A compact H-band Power Amplifier with High Output Power

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Outline

• Motivation for sub-THz frequencies.
• Prior work at H-band.
• Potential applications for the amplifier.
• Amplifier design
  – unit cell and low-loss compact combiner
• Measurement results
• Summary and conclusion
Motivation

- **Objective:** support high data rates.
- **Sub THz (~300GHz)**
  - More available spectrum -> high data rates.
  - Shorter $\lambda$: more channels for the same array size.
- **Main challenge:** high losses (path loss $P_R \alpha \frac{\lambda^2}{R^2} e^{-\alpha R}$ + interconnect)
- **Solution:**
  - Phased arrays increase the directivity, the transmission range.
  - Use III-V technologies to produce more output power per element.

$$\frac{P_{\text{received}}}{P_{\text{trans}}} = \left( \frac{D_t D_r}{16\pi^2} \right) (\lambda / R)^2$$
Prior Work at H-band

• CMOS shows \(-3.9\) dBm at 257GHz [1].
• III-V technologies show better performance, though power and efficiency are still low.

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• Compact, low –loss combiner and high-efficiency power cell -> increase the efficiency and $P_{\text{sat}}/\text{area}$. 
This Work and Potential Applications

• Target ~ 17dBm output power with 4%PAE.
• \( P_{\text{out}} \approx 17\text{dBm} \) output power per element extends the link range to ~50m* (8x8 array, vertical and horizontal beam angles=7\(^{\circ}\))*
• Candidate PA for subTHz transmitters for long-range applications
• Drivers could be designed in InP or low-cost technologies.

• Measuring equipment->boost the output power of the sources.

*https://web.ece.ucsb.edu/Faculty/rodwell/Classes/ece218c/ECE218c.htm
250nm InP HBT Process, Teledyne [12]

- subTHz amplifier requires fast technologies.
- $f_{\text{max}} = 650\text{GHz}$.
- $BV_{\text{CEO}} = 4.5\text{V}$.
- $J_{\text{max}} = 3\text{mA/µm}$.
- Four Au interconnect.
- MIM cap (0.3fF/µm2).
- TFR (50Ω/square).
Power Amplifier Design

- Four-stage amplifier.
- Combine four power cells.
- Driver scaling sustains good PAE.

- Power combining techniques
  - Parallel combining: 4:1 transmission line combiner.
  - Series combiner: stacked unit cell.

Chip micrograph of the amplifier

Block diagram of the amplifier
Unit Cell Comparison

- Comparison between CE, grounded CB and CB with base capacitor
- Simulation under same bias condition
- Large signal simulation is more relevant in power amplifier
- CB with base capacitor shows the highest $\text{OP}_{1\text{dB}}$ with associated PAE
- Design is still challenging.

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<tr>
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<th>Gain*, dB</th>
<th>PAE @ $\text{OP}_{1\text{dB}}$**</th>
<th>$\text{OP}_{1\text{dB}}$, dBm</th>
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<tr>
<td>CE</td>
<td>4.9</td>
<td>13.6</td>
<td>13.1</td>
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<tr>
<td>Grounded CB</td>
<td>10.8</td>
<td>8.4</td>
<td>9.6</td>
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<tr>
<td>CB with 208f cap</td>
<td>5.6</td>
<td>16</td>
<td>13.7</td>
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*under opt load line condition without compression

At 270GHz

$P_{\text{out}}$, gain, and PAE for CE, grounded CB, and CB with base capacitor.
Unit Cell Design

- Shunt inductor: tunes the transistor parasitics.
- The cell requires resistive load impedance (~18Ω).
- Base capacitance is significantly reduced (~208fF).
  - Lower parasitic inductance → higher self resonance frequency.
  - Avoid gain uncertainty and stability problems.

![Schematic of the unit cell](image)

ZL~18Ω

- tuning cap
- series tuning
- shunt tuning
- bias line
- Bypass cap

Schematic of the unit cell
Combiner Design

• Wilkinson
  – Two $\lambda/4$ sections -> Bulky
  – High loss and skinny line
  – Works only with 50Ω cells
  – Higher BW

• Proposed combiner
  – Single $\lambda/4$ section -> very compact
  – Low loss
  – Works with non 50Ω cells
  – Smaller BW compared to Wilkinson
Combiner Design

- Low loss 4:1 transmission line combiner.
- Transforms 50Ω to the required loadline impedance for each cell using a single \(\lambda/4\) transmission line.
- Each two cells are combined by a TL with negligible electrical length.
- The required impedance for the two combined cells is 18/2Ω.
- The quarter line’s impedance is chosen to transform 100Ω to 18/2Ω.

Chip micrograph of the proposed combiner
Measurement Results: s-parameters

- Setup: PNA with 220-325GHz Oleson extender modules.
- Measured 3-dB bandwidth=48GHz.

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<td>172mA</td>
<td>9.4mA</td>
<td>275.5mA</td>
<td>14.8mA</td>
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Power Measurement: setup

- 110-170GHz VDI+ doupler -> 270-290GHz -> coupler
- Input power is sensed by the coupler and monitored by the spectrum analyzer
- Power is varied by changing the signal generator power.

![Diagram of Power Measurement Setup]
Calibration phase

- Correction factor = power difference between the power meter and spectrum analyzer readings.
Measurement Phase

- Sweep the signal generator power.
- Report the spectrum analyzer readings + correction factors = input power.
- Report the power meter reading.
- The power meter readings + probe losses = amplifier output power
Many points are recorded at different frequencies.

At 270GHz: $P_{\text{out}} = 16.8\text{dBm}$, 4\%PAE

No heatsink was used.

Better performance is expected with proper heatsinking.

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Power Measurement Results

- More points are taken at different frequencies.
- \( P_{\text{sat}} = 14 - 16.8 \text{dB}_m \), with \( \text{PAE} = 2.2 - 4\% \) over 266-285GHz.

Measured \( P_{\text{out}} \) vs \( \text{Pin} \) at various frequencies.

Measured \( P_{\text{out}} \) with the associated PAE and gain vs. frequency reported at the peak PAE.
State-of-the-art results

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<td>12.2-17</td>
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<td><strong>BW_{3dB}, GHz</strong></td>
<td>55</td>
<td>53c</td>
<td>9</td>
<td>~100c</td>
<td>10</td>
<td>40</td>
<td>57</td>
<td>21</td>
<td>15c</td>
<td>48c</td>
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<td><strong>Chip Size (mmxmm)</strong></td>
<td>1.5x0.75</td>
<td>2.14x1.58</td>
<td>0.98x1</td>
<td>0.5x1.35</td>
<td>2x0.75</td>
<td>0.55x0.5</td>
<td>5b</td>
<td>2x0.75</td>
<td>1.45x0.44</td>
<td>0.67x0.68</td>
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<td><strong>P_{DC} (W)</strong></td>
<td>-</td>
<td>5.24</td>
<td>1.12</td>
<td>0.129d</td>
<td>0.29</td>
<td>0.72</td>
<td>0.2</td>
<td>0.85</td>
<td>1.49</td>
<td>-</td>
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<tr>
<td><strong>P_{sat}/Area mW/mm²</strong></td>
<td>10.6</td>
<td>72.5</td>
<td>15.7</td>
<td>13.9</td>
<td>4.5</td>
<td>6.66</td>
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- This work shows a record $P_{sat}/\text{mm}^2$ over 266-285GHz frequency range.
Summary

- Record $P_{sat}$/area at H-band
- Common base cell with finite base impedance shows a good performance at subTHz frequency.
- Transmission line combiner are compact and have low losses
- Careful EM simulation is necessary to get accurate results
- Millimeter wave communication becomes more feasible.
Acknowledgement

- This work was supported in part by the Semiconductor Research Corporation and DARPA under the JUMP program.

- The authors thank Teledyne Scientific & Imaging for the IC fabrication.
Thank You
References


More Details: power amplifier family

- Record output power and efficiency (125-285GHz)

[13] 140GHz, 20.5dBm, 20.8% PAE

[14] 130GHz, 200mW, 17.8%PAE

[15] 194GHz, 17.4dBm, 8.5%PAE

This work

• Record output power and efficiency in the frequency range of 125-285GHz.