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Defected Ground Structure Based Microstrip Patch Antenna for WLAN and WiMAX Applications

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Abstract: The paper presents a novel microstrip-fed triple band microstrip patch antenna for Wireless LAN and WiMAX applications. This antenna has a compact size of 25x40 mm^2, uses FR4 epoxy as the substrate material, and has a relative permittivity of 4.4. A cambered defected ground structure, three ring patches of different widths, and HFSS software are used to design and simulate the antenna. The designed antenna resonates effectively between 2.5-2.7GHz, 3.4-3.7GHz and 5.25-5.75GHz, and simulation results indicate that it can be used effectively for WLAN and WiMAX.

Keywords*: Defected Ground structure, Triple band frequencies, HFSS, Return loss, Gain*

1. Introduction

As the demand for high-speed data transfer increases, wireless communication has become an integral part of our daily lives. Therefore, it is crucial to develop wireless communication systems that are efficient and effective. Microstrip patch antennas have gained significant attention owing to their compactness, conformal nature and ease of fabrication. Moreover, capability of microstrip patch antenna to work over a wide range of frequencies makes them an attractive option for various wireless communication applications.

In past few years, the demand for WiMAX and WLAN applications has increased significantly [1]-[7]. However, one of the major challenges in these applications is to design high gain antenna while maintaining a compact size of the same. In order to overcome this challenge, defected ground structures (DGS) based microstrip patch antennas can be used [4].

It consists of a periodic pattern imprinted on the ground plane of the microstrip patch antenna, which effectively suppresses surface waves and improves radiation characteristics. The use of DGS has been reported to improve the antenna's gain, directivity, and bandwidth. In [1] and [4] the ground plane is rectangular shaped, consisting of a rectangular slot. The rectangular shape ground plane without slots is considered in [5].In [2] the cambered ground plane is used which increases the impedance matching of the antenna.

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In this paper, we proposed a design and analysis of a microstrip patch antenna using a DGS for WiMAX and WLAN applications. The frequency band taken for WLAN and WiMAX applications are 2.5-2.7, 3.4-3.7, and 5.25-5.75 GHz) respectively. [1-2]

In [2] and [4] the designs consisting of a circular ring have been tested and studied. The HFSS software is used to design and simulate the proposed antenna, and its performance is evaluated in terms of return loss, radiation pattern, and gain.

The rectangular MPA with a rectangular slot (DGS) was created and simulated using HFSS software with an operating frequency of 2.4 GHz in [10).A rectangular MPA's performance can be measured by varying the position of the rectangular slot and measuring its return loss, bandwidth, VSWR, and gain. The antenna's performance is enhanced by adding a rectangular slot defect to the ground plane; the simulated results indicate that this increases the bandwidth from 56 MHz to 111 MHz.. Wen-Chung Liu et al. [11] have proposed a triple frequency antenna. The antenna is a monopole antenna designed for multiband use. Two inverted L-shaped strips join the rectangular patch, and DGS is utilized along with a cross-shaped strip line for feeding.It is appropriate for WLAN and WiMAX and has a frequency range of 2.14-2.52 GHz, 2.82-3.74 GHz, and 5.15-6.02 GHz. The designed antenna is compact in size, and it operates on three different frequency bands. WLAN and WiMAX systems are suitable well with antennas as excellent antenna gains have been obtained. The author in [12] gives an antenna suitable for the WLAN application. The antenna is designed to run at 2.4GHz with FR4 substrate and DGS on the antenna ground plane.The substrate is 1.6 mm thick, has a dielectric constant of 4.7, and experiences a 65% size reduction when using DGS.A multiband antenna featuring a square-shaped slot and a defective ground was implemented by Bhanu Priya Kumawat et al. [13]. The antenna is powered by a 50-ohm microstrip line, and FR4 is the substrate that is utilized.The MPA is made to be symmetrical about both axes by its design. Three frequencies used by a multiband antenna are 2.3 GHz, 5.3 GHz, and 6.7 GHz.WiMax, GSM, WiFi, and Bluetooth are the applications for which this MPA can be used. The return loss, radiation pattern, and surface current are all simulated using CST simulation software. This antenna is powered by a modified 50 Ohm micro strip line and constructed on a FR4 substrate. The overall dimensions of this antenna are 50x50mm^2. Return Loss (S11), VSWR, surface current, and radiation characteristics are measured. In [14] a fork-shaped monopole antenna with multiple bands is proposed. The patch is shaped like a fork. The DGS used is a ‘T’ shaped slot in a partial ground. The feeding of an antenna is accomplished via a microstrip line. Radiation pattern, VSWR, and return loss are used to verify an antenna's performance. The antenna operates at three frequency ranges that are suitable for wireless applications: 1.21-1.29 GHz, 3.65-3.94 GHz, and 5.0-5.20 GHz. The designed antenna has good Return Loss and operates over frequency ranges of 1.21-1.29 GHz, 3.65-3.94 GHz, and 5.0-5.20 GHz, making it suitable for wireless applications. The proposed antenna measures 48.64 x 57.23 x 1.6 mm^3. The antenna with DGS outperforms the antenna without DGS in terms of outcomes. A zigzag slit cut with two 'T' shaped slits on either side of the rectangular patch was suggested by the authors in [15]. On the ground plane, the DGS of circular dumbbell shape is used. The WLAN and WiMAX bands are covered by the antenna. The antenna is small, and its Return Loss, Impedanceand Bandwidthparameters are improved along with its radiation characteristics. A gain increase of 4-6dBi is obtained and the results agree well with what is measured and simulated. A small rectangular MPA with circular DGS and a zigzag-shaped slit is developed for wireless applications. It is designed to be a probe-fed antenna with a circular dumbbell-shaped defective ground plane, two 'T'-shaped slits on either side of a rectangle patch, and a zigzag-shaped slit.The MPA was able to produce three distinct resonances to span the 3.5 GHz WiMAX channels as well as the 2.45/5.28 GHz WLAN frequencies, all while keeping its overall size minimal.The Return Loss, Impedance, and Bandwidth values are much higher for the three resonant frequencies. Improved emission patterns and a theoretically steady gain of 4-6 dBi across the operating bands characterize the developed antenna.A Slit-loaded triband patch antenna with DGS is modeled, tested, and built for wireless applications in paper [16]. Antenna structure is given and contrasted with and without defective ground planes. Excellent agreement is seen between the simulated and measured resonant frequencies of the modes and related impedance bandwidths of the patch antennas. One appealing aspect is how little the bandwidths at various frequency bands differ from one another. Measurements are also made of the gain values at the innovative structure's operating frequencies and there is good agreement between simulated and measured radiation patterns. The suggested antenna can be used with wireless communication systems that have more bandwidth, particularly those that operate in the L and C bands. A novel highly miniaturized antenna resonating at three frequencies is proposed in [17]. The antenna resonating at 2.5 GHz is of the lower WiMAX band, 3.47 GHz is the middle band, and 5.75 GHz is the higher band. Two unique cascaded unit cell structures of E shape DGS are etched together with a 'F' shaped slot on the patch to reduce the antenna size; multiband operations are achieved by etching U and H shaped slots on the patch. Good impedance matching and a consistent radiation pattern are achieved.

In [18], the antenna is small, and it is resonating at multiple frequencies i.e. at 2.97, 5.92, and 11.29 GHz. The square and triangular slots are used on the ground plane and the radiation properties of the antenna are satisfactory. Applications for WLAN, WiMAX, and Direct Broadcast Satellite are compatible with the MPA. A rectangular MPA is designed, and it resonates at 2.45 GHz in [19]. The antenna is miniaturized, and the bandwidth is improved by using dumbbell shaped DGS. The antenna can be used for L band and satellite phone applications. Sakshi Gupta et al. [20] have designed an MPA to resonate at two frequencies which can work for C and X band applications. Four U slots make up the rectangular patch, and the DGS of I and H shaped slots is utilized.The antenna is 25 mm by 23 mm in size and its properties are significantly enhanced with the application of the slot.

In order to increase performance and compactness, photonic band gap structures, or DGSs, are employed in microwave devices. The unwanted frequency is rejected, and the circuit size is reduced. DGS is a simple defect created by engraving any shape slot on the surface plane. The bottom plane's slots cause current disruption, allowing radio waves to excite and spread throughout the substrate layer. The transmission line's characteristics are altered and the inductance and capacitance change.

The structure of the paper is as follows. A synopsis of microstrip patch antennas and defected ground structures is provided in Section II.Section III presents the antenna's performance analysis and simulation findings. The paper is finally concluded with a summary of the major findings in Section IV.

2. Antenna Design

Design equations for MPA:

The patched area having dimensions L by W is made of copper. The ground section may also include copper, depending on the design limitations. The MPA is printed on the circuit board.

The patched length (L) can be calculated as,

$$L = L_{eff} - 2\,\Delta L \qquad ...(1.1)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \qquad \ldots(1.2)$$

$$\Delta L = 0.412h \times \frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad \ldots(1.3)$$

The width (W) of the patch is defined as,

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad \ldots(1.4)$$

Where the f_r is resonating frequency. The height, h of the substrate can be calculated as,

$$\frac{W}{h} > 1 \qquad \ldots(1.5)$$

The constant effective dielectric (ε_{eff}) is,

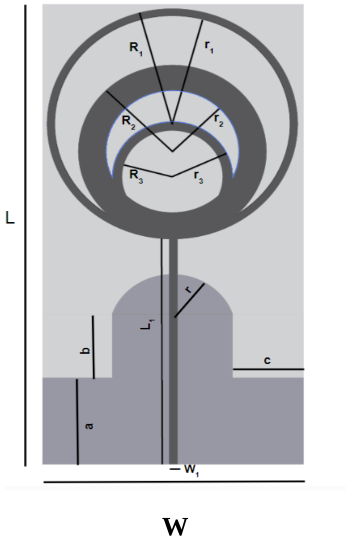
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5} \qquad \ldots(1.6)$$

L is the length variation brought on by the fringing effect. The ground plane's dimension is

$$L_g = L + 6h \qquad \ldots(1.8)$$

$$W_g = W + 6h \qquad \ldots(1.9)$$

Figure 1 depicts the proposed triple-band microstrip patch antenna for WLAN and WiMAX applications, which is based on a Defected Ground Structure (DGS). The proposed antenna is constructed on a 1.6 mm thick FR4 dielectric substrate with a relative permittivity of 4.4.



– **Fig.1**. Design of antenna

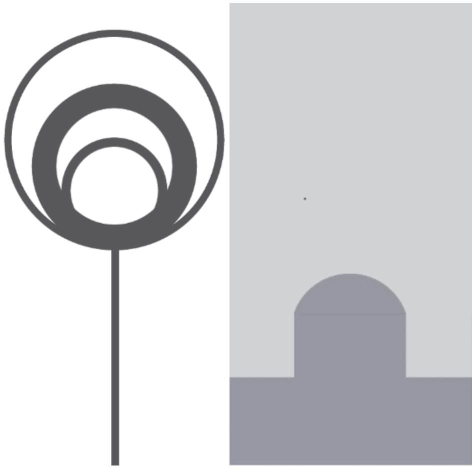


Fig.2. (a) top view (b) bottom view

The overall size of the antenna is 25 mm × 40 mm, and the patch of the proposed antenna is composed of three circular rings of varying thicknesses etched one into another.

For Ring 1, the outer radius R1 is 10 mm and inner radius r1 is 9.4 mm with centre at (0, -9.4, 1.6), for Ring 2, the outer radius R2 is 7.25 mm andinner radius r2 is 5.7 mm with centre at (0, -7, 1.6) and for Ring 3, the outer radius R3 is 4.8 mm and inner radius r2 is 4mm with centre at (0, -4.8, 1.6).

Thusring 1 being the biggest ring and ring 3 the smallest and innermost ring.

By using the HFSS software to optimize its characteristics, the antenna structure is improved. Table I displays the optimum parameters of the suggested antenna, and Fig. 2 displays a snapshot of the fabricated antenna.

TABLE I

PARAMETERS OF THE SUGGESTED ANTENNA

Parameter	Size	Parameter	Size
W_1	0.65 mm	W	25mm
L_1	19.65 mm	L	40mm
R_1	10 mm	a	5.5mm
r_1	9.4 mm	b	7.5mm
R_2	7.25 mm	c	5.63mm
r_2	5.7 mm	r	7.5mm
R_3	4.8 mm	r3	4mm

Important factors governing the antenna's performance are the rings' sizes and spacing from one another.

Thus, the antenna was designed in a stepwise manner, beginning with a single ring antenna and evaluating its performance. It was found that when the first ring i.e., the innermost ring was made, all the three frequencies were not in the desired range.

Thus, a second ring was added to the design, and the antenna's performance was measured again. It was observed that due to the addition of second ring, 2 out of three frequencies were obtained in the required frequency ranges.However, the antenna began resonating at an ineffective frequency, necessitating further modification.

This process was repeated with the addition of a third ring, and the final antenna design was determined based on the optimal performance achieved through this stepwise approach. This final antenna had all three frequencies in the desired range of WiMAX and WLAN with the best return loss.

Fig.3. shows the step wise approach for the designing of the antenna.

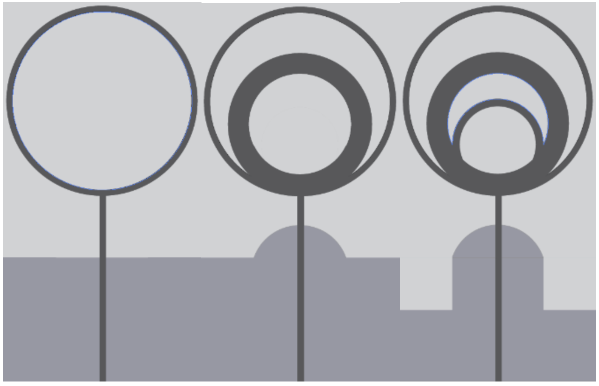


Fig.3. Stagewise patch design

(a)Stage1 (b)Stage2 (c)Stage3

The stepwise approach allowed the determination of the optimal size and spacing between the rings to achieve the desired antenna performance, such as radiation pattern, gain, and return loss.Fig.4. gives the return loss plots as per the patch design modifications.

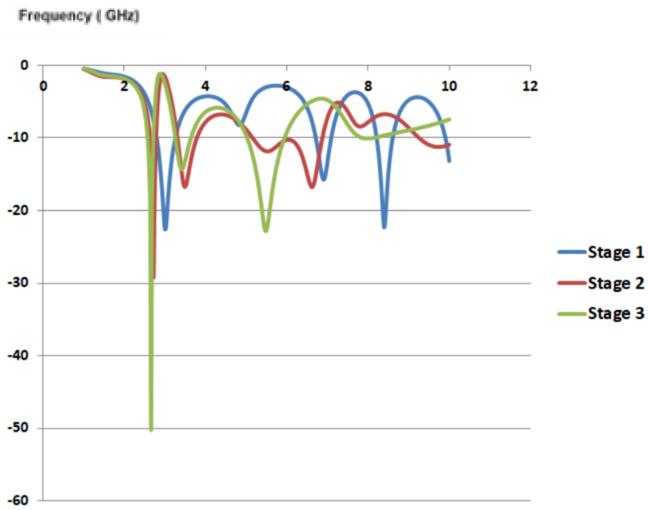


Fig.4. Stagewise Return Loss plots

After removing two rectangular slots and constructing the dome-shaped structure, it was discovered that the antenna's gain for the defective ground had been much boosted. Using a graphical depiction, Fig. 5 illustrates the variation in the antenna's return losses before and after adding DGS.

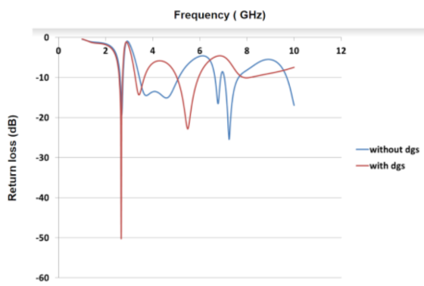


Fig. 5. Comparison of return loss plots with and without DGS

3. Results

A. Return Loss

The return loss for the suggested triple band antenna based on DGS is displayed in Fig. 6. This observation indicates that the suggested antenna satisfies the bandwidth requirements of WLAN/WiMAX applications, resonating at 2.66GHz, 3.42GHz, and 5.48GHz, respectively. At each frequency, the obtained return loss is -50.24dB, -14.31dB, and -22.83dB, respectively.

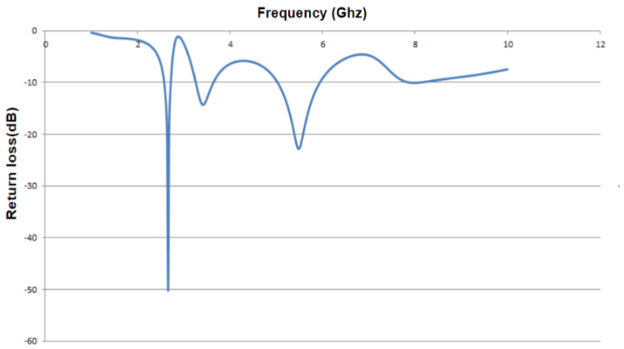
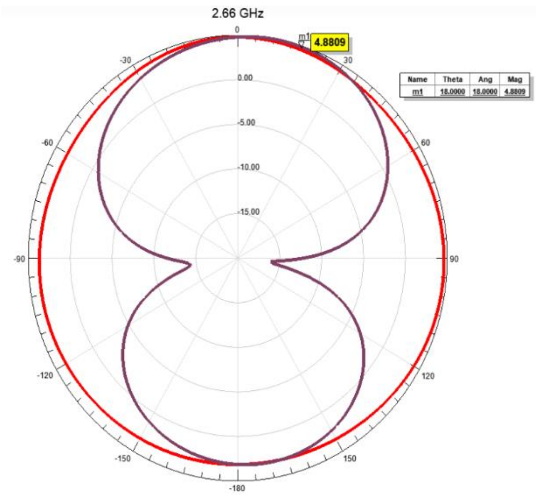
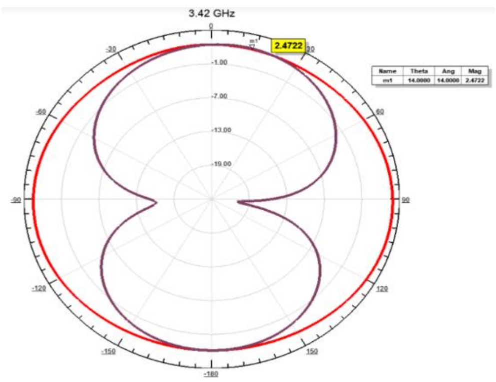


Fig.6. Return Loss Plot

B. Gain Plot

Fig.7. shows the gain plot of the designed antenna. From the measured results, the obtained gains at 2.66GHz, 3.42GHz and 5.48GHz is 4.8809dBi, 2.4722dBiand 3.8454dBirespectively.





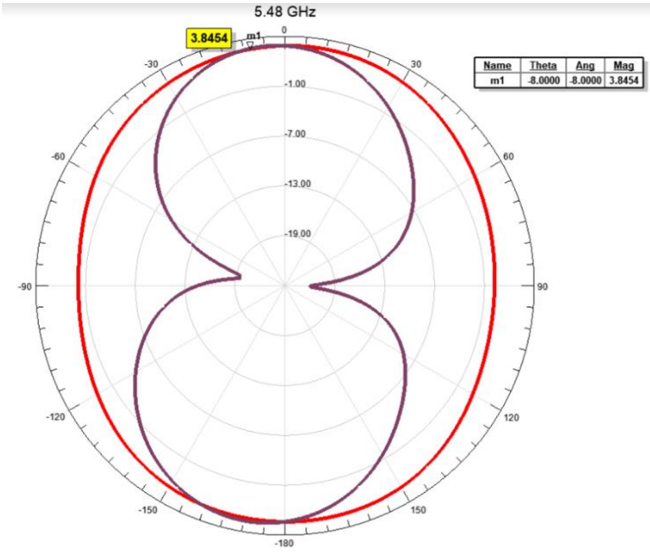
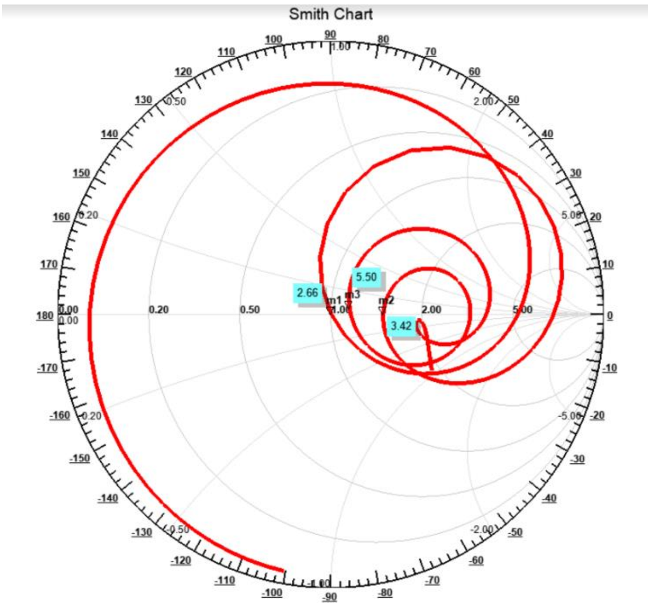


Fig.7. Gain Plots at resonant frequencies

C. Smith Chart



Name	Freq	Ang	Mag	RX
m1	2.6600	69.5717	0.0031	1.0021 + 0.0058i
m2	3.4200	0.1481	0.1923	1.4762 + 0.0015i
m3	5.5000	18.4889	0.0731	1.1476 + 0.0535i

Fig.8.Smith Chart

The Smith chart provides the most accurate analysis of the antenna's impedance fluctuation with respect to frequency. It offers a graphical depiction of the antenna's impedance at the given frequency. At the resonant frequencies, the obtained impedance values for the proposed antenna are 50.105 ohms, 73.81 ohms, and 57.38 ohms, respectively. In Fig. 8, the Smith chart is displayed.

D. Bandwidth

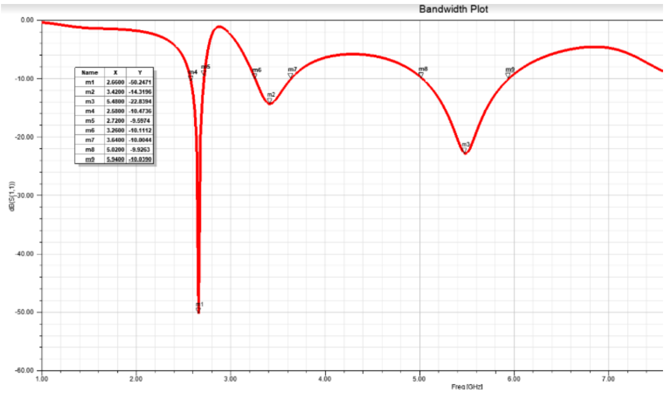


Fig.9 Impedance Bandwith Plot

As shown in Fig.9. the Impedance bandwith/Return loss bandwidth obtained for the resonant frequencies are 0.14GHz, 0.38GHz and 0.92GHz respectively. The gain bandwidth peoduct is always constant and it can also be verified in the above plot i.e. the gain at 2.66GHz is maximum and obatined bandwidth at this frequency is minimum.

4. Conclusion

This paper presents a triple-band MPA based on DGS that is appropriate for WLAN/WiMAX applications. The antenna's gain, return loss, and radiation properties were all improved by the employment of three rings and a defective ground structure.

The suggested antenna can radiate frequencies in the triple band, which is compliant with WiMAX and WLAN requirements at 2.66GHz, 3.42GHz, 5.48GHz. At these frequencies, the simulated return loss and Gain values are -50.24dB and 4.8809dBiat 2.66 GHz, -14.31dB and 2.4722dBi at 3.42 GHz, and -22.83dB and 3.8454dBiat 5.48 GHz respectively. Furthermore, the antenna's dimensions are also small making it suitable for WLAN/WiMAX applications.

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