Submission Title: A first 300 GHz Phased Array Antenna
Date Submitted: 11. July 2017
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Re: -

Abstract: A concept of a phased array operating at 300 GHz with horn elements and some simulation and measurement results are presented.

Purpose: Provide Information to the Interest Group

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A first Phased Array Antenna with horn elements operating at 300 GHz
Outline

- TERAPAN Framework
- Phased Array Antenna at 300 GHz
- Performance in Simulations
- Measurement Results
- Summary
TERAPAN – SISO-Link

- Collaboration project (University of Stuttgart, Fraunhofer IAF, TU BS)
- 35nm GaAs mHEMT
- Fully integrated 300 GHz transmitter & receiver MMICs
- Compact high performance waveguide modules
- Link budget
  - -4.0 dBm transmit power
  - +24.2 dBi horn antenna gain (Tx)
  - -88.0 dB free space path loss 2 m
  - +24.2 dBi horn antenna gain (Rx)
  - -(-59.2 dB) receiver noise (noise figure 6.7 dB, 64 GHz bandwidth)

  = 15.6 dB SNR

- Successfully demonstrated 64 Gbit/s data transmission with QPSK (limited by measurement equipment and linearity)
Constraints and Targets for the Design

- Max. **4 channels**
  - Max. number of available AWG channels
  - Enough for beam steering demonstration
- Standard **WR-3 wave guide flange** for each element
  - Easier characterization of components
  - Practical reasons (easy exchange in case of defect, etc)
  - Flexibility
- Operational frequency range 275 to 325 GHz
- At least a **gain of 20 dBi** (whole array), 14 dBi single element
  - SISO-link used 24.2 dBi horn antenna
  - Transmitter: 20 dBi (array gain) + 6 dB (4 channels with the same power)
- Linear array in one dimension
  - Narrower main lobe
  - Better steering capabilities than 2x2
- Manufacturability
Proposed Antenna

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>3.0 mm (horn width)</td>
</tr>
<tr>
<td>C</td>
<td>1.0 mm (horn height)</td>
</tr>
<tr>
<td>D</td>
<td>0.8640 mm (WR3)</td>
</tr>
<tr>
<td>E</td>
<td>0.4320 mm (WR3)</td>
</tr>
<tr>
<td>F (flare)</td>
<td>3.577 mm</td>
</tr>
<tr>
<td>spacing</td>
<td>1.25 mm = C + 0.25 mm</td>
</tr>
</tbody>
</table>
Simulation Results – Single Element

- 300 GHz Pattern
- Single (inner) horn
  - 14.8 dBi gain
  - 50.0° horizontal HPBW (along width)
  - 23.6° vertical HPBW (along height)

- Outer elements
  - -0.2 dB less gain; Horizontal HPBW approx. 2° wider

- Average S11 of -25.7 dB; max. -22.7 dB
Simulated Impedance Matching

- Average $S_{11}$ of -25.7 dB; max. -22.7 dB
Simulation Results – Array

- 300 GHz Pattern
- Array
  - 20.7 dBi gain
  - 10.3° horizontal HPBW (along width)
  - 23.6° vertical HPBW (along height)
  - Grating lobes

All values for 300 GHz with Time Domain Solver of CST Microwave Studio
  - For 275 GHz 19.9 dBi, 11.3°, 24.9°
  - For 325 GHz: 21.4 dBi, 9.5°, 22.3°
Simulation Results – Grating Lobes

- 300 GHz Pattern
- Array
  - Grating lobes
  - Spacing bigger than half of the wavelength

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Antenna Scanner Setup

- Inhouse made antenna scanner in a semi-anechoic chamber at PTB in Braunschweig
- Vector network analyzer Rohde & Schwarz ZVA 50 with frequency extensions ZV-Z325
- S12 is recorded and analyzed
- Known reference horn on port 1, single element of the phased array at port 2
- Measurement bandwidth 10 Hz, 220 – 325 GHz in 5 GHz steps, angular range +/- 90 degree

Measurements of the array as a whole:
- No 5 port VNA at 300 GHz available
- with TERAPAN 4 Channel Rx/Tx-Modules
Antenna Patterns – Outer Elements

- Measurements match the simulation very well
  - Less than 0.6 dB mean error for horizontal patterns, standard deviation <1.35 dB
  - Less than 1.2 dB mean error for vertical patterns, standard deviation < 3.3dB
- Restricted to -45…45 deg. (horizontal)/45…135 deg. (vertical)
  - Mean error below 0.75 dB/1.6 dB with a standard deviation <0.4 dB/1.3 dB
Antenna Patterns – Inner Elements

- Measurements match the simulation very well
  - Less than 0.3 dB mean error for horizontal patterns, standard deviation < 0.82 dB
  - Less than 1.1 dB mean error for vertical patterns, standard deviation < 3.5 dB
- Restricted to -45...45 deg. (horizontal)/45...135 deg. (vertical)
  - Mean error below 0.4 dB/1.6 dB with a standard deviation < 0.3 dB/1.2 dB
Antenna Patterns – Frequency

- Measurements match the simulation very well
  - Increasing directivity with frequency
  - (Increasing gain with frequency)
Antenna Matching

- **Setup**
  - Single Element is aligned to the direct path ($0^\circ$).
  - VNA Sweep in 5 GHz steps

- S11 is below -20 dB for each antenna element: excellent matching
Demonstration of Beam Steering at NGMN IC&E 2016

Demo at NGMN IC&E 2016

- 60 cm distance
- single transmitter
- 4 channel receiver with phased array antenna
- electronic beam steering shown and verified by mechanical rotation
- QPSK modulation
- data rate of 12 Gbit/s (to see data transmission even within a side lobe)
- Local oscillator generated by DDS modules
Summary

• Requirements for 300 GHz antennas have been briefly reviewed
• A phased array with horn elements has been introduced
• Simulation and measurement results have been shown

• References:
Vielen Dank für Ihre Aufmerksamkeit.

Thank you for paying attention!