SUB-THZ RULER: SPECTRAL BISTABILITY IN A 235GHZ SELF-INJECTION-LOCKED OSCILLATOR FOR AGILE AND UNAMBIGUOUS RANGING

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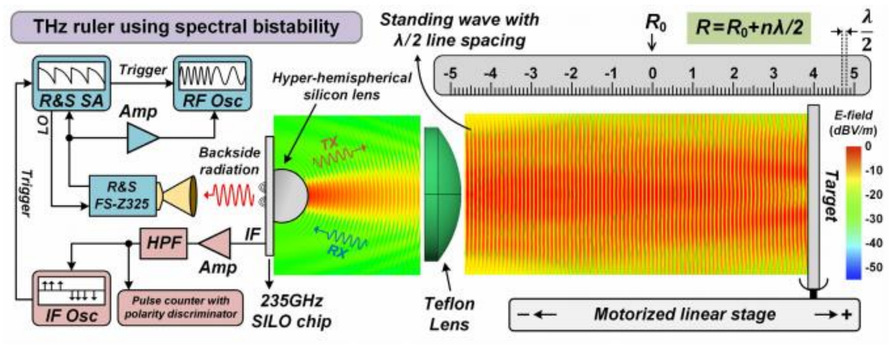
Sub-THz/THz Radars: Advantages and Challenges

- Sub-THz/THz radars provide high-precision, fast-acquisition target ranging, widely used in scientific and industrial metrology.
- The two main types, FMCW and pulse radars, measure range using interferometry and time-of-flight techniques, respectively, while both utilize the Doppler effect to estimate velocity.
- A key challenge is the ambiguity in simultaneous range and velocity measurement. This limits accuracy and requires complex hardware.

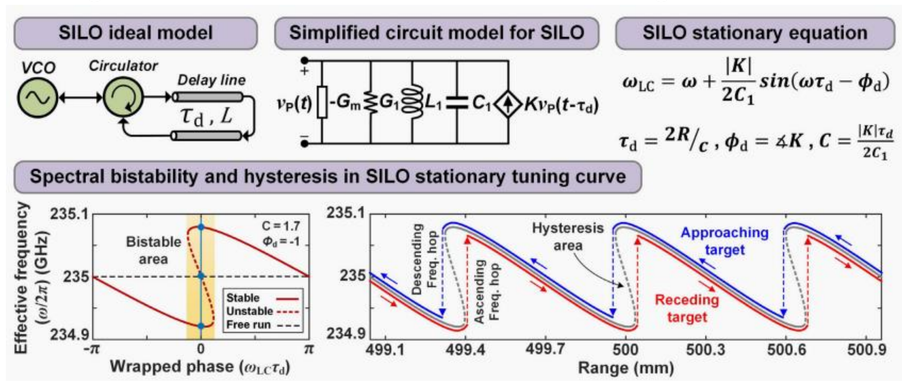
Sub-THz Ruler Sensor

- To address radar ambiguities, we propose a sub-THz ruler sensor that leverages self-injection-locking (SIL) nonlinearity in a sub-THz oscillator.
- For absolute ranging, an integrated FMCW radar establishes the initial range (R_0) with a 16GHz bandwidth from 230–246GHz.
- The system achieves 638μm range accuracy and measures velocities up to 638m/s (receding) and 840m/s (approaching).
- This is the first demonstration of SIL technology in the sub-THz band, offering a breakthrough in agile and unambiguous ranging and velocimetry.



Self-Injection-Locked Oscillator (SILO)

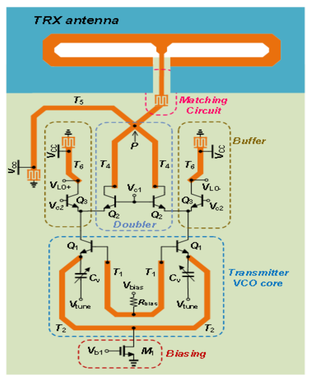
- A self-injection-locked oscillator (SILO) is key to the proposed sub-THz ruler sensor. SILO re-injects an attenuated and delayed version of its own signal, forming a self-mixing interferometer that modulates both frequency and amplitude.
- The SILO's effective frequency deviates from its free-running frequency based on target distance and radar cross-section (RCS), leading to spectral bistability.



- For moderate feedback (1 < C < 4.6), the SILO exhibits periodic frequency hops when the target moves, with ascending hops for receding targets and descending hops for approaching targets.
- By counting the number, polarity, and time intervals of impulse signals at the sensor's intermediate frequency (IF) output, the relative range and velocity of the target can be determined instantly and unambiguously.

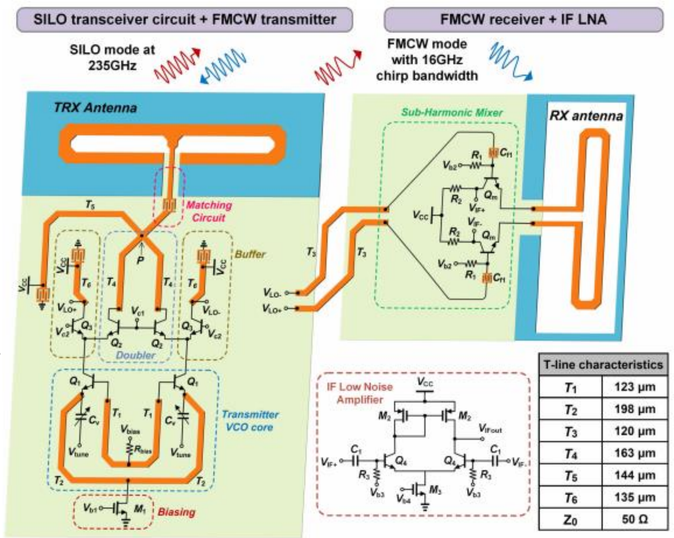
Circuit Implementation for SILO

- SILO Core and Frequency Doubler
  - 2nd-harmonic differential Colpitts oscillator
    - Wider tuning range Oscillator tank
  - Q2 operates as doubler due to:
    - Strong fundamental power generated by Q1
  - 2nd harmonic power gets summed up at point P and radiated by the slot antenna
  - Slot antenna also acts as a receiving antenna for SILO



- Transmitter VCO core operating @ ~120 GHz
- For SIL operation:
  - Vtune is fixed for 235 GHz
- For FMCW operation:
  - Vtune is swept for frequency-chirp generation

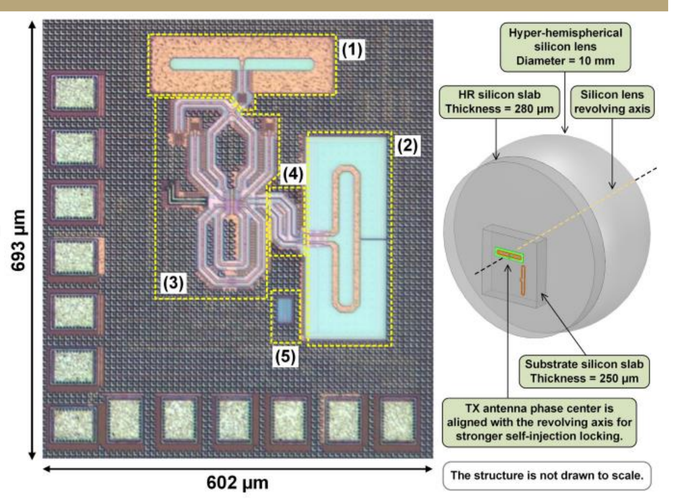
- FMCW Receiver
  - Common-base mixer
    - More linear in comparison to common-emitter
    - Helps in TX/RX leakage reduction
  - A folded dipole antenna functions as both an RX antenna and an impedance-matching structure.

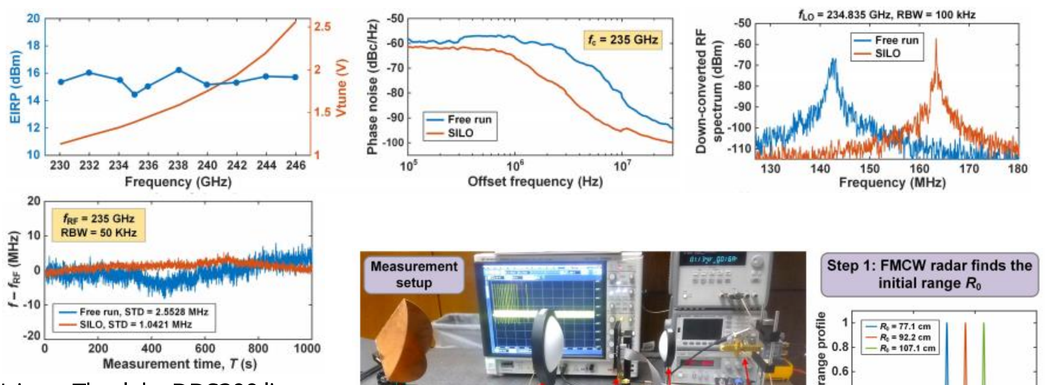


T-line characteristics	
T_1	123 μm
T_2	198 μm
T_3	120 μm
T_4	163 μm
T_5	144 μm
T_6	135 μm
Z_0	50 Ω

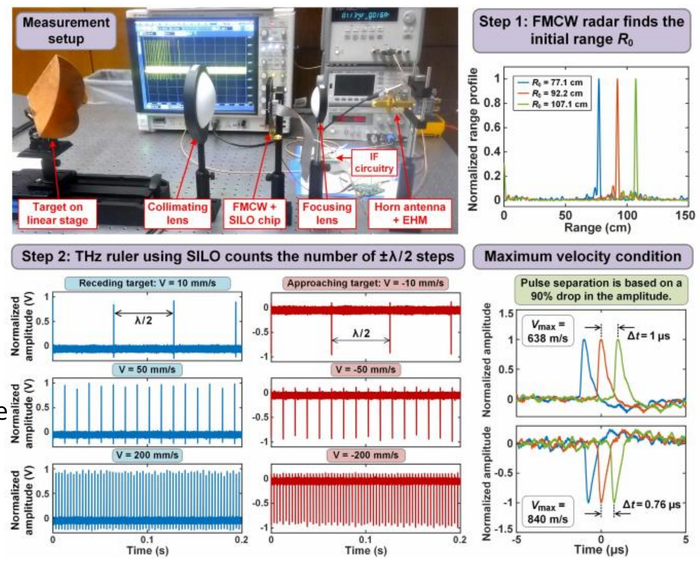
Performance of the Sub-THz Ruler Sensor

- The chip has been fabricated in BiCMOS55 technology (STMicroelectronics).
- The 0.42mm² chip consumes 186mW of DC power.
- A 1cm hyper-hemispherical silicon lens enhances antenna directivity in both E- and H-planes.
- The measured EIRP peaks at 16.2dBm with a 1.8dB variation over the 230-246GHz range.
- SIL operation improves frequency stability, as confirmed by phase noise, power spectrum linewidth, and frequency standard deviation measurements.





- Using a Thorlabs DDS300 linear stage, the FMCW mode first determines the initial range (R_0) before switching to SILO mode at 235GHz. Target movement generates positive/negative impulses, where their density in time corresponds to velocity. Maximum measured velocities are 638m/s (receding) and 840m/s (approaching), verified by time interval calculations between impulses.



References, and Acknowledgments

Faculty: Hossein Naghavi
Graduate Students: Xiangyu Zhao, Zi Zhang
Chip fabrication: STMicroelectronics

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