High gain 60 GHz band printed quasi-Yagi antenna using a novel microstrip-slotline transition feed

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Abstract—**In this paper, a high gain printed quasi-Yagi antenna is introduced for 60 GHz wireless applications. The antenna is fed by a novel microstrip-slotline transition consisting of a curved microstripline and circular slot in order to allow wideband characteristics. A corrugated ground plane is employed as a reflector for improving gain and small gain variation. The proposed antenna has an impedance bandwidth of 49.8–68.5 GHz for a –10 dB reflection coefficient and a gain of 10.50–12.8 dBi within this bandwidth. In addition, the antenna exhibits a stable radiation pattern with half power beamwidths of 36°–50° and 41°–52° in the *E*- and *H*-planes, respectively.**

Keywords: Microstrip-slotline transition, quasi-Yagi antenna, 60–GHz communications

I. INTRODUCTION

The international spectrum around 60 GHz is assigned for unlicensed wireless communications. Alternative spectrums are reserved in different areas of the world, e.g. 57–64 GHz in North America and Korea, 59–66 GHz in Europe and Japan, and 59–64 GHz in Australia [1, 2]. Wireless communications near 60 GHz are ideal for high throughput, short-distance systems due to many attractive properties, such as wide bandwidth and high atmospheric absorption. Therefore, 60 GHz antennas require characteristics such as a wide bandwidth over the 57–66 GHz spectrum, high directivity, and narrow beamwidth in order to avoid significant path loss, and small gain variation for stable operation.

In the past several years, various kinds of antennas were introduced for 60 GHz communications. On-chip antennas were demonstrated using complementary metal oxide semiconductor (CMOS) compatible manufacturing technology [3, 4]. However, the gain of these antennas is fairly low due to on-chip integration for compact sizes. Microstrip antennas are utilized in multi-layer substrates with parasitic patches in order to achieve high gain characteristics [5, 6]. Substrate integrated waveguide antennas were also developed based on a horn structure [7] and Yagi-Uda [8, 9] models. However, the bandwidths of these antennas were insufficient to cover the 60 GHz bands. A compact tapered slot antenna printed on a liquid crystal polymer substrate [10] was presented with a gain of 6.8 – 9.9 dB at 57 – 66 GHz, but had a very complicated topology owing to the use of a horizontal metallic reflector.

This paper describes a printed high gain 60 GHz quasi-Yagi antenna fed by a novel microstrip-slotline transition. A corrugated ground plane and five parasitic strips are employed as the reflector and directors, respectively, in order to achieve high directivity and small gain variation. The proposed antenna has an impedance bandwidth of 49.8 – 68.5 GHz for a –10 dB reflection coefficient and a gain of 10.5 – 12.8 dBi within this bandwidth.

II. ANTENNA DESIGN AND CHARACTERISTICS

Figure 1 shows the geometry of a high gain 60 GHz printed quasi-Yagi antenna. The antenna was designed on an 8×22 mm2 Rogers RT/Duroid 5880 substrate with a dielectric constant of 2.2 and a thickness of 0.254 mm. The antenna is comprised of a microstrip-slotline transition as the feed with an input impedance of 50 Ω, a truncated ground plane as a reflector, a printed dipole driver, and five parasitic strip directors. The ground plane was corrugated in order to improve antenna gain with a small gain variation. The antenna is fed by a novel microstrip-slotline transition specially designed for 60 GHz bands. The microstripline was designed on the back side of a substrate with an input impedance of 50 Ω. The slotline was designed on the top side of a substrate with a characteristic impedance of 137 Ω. In order to match the impedance between the microstripline and slotline, a curved microstripline and circular slot were inserted into the transitions. A full-wave electromagnetic simulator, CST Microwave Studio, was used to investigate the characteristics of the proposed antenna. The design parameters of the optimized antenna were chosen in terms of wide impedance bandwidth, high directivity, and small gain variation, as follows: W_{ms} = 0.8 mm, L_f = 5 mm, L_s = 2 mm, r_c = 0.3 mm, r_f = 0.5 mm, w_f = 0.22 mm, g = 0.1 mm, L_p = 1.8 mm, s_p = 0.1 mm, w_p = 0.2 mm, w_s = 0.2 mm, S_1 = S_2 = S_3 = 0.95 mm, L_1 = 1.8 mm, L_2 = 1.3 mm, w_c = 0.4 mm, and h = 0.254 mm. Based on the above optimized design parameters, we investigated the corresponding variations in the antenna characteristics due to the change of main design parameters.

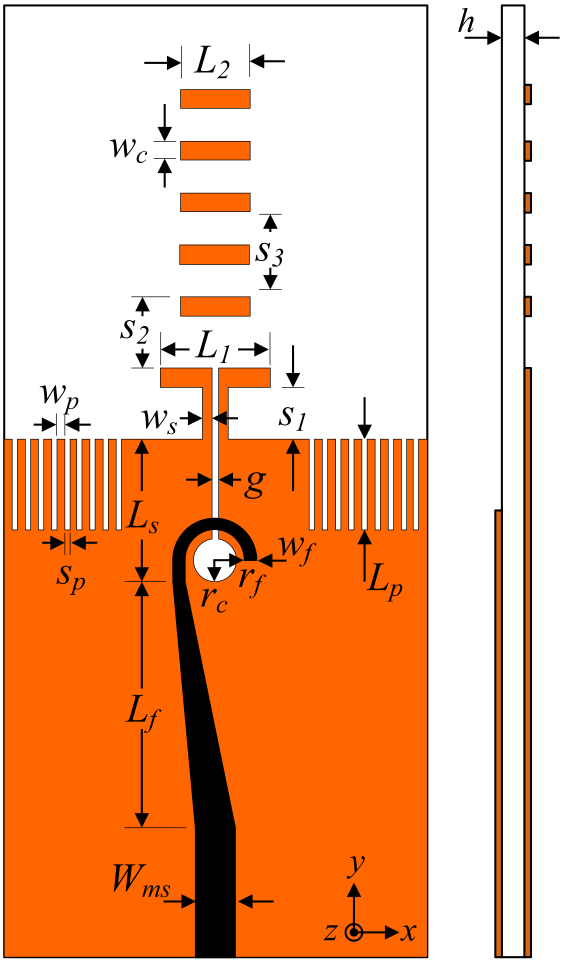
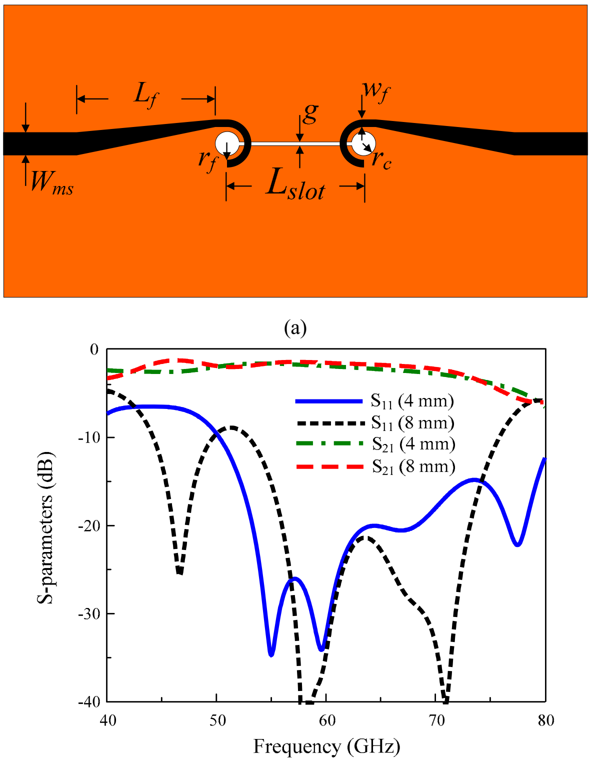


Figure 1. Geometry of the high-gain 60 GHz band printed quasi-Yagi antenna.

As mentioned above, the 60 GHz printed quasi-Yagi antenna is fed by a novel microstrip-slotline transition that was specially designed for 60 GHz bands. Fig. 2(a) shows the back-to-back transition structure and Fig. 2(b) plots its simulated S-parameters for different slotline lengths (L_{slot}). The microstripline was designed on the back side of substrate with characteristic impedance of 50 Ω and W_{ms} = 0.8 mm. The slotline was designed on the top side of substrate with a characteristic impedance of 137 Ω and g = 0.1 mm. To match the impedance between the two, a curved microstripline and circular slot were inserted to the transitions. The curved microstripline comprised a 50 Ω to 100 Ω tapered feedline as a wideband transformer and a half of printed ring. The transformer was shaped from wide-line width (Z_o = 50 Ω) to narrow-line width (Zo = 100 Ω) with a length L_f = 5 mm. The half of printed ring has line width w_f = 0.22 mm and a radius of r_f = 0.5 mm. The circular slot was etched on the ground plane with a radius of r_c = 0.3 mm. As shown in Fig. 2(b), for both cases of L_{slot} = 4 mm and L_{slot} = 8mm, the reflection (S_{11}) and transmission (S_{21}) coefficients were < –20 dB and ~ –2 dB, respectively, at 57 – 66 GHz. These make the transition widely suitable for the 60 GHz communications.



(a)

(b)

Figure 2. (a) Back-to-back microstrip-slotline transition and (b) Simulated S_{11} and S_{21} for the slotline length (L_{slot}) of 4 mm and 8 mm.

Fig. 3 shows the reflection coefficient of the antenna as a function of frequency for different lengths of the driver, L_1. As the length L_1 was varied from 1.6 to 2.0 mm in steps of 0.2 mm, the lower resonant frequency decreased while the higher one hardly changed. This indicates that the length of the driver mainly determines the lower resonant frequency. Fig. 4 shows the reflection coefficient of the antenna as a function of frequency for different lengths of the director, L_2. As L_2 was varied from 1.1 to 1.5 mm in steps of 0.2 mm, the higher resonant frequency decreased while the lower resonance remained unchanged. This indicates that the length of the driver mainly determines the upper resonant frequency. Fig. 5

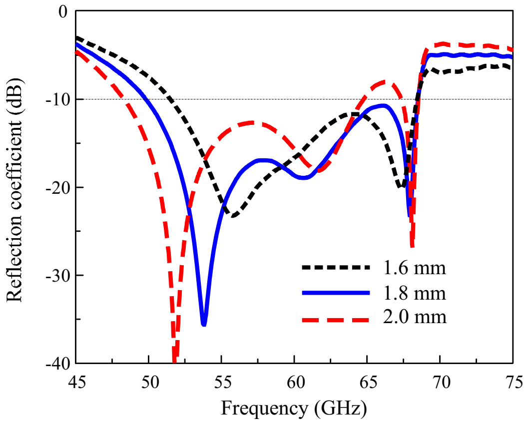


Figure 3. Reflection coefficient as a function of frequency for different length of the driver (L_1).

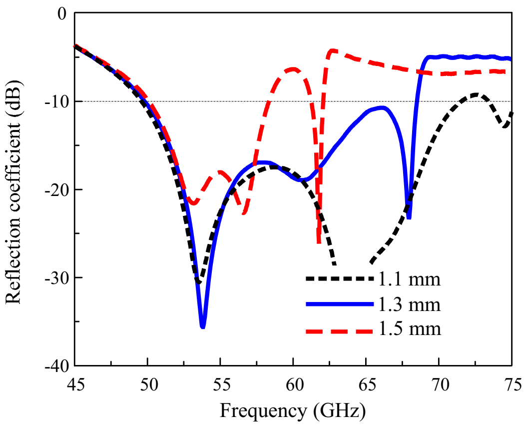


Figure 4. Reflection coefficient as a function of frequency for different length of the director (L_2).

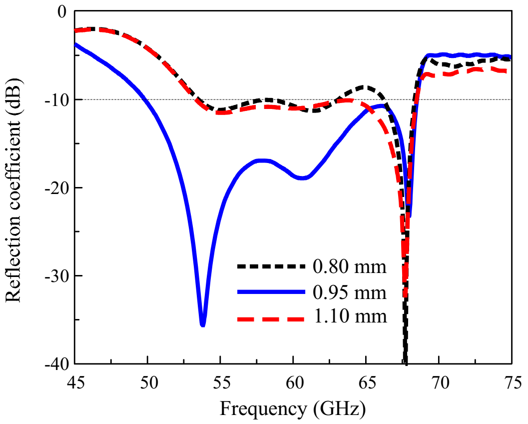


Figure 5. Reflection coefficient as a function of frequency for different spacing (S_2) between driver and director.

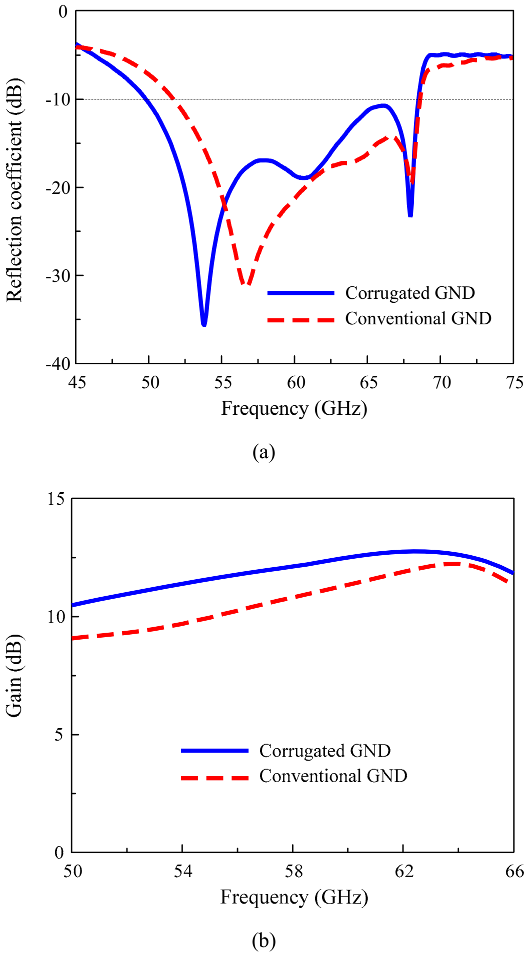


Figure 6. Reflection coefficient and (b) Gain of the antenna with and without corrugated ground.

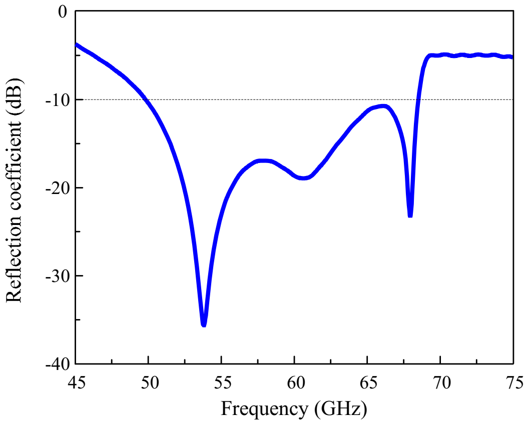
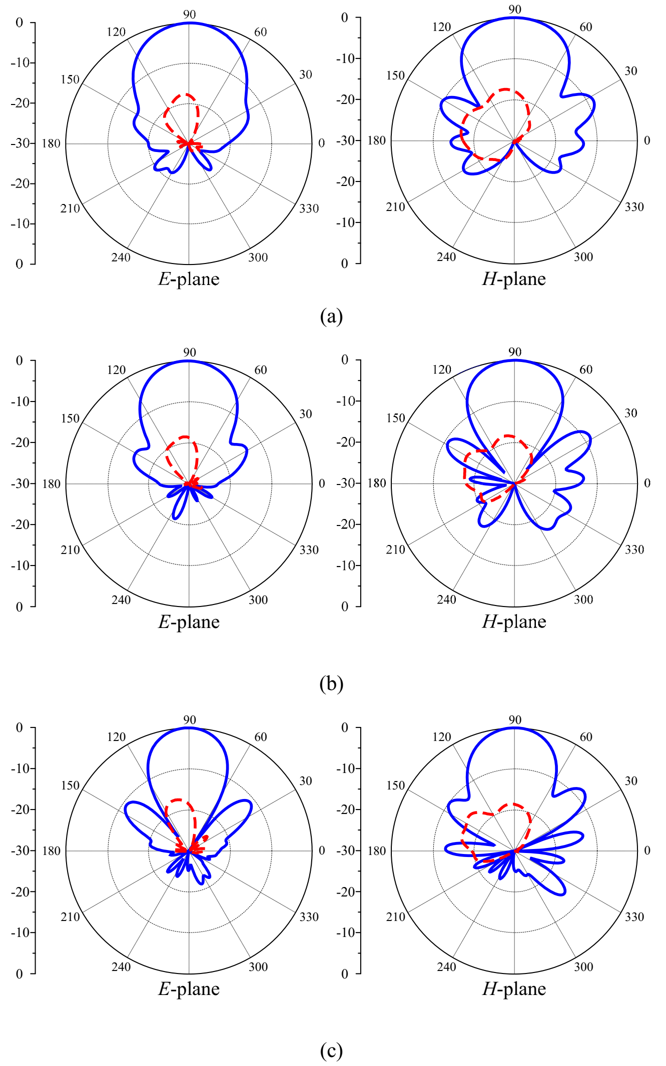


Figure 7. Reflection coefficient of the proposed antenna.

shows the reflection coefficient of the antenna as a function of frequency for different spacing (S_2) between the driver and directors. The effect of the spacing on the reflection coefficient is relatively significant. The reflection coefficient is optimized at a spacing of 0.95 mm, which is approximately one quarter of the effective wavelength ($\lambda_{eff}/4$) at the frequency of 60 GHz.

The proposed antenna utilizes a corrugated ground plane for enhancing the bandwidth and improving the gain in the low frequency region of the operating bandwidth. Fig. 6 shows a comparison of antenna characteristics with conventional and corrugated reflectors. The bandwidth was extended in the low frequency region but changed little in the high frequency region with the corrugated ground plane as shown in Fig. 6(a). The antenna has a maximum gain of 12.2 dBi at 64 GHz and a gain variation of 9.5 – 12.2 dBi with a conventional ground plane. With a corrugated ground plane, a maximum gain of 12.77 dBi at 62.5 GHz and a gain variation of 10.5 – 12.8 dBi at 50 – 66 GHz are achieved, as shown in Fig. 6(b). These results indicate that antenna gain can be improved and small gain variation can be achieved using a corrugated ground plane.

The results of the optimized antenna are shown in Figs. 7, 8, and 9, including the reflection coefficient, radiation patterns, and peak gain, respectively. As shown in Fig. 7, the antenna yielded an impedance bandwidth of 49.8 – 68.5 GHz for a –10 dB reflection coefficient, which covered all 60 GHz bands. As shown in Fig. 8, the radiation patterns were stable and quite symmetric across the bandwidth with high front-to-back ratio (>20 dB) and low cross-polarization level (<–17 dB). Fig. 4 also shows half power beamwidths of 36° – 50° and 41° – 52° in *E*- and *H*-planes, respectively. The peak gain of the proposed antenna ranged from 10.5 to 12.8 dBi within the impedance matching bandwidth and yielded a small gain variation of ±0.5 dBi at 57 – 66 GHz, as shown in Fig. 9.



(a)

(b)

(c)

Figure 8. Radiation patterns: (a) 52 GHz, (b) 58 GHz, and (c) 64 GHz. ━━ Co-polarization and ‒ ‒ ‒ Cross-polarization.

III. CONCLUSION

A printed 60 GHz quasi-Yagi antenna has been introduced with a novel microstrip-slotline transition feed that employs a curved microstripline and circular slot in order to match the impedance between the microstripline and the slotline. A corrugated ground plane is used as a reflector in order to enhance the gain, and consequently achieve minimum gain variation. The proposed antenna has an impedance bandwidth of 49.8 – 68.5 GHz for a –10 dB reflection coefficient, gain of 10.5 – 12.8 dBi, and a front-to-back ratio and cross-polarization level better than 20 dB and –17 dB, respectively. With this wideband, high gain, small gain variation, and stable radiation pattern, the microstrip-slotline transition fed quasi-Yagi antenna can be widely used in 60 GHz wireless communication systems.

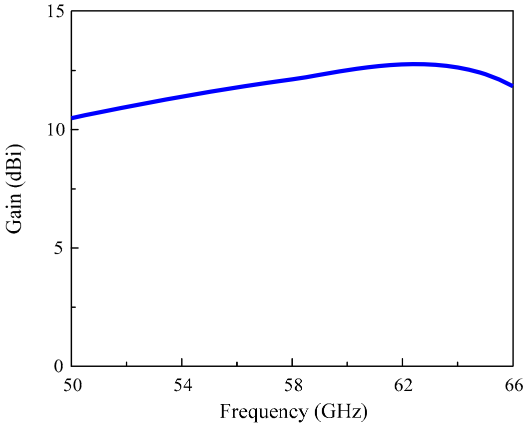


Figure 9. Gain of the printed quasi-Yagi antenna.

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