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Research Article

Millimeter Wave Antenna with Mounted Horn Integrated on FR4 for 60 GHz Gbps Communication Systems

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A compact high gain and wideband millimeter wave (MMW) antenna for 60 GHz communication systems is presented. The proposed antenna consists of a multilayer structure with an aperture coupled microstrip patch and a surface mounted horn integrated on FR4 substrate. The proposed antenna contributes impedance bandwidth of 8.3% (57.4–62.4 GHz). The overall antenna gain and directivity are about 11.65 dBi and 12.51 dBi, which make it suitable for MMW applications and short-range communications. The proposed antenna occupies an area of 7.14 mm × 7.14 mm × 4 mm. The estimated efficiency is 82%. The proposed antenna finds application in V-band communication systems.

1. Introduction

During the last decade, a lot of knowledge about 60 GHz millimeter wave (MMW) has been congregated, and different architectures have been proposed and scrutinized in developing commercial applications for millimeter wave communication systems [1]. Large propagation and penetration losses at 60 GHz make it viable for use in short-range and single room environments communication. The demand for high-speed multimedia communications, such as real-time video streaming and huge data file transmission, are increasing rapidly. One of the most promising solutions to fulfill the speed and bandwidth requirements is to make use of MMW gigabit wireless communication. Short-range high data bit rate communication systems operating at 60 GHz are considered today as emerging solutions for video data streaming or video downloading needs. The recent trend on the development of millimeter wave frequencies systems has led to many innovative techniques with their successful demonstrations in different applications.

The elementary single element microstrip antenna designed on a thin substrate has limited gain of 5–7 dBi and a narrow bandwidth of around 1.5%–2.5%. Efforts have been made to increase both the gain and bandwidth with the help of stacked parasitic patch [2]. The aperture coupled microstrip patch antenna's (ACMPA) feeding technique [3] has intrinsic properties which makes it an attractive feature for millimeter wave applications [4]. Wide band operation of this type of microstrip antenna has been demonstrated at microwave frequencies (1–10 GHz) using either single [5, 6] or stacked patch configurations [7]. However, this structure can be optimized either for the gain or for the bandwidth. There is a need to increase the gain of radiating patch element without sacrificing the bandwidth.

One method to increase the gain of the antenna is to make use of array principle, but the antenna size and feeding network complexity become a limitation factor. The most promising solution to improve the gain of the antenna while keeping the overall antenna size within limits is to make use of hybrid configurations [8–14] where multiple antennas are excited together over the same frequency range of operation. Costanzo [8] proposed a hybrid configuration to increase the gain of an antenna by making use of circular waveguide elements, which were electromagnetically coupled to circular apertures via a stripline. Correspondingly, in [15] a surface mounted short horn is used with an aperture antenna where slant angle of horn antenna with respect to frequency is optimized in order to view its impact on gain of the antenna.

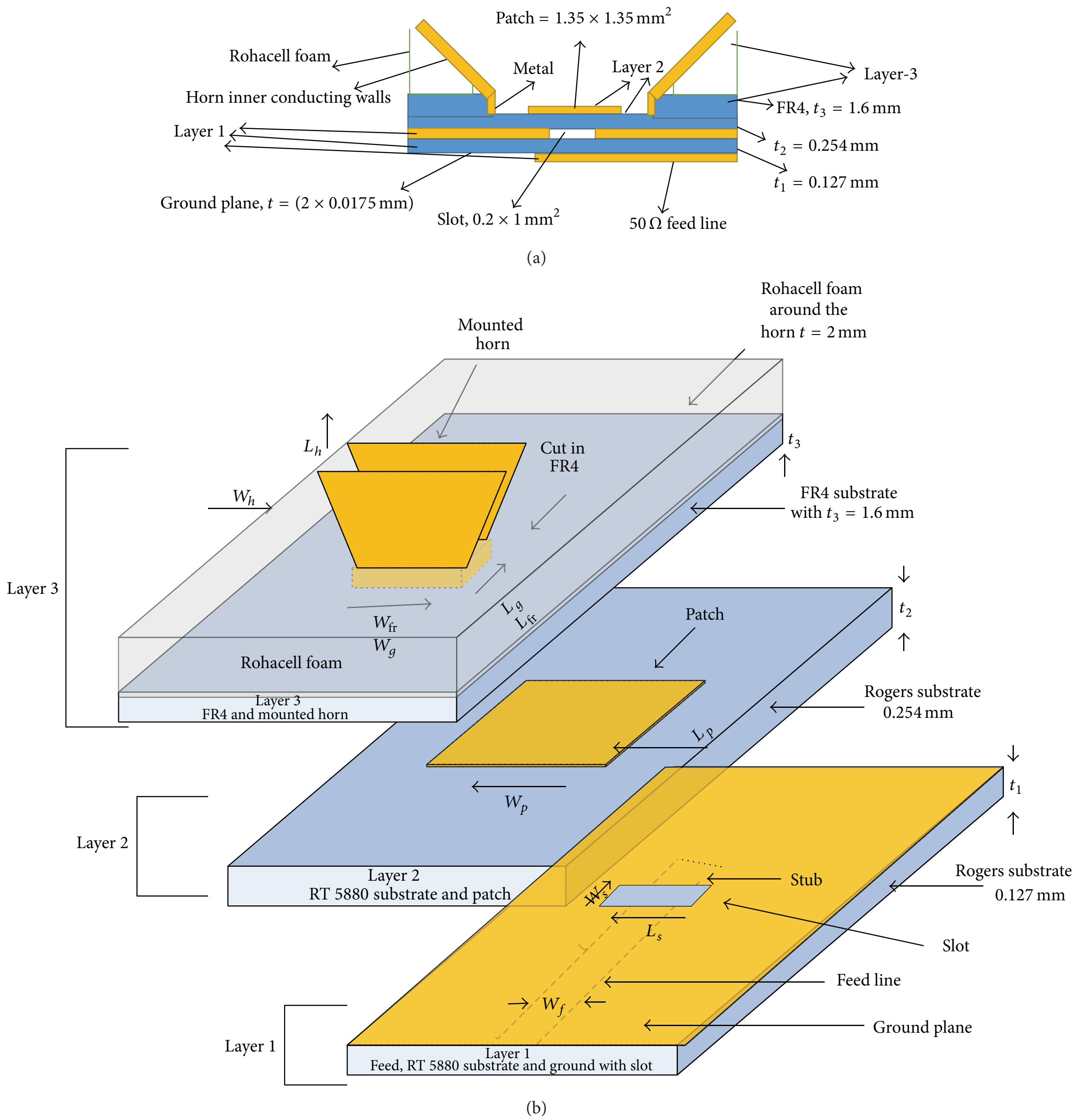

Figure 1: (a) Cutting Plane of a multilayer ACMPA with mounted Horn on FR4. (b) Exploded view of the proposed antenna.

Another configuration uses a surface mounted pyramidal horn excited by a rectangular patch antenna and a dipole as in [9] or by a patch surrounded by a resonating ring as in [10]. Use of superstrate with or without parasitic radiators is another method considered as one of the novel gain-enhancing techniques [14].

In this paper, we propose a high gain and wide band aperture coupled microstrip antenna with a mounted Horn on a FR4 substrate in the frequency range of 57–64 GHz. The structure has bandwidth of 8.3% with a maximum gain of 11.65 dBi.

2. Antenna Design

Figure 1(a) shows the side view of the proposed multilayer antenna, while the exploded 3D view is displayed in Figure 1(b). The design is a combination of ACMPA and a Horn antenna mounted on FR4 substrate, where the

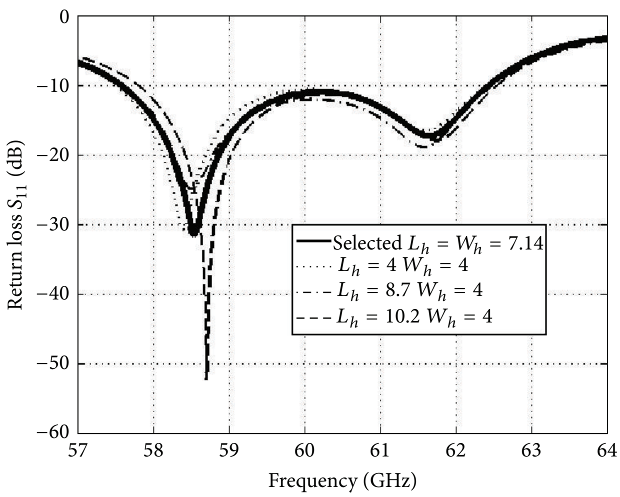

Figure 2: Varied Horn dimensions.

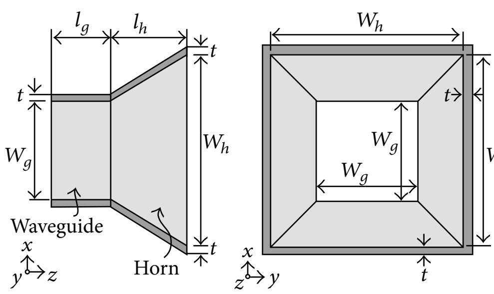

Figure 3: Dimensions of waveguide and pyramidal horn.

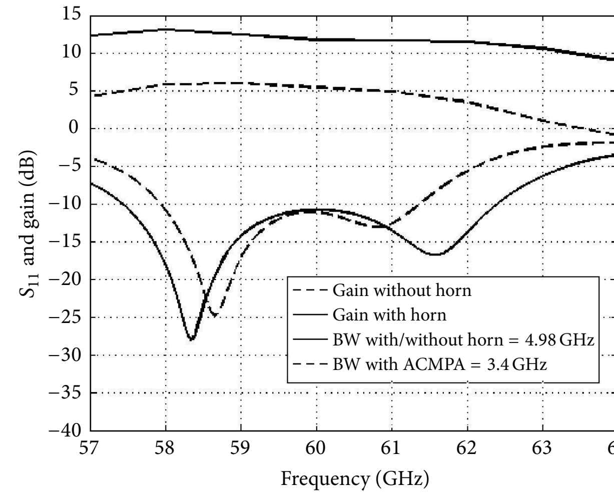

Figure 4: Comparison of gain and bandwidth of ACMPA with and without Horn.

waveguide part of the horn is integrated on FR4 substrate. The model was simulated and optimized using RF simulation software CSTMicrowave Studio. The antenna is tuned to operate in a wide band of frequencies at 60 GHz. The multilayer antenna has three substrates with layers 1 and 2 having Rogers Duroid RT-5880 with $\epsilon r = 2.2$, $\tan\delta = 0.003$ and thickness $t_1 = 0.127$ mm and $t_2 = 0.254$ mm, while the third layer has FR 4 as a substrate with $\epsilon r = 4.3$ and thickness $t_3 = 1.6$ mm and a mounted Horn. A Rohacell foam of thickness $t = 2$ mm is placed around the Horn on top of third layer. The addition of FR4 and foam has no other effect, except to provide support to the mounted Horn, on the antenna performance. The ground with thickness ($t = 2 \times 0.0175$ mm) is made of conducting metal with a rectangular slot perpendicular to the microstrip feed having dimensions of L_s and W_s as given in Table 1. The patch is located on the top of the substrate, at layer 2, has dimensions of L_p and W_p as given in Table 1. The dimensions of substrates and ground are taken as $30 \times 30\,\text{mm}^2$ for the manufacturing point of view. The $50\,\Omega$ microstrip feed line at the bottom of lower substrate has a feed width of $W_f = 0.386$ mm as calculated from Ansoftdesigner. The feeding mechanism of the ACMPA excites the square patch that feeds the metallic pyramidal horn with a thin wall (2 mm). The horn has a great effect on enhancing the overall gain of the antenna without influencing the center frequency or the operating bandwidth. Table 1 shows the optimized values for the proposed antenna.

3. Results and Discussion

The effect on the simulated return loss, gain, and directivity with and without FR4 mounted Horn is clarified in this section. The addition of FR4 mounted Horn on ACMPA improves the gain from 5.6 dBi to 11.65 dBi. The variations of the return loss with horn dimensions are shown in Figure 2. The addition of Horn does not affect the return loss. The dimensions of the waveguide and the optimized mounted Horn are given in Table 1. Figure 3 shows the pyramidal horn antenna with a rectangular input waveguide. The initial length of the rectangular waveguide is chosen to be $L_g = \lambda_0/2$, which is a half wavelength at 60 GHz. The rectangular waveguide length has an effect on the reflection coefficient, which is minimum when L_g is around $\lambda_0/2$. For the pyramidal section we choose initial dimensions such that $W_h = 2W_g$ and $L_h = \lambda_0/2$ [14]. Starting from initial dimensions of the horn, we first adjusted the length of the rectangular waveguide such that a minimum reflection coefficient occurs at 60 GHz. Next, the length and aperture size of the pyramidal section were optimized to get the maximum bandwidth and gain of the proposed structure. The improved gain by the addition of pyramidal horn was established by using the well-known gain expression [16, 17] given as

$$G = 10\log 6.464\left(\frac{W_h L_h}{\lambda^2}\right). \qquad (1)$$

After numerous sessions of parameter sweeping, we obtained the following optimum dimensions: $W_g = 4.25$ mm, $L_g = 3$ mm, $W_h = 7.14$ mm, $L_h = 7.14$ mm, and $t = 2.0$ mm.

The S_{11} parameters of the proposed structure with ACMPA alone and after the addition of Horn antenna remain the same at 8.3%, while the gain and directivity of the structure without the addition of Horn is 5.6 dB and 6.68 dBi, respectively. The beamwidths of the E-plane and H-plane,

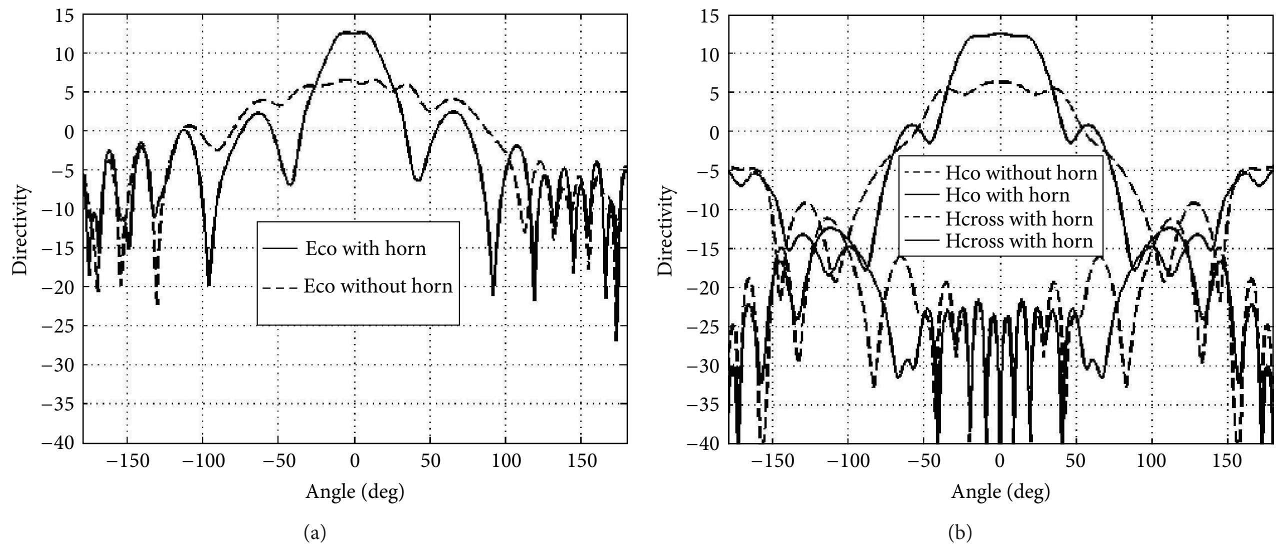

Figure 5: (a) Simulated E-plane radiation pattern with and without Horn. (b) Simulated H-plane radiation pattern with and without Horn.

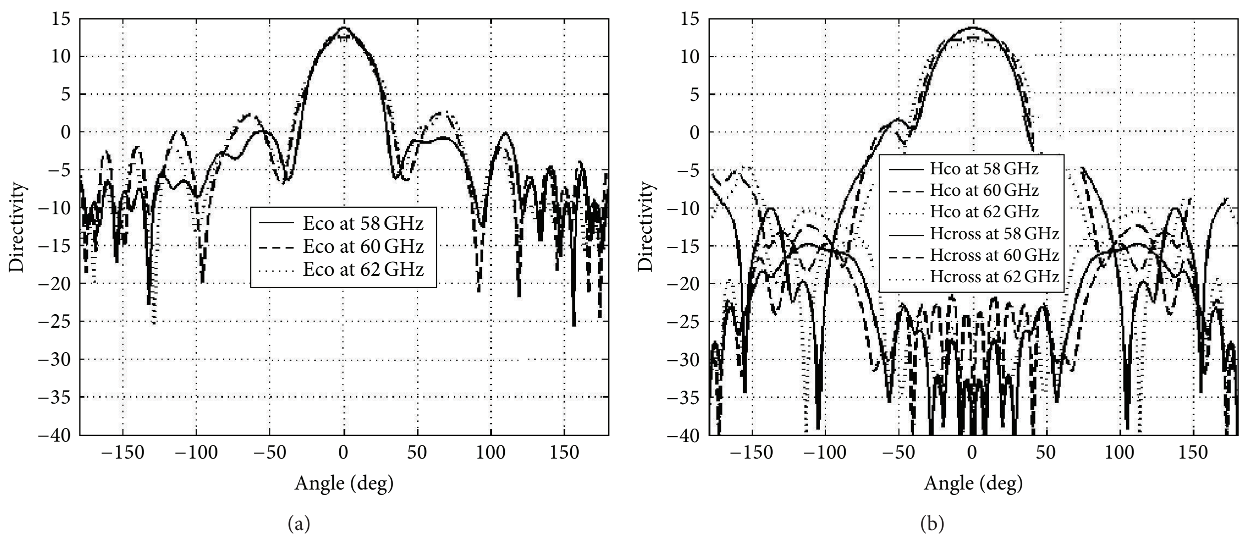

Figure 6: (a) Simulated E-plane radiation pattern at 58, 60, and 62 GHz. (b) Simulated H-plane radiation pattern at 58, 60, and 62 GHz.

without the Horn, for the proposed antenna at 60 GHz are 89.5° and 91.7°, respectively. Figure 4 shows the comparison and improvement of gain and bandwidth of ACMPA alone and after the addition of Horn antenna. With the ACMPA structure alone having the same thickness at $t_1 = t_2 = 0.127$ mm, the bandwidth achieved is 3.4 GHz. With different thickness at $t_1 = 0.127$ mm and $t_2 = 0.254$ mm, the improved bandwidth is 4.98 GHz. The final bandwidth achieved is 8.3% (57.437–62.426 GHz). The addition of Horn results in an increase in the directivity and gain of the proposed antenna and has no effect on the bandwidth. The maximum directivity and gain achieved are 12.51 dBi and 11.65 dBi. The simulation has taken into account the substrate and metallic losses. The estimated efficiency is 82%.

Figures 5(a) and 5(b) show the comparison of the simulated radiation patterns, in both the E-plane and the H-plane, with and without horn for the proposed antenna at 60. The ACMPA influences the side-lobe level and radiation pattern symmetry of the proposed horn-patch combined structure, in the E-plane and H-plane. Thus for the horn-patch combined structure the E-plane has side-lobe of level −10.3 dB, half-power beamwidth of 34.9°, and a back radiation of −18.11 dB. The H-plane radiation pattern has a side-lobe of −17.6, half-power beamwidth of 54.4°, back radiation of −17.67 dB, and cross polarization level of < -30 dB. Figures 6(a) and 6(b) show the E-plane and H-plane radiation patters, of the proposed antenna with horn, for the frequencies at 58, 60, and 62 GHz, respectively.

4. Conclusion

From many hybrid techniques available for achieving a high gain antenna with stacked elements, one ACMPA with a FR4 mounted Horn for millimeterwave (MMW) application has

Table 1: Parameters of the proposed antenna in mm.

Design	Antenna element	Dimensions/parameters (mm)
Layer 1	Microstrip feed	Feed width, $W_f = 0.386$ Thickness, $t = 0.0175$ Stub length, $L_{fs} = 0.865$
	Substrate	RT Duroid 5880 Length, $L = 30$ Width, $W = 30$ $\epsilon r = 2.2$ $\tan\delta = 0.003$ Thickness, $t_1 = 0.127$
	Ground	Thickness, $t = 0.0175$ Length, $L = 30$ Width, $W = 30$
	Rectangular slot	Thickness, $t = 0.0175$ Slot length, $L_s = 1$ Slot width, $W_s = 0.2$
Layer 2	Substrate	RT Duroid 5880 Thickness, $t_2 = 0.254$ $\epsilon r = 2.2$ $\tan\delta = 0.003$ Length, $L = 30$ Width, $W = 30$
	Patch	Length, $L_p = 1.35$ Width, $W_p = 1.35$
Layer 3	Substrate	FR4 Thickness, $t_3 = 1.6$ $\epsilon r = 4.3$ $\tan\delta = 0.025$
	Cut in FR4	Length, $L_{fr} = 3$ Width, $W_{fr} = 4.25$
Horn	Horn dimensions	Horn length, $L_h = 7.14$ Horn width, $W_h = 7.14$ Waveguide length, $L_g = 3$ Waveguide width, $W_g = 4.25$ Thickness of metal horn, $t = 2$
Full structure	Total height	4

been simulated using CST Microwave Studio. An enhanced bandwidth and gain have been achieved by the addition of FR4 mounted horn antenna. The simulated antenna satisfies the < -10 dB return loss bandwidth of 8.3% around 60 GHz with 11.65 dBi of maximum gain. The estimated efficiency is 82%.

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