Design of a 60 GHz Antenna for Multi-Gigabit WiGig Communication in Industry 4.0

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***Abstract*—In this paper, a high gain modified planar patch antenna at 60 GHz band is proposed for URLLC in Industry 4.0 applications. The proposed single antenna element has -10 dB impedance bandwidth from 56.5 GHz to 63 GHz (11% fractional bandwidth at the center frequency of 60 GHz). The radiation efficiency is greater than 86.6 % in the whole band and the peak realized gain is 8.87 dBi, with less than 1 dB variation in the whole band. The proposed antenna has high front-to-back ratio value of 22.6 dB at 60 GHz. The radiation pattern is stable in the whole band, with very low side-lobe levels. The proposed antenna design can serve as a building block for a complete adaptive smart antenna system with high performance, while covering bandwidth of 6.65 GHz for IEEE 802.11ad/ay standard. The proposed antenna is a promising candidate for multi-gigabit wireless communication in 60 GHz ISM band for factory automation and Industry 4.0 applications.**

Keywords—Microstrip patch antenna, mmWave, WiGig, Industry 4.0

I. INTRODUCTION

The potential of smart wireless communication at 60 GHz industrial, scientific, and medical (ISM) band is imminent in Industry 4.0. Industry 4.0 is a new paradigm of smart automation and sophisticated services with various enabling technologies such as 5G, cyber-physical systems, digital twins, and industrial internet of things, to name but a few [1]. As a result of spectral congestion and very limited available bandwidth at sub-6 GHz ISM band, industrial wireless communication is embracing the realm of millimetre-wave (mmWave) regime to envisage ultra-reliable low latency communication (URLLC) [2]. Under the ambit of Wireless Gigabit Alliance (WiGig), the motivation to employ the huge potential of unlicensed 60 GHz band in industrial automation applications is looming [3]. WiGig is the next generation ultra-high speed wireless that intends to support multi-gigabit per second level wireless communication [4].

The design of high-performance antennas at 60 GHz ISM band is need of the hour, so that URLLC in viewpoint of Industry 4.0 could soar to its full potential. Various antenna designs at 60 GHz band are reported in literature based on different manufacturing techniques such as Printed Circuit Board (PCB), additive manufacturing and Low Temperature Co-fired Ceramic (LTCC) etc. Nevertheless, PCB technology is the most cost-effective solution for antenna design [5]–[7].

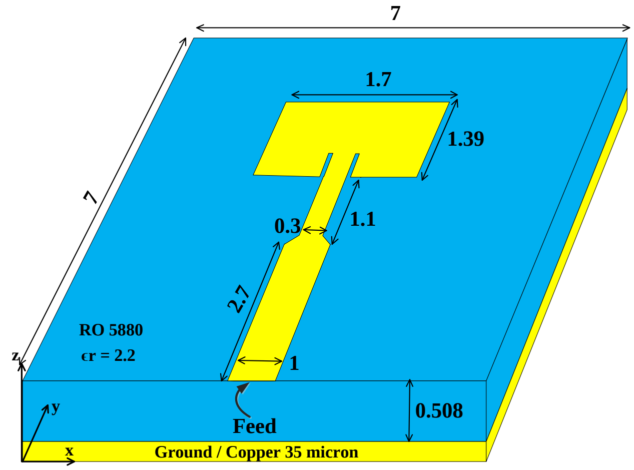

Fig. 1. Perspective view of the proposed antenna with dimensions in mm.

In this paper, we propose a modified microstrip patch antenna that works at 60 GHz while covering the maximum unlicensed WiGig band. The proposed antenna is easy to fabricate and shows good performance. It is a promising candidate to support URLLC in Industry 4.0 applications.

II. PROPOSED ANTENNA DESIGN

The proposed antenna is designed on Rogers 5880 substrate with a thickness of 0.508 mm as depicted in Fig .1. As opposed to conventional patch design, a chamfered transition in the width of feedline was deliberately introduced after 1 mm length of feedline towards the patch. This transition was analyzed to increase the gain, and reduce the sidelobe levels (SLL) as well as spurious radiations from the feed line at higher frequencies. Otherwise, if the patch is directly attached to the feedline (as in conventional designs), the SLLs increase and affect the overall gain at 60 GHz. The dimensions of the feed lines, inset slots, and those of the patch were carefully optimized such that the center frequency remains at 60 GHz with at least 6 GHz of available bandwidth to cover the WiGig band. The final optimized dimensions are shown in Fig. 1. The overall size of the antenna is 7 mm × 7mm (1.4 λ_0 × 1.4 λ_0; at 60 GHz).

III. RESULTS AND DISCUSSION

The proposed antenna presents high performance in terms of high gain, efficiency, and clean radiation patterns with very low SLLs. The reflection coefficient is shown in Fig. 2,

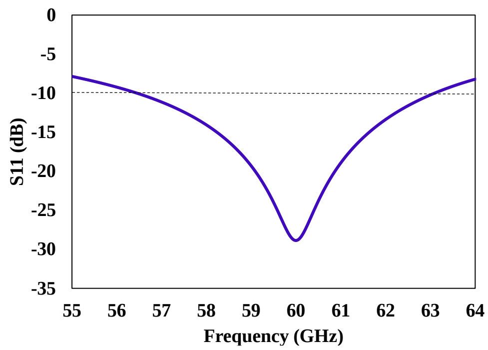

Fig. 2. Reflection coefficient of the proposed antenna element

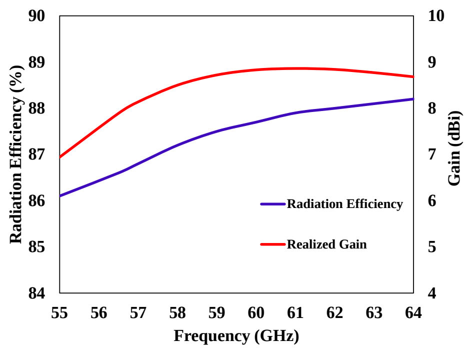

Fig. 3. Radiation efficiency and realized gain of the proposed antenna.

which is below -28 dB at 60 GHz. The -10 dB impedance bandwidth is from 56.5 GHz to 63 GHz which covers complete WiGig band. The antenna achieves a high gain of 8.87 dBi, with greater than 8 dBi gain above 57 GHz as shown in Fig. 3. The gain variation is less than 1 dB in the whole band. The antenna is more than 86 % efficient throughout the operational band as presented in Fig. 3.

The radiation patterns are shown in Fig. 4, for phi 0º (x-z plane) and phi 90º (y-z plane) at 58, 60, and 63 GHz. The radiation pattern is highly stable throughout the band. For phi 0º, the half-power beamwidths (HPBW) are 64.3º, 65.8º, and 65.6º, whereas the SLL are -18.3, -22.5, -24.4 dB at 56.5 GHz, 60 GHz, and 63 GHz respectively. Similarly, for phi 90º, the HPBW are 51.3º, 49.8º, and 48.6º, with SLL of -13.2, -11.3, and -15.1 dB at 56.5 GHz, 60 GHz, and 63 GHz respectively. At 60 GHz, the antenna has a high front-to-back ratio of 22.6 dB. Performance comparison of the proposed antenna with some of the other related works is summarized in Table I.

Finally, due to the high performance of the proposed antenna, the dynamic beamforming and beam-steering capabilities will be used with array configuration to produce a complete agile smart antenna system at 60 GHz band, the results of which are not reported here due to brevity.

IV. Conclusion

In this paper, the design of a planar modified patch antenna is proposed which covers a WiGig ISM band from 56.5 GHz to 63 GHz. The proposed antenna presents radiation

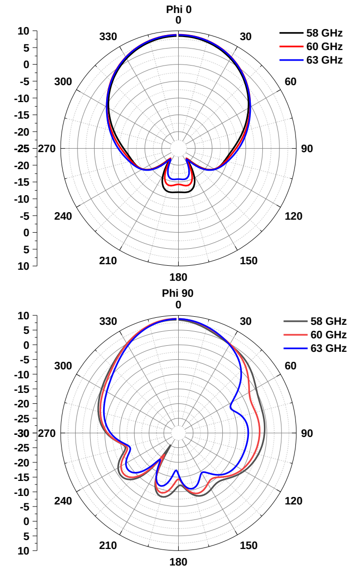

Fig. 4. Radiation patterns for the proposed antenna for phi 0º and phi 90º.

TABLE I. PERFORMANCE COMPARISON OF THE PROPOSED ANTENNA

Ref.	Covered Band (GHz)	Radiation Efficiency (%)	Peak Gain Single Element (dBi)	Single Element Size (mm × mm)
[5]	57.2 - 63.8	85	9.9	12 × 9.6
[6]	58.01 - 60.53	79.87	5.5	3 × 2
[7]	57.4 - 66	79.2	6	5 × 2.75
This work	**56.5 - 63**	**86.6**	**8.87**	**7 × 7**

efficiency of 86.6 %, peak gain of 8.87 dBi, and stable radiation pattern in the whole band with very low side lobe level, and high front-to-back ratio. The proposed antenna design is suitable to support URLLC at 60 GHz ISM band in Industry 4.0 and factory automation applications.

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