A Novel Shorted Higher-Order Mode Millimeter-Wave Patch Antenna

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Abstract

This paper presents a novel shorted higher-order mode patch antenna working at 60 GHz whose size has been enlarged for easy fabrication, lower cost as well as higher tolerance. From experiment, the antenna achieves a 4.5% impedance bandwidth, 6.1dBi gain and symmetric broadside radiation. Measured results validated the proposed design.

Keywords : Higher-Order Mode, Millimeter-Wave, Patch Antenna, PIFA, Differential-Fed

1. Introduction

Millimeter-wave wireless communication system is highly demanded for short-range applications, especially for Wireless Personal Area Network (WPAN). It provides sufficient unlicensed bands as well as a higher transmission rate at the level of Gb/s. Oxygen absorption characteristic of millimeter-wave limiting the transmission in short range is also preferable for WPAN. Many countries have already set up bands around 60 GHz [1] for high-speed and short-range communication and wideband, low-cost and high-performance 60 GHz antennas are indispensable components. Several antennas have been proposed in this band [2], [3]. However, because of their minute size, 60 GHz antennas necessitate expensive cost as well as strict restrictions on fabrication processes and facilities. In [4], a high-gain 8-by-8 microstrip patch array and a low-gain 10-cell uniform line width rampart antenna were developed. At the 60 GHz band, the dimensions of these antenna arrays are only a few centimeters but the required etching tolerance is 10 microns. Thus, unlike conventional low-frequency band antennas, a more accurate fabrication technology is needed which essentially increases the cost of the antenna. In [5], an integrated active patch antenna array using benzocyclobutene (BCB) and silicon substrate was proposed and built. For each antenna in the array, a cavity-backed patch with dimensions 1.53mm and 2.13 mm is applied. Again, due to the small size of the antenna it is hard to achieve an antenna array where many identical elements are required. When the antennas are fabricated, the center frequency varies as much as 3% from wafer to wafer which is not acceptable. Consequently, it necessitates more sophisticated fabrication approaches, and thus increases the overall cost.

For addressing fabrication cost and tolerance issues, an alternate solution which is cost effective and suitable for most current electronics manufacturing services providers is presented in the paper in which we propose to operate the antenna at a higher-order mode for antenna size enlargement. It can be easily fabricated with existing facilities and simple PCB manufacturing techniques, so as to reduce the expense of fabrication. In order to eliminate the side-lobe radiation of higher-order mode patch and limit the overall size of the antenna, shorting pins are applied to the patch as employed in PIFA [6]. However, it is known that the asymmetric structure of PIFA antenna results in deteriorated radiation patterns. Nevertheless, it is reported in [7] and [8], that the differential feeding structures can enhance the performance of the radiation pattern. Thus, this technique is also applied to achieve higher gain and symmetric broadside radiation.

Table 1: Dimensional parameters for the proposed antenna.

Parameters	*G*	*H*	*W*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	Pin diameters
Dimensions(mm)	15	0.254	0.3	2.6	2	1.2	0.1	0.6	0.45	0.7	0.3
Dimensions in term of λ_g	4.450	0.075	0.089	0.771	0.593	0.356	0.030	0.178	0.133	0.208	0.088

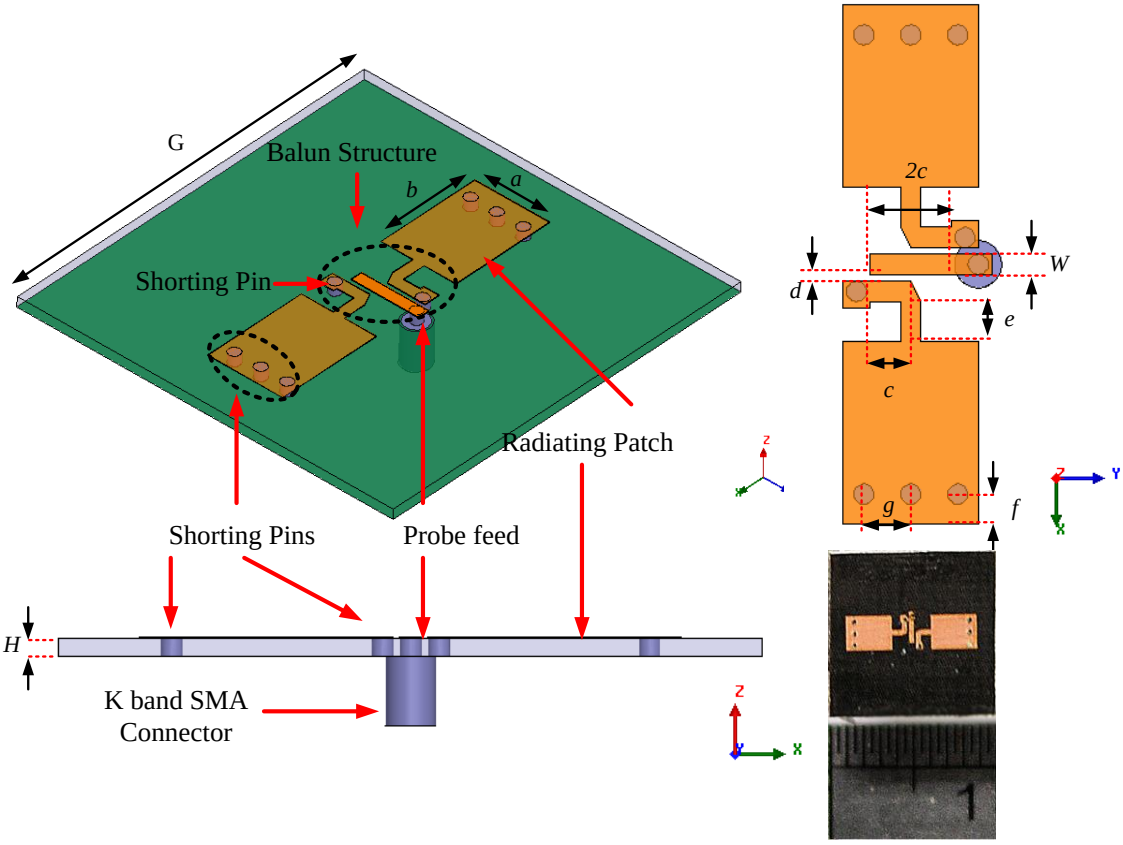

Figure 1: Antenna geometry and fabricated prototype.

2. Antenna Design and Working Principle

The geometry of the antenna is shown in Fig. 1 whose center frequency is designed at 60 GHz band. The substrate chosen is Duroid® 5880 with ε_r=2.2 (λ_g=3.371mm at 60 GHz) and *H*=0.254mm (0.078 λ_g). There are two identical shorted patch with length *a* and width *b* printed on the substrate and the shorting pins are fabricated by applying plated-through-hole technique. At the center of the antenna, a modified Marchand balun is set up for differential feeding. Two coupling sections, one for each radiating patch, are used and a shorting pin is added at the end of each coupling line. A probe is fed to the middle feeding line and a V band SMA connector is put beneath the ground plane. Additional feed lines with length *e* are used to connect the balun to the radiating patches. All the parameters involved are given in Table 1.

To achieve differential signal, the parameters (*w*, *d* and *c*) of Marchand balun need to be carefully tuned. The signal is injected from the SMA connector and fed to the feed line in the middle. It will then be coupled to the shorted microstrip coupling lines on both sides. To enlarge the antenna size, higher-order mode patches are used. The original length of the patch is chosen to be about 1.5 λ_g to work at TM_{30} mode. However, due to multi-direction current distributing on the patch, two undesirable side lobes will appear in the E-plane radiation pattern. Thus shorting pins are added and the patch length is reduced to *a* which is about 0.771 λ_g. Comparing with a conventional half-wavelength rectangular patch printed on the same substrate where the length is about 0.46 λ_g, the antenna is enlarged about 1.68 times along the current direction. Nevertheless, the shorted patch will result in a broadside but asymmetric radiation pattern. Thus, differential feeding technique is employed to alleviate the problem, achieving symmetric radiation patterns. It is also worth to note that the proposed antenna is a single layer structure with 0.3mm pins. The minimum width of the strip lines and the minimum gap width are merely 0.3mm and 0.1 mm respectively. Unlike antennas in [4] and [5], the proposed design is much easier to fabricate with typical PCB facilities.

3. Measurement and Result

In order to examine performance of the proposed antenna, a prototype was built as shown in Fig. 1. The performance of the balun was first studied and simulated with Ansoft HFSS. The result is potted in Fig. 2 (a). Crossing the frequency band (55 GHz to 70 GHz) which we are most interested in, the balun has an excellent performance. The phase difference of the balun changes from 180.2 ° to 177.1 ° while the amplitude difference of port 2 and port 3 is limited within 0.7 dB variation. The bandwidth of this balun is wide enough for our proposed antenna design. The return loss of the antenna was measured by a millimetre-wave Agilent Network Analyser ranging from DC up to 110 GHz (E8361A with N5260-60003 wave guide T/R module) and plotted in Fig. 2 (b). The antenna is working at 62.2 GHz with 4.5% impedance bandwidth from 60.8 GHz to 63.6 GHz ($S_{11} \leq$ -10 dB). Comparing with the original design from simulation, the center frequency shifts 0.8 GHz higher from 61.4 GHz but with a better impedance bandwidth. The simulated antenna has 3.6% bandwidth. The variation on center frequency is mainly due to the unavoidable fabrication errors. However, due to the enlarged structure, the frequency shift in this design is merely 1.3%, which is twice better than the variations involved in [5]. We have also noticed that, the absolute impedance bandwidth of 2.8 GHz is insufficient for the WPAN applications. This is mainly due to the relatively thin substrate applied for designing the antenna. If the substrate is increased further, the bandwidth can be improved, but a thicker substrate will result much poorer balun performance. Therefore, at this state, we are still searching for methods that may be applied for bandwidth enhancement. In spite of that, this antenna has already demonstrated an improved bandwidth than regular patch antennas described in [4] and [5] (about 1.5%). For gain and radiation patterns, we employed a home-made tester described in [9] for measurement. The measured gain of 6.1 dBi is achieved by comparing with a standard antenna. The radiation pattern can only be measured from -80 ° to +80 ° (with correction) due to the limitation of the facility. Both simulation and measurement results are shown in Fig. 3. The co-polarizations on both E- and H-plane are in broadside direction and symmetric. The side lobes of the higher-order mode radiation are eliminated by adding shorting pins. The measured cross-polarizations on both planes are about 10 dB lower than co-polarization. This is mainly due to the orthogonal currents flow through the balun structure. The simulated front-to-back ratio is about 15 dB which is also acceptable. The measured results are in good agreement with the simulation.

4. Conclusion

A novel differential-fed, shorted higher-order mode millimeter-wave patch antenna is proposed. The antenna working at 62.2 GHz has 4.5% ($S_{11} \leq$ -10 dB) impedance bandwidth with 6.1 dBi gain at the center frequency. Higher-order mode patch was employed to increase the size of the antenna. With the presence of shorting pins and differential feeding scheme, the antenna retains broadside symmetric radiation on both E- and H-plane. Moreover, the antenna is designed on a single layer substrate with dimensions that can be fabricated easily with typical PCB facilities and simple techniques. Without performance sacrificed, a low-cost, easily fabricated millimetre-wave patch antenna has been demonstrated and it provides an alternate solution for antennas working for high speed and short range wireless communication systems. Further refinement is needed to meet the bandwidth for WPAN at 60 GHz.

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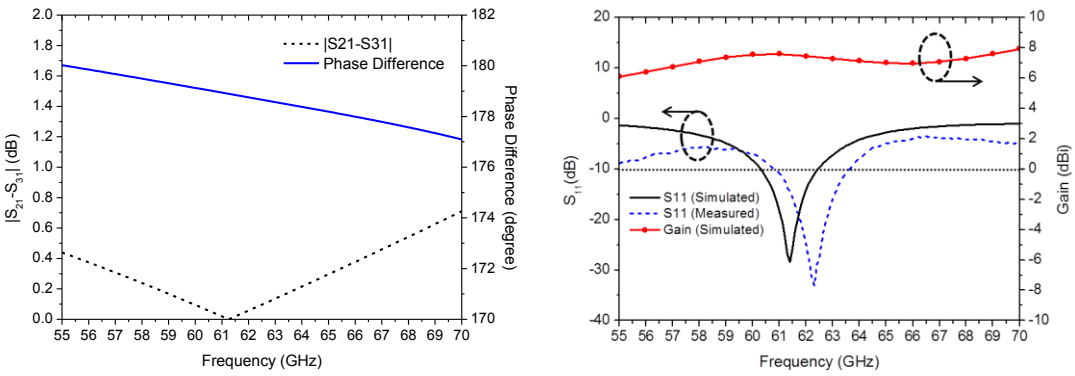

Figure 2: (a) Simulated amplitude difference and phase difference of the balun. (b) Return loss and gain of the proposed antenna.

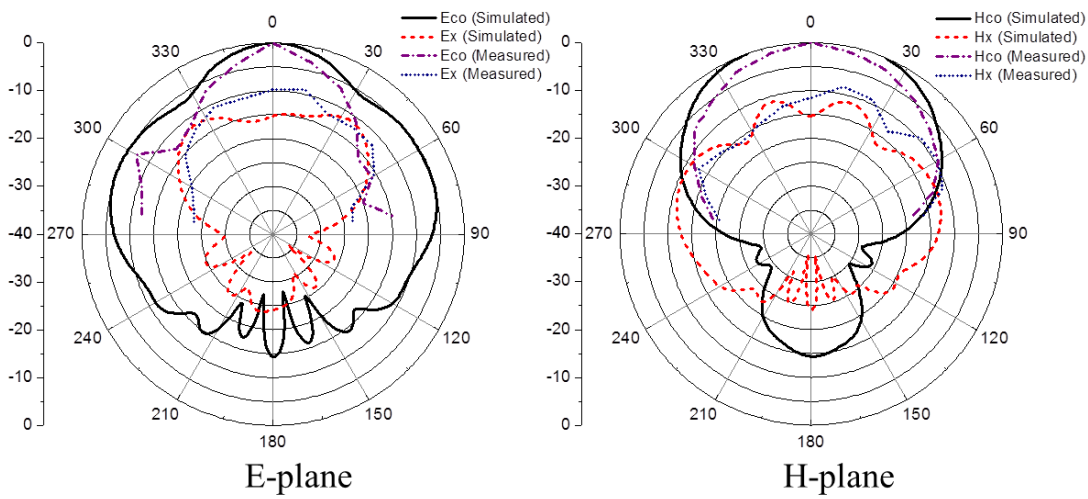

Figure 3: Measured and simulated radiation patterns of the proposed antenna at center frequency.