Compact Wideband Antenna for 60 GHz Millimeter Wave Applications

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Abstract – **In this paper, a gap coupled rectangular monopole antenna for millimeter wideband applications is proposed. The bandwidth of a rectangular radiator fed by a microstrip feedline is enhanced by using the technique of gap coupling along its radiating edge and by using rectangular notch loaded partial ground plane. It has an impedance bandwidth of 42-68.1 GHz ($VSWR \leq 2$) and an overall size of 3.5×3×0.42 mm^3. It has resonances at the frequencies of 45.5, 56.1 and 65.8 GHz. H-plane and E-plane patterns are observed to be omnidirectional and bidirectional respectively. It has its radiation efficiency more than 94% with a peak gain of 4 dB across the entire band of operation. Finite element method based HFSS simulator is used to design and analyze this antenna geometry.**

Keywords – **Gap coupling, Millimeter wave applications, Rectangular monopole, Notch loading, Partial ground plane.**

I. Introduction

With increasing demands of high data rate, millimeter-wave communication in the unlicensed frequency spectrum around 60 GHz received a lot of attention from academic as well as industrial researchers. Due to atmospheric attenuation in the order of 10-15 dB/km, the applications of frequency spectrum around 60 GHz are confined to only short-range radar and indoor wireless communication. These applications include Wireless Local Area Network (WLAN) and Wireless Personal Area Network (WPAN) with a data speed of Gbps. Since the attenuation losses can be recovered by using antennas having high radiation efficiency and wide bandwidth, therefore due to their higher efficiency horn antennas were used for millimeter-wave communication at 60 GHz in the initial stage. But, their three dimensional geometry, heavy weight and high cost limited their applications. Afterwards, various other antenna geometries including dielectric resonator antenna, surface integrated waveguide antenna etc were explored and reported in literature [1-18] for millimeter-wave communication at 60 GHz. Among those geometries, microstrip antenna structures are proven to be better candidates due to their advantages like low profile, easy fabrication, easy integration etc. The challenges faced by antenna designers are the narrow bandwidth and low efficiency of microstrip antennas. In the literature, several methods like micro-machining, aperture coupling, recessed ground, stacked patches, gap coupling etc are reported for microstrip antenna performance improvement. Among these methods, gap coupling method has advantages of simplicity, easy and fast fabrication. Therefore, gap coupling method is selected to design the proposed antenna geometry.

In this paper, a gap coupled rectangular microstrip antenna is investigated for wideband millimeter wave applications at 60 GHz. The methods of gap coupling and rectangular notch loaded partial ground plane are utilized to enhance the antenna bandwidth. It is derived from a rectangular monopole antenna. The LTCC substrate is used to design the antenna. A fractional bandwidth of ~47% is achieved. The antenna is designed and analyzed using HFSS simulator.

II. Antenna Design

The proposed antenna configuration is shown in Fig. 1. It is designed and analyzed on a 0.42 mm thick LTCC substrate. It comprises a rectangular monopole fed by a microstrip feedline, a parasitic patch along its width and notch loaded partial ground plane. Initially, a microstrip line fed rectangular monopole is designed. Thereafter, a parasitic rectangular patch is added to the radiator along its width. For bandwidth enhancement, the conventional rectangular ground plane is replaced with the partial ground plane. In the last stage, the partial ground plane is loaded with a rectangular notch symmetrical to the feedline. The antenna design steps are shown in Fig. 2. The radiator and parasitic patch dimensions are taken from [1]. The ground and radiator are designed by using copper having a thickness of 7 µm. All metallic sections are considered to be perfect conductors.

III. Results and Discussion

The reflection coefficient curves of intermediate antenna design steps are displayed in Fig. 3. Their quantitative analysis is listed in Table I. It is observed that in case of simple rectangular monopole, a single resonance at 59.75 GHz as the monopole was designed for 60 GHz is achieved. On addition of a parasitic patch, three resonances are observed around 40.25, 51.5 and 66.5 GHz. These resonances are due to the main radiator, parasitic patch and combination of the main & parasitic radiator. In case of Antenna III, the partial ground plane provides a capacitive effect to nullify the inductive effect of the radiator resulting into improved impedance matching. This improved impedance matching leads to a single wideband of 41.91-65.7 GHz with resonances at 45 and 56.25 GHz. For the last configuration i.e. antenna IV, three resonances at 45.5, 56 and 65.75 GHz with a wide operating band of 42-68.12 GHz are observed. This bandwidth enhancement is due to the improvement of impedance matching by the ground notch. This is in accordance with the results reported in [19-22].

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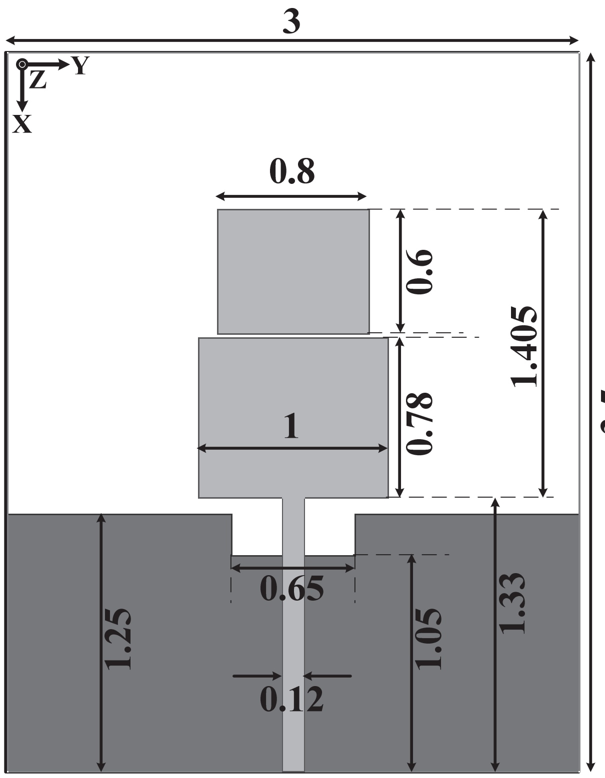
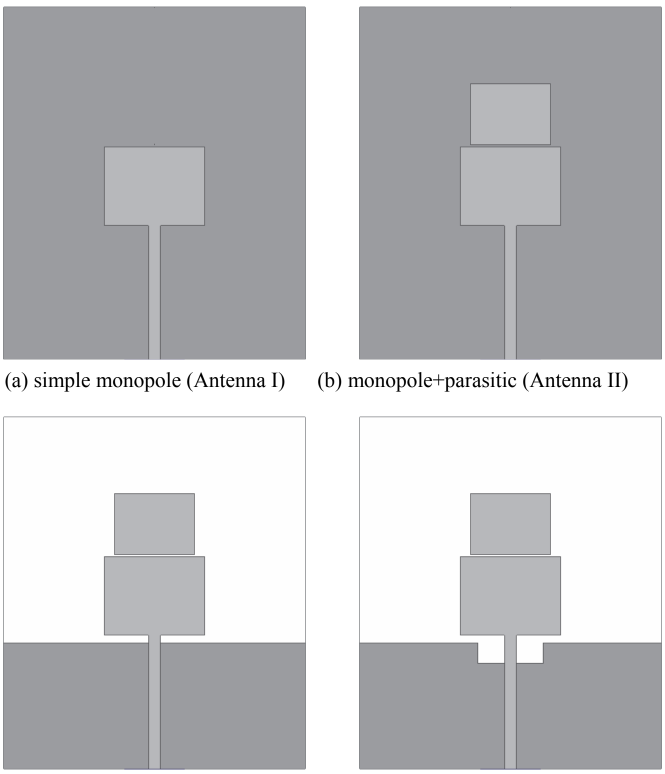


Fig. 1. Proposed antenna geometry (all dimensions are in mm)



(a) simple monopole (Antenna I) (b) monopole+parasitic (Antenna II)

(c) partial ground plane (Antenna III) (d) Proposed antenna (Antenna IV)

Fig. 2. Intermediate antenna design steps

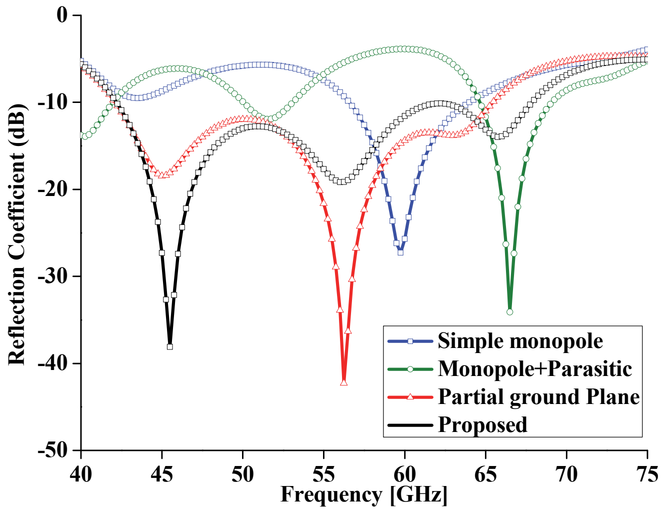


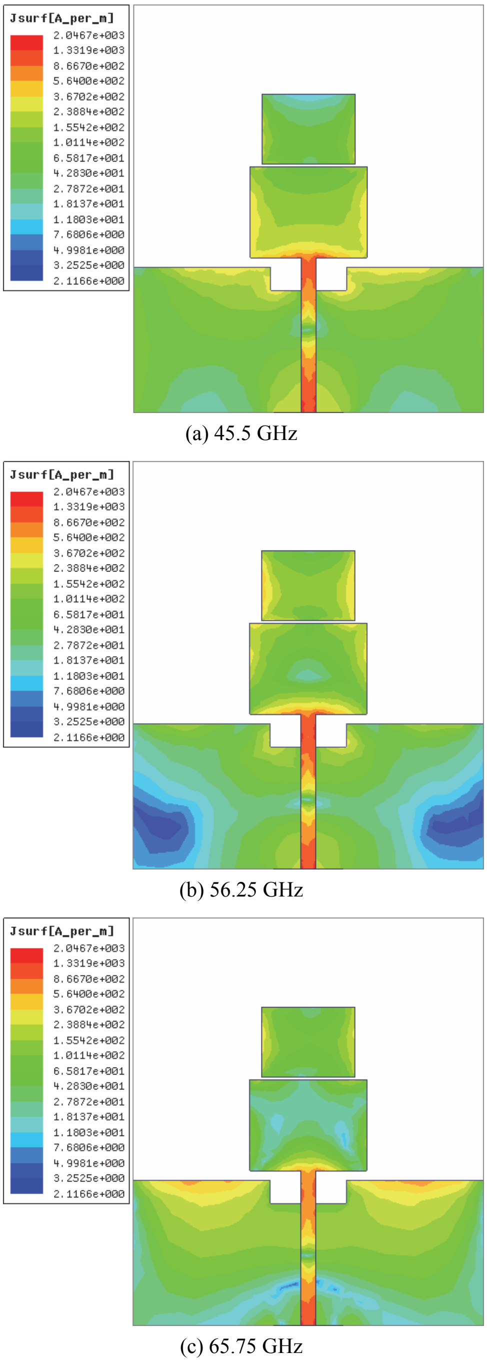
Fig. 3. Reflection coefficient of intermediate antenna design steps

TABLE I
COMPARISON OF INTERMEDIATE ANTENNA DESIGN STEPS

Antenna	Band 1 [GHz]	Band 2 [GHz]	Band 3 [GHz]
Antenna I	56.35-64.43	-	-
Antenna II	39 - 42.2	49.77-53.35	64.53-69.37
Antenna III	41.91-65.7	-	-
Antenna IV	42.01-68.12	-	-

The surface current density plots for the proposed antenna geometry at resonance frequencies are shown in Fig. 4. It is observed that at 45.5 GHz, the current is distributed uniformly across the entire antenna geometry. This uniformly distributed surface current distribution indicates that this resonance is created by the combination of ground plane, main radiator and parasitic patch. In case of 56.25 GHz resonance, surface current is concentrated along the radiating patch and parasitic patch. Therefore, this resonance is being excited by the combination of radiator and parasitic patch. For 65.75 GHz, maximum surface current is observed around the ground notch and the parasitic patch with negligible current density across radiating patch. This indicates that this resonance is mainly generated by the parasitic patch and ground plane.

Figure 5 presents the co and cross polar patterns of the proposed antenna in both E- ($\Phi = 0^{o}$) and H- ($\Phi = 90^{o}$) planes at the resonance frequencies. It is observed that for E-plane patterns the difference between co and cross polar patterns is almost constant at 35 dB at all resonances but for H-plane patterns, the difference is reduced from 10 dB to 0 dB with increase in frequency. In addition to this, it is also observed that the co-pol patterns in H-plane are omnidirectional at all frequencies but the shape of E-plane patterns has shifted from bi-directional to distorted omnidirectional with increase in frequency.



(a) 45.5 GHz

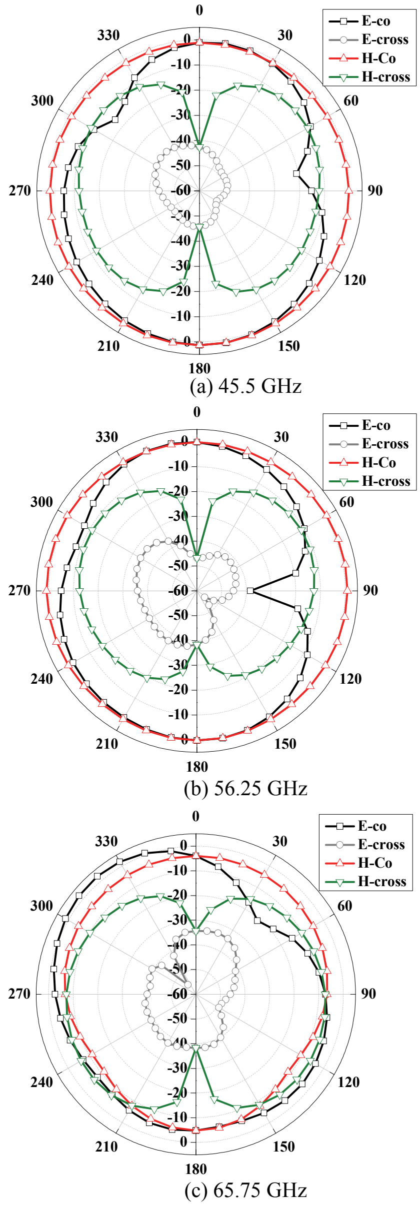
(b) 56.25 GHz

(c) 65.75 GHz

Fig. 4. Surface current density plots of proposed antenna

The peak realized gain and radiation efficiency of the antenna are depicted in Fig. 6. The peak realized gain is observed to be increasing from 0.57 to 4 dBi with increase in frequency. The radiation efficiency is varying from 94% to 96% over the entire band of operation.

The tabular comparison of proposed antenna with previously reported 60 GHz antenna structures is presented in Table II. It is observed that the proposed antenna has higher fractional bandwidth. In addition to this, the proposed geometry has efficiency comparable to few structures and higher than remaining structures.



(a) 45.5 GHz

(b) 56.25 GHz

(c) 65.75 GHz

Fig. 5. Co and cross polar radiation patterns of proposed antenna

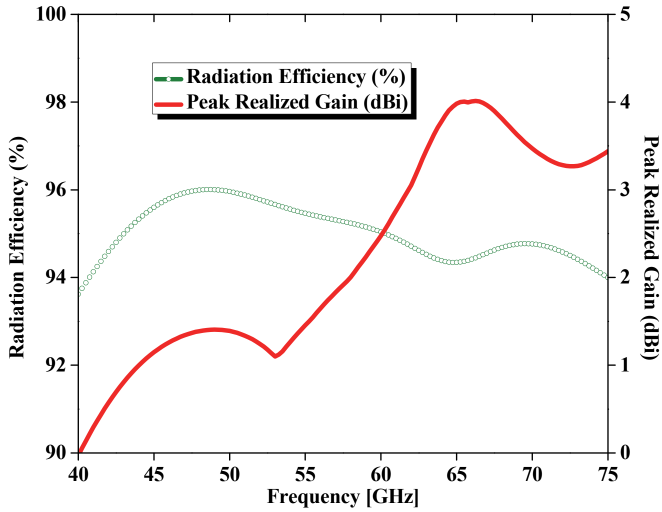


Fig. 6. Peak realized gain and radiation efficiency of proposed antenna

TABLE II
COMPARISON OF PROPOSED ANTENNA WITH PREVIOUSLY REPORTED STRUCTURES

Antenna	% Bandwidth	Antenna Type	Efficiency (%)
[1]	27.3	Array	26
[2]	9.42	Patch antenna	94
[3]	8.13	Antipodal Tapered Slot (ATS) antenna	-
[4]	26.53	Three Dimensional Antipodal Tapered Slot (ATS)	94
[6]	6.59	Aperture coupled superstrate antenna	76
[7]	17	Circularly polarised stacked patch antenna array	-
[8]	14.63	Substrate integrated waveguide	98
[9]	11.33	Microstrip patch antenna	87.44
[10]	6.11	Aperture coupled microstrip patch antenna	73
[11]	4.83	Microstrip patch antenna	-
[12]	3.78	Microstrip patch antenna	79.35
[13]	7.1	Slot	95
[14]	11.6	Slot	
[15]	9.9	Circularly polarized microstrip patch antenna	90
This work	47	Microstrip patch antenna	95

IV. CONCLUSION

A wideband rectangular microstrip antenna for 60 GHz millimeter wave applications is investigated and analyzed in this paper. The impedance bandwidth is enhanced by incorporating techniques of radiating edge parasitic patch and rectangular notch loaded partial rectangular ground plane. It has an impedance bandwidth of 42-68.1 GHz with an efficiency of more than 94% and peak gain of 4 dB. Due to wider bandwidth, moderate gain and high efficiency, this antenna will be useful in millimeter wave wireless applications either as an individual radiator or as an array element. In addition to this, because of its easy integratability with integrated circuits, this antenna can be used in RF modules of future WPAN systems or system on chip (SOC) applications.

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