Tu3E-2

An All-Digital Carrier Synthesis for Stepped OFDM Radars

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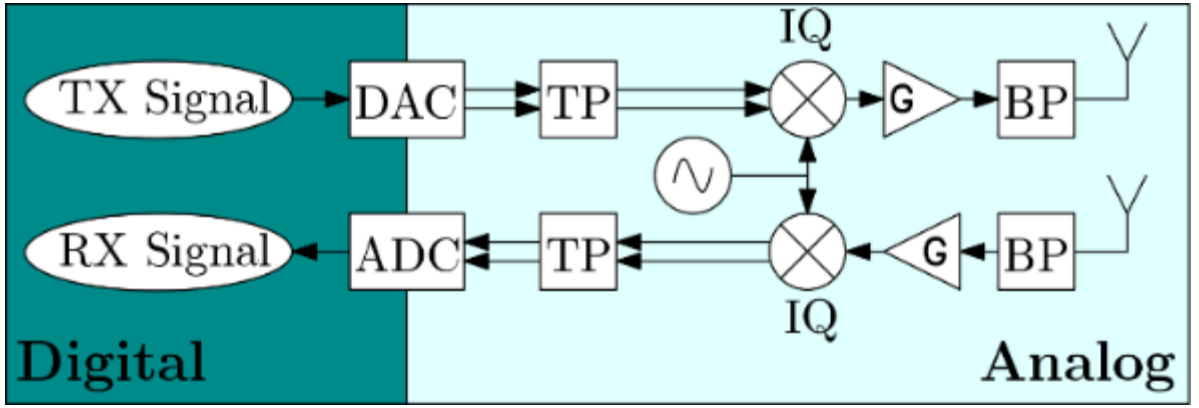
[2] Robert Bosch GmbH, Germany

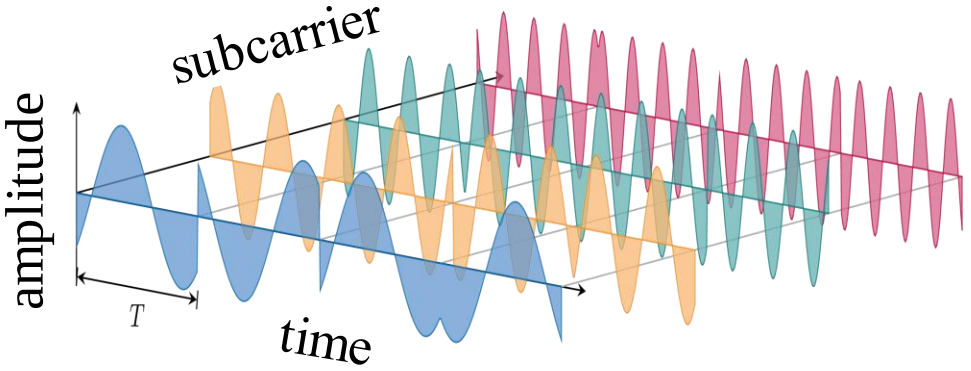
Digital Radars

- Digital baseband signal generation & evaluation
- E.g. OFDM radars, PMCW radars



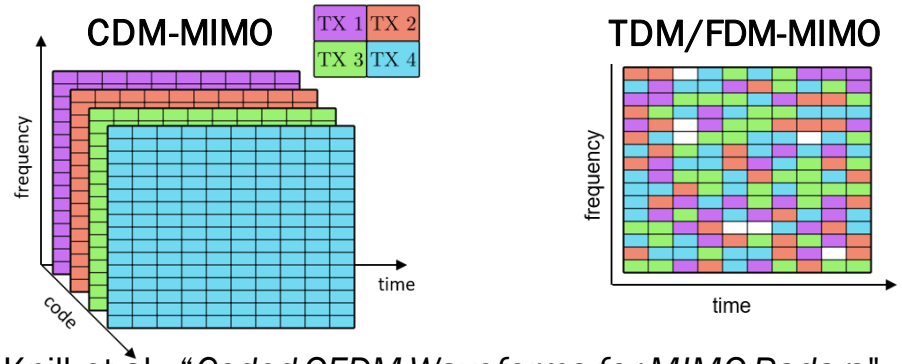
→ Extremely flexible signal design with many degrees of freedom
→ Arbitrary waveforms
→ Adaptive waveforms

OFDM



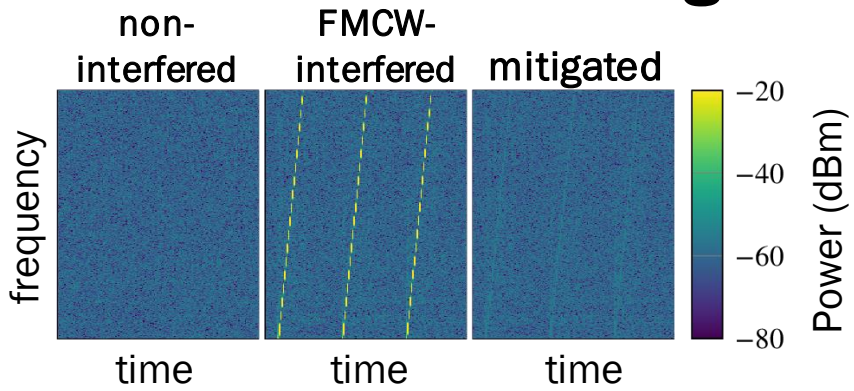
OFDM Radars – Advantages

New and Better MIMO Capabilities



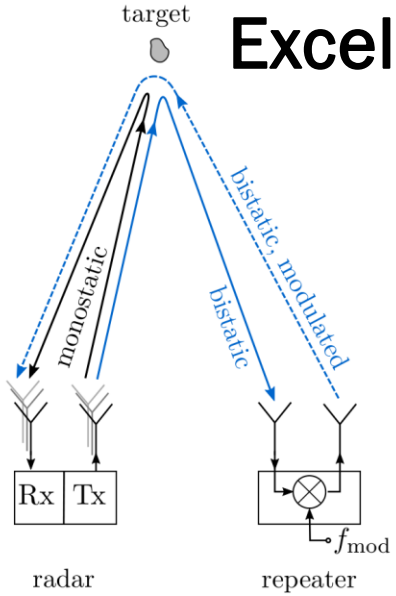
C. Knill et al., "*Coded OFDM Waveforms for MIMO Radars*", IEEE Trans. on Vehicular Technology 2021

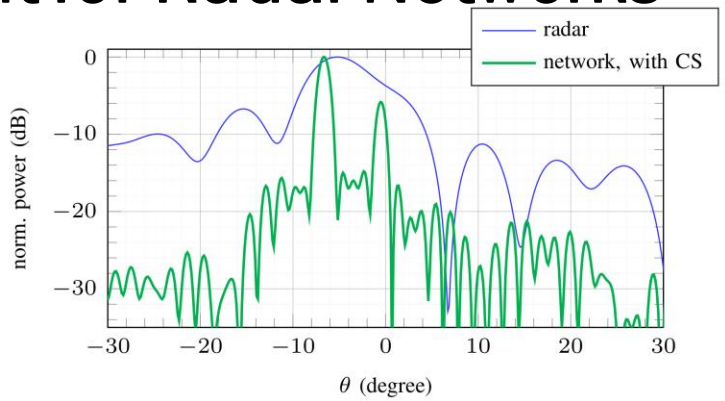
Simple Interference Mitigation



C. Knill et al., "*Impact of an Automotive Chirp Sequence Interferer on a Wideband OFDM Radar*", EuRAD 2018

Excellent for Radar Networks

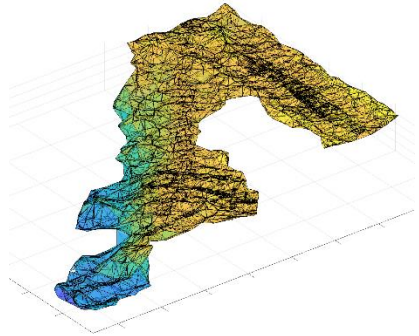




D. Werbunat et al., "*OFDM-Based Radar Network Providing Phase Coherent DOA Estimation*", IEEE Trans. MTT, 2020

New Applications

Surface model



F. Koderer et al., "*Robust UAV-Born Fully Digital MIMO OFDM Radar for the Generation of a Digital Elevation Model*", EuRAD 2022

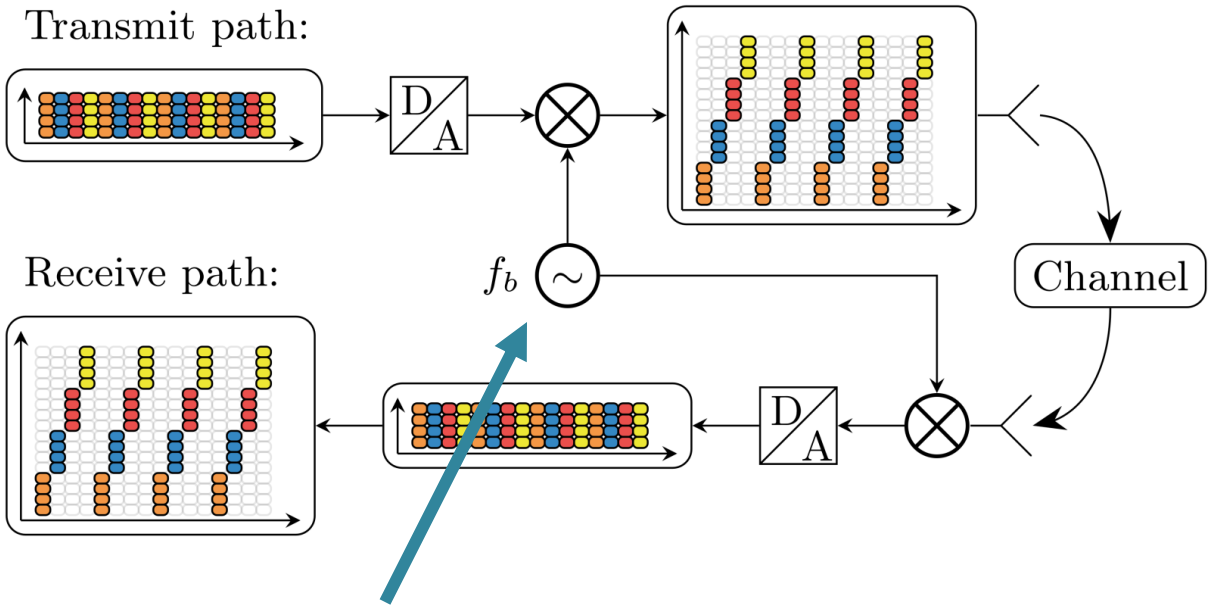
OFDM Radars – Challenges

High resolution → **Large bandwidth** ← Sampling of entire RF BW

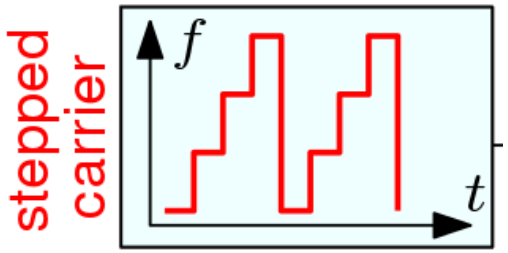
Solutions:

a) ADC/DACs with high sampling rate (>2 GS/s)
But: Expensive!

b) Clever signal design and post-processing
Idea: Reduce ADC/DAC rate *and* keep full/high resolution
Solution using agile carriers:
→ Stepped OFDM

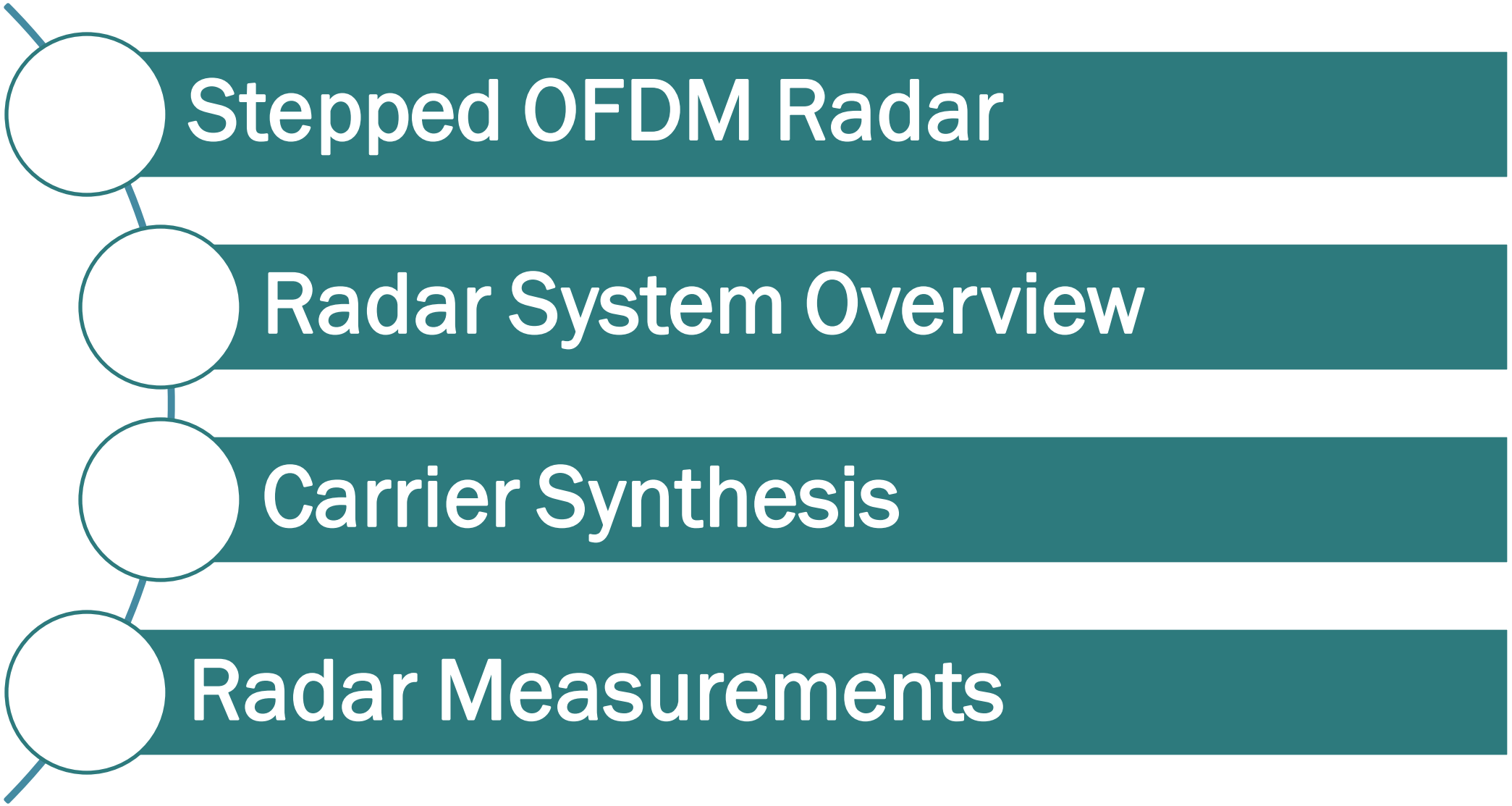


→ Frequency-agile carrier synthesis necessary



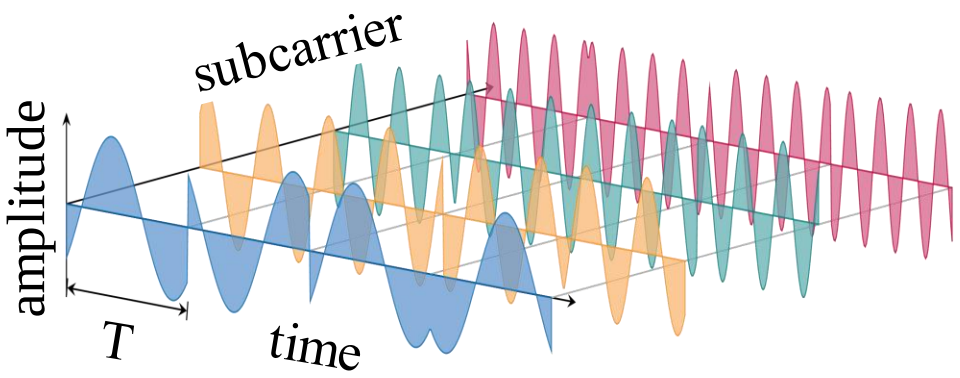
→ **DDS-based carrier synthesis!**

Outline

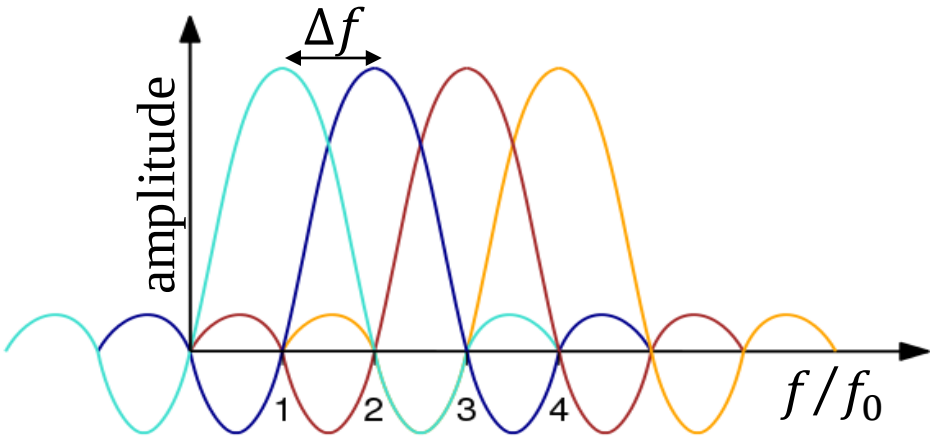

Stepped OFDM Radar
Radar System Overview
Carrier Synthesis
Radar Measurements

OFDM Radar

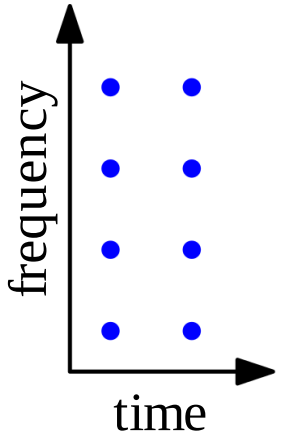
- Many *parallel* CW signals
  - Transmitted simultaneously
- Phase-coded
  - Symbol duration T
- Evaluation with 2D-FFT



Spectrum of OFDM subcarriers



Abstraction



Modulation symbol (QPSK)

Stepped OFDM

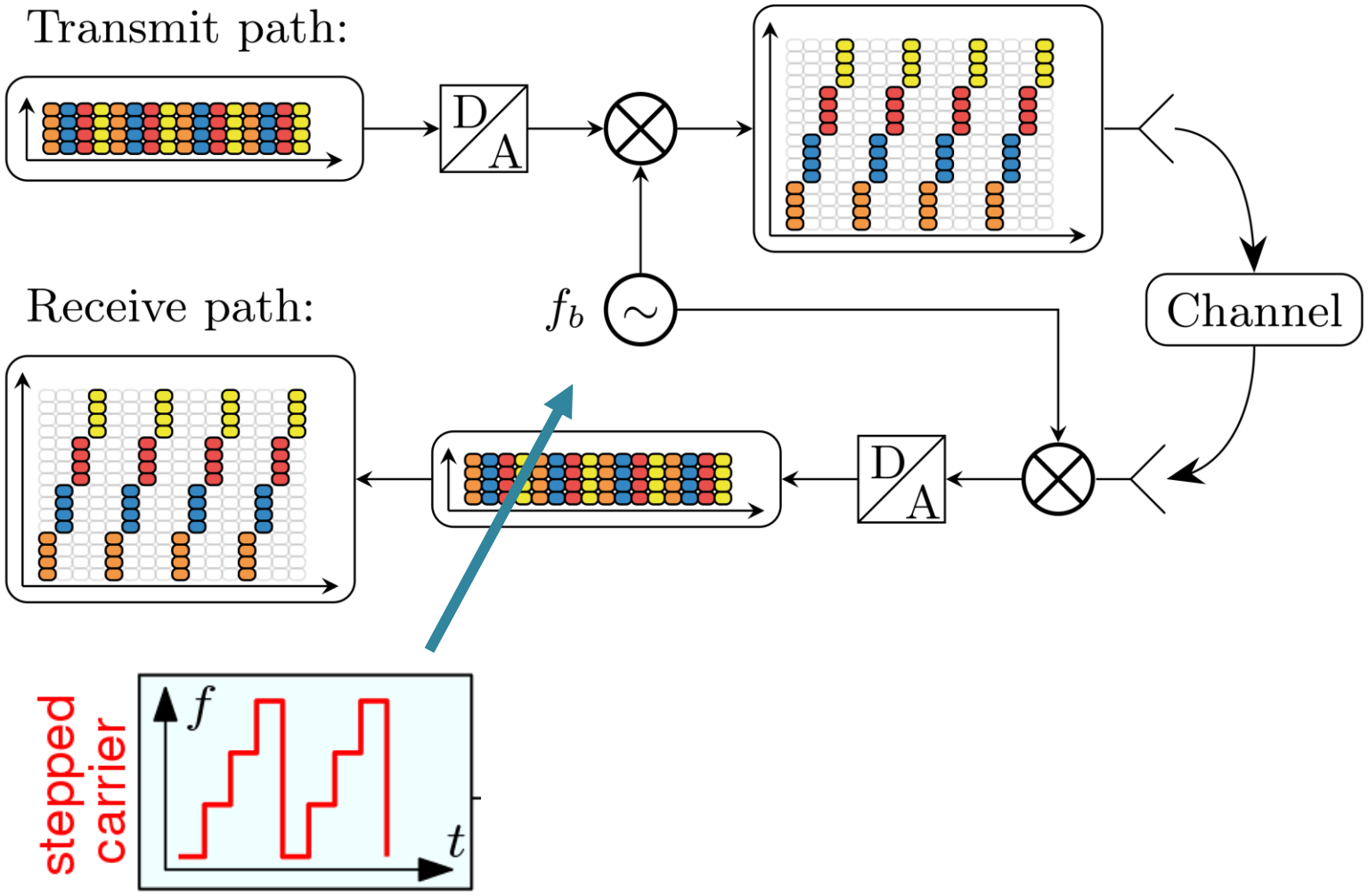
TX

- Sampling of a low bandwidth OFDM
- Upconverting with a stepped carrier

→Large RF bandwidth

RX

- Downconverting with a stepped carrier
- Sampling with low bandwidth
- Evaluation according to the RF frequencies



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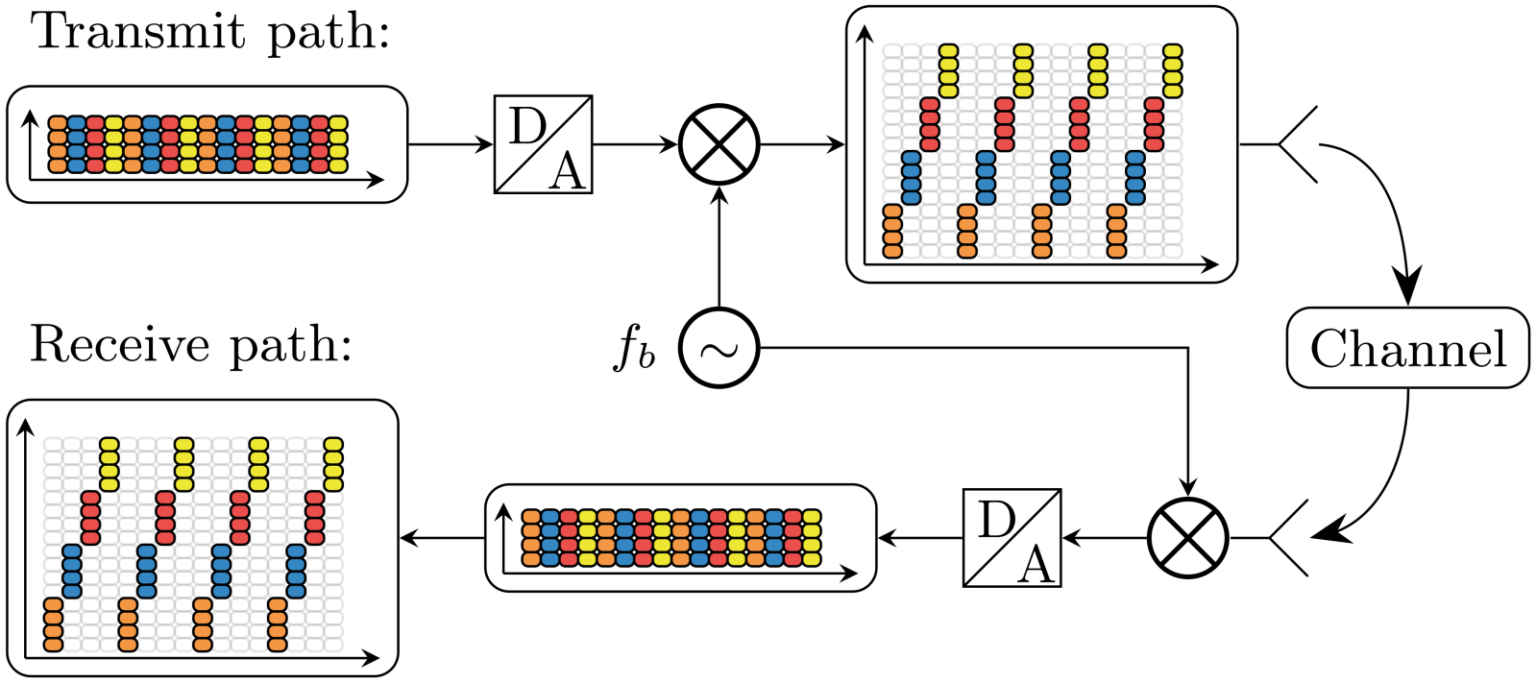


Low baseband bandwidth
+
Agile carrier
=
Large RF bandwidth
→ High range resolution

Costs: Loss in unambiguous velocity

Digital Radar – System Overview

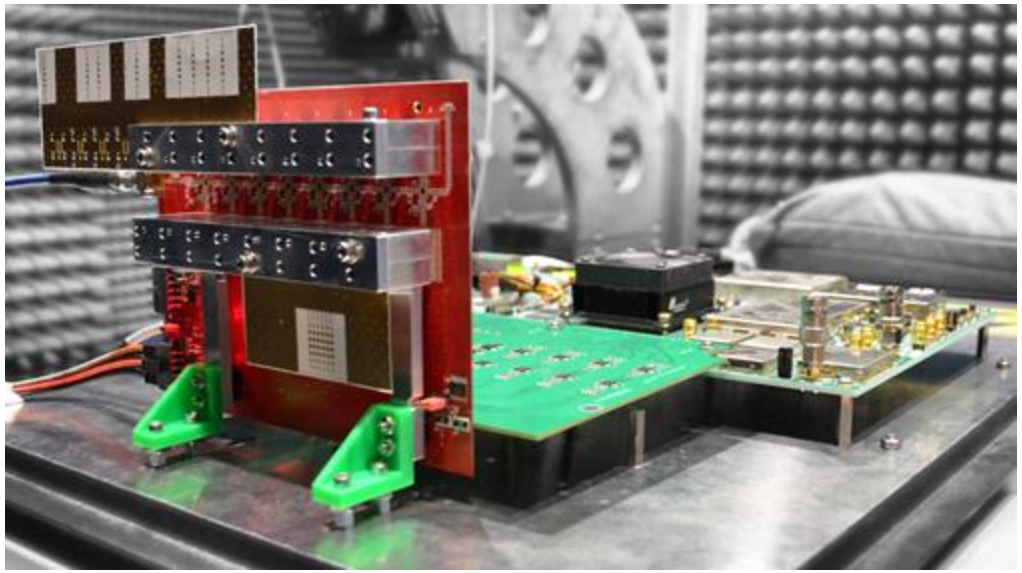
Frontend:

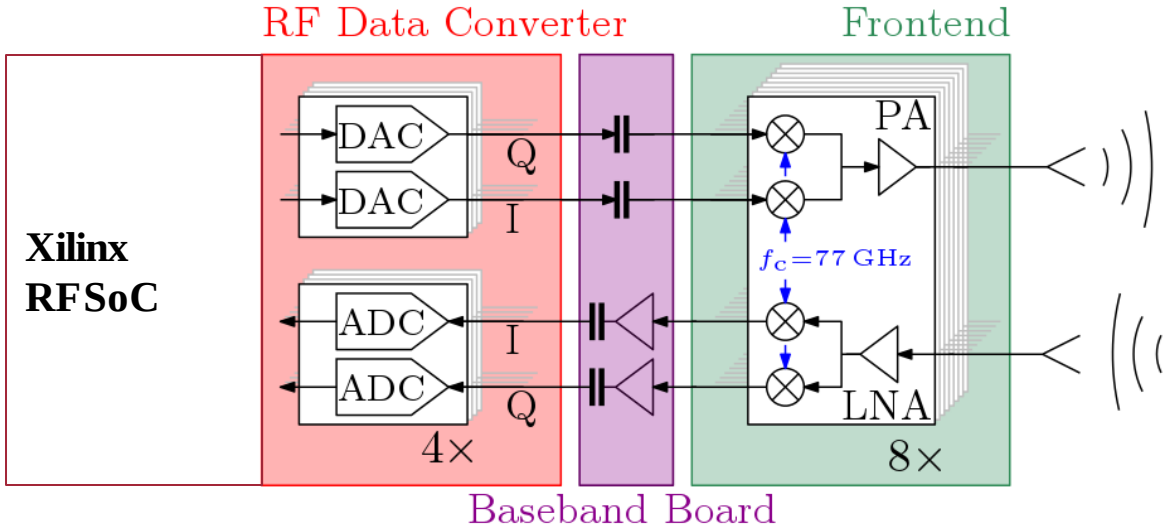
- Eight TRX MMICs used for 4x4 MIMO
- Exchangeable antenna arrays with waveguide transition
- Daisy-chain LO distribution

Backend:

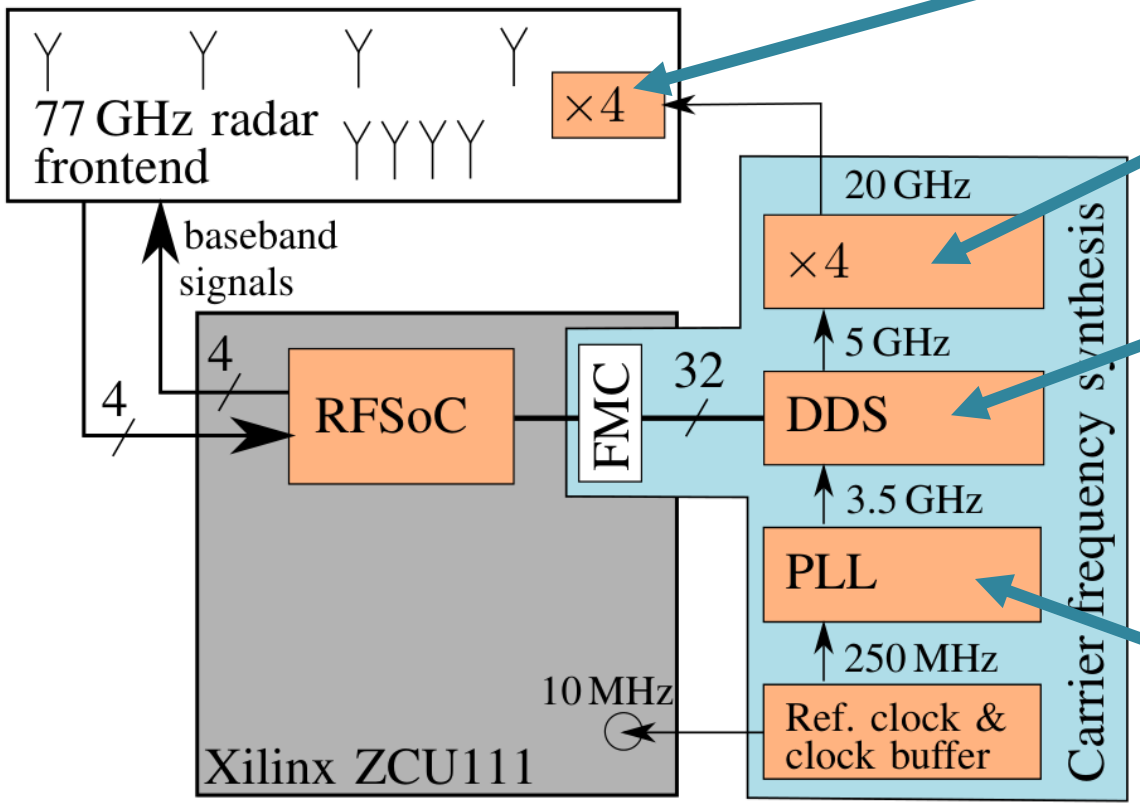
- Xilinx RFSoC (ZCU111)
- 8 ADC, 8 DAC
- 1 GSa/s possible

→ 400 MHz baseband bandwidth





Stepped Carrier Synthesis – System



Subharmonic mixers on frontend:

→ Multiplication by 4

X4 frequency multiplier:

→ Provides 20 GHz Output (~77 GHz / 4)

DDS:

- Instantaneous frequency steps
- 5 GHz Output

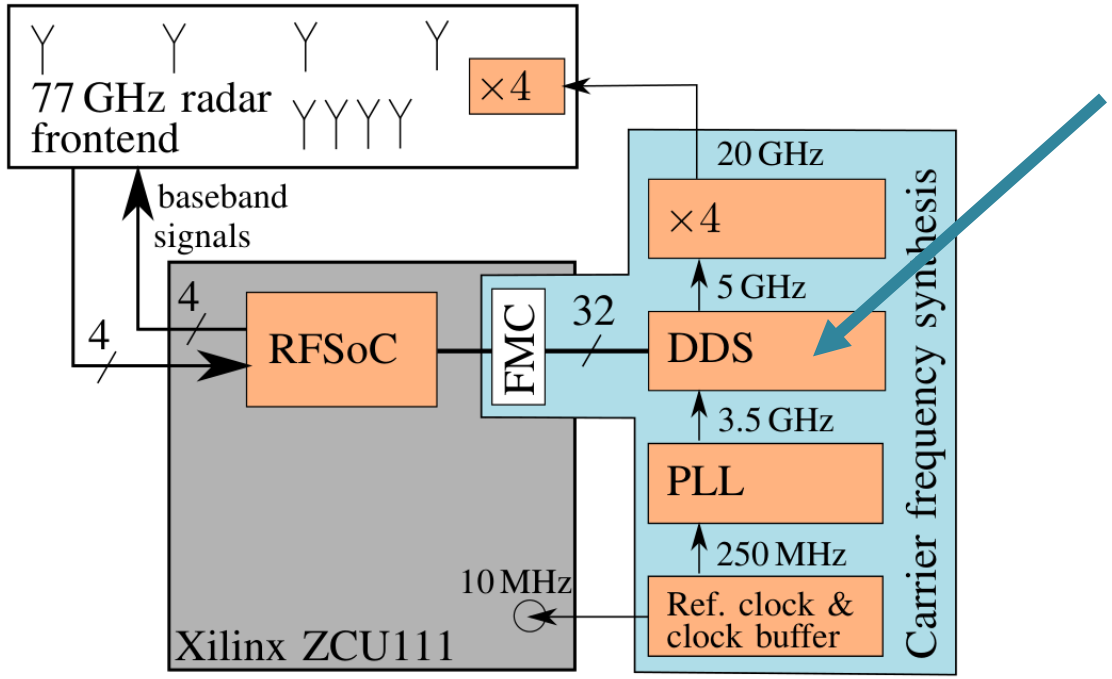
→ Agility and flexibility for stepped OFDM!

PLL:

- DDS reference clock generation
- Low tuning-range VCO

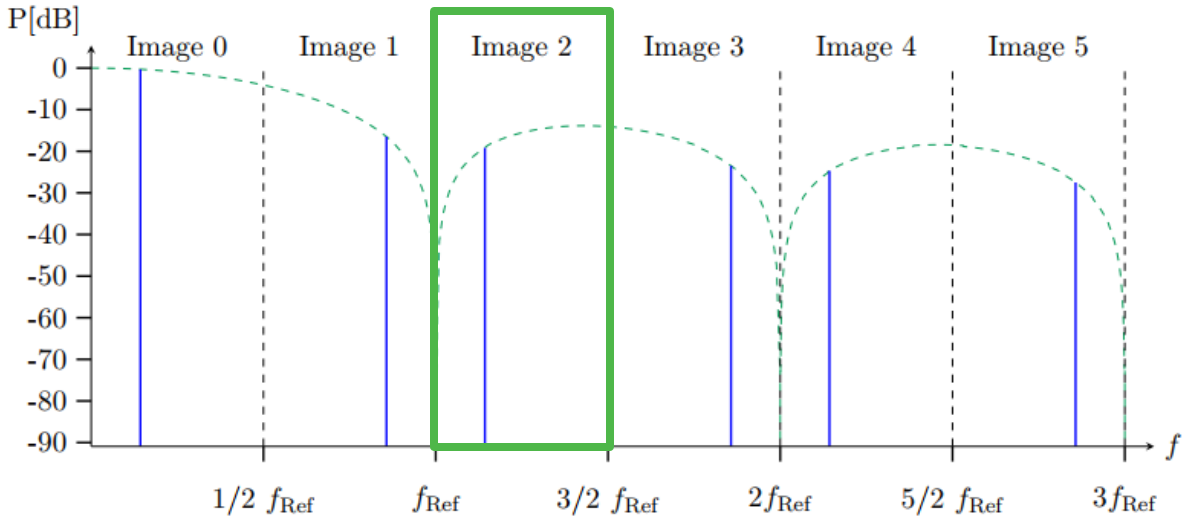
→ Low phase noise reference

Stepped Carrier Synthesis – DDS

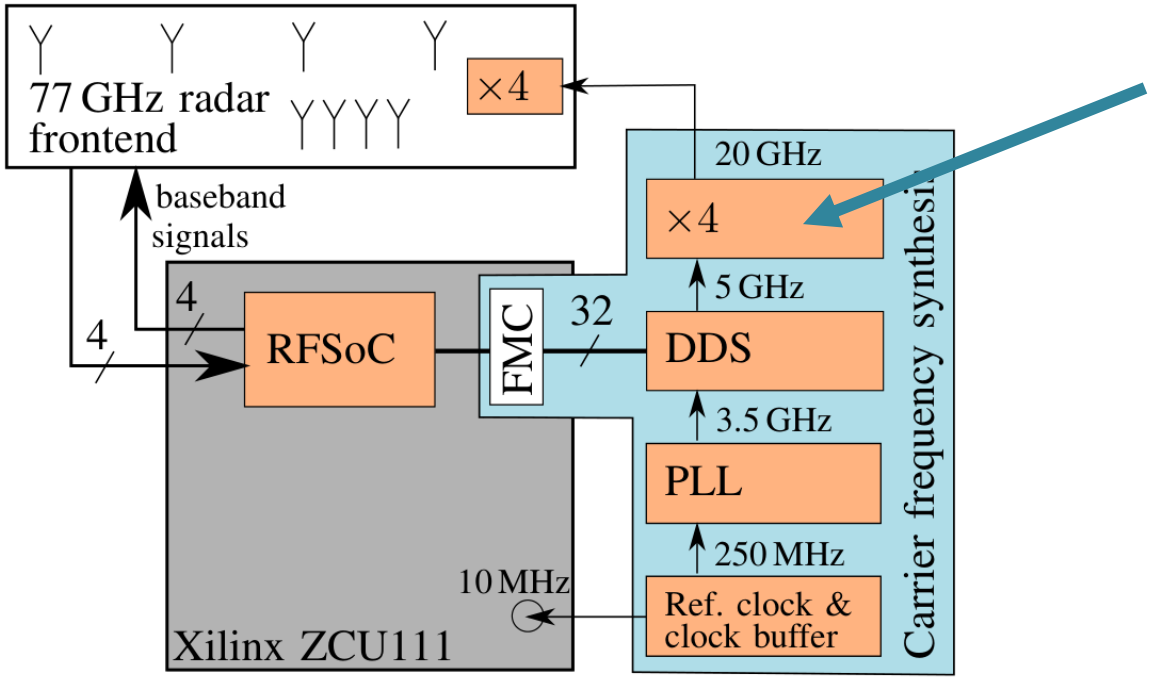


DDS:

- Analog AD 9914
- 32 bit frequency word
  → Instantaneous frequency changes
  → Full flexibility
  → 13 Hz precision @ RF
- Nyquist image 2
  → 5 GHz output possible
  → Less frequency multiplier

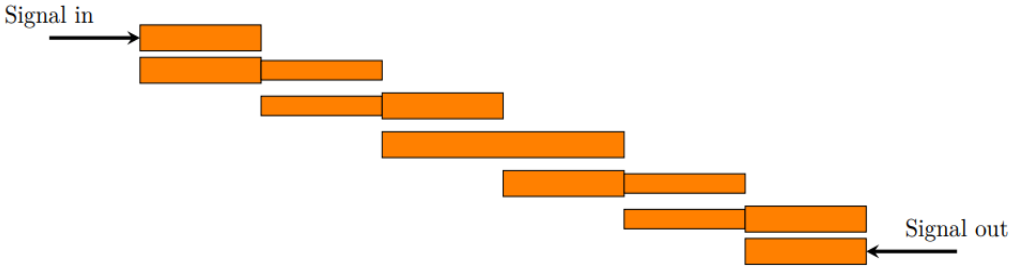


Stepped Carrier Synthesis – X4

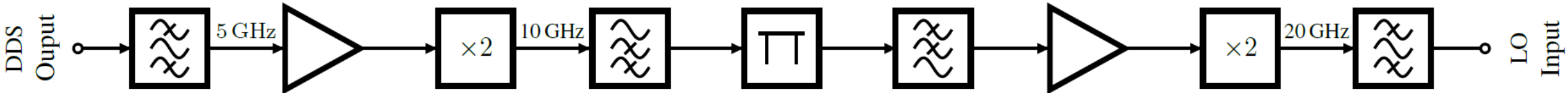


X4 frequency multiplier:

- Two frequency doubler
- Custom designed microstrip bandpass filters (5th-order Chebyshev)
  → Spur suppression



- Amplifier and attenuators to match output and input powers

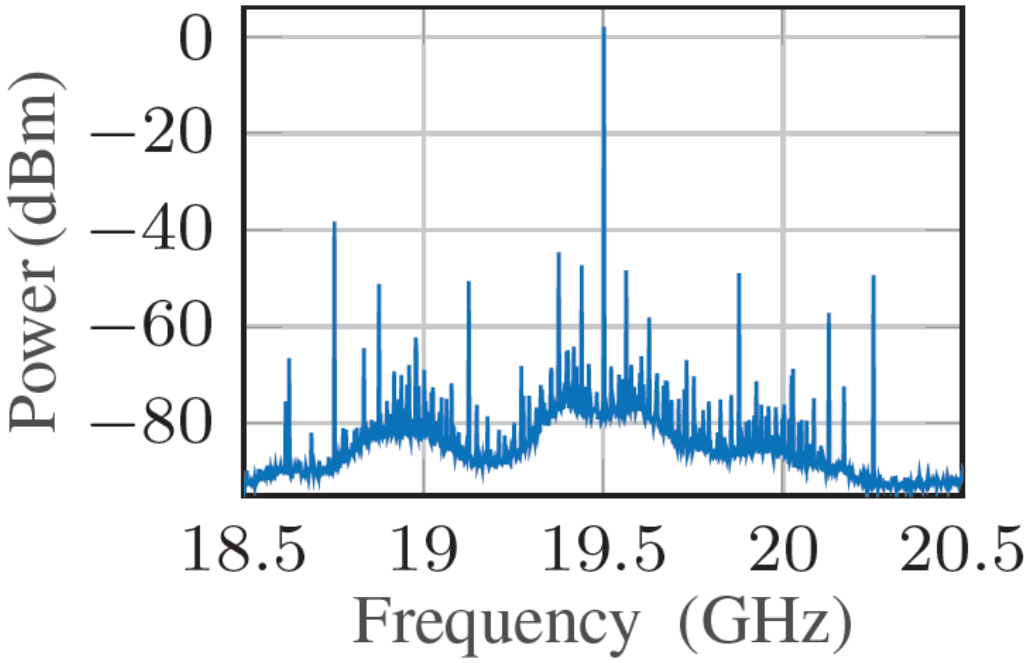


Microstrip BP

Microstrip BP

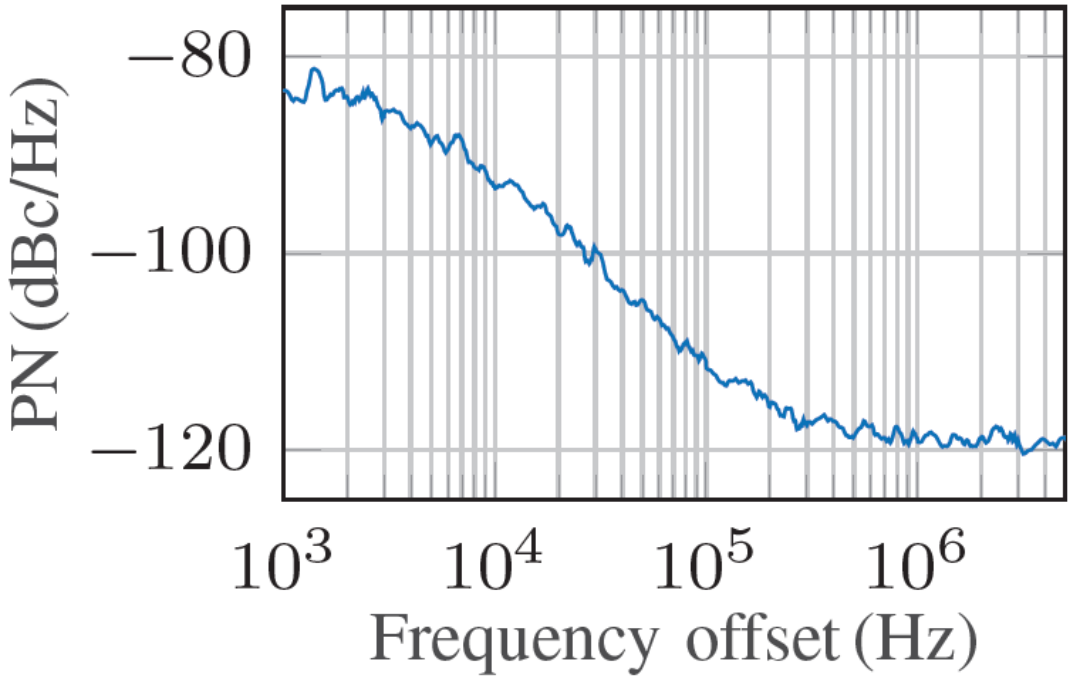
Carrier Synthesis – Characterization

Output Spectrum



- 40 dB spur suppression
- At least 2 MHz spur offset
  → No ghost targets

Phase Noise



- Very low phase noise: -110 dBc/Hz @ 100 kHz
  → Radar performance not limited by phase noise

Radar Performance

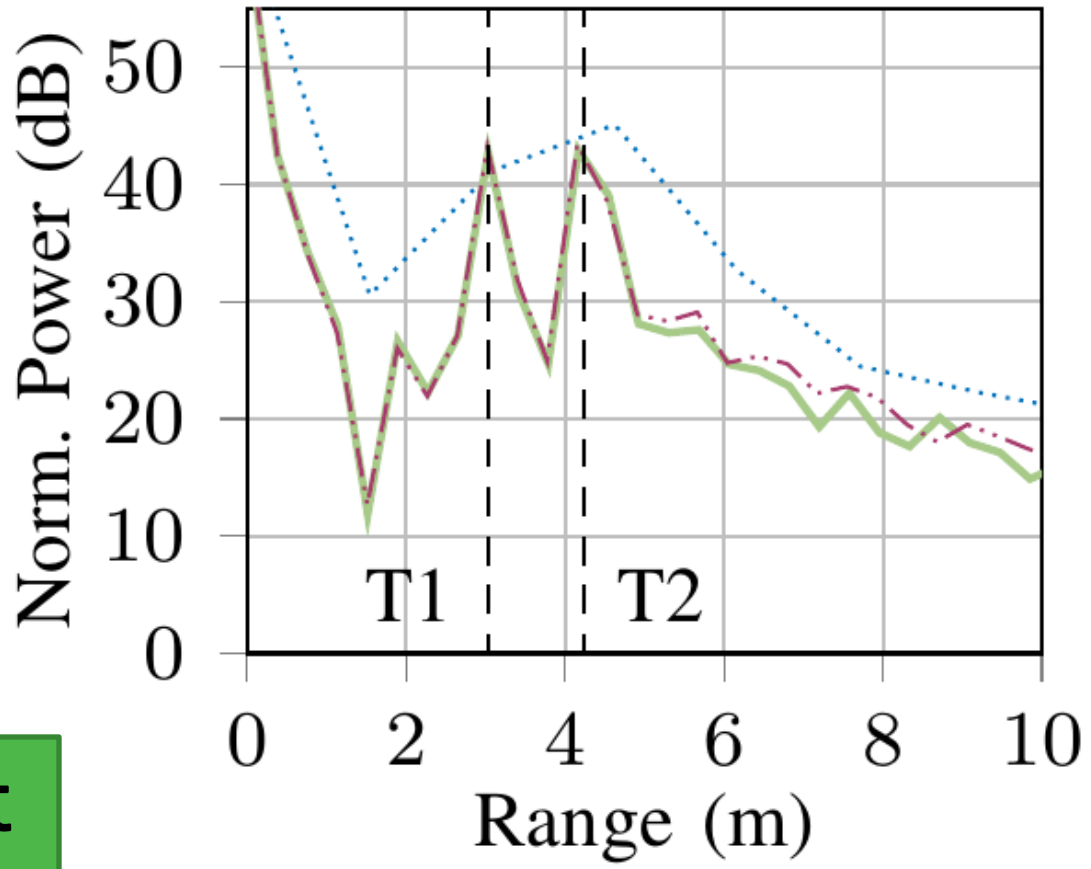
- Two corner reflectors
- Distance: 1.2 m

No steps, 100 MHz

4 steps of 100 MHz

No steps, 400 MHz

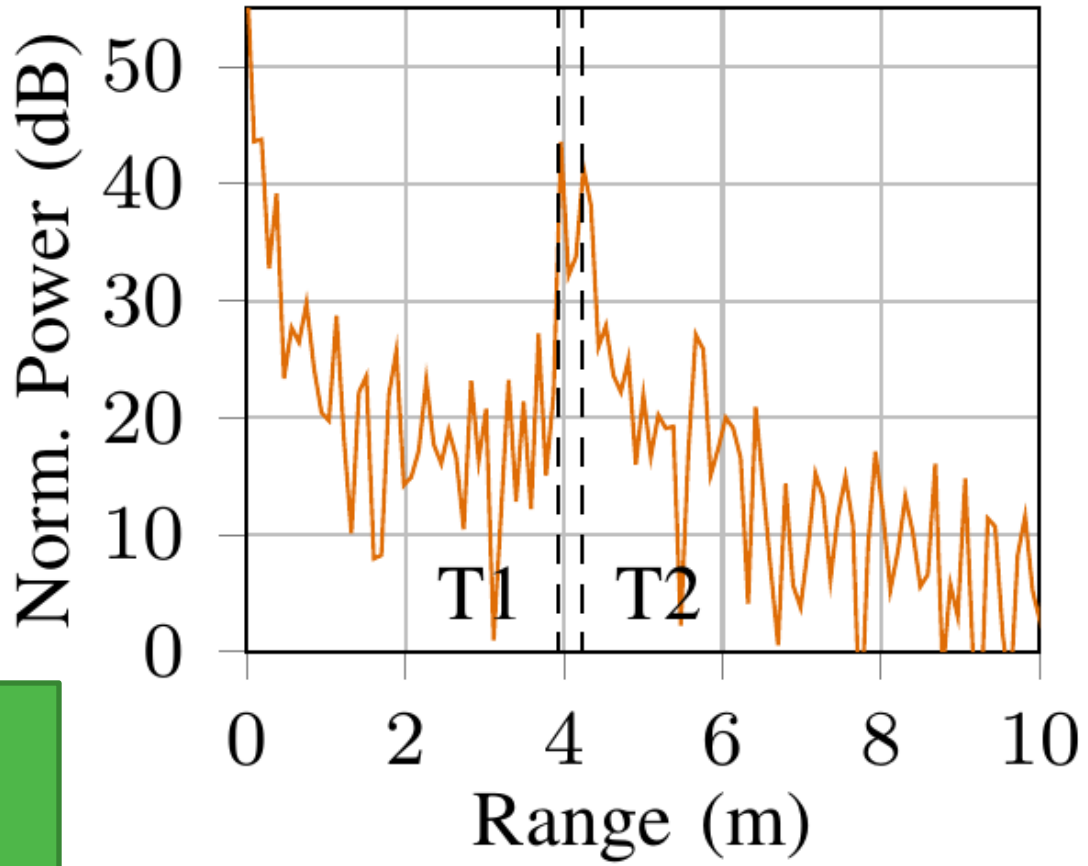
Identical performance



Stepped carrier synthesis does not affect radar performance!

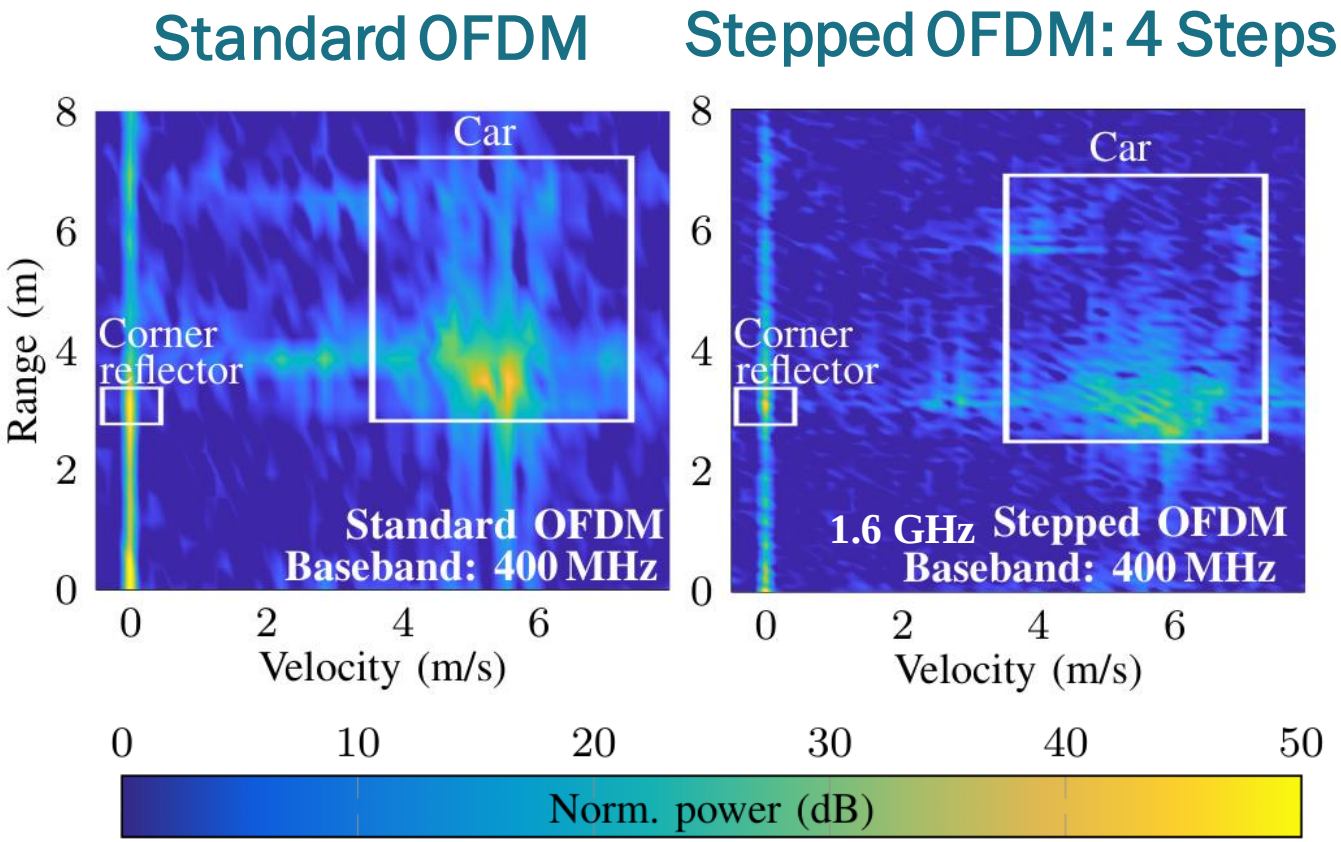
Radar Performance

- Two corner reflectors
- Distance: 0.3 m
- 4 steps of 400 MHz
  → 1.6 GHz RF bandwidth!
  → 0.09 m range resolution



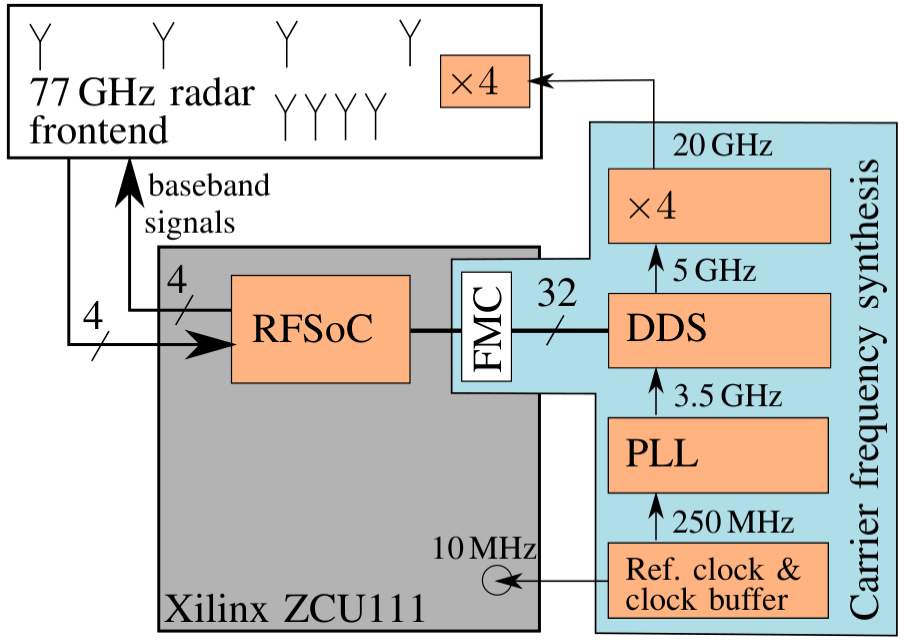
High range resolution & target separability with low baseband bandwidth!

Automotive Measurements



Conclusion

- OFDM-radars
  - High flexibility
  - Drawback: High baseband bandwidth to be sampled
- Stepped OFDM
  - High RF Bandwidth with low baseband bandwidth
  - Agile carrier necessary!
- DDS-based carrier synthesis
  - Fast & flexible
  - Low spurs, low phase noise
  - → Allows for excellent stepped OFDM performance



Stepped carrier synthesis enables high range resolution with low baseband bandwidth

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