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A Novel Integrated Bluetooth Dual Band UWB Antenna for Wireless Communication

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Abstract- **A novel, compact printed dual band monopole antenna for Bluetooth and ultrawideband (UWB) applications is proposed and investigated. Antenna consists of half octagonal ring shape radiating patch with modified ground plane to exhibit UWB characteristics. It is demonstrated that by embedding a rectangular strip, resonating at 2.45 GHz below the centre of radiating patch through via-hole dual band operation can be obtained. Comparison of novel antenna with traditional dual band antenna shows increase in gain, efficiency and 20 % size reduction of Bluetooth element while maintaining the dual band characteristic. The proposed antenna is designed, simulated fabricated and tested. Antenna is fabricated on FR4 substrate having dimensions of 38 (L_{sub}) x30 (W_{sub}) x1.6 (H) mm^3 and fed by a 50Ω microstrip line. Measured VSWR is ≤ 2 over 2.4-2.5 and 3.1-14 GHz. The structure shows good frequency and time domain characteristics over a desired band. Simulated and measured results of the proposed antenna are in good agreement.**

Index Terms- **Bluetooth, Monopole antenna, Time domain characteristics, UWB, Via-hole.**

I. INTRODUCTION

Due to the aesthetical properties such as light weight, small size, low profile, low cost and higher data rate planar and printed monopole antennas are most widely used in UWB wireless communication system. In February 2002, Federal Communication Commission (FCC) declared the usage of unlicensed frequency band from 3.1 to 10.6 GHz for the UWB communication [1] and since then the researchers from academia and industries focused on the UWB antenna design and the UWB systems. UWB antenna is an important part of UWB system and should have small size, light weight, omnidirectional radiation pattern and all other characteristics required for UWB communication [2].The release of an extremely wide spectrum of 3.1-10.6GHz for commercial applications has generated a lot of interest in research and development of UWB technology for short range wireless communications, imaging radar, remote sensing and localization applications [3]. Number of designs and analysis approach of antenna such as genetic algorithm [4], rectangular slot [5], rounded diamond [6], trident shape feed [7], Quasi-self-complimentary [8], antipodal Vivaldi [9], tapered connection between feed line and patch [10] and many more have been reported to obtained UWB frequency band. However Bluetooth covering frequency band from 2.4-2.484GHz is licenced free frequency band assigned by IEEE 802.11/g standard in Industrial Scientific and Medical (ISM) band and can be integrated with the UWB to have advantage of both unlicensed frequency band in a single antenna for hand held wireless devices. Dual band antenna operating in Bluetooth and UWB proposed by [11 -14].In [11] fork shaped antenna is designed to operate in Bluetooth and UWB frequency band. Effect of the metallic plane on the performance of dual band antenna is proposed in [12]. In [14] Bluetooth frequency band is realized by inserting two U-shaped parasitic strips bilaterally besides the feed line.

In this paper, we propose a simple octagonal ring dual band antenna for Bluetooth and UWB applications. First we have designed an octagonal monopole antenna. Bevel angle and rectangular slot in the modified ground plane of antenna have

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been optimized to operate over a UWB frequency band and can be used as basic structure for integrated Bluetooth UWB antenna. This basic UWB antenna is referred to as an Antenna1. Surface current distribution on the radiating patch shows current concentrates mainly on the edges of patch with negligible current in the inner region. Hence rectangular slot of length 'L_n' and width 'W_n' is removed from the radiating patch of Antenna1, without affecting its UWB behaviour this antenna is referred to as Antenna2. Traditional dual band antenna operating over Bluetooth and UWB frequency band having a quarter wavelength rectangular Bluetooth element resonating at 'f_r' =2.45GHz embedded at the central position of half octagonal ring radiating patch, is referred to as Antenna3. Finally a novel antenna containing rectangular strip resonating at 2.45 GHz placed below the radiating patch and connected to centre of patch through via-hole, creates a dual band operation, is designed referred to as Antenna4. Due to embedding a quarter wavelength rectangular strip below the centre of patch through via- hole not only improves the gain and efficiency of Antenna4 but also reduces the overall size of Bluetooth element placed in the ground plane. Hence creating more space available between the octagonal ring radiating patch to integrate additional element operating at GPS, GSM band and MMICs.

II. ANTENNA DESIGN

A. Evolution of proposed antenna

Evolution of proposed antenna and its impedance bandwidth is shown in Fig.2. The antenna uses FR4 substrate with permittivity 'ε_r' = 4.4, height 'h'=1.6mm and loss tangent 'tan δ'=0.02. Overall dimensions of proposed antenna is 30 x 38 mm^2. Radiating patch is fed by a 50Ω microstrip line of length 'L_f' and width 'W_f'. W_{gnd} =30mm and L_{gnd} =13mm are the width and length of the conducting modified ground plane, placed at the other side of the substrate.

B. Design of UWB antenna (Antenna1 and Antenna2)

Proposed Antenna1 structure consists of octagonal radiating patch, microstrip feed line and modified ground plane. Dimensions and position of notch below feed line in ground plane (Fig.1) and bevel angle of ground plane has been optimized to obtained good impedance bandwidth over UWB frequency band. Minimum current is concentrated on the centre of octagonal radiating patch hence rectangular slot of dimensions L_n x W_n (12 x 8) is cut from the centre of patch, leading to octagonal ring UWB antenna (antenna2).

C. Design of Integrated Bluetooth UWB Antenna (Antenna3)

Now a days, due to limited available space, it is essential to have a support of single antenna for more than one communication standards [15]. Bluetooth frequency band operating from 2.400-2.484 GHz has a benefit of licensed free frequency band and can be integrated with UWB to overcome the above limitation.

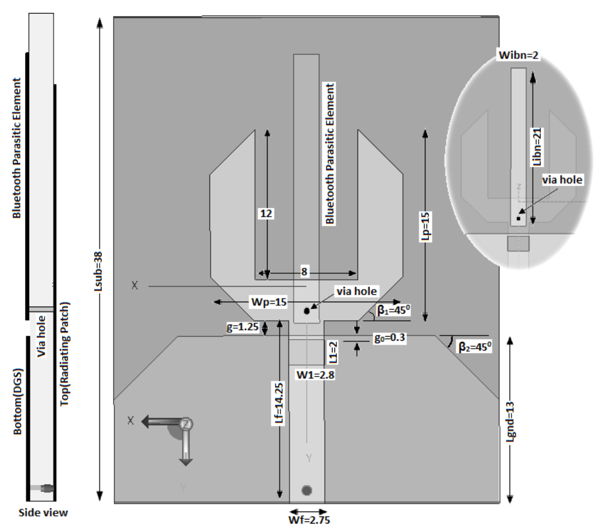


Fig. 1.Geometry of proposed antenna (all dimensions are in mm.)

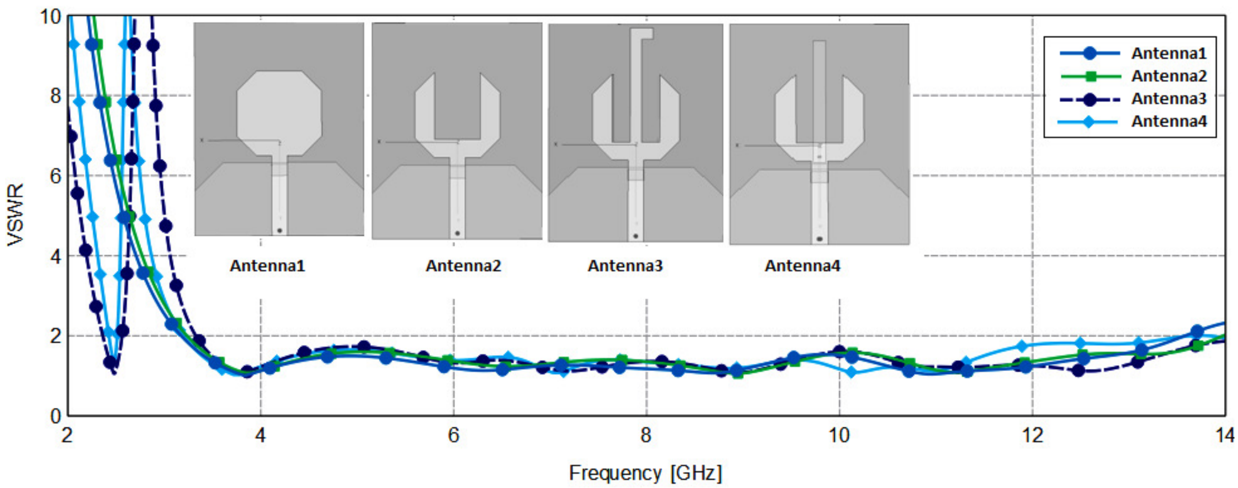


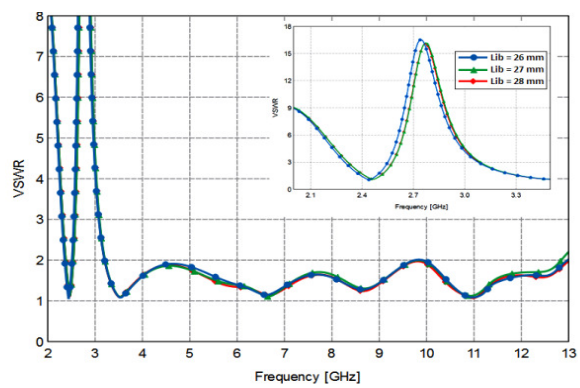
Fig.2 Simulated VSWR of the antenna at different stages during evolution of the integrated Bluetooth UWB

A quarter wavelength rectangular Bluetooth element resonating at 'f_{ib}' =2.45GHz is embedded at the central position of half octagonal ring radiating patch, at minimum current distribution position to ensure less coupling between radiating patch and Bluetooth element. 'L_{ib}' and 'W_{ib}' are the length and width of the rectangular Bluetooth element respectively. Following equation is used to calculate L_{ib}:

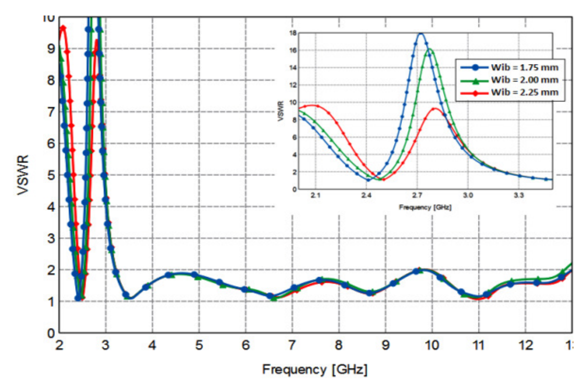
$$\mathbf{L_{ib}} = \frac{\mathbf{C}}{\mathbf{4f_{ib}\,\varepsilon_{reff}}} \ldots (\mathbf{1})$$

where, C = speed of light, f_{ib}= resonant frequency (2.45GHz), ε_{reff}= effective dielectric constant.

L_{ib} and W_{ib} of rectangular Bluetooth element is optimized to operate in Bluetooth frequency band (2.40-2.484GHz).W_{ib} =2mm and L_{ib} =27mm are the optimized dimensions of rectangular Bluetooth element. Fig.3 (a) and (b) depicts the VSWR variations for different values of L_{ib} and W_{ib}. Resonance frequency shifts to lower edge with increase in L_{ib} and bandwidth & resonance frequency of Bluetooth frequency band increases with increase in W_{ib}.



(a)



(b)

Fig. 3 Simulated VSWR of antenna3 for (a) different parasitic element length 'L_{ib}' (b) different parasitic element width 'W_{ib}'

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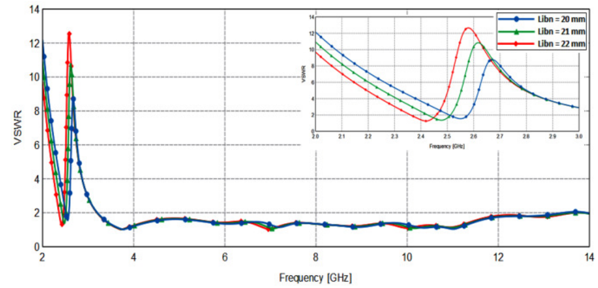
D. Design of Novel Integrated Bluetooth UWB Antenna (Antenna4)

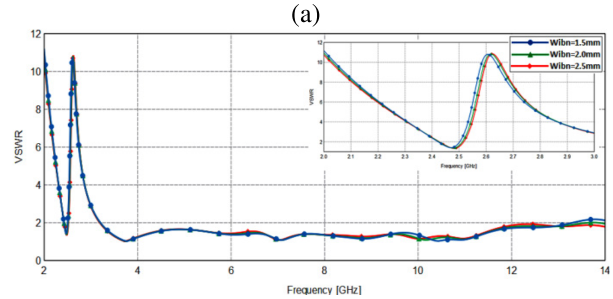
A novel Integrated Bluetooth UWB antenna structure includes a rectangular parasitic strip resonating at 2.45GHz below the radiating patch and excited through via-hole by connecting to the radiating patch.

Optimized dimension of rectangular Bluetooth element of antenna4 is 'W_{ibn}' =2mm and 'L_{ibn}' =21mm. Parametric study of antenna4 is conducted by changing the 'L_{ibn}' and 'W_{ibn}' as depicted in Fig. 4 (a) and (b) . Resonance frequency of the Bluetooth band shifts to the lower edge with increase in 'L_{ibn}' while bandwidth of the Bluetooth band increases with the increase in 'W_{ibn}'.

Surface current distribution of proposed antenna4 is depicted in Fig.5, gives insight into the understanding of dual band characteristics of antenna. At 2.45GHz, maximum current concentration is observed along rectangular Bluetooth element while half octagonal ring radiator appears to be non-radiating at this frequency. Other than Bluetooth frequency band maximum current concentration is observed on the edges of patch showing UWB behaviour of antenna.



(a)



(b)

Fig. 4 Simulated VSWR of antenna4 for (a) different Bluetooth element length 'L_{ibn}' (b) different Bluetooth element width 'W_{ibn}'

III. RESULTS AND DISCUSSIONS

Antenna3 and Antenna4 were successfully fabricated as shown in Fig. 6. The impedance bandwidth was measured using an Agilent Field-fox N9916A vector network analyzer as depicted in Fig.7. Good agreement between simulated and measured results are observed. The measured result shows that the proposed antenna integrates Bluetooth frequency band from 2.4-2.5GHz, while providing the wide impedance bandwidth from 3.1GHz to 14 GHz.

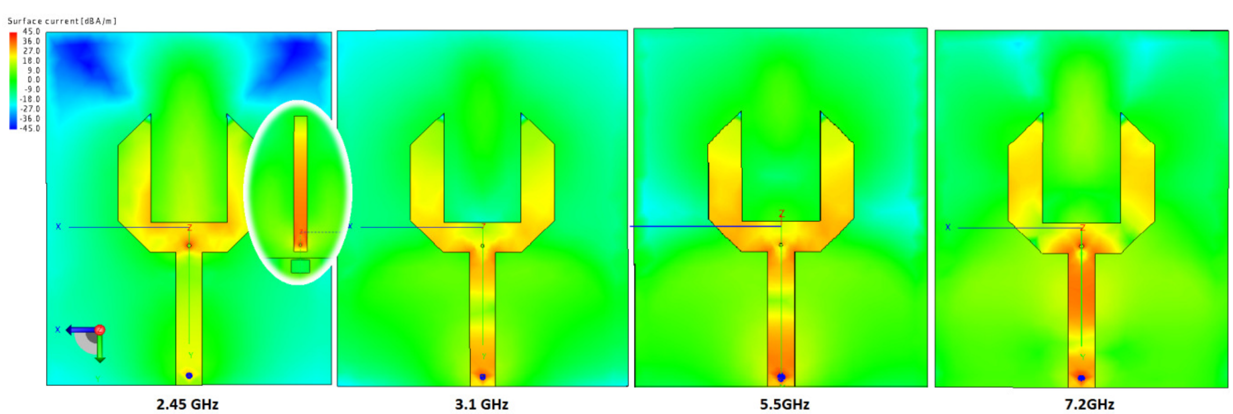


Fig.5 Surface current distribution of antenna4 at (a) 2.45GHz (b) 3.1GHz (c) 5.5GHz (d) 7.2GHz.

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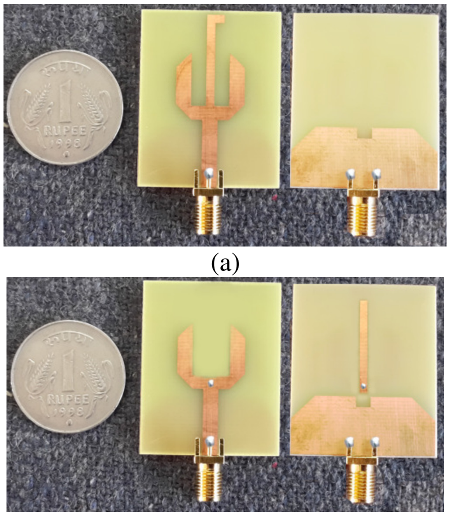

(a)

(b)

Fig.6 Prototype of fabricated (a) Traditional integrated Bluetooth UWB Antenna (antenna3) and (b) Novel integrated Bluetooth UWB Antenna (antenna4)

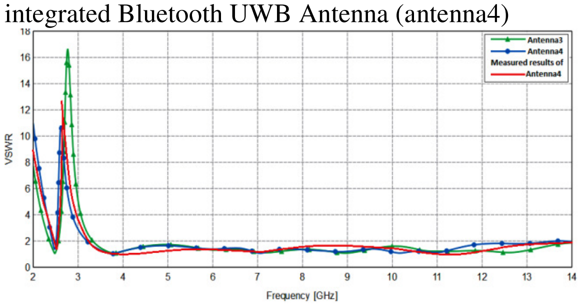

Fig.7 Simulated and Measured VSWR of antenna4

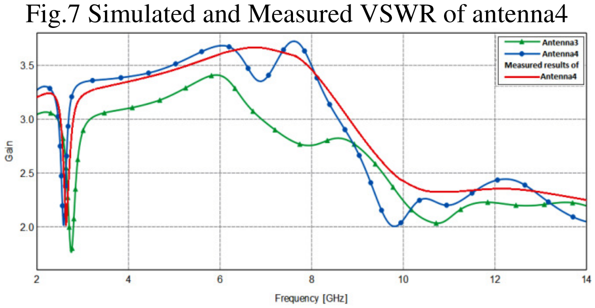

Fig.8 Simulated and Measured gain of antenna 4

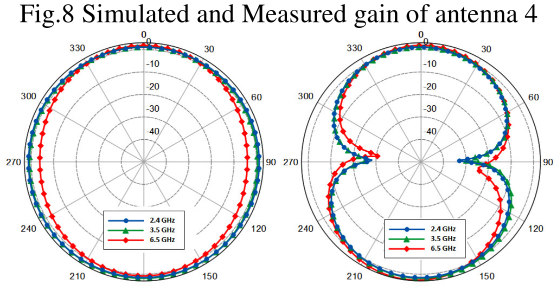

Fig. 9 Simulated radiation pattern of the proposed antenna4 for (a) H-plane and (b) E- plane at 2.4 GHz, 3.5 GHz and 6.5 GHz.

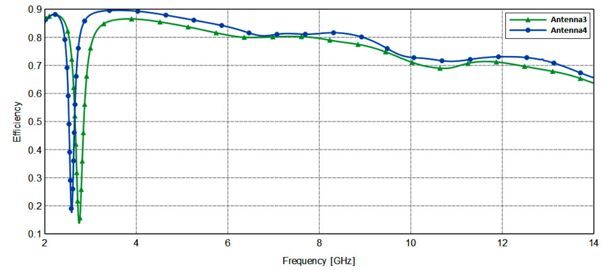

Fig.10 Efficiency of antenna3 and antenna4.

Radiation patterns of Antenna4 across H-plane and E-planes at 2.4 GHz, 3.5 GHz and 6.5 GHz are presented in Fig. 9(a) and (b).Directional pattern in E-plane and omnidirectional pattern in H-plane are observed over a Bluetooth and UWB frequency band.Average radiation efficiency across the UWB frequency band is about 75% and decreases at higher frequency edge due to the lossy substrate. Efficiency of Antenna4 is better than antenna3. Gain variation of Antenna4 is between 2-3.75db as depicted in Fig.8. Maximum gain is observed in antenna4 compared to Antenna3, this is due to minimum disturbances produced by Bluetooth element to octagonal radiating patch for antenna4 compared to Antenna3. In Antenna3 the Bluetooth element is in direct contact with octagonal radiating patch. Good time domain performance is an important requirement of UWB antenna [16, 17]. Group delay of proposed UWB antenna is shown in Fig. 12. Pulse spreading behaviour of proposed antenna is obtained using time domain analysis of CAD FEKO [18]. Excited Gaussian pulse and received signal of proposed antenna4 is shown in Fig. 11. A small ringing effect in the received pulse is observed. Group delay is a time domain characteristics, it gives the time delay of impulse signal at different frequencies. Constant group delay shows the linear variation of phase over a frequency. For measurement of group delay two identical antennas are placed face to face 30cm apart from each other. Small variation in group delay is observed over a UWB frequency range.

From the comparison in Table1, it is observed that the proposed antenna has a wide impedance bandwidth, high efficiency, decreased Bluetooth element size and moderate size of the overall antenna geometry.

Table 1: Comparison between reported integrated Bluetooth antenna and proposed antenna

Parameter	Ref.[14]	Ref.[13]	Ref.[11]	Proposed Antenna
UWB operating frequency	3.1-12GHz	3.1-10.6GHz	3.1-12GHz	3.1-14GHz
Bluetooth frequency band	2.475-2.520GHz	2.32-2.5GHz	2.3-2.5GHz	2.4-2.5GHz
Maximum efficiency	Not mentioned	82%	Not mentioned	90%
FR4 Thickness(mm)	0.8	1.6	1.6	1.6
Size(mm^2)	32x18	43x23	42x24	38x30
Total size of Bluetooth element	36.6mm	29mm	29mm	23mm
Placement of Bluetooth element	Bilaterally besides the feed line	In central portion of radiating patch	In central portion of radiating patch	Coupled to the radiating patch through via-hole

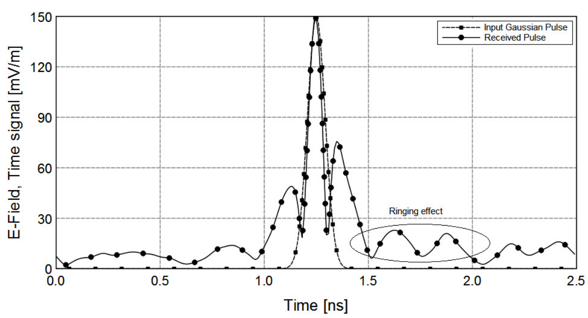

Fig.11 Time Domain Analysis

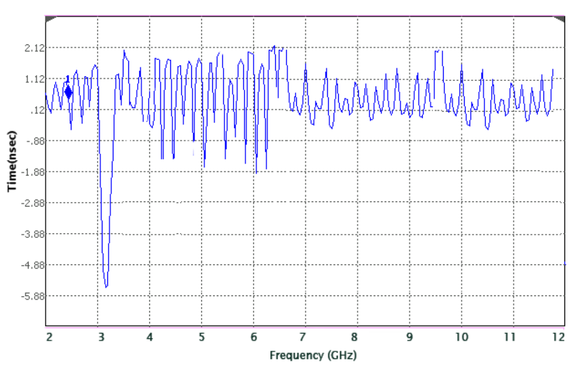

Fig. 12 Measured group delay of proposed Integrated Bluetooth UWB Antenna.

IV. CONCLUSIONS

A novel, compact dual band integrated Bluetooth UWB antenna has been proposed and investigated. Comparative study between the two dual band antennas has been conducted. A novel integrated Bluetooth UWB antenna (Antenna4) shows increased gain, efficiency and 20% decrease in the size of Bluetooth element as compared to the Bluetooth element of the traditional integrated Bluetooth UWB antenna (Antenna3). Parametric study of length and width variation of the Bluetooth element in both antennas shows the shift in resonance frequency to the lower edge with increase in its length while increase in the bandwidth of the Bluetooth band with increase in the width of Bluetooth element. The proposed antenna shows stable radiation pattern, gain & efficiency and nearly constant group delay across Bluetooth and UWB band. This shows, the proposed antenna is a good candidate for Bluetooth and UWB wireless communication.

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