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Millimeter Wave Antenna for Intelligent Transportation Systems Application

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***Abstract*—A compact broadband millimeter wave antenna for intelligent transportation (ITS) application is proposed in this paper. This antenna uses coplanar wave guide feeding technique for broad bandwidth. The proposed antenna works at 79 GHz resonant frequency having a large bandwidth of 78.2 GHz. The measured gain of the antenna is 17.5 dBi. The proposed antenna is very suitable for short range radar (SRR) application and %G technologies.**

***Index Terms*—** Millimeter wave, ultra wide band, coplanar waveguide, defected ground, short range radar.

I. INTRODUCTION

Intelligent transportation system (ITS) is important part of human life and country. It supports human economy and helps in easily running of country. ITS have many applications lies in millimeter-wave frequency range like automotive radar applications and enabling wireless technologies. Automotive radar application is divided into two part like long range radar (LRR) and short range radar (SRR). Short range radar (SRR) system is a crucial element in automobile safety. It is responsible for detection and prevention of potential collisions. Thus, helps in reducing the number and severity of road accidents. It has many more applications like, pre crash sensing / control firing of restraints, airbags / break boosting, stop and go functionality, lane change warning, lane change aid, blind spot detection, parking aid and back drive assistance [1] [2]. *Fig.*1 shows the coverage area of automotive radar antenna. Short range radar has four types: continuous wave (CW) radar, frequency modulated continuous wave (FMCW) radar, synthetic aperture radar (SAR), phased array radar, and ultra wide band (UWB) impulse radar. Small CW Doppler radar systems are used as motion sensors and for measuring the speed of automobiles. FMCW radar is used for radar altimeters in aircrafts. SAR is developed for airborne ground mapping at a stand-off distance. Phased array radar is used for imaging system. The millimeter wave antenna is used for short range radar application [3]. The SRR for automotive application has three centre frequencies – 24.5 GHz, 26.5 GHz, and 79 GHz. Their respective bandwidths are 5 GHz, 4 GHz, and 4 GHz respectively [4]. 5G is one the enabling technologies that works in millimeter-wave frequency range. It works in the frequency range of 24 GHz to 86 GHZ [5].

This paper focuses on design and development of millimeter wave antenna for intelligent

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transportation systems (ITS) application. This paper focuses on the safety and connectivity applications of vehicles. For safety application 79 GHz is the centre frequency [6] and for connectivity 5G technologies used.

A 79GHz millimeter wave automotive radar front–end with monolithic microwave integrated circuit (MMIC) technology having bandwidth of 9.05GHz and gain of 6.5dBi is discussed in [7]. A 79GHz millimeter wave antenna based on a conformal waveguide with slot array having 15.7 dBi gain is discussed in [8]. A 77 GHz frequency modulated continuous-wave (FMCW) radar system having bandwidth of 6 GHz and gain of 10 dBi is discussed in [9].

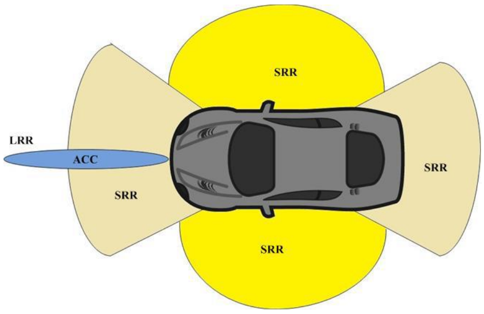

Fig. 1. Placement and coverage area of automotive radar antenna [10].

A 79 GHz patch antenna array for short range radar system having bandwidth of 9.6 GHz and gain of 14.5 dBi is discussed in [11]. A 77 GHz electronically beam-steerable integrated lens millimeter wave antenna having bandwidth of 35 GHz is discussed in [12]. A 77 GHz Yagi–Uda antenna for automotive radar sensor having gain of 15.8 dBi is discussed in [13]. A 77 GHz and 94 GHz millimeter wave radar system having bandwidth of 2 GHz and 4.9 GHz respectively is discussed in [14]. A 77 GHz multi-channel directional folded dipole radar antenna having gain of 8.2dBi is discussed in [15]. A 77 GHz lens antenna for automotive radar having bandwidth of 4GHz is proposed in [16]. A 77 GHz millimeter wave technology for automotive radar sensors having bandwidth of 4 GHz and half power beam width gain of 5 dBi is discussed in [17]. A 77 GHz micro-electromechanical systems based active phase shifter for W–band automotive radar having gain of 14 dBi is proposed in [18]. A 76–77GHz radar having gain of 14.2 dBi is discussed in [19]. A microstrip grid array antenna for millimeter wave frequencies having centre of 60 GHz and bandwidth of 5 GHz with gain 14 dBi is reported in [20]. A 60 GHz printed millimeter array antenna for millimeter wave application is discussed in [21]. A cavity back antenna works in frequency range of 28 GHz to 60 GHz for millimeter wave application is discussed in [22]. A substrate integrated dielectric resonator antenna having centre frequency for millimeter wave application is reported in [23]

These antennas have relatively lower bandwidth and gain. In this paper, an antenna with very large bandwidth and high gain is proposed. A novel antenna design is proposed based on defected ground structure. Optimization is done to get best design parameters for proposed antenna. It is also circularly polarized and hence, it can be used as millimeter wave antenna for short range radar application. The proposed antenna is fabricated in the lab. The validation of proposed antenna is done by both

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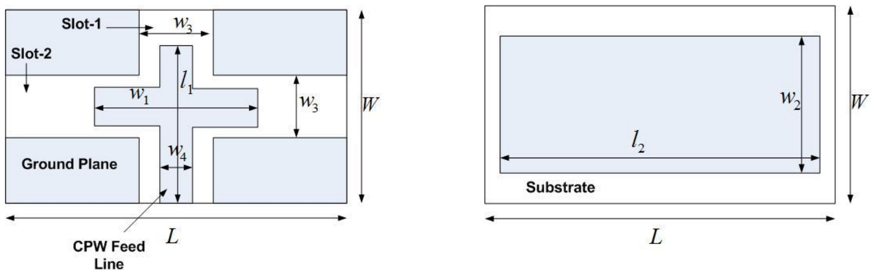
simulation and experimental methods. The Simulated and experimental results match very well.

This paper is organized as follows: section II shows design specifications of proposed antenna. Section III shows simulation result and discussion. The conclusion is presented in section IV.

II. Design Specification

In this section we discuss the structure of proposed antenna and its design procedure. In order to get high centre frequency the size of the antenna should be small and dielectric constant of substrate should be high. In proposed antenna design coupling of energy between the coplanar wave guides feed line and square patch yields resonance at desired centre frequency. Further, the energy coupling between coplanar wave guide feed line and defected ground structure results in a very large bandwidth.

The structure of proposed antenna is shown in *Fig.*2. The top view of the proposed antenna structure is shown in *Fig.*2 (a).



(a) (b)

Fig. 2 Proposed antenna structure shows (a) top view and (b) bottom view.

The top view of the proposed antenna structure shows the defected ground plane with CPW feed line in *Fig.*2 (a). There are two slots in the ground plane each having width w_3. The length of the feed line is l_1 and its arm length is w_1. The width of the feed line is w_4. Bottom view shows copper plane in *Fig.*2 (b) having dimension of $l_2 \times w_2$. The substrate material used is Roger 3210 having dielectric constant 10.2 with height 1.28 mm. The length and width of substrate are L and W respectively. The antenna is simulated using HFSSv18 [24]. The values of parameters are given in Table I.

TABLE I. VALUES OF PARAMETERS (IN MM)

Parameter	L	W	l_1	w_1	l_2	w_2	w_3	w_4
Value	24	14	11	8	18	10	4	2

III. Result and Discussion

*Fig.*3 shows the simulated result of return loss by varying the length and width of the patch of proposed antenna structure. *Fig.*4 shows the simulated result of return loss by varying the parameters of feed line and ground slots. The results are shown in Table II.

It shows the parametric analysis of proposed antenna structure. From parametric analysis the values of the parameters are chosen which are best fit at 79 GHz centre frequency. The details of

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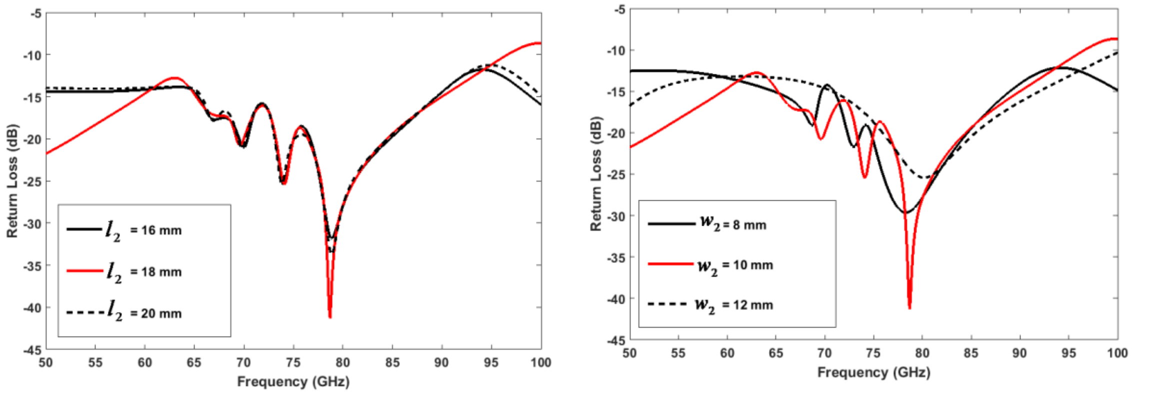
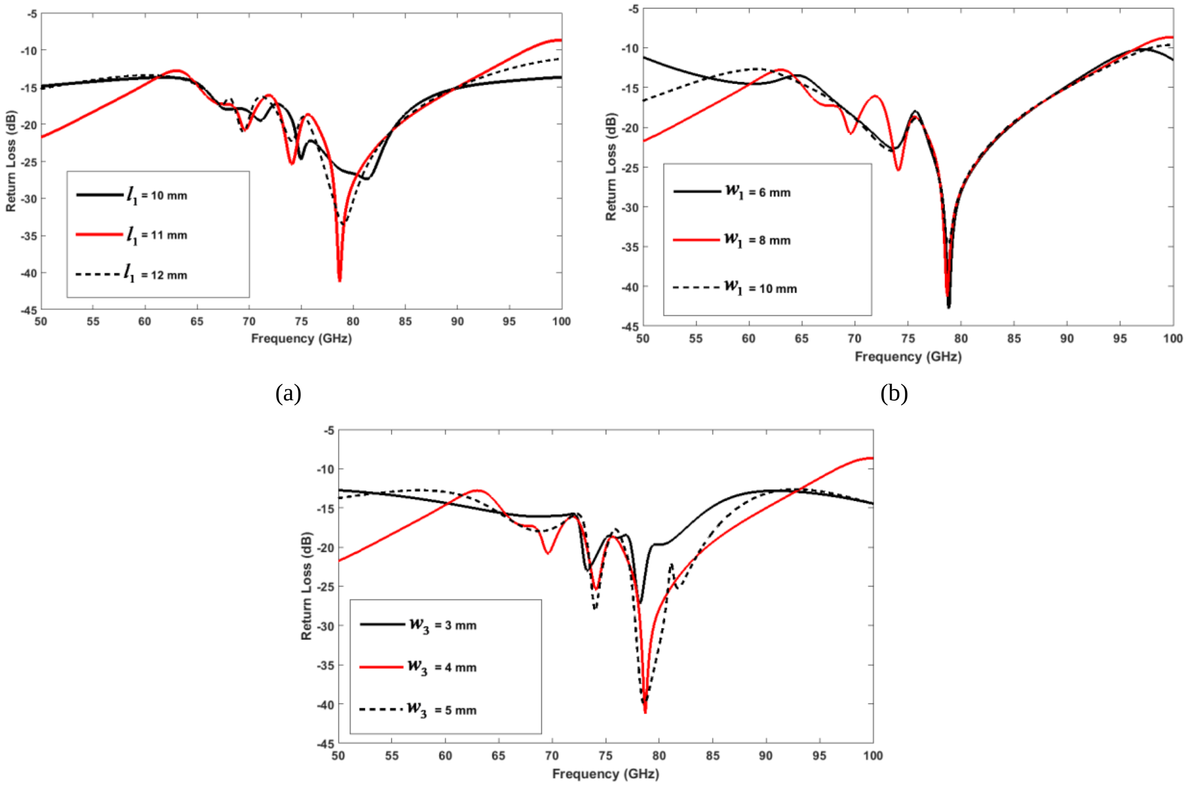
optimization are shown in Table II.



(a) (b)

Fig. 3. Simulated return loss in dB by (a) variation in length of bottom plane l_2 and (b) variation in width of bottom plane w_2.



(a) (b)

(c)

Fig. 4. Simulated return loss in dB by (a) variation in length of feed line l_1, (b) variation in length of arm of feed line w_1 and (c) variation in width of slots of the ground plane w_2.

TABLE II. RETURN LOSS RESULTS DATA BY VARYING PARAMETERS

Parameter	Values (in mm)	Centre Frequency (in GHz)	Return loss (in dB)	Bandwidth below -20dB return loss (in GHz)
	10	81.3	-27.27	10
l_1	11	79	-41.29	8.1
	12	79.1	-33.37	8.7
	6	78.8	-42.78	8.2
w_1	8	79	-41.29	8.1
	10	78.8	-34.8	8.2
l_2	16	78.9	-31.84	8.2

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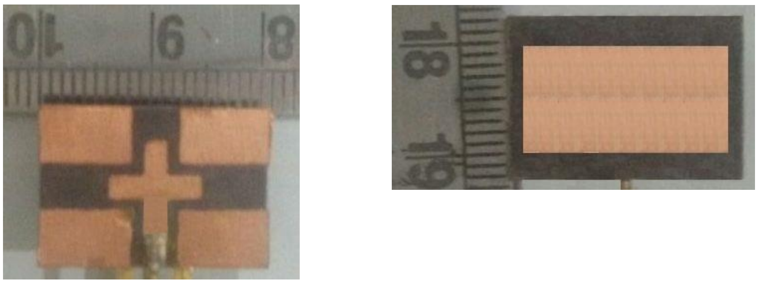
	18	79	-41.29	8.1
	20	78.9	-33.68	8.2
w_2	8	78.3	-29.64	10.1
	10	79	-41.29	8.1
	12	80.2	-25.44	9.6
w_3	3	78.1	-27.08	2
	4	79	-41.29	8.1
	5	78.6	-40.09	7.4

The prototype of antenna is shown in *Fig*.5. The proposed antenna structure is fabricated and tested in the laboratory. The prototype antenna is connected with keysight 11500J test port cable and tested with keysight N5250A-017 PNA millimeter-wave network analyzer. The simulated and measured results for return loss are shown in *Fig*.6. It is noted that the measured and simulated results match very well. The observed centre frequency is 79 GHz. The measured value of the return loss is -40.9 dB. The measured bandwidth is 78.2 GHz below -10 dB return loss having band range of 18.1 GHz – 96.3 GHz.



(a) (b)

Fig. 5. Prototype of proposed antenna shows (a) top view and (b) bottom view

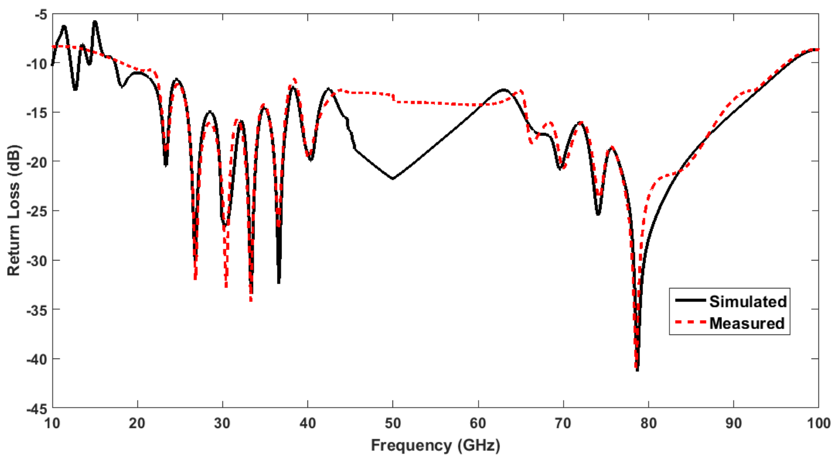


Fig. 6. Simulated and measured result of return loss of the proposed antenna structure.

The vector current distribution of proposed antenna is shown in Fig.7. This figure shows that there is energy coupling between the feed line and the defected ground structure. This coupling of energy produces very low value of capacitance and inductance of the antenna. The low value of capacitance and inductance produces high value of centre frequency. There is also coupling of energy between the

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feed line and bottom plane. This helps in the impedance matching, which in turn produces the desired centre frequency. Due to coupling, this antenna produces a very wide bandwidth

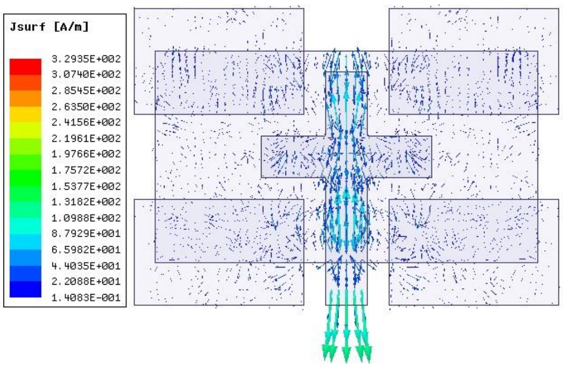

Fig. 7. Current distribution on the proposed antenna structure.

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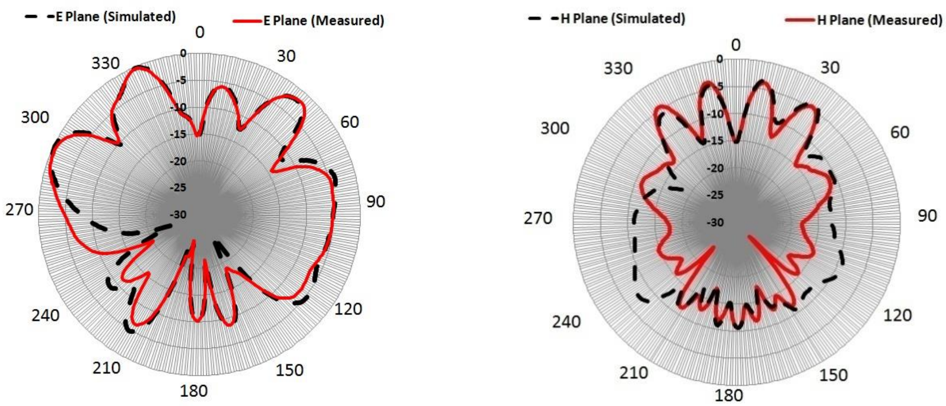

(a) (b)

Fig. 8. Simulated and measured result of radiation pattern (a) E plane, and (b) H plane

The simulated and measured radiation pattern results are shown in *Fig.*8. The simulated and measured results of E Plane and H Plane are shown in *Fig.*8. It can be observed that E plane radiation of proposed antenna covers broad range while H plane has less backward radiation and covers small range with high gain value.

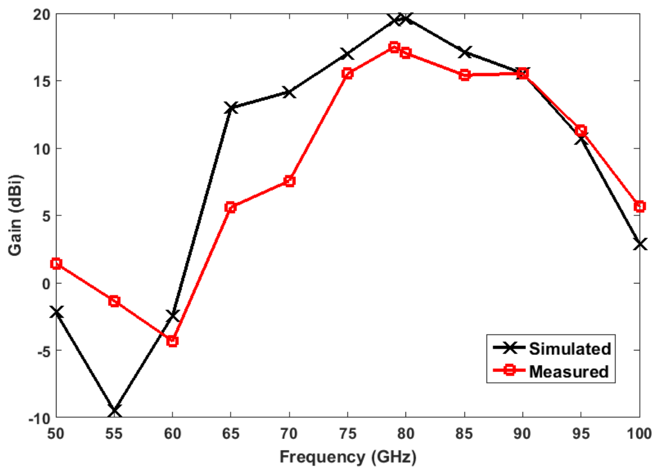

Fig. 9. Simulated and measured gain in dBi.

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The proposed antenna produces high gain as shown in *Fig.*9. The simulated and measured gains of the antenna are 19.46 dBi and 17.5 dBi respectively. This shows that antenna is suitable for automotive radar system.

TABLE III. COMPARISON OF RECENTLY PUBLISHED WORK ON MILLIMETER WAVE ANTENNA WITH PROPOSED WORK

Parameter	**Abdellatif et.al. 2015 [11]**	**You Chao Tu et.al. 2016 [25]**	**Yujian Li et.al. 2017 [26]**	**Proposed Work**
Centre Frequency	79 GHz	35 GHz	34 GHz	79 GHz
Bandwidth	9.6 GHz	8.75 GHz	13.5 GHz	78.2 GHz
Gain	14.5 dBi	4.6 dBi	13.6 dBi	17.45 dBi

Further, a comparison of results of proposed work with newly reported antenna is shown in Table III. It is noted that the proposed antenna gives better result than the reported antenna. The proposed antenna is suitable for SRR in ITS applications.

IV. CONCLUSION

The proposed antenna gives a very wide band range of 18.1 GHz to 96.3 GHz. The measured bandwidth of proposed antenna structure is 78.2 GHz. The proposed antenna is circularly polarized in nature. In this paper parametric analysis of proposed antenna is also discussed. The measured and simulated results match very well. The prototype of antenna has very high gain of 17.5 dBi. High gain, large and bandwidth of antenna make it suitable for intelligent transportation application.

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