A Dual Band AMC Backed Antenna for WLAN, WiMAX and 5G Wireless Applications

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Abstract **─** This paper presents a multiband low profile antenna aimed for its application in existing WLAN, WiMAX and sub-6 GHz fifth generation (5G) frequency bands. The design incorporates a simple planar monopole antenna with slots etched on it to be able to operate in two frequency bands with (S11< -10 dB) ranging from 2.38 - 2.7 GHz and 3.28 - 5.8 GHz with percentage impedance bandwidths of 16 and 56. The peak gains of the antenna within the bands were observed to be 2.1 and 4.3 dBi respectively. In order to further enhance the Gain and improve the radiation characteristics of the antenna, a dual band artificial magnetic conductor (AMC) surface is designed and employed as a reflector at the ground side of the main radiator. The antenna and AMC 4x4 array prototypes are fabricated and its performance is measured. It is observed that there is an enhancement in the gain of 5 dB in the first band and 2.8 dB in the second band of operation.

Index Terms **─** AMC, WiMAX, WLAN.

I. INTRODUCTION

With ever-growing wireless communication systems there is a need for the subsequent increase in the growth of the antenna technology that is being employed in these systems. The requirement for a simple design yet well performing antenna is the need of the hour. 5G wireless communications are being initiated all around the world and the necessity emerges for the design of an antenna covering these 5G bands and the already existing wireless frequency bands. 5G spectrum being divided into three bands low frequency band (below 1GHz), mid frequency band (sub-6 GHz) and high frequency band (mm Wave) with the mid-band offering good data rates with decent coverage.

Multiband antennas are most desirable because they are flexible, and their role becomes even more important in this switching phase as they should be able to operate at both the existing WLAN and WiMAX bands as well as the upcoming technology. The frequency band between 3-5 GHz being promoted for the sub-6 GHz mid-band communications, the N77/N78/N79 bands are being operated in this range and a wider bandwidth covering the entire range is of the interest. Microstrip antennas has become a popular choice amongst the different available antennas because they are low profile, inexpensive and easy to integrate within the IC's. Several multi-band antennas are reported in the literature with slots on the radiating surface, especially the microstrip antenna with a U-shaped slot has proved to be a good wideband solution [1].

Several 5G antennas have come through in the recent times covering the sub-6GHz band. A planar antenna [2] with strips on either side of the substrate is proposed, but the gain is not stable over the entire frequency range. A multi-slotted antenna [3] with a partial ground plane was introduced for 3.15-5.55 GHz frequency with a maximum gain of 2.69 dBi in the band. The wideband folded wall antenna with an increased gain [4] was proposed with a bandwidth of 58%. An AMC based multi band antenna [5-6] with unidirectional radiation patterns and increased gain has been discussed. A dual band AMC reflector-based antenna [7] was designed (for 5G communications with relatively narrow (19.2% and 13.8%) bandwidths. Several other antennas aimed at sub-6 GHz, 5G applications were presented [8-9].

In this paper, a dual band U-slot monopole antenna has been designed to operate at 2.38 – 2.7 GHz and 3.28 – 5.8 GHz bands covering the already existing 2.4 and 5 GHz WLAN, 2.5, 3.5 and 5.5 GHz WiMAX and the sub-6 GHz, 5G bands which include N77 band with frequency ranging from 3.3-4.2 GHz, N78 band ranging from 3.3-3.8 GHz and N79 band ranging from 4.4-5 GHz. Moreover, an AMC unit cell is designed with zero reflection phase at two frequencies, 2.5 and 5.5 GHz and is periodically repeated to form a metasurface and is used as a reflector on the ground side of the radiating antenna to enhance its gain and radiation characteristic performance. The antenna can be used alone or including the AMC reflector for unidirectional radiation and enhanced gain.

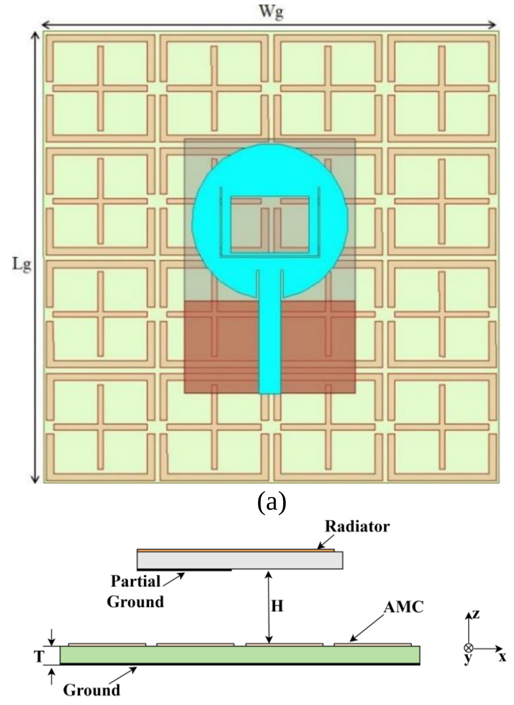
Submitted On: May 28, 2021
Accepted On: September 2, 2021

https://doi.org/10.47037/2021.ACES.J.360913

II. ANTENNA DESIGN

A. Configuration of the proposed antenna

Figure 1 shows the configuration of the proposed dual band antenna with AMC reflector. The radiator is a microstrip circular patch antenna with a U-shaped slot and a rectangular slot incorporated on it, a symmetrical AMC reflector surface of the size 64 x 64 x 1.6 mm^3 is employed at a distance of H = 14mm on the ground side of the antenna. A Styrofoam layer with a permittivity value of 1.1, is used to separate the two structures.



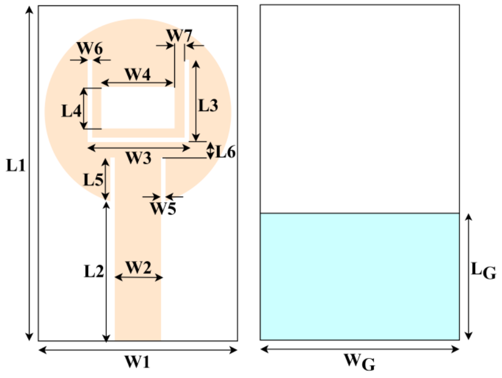
(a)

(b)

Fig. 1. Configuration of the proposed dual band AMC backed antenna: (a) top view and (b) side view.

B. Radiator design

The geometry of the main radiator is shown in the Fig. 2. It is printed on a 1.6 mm thick rectangular FR-4 substrate having a relative permittivity of 4.4 and a loss tangent value of 0.02. The size of the antenna is of the order of $0.3\lambda_0$ x $0.2\lambda_0$ x $0.01\lambda_0$ (where λ_0 is wavelength corresponding to the centre frequency of the first band). It is a microstrip fed antenna with inset feed for better impedance matching. A partial ground plane is being employed on the other side of the substrate in order to achieve a wider bandwidth. A U-shaped slot is introduced at an optimized position on the patch to enhance the bandwidth and lower the cross-polarization levels. Further an additional rectangular slot is also introduced to achieve proper impedance matching levels in the second band of operation. The dimensions of the designed antenna are stated in the Table 1. The simulations were carried out on the Ansys HFSS tool.



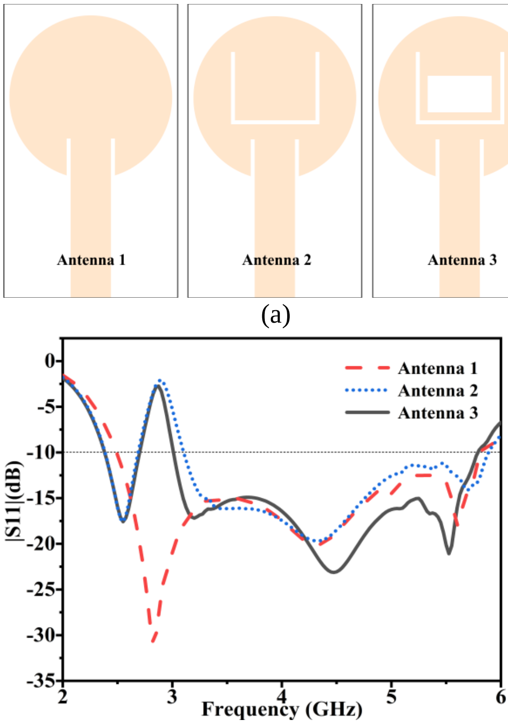
(a) (b)

Fig. 2. Design of the radiator: (a) top view and (b) bottom view.

Table 1: Optimized dimensions of the proposed antenna

Parameters	Value (mm)	Parameters	Value (mm)
H	14	*T*	1.6
Lg	64	*Wg*	64
L1	36	*W1*	24
L2	13.55	*W2*	3.059
L3	10	*W3*	14
L4	8	*W4*	11
L5	3.9	*W5*	0.3
L6	1.8	*W6*	0.2
L_G	13	*W7*	1.3
La1	16	W_G	24
La2	15.2	*Wa1*	16
La3	2	*Wa2*	15.2
La4	0.6	*Wa3*	0.8
La5	0.8	*Wa4*	0.8

The evolutionary steps involved in the design of the radiating patch are shown in the Fig. 3 (a). The S11 response of all the antennas is shown in the Fig. 3 (b). A conventional circular patch antenna is initially designed for, which a wide band resonance is achieved from 2.9 GHz to 5.9 GHz. Then a U-shaped slot is etched on the patch, which introduces a notch at the frequency band between 2.73-3.23 GHz. Hence, the antenna now works as a dual band antenna with operating frequencies ranging from 2.49–2.73 GHz and 3.23–5.73 GHz. Further with the introduction of an additional rectangular slot the impedance matching and the bandwidth of the antenna are enhanced. Finally the design of the antenna is simple making use of a low cost FR-4 substrate, operating in two bands with good impedance bandwidths covering the entire sub-6 GHz 5G frequency bands besides the existing 2.4/5 GHz WLAN, 2.5/3.5/5.5 GHz WiMAX bands.



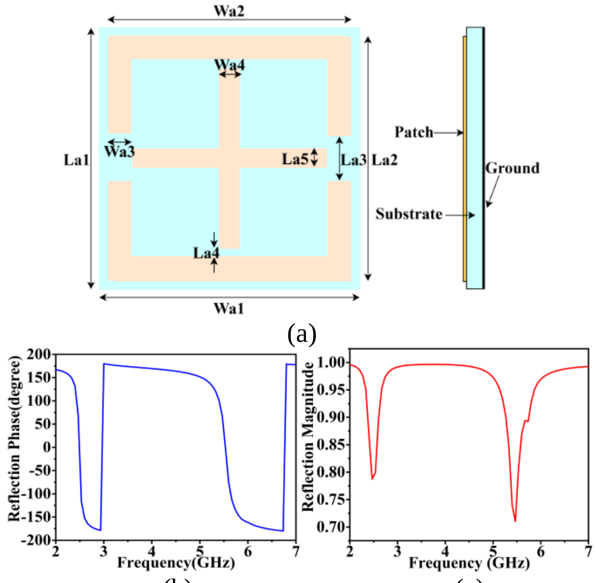
(a)

(b)

Fig. 3. (a) Evolutionary steps in the design of the radiator, and (b) reflection coefficients of radiating elements.

C. AMC design

The design geometry of the artificial magnetic conductor unit cell incorporates a square outline with slots at the centre on the opposite sides and an additional cross shaped patch at the centre as shown in the Fig. 4 (a). A low cost FR-4 substrate is employed with relative permittivity of 4.4 and a loss tangent value of 0.02. A metal ground is present at the bottom surface of the unit cell. The unit cell is simulated using the master-slave boundary set up. The reflection phase plot of this dual band AMC is as shown in the Fig. 4 (b). Initially a single band AMC with the reflection phase and of zero at 2.5 GHz is designed with no central cross shaped patch and with the introduction of the cross, a dual band AMC is realized with the other zero reflection phase occurring at 5.5 GHz. The reflection magnitude plot is shown in the Fig. 4 (c) and the values about 0.78 and 0.71 and is high enough to realize the gain enhancement of the antenna. The dimensions of the AMC unit cell are evaluated in accordance with the operating frequency range of the antenna and are listed in the Table 2.



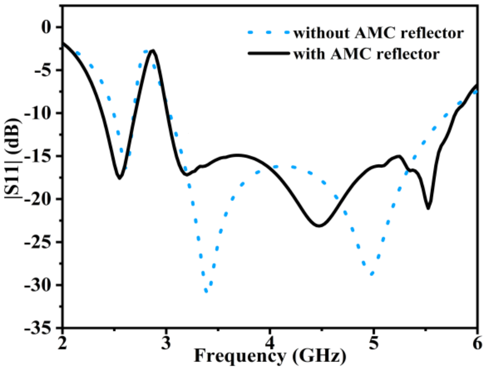
(a)

(b) (c)

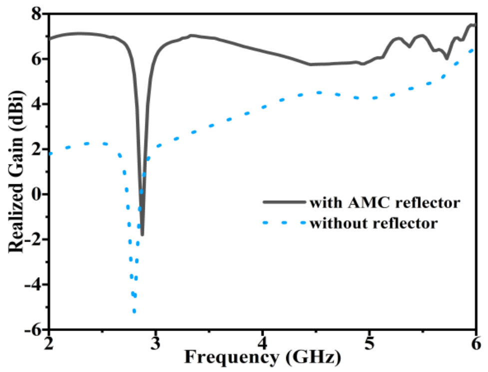
Fig. 4. (a) Geometry of the proposed dual band AMC unit cell, (b) reflection phase of the AMC unit cell, and (c) reflection magnitude of the AMC unit cell.

D. Antenna loaded with AMC reflector

The designed dual band AMC unit cell is periodically repeated in x and y directions to form a 4 x 4 array metal surface and is placed at the groundside of the antenna separated by Styrofoam. The effect of the AMC surface on the S11 curve is depicted in the Fig. 5 (a). The performance of the antenna is influenced by the extent of separation between the antenna and the AMC surface. The radiations from the radiating antenna get reflected from the AMC surface with zero phase reversal to aid the radiations unidirectionally and hence increasing the gain of the antenna. A significant increase in the gain is observed in the first band and a reasonable increase in the second band of operation as shown in the Fig. 5 (b).



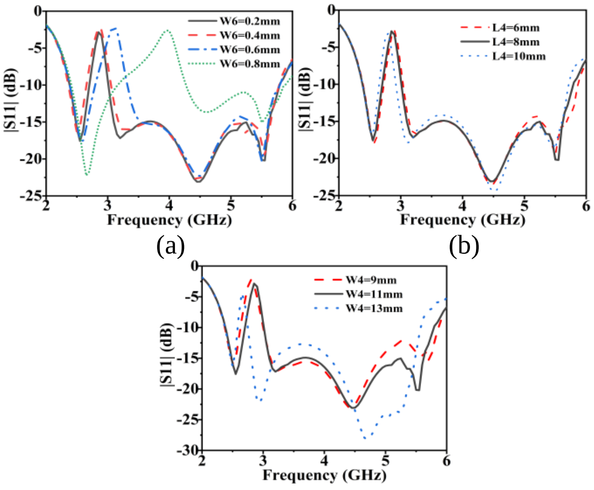
(a)



(b)

Fig. 5. (a) Simulated S11 of the antenna with and without AMC reflector, and (b) simulated gains with and without AMC reflector

The performance of the antenna in terms of the band selection and bandwidth depends on the dimensions of the slots. A parametric analysis based on the variation of these dimensions is as shown in the Fig. 6. The optimal values of these dimensions for which the choice of frequency bands is covered, is considered in the design.



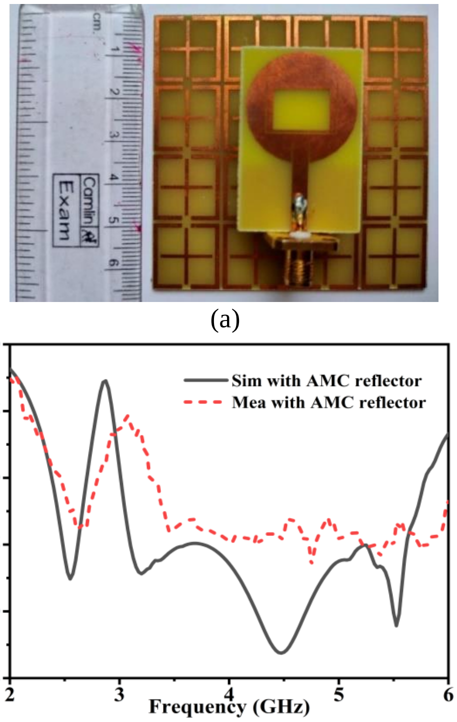
(a) (b)

(c)

Fig. 6. Simulated S11 of the antenna for different (a) W6, (b) L4, and (c) W4.

III. RESULTS AND DISCUSSION

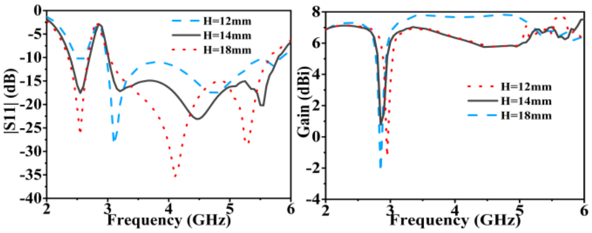
The simulated design of the dual band operating antenna and the AMC surface are fabricated and is as shown in the Fig. 7 (a) and is of the size $0.53\lambda_0$ x $0.53\lambda_0$ x $0.14\lambda_0$. The measured and simulated S11 of the antenna and the AMC surface are shown in the Fig. 7 (b). The slight variation in the measured results from the simulated is due to the losses incurred during the fabrication process. A quarter wavelength separation should be maintained between the antenna and the AMC reflector in order to have a significant effect on the performance of the antenna, but, the low profile nature of the design will get affected. So, a trade-off between the performance and size of the antenna needs to be considered. It can be observed from the Fig. 8, that as the separation decreases, though the gain of the antenna increases, there is deterioration in the S11 performance of the antenna. So, an optimal separation (H=14mm) is chosen in order to preserve both the performances. The antenna is suited for 2.4/5 GHz WLAN applications, 2.5/3.5/5.5 GHz WiMAX applications and with the second band being wideband is able to cover the entire sub-6 GHz, 5G bands (3.3-3.8 GHz, 3.3-4.2 GHz and 4.4–5 GHz).



(a)

(b)

Fig. 7. (a) Fabricated prototype and the, and (b) simulated and measured S11, of the antenna with AMC.

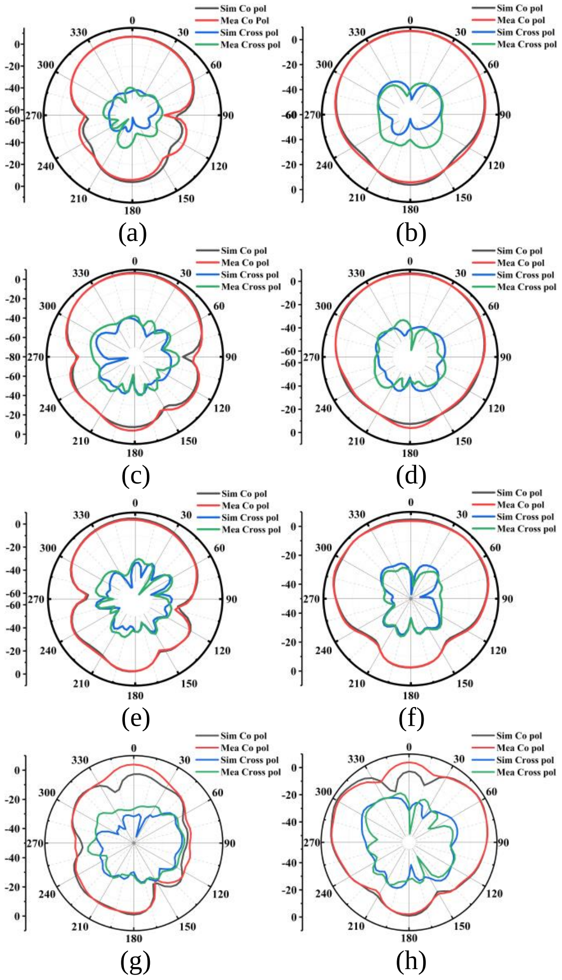


(a) (b)

Fig. 8. Simulated (a) S11 and (b) gain, for different H.

Table 2: Comparison of the dual band proposed antenna to the existing

References	Size	With AMC Reflector	Operating Range (GHz)	Gain (dBi)	Radiation Efficiency
[2]	135 x 80 x 0.8	No	0.7 – 0.9 1.6 – 5.5	-1.3 – 4.7	(41 – 88)%
[3]	20 x 30 x 1.5	No	3.15 – 5.55	1.8 – 2.7	(68.4 – 79.6)%
[4]	63 x 51.2 x 4.5	No	2.84 – 5.15	4.4 – 6.2	64%
[5]	104 x 104 x 11	Yes	2.36 – 2.76 5.12 – 5.62	7.2 7.3	65%
[7]	63 x 63 x 7	Yes	3.14 – 3.83 4.40 – 5.02	8.2	90%
[8]	105 x 105 x 25	Yes	2.5 – 2.7 3.3 – 3.6	8.4	N/A
Proposed	36 x 24 x 1.6	No	2.48 – 2.73 3.15 – 5.8	2.1 4.3	>90% >80%
Proposed (with AMC)	64 x 64 x 17.2	Yes	2.38 – 2.7 3.28 – 5.8	7.1 7.1	>90% >80%



(a) (b)

(c) (d)

(e) (f)

(g) (h)

Fig. 9. Simulated and measured radiation patterns of the antenna in the plane: (a) XZ at 2.55 GHz, (b) YZ at 2.55 GHz, (c) XZ at 3.6 GHZ, (d) YZ at 3.6 GHz, (e) XZ at 4.7 GHz, (f) YZ at 4.7 GHz, (g) XZ at 5.5 GHz, and (h) YZ at 5.5 GHz.

The measured and simulated radiation patterns of the antenna loaded with the AMC reflector at frequencies 2.55 GHz, 3.6 GHz, 4.7 GHz and 5.5GHz are shown in the Fig. 9. The measured and simulated patterns were observed to be agreeing well with each other. The inconsistency in the cross polarization plots is due to losses that were incurred during the fabrication and measurement process. The antenna exhibits unidirectional patterns because of the reflections from the AMC surface. The radiation patterns at 5.5 GHz diverge because the antenna is operating in its second mode.The gains of the antenna along with the simulated radiation efficiency are shown in the Fig. 10.

It can be ascertained from the Fig. 10, that the radiation efficiency is above 90% for the entire first band and the sub-6 GHz 5G operating bands. The measured and simulated gains are about 6.7 dBi and 7.1 dBi in the first band and almost agree with each other for the entire range in the second band.

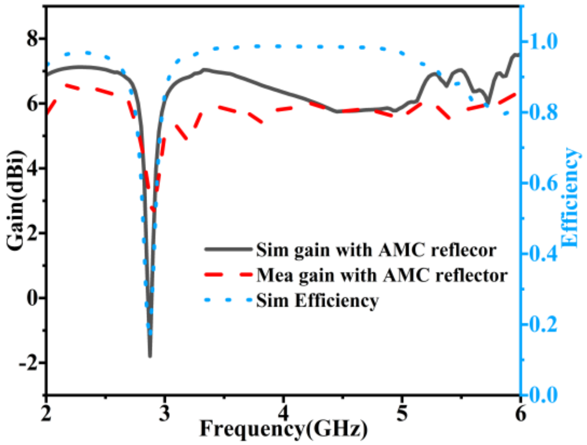


Fig. 10. Simulated and measured gain, simulated efficiency of the proposed antenna.

IV. CONCLUSION

This paper presents a low profile dual band antenna configuration designed for 2.4/5 GHz WLAN, 2.5/3.5/5.5 GHz WiMAX and sub-6 GHz 5G bands. The antenna is fabricated and the measured results are in agreement with the simulated. The size of the antenna without AMC reflector is of the order of $0.3\lambda_0$ x $0.2\lambda_0$ x $0.01\lambda_0$ and with AMC, it is of the order $0.53\lambda_0$ x $0.53\lambda_0$ x $0.14\lambda_0$ (where λ_0 is the free space wavelength corresponding to the centre frequency of the first band) with impedance bandwidths of 9.8% (2.48–2.73 GHz) and 56% (3.28 – 5.8 GHz). The gains of the antenna within the bands was observed to be 2.1 and 4.2 dBi respectively. In order to enhance the gain and radiation of the antenna a dual band AMC reflector which was designed at 2.5 GHz and 5.5 GHz was employed. A significant improvement in the gain of 5 dBi in the first band and 2.8 dBi in the second band was observed. Therefore, the antenna can be used alone for WLAN, WiMAX and 5G applications or with the AMC reflector for high gain base station applications.

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