IEEE Signal Processing Society

IEEE

Radar Signal Processing Mastery

Theory and Hands-On Applications with mmWave MIMO Radar Sensors

Date: 7-11 October 2024
Time: 9:00AM-11:00AM ET (New York Time)

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Website: https://radarmimo.com/

Outline

Time: 9:00AM-11:00AM ET (New York Time)

Lecture	Duration	Date
Lecture 1: Radar Systems Fundamental	**2 Hours**	October 7th , 2024
Lecture 2: Advanced Radar Systems	**2 Hours**	October 8th , 2024
Lecture 3: Practical Radar Signal Processing - Motion Detection	**2 Hours**	October 9th , 2024
Lecture 4: Practical Radar Signal Processing - Breathing and Heart Rate Estimation	**2 Hours**	October 10th , 2024
Lecture 5: Practical Radar Signal Processing – Angle estimation with MIMO radar	**2 Hours**	October 11th , 2024

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Lecture 4

Practical Radar Signal Processing (Python Scripting): Breathing and Heart Rate Estimation with Infineon BGT60TR13C

What we learn in Lecture 4

- Review of FMCW Radars main parameters
- Getting started with BGT60TR13C
- Radar-based breathing and heart rate estimation
- Real-time data measurement
- Signal processing

Scan the QR code for access to the codes

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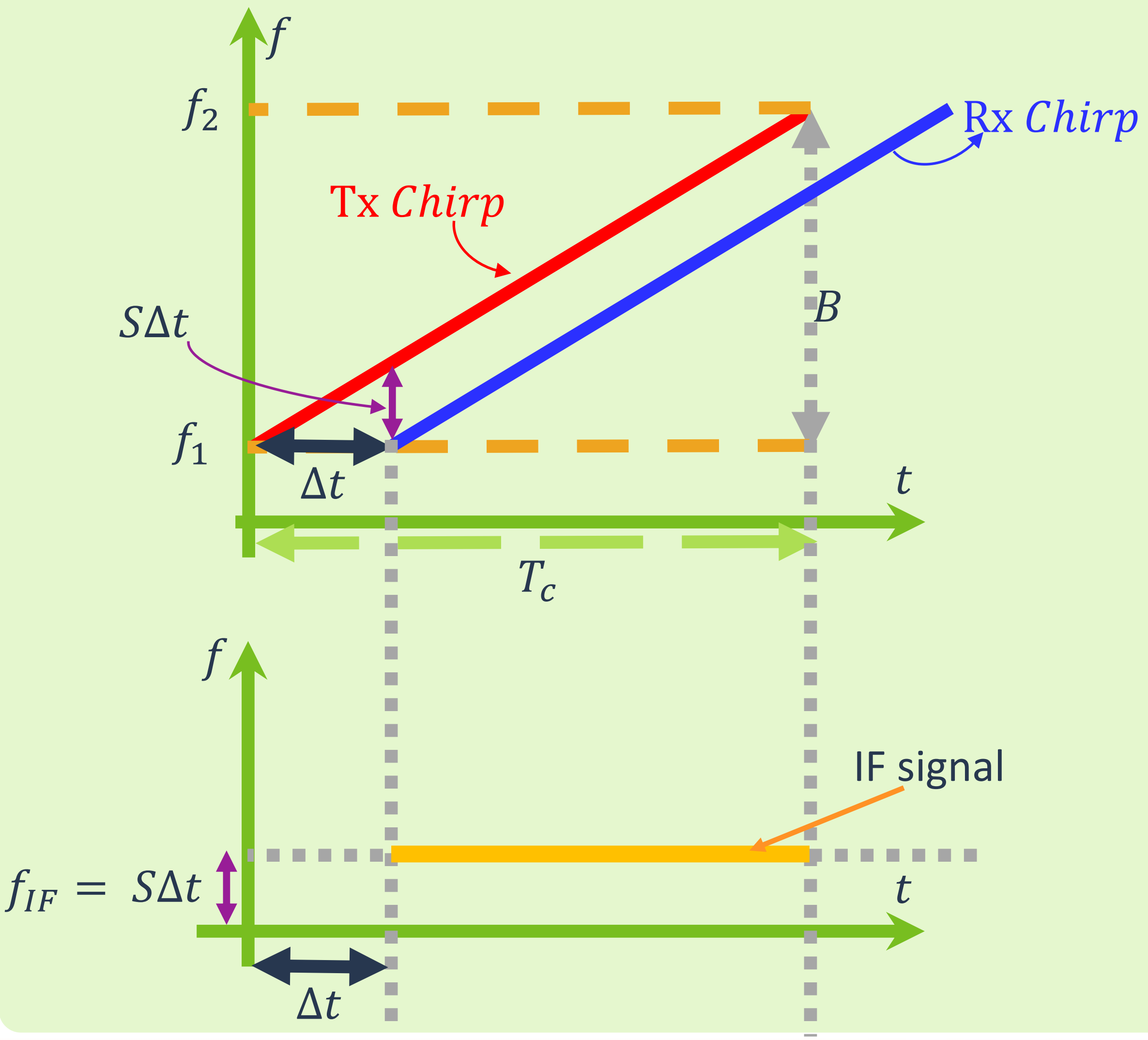
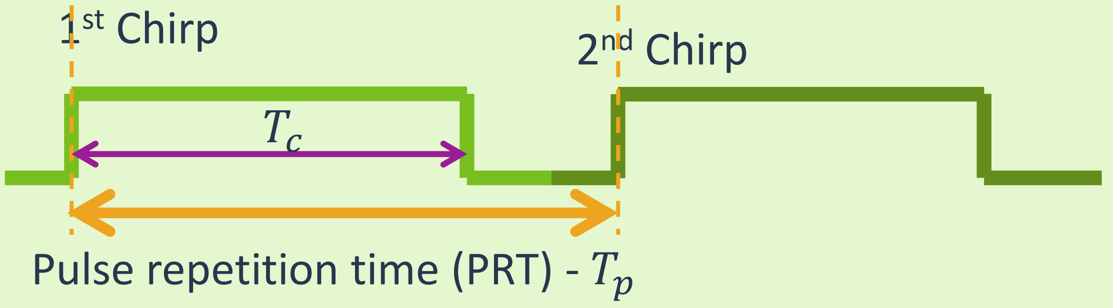
FMCW Radar





$$f_p = \frac{1}{T_p}$$

$$v_u = \frac{\lambda f_p}{4}$$

Increase f_p

$$R_u = \frac{cT_p}{2} = \frac{c}{2f_p}$$

Decrease f_p

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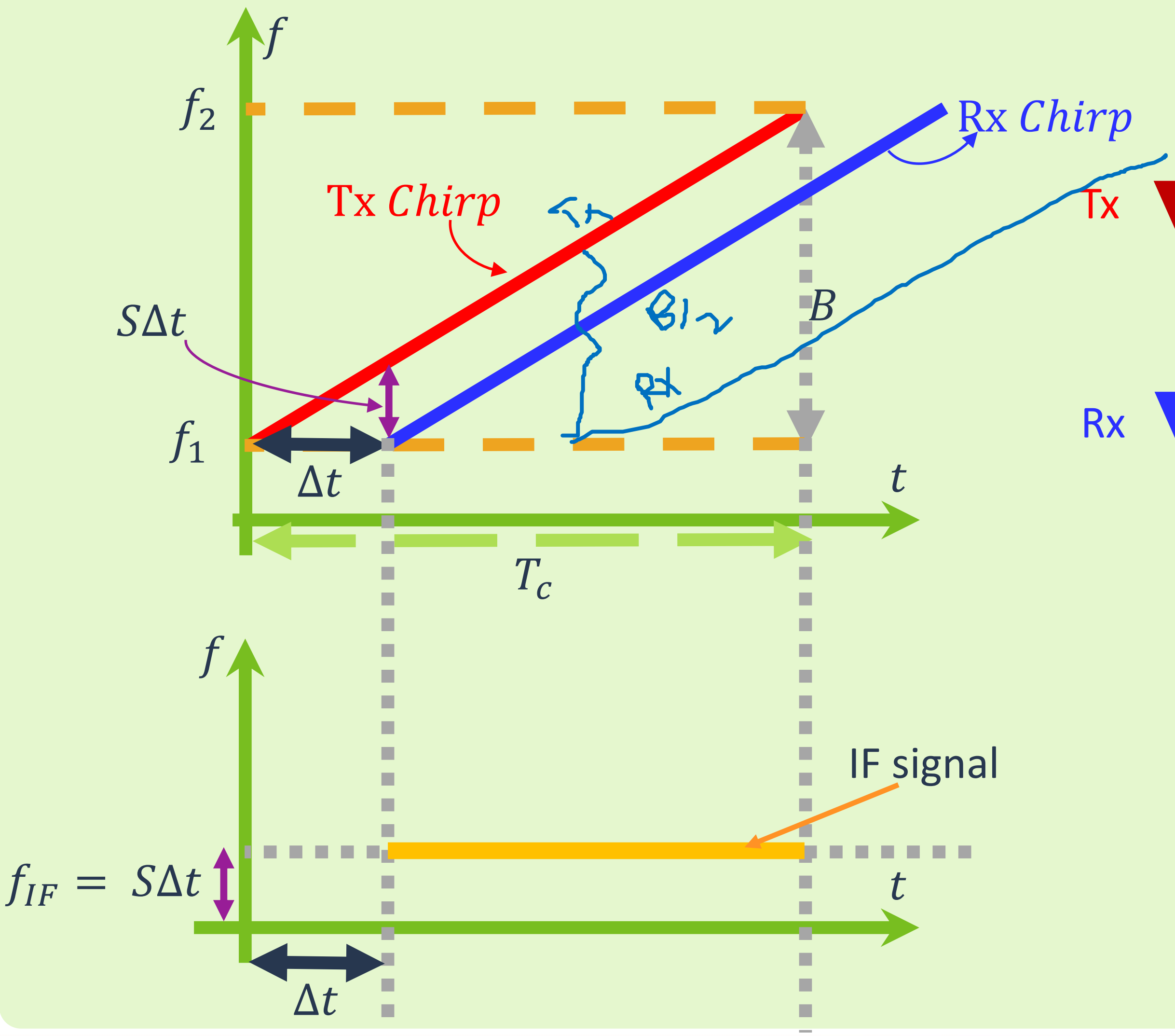
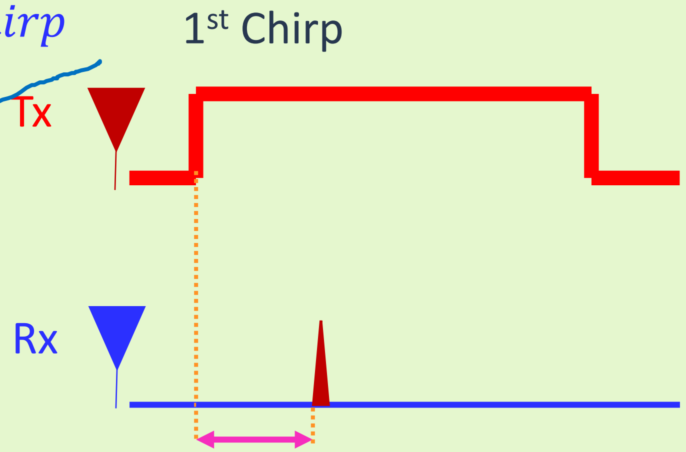
FMCW Radar





$$\Delta t = \frac{2R}{c}$$

Note that Δt is typically a small fraction of T_c=> non-overlapping segment of the Tx chirp is usually negligible.

$$\left.\begin{aligned} R &= c\frac{\Delta t}{2} \\ \Delta t &= \frac{f_{IF}}{S} \end{aligned}\right\} R = c\frac{f_{IF}}{2S}$$

A single object in front of the radar produces an IF signal with a constant frequency of $\frac{2}{c}RS$

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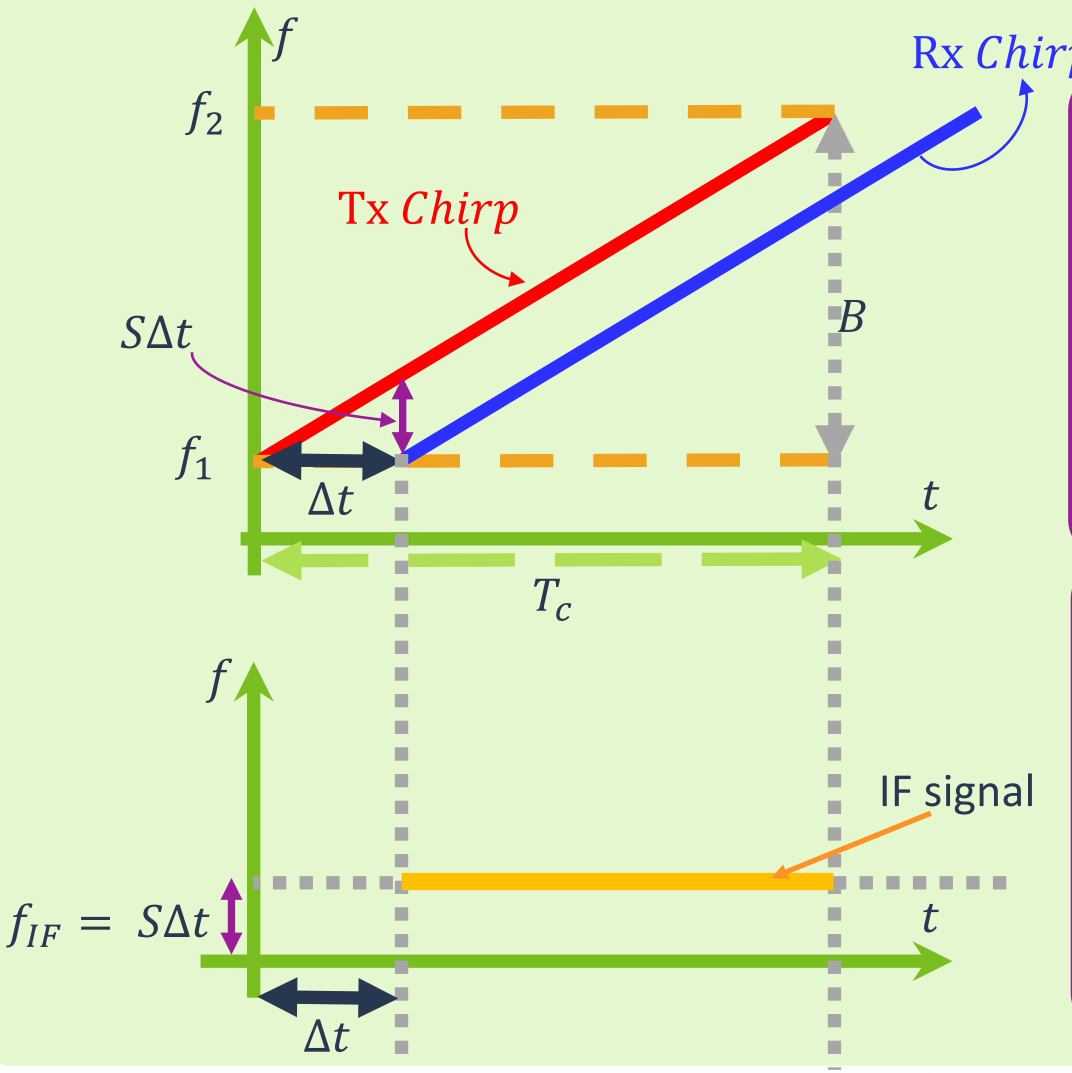
FMCW Radar



Range Resolution

$$\left.\begin{array}{l} f_{IF} = S\dfrac{2R}{c} \\ \Delta f_{IF} > \dfrac{1}{T_c} \end{array}\right\} \Rightarrow S\frac{2\Delta R}{c} > \frac{1}{T_c} \Rightarrow \Delta R > \frac{c}{2ST_c} = \frac{c}{2B}$$

Some typical Range Resolution numbers

Bandwidth	Range Resolution
4GHz	3.75cm
2GHz	7.5cm
1GHz	15cm
600MHz	25cm

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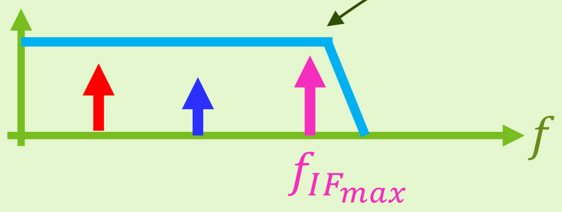
FMCW Radar

Maximum Range

$$\begin{cases} f_s > f_{IF\,max} & \text{Complex ADC} \\ f_s > 2f_{IF\,max} & \text{Real ADC} \end{cases}$$

$$\Rightarrow \quad f_{IF_{max}} = S\frac{2R_{max}}{c} \quad \Rightarrow \quad \begin{cases} R_{max} < \dfrac{cf_s}{2S} \\ R_{max} < \dfrac{cf_s}{4S} \end{cases}$$

Filter → ADC → DSP



$$\Rightarrow \begin{cases} f_{IF_{max}} < 0.9\, f_s & \text{Complex ADC} \\ f_{IF_{max}} < 0.45\, f_s & \text{Real ADC} \end{cases}$$

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FMCW Radar – Main Parameters

Unambiguous Range

$$R_{un} \leq \frac{cT_p}{2} = \frac{c}{2f_p}$$

Maximum Range

$$R_{max} = \frac{cf_{IF_{max}}}{2S}$$

Maximum Doppler

$$f_{d_{max}} < \frac{1}{2T_p} = \frac{f_p}{2}$$

Range Resolution

$$\Delta R = \frac{c}{2ST_c} = \frac{c}{2B}$$

$f_{IF_{max}} < 0.9\ f_s$ Complex ADC

$f_{IF_{max}} < 0.45\ f_s$ Real ADC

Doppler Resolution

$$\Delta f_d = \frac{1}{T_{CPI}}$$

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Infineon DEMO BGT60TR13C

Product	Description
BGT60LTR11AIP	XENSIV™ 60 GHz first completely autonomous radar sensor for motion sensing
BGT60LTR11SAIP	XENSIV™ 60 GHz first completely autonomous radar sensor for motion sensing
DEMO BGT60LTR11AIP	XENSIV™ BGT60LTR11AIP 60 GHz radar sensor pulsed Doppler demo board
SHIELD_AUTONOM_BGT60	Shield for autonomous operation of BGT60LTR11AIP; directly fits on Arduino MKR board
REF BGT60LTR11AIP M0	Reference design with Cortex®-M0 MCU for data processing
S2GO RADAR BGT60LTR11	Shield2Go version
BGT60TR13C	XENSIV™ 60 GHz radar sensor for advanced sensing
DEMO BGT60TR13C	XENSIV™ 60 GHz radar sensor demo board for advanced sensing
BGT60UTR11AIP	XENSIV™ highly integrated 60 GHz FMCW radar sensor
DEMO BGT60UTR11AIP	XENSIV™ BGT60UTR11AIP 60 GHz radar sensor FMCW demo boar

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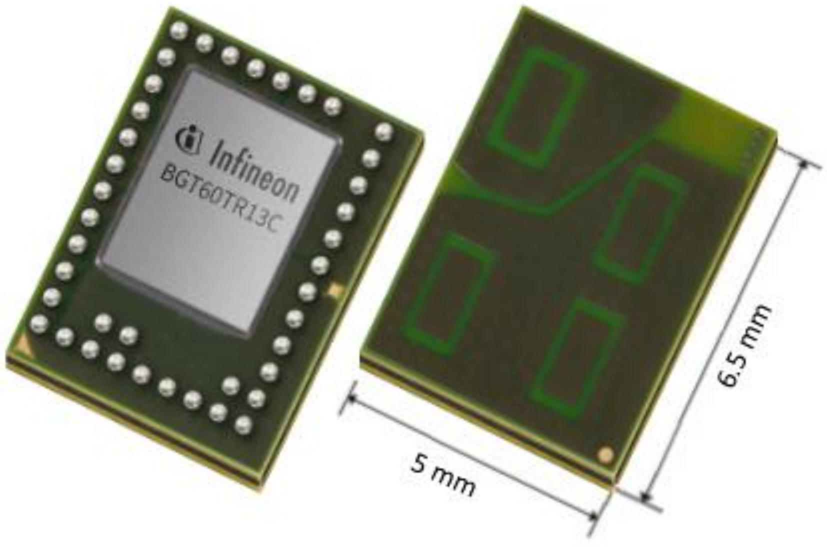
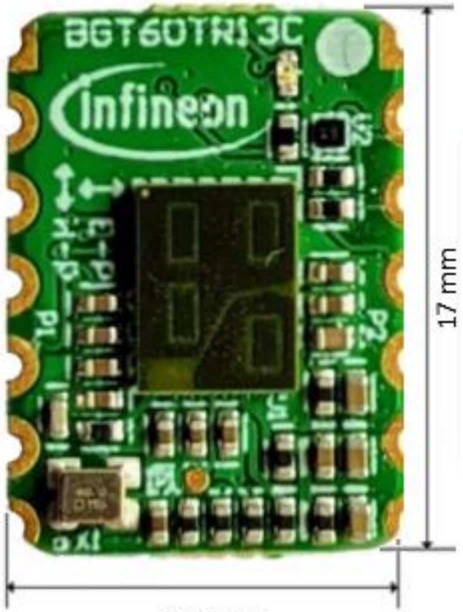
Infineon DEMO BGT60TR13C

BGT60TR13C MMIC

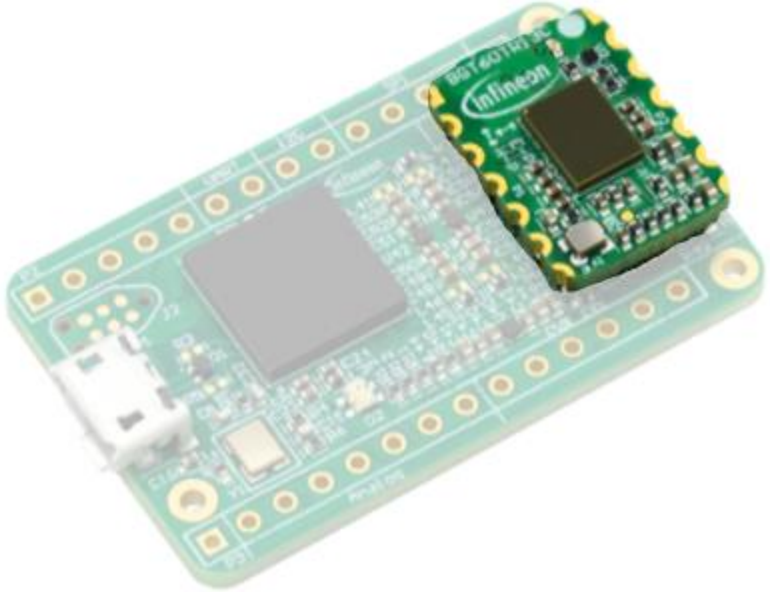


BGT60TR13C Shield



DEMO BGT60TR13C

= Radar Baseboard MCU7
+ BGT60TR13C Shield



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XENSIV™ 60GHz Radar Sensors - BGT60TR13C

Parametrics	DEMO BGT60TR13C
Angle of Arrival	Yes
Antenna	Antennas in package
Direction of Motion	Yes
Frequency min max	58 GHz 63.5 GHz
Max Detection Range	15 m
Min Detection Range	0.2 m
Motion	yes
Number of Rx Antennas max	3
Number of Tx Antennas max	1
Target Application	Automated door openers ; Contactless switches ; Displays such as TVs ; Lighting systems and lighting control (mainly indoor lighting) ; Multicopter and drones ; Smart Home devices ; Smart home security and alarm systems including IP cameras ; laptops or tablets

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Tools for XENSIV™ 60GHz Radar Sensors

Development Tools

XENSIV™	Development Tools **Radar Development Kit**	infineon	Infineon	> Read More
XENSIV™	Development Tools **Radar Fusion GUI**	infineon	Infineon	> Read More

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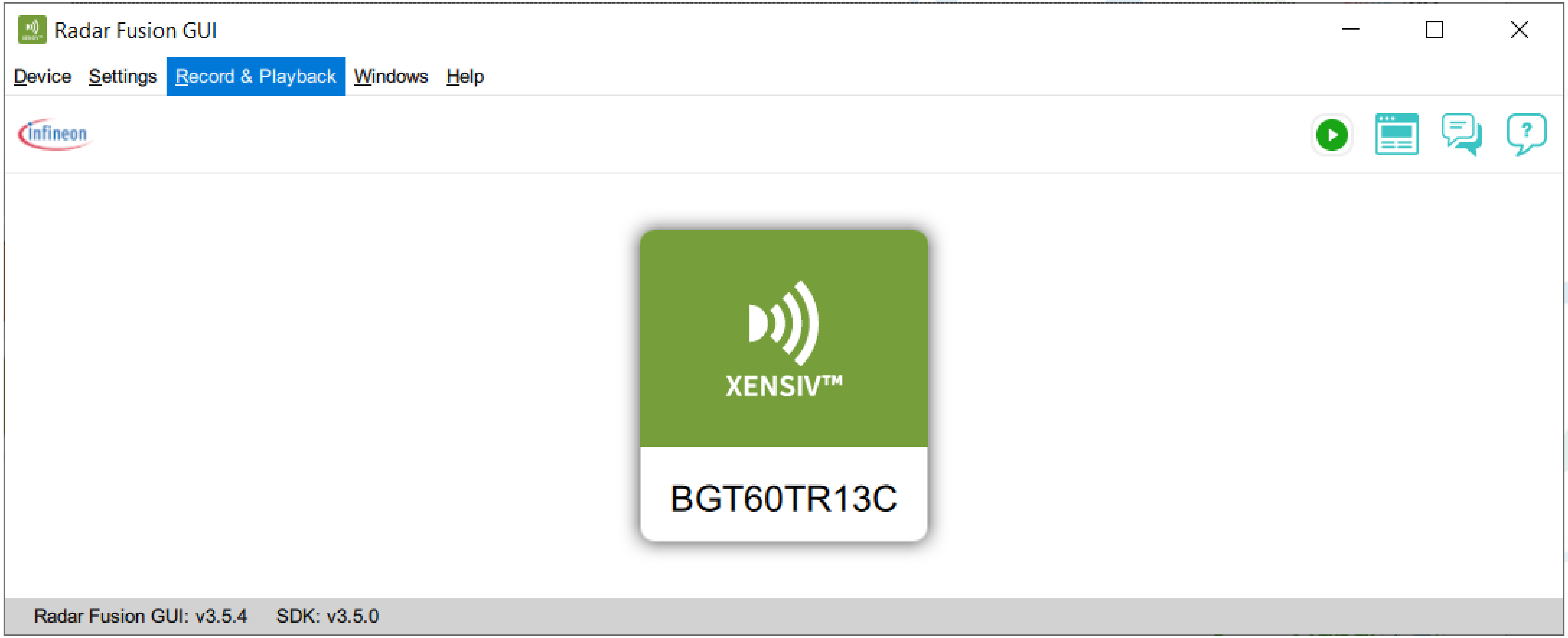
Radar Fusion GUI



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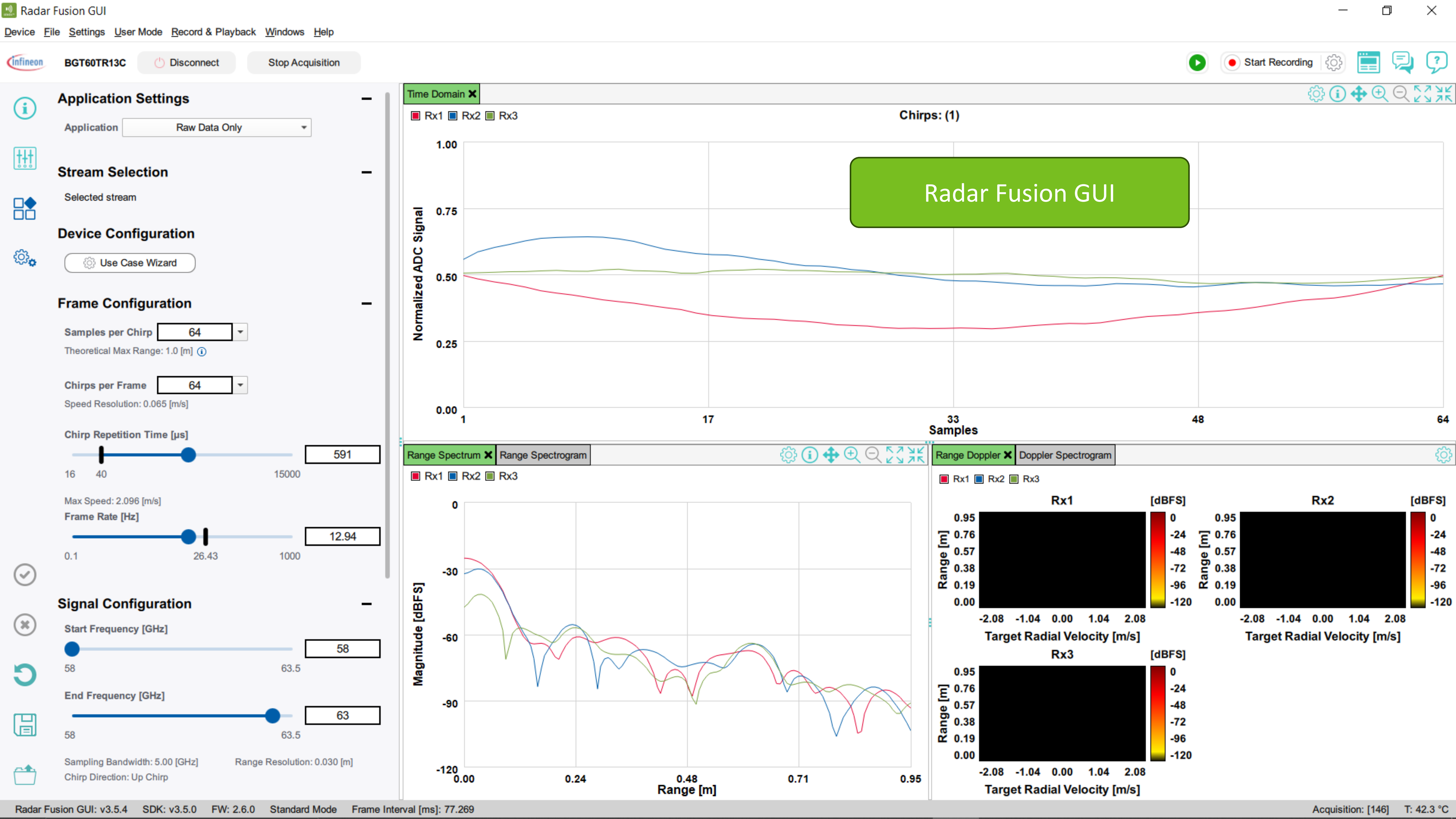
Radar Fusion GUI
Device File Settings User Mode Record & Playback Windows Help
BGT60TR13C
Disconnect
Stop Acquisition
Start Recording
Application Settings
Application
Raw Data Only
Stream Selection
Selected stream
Device Configuration
Use Case Wizard
Frame Configuration
Samples per Chirp
64
Theoretical Max Range: 1.0 [m]
Chirps per Frame
64
Speed Resolution: 0.065 [m/s]
Chirp Repetition Time [µs]
591
16
40
15000
Max Speed: 2.096 [m/s]
Frame Rate [Hz]
12.94
0.1
26.43
1000
Signal Configuration
Start Frequency [GHz]
58
58
63.5
End Frequency [GHz]
63
58
63.5
Sampling Bandwidth: 5.00 [GHz]
Range Resolution: 0.030 [m]
Chirp Direction: Up Chirp
Time Domain
Rx1 Rx2 Rx3
Chirps: (1)
Radar Fusion GUI
Normalized ADC Signal
1.00
0.75
0.50
0.25
0.00
1
17
33
48
64
Samples
Range Spectrum
Range Spectrogram
Rx1 Rx2 Rx3
Magnitude [dBFS]
0
-30
-60
-90
-120
0.00
0.24
0.48
0.71
0.95
Range [m]
Range Doppler
Doppler Spectrogram
Rx1 Rx2 Rx3
Rx1
Rx2
Rx3
[dBFS]
Range [m]
0.95
0.76
0.57
0.38
0.19
0.00
0
-24
-48
-72
-96
-120
-2.08
-1.04
0.00
1.04
2.08
Target Radial Velocity [m/s]
Radar Fusion GUI: v3.5.4
SDK: v3.5.0
FW: 2.6.0
Standard Mode
Frame Interval [ms]: 77.269
Acquisition: [146]
T: 42.3 °C

Radar Development Kit

infineon

Releases Quickstart Software Hardware Documentation

Software

Radar Software Development Kit (SDK)

Download

radar_sdk.zip

Name
- 3rd_party
- build
- cmake
- CMakeFiles
- doc
- examples
- external
- libs
- python_wheels
- sdk
- tools
- CMakeCache
- CMakeLists
- VERSION

- ifxradarsdk-3.5.0+8c595dbb-py3-none-linux_armv7l.whl
- ifxradarsdk-3.5.0+8c595dbb-py3-none-linux_x86_64.whl
- ifxradarsdk-3.5.0+8c595dbb-py3-none-macosx_10_14_universal2.whl
- ifxradarsdk-3.5.0+8c595dbb-py3-none-win_amd64.whl

```
cd C:\path\to\your\whl\file
```

```
pip install ifxradarsdk-3.5.0+8c595dbb-py3-none-win_amd64.whl
```

The Radar SDK is used to evaluate the following XENSIV™ Radar sensors.:

- FMCW Radars
  - BGT60 UTR11AIP
  - BGT60 TR13C
  - BGT60 ATR24C
- Doppler Radars
  - BGT60 LTR11AIP

Radar SDK allows users to configure and fetch raw data from above mentioned XENSIV™ radar sensors using C/C++, Python and Matlab programming languages. In addition, it contains sophisticated propriety algorithms to solve target detection and localization use-cases, and some useful tools to e.g. data recording and flash firmware etc.

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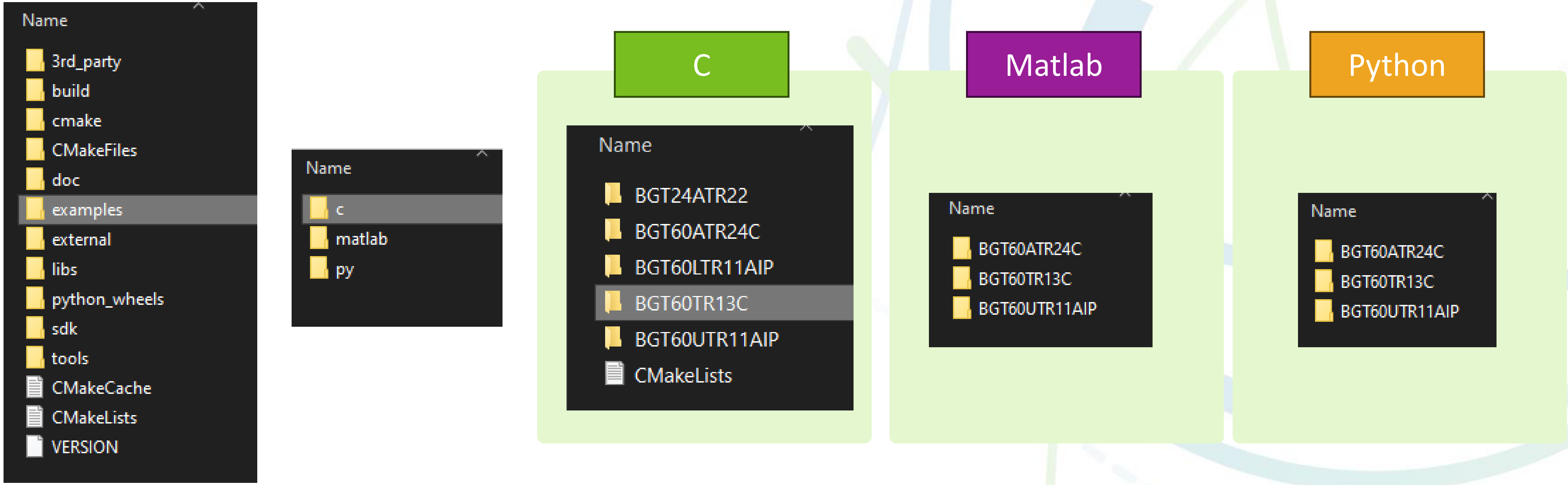

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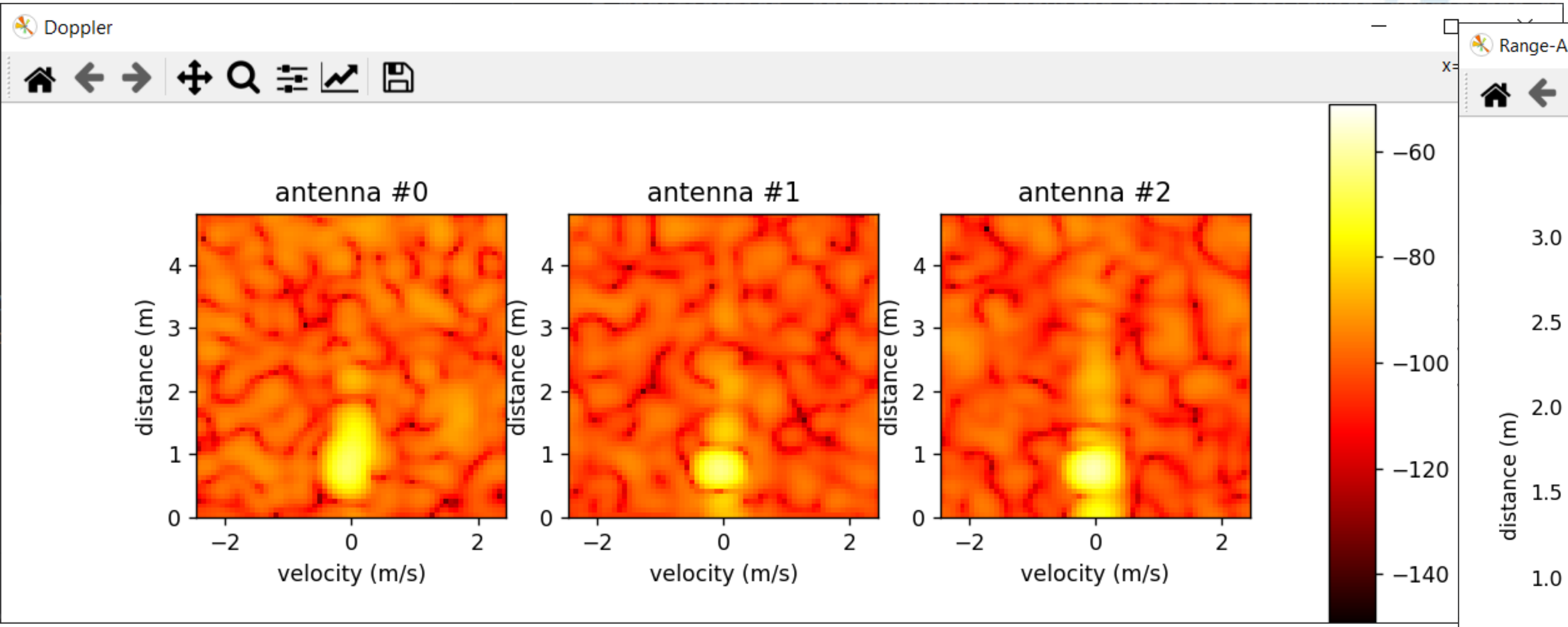
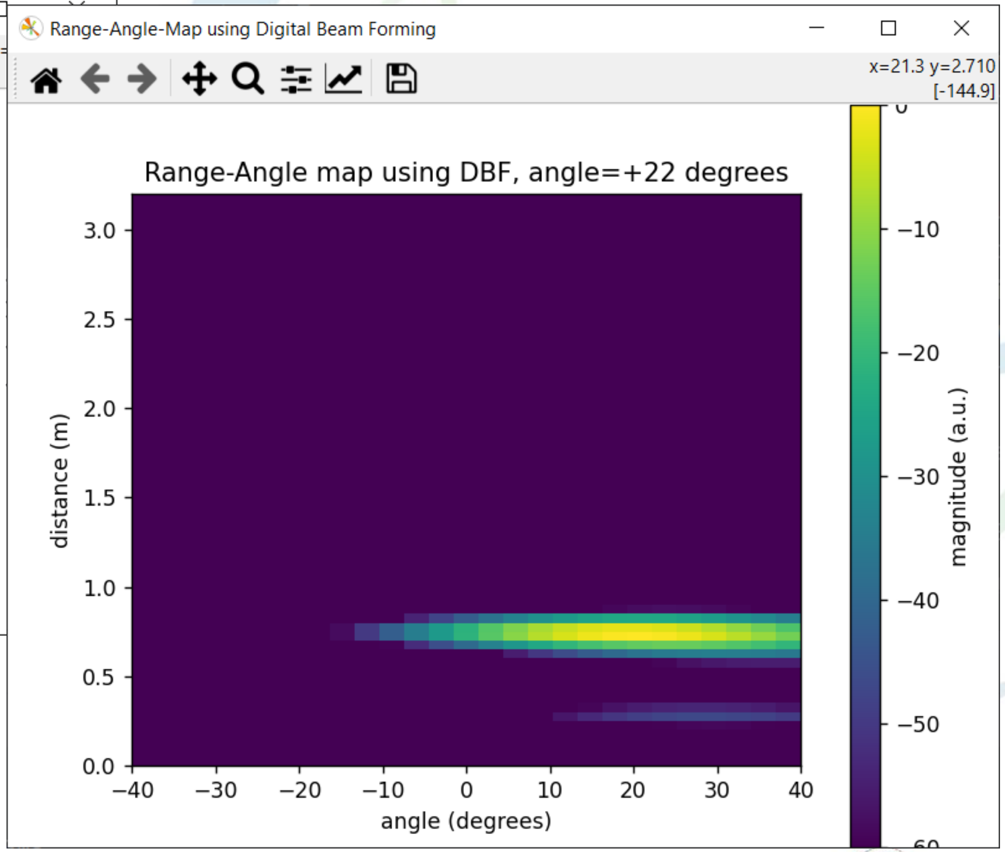
Python Examples



range_doppler_map.py



range_angle_map.py

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Vital Signs Monitoring with DEMO BGT60TR13C

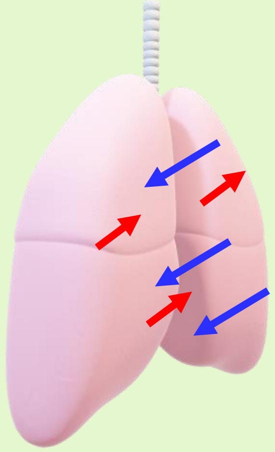
I and Q signal

Phase angle estimation

Phase unwrap

Appropriate Filtering

Breathing and Herat Rate Estimation (Spectrum Analysis)



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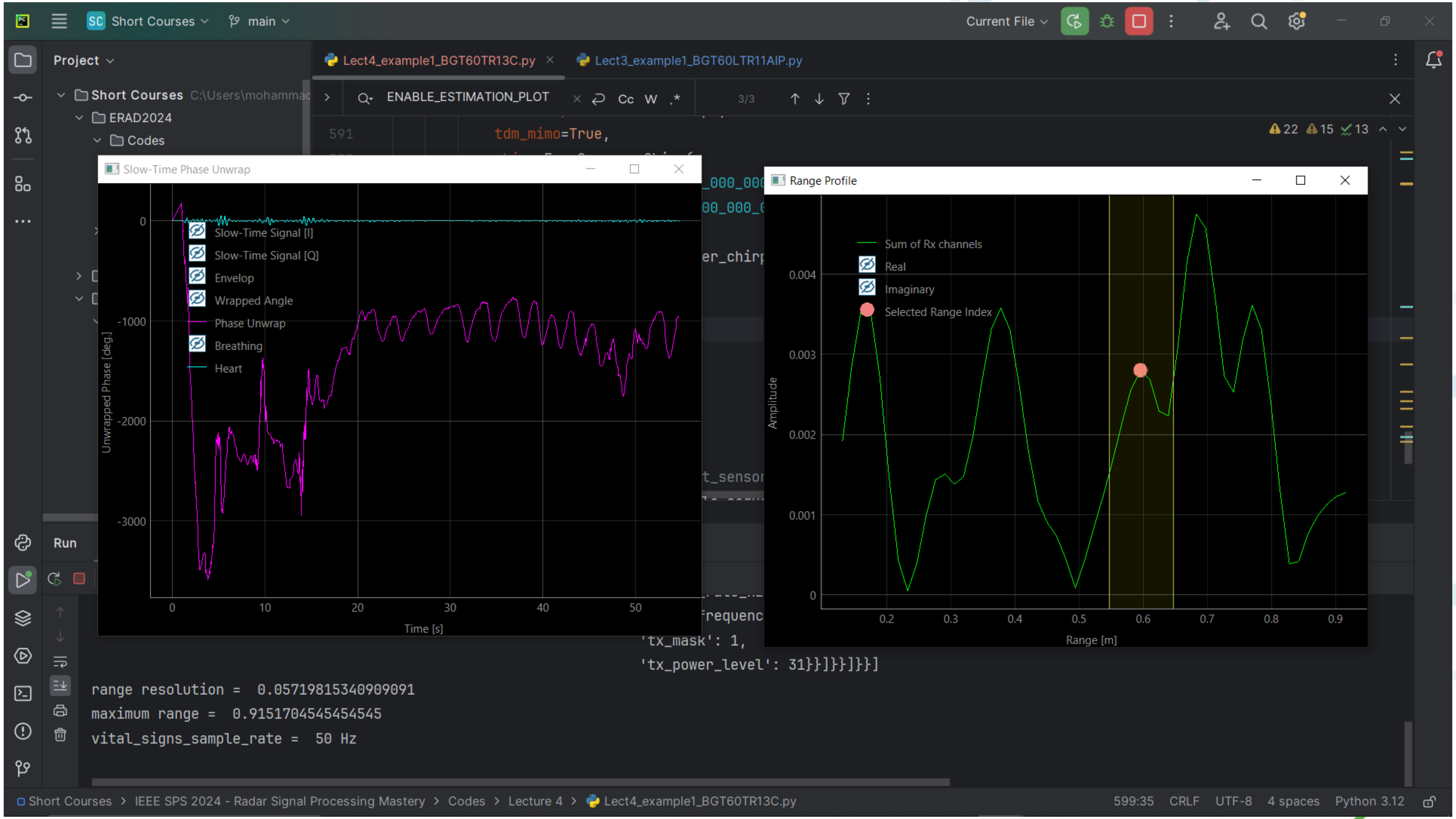
Vital Signs Monitoring with DEMO BGT60TR13C



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What we learned from Lecture 4

- In Lecture 4 we used BGT60TR13C to capture real data and processed it to extract vital signs of human. Different signal processing techniques to this end has been applied in real-time operation.

Scan the QR code for access to the codes

Q & A

Using a FMCW radar, how angle estimation can help to improve the performance?

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