

WE2B-1



300-GHz-Band 4-Element CMOS-InP Hybrid Phased-Array Transmitter with 36° Steering Range

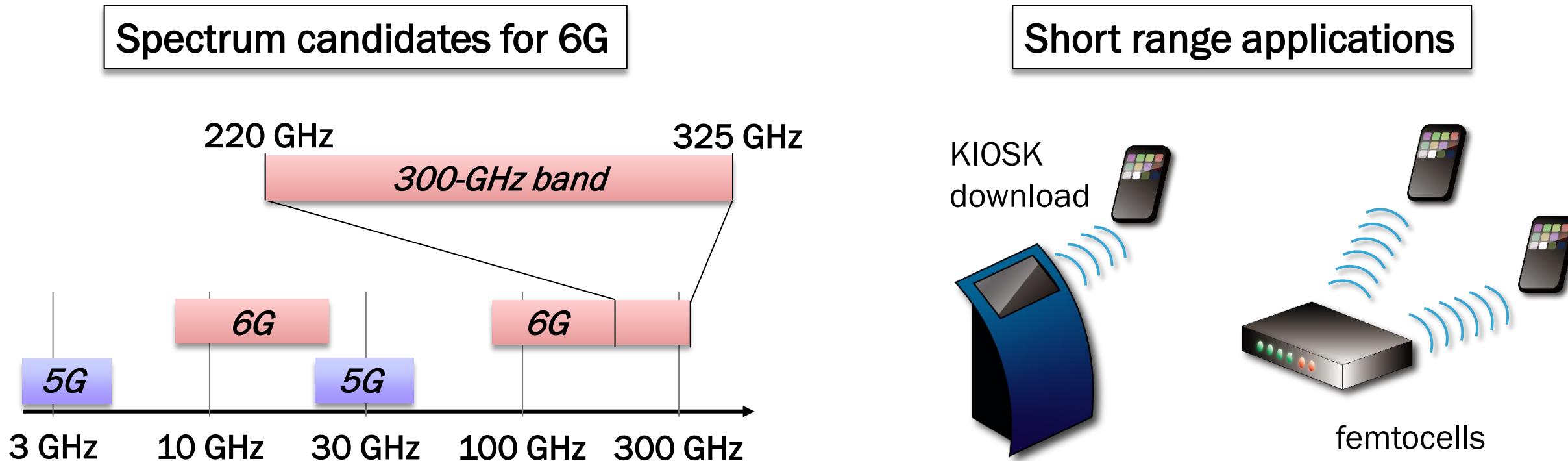
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- Introduction
- Proposed InP-CMOS Hybrid TX
 - Flip-Chip-on-Chip Implementation
- Sparse Phased-Array Implementation
- Measurement Results
- Performance Comparison
- Conclusion

- Wide bandwidth to enable multi-Gb/s links



- Path loss and system requirements



Path loss (dB)
 = Propagation loss
 - total antenna gain

$$\text{Path loss} = \frac{P_{\text{RX}}}{P_{\text{TX}}} = \frac{G_{\text{TX}} G_{\text{RX}}}{\text{Total antenna gain}} \left[\frac{\lambda}{4\pi d} \right]^2$$

Propagation loss

P_{TX} : transmitted power
 P_{RX} : received power
 G_{TX} : transmitter antenna gain
 G_{RX} : receiver antenna gain
 λ : wavelength
 d : link distance

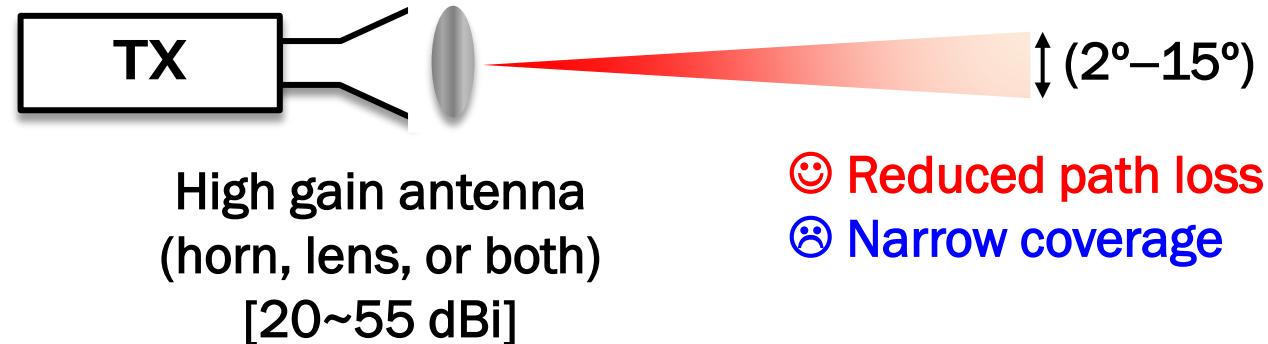


~62 dB @ 10-cm distance

~82 dB @ 1-m distance

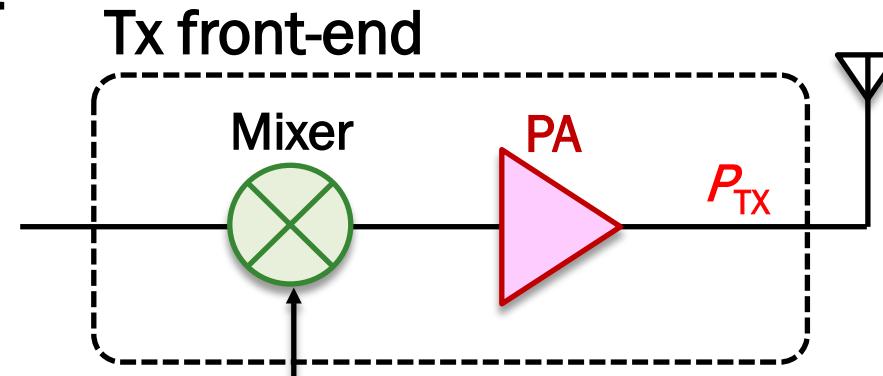
- Overcoming the high path loss

- High gain antenna (G_{TX} and G_{RX})



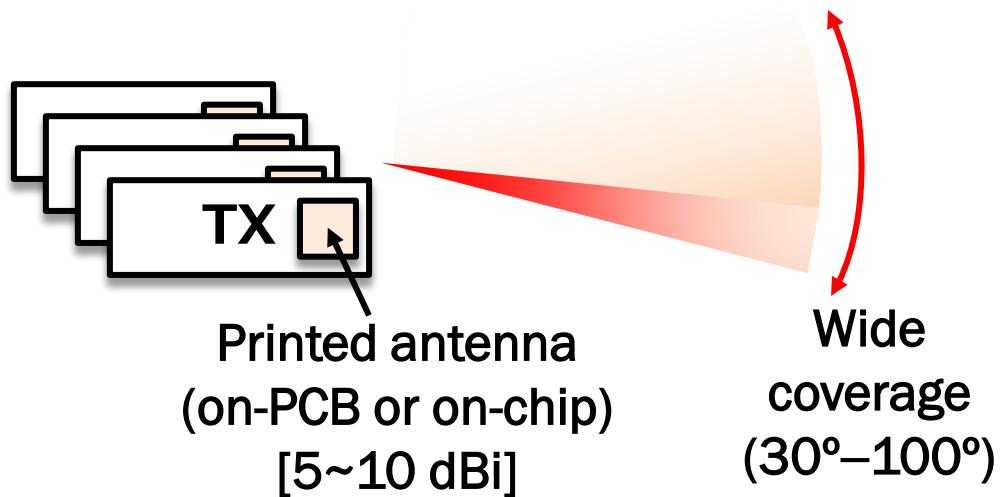
- ☺ Reduced path loss
- ☹ Narrow coverage

- High output power (P_{TX})

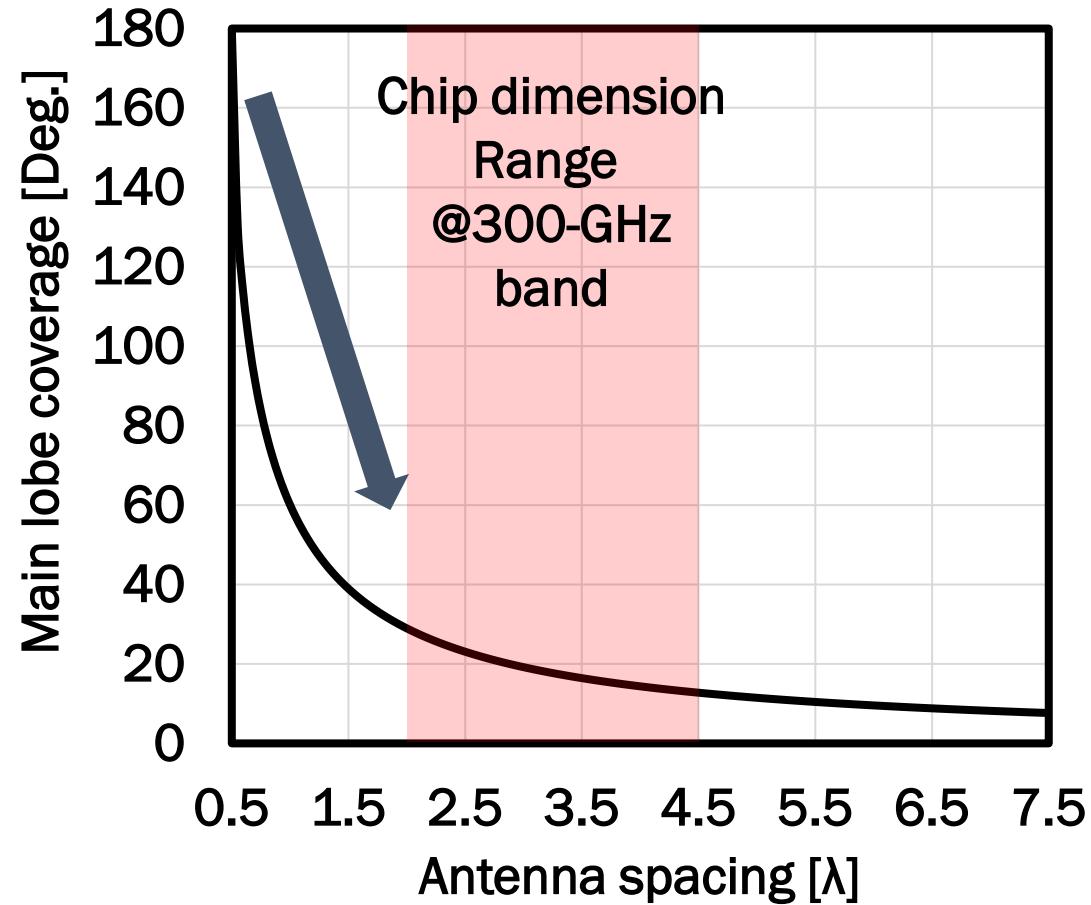


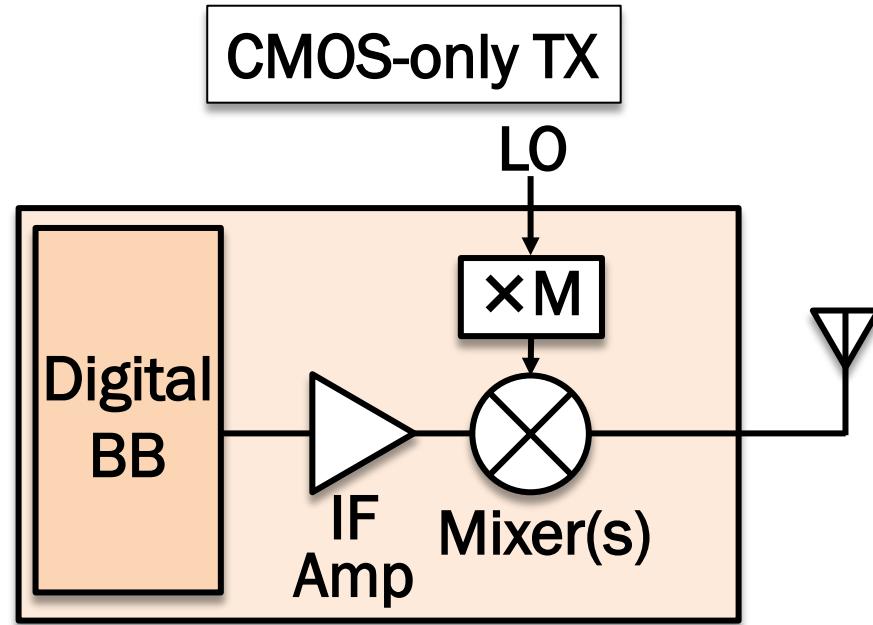
- ☺ More than 5 dBm at 300 GHz
- ☹ Integration difficulties

- Phased-array to widen the range



- ☺ Wider coverage
- ☺ High array gain
- ☹ Wide antenna spacing @300-GHz band

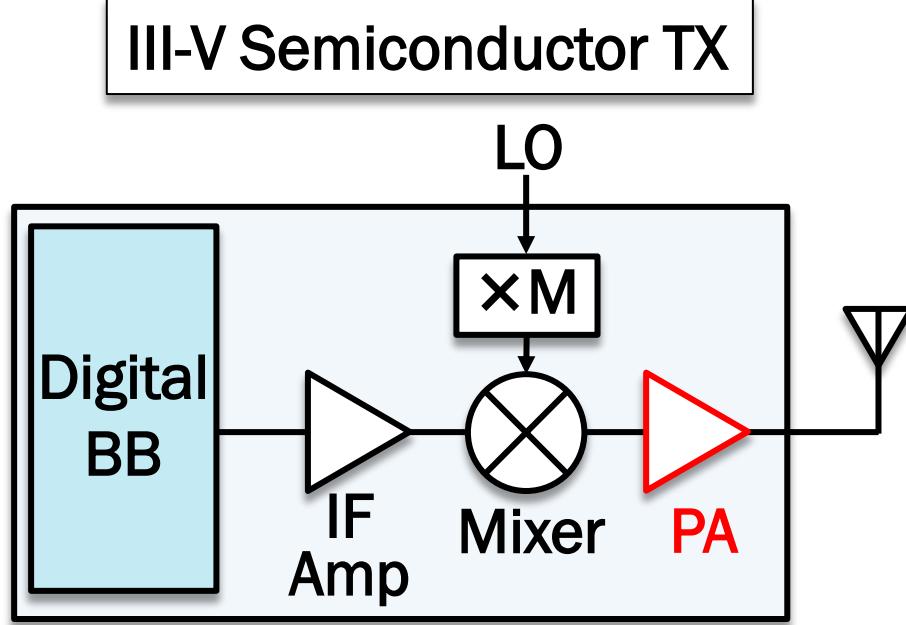




CMOS chip

- 😊 **Low cost**
- 😊 **Easy integration for BB and IF**
- 😢 **Low f_{max} → Mixer-last**
- 😢 **Low P_{TX}**

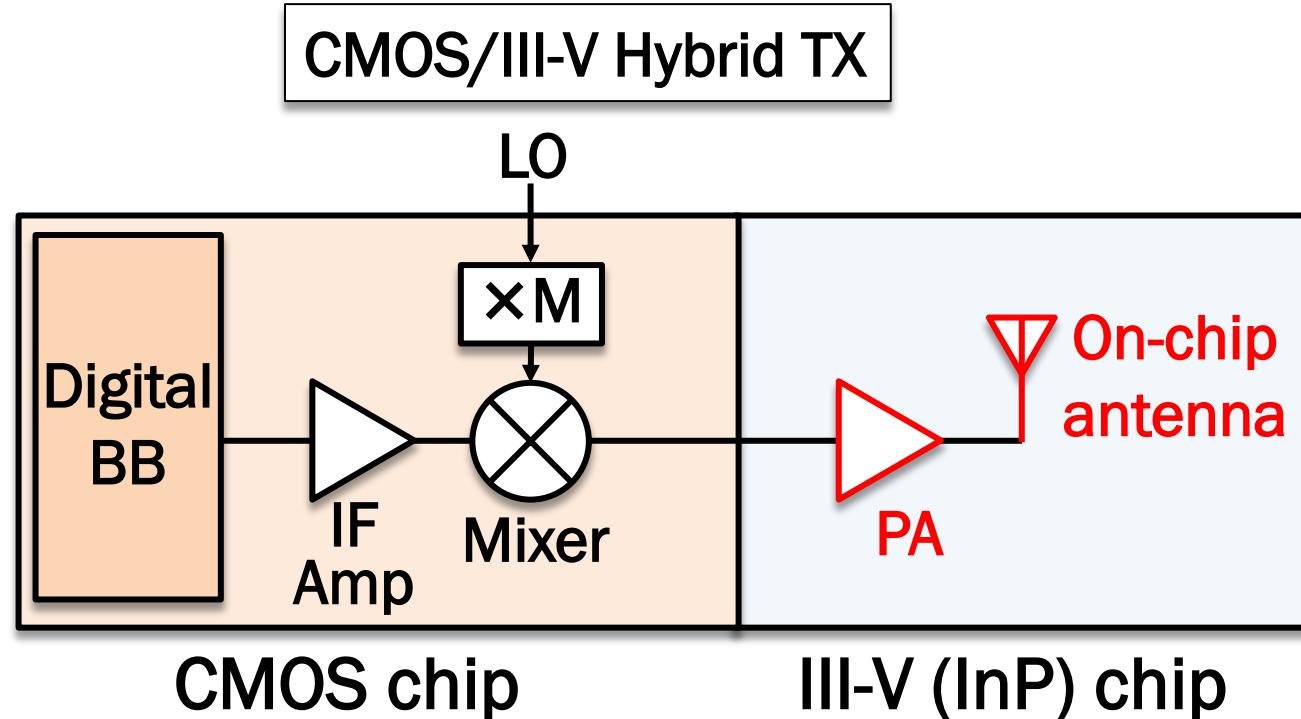
[S. Lee et al., JSSC, 2019]
 [I. Abdo et al., JSSC, 2022]



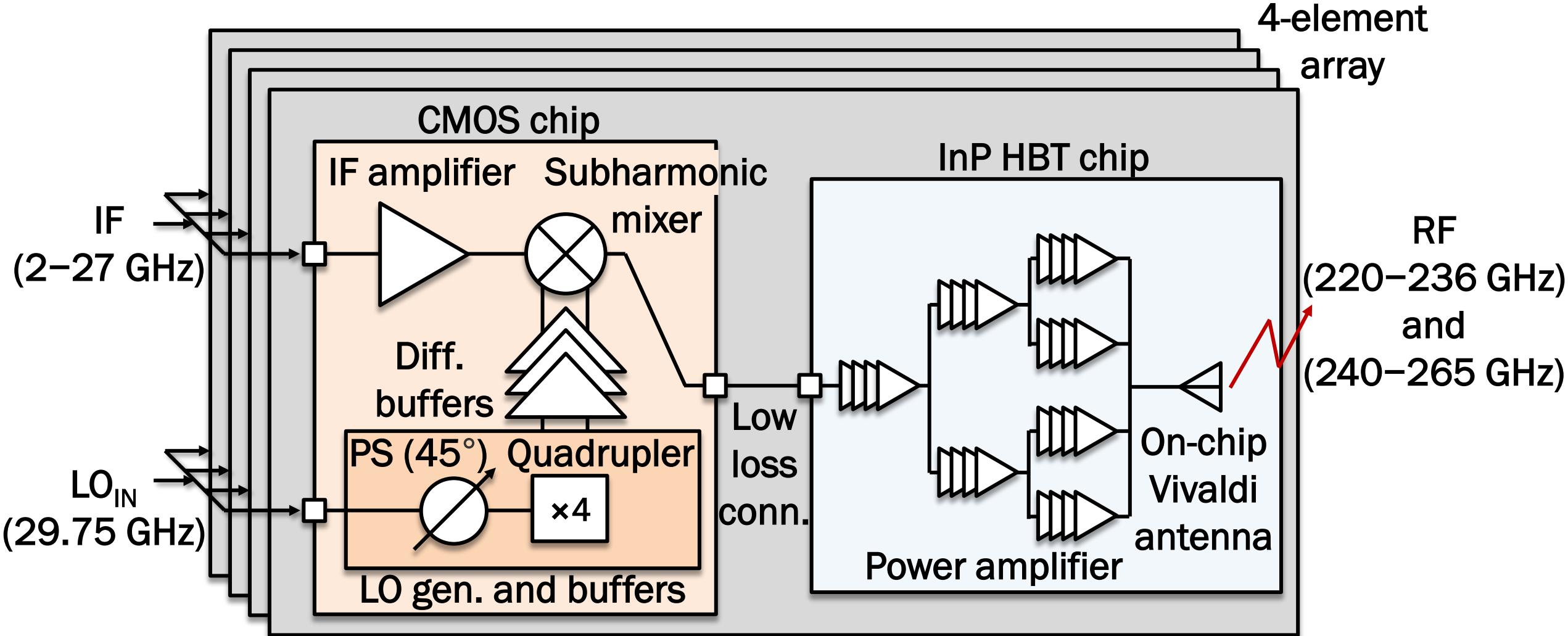
III-V semiconductor chip

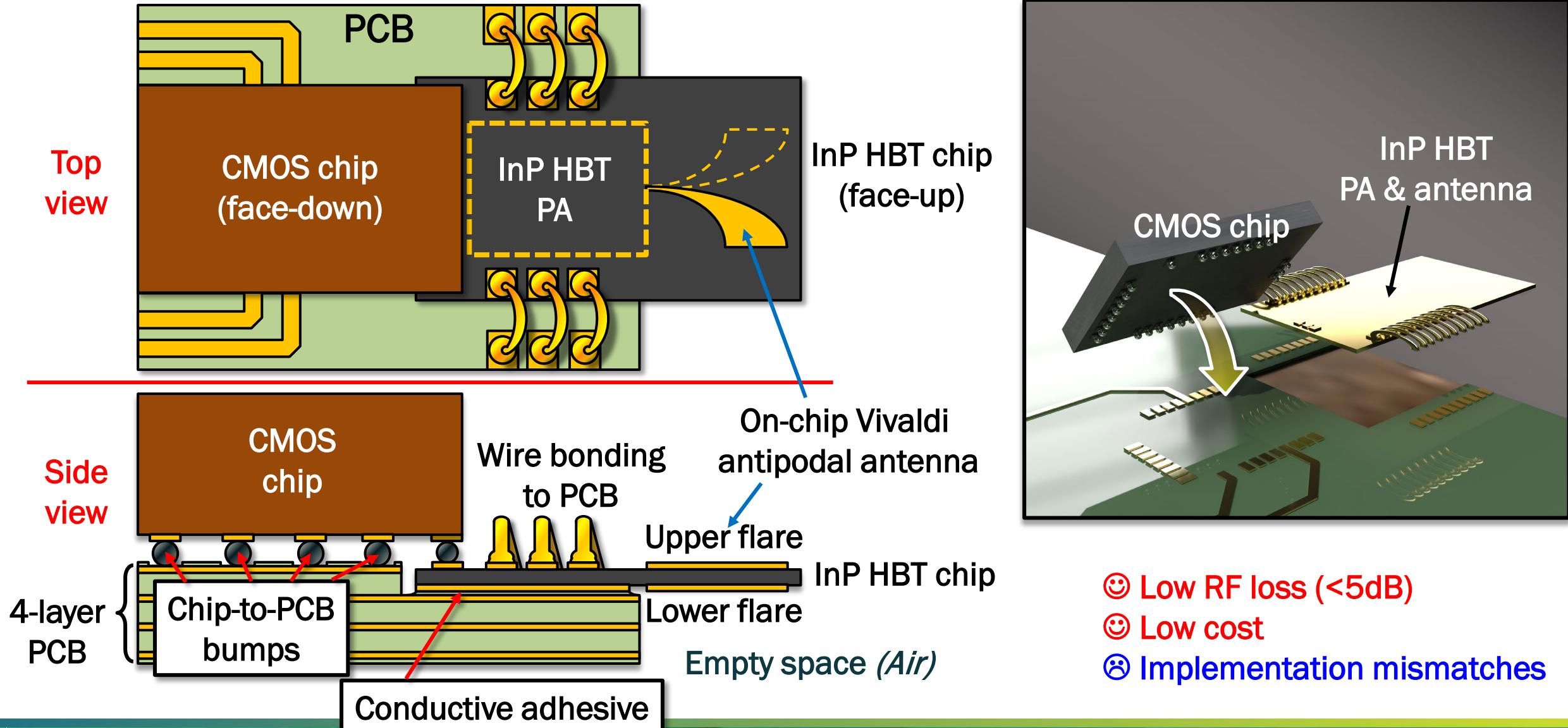
- 😢 **Expensive**
- 😢 **Not suitable for dense circuits**
- 😊 **High f_{max} → PA-last**
- 😊 **High P_{TX}**

[H. Hamada et al., JSSC, 2020]

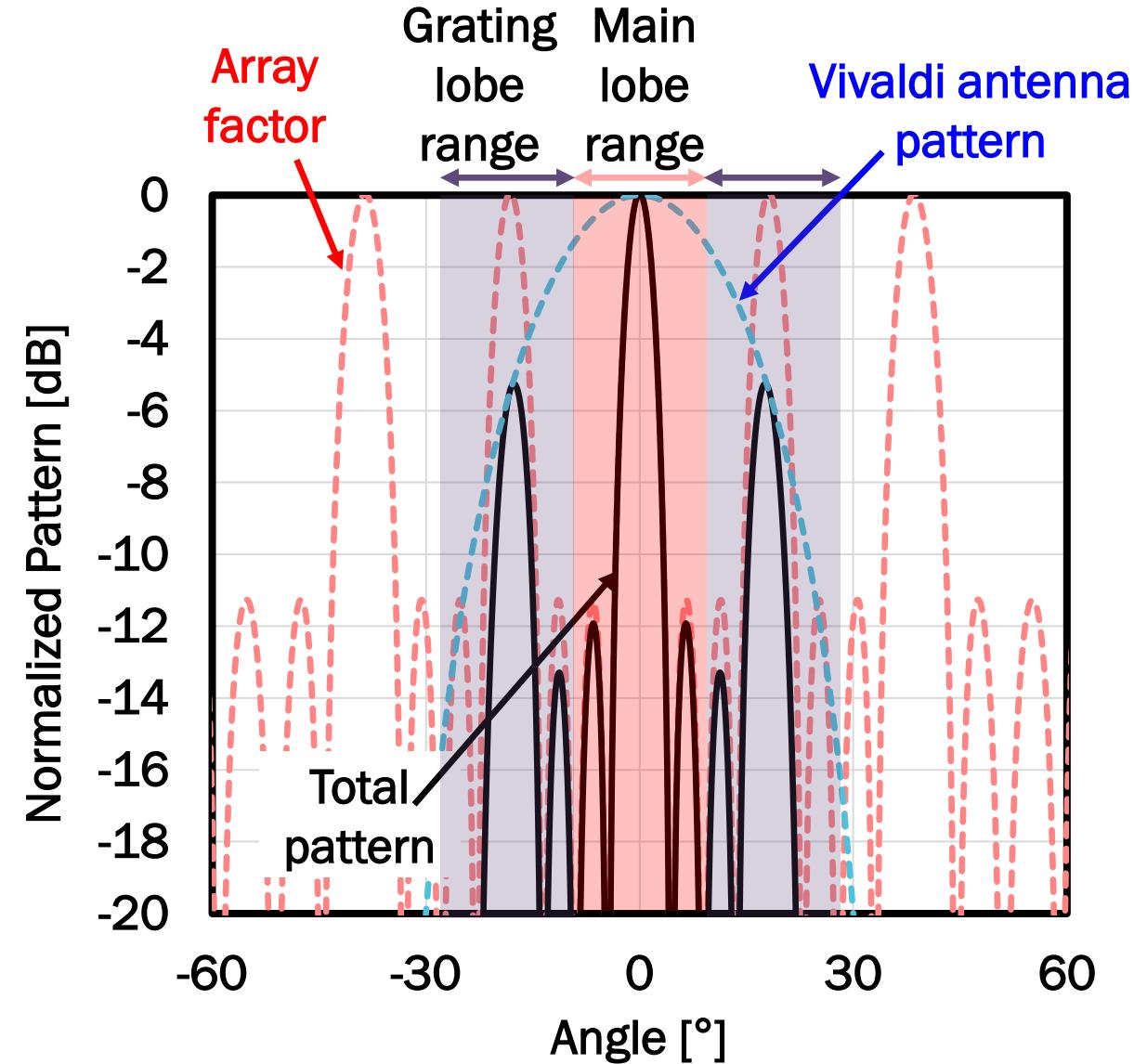
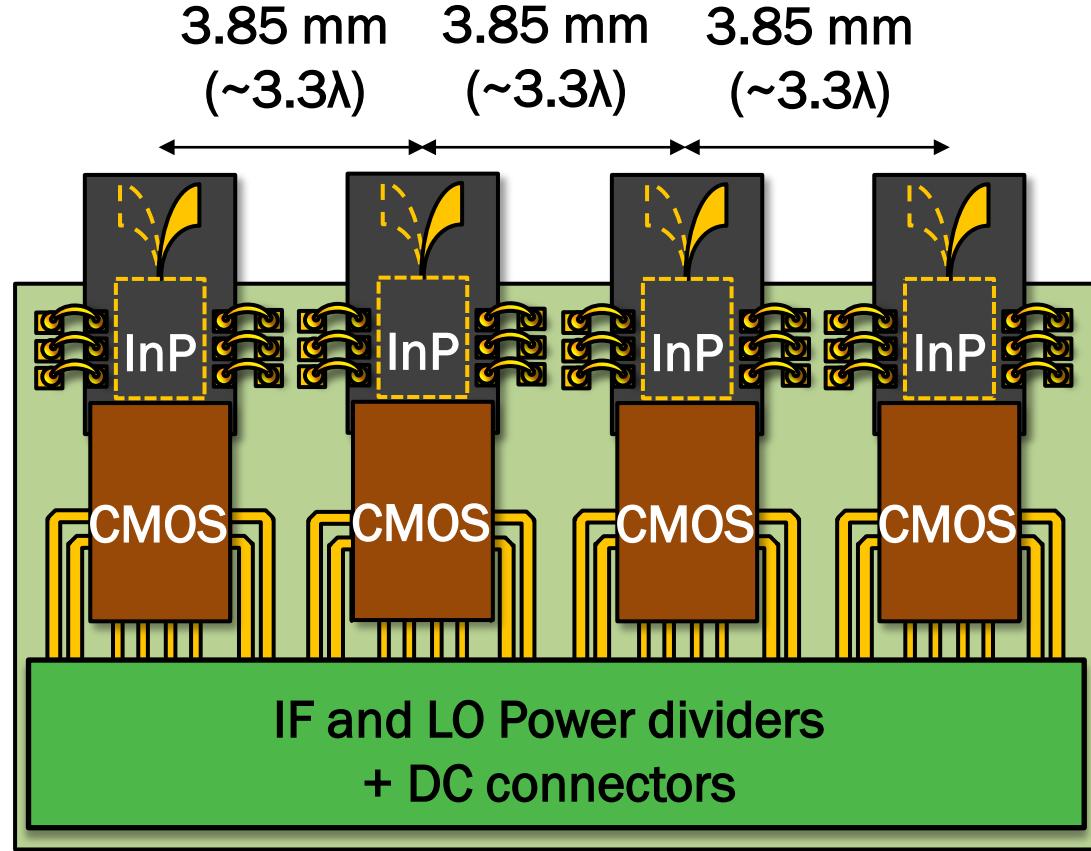


- ☺ Medium cost
- ☺ Easy integration for BB and IF
- ☺ High f_{\max} → PA-last
- ☺ High P_{TX}
- ☹ Challenging implementation

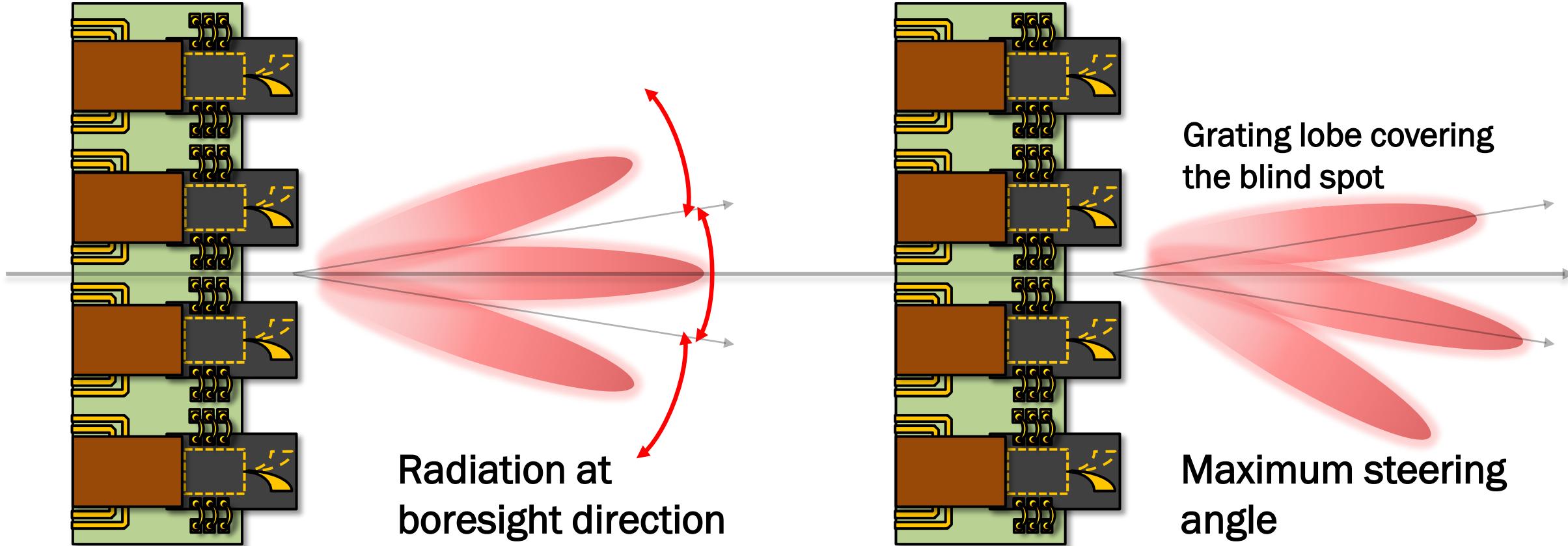




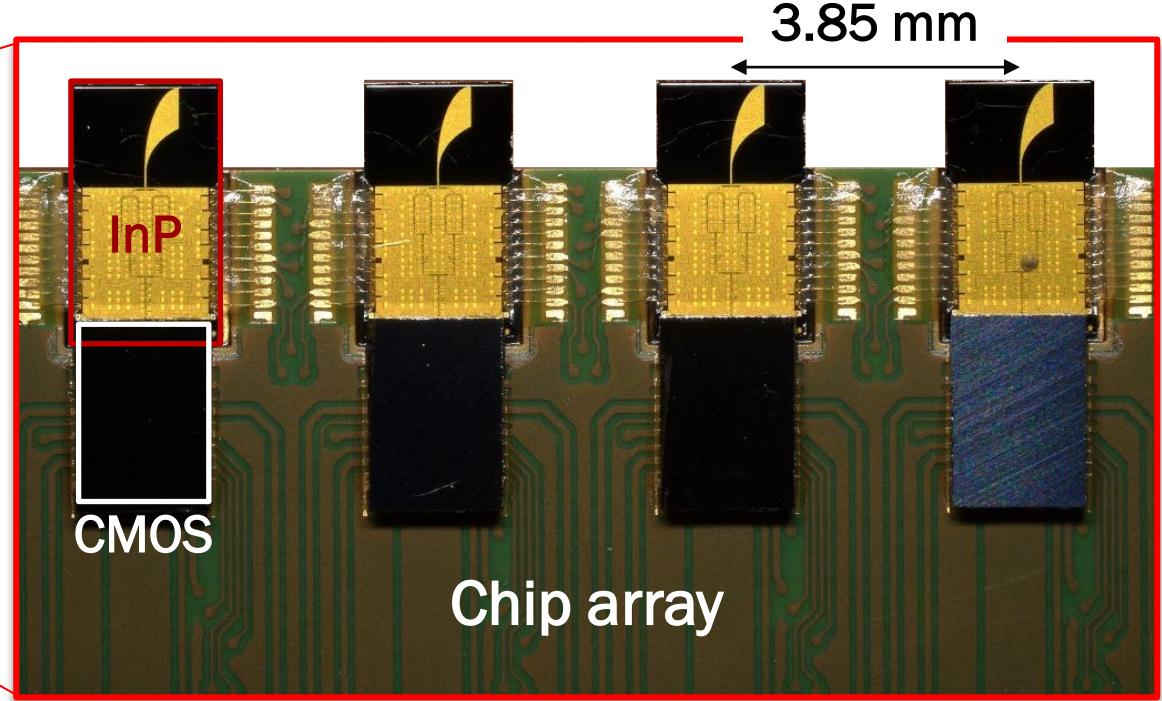
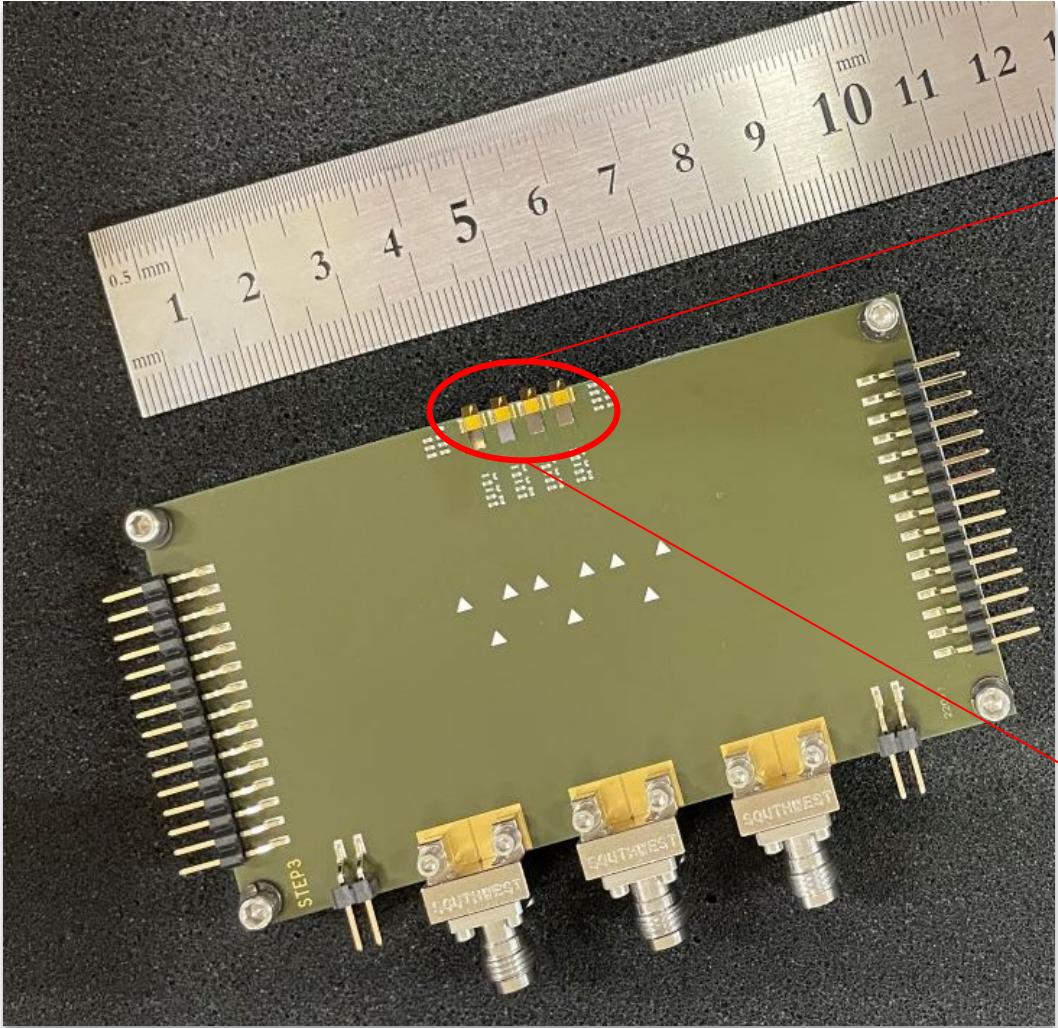
- Sparse phased-array



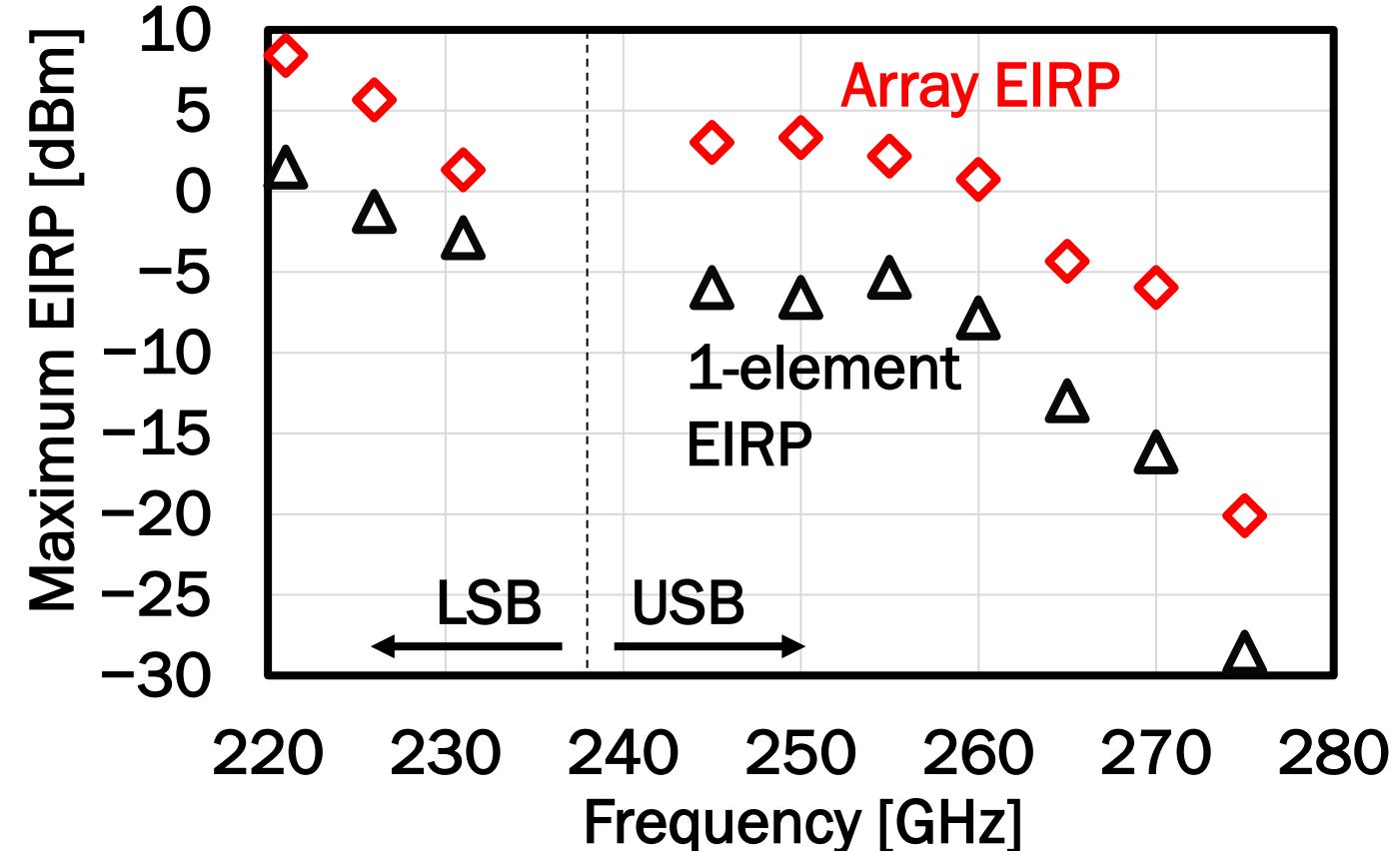
- Utilizing grating lobes to double the coverage



Implemented TX Array Module

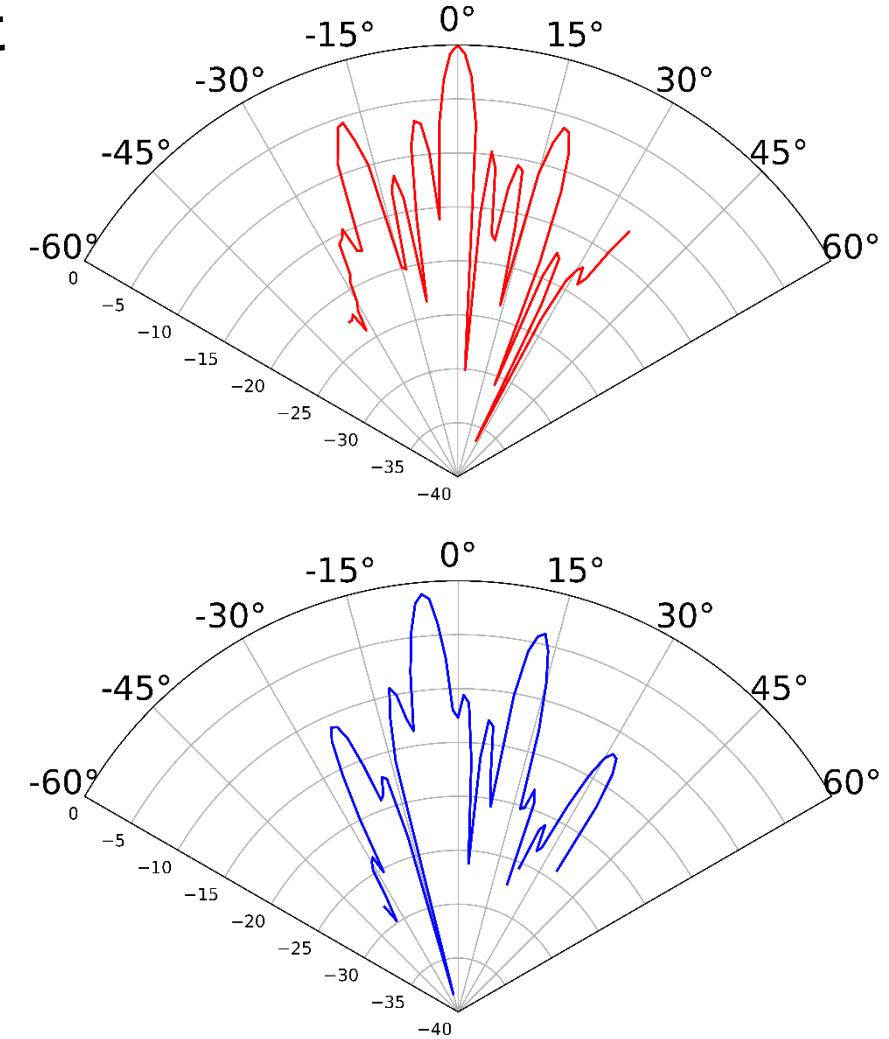
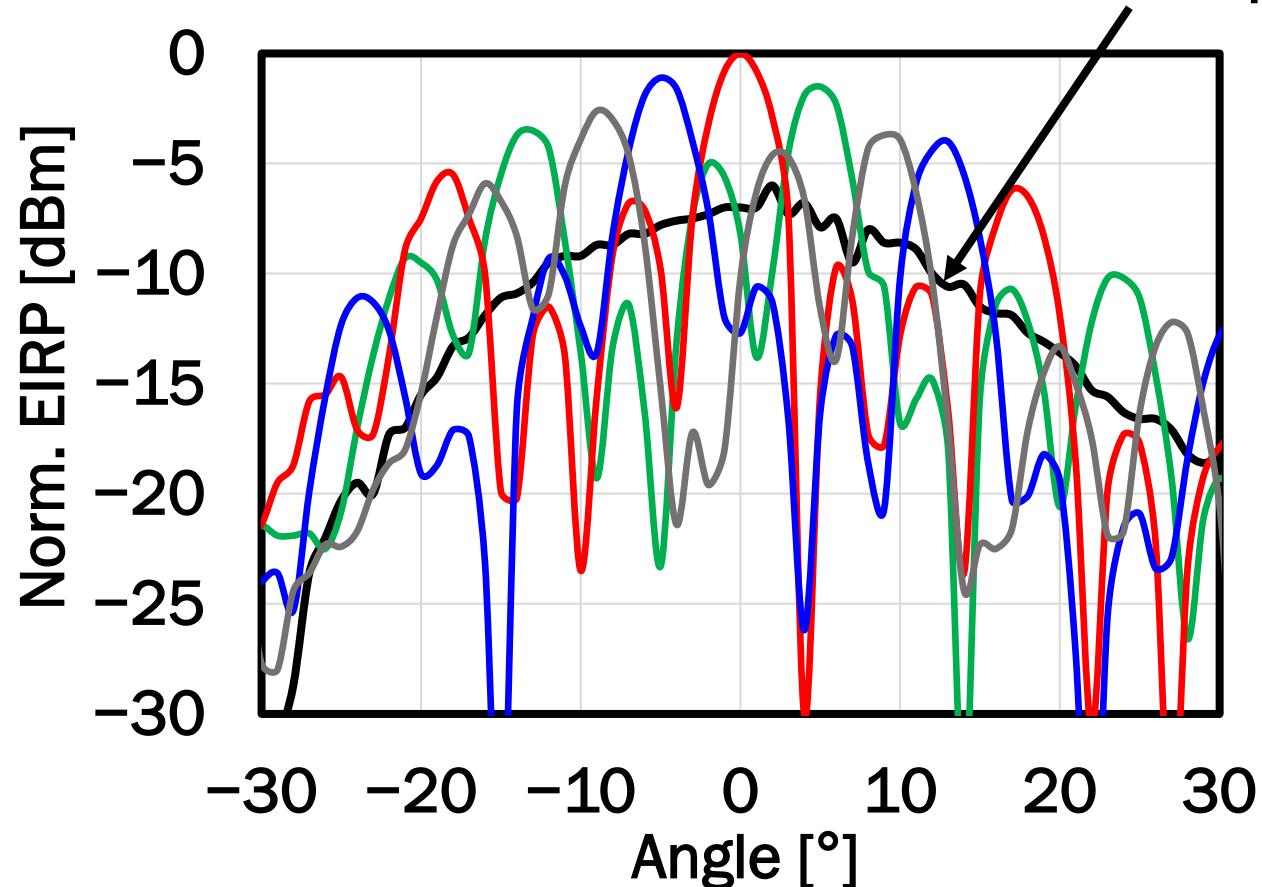


- Measured EIRP vs Frequency



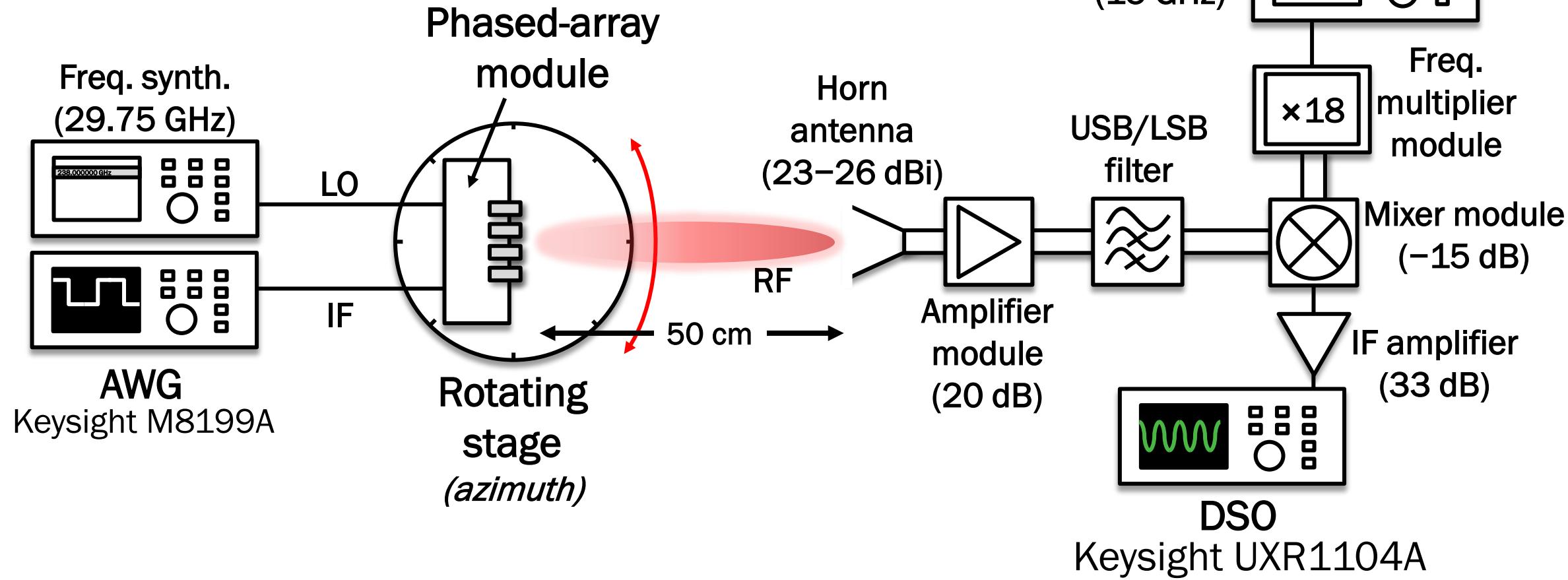
Measurement Results

- Radiation Pattern @ 258 GHz

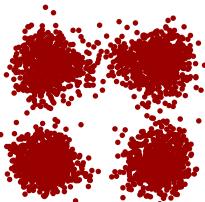
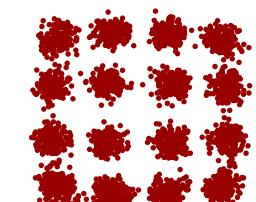
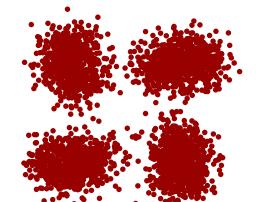
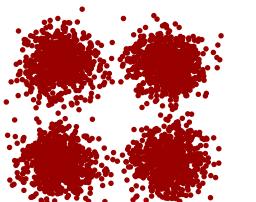


Measurement Results

- OTA Measurement Setup



- OTA results over 50 cm

| | | | | |
|---------------------------|---|--|--|--|
| Beam angle [°] | 0 | 0 | 9 | 18 (Grating) |
| f_{centre} [GHz] | 253 (USB) | 228 (LSB) | 253 (USB) | 253 (USB) |
| Modulation | QPSK | 16-QAM | QPSK | QPSK |
| Symbol rate [Gbaud] | 15 | 5 | 10 | 8 |
| Data rate [Gb/s] | 30 | 20 | 20 | 16 |
| Constellation |  |  |  |  |
| EVM [dB] | -10.5 | -17.1 | -9.9 | -9.8 |

Performance Comparison

| | Hiroshima [10] | TokyoTech [11] | TokyoTech [9] | NTT [4] | IHP [7] | IHCT [6] | This work |
|----------------------------------|-------------------|---------------------------|------------------|----------------|----------------|----------------|-----------------------------|
| Technology | 40-nm CMOS | 65-nm CMOS | 65-nm CMOS | 80-nm InP-HEMT | 130-nm SiGe | 130-nm SiGe | 65-nm CMOS + 250-nm InP HBT |
| RF freq. [GHz] | 252–279 | 240–280 | 278–304 | 278–302 | 225–255 | 220–255 | 220–265 |
| Structure | Single-element | Phased-array [#] | Single-element | Single-element | Single-element | Single-element | Phased-array |
| Antenna type | Horn | On-PCB | Horn | Horn +Lens | On-chip +Lens | On-chip +Lens | On-chip |
| Max. EIRP* [dBm] | 22.4 | N/A | 15 | 56 | 33 | 32 | 8.4 |
| Max. symbol rate [Gbaud] | 28 (16-QAM) | 26 ^{\$} (QPSK) | 17 (QPSK) | 30 (16-QAM) | 25 (16-QAM) | 23.75 (16-QAM) | 15 (QPSK) |
| Distance [m] | 0.03 | N/A | 0.01 | 9.8 | 0.8 | 1 | 0.5 |
| P _{DC} [W] | 0.89 | 3 | 0.27 | 6.6 | 1.24 | 0.96 | 1.2 (CMOS) 1.44 (InP) |
| Est. -6-dB beam coverage* [Deg.] | 15 | 36 [#] | 13 | 0.7 | 3.5 | 12 | 36 |

* The EIRP and beam coverage are estimated on the basis of published antenna type, gain, and beam pattern. [#] Only evaluated for CW.

^{\$} 1-element performance (direct waveguide connection). [&] 1-element efficiency

Conclusion

- A 300-GHz band CMOS-InP hybrid phased-array transmitter that achieves a 36° steering range was presented.
- A sparse phased-array implementation was used while utilizing the grating lobes to overcome the large chip width/wavelength ratio issue at 300-GHz band.
- The first data transmission with beam steering was demonstrated achieving a maximum 30Gb/s data rate.

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Thank you