A 60 GHz Conical Horn Antenna Excited with Quasi-Yagi Antenna

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Abstract — **A conical horn antenna excited with a quasi-Yagi antenna is presented. This antenna comprise a micro strip to circular wave guide transition and a circular horn into single unit. Transition was made non-contacting, which relax mechanical tolerance requirements. Antenna is simple to fabricate and feed, and provides single mode operation with medium gain and bandwidth. A gain of 16.5 dB with cross polarization of 19 dB is measured at 60 GHz, a 4 GHz return loss bandwidth (-11 dB) is achieved from 59 GHz to 63 GHz.**

I. INTRODUCTION

Ever increasing use of mm-wave frequencies in various communication systems with high data rate requires efficient antennas. In order to over come the high free space losses at mm-wave frequencies, which take place already with relatively short distance, antenna directivity and radiation efficiency has to be reasonably high. Large arrays can have considerable feed losses, and a high gain radiator is thus desirable. A horn antenna is in this perspective in favor.

In [1] a planar quasi-Yagi array with 8-element was presented, and a 12 dBi gain was measured over frequency range 8 to 11.7 GHz with element spacing of 0.5 λ. Radiation efficiency was 65 %, and in a similar 2-D array of [2] it was 50 %. The radiation efficiency of the quasi-Yagi itself exceeds 90 % [3]. By using horns as an array element mutual coupling is reduced. Still a planar approach can be applied for the feed network when horns or wave guides are excited directly with quasi-Yagi antenna. In some applications a single antenna will do, and the entire feeding network is avoided and a high aperture and radiation efficiency is achieved. This is acceptable especially if the length of the antenna is not excessive. In the active antenna concept quasi-Yagi antenna can be treated as a two port. By using quasi-Yagi antenna in a horn equal and symmetric receiving characteristics can be obtained for each arm for all angles of reception due to axial propagation of the wave in the horn.

In [4] a coaxial-wave mode was gradually converted into surface-wave mode in a conical horn section. A 40 % bandwidth around 2 GHz was achieved. The total lentg of the antenna without the radome was about 3 λ with a flare angle of 25°. The substrate was cut to the cross section of the cone. More recently a planar microstrip to rectangular waveguide transition (RWGT) based on quasi-Yagi antenna [5] has been investigated. A transition fabricated on standard 5 mil alumina substrate was found to cover the whole V-Band [6]. This suggest that a direct mm-wave microstrip to horn transition can be done by operating a quasi-Yagi antenna in a conical horn. In order to ease mechanical tolerances a non-contacting rectangular substrate is used.

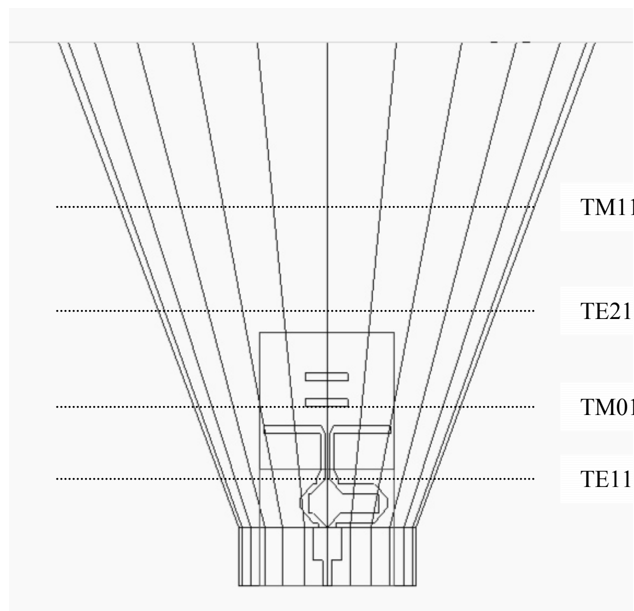

Fig. 1. Quasi-Yagi antenna placed in a conical horn to excite the dominant TE_{11} mode. The cutoff planes of the dominant mode and the three lowest higher order modes are marked on side. The length of the circular waveguide (D=1.25 mm) section is 0.8 mm, followed by a 6.7 mm conical horn section with an aperture diameter of 8.4 mm.

II. DESIGN

Microstrip to circular waveguide transition (CWGT) is placed symmetrically in a conical horn as shown in Fig. 1, the microstrip input is on the axis of the horn. A short circular waveguide section precedes the horn. The antenna as whole was analyzed and optimized with HFSS full wave EM-simulator. The length of the antenna was

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reduced to 1.5 λ due to computer memory, still enough to capture the whole transition effect. Transition, its location in the horn, and the flare angle of the horn is found to be responsible for the input match, as the length and the flare angle of the horn is due to radiation pattern.

The starting point for the horn transition was the RWGT [6]. In the CWGT case the impedance is higher due to proximity of the cutoff plane of the dominant TE_{11} mode (for empty circular wave guide), and the radiation element lengths and impedance levels has to be accommodated thereafter. Due to proximity of the cutoff plane impedance will change faster than in RWGT case. The surface wave coupling from the quasi-Yagi antenna to wave guide mode is more efficient in the RWGT, because the substrate extends over the whole waveguide section. These factors make the transition more narrow band than RWGT, but still provide more bandwidth than a regular patch antennas.

An additional director is used to enhance the coupling through directors at the high frequency range. The cutoff plane of the dominant mode is just behind the ground truncation of the microstrip line. The cutoff planes of the higher order modes TM_{01},TE_{21} and TM_{11} are also shown in Fig. 1. TM_{01} could be excited due to coupled line section presiding the drivers and TM_{11} due to directors and substrate. TE_{21} is possible due to substrate and asymmetry of the substrate in the horn. Simultaneous excitation of the dominant mode and higher order mode(s) for better aperture efficiency proved not to be functional. Since the antenna is operating only in the dominant mode, horn length can varied and a relatively large opening angle can be used. The optimum flare angle of the horn was found to be 50° for maximum gain.

EM simulation predicts a 13.5 dB gain and a 24 dB front-to-back ratio. This horn does not provide maximum gain with the given axial length [7] due to matching requirements, but gives the maximum gain with the given aperture diameter with a minimum length. The predicted gain of [7] is 13.3 dB.

An antenna of length 3 λ with aperture diameter of 14.7 mm (4.9 dB larger aperture area) was fabricated also. The aperture diameter and the axial length of this horn corresponds closely to an optimum horn of [7] with 17.5 dB gain

III. Measurements

Antenna performance is measured with HP8510C mm-wave waveguide setup. A RWGT is used to excite the microstrip feed of the horn antenna. Results were referred to antenna microstrip input by using measured RWGT data. The antenna gain was measured by using a calibrated reference antenna.

Figs. 2. and 3. show the measured return loss and the gain of the antennas. Both antennas have 11 dB return loss bandwidth of 4 GHz centered around 61 GHz. At the 60 GHz center frequency the gain is 12.0 dB and 16.5 dB for the short and long antennas respectively. Maximum gain range is shifted 1 GHz higher than anticipated. The radiation efficiency of the quasi-Yagi antenna was estimated to reduce the gain by 0.3 to 0.4 dB [6]. Gain loss due to finite separation between the antennas during the measurement [8] was less than 0.1 dB.

Measured aperture efficiencies referred to microstrip input are shown in fig. 4. By excluding the losses in the quasi-Yagi antenna the efficiency is 3 to 4 % higher than the shown values. The shorter antenna is slightly better.

Figs. 5. to 7. show the measured patterns of the 3 λ antenna at 58.5, 60 and 61.5 GHz. E-plane is slightly narrower than H-plane. The asymmetry in the E-plain is mainly due to balun and in the H-plain due to substrate, which make the aperture field distribution slightly asymmetric. At the low frequency range, where the field is launched into horn closer to ground truncation, the patterns get better. Error in probe position affects more at the high frequency end. The first side lobe in the E-plane is more or less merged in the main lobe, which is characteristics for an optimum length horn [7]. Cross polarization in the main beam direction is below 15 dB in all three cases. Similar patterns were obtained with the 1.5 λ antenna.

IV. Conclusion

Circular horn antennas excited with a quasi-Yagi antenna were presented. Single mode operation was achieved by placing the CWGT in the horn by suppressing potential higher order modes. Typical aperture efficiency for single mode circular horn antennas was achieved due to high radiation efficiency of the Quasi-Yagi antenna. The measured antenna gain and radiation patterns of the longer horn corresponds to an optimum horn characteristics with a waveguide input [7]. Wider bandwidth can be achieved by doing the transition in waveguide, which feeds the horn.

The use of quasi-Yagi antenna in horn makes this antenna a symmetric two port regardless of the angle of reception, which can be utilized in balanced receivers and transmitters. The edge diffraction from the incoming horn aperture is reduced, which can be of use in corrugated horns. Single mode operation of the antenna allows to integrate a polarizer directly at the aperture.

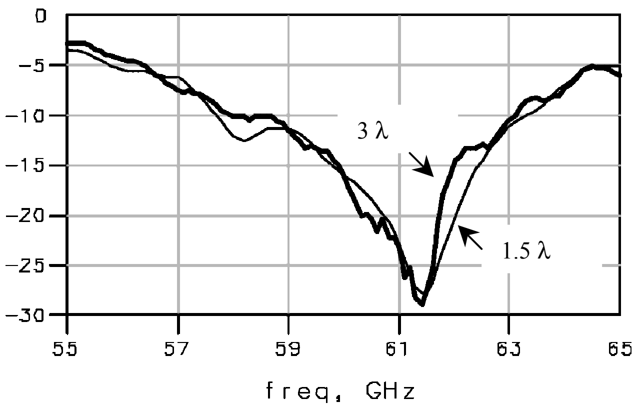

Fig. 2. Measured return loss of the 1.5 λ and 3 λ antenna on dB-scale from 55 to 65 GHz.

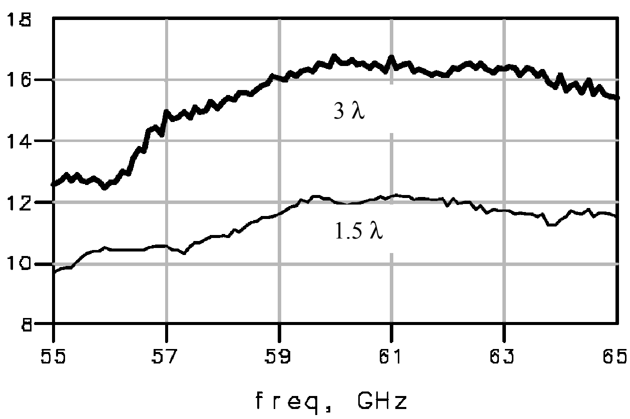

Fig. 3. Measured gain of the 1.5 λ and 3 λ antenna on dB-scale from 55 to 65 GHz.

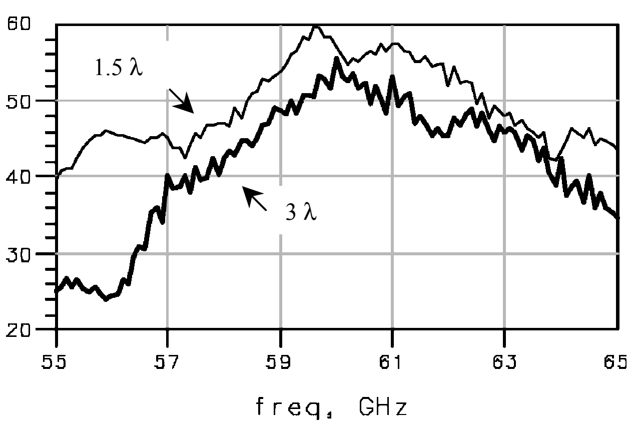

Fig. 4. Measured aperture efficiency of the 1.5 λ and 3 λ antenna on %-scale from 55 to 65 GHz.

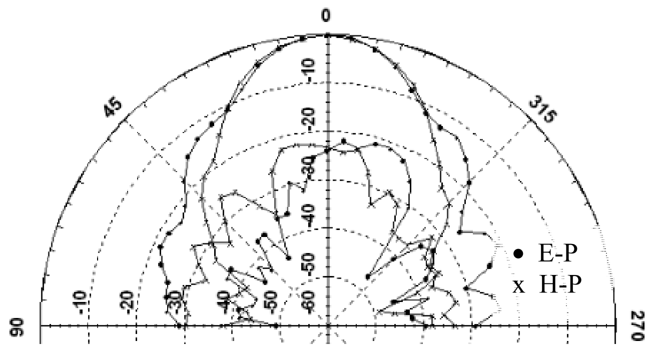

Fig. 5. Measured 58.5 GHz patterns of the 3 λ antenna on dB -scale.

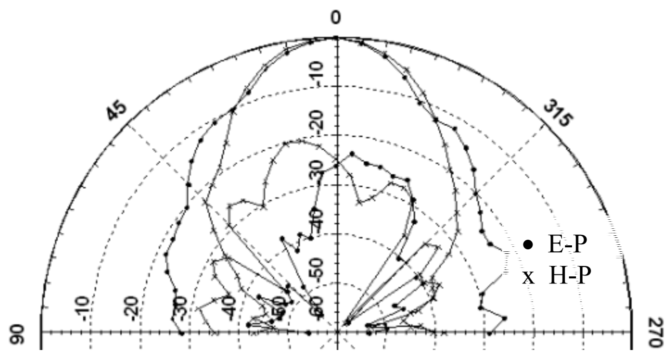

Fig. 6. Measured 60 GHz patterns of the 3 λ antenna on

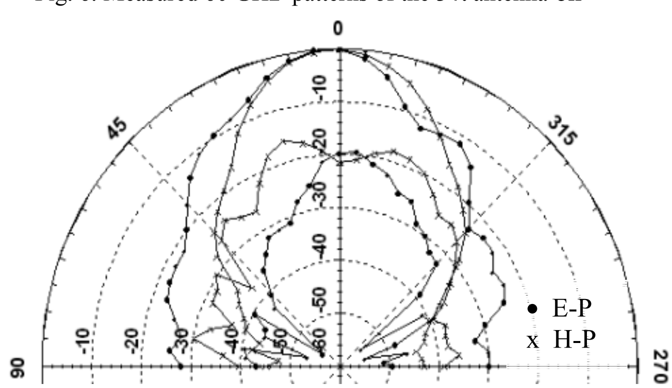

Fig. 7. Measured 61.5 GHz patterns of the 3 λ antenna on dB- scale.

ACKNOWLEDGEMENT

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