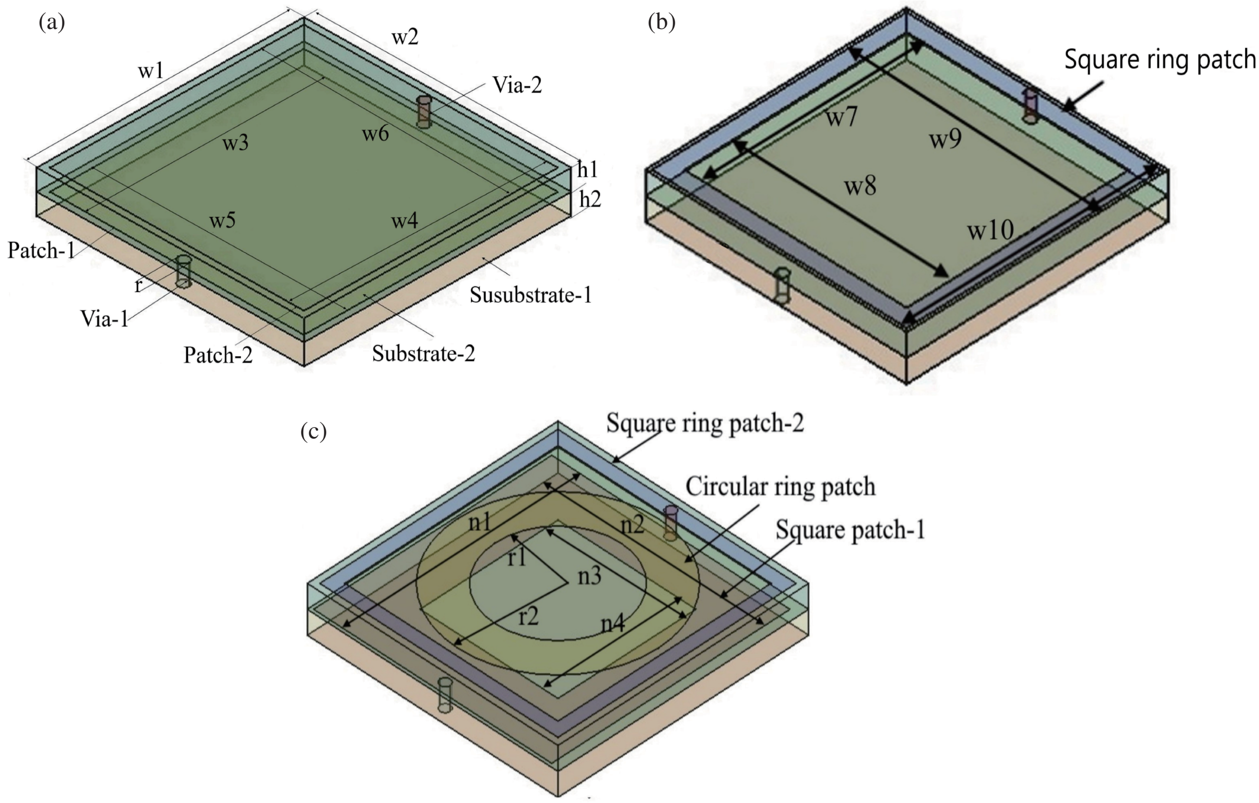

FIGURE 1. Evolution of proposed double layer EBG structure (a) Dual square Patch EBG(DP-EBG) with (w_1, w_2, w_3, w_4, w_5, w_6, h_1, h_2, r) = (10 mm, 10 mm, 9.5 mm, 9.5 mm, 9.5 mm, 9.5 mm, 0.8 mm, 0.8 mm, 0.2 mm), (b) Square Ring patch EBG (SR-EBG) with (w_7, w_8, w_9, w_{10}) = (8.5 mm, 8.5 mm, 9.5 mm, 9.5 mm), (c) Proposed Double layer two via EBG (DLTV-EBG) with (n_1, n_2, n_3, n_4, r_1, r_2) = (9.5 mm, 9.5 mm, 5.5 mm, 5.5 mm, 2.5 mm, 4 mm).

two extreme edge loaded vias and a patch of layer-1 as shown in Figure 2(d). The Equivalent Circuit Model (ECM) is also simulated in Advanced Design Software (ADS), and the obtained results are shown in Figure 3. The approximate values of capacitors and inductors are calculated by using the formulas given in [26]. The DLTV-EBG is designed on layer-1 and 2 with substrate height of 0.8 mm each and dielectric constant of $\varepsilon_r = 4.4$. The other parameters of the proposed EBG are as shown in Figure 2. The reflection phase results of various evolution stages of the proposed DLTV-EBG are shown in Figure 3. It is observed from simulated results as shown in Figure 3, dual square patch EBG, shown in Figure 1(a), resonates at 5.09 GHz with patch size of 0.16λ. Rectangular Ring Square Patch EBG 1(b) center frequency is at 2.93 GHz with a patch size of $0.097\lambda_{2.93\,\text{GHz}}$. The proposed DLTV-EBG center frequency is at 1.65 GHz with a patch size of $0.05\lambda_{1.65\,\text{GHz}}$. The proposed DLTV-EBG gives a compact size as compared to the other stages. Further study and analysis of the proposed EBG structure measurement results are discussed in the following section.

3. MEASUREMENT RESULTS

To validate the simulated results of the proposed DLTV- EBG, a 5×5 array of DLTV-EBG is printed on an FR4 substrate with a dielectric constant $(\varepsilon_r) = 4.4$, dielectric loss tangent ($\tan\delta$) 0.02, and a substrate thickness of 0.8 mm each. The other parameters of the DLTV-EBG are mentioned in Figure 1. The suspended microstrip line (SML) method [24, 25] is used to find the transmission characteristics of the proposed DLTV-EBG. A 50 Ohm microstrip line is printed on the substrate, with a thickness of 0.8 mm, (ε_r) = 4.4, and loss tangent of ($\tan\delta$) 0.02. Furthermore, the measurement is carried out using the FieldFox RF Vector Network Analyzer N9923A with a maximum measurable frequency of 6 GHz. The measured results are presented in Figure 3(b). It is observed from the measurement results that the frequency is f_0 1.5 GHz with a lower cut-off frequency $f_{c(l)}$ 1.45 GHz and a higher cut-off frequency $f_{c2(h)}$ 1.6 GHz. As shown in Figure 3(b), measurement results agreed well with the simulated one. A small discrepancy is due to the tolerance in the fabrication process and the effect due to the sub-miniature A (SMA) connector. The fabricated prototype and measurement setup are shown in Figure 3(b). The reduction in the center frequency is achieved due to an increase in the current path between via-1 and via-2 through layer-1 square patch ring as discussed earlier. The comparative analysis of the DLTV-EBG with the reported EBG structure is presented in Table 1. It is observed from the comparison of Table 1 that the proposed DLTV-EBG has achieved good compactness with a patch size of $0.05\lambda_{1.65\,\text{GHz}}$. Therefore, the DLTV-EBG is a good candidate for the reduction of the RCS in a multilayer, f_0 low-frequency environment.

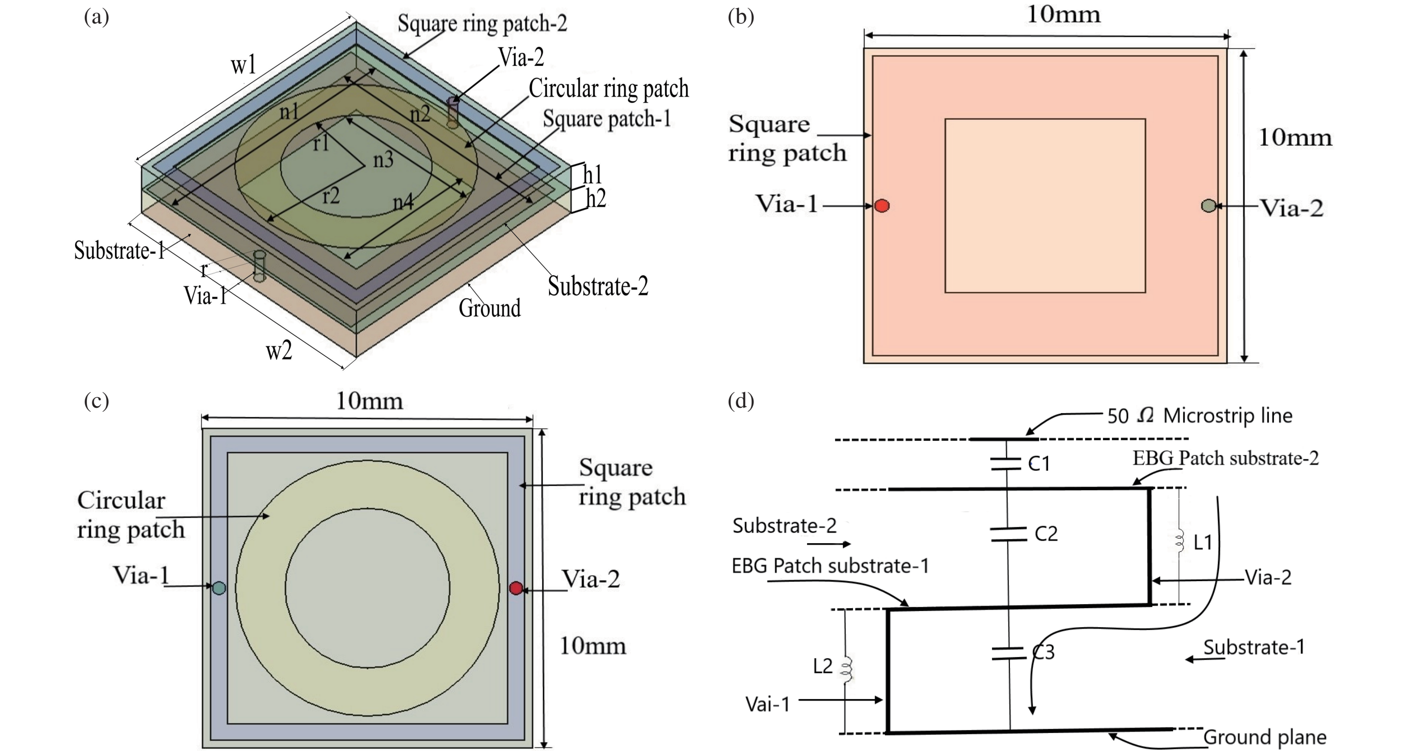

FIGURE 2. DLTV-EBG Design (a) unit cell with $(n_1, n_2, n_3, n_4, r, r_1, r_2)$ = (9.5 mm, 9.5 mm, 5.5 mm, 5.5 mm, 0.2 mm, 2.5 mm, 4 mm). (b) Top view of layer-1, (c) top view of layer-2, (d) equivalent circuit.

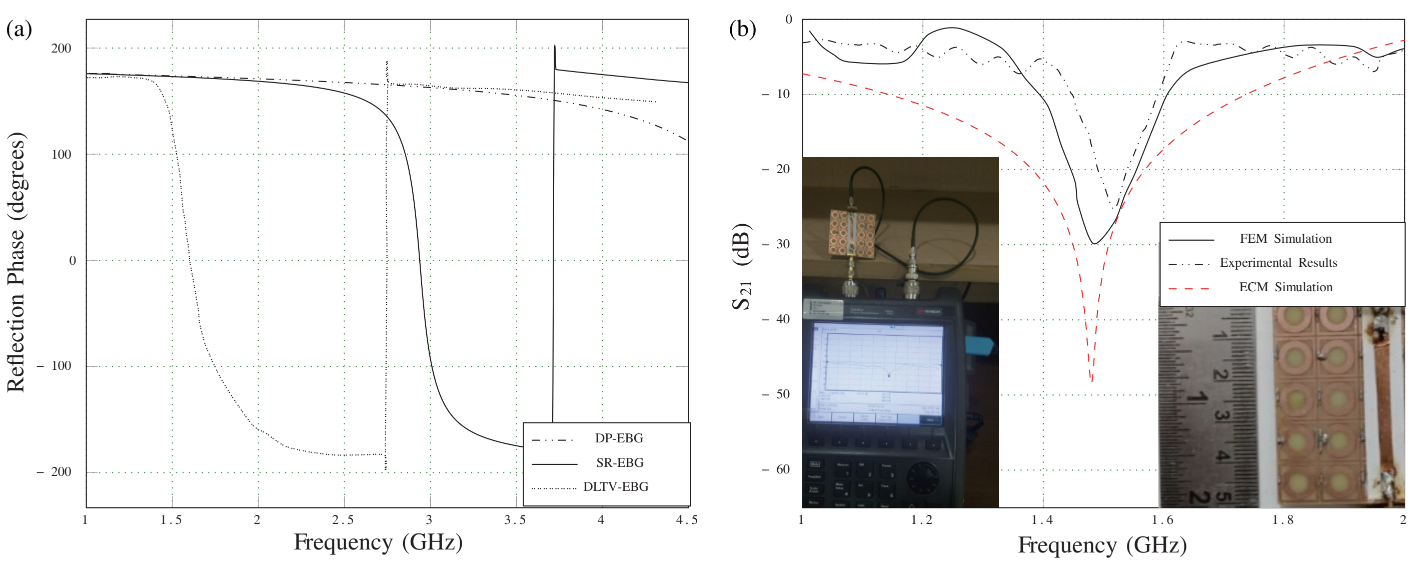

FIGURE 3. (a) Simulated reflection phase of different evolution stages of DLTV-EBG, (b) Photograph of measurement set up, FEM simulated S_{21} and Experimental measured S_{21} using suspended microstrip line method with circuit parameters $(C_1, C_2, C_3, L_1, L_2)$ = (5.51 pF, 12 pF, 12 pF, 0.6 nH, 0.3 nH), Equivalent Circuit Model (ECM) results S_{21} for the proposed Double layer EBG.

4. APPLICATION

This section describes the application of the proposed DLTV-EBG structure to reduce the radar cross-section. Radar cross section (RCS) measures the ability to detect the target when it is illuminated by electromagnetic waves. The measurement of RCS total was carried out with two standard gain horn antennas, where one as a transmitter and the other as a receiver. A 2×40 mm period of checker board was selected to get four scattered beams whose maxima were near 45° from the direction of incidence [7]. It is measured in terms of the ratio of the backscattered power from the target in the direction of the radar. Therefore, RCS is a very important parameter to reduce the visibility of the target. There are various methods to reduce the RCS like changing shape, applying radar absorption

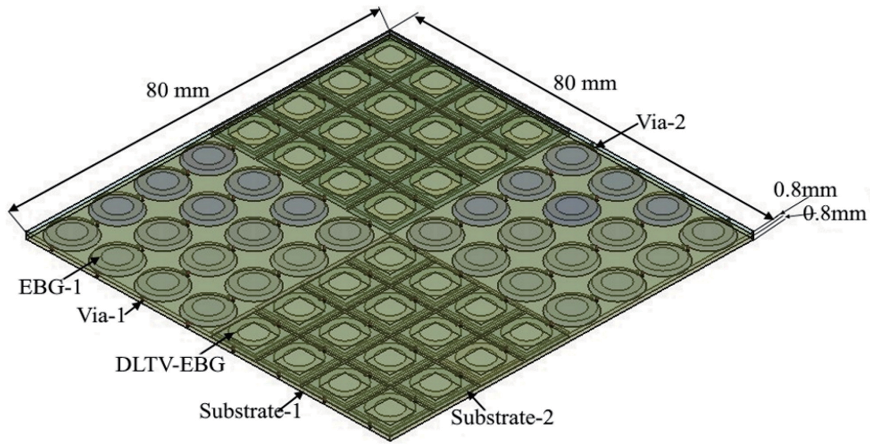

FIGURE 4. The Double layer checkerboard surface with 4×4 EBG structure.

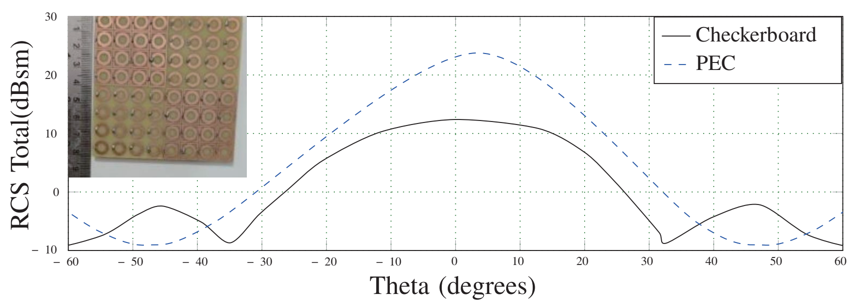

FIGURE 5. RCS pattern for checkerboard surface along the principle planes with proposed DLTV-EBG and PEC at 1.5 GHz.

TABLE 1. Comparison of polarization, S_{21}, and EBG patch size with previous work.

Sr. No.	Name of EBG	No. of layers	f_c (GHz)	h (mm)	ϵ_r	EBG Patch Size	% Band Gap
[11]	ML-EBG	04	2.55	6.4	4.4	$0.119\lambda_{2.55\,\text{GHz}}$	28.57
[12]	LPDL-EBG	02	5	0.889	3.55,2.2	$0.26\ \lambda_{5\,\text{GHz}}$	N.M.
[13]	DLDP-EBG	02	5.39	3.2	4.3	$0.23\ \lambda_{5.39\,\text{GHz}}$	43
[16]	IDL-EBG	02	3.44, 6.24	4.4, 2.45	3.5	$0.083\lambda_{2.45\,\text{GHz}}$	N.M.
[17]	Jun-EBG	02	2.4 to 2.2	3.175	2.2	$0.299\ \lambda_{2.40\,\text{GHz}}$	12.24
[18]	Cesaro-EBG	02	2.32 to 2.45	3.175	2.2	$0.22\lambda_{2.45\,\text{GHz}}$	7.40
[19]	DS-EBG	02	11.4	0.1	5.9	$0.14\ \lambda_{11.4\,\text{GHz}}$	68.33
[20]	Dey-EBG	02	29.1	0.51	2.2,4.4	$0.19\ \lambda_{29.12\,\text{GHz}}$	20
[21]	TL-EBG	02	2.20	0.55	4.4	$0.098\lambda_{2.20\,\text{GHz}}$	34.6
[22]	E-EBG	02	1.7	3.20	4.4	$0.147\lambda_{1.7\,\text{GHz}}$	N.M.
[23]	EM EBG	02	2.25	1.625	3.38	$0.105\lambda_{2.25\,\text{GHz}}$	N.M.
[P.E.]	**Proposed EBG**	**02**	**1.65**	**1.6**	**4.4**	$\mathbf{0.05\lambda_{1.65\,GHz}}$	**10.90**

N.M. = Not Mentioned, P.E. = Proposed EBG

material (RAM), circuit loading, etc. These methods are suitable for high frequencies. Therefore, EBG checkerboard surface draws more attention, due to similar redirecting of scattering fields within frequency bands. A checkerboard pattern with DLTV-EBG is proposed to reduce the RCS as shown in Figure 4. The proposed compact DLTV-EBG exhibits 0° reflection phase at 1.65 GHz which cancels the electromagnetic wave at this frequency in the normal direction. A single band checkerboard surface with the proposed EBG structure is shown in Figure 5 and is simulated and fabricated with overall dimensions of 80 mm $\times$ 80 mm. The measured RCS with the proposed EBG checkerboard and perfect electric conductor (PEC) at 1.65 GHz is shown in Figure 5. It is clear that compared to the PEC surface, the EBG checkerboard surface gives more than 11 dB

RCS reduction at the operating frequencies with the same periodic size. Therefore, it shows that the proposed mushroom-type double-layered EBG structure is useful where compact size is highly desirable.

5. CONCLUSION

A DLTV-EBG structure is proposed, and the band gap characteristics are presented and investigated. A lumped LC-equivalent circuit model is established to approximate its operation. The DLTV-EBG structure is simulated and validated experimentally. It is observed from the results that the good compactness is achieved with the proposed EBG as compared to reported EBGs. The application of the proposed EBG structure has been demonstrated by forming the checkerboard surface for RCS reduction. Therefore, the proposed EBG is very useful in RCS reduction applications where compact size is highly desirable.

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