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Multi-Band Patch Antenna for THz Applications

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ABSTRACT

With the advent of miniaturisation in electronic components, the terahertz applications are expanding rapidly. A miniature and high gain antenna has been proposed for terahertz applications and its effect on bending has been investigated. The model has been designed using copper and graphene as conducting media for its resonance in multi-band frequencies of 1.465 THz, 2.859 THz and 3.266 THz. Various parameters such as return loss, gain, directivity, bandwidth and efficiency has been compared for two different conducting media and the bending effect has been analysed for these parameters.

Keywords: Antenna, Flexible, Miniature, Patch, Terahertz

I. INTRODUCTION

Medical and wearable electronics has provided an opportunity to integrate and design various small, compact and flexible components including conducting patches. A key feature of the electronics communication is over terahertz (THz) range due to the overcrowding of the bandwidth in GHz range and untapped spectrum of electromagnetic waves in THz range [1 – 4]. At the same time due to miniaturization of electronics devices and rapid prototyping within a PCB environment, the antenna needs to be compact and small with high gain. Hence a patch antenna in the size of micrometer (µm) for its good directivity, gain and radiation efficiency has been designed [5 – 8] and these parameters have been compared to its bend shape. The paper talks about these patch antennas working at multiband frequency with 1.465 THz, 2.859 THz and 3.266 THz for its application using copper and graphene as conducting media with Fr4 as substrate and PEC as ground. Various past papers have presented the bending effect due to its upcoming applications such as antenna printed on a textile and wearable electronics [8]. The paper has been set into various sections such as design methodology, modeling and simulation results, comparison of parameters, conclusion and acknowledgement.

II. DESIGN METHODOLOGY

A patch antenna can be defined by a conducting patch with substrate over a ground plane. Although the patch can form various shapes but an efficient radiating element can be defined with its proper size and characteristic of the conducting patch, substrate and ground plane. The dimension and characteristic of the material can also provide the flexibility of antenna for its wearable and medical electronics application. The material of the radiating patch presented in this paper is very thin sized copper/graphene while a thin Fr4 has been selected as a substrate and a thin PEC material has been selected for its ground plane.

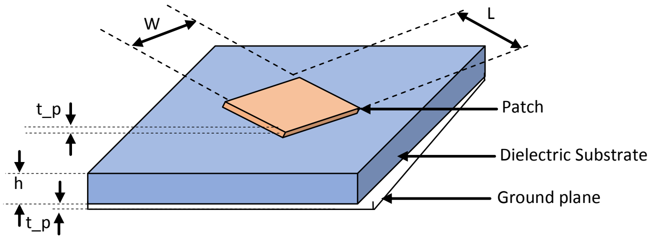

Fig. 1 Patch planar antenna

So far little research has been done on miniature flexible antenna for copper and graphene with planar and bend surface. The present work provides a comparison of these structures. Performance of a patch antenna can be defined by its reflection co-efficient, directivity, gain and efficiency and these parameters can be calculated using various factors such as conductivity and dimension of the patch, substrate media, matching impedance and feeding mechanism. The patch can be defined using its length 'L', width 'W' and thickness 'tp'. The thickness 'tp' is considerably small in comparison of the wavelength of the propagation, λ_0 and has been defined using a very thin layer of copper, 10 nm thickness. Equations (1) - (7) [9] can be used to calculate various design parameters of its patch. The effective dielectric constant of effective permittivity is dependent on surrounding media (it can be homogenous or inhomogeneous) and its effective dielectric constant. Assuming 'W' being the width of the metal plate and 'h' being the height of dielectric slab, a wide microstrip trace (electric field can be considered to be located at the center of the strip) ε_{eff} can defined by (1) for the condition W >> h. Similarly W, L_{eff}, ΔL and L can be obtained using (2), (3), (4) and (5) [9].

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1+\frac{12h}{W}}} \quad \text{for } \frac{W}{h} \geq 1 \qquad (1)$$

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

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \qquad (3)$$

$$\Delta L = 0.412 * h * \frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (4)$$

$$L = L_{eff} - 2\Delta L \qquad (5)$$

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

$$W_g = 6h + W \qquad (7)$$

Using above equations, we can obtain geometric shape of the radiating plate L, W, ε_{reff}, L_{eff}, ΔL and size of its substrate and ground plane (L_g and W_g). For its application at various resonating frequencies in THz, the dimension of the patch configuration has been obtained as 50 µm arm length and width with a copper/graphene thickness of 0.01 µm over a thin layer (3 µm) of Fr4 substrate with the dimension of 100 µm x 127.6 µm and permittivity of 4. The ground layer is made of PEC and is the same size as of substrate with its thickness of 0.01 µm while the feed of the patch antenna has been designed for 50 ohm characteristic impedance with patch width of 6.2 µm, length of 23.8 µm and thickness of 0.01 µm. The impedance matching circuit also known as transformer circuit has the dimension of 0.8 µm width and 15 µm length, while its thickness is 0.01 µm and has

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been defined to match the antenna impedance to a characteristic impedance of 50 Ω. These patch configurations has also been bent with a radius obtained from its substrate/ground width size as its perimeter that is a radius of (50/π) μm to create corresponding bend structures. The feed of the antenna has been designed for 50 Ω impedance considering the matching impedance across the PCB however the impedance of the patch antenna does not match to 50 Ω and this requires an impedance matching circuit between the feed and patch element. One mechanism is with the use of quarter wave transformer circuit. The matching circuit is formed by a transmission line with its characteristic impedance Z_1 and the length, a quarter of the impinging wavelength.

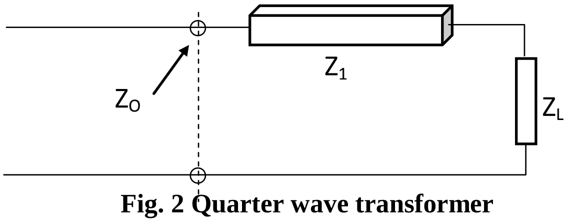

Fig. 2 Quarter wave transformer

Fig. 2 shows the Load impedance Z_L, transformer impedance Z_1 and transmission line characteristic impedance Z_o, the transformer impedance can be obtained using (8) [10].

$$Z_1 = \sqrt{Z_O Z_L} \tag{8}$$

A. Copper and Graphene media

Copper with its conductivity 5.8e7 S/m and graphene with its average surface conductivity 1e5 S/m has been used in the antenna design [9]. The thin layer of the surface with 10 nm thickness makes the design an excellent choice for its analysis of bending behaviour.

III. MODELLING AND SIMULATION RESULTS

The parametric effect of the antenna has been investigated using the CST software. While section 'A' talks about the planar shape antenna for two different conducting media (copper and graphene), section 'B' presents the corresponding result of a bend shape for its two different conducting media.

A. Planar configuration

Fig. 3 shows the planar shape antenna for two different conducting media with copper and graphene. The PEC has been used as ground plane here.

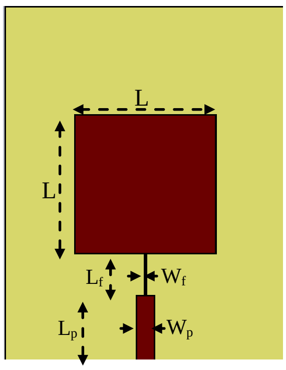

Fig. 3 Planar shape antenna

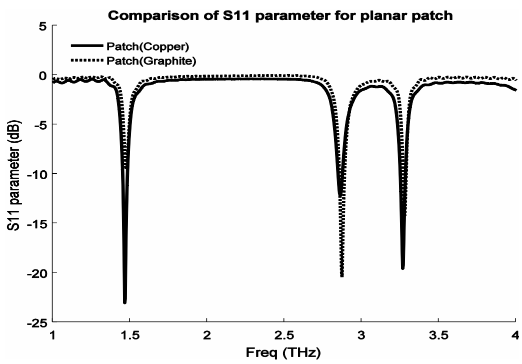

Fig. 4 S11 parameter

The reflection coefficient of the patch antenna has been shown and compared in Fig. 4. As shown in Fig. 4, copper and graphene patch shows the resonating behaviour at 1.465 THz, 2.859 THz and 3.266 THz. The copper patch shows the reflection coefficient of -23.03 dB at 1.465 THz, -12.14 dB at 2.859 THz and -19.45 dB at 3.266 THz while the graphene patch shows its resonating behaviour with reflection coefficient -8.92 dB at 1.473 THz, -22.10 dB at 2.859 THz and -12.56 dB at 3.266 THz.

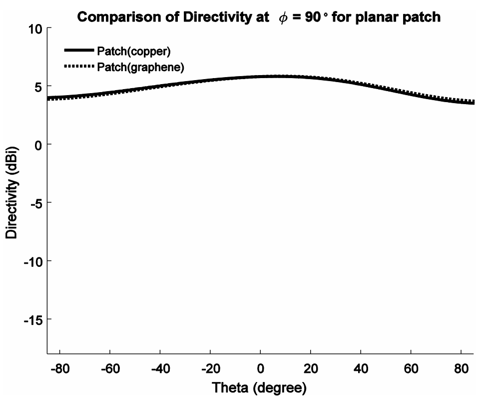

Fig. 5 Directivity at 1.465 THz

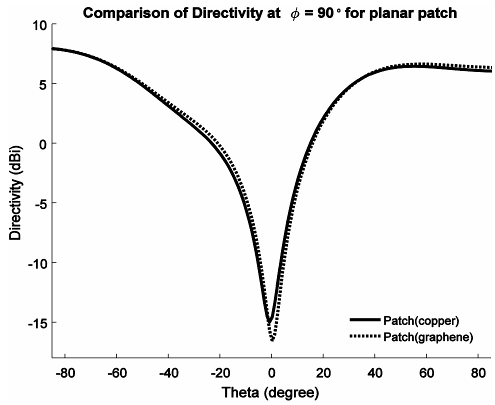

Fig. 6 Directivity at 2.859 THz

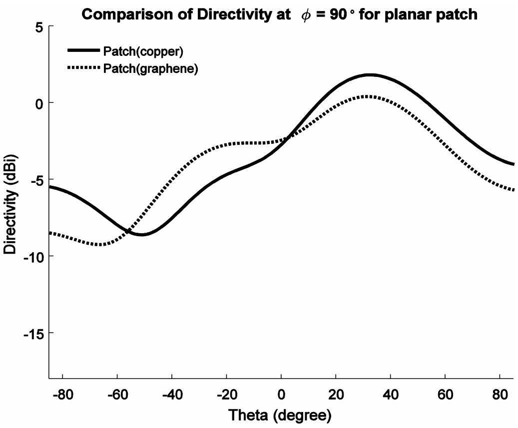

Fig. 7 Directivity at 3.266 THz

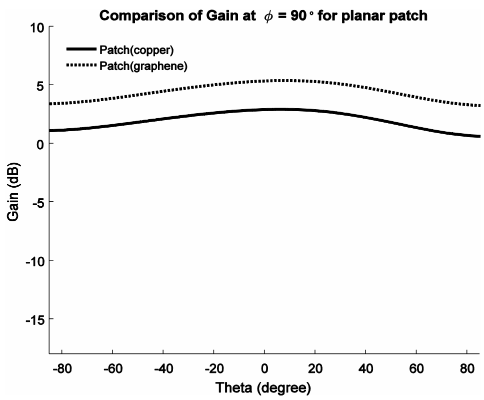

Fig. 8 Gain at 1.465 THz

Figs. 5 and 6 show the similar directivity for copper and graphene planar patch antenna with 5.86 dBi at 1.465 THz and 5.89 dBi at 1.473 THz and 8.02 dBi and 7.94 dBi at 2.859 THz for ϕ = 90° while the directivity at its resonating frequency 3.266 THz of Fig. 7 shows a difference in directivity of about 0.17 dBi for copper and graphene media.

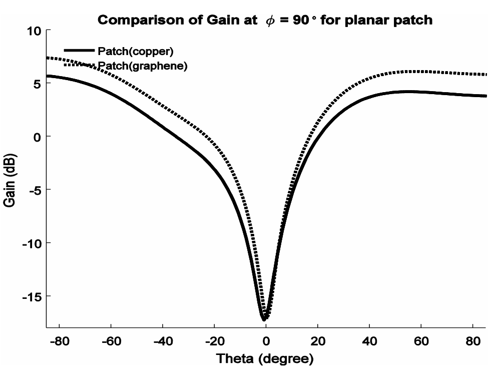

Fig. 9 Gain at 2.859 THz

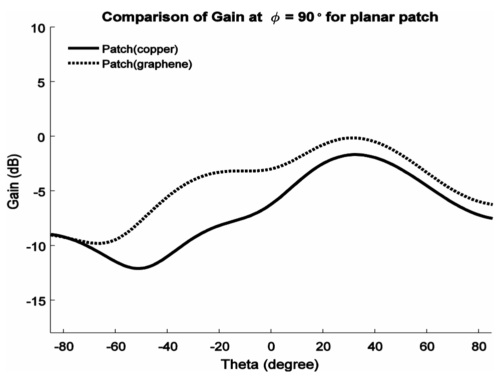

Fig. 10 Gain at 3.266 THz

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Figs. 8 – 10 show the comparison of gain for these patch antennas with copper and graphene conducting media at its resonating frequencies, 1.465 THz, 2.859 THz and 3.266 THz. As shown here, Graphene patch show higher gain in these instances with 2.49 dB, 1.69 dB and 3.17 dB difference at $\phi = 90°$.

B. Bend configuration

Fig. 11 Bend shape antenna

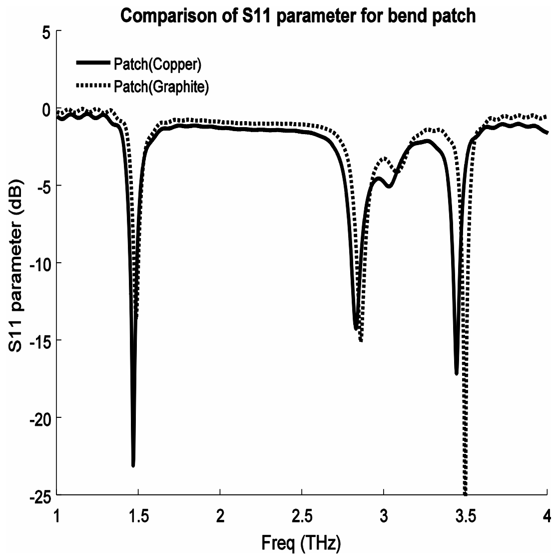

Fig. 12 S11 parameter for bend patch

The bend configuration of the antenna for copper and graphene as conducting media has been shown in Fig. 11 and its reflection coefficient has been compared in Fig. 12. As seen from Fig. 12, the copper patch shows the reflection coefficient of -23.05 dB at 1.465 THz, -14.10 dB at 2.829 THz and -16.85 dB at 3.444 THz while the graphene patch shows its resonating behaviour with reflection coefficient -13.40 dB at 1.485 THz, -14.83 dB at 2.859 THz and -30.19 dB at 3.493 THz.

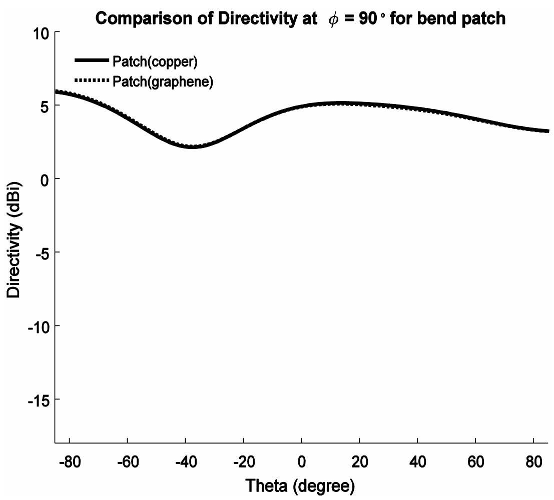

Fig. 13 Directivity at 1.465 THz

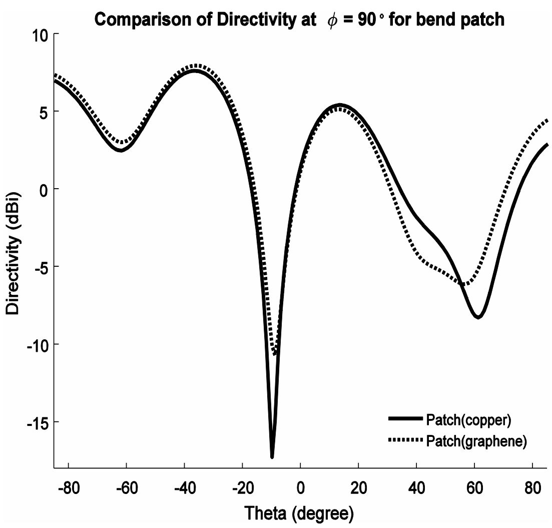

Fig. 14 Directivity at 2.829 THz

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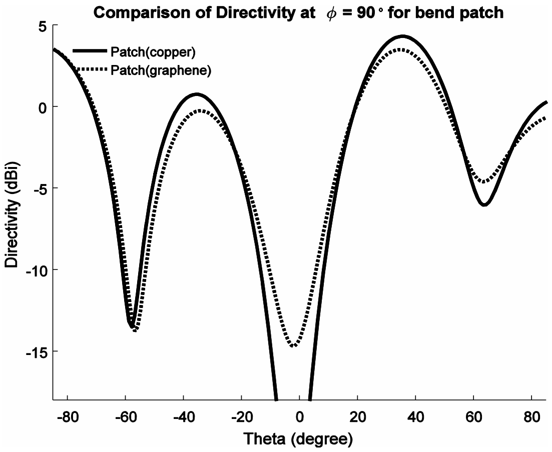

Fig. 15 Directivity at 3.444 THz

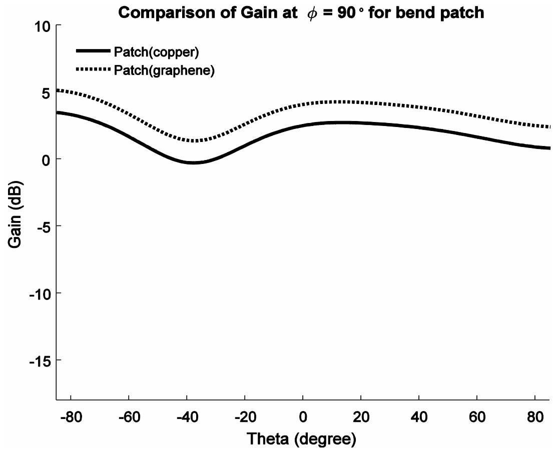

Fig. 16 Gain at 1.465 THz

Figs. 13, 14 and 15 show the comparison of its directivity for various bend structures at ϕ = 90°. As seen here the bend structure provides a higher gain and radiation efficiency for copper patch and lesser gain and radiation efficiency for graphene patch with other parameters being similar though there is a slight shift in the resonating frequency for the copper and graphene patch.

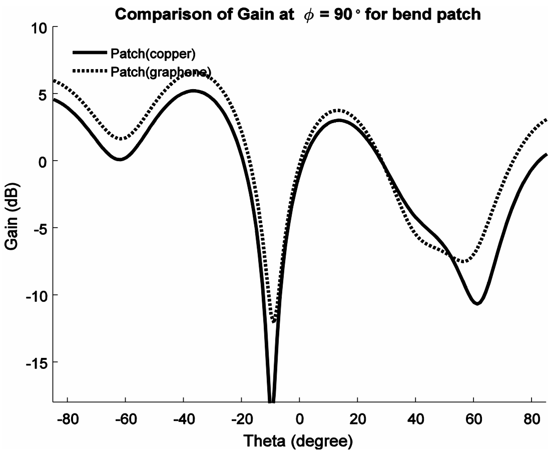

Fig. 17 Gain at 2.829 THz

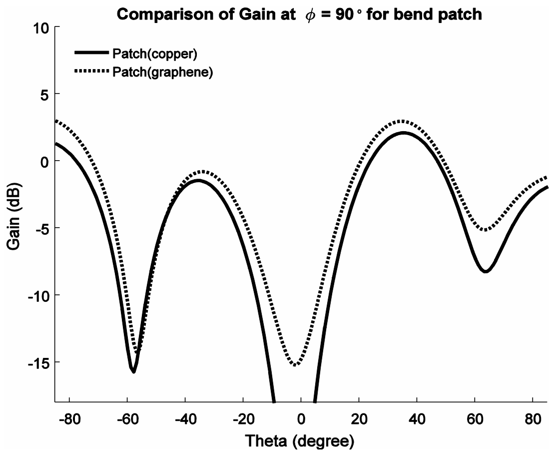

Fig. 18 Gain at 3.444 THz

Similarly Figs. 16, 17 and 18 show the comparison of gain for these patch configurations at ϕ = 90° where obtained gain has difference of about 1.67 dB, 1.38 dB and 1.86 dB at their resonating frequencies. These results show that after bending these patch configurations provide similar behaviour and there is an increase in gain and efficiency of the radiating element.

IV. COMPARISON OF PARAMETRS

TABLE I COMPARISON OF PLANAR ANTENNA PARAMETERS

Patch (planar)	Freq (f_o) in THz	S11 (dB)	VSWR	Gain (dB)	Directivity (dBi)	Main Lobe direction (°)	3 dB Angular width (°)	Total efficiency (%)
Copper	1.465	-23.03	1.15	2.95	5.86	6.0	180	71.28
	2.859	-12.14	1.65	5.75	8.02	-90	38.9	74.64
	3.266	-19.45	1.24	5.03	8.51	32	53.0	66.68

Graphene	1.473	-8.92	2.11	5.44	5.89	8	180	88.71
	2.859	-22.10	1.17	7.44	7.94	-90	39.7	93.64
	3.266	-12.56	1.61	8.2	8.68	31	78.6	91.8

TABLE II. COMPARISON OF BEND ANTENNA PARAMETERS

Patch (Bend)	Freq (f_o) in THz	S11 (dB)	VSWR	Gain (dB)	Directivity (dBi)	Main Lobe direction (°)	3 dB Angular width (°)	Total efficiency (%)
Copper	1.465	-23.05	1.15	3.56	6.01	-90.0	39.4	75.34
	2.829	-14.10	1.49	5.22	7.65	-37.0	29.4	74.47
	3.444	-16.85	1.33	5.62	7.83	35.0	27.5	76.64
Graphene	1.485	-13.40	1.54	5.23	6.06	-90.0	39.6	88.71
	2.859	-14.83	1.44	6.6	7.99	-36.0	29.9	84.04
	3.493	-30.19	1.06	7.48	8.01	-90.0	17.0	93.97

Table I shows the comparison of reflection coefficient, VSWR, and Gain at ø = 90° for planar antenna with copper and graphene as its conducting media in its tri-band frequency (1.485 THz, 2.829 THz and 3.444 THz). As seen from Table I and II, the gain, directivity and total efficiency of the graphene radiating element is higher than the copper conducting media. This can be an important factor in the selection of the conducting material for its patch configuration. Similarly the comparison of Table I to Table II shows that the bending of the patch provides an increased parametric result for its gain and radiation efficiency, although the bend structure in comparison of planar structure provides a lesser bandwidth.

V. CONCLUSION

Here the modelling and simulation results of a small patch antenna operating over THz range have been investigated for two different conducting media, copper and graphene. As seen from their various simulation results, these small patch antennas provide multi-band frequency range of operation while providing good gain, directivity and radiation efficiency. The antenna parametric effect has been also investigated for its bend structure. Looking from Table I and II, the bending of the structure provides an improvement in the parametric results such as reflection coefficient, gain, directivity, and radiation efficiency of the planar antenna. The designed antenna being in the μm range, its gain and other parameters can be enhanced considerably with an array. The thin layers of these designed antennas can make it an excellent choice for wearable electronics applications apart from many other automotive and medical applications.

VI. ACKNOWLEDGMENT

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