



We3B-5

# Experimental Demonstration of Multi-Band Comb-Enabled mm-Wave Transmission

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- mm-wave source generation
  - Frequency multiplication
  - Source distribution
- Overview system architecture
- Electro-optic frequency comb
- Measurement and characterization
  - Phase noise
  - Frequency domain
  - End-to-end
- Conclusion

# Need an enabling paradigm...

- The 6G envisages new services: connected car, virtual reality and IoT, which requires high **throughput**.
- RF carriers with low **phase noise** enables high transmission capacity.
- Cooperative Radio requires **synchronization** between base stations



D-band mm-wave link



AR/VR



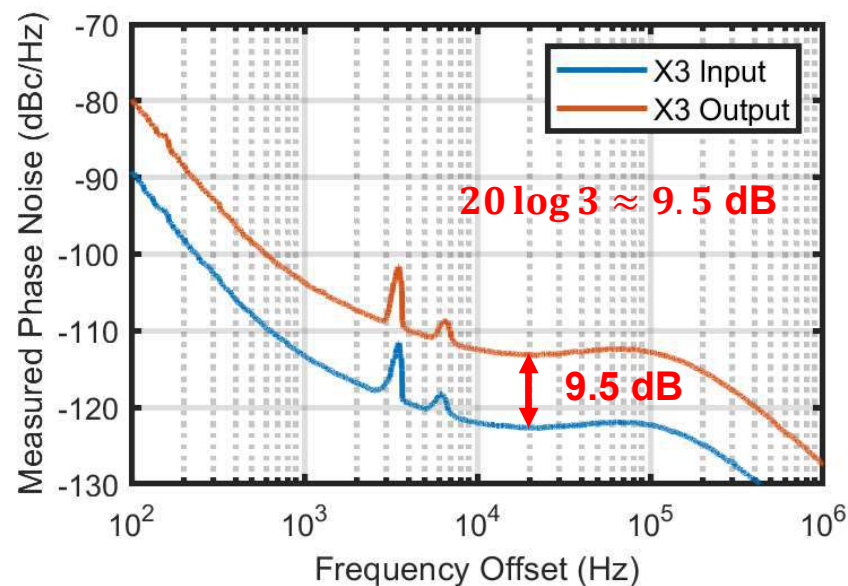
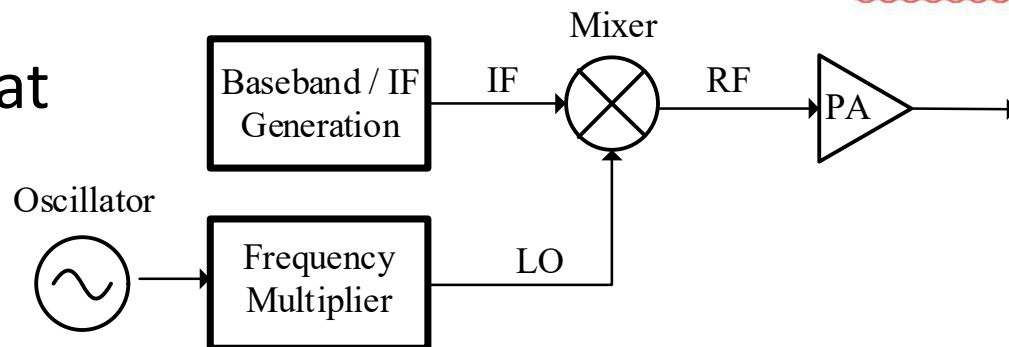
Connected car  
fleets



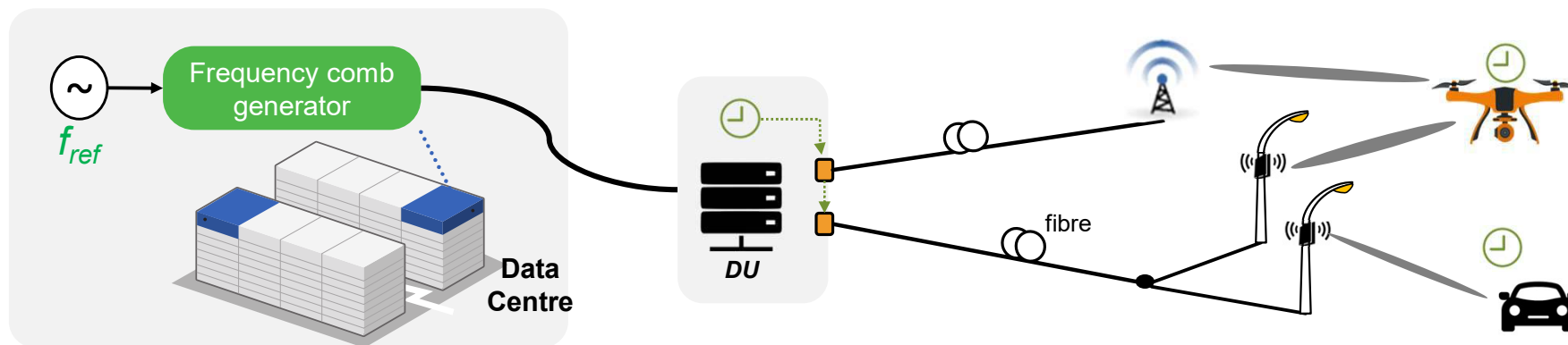
Drones

# A mm-wave source

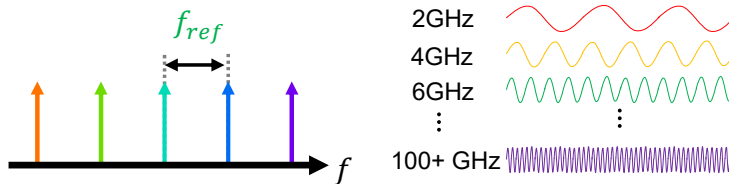
- Difficult to generate fundamentals at mm-wave
- Typically relies on frequency multipliers ( $\times \beta$ )
- Phase noise degrades by  $20 \log \beta$  dB.
- **Source quality pre-multiplication must be exceptional.**
- Non-scalable: multiple oscillators at each frequency. Costly and need external synchronization.



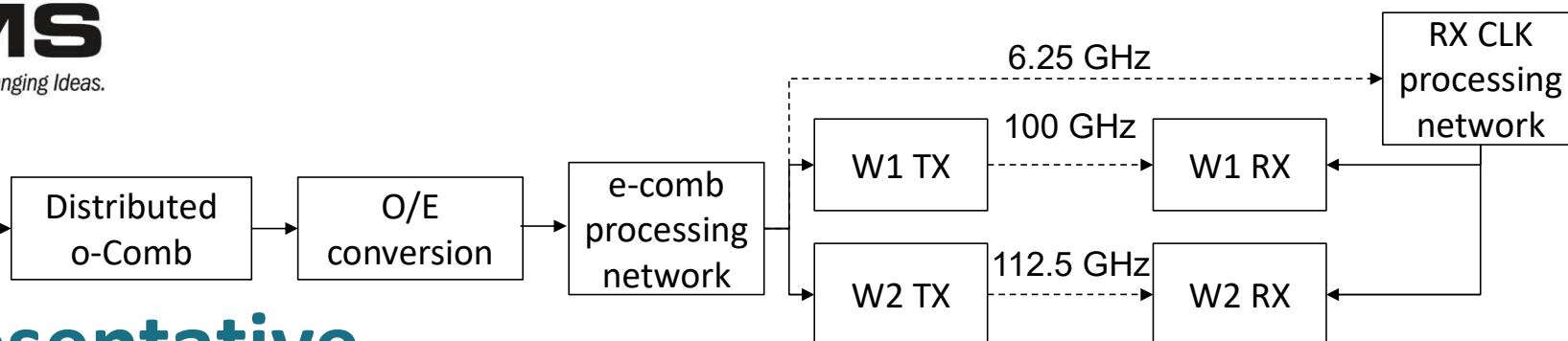
# Source Distribution



- A high-quality optical frequency comb can be distributed to multiple sites; **economy-of-scale**.
- Enabling **simultaneous access to multiple frequencies**
  - Low Phase Noise
  - High stability
- Inherent **frequency synchronization** between each tone.



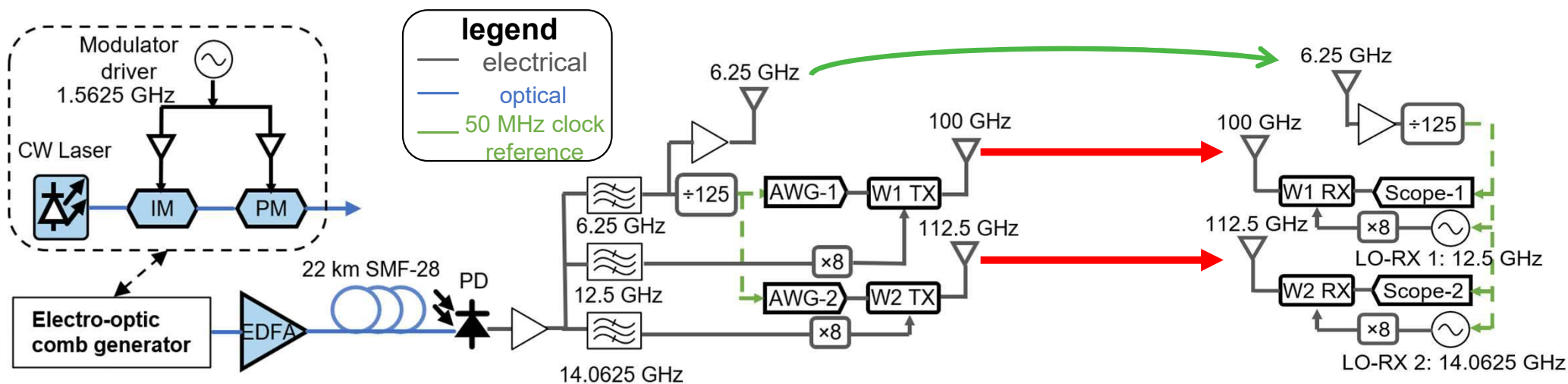
22-km  
away



# Representative study-case scenario

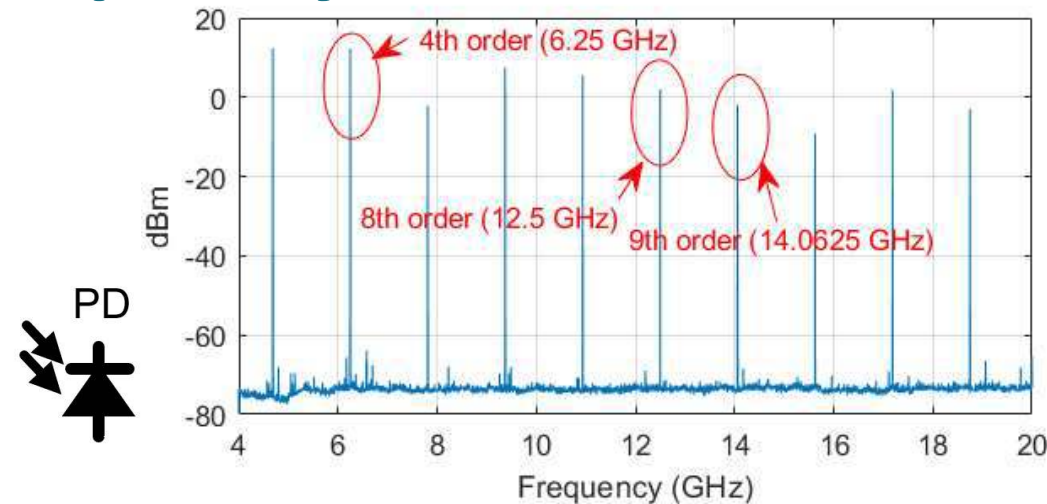
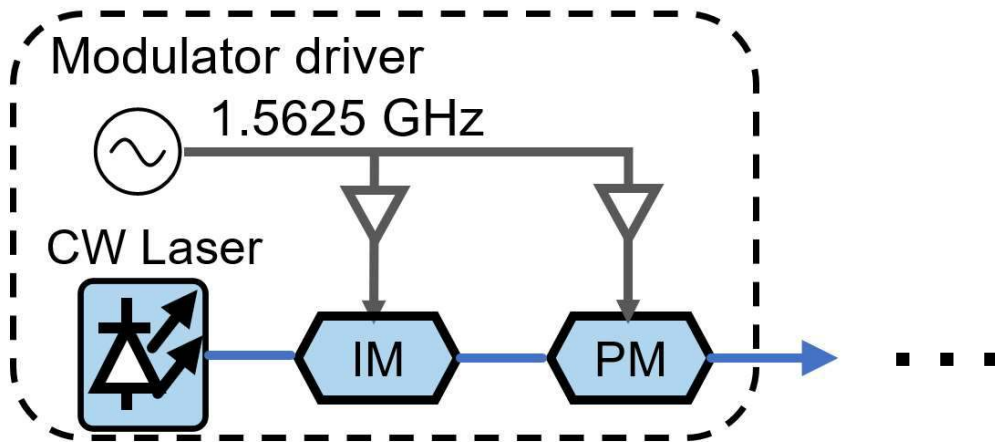
- mm-wave simultaneous **dual-band** data transmission
  - Two W-band sub-bands: **100 (W1) and 112.5 (W2) GHz**
  - Unidirectional: The 2 TXs sit at a site, the 2 RXs sit at another.
- Distribution
  - The **TX site has access to the optical comb**, generated 22 km away.
  - The **RX site is remote**, without direct access to the optical comb.
- Synchronization of CLKs and sources
  - Intra-site: between the 100 and 112.5 GHz sources and the CLK signal.
  - Inter-site: between the TX and RX sites.

# System overview



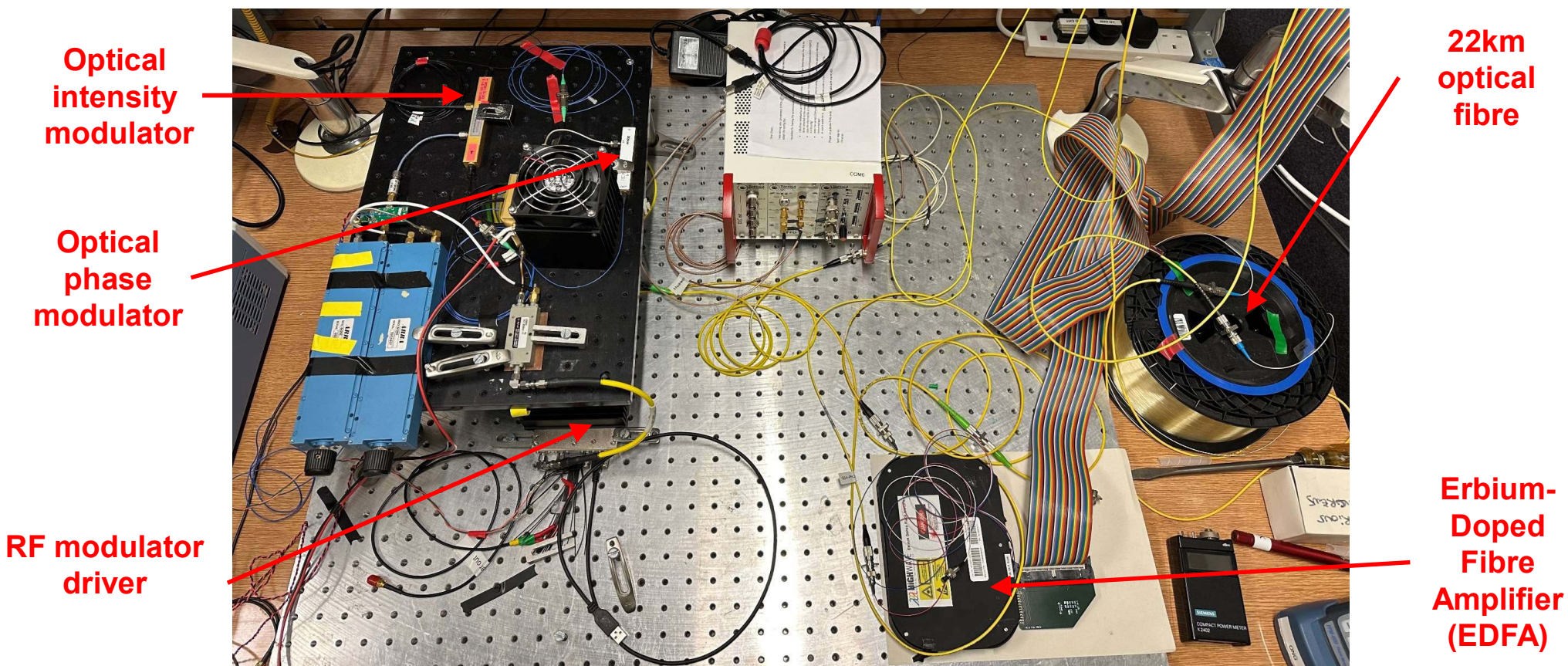
- W-band TXs and RXs: Gotmic GaAs pHEMT up to 24 dBm P1dB with X8
- AWGs and Scopes: Keysight and R&S
- BPFs: Resonant cavity filters
- Frequency divider: Modified Hittite
- RX LOs: R&S
- PD: APIC 20 GHz InGaAs PIN
- W Antennas: Flann Rect Horns

# Electro-Optic Frequency Comb



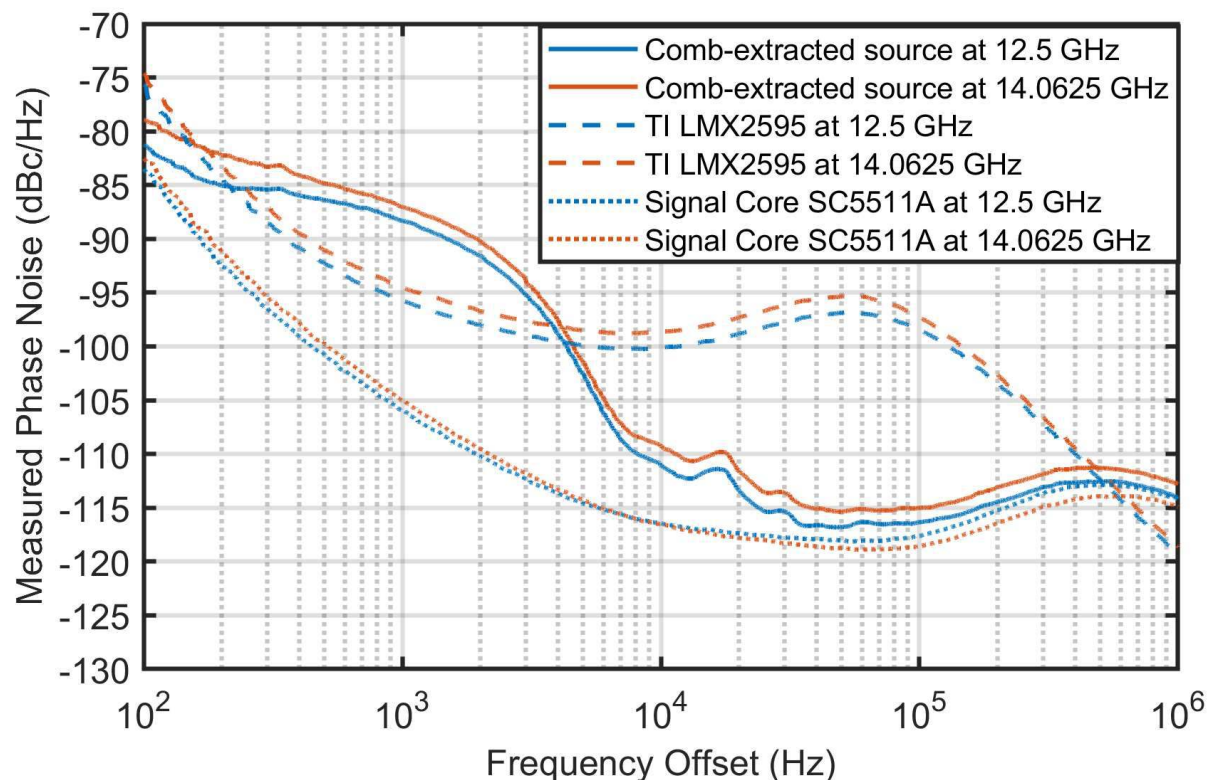
- RF driver: 1.5625 GHz Signal Core (–137 dBc/Hz at 10 kHz)
  - Comb frequency spacing
  - Comb fundamental
  - Comb element phase noise
- Inherent sync capability
- 8<sup>th</sup> order 12.5 GHz: W1 LO
  - $12.5 \times 8 = 100$  GHz
- 9<sup>th</sup> order 14.0625 GHz: W2 LO
  - $14.0625 \times 8 = 112.5$  GHz
- 4<sup>th</sup> order 6.25 GHz (low path-loss): CLK sync (external sync)

# EO comb setup

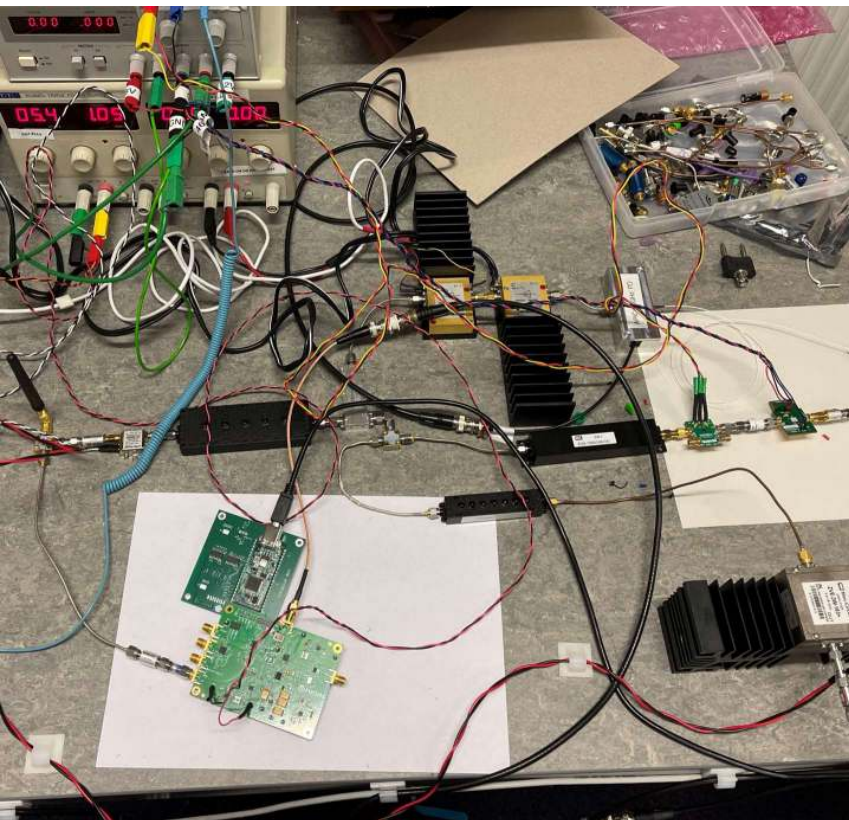


# Measured Phase Noise Performance

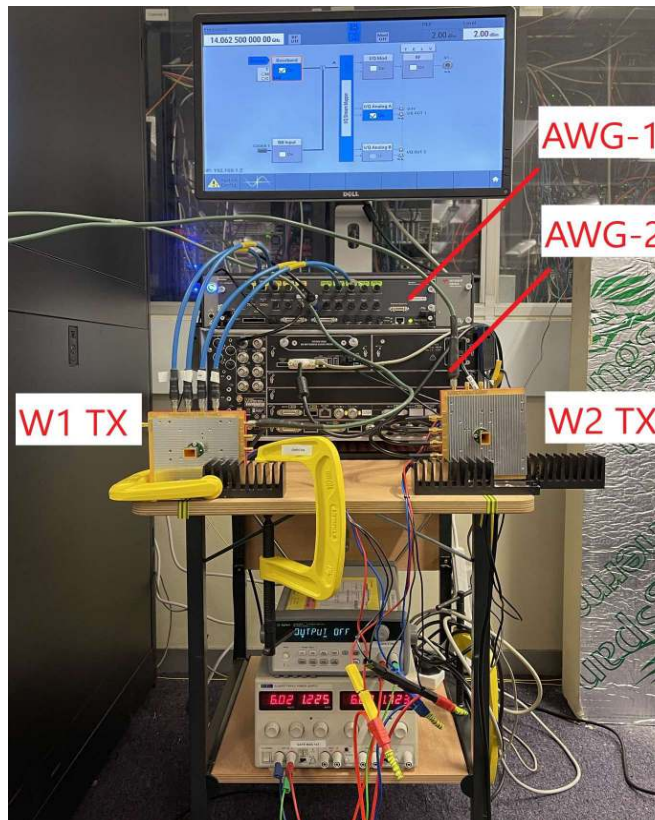
- Against **candidate commercial oscillator** 20 GHz TI (same range as the PD)
  - Performed better in the near-carrier region below 200 Hz offset
  - a slight disadvantage from 200 Hz to 4 kHz.
  - Beyond 4 kHz, the comb performed significantly better.
- Against **Comb RF driver** (implementation penalty)
  - Expansion below 30 kHz from dispersion
  - No penalty beyond 30 kHz.



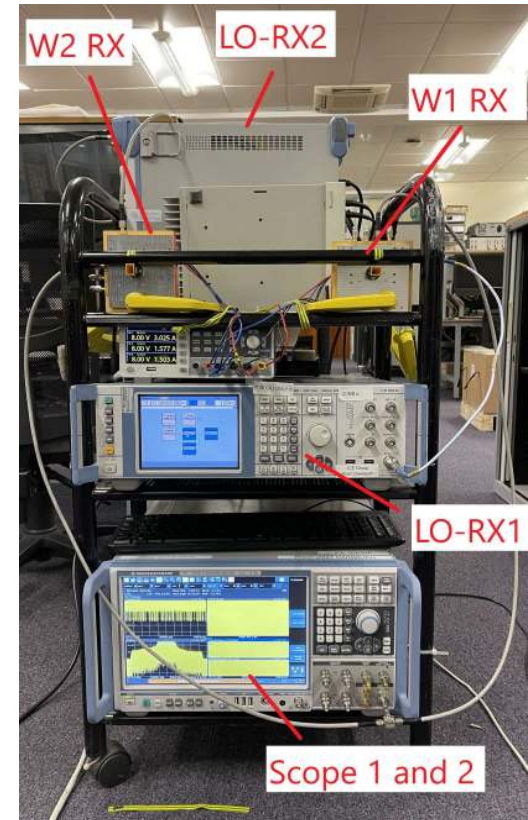
# W-band Setup



Comb processing network

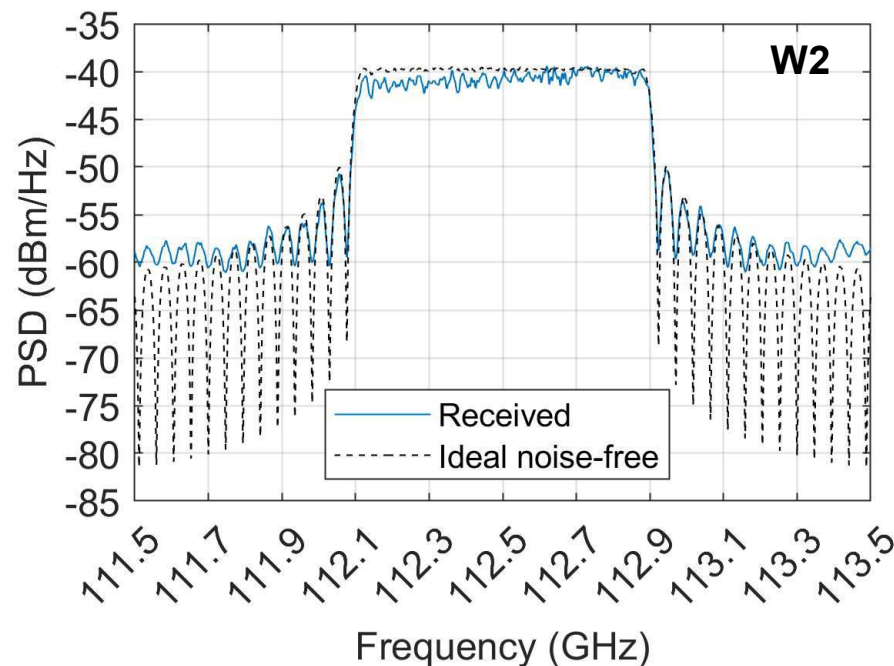
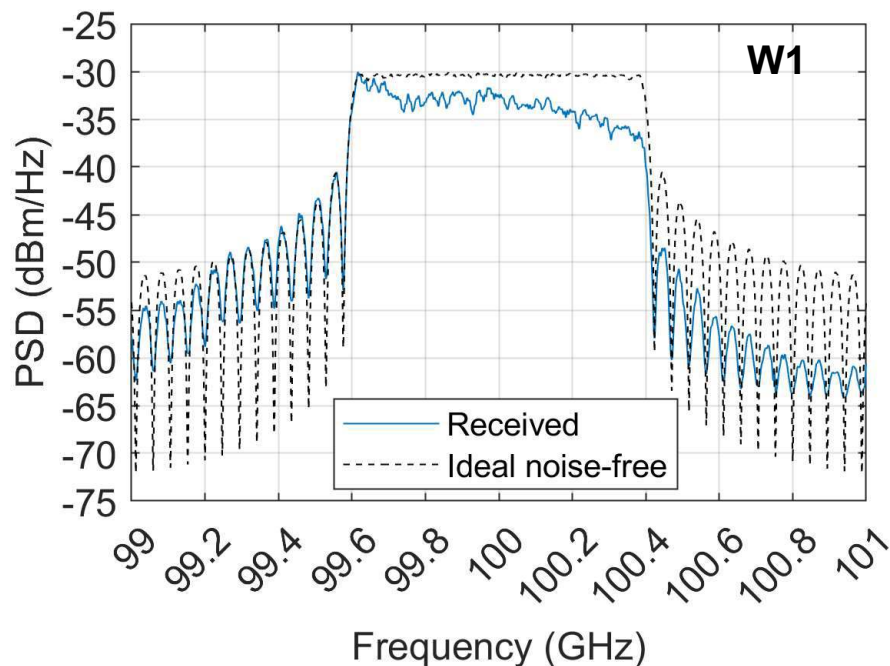


TX site



RX site

# Measured Signals at 5m

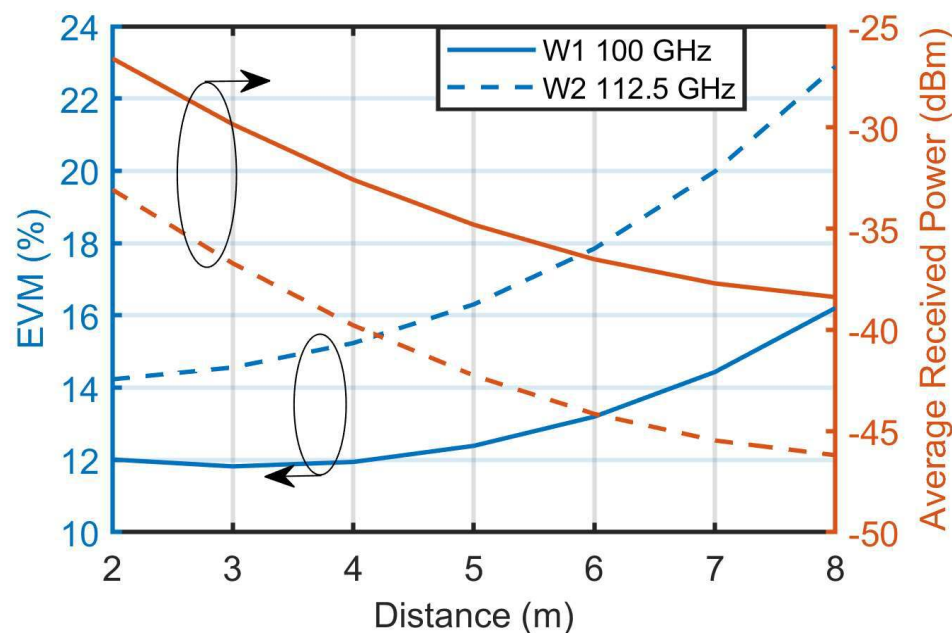
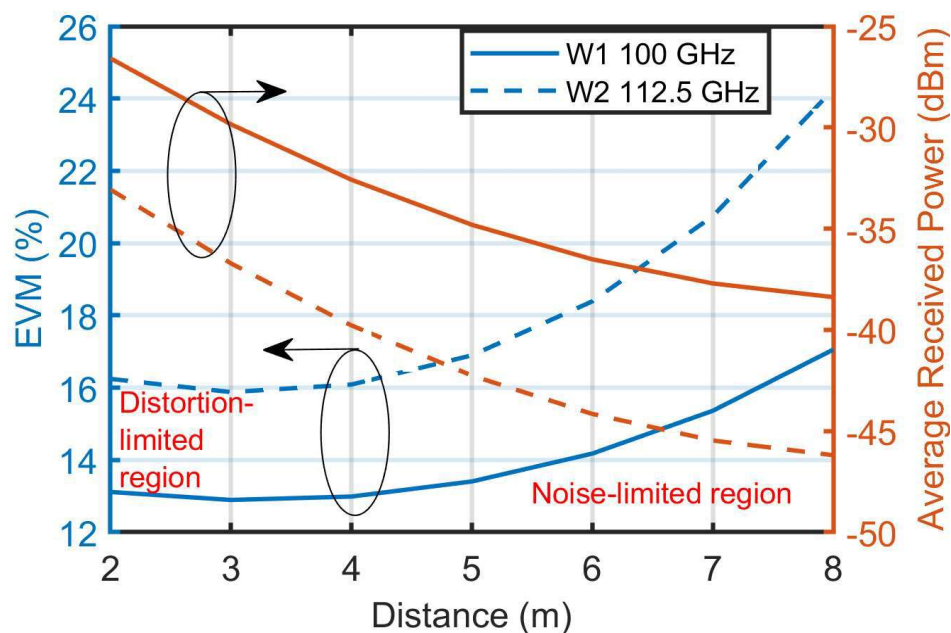


- 16-QAM OFDM
- 17 subcarriers
- 3.2 Gbit/s per TX

- Responses follow TX PA gain profiles

# Measured Performance

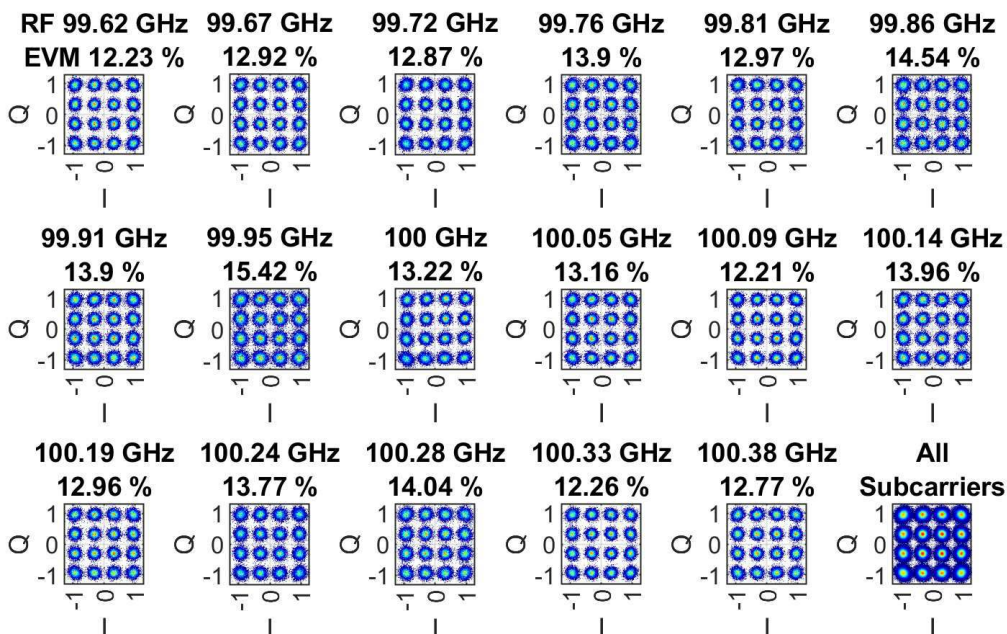
With nonlinear equalization



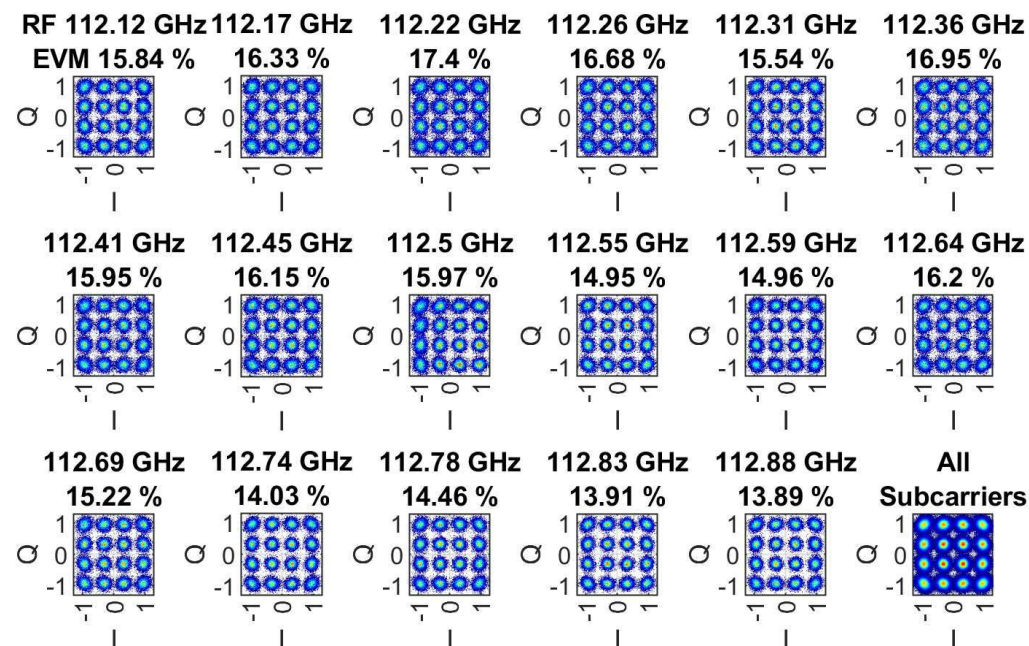
- Indoor cluttered environment
- 2 to 8 meters

# Within each band at 5m

**W1**

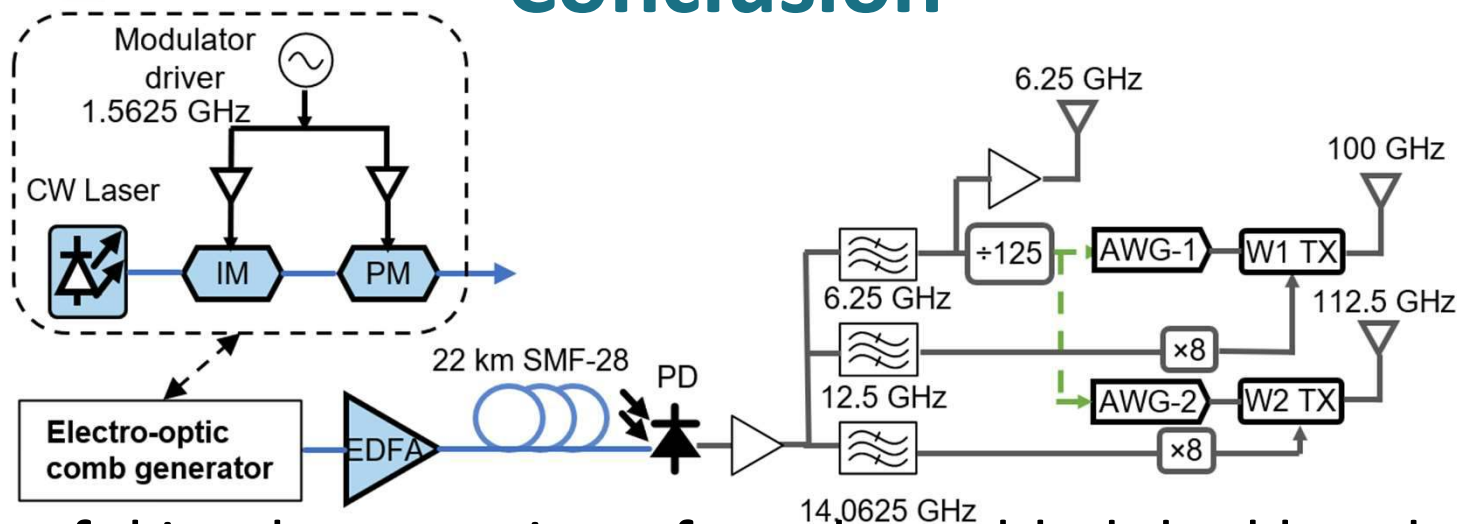


**W2**



- No indication of phase noise and frequency instability limited behaviour

## Conclusion



- Successful implementation of comb-enabled dual band transmission at W-band
  - Distributed frequency scalability both within and across sites
  - Inherent frequency synchronization across comb frequency range
  - External frequency synchronization through broadcast
- Direct mm-wave generation with advancement of PD?