SUPER-LATERAL-RESOLUTION IMAGING USING SUB-THZ SUBTRACTIVE RADAR IN 65NM CMOS

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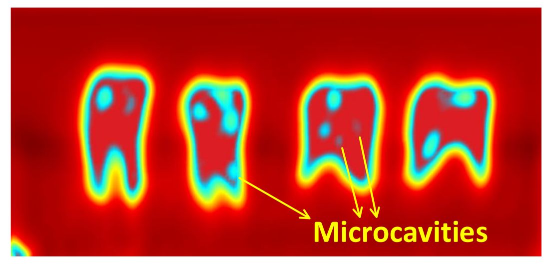
Abstract

- This project presents a sub-terahertz (sub-THz) frequency-modulated continuous wave (FMCW) radar system that achieves super-lateral-resolution through subtractive imaging. Operating at 205 GHz with an 8.4 GHz tuning range, the system integrates four injection-locked transceivers configured with two transmitter (TX) antennas and four receiver (RX) antennas for 3D imaging. By exploiting the narrow null between RX beams, which is achieved by subtracting signals from diagonal RX pairs, the system significantly enhances lateral resolution. Meanwhile, the sum of the received signals provides conventional range information. The proposed super-lateral-resolution capability enables this integrated sub-THz radar system to support applications in medical imaging, security screening, and high-precision positioning.

Introduction

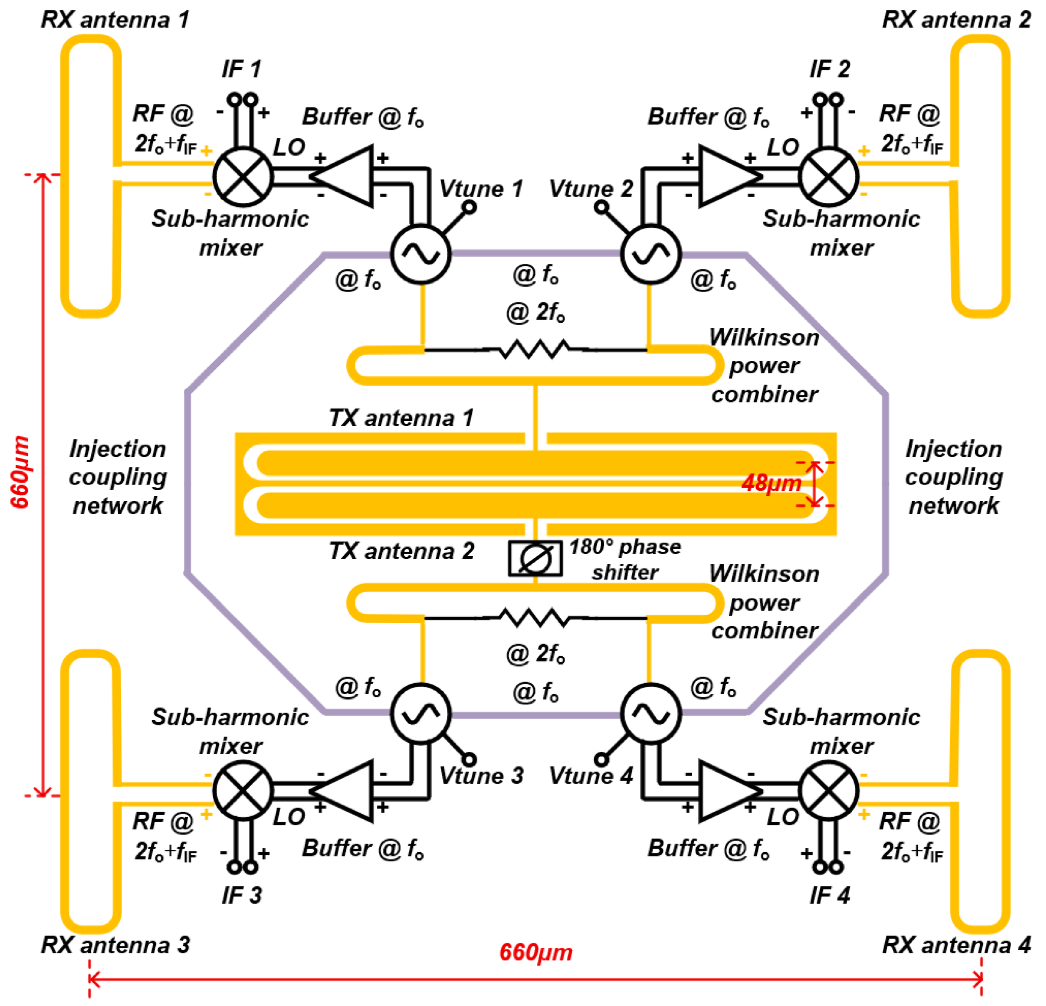
- Super lateral resolution applications
  - Medical imaging
  - Security screening
  - High-precision positioning



- Challenges
  - Chip area limits antenna aperture (D) ⟹ Large half-power beamwidth (HPBW) ⟹ Poor lateral resolution (Δx_{lat})
  - Synchronization is required in the transceiver array.

$$\Delta x_{lat} \approx \frac{\lambda R}{D} \approx R \times HPBW$$

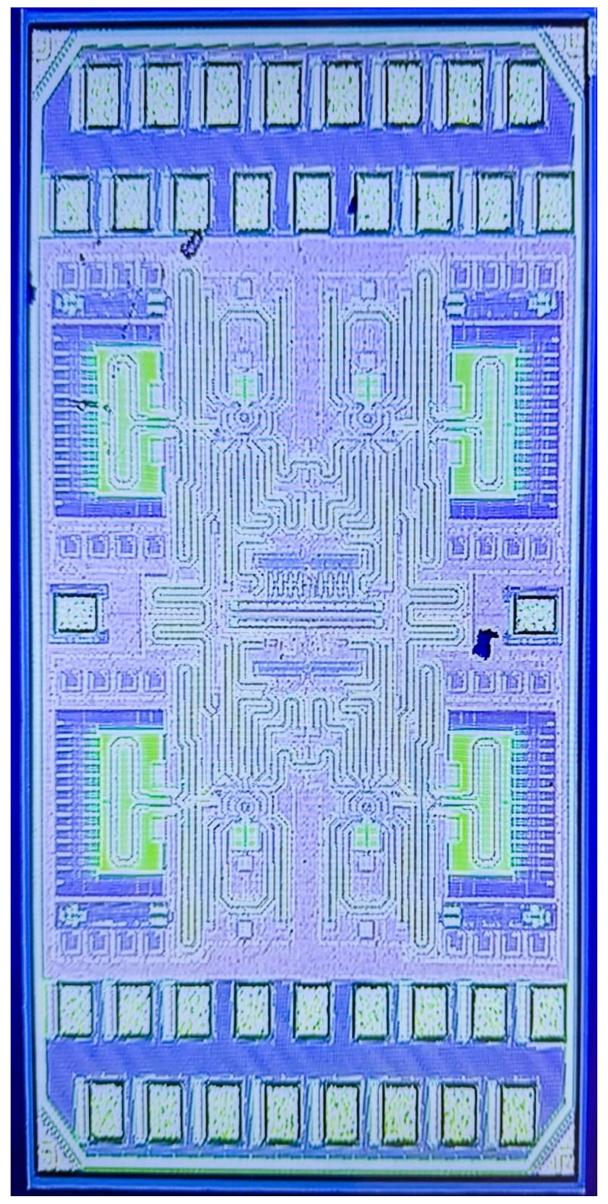
- Our solutions
  - IF signals from diagonal RX pairs are **subtracted** to create an equivalent **narrow null** between beams and improve resolution.
  - VCOs in four cells are **injection locked** to ensure phase coherence across all transceiver cells.

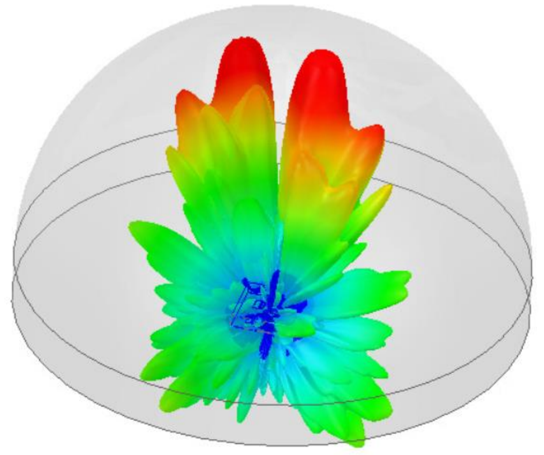


(drawn not to scale)

System Architecture

- The chip integrates four injection-locked transceivers in a 2×2 architecture.
- Antenna Configuration
  - 2 TX folded slot antennas
  - 4 RX folded dipole antennas
  - Backside radiation through high-resistivity silicon lens
- The system works @ 2f0 = 205 GHz, 8.4 GHz tuning range
- IF signals will be used for additive and subtractive processing off chip

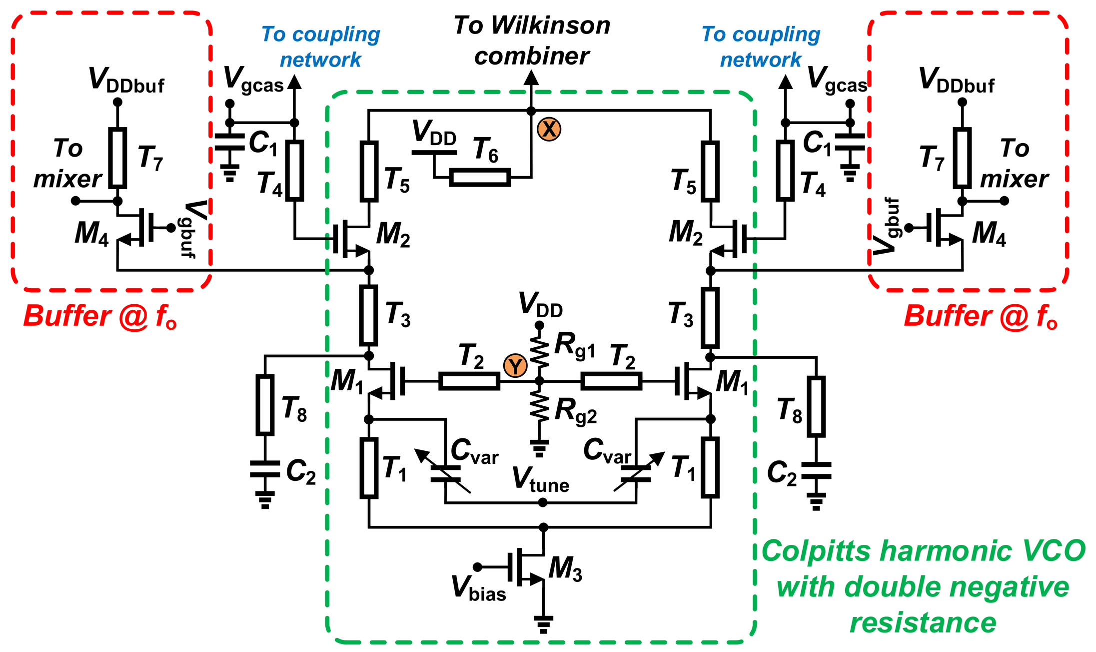




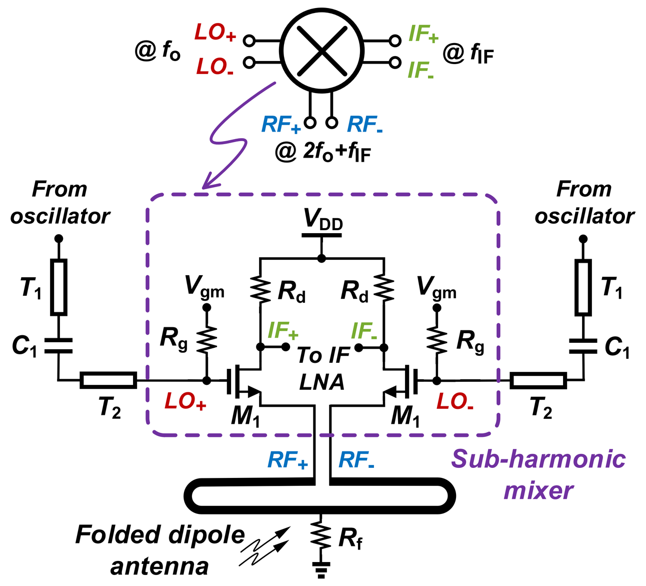
Backside radiation pattern

Circuit Implementation

- Transmitter
  - Differential Colpitts harmonic VCO:
    - Provides signals @2f0 for radiation
    - provides LO signals @f0 for mixer
  - Wilkinson power combiner combines VCO outputs
  - 180° phase shifter provides differential excitation
- Injection Locking Network
  - Synchronizes four VCOs (four transceivers)
  - Use transmission lines and customized finger capacitors to provide desired boundary conditions
- Receiver
  - Four RF signals received from four RX antennas
  - RF down-convert to IF using sub-harmonic mixers
  - LO signal @ f0 derived from VCO



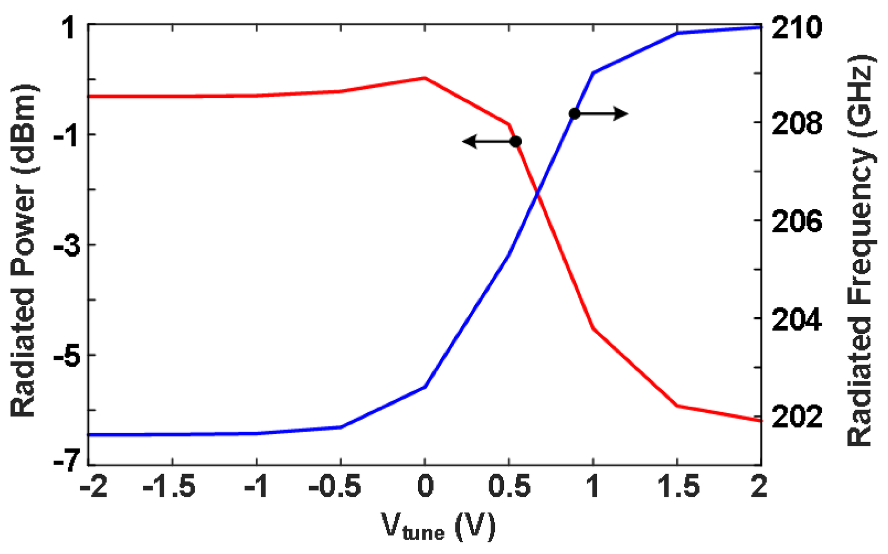
Colpitts Harmonic VCO



Sub-harmonic mixer

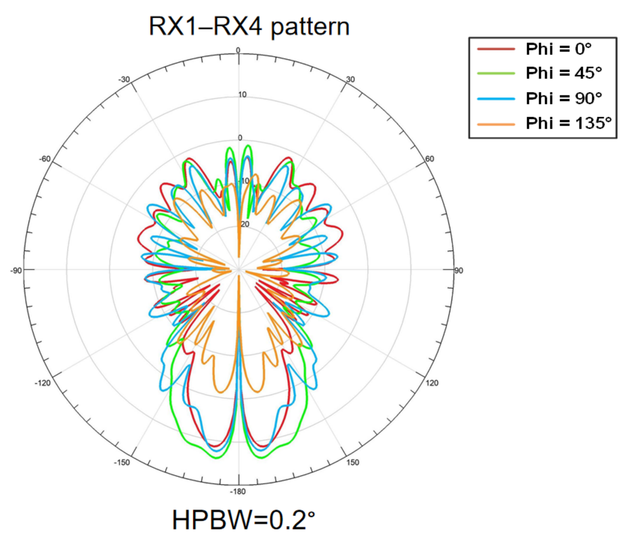
Simulation Results

- Chip size: 1×1.77 mm²
- VCO Performance
  - Tuning range: 201.6 - 210 GHz
  - Output power: 0 to −6.2 dBm
- Phase Shifter
  - Phase difference: 180° ± 5°
  - Amplitude imbalance < 0.7 dB
- Wilkinson Combiner
  - S11 < −20 dB
  - Isolation: S23 <−20 dB
- Antenna Performance
  - RX gain: 15.4 dBi
  - TX gain: 14.1 dBi
- Subtractive Imaging Principle
  - Subtractive Mode
    - Produces a narrow null between beams
    - Achieves super-lateral-resolution
  - Additive Mode
    - RX signals summed
    - Provides conventional radar range information

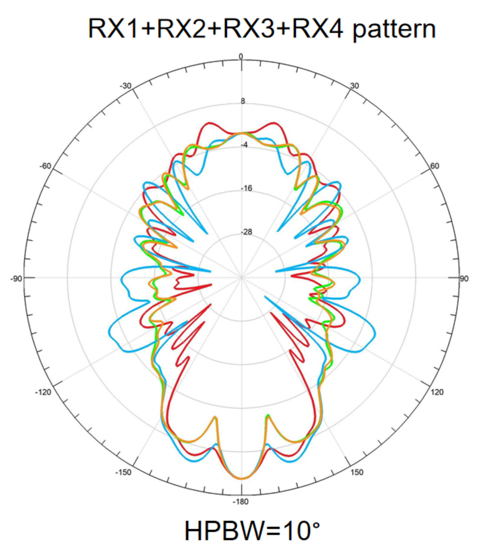


Output power & tuning range for two injection locked VCOs

Subtractive pattern: two diagonal RX antennas out of phase



Additive pattern: four RX antennas in phase



Conclusion

- A compact fully integrated 205-GHz FMCW radar for subtractive imaging is presented.
- Key innovations: Injection-locked harmonic VCO network; On-chip antenna array with silicon lens; Subtractive signal processing for super-resolution.
- This architecture provides a promising solution for high-precision sub-THz imaging systems.

References

[1] S. H. Naghavi, M. T. Taba, M. Aseeri, and E. Afshari, "An integrated 100-ghz fmcw imaging radar for low-cost drywall inspection," IEEE Transactions on Microwave Theory and Techniques, vol. 72, no. 2, pp. 1070–1084, 2023.

[2] A. Mostajeran, A. Cathelin, and E. Afshari, "A 170-ghz fully integrated single-chip fmcw imaging radar with 3-d imaging capability," IEEE Journal of Solid-State Circuits, vol. 52, no. 10, pp. 2721–2734, 2017.

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