Wideband Planar Yagi Antennas for Millimetre Wave Frequency Applications

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***Abstract*: In this paper, a very wide-band Yagi antenna suitable for high-data rate communication in the millimetre-wave frequency range is presented. The coplanar waveguide (CPW) fed antenna is realised on InP substrate using the CPW ground planes as the reflector elements. The measured S_{11} return loss under -10 dB shows a 100% bandwidth for the 140-220 GHz frequency band antenna and 50% for the 220-325 GHz frequency band antenna. The maximum measured gain of the antenna is 7.35 dB at 202 GHz and 4.75 dB at 260 GHz.**

Keywords: Wideband antennas, millimetre-wave antennas, planar antenna, Yagi antenna.

Introduction

Applications of signals with frequencies above W-band (75-110 GHz) have been generating lots of interests in recent years. Some of these applications include wide-band communication systems, automotive radar, radio navigation and radio astronomy. Compact and easily integrable planar antennas would meet most of the requirements for these applications. Wide bandwidth would allow for increased data rate currently in demand for most high-speed wireless communications applications. Yagi-Uda antennas can be used for applications requiring high directivity where the power density is concentrated in a desired direction, such as point-to point wireless communication.

Although planar Yagi antenna generally has a larger bandwidth than patch antenna which is one of the simplest form of planar antennas, many techniques have been developed to increase the bandwidth of planar antennas. One method been used is the transition from one transmission line to another to improve matching. A compact wideband planar printed quasi-Yagi antenna was reported in [1]. This uses a microstrip-to-slotline transition with a stepped connection to improve impedance matching. A measured bandwidth of 92.2% from 3.8 to 10 GHz is reported with gain between 4.1-7 dB. Others have employed integrated baluns of microstrip-to-slotline transition [2] and reported 70% bandwidth from 3.1 to 10.6 GHz with 4 dBi gain. Another of such transition was reported for a modified quasi-Yagi antenna with microstrip-to-coplanar strip transition using artificial transmission lines [3]. Here the artificial transmission lines are implemented using quasi-lumped elements which require fine tuning to account for cross-coupling between the lumped elements. The reported bandwidth was 38.3% with gain around 4 dBi. These methods introduce complexity due to the balun feeding systems and the transition. Also implementing transmission lines using quasi-lumped components leads to a lot of problems as frequency increases.

Another method being proposed is the use of antenna arrays [4]. Here a 32×32 patch antenna array was proposed and reported to greatly improve bandwidth and gain. Here the arrays are implemented on multi-layered substrate with sub-arrays fed by a 1-to-4 micro-strip divider. The measured gain was reported to be within the range of 28.81-29.97 dBi with a working bandwidth of 91-97 GHz. While the reported gain for this method is quite high, it should be noted that the entire size is 92×66 mm^2 making it quite large and the need for multi-layered substrate introduces complexity.

In this paper, we have presented simple quasi-Yagi antenna which employs a simple coplanar waveguide feed proposed in [5] and optimized it for frequency bands at 140-220 GHz and 220-325 GHz. The antenna features a very wide bandwidth and decent gain. The antenna measured and simulated return-loss (S_{11}) and gain will be presented and discussed.

Antenna Design and Simulations

The design for the wideband planar quasi-Yagi antenna employs a simple CPW feed eliminating the need for complicated balun.

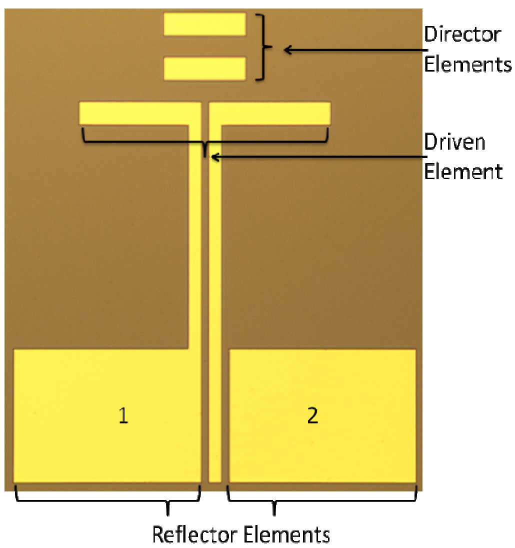

Figure 1. Planar quasi-Yagi antenna configuration

Planar Quasi-Yagi Antenna Configuration

The asymmetrical antenna geometry is shown in Figure 1 and consists of a driven element, two director elements and uses the CPW feed line ground planes as the reflector elements. It is implemented on a 600 μm thick indium phosphide (InP) substrate with dielectric constant, ε_r of 12.56. Gold, 400 nm thick is deposited using electron beam evaporator to pattern the antenna elements. With the effective wavelength, λ_{eff} calculated, the antenna dimensions calculated for design frequencies of 200 and 300 GHz are; driven element length, L_{Driven} = 418 and 279 µm, director element, $L_{director}$ = 135 and 90.3 µm and reflector lengths, $L1_{Reflector}$:$L2_{Reflector}$ = 295:311 and 204:207.4 µm respectively.

Simulations
The simulations for the antennas were carried out using the commercial HFSS simulation package which employs finite element method to optimize the designs. From the simulated return loss shown in Fig. 2 the optimized antenna design shows a bandwidth spanning the entire simulated frequency range.

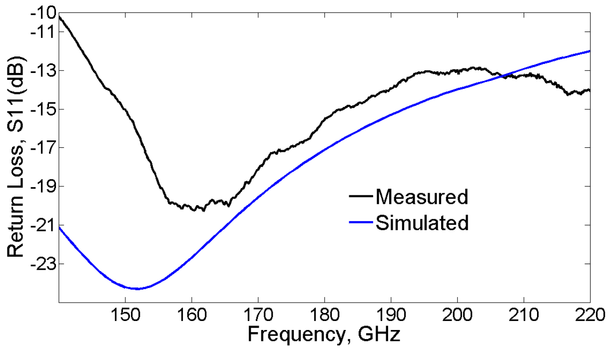

Figure 2. Return loss of the antenna at 140-220 GHz frequency band.

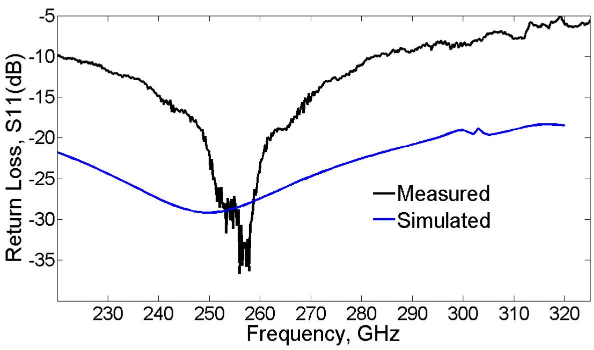

Figure 3. Return loss of the antenna at 220-325 GHz frequency band.

Measurements Results

The measurements were carried out in G and J band using Agilent PNA and Virginia Diode Inc (DVI) frequency extender for 140-220 GHz and 220-325 GHz frequency bands. The CPW transmission line feed allows for RF on wafer probing using narrow pitch ground-signal-ground (G-S-G) probes. The simulated and measured return loss of the 140-220 GHz band antenna is shown in the plot in Fig. 2, and Fig. 3 shows plot of the measured and simulated return loss for the 220-325 GHz frequency band antenna. The discrepancies can be attributed to signal reflections due from the metal chuck of the probe station. Fig. 2 shows a -10 dB bandwidth which spans the entire frequency band from 140 -220 GHz. The 220-325 GHz frequency band antenna measured return loss shown in Fig. 3 shows a -10 dB bandwidth of 50% from 222-275 GHz. The gain of the antennas at is obtained using the Friis transmission equation shown in Eqn. 1 by,

$$G_r G_t = G^2 = \left(\frac{P_r}{P_t}\right)\left(\frac{4\pi R}{\lambda_o}\right)^2 \qquad (1)$$

The maximum measured gain of the 140-220 GHz frequency band antenna is 7.35 dB at 202 GHz and for the frequency band covering 220-325 GHz the maximum measured gain is 4.75 dB at 260 GHz.

Conclusion

Planar Yagi antennas have been presented at millimetre wave frequency range. The bandwidth of the return loss under -10 dB is 100% and 50% for the 140-220 GHz frequency band antenna and the 220-325 GHz frequency band antenna respectively. The maximum measured gain for the 140-220 GHz frequency band and the 220-325 GHz frequency band antennas are 7.35 and 4.75 dB respectively. The bandwidth and the frequency range make it a good option for high data rate point-to-point wireless communication and terahertz applications.

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