We2G-1

A Compact 140-GHz Radar MMIC with I-Q Downconverter in SiGe BiCMOS Technology

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Presentation Outline

Monostatic Doppler Radar

Continuous wave radar:

- Permanent transmission of RF signal with constant frequency

Conventional monostatic radar:

- One antenna for both transmitted and received signal
- Typically requires coupler to seperate RX/TX paths

I/Q Mixer realization:

- Allows to obtain phase information
- Typically realized by 90-deg coupler

Monostatic Doppler Radar

D-band Doppler Radar:

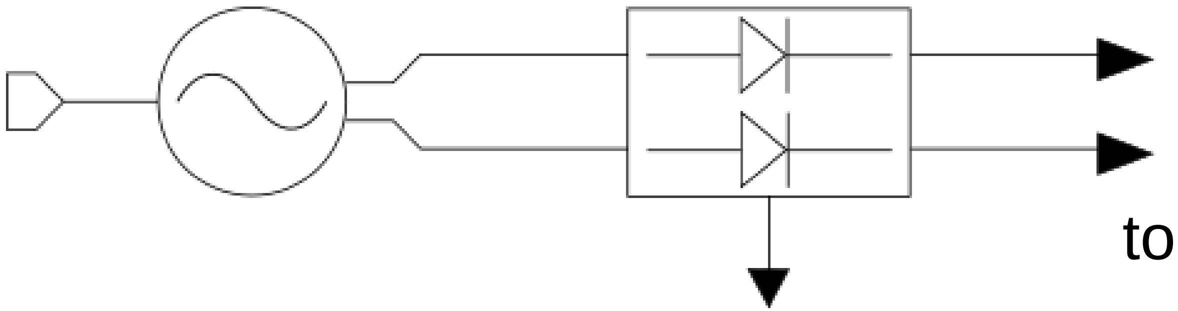
- D-band frequencies (110 to 170 GHz) increasingly relevant for radar systems
- Doppler radar: $f_D = \frac{2v_r}{\lambda} \sim f_{TX}$ with $\lambda = \frac{c}{f_{TX}}$
- Compact Doppler sensor realization:
  - monostatic structure (single RX/TX antenna)
  - low current consumption (passive mixer)

Monostatic Doppler Radar

Conventional Diode Mixer Topology

- No dedicated ratrace coupler for monostatic radar system
  - Enables better SNR
  - Enables compact layout realization

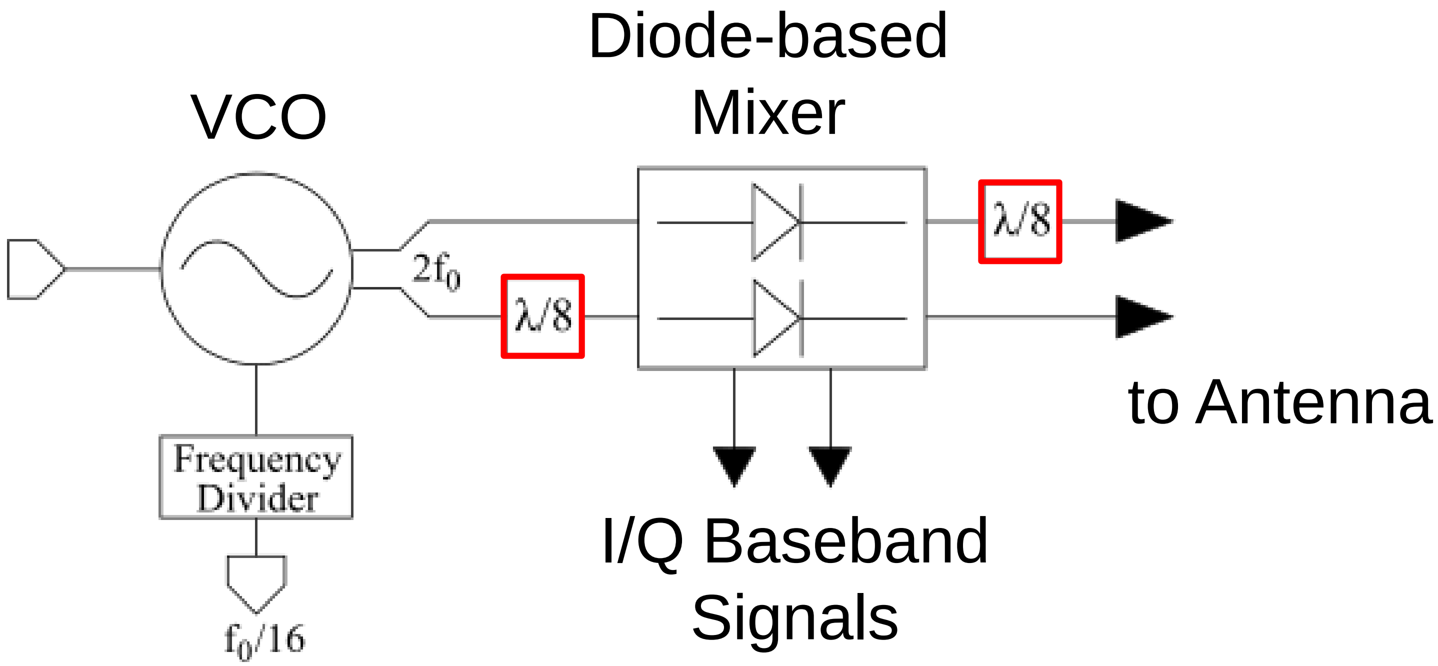
- No phase information, redundant baseband signals



I/Q Diode Mixer

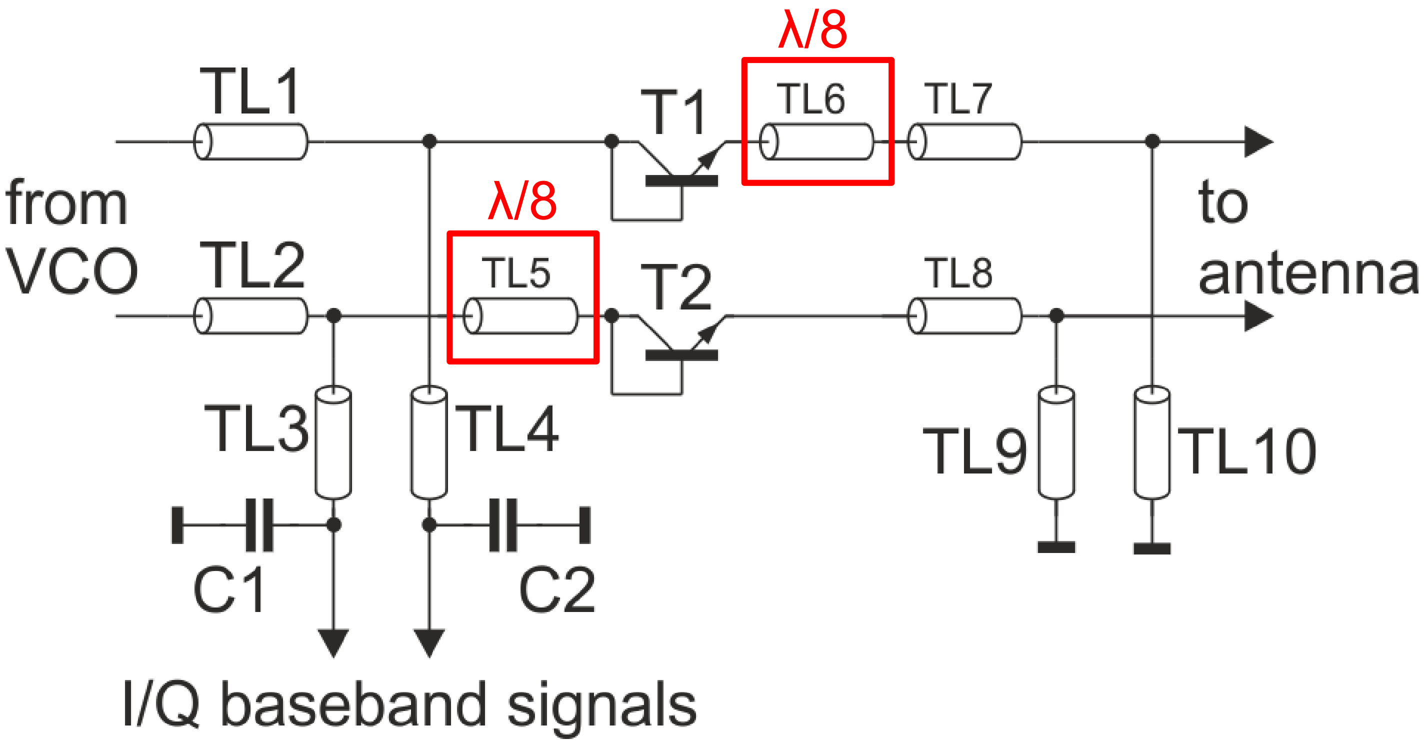
Adaptions for I/Q output:

- Shifted λ/8 lines added
  - result in relative 90° shift for baseband signals
  - I/Q signal at baseband output provides additional phase information
- Differential output signal to antenna not affected



I/Q Diode Mixer

- Transistors T1, T2 as mixing diodes
  - small bias current through diodes
- λ/4 lines TL3, TL4 transform RF short (C1, C2) into open
- Stub lines TL9, TL10
  - compensate parasitic pad capacitance
  - provide return path for mixer bias current diodes

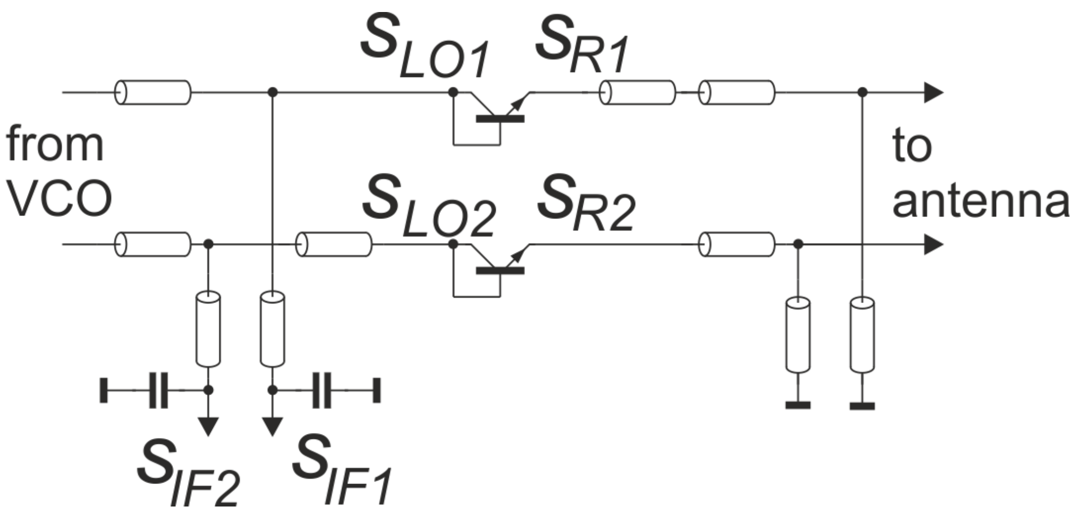


I/Q Diode Mixer

- $s_{LO1}(t) = cos(2\pi f_0 t + \varphi_0)$
- $s_{LO2}(t) = cos\left(2\pi f_0 t + \varphi_0 - \pi - \frac{\pi}{4}\right)$

- $s_{R1}(t) = cos\left(2\pi(f_0 \pm f_D)t + \varphi_{RX} - \frac{\pi}{4}\right)$
- $s_{R2}(t) = cos(2\pi(f_0 \pm f_D)t + \varphi_{RX} - \pi)$

- Phase shift due to differential signal
- Phase shift due to shifted λ/8 lines

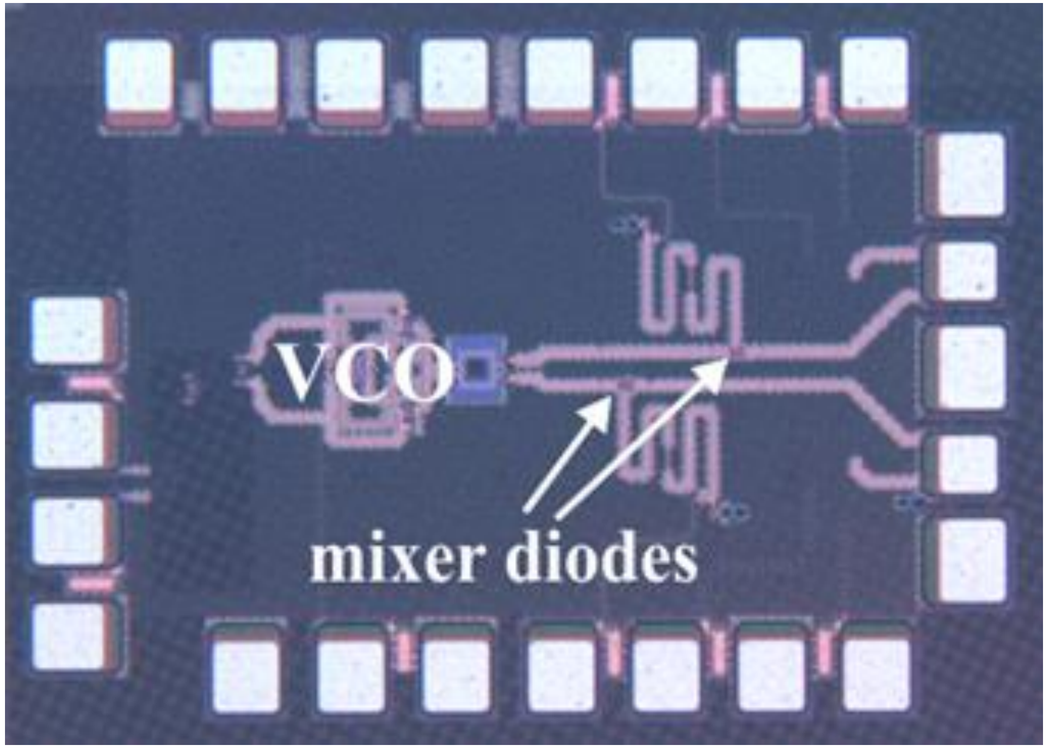


Baseband output:

$$\Delta\varphi = \pm\frac{\pi}{2}$$

Circuit Realization

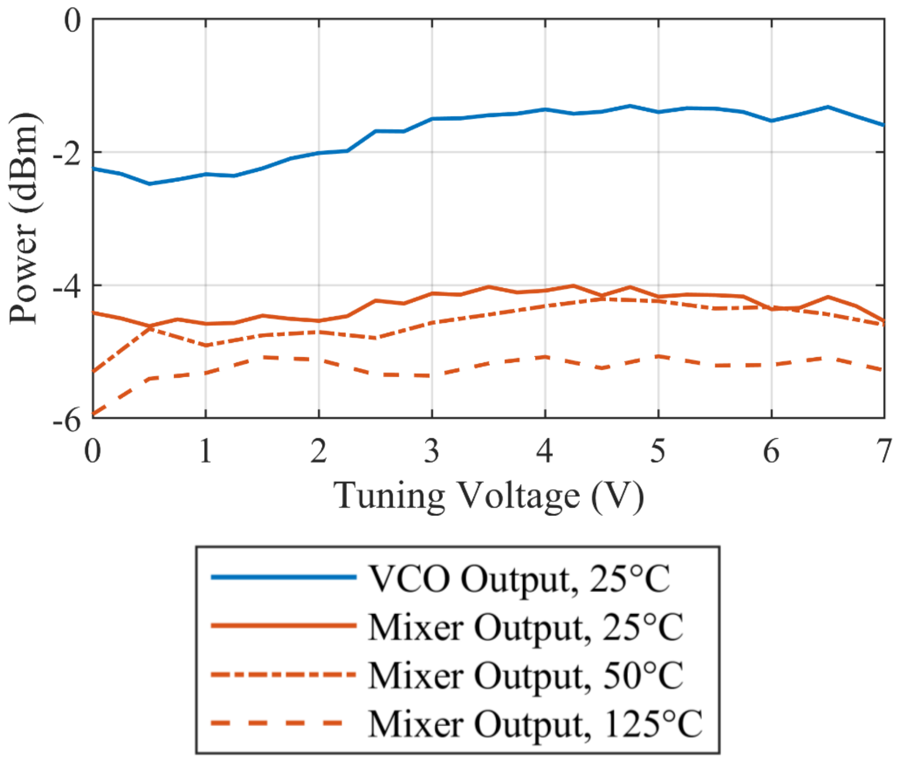
- Circuit realized with on-chip D-band VCO
- Infineon‘s 130nm SiGe BiCMOS process B11HFC
- fT/fmax = 250 GHz/370 GHz
- 800×1160µm^2 (including pads)



Measurement and Results

Transmitted Power over Temperature

- Diode insertion loss ≈ 2,5 dB
- Moderate decrease of output power at 125°C
- Transceiver remains functional at temperatures > 200°C (sufficient output power for meaningful Doppler measurements)

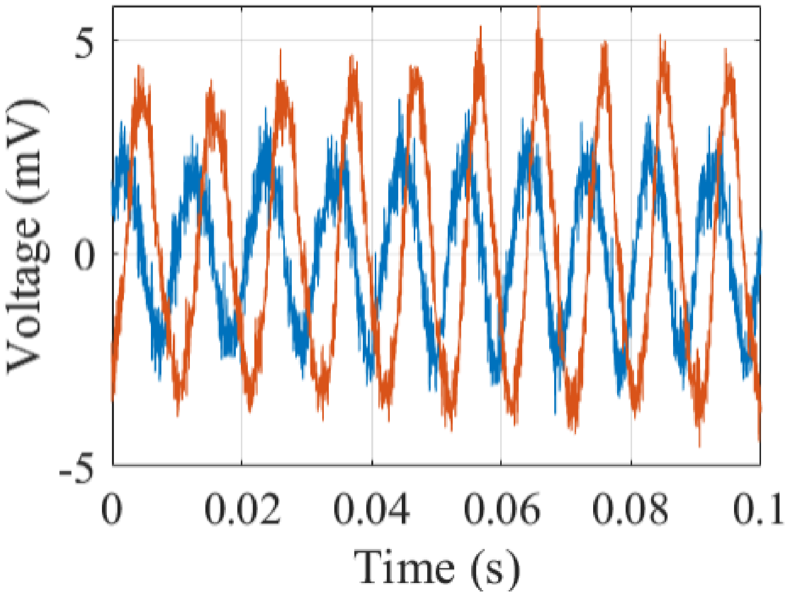


Measurement and Results

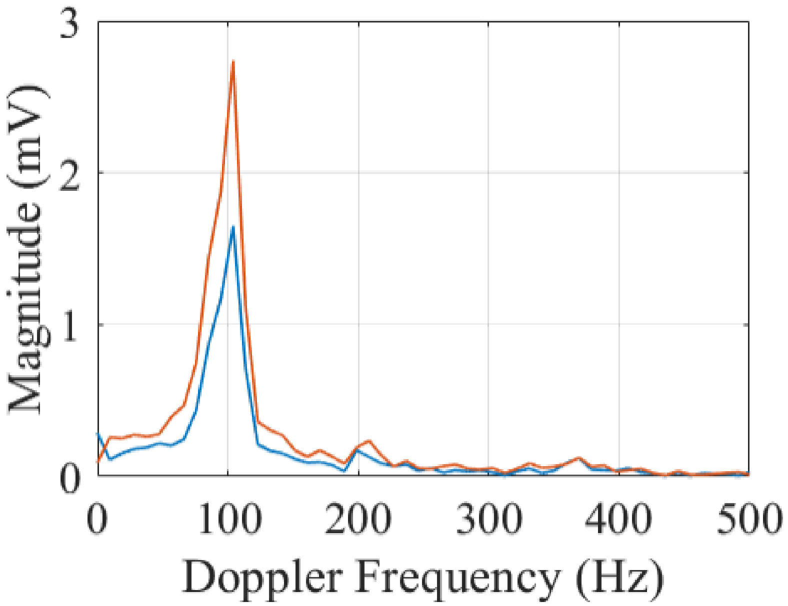
Moving Target with Constant Radial Velocity

- Radial velocity 0.11 m/s
- Transient voltage signals with consistent phase shift (no change in direction)
- Doppler spectrum shows corresponding peak at 102 Hz

Time signal



Spectrum

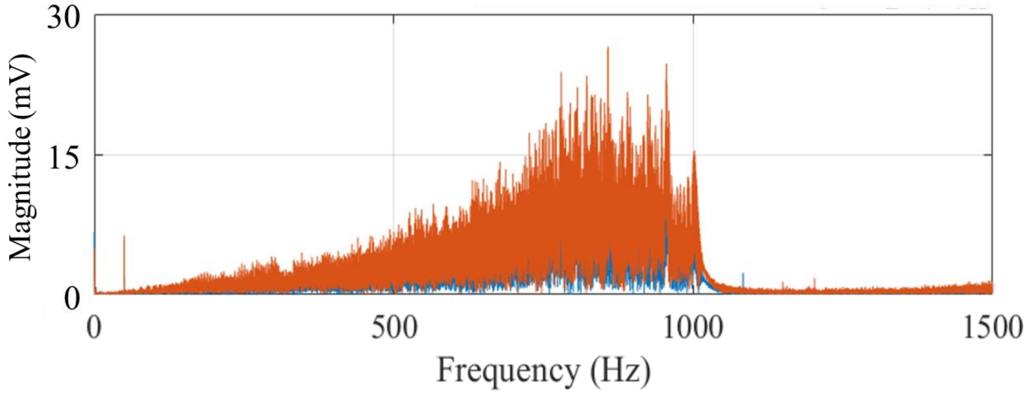


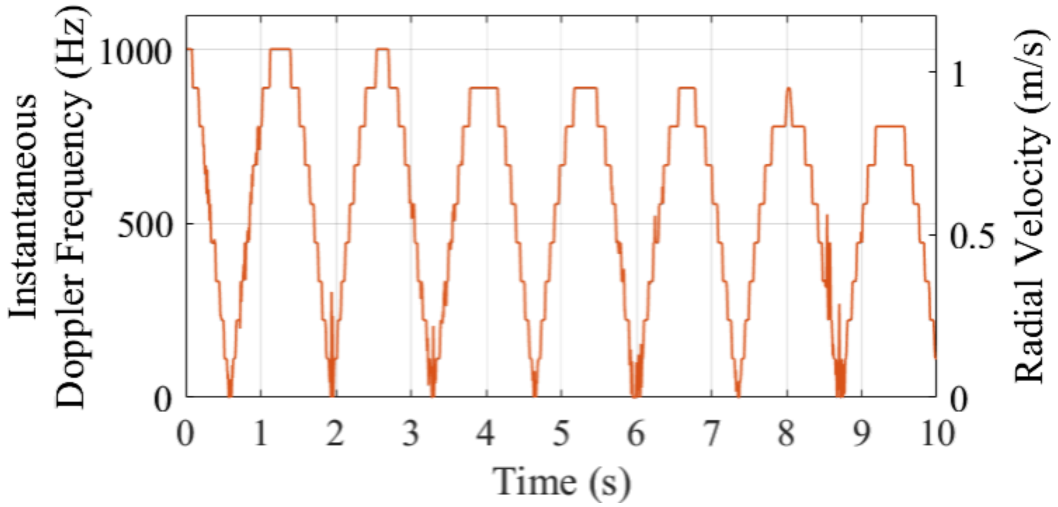
Measurement and Results

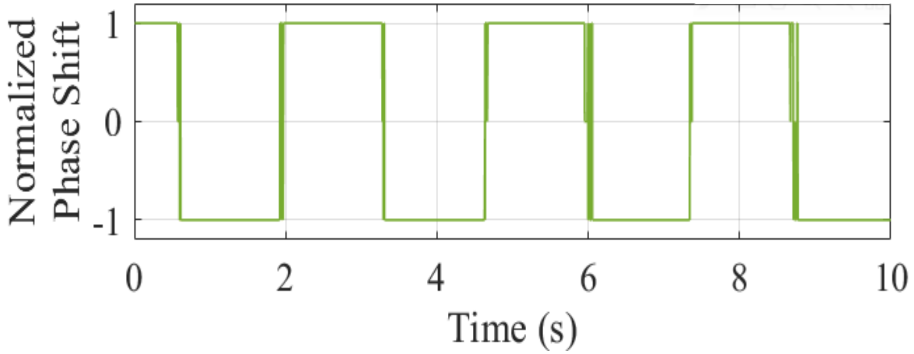
Moving Target with Periodically Oscillating Radial Velocity

Corner Reflector mounted on pendulum, oscillating in radial direction to antenna

Spectrum







Concept Comparison

	[9]	[10]	[5]	This Work
Frequency Range	160 GHz*	122 GHz*	144.6-160 GHz	136-146 GHz
RF Channels	2x1 RX/TX (monostatic, with rat race coupler)	2 RX, 1 TX	1 RX/TX (monostatic)	1 RX/TX (monostatic)
RX Mixer	Gilbert-cell (IQ output)	Gilbert-cell (IQ output)	diode-based	diode-based (IQ output)
IQ Realization	90-degree coupler (branchline)	90-degree coupler	n/a	shifted diodes/ t-lines
TX Signal Generation	external LO with on-chip PA	external LO with on-chip PA	on-chip power VCO	on-chip power VCO

* center frequency (external LO input)

Summary and Outlook

Summary:

- Compact monostatic D-band Doppler transceiver
- No 90-deg coupler needed for I/Q, no Ratrace coupler needed for RX/TX separation
- System still working at temperatures > 150°C

Outlook:

- On-chip VCO allows FMCW radar operation
- Adjustable diode current possibly allows tradeoff of NF and P_{out}