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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SnT, University of Luxembourg
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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 5

Practical Radar Signal Processing (Python Scripting): Angle estimation with MIMO radar

Lecture 5: Angle estimation with MIMO radar xWR6843ISK

What we learn in Lecture 5

- **Review of virtual array and angle estimation in MIMO Radar**
- **Angular resolution in MIMO radar**
- **Getting started with xWR6843-ISK**
- **Real-time data measurement**

Scan the QR code for access to the codes

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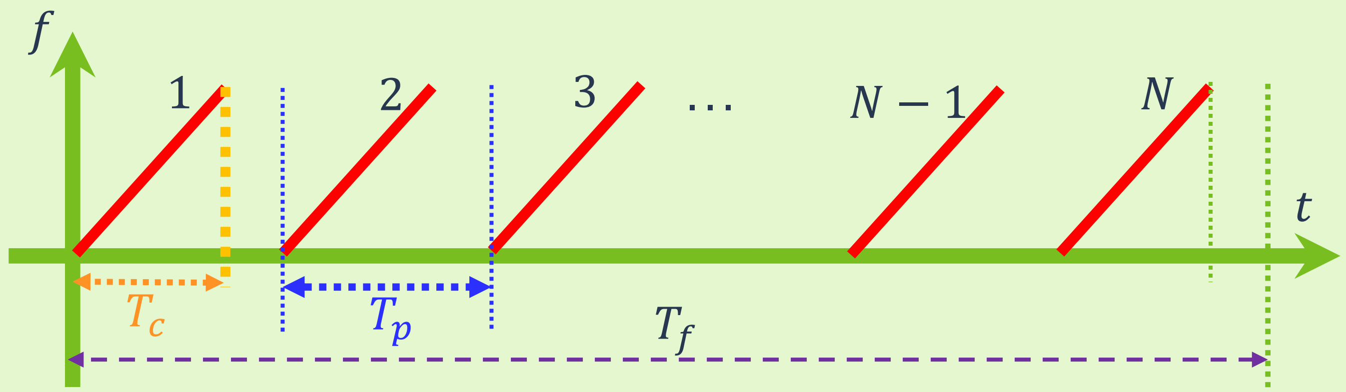
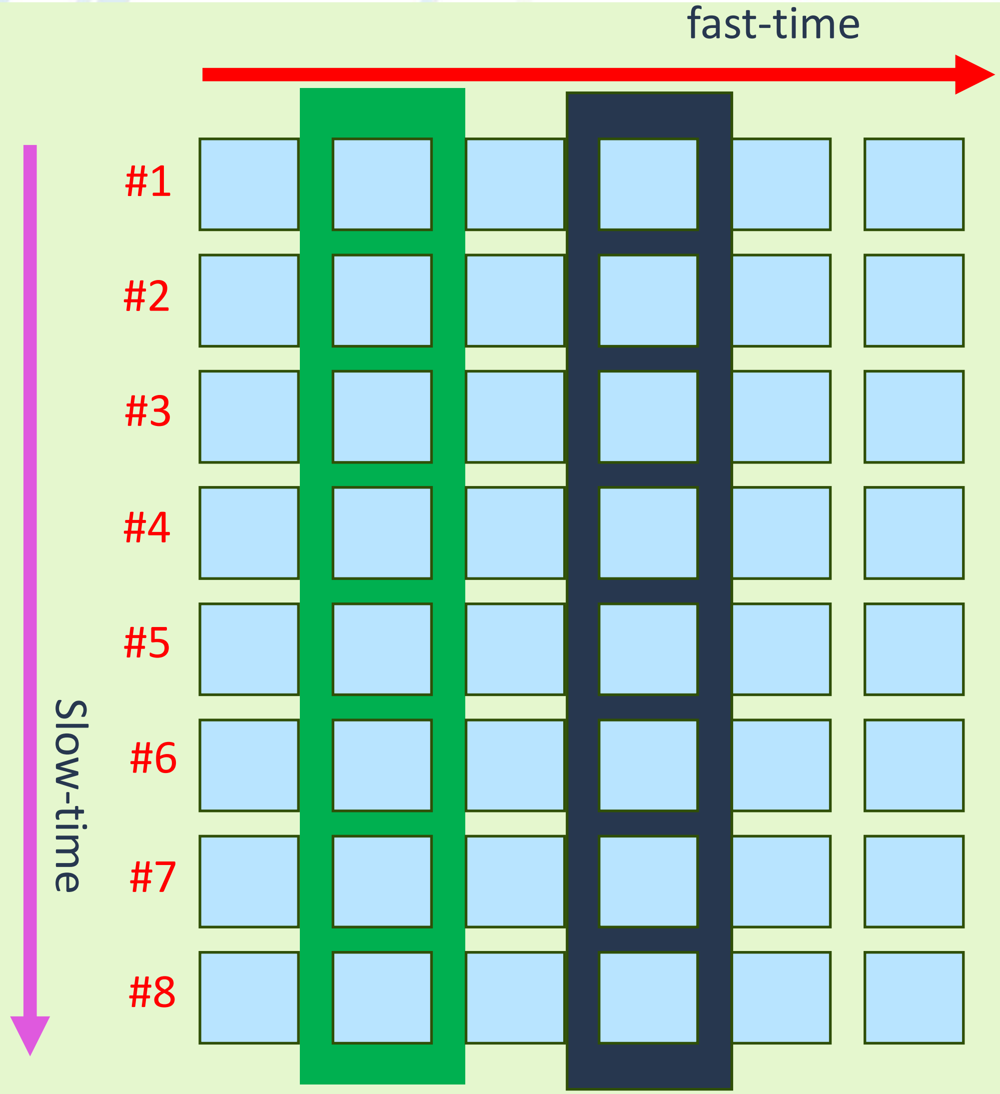
FMCW Radar



A range-FFT on each row resolves objects in range



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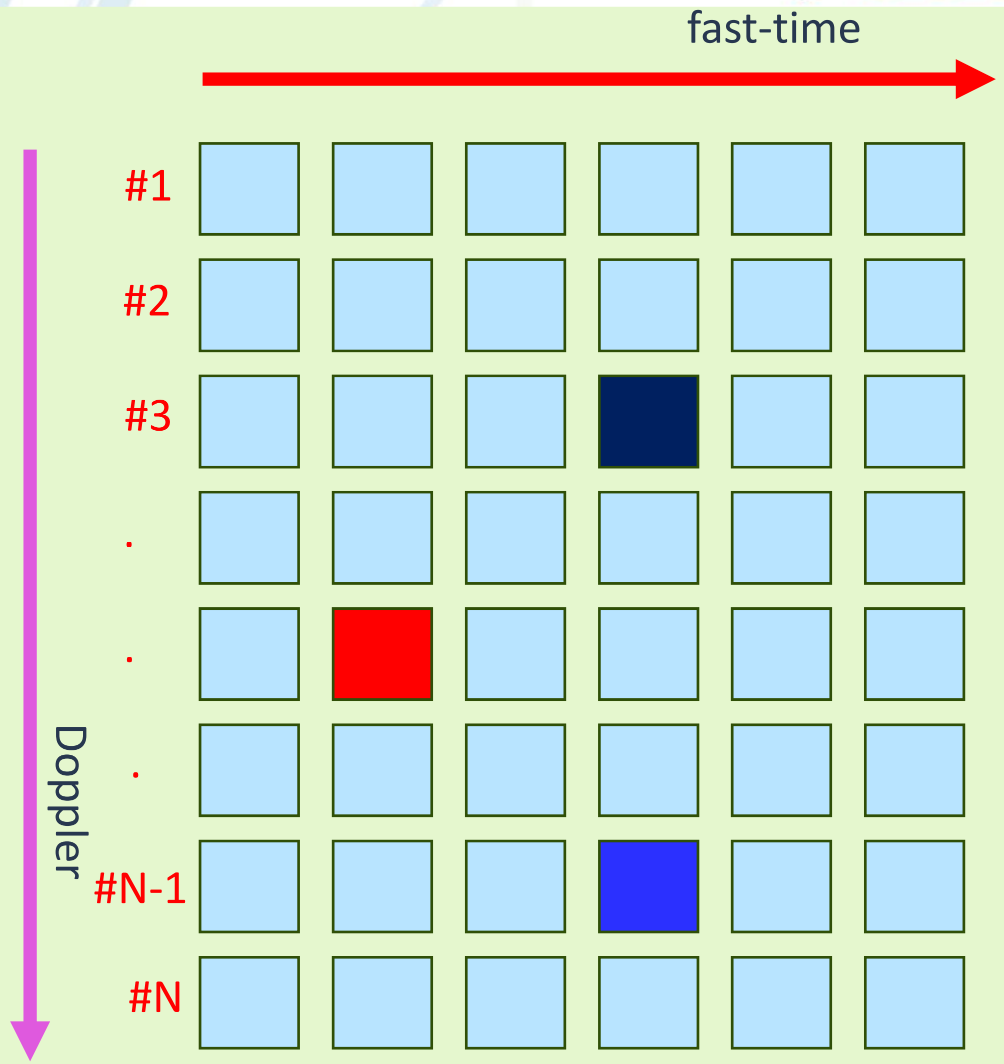
FMCW MIMO Radar

A doppler-FFT along the column resolves each column ('range-bin') in Doppler (Radial Velocity)

This is for one receive channel !



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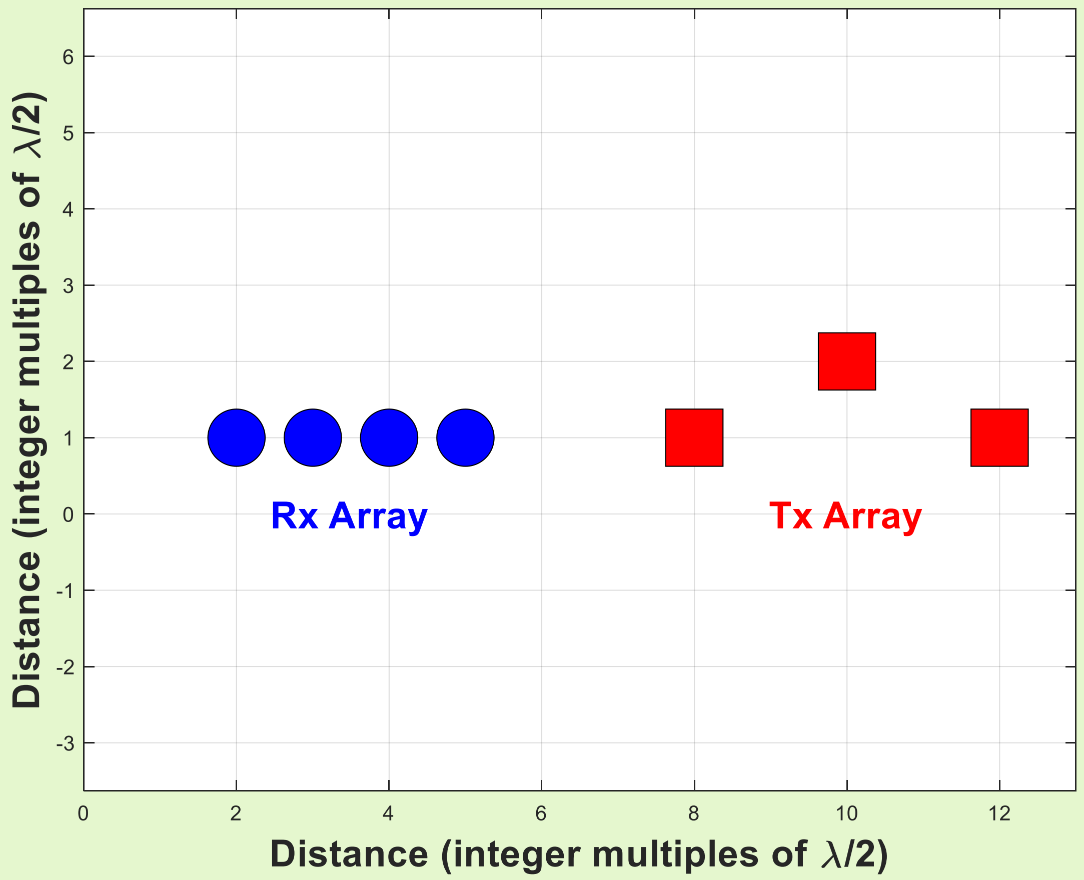
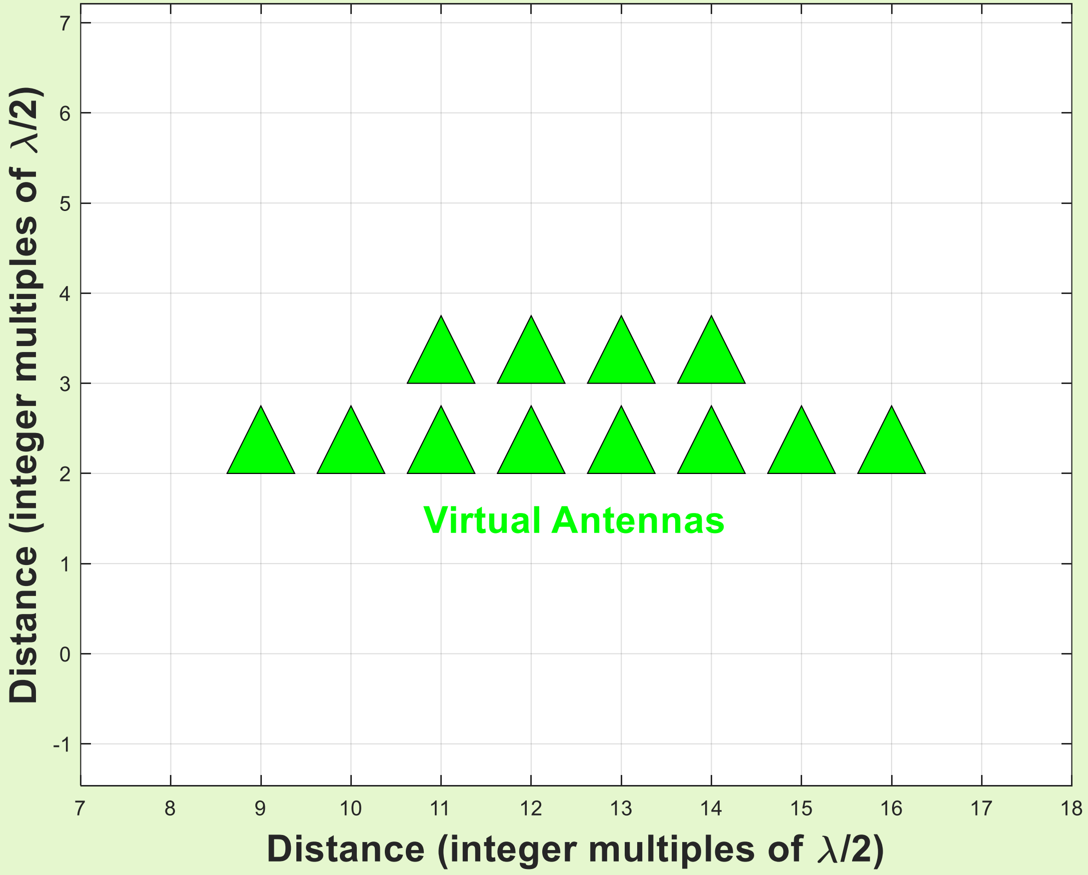
Virtual Array in FMCW MIMO Radar





Lect5_example1.m

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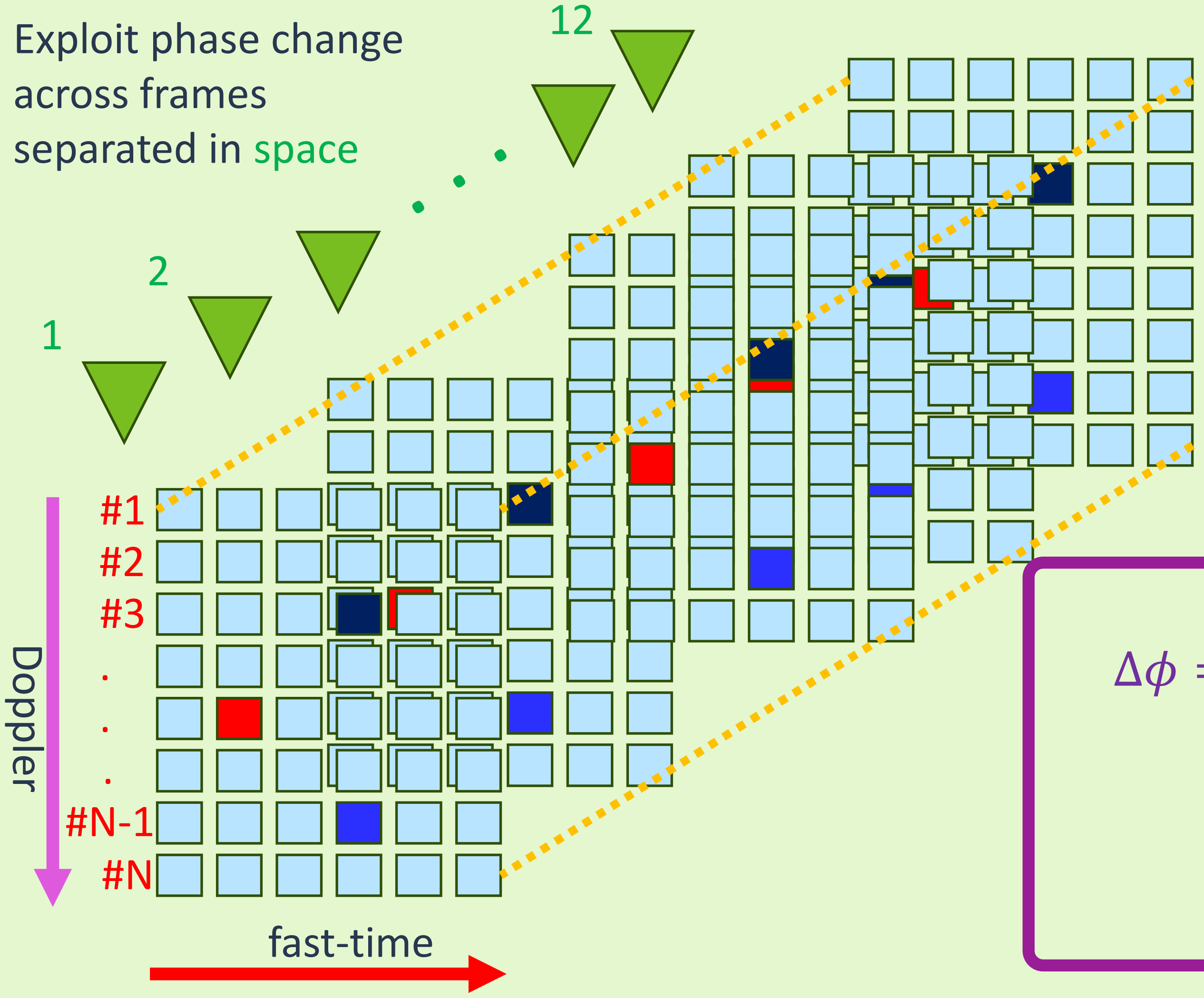
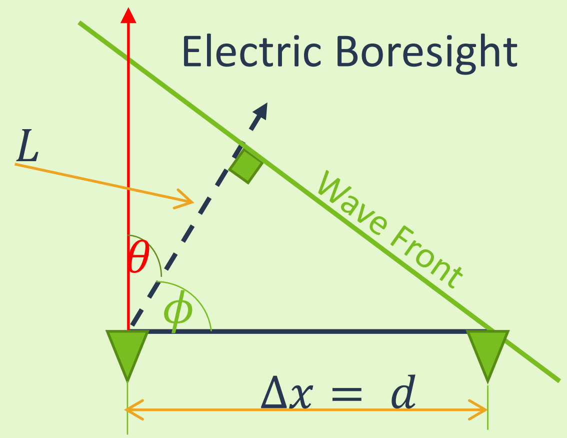
Angle Estimation in FMCW MIMO Radar

Exploit phase change across frames separated in space





$$\Delta\phi = \frac{2\pi\Delta d}{\lambda} = \frac{2\pi d \sin\theta}{\lambda}$$

$$\longrightarrow \quad \theta = \sin^{-1}\left(\frac{\lambda\Delta\phi}{2\pi d}\right)$$

a non-linear relationship!

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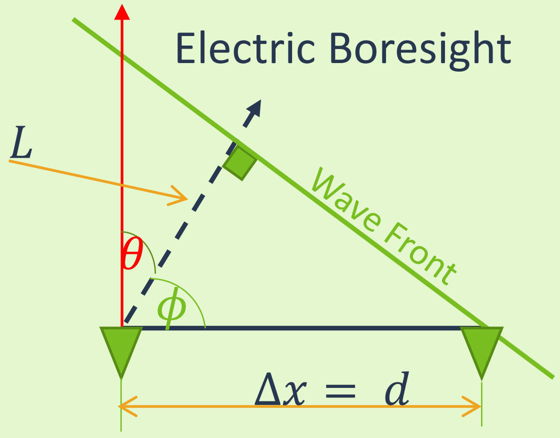
Angular Resolution in FMCW MIMO Radar

How much is angular resolution in a MIMO radar system?



How much phase of two targets should be different such that we can discriminate them?

Angular Field of View

$$\frac{2\pi d \sin\theta}{\lambda} < \pi \quad \Longrightarrow \quad \theta < \sin^{-1}\left(\frac{\lambda}{2d}\right)$$

A spacing d of $\frac{\lambda}{2}$ results in the largest field of view ($\pm 90°$)

The virtual array has inter-element space of $\frac{\lambda}{2}$

$\Longrightarrow$

No grating lobe!

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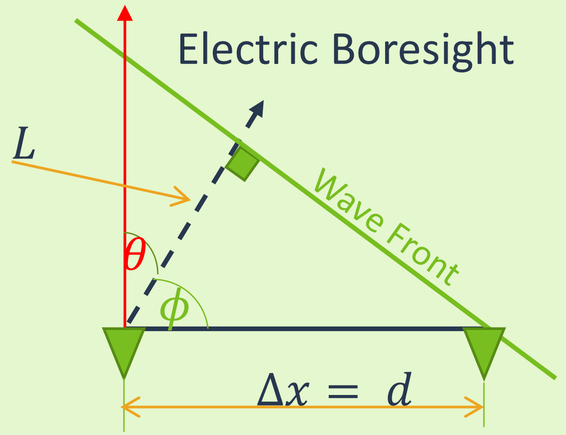
Angular Resolution in FMCW MIMO Radar



1

$$\exp -j\frac{2\pi(1)d\sin\theta}{\lambda}$$

$$\exp -j\frac{2\pi(2)d\sin\theta}{\lambda}$$

⋮

$$\exp -j\frac{2\pi(\mathrm{N}-1)d\sin\theta}{\lambda}$$

How much phase of two targets should be different such that we can discriminate them?

(3dB) Beamwidth [rad] $\cong \dfrac{\alpha\lambda}{N\,d}$

$$\Delta\phi = \frac{2\pi d}{\lambda}(\sin(\theta+\Delta\theta)-\sin(\theta))$$

Since derivative of $\sin(\theta)$ is $\cos(\theta)$ $\quad \dfrac{\sin(\theta+\Delta\theta)-\sin(\theta)}{\Delta\theta} \approx \cos\theta$

$$\Delta\phi \approx \frac{2\pi d}{\lambda}(\cos\theta)\Delta\theta \qquad \Delta\phi > \frac{2\pi}{N_{VA}} \Rightarrow \frac{2\pi d}{\lambda}(\cos\theta)\Delta\theta > \frac{2\pi}{N_{VA}}$$

best resolution at $\theta = 0$

$\Rightarrow$ assuming $d = \lambda/2$ and $\theta = 0$ $\Rightarrow$ $\boxed{\theta_{res} = \dfrac{2}{N_{VA}}}$

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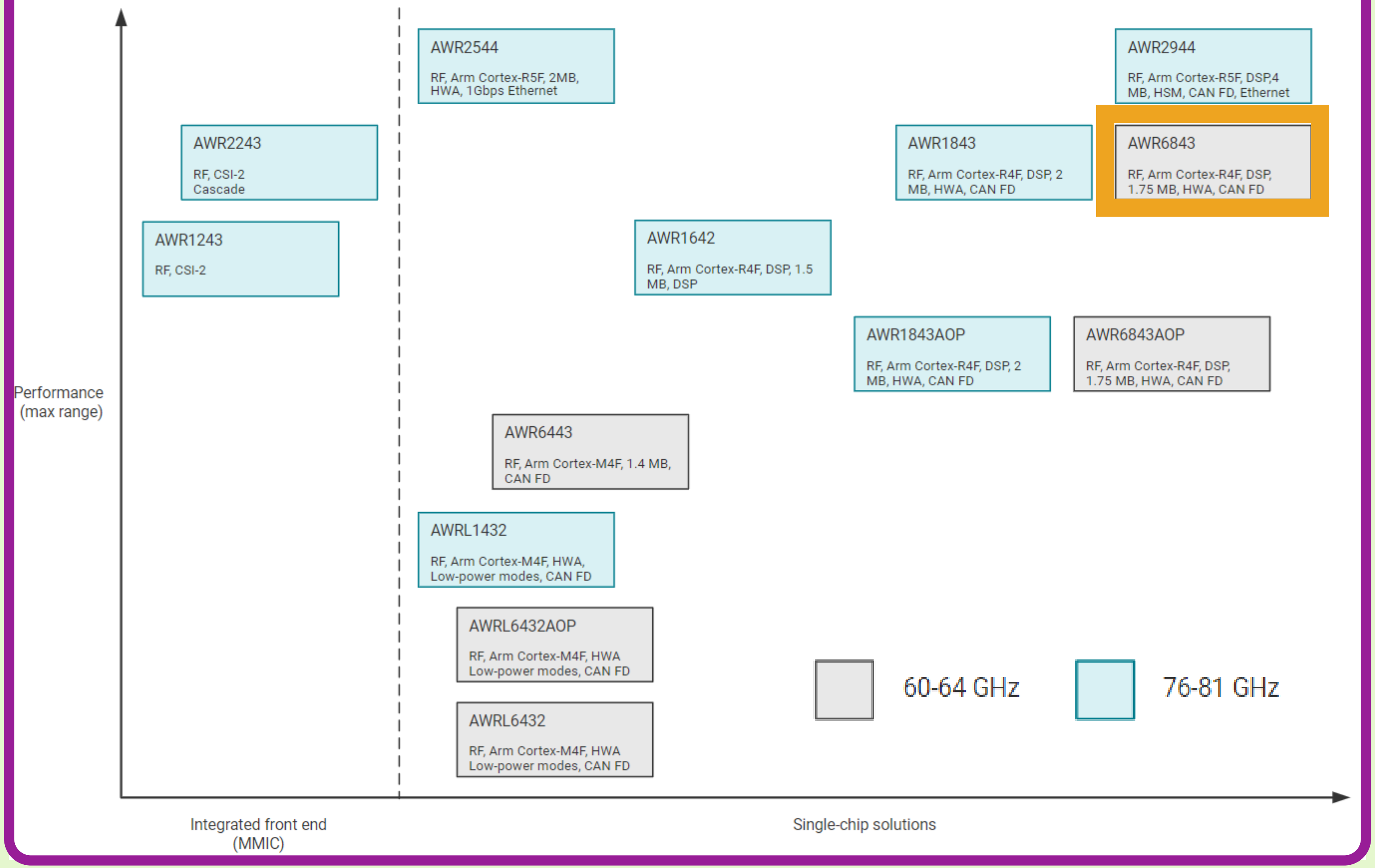
mmWave radar sensors at Texas instruments

- FMCW transceiver
  - Integrated PLL, transmitter, receiver, Baseband, and ADC
  - 60- to 64-GHz coverage with 4-GHz continuous bandwidth
  - Four receive channels
  - Three transmit channels
  - Supports 6-bit phase shifter
  - Ultra-accurate chirp engine based on fractional-N PLL
  - TX power: 12 dBm
  - RX noise figure:
    - 12 dB
  - Phase noise at 1 MHz:
    - −93 dBc/Hz
- Built-in calibration and self-test
  - Arm Cortex-R4F-based radio control system
  - Built-in firmware (ROM)
  - Self-calibrating system across process and temperature
  - Embedded self-monitoring with no host processor involvement on Functional Safety-Compliant devices



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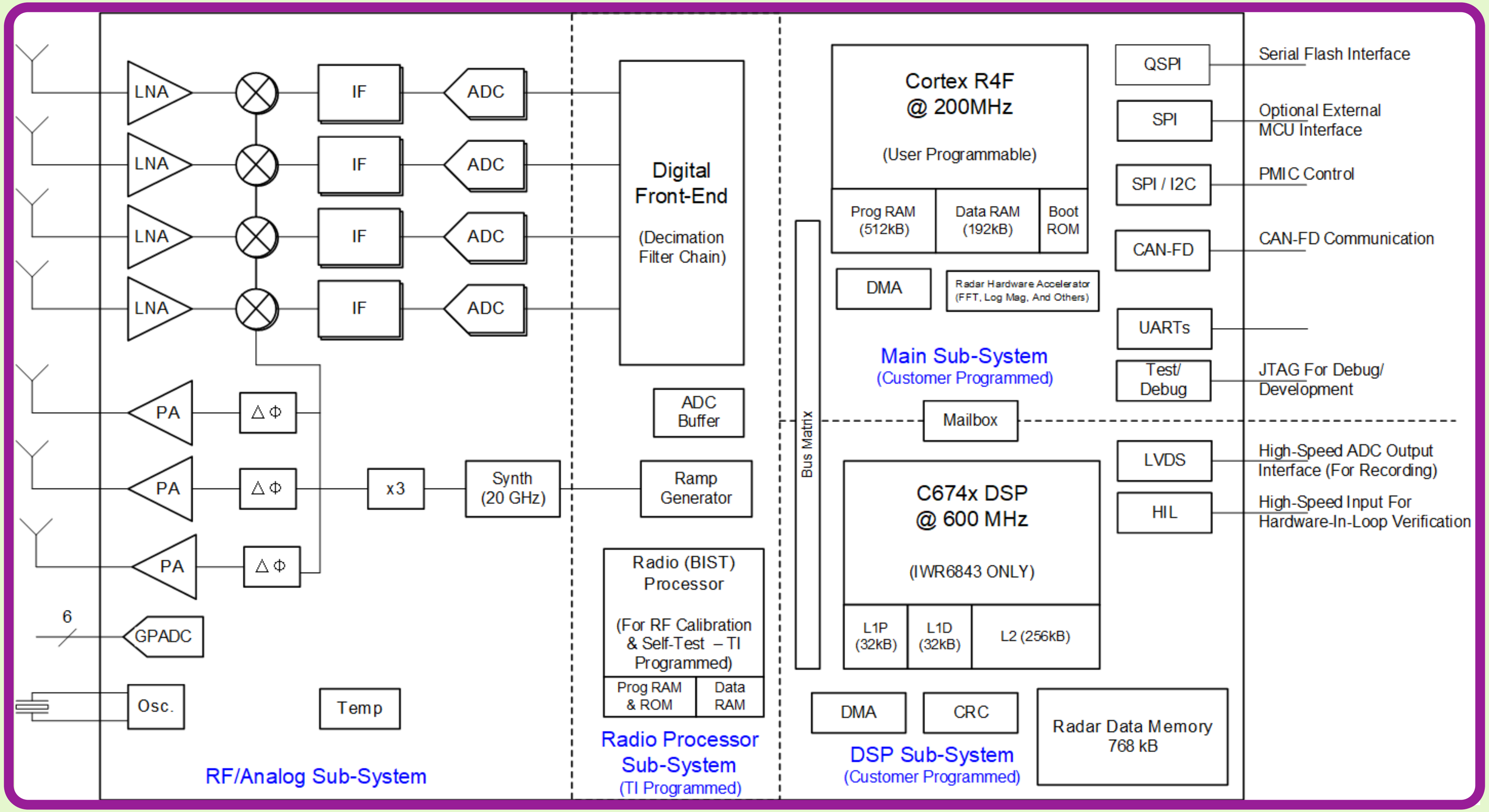
xWR6843ISK evaluation module - Texas instruments



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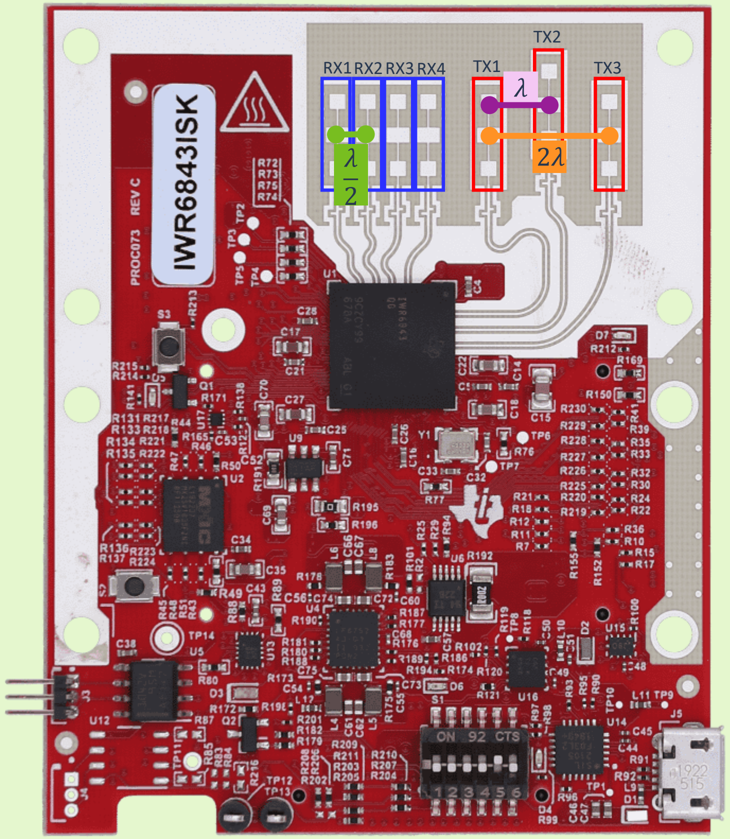
IWR6843ISK evaluation module - Texas instruments

	ntegrated Antenna 60-GHz Intelligent Edge Sensor IWR6843AoPEVM	High Performance 60-GHz Intelligent Edge Sensor xWR6843ISK	60-GHz Intelligent Edge Sensor IWR6843ISK-ODS
Tuning Frequency	60-64 GHz	60-64 GHz	60-64 GHz
Number of Receivers	4	4	4
Number of Transmitter	3	3	3
Processing	• MCU• FFT accelerator• DSP	• MCU• FFT accelerator• DSP	• MCU• FFT accelerator• DSP
Memory	1.75 MB	1.75 MB	1.75 MB
Antenna	Antenna on Package	Antenna on PCB	Antenna on PCB
Azimuth FOV (deg)2	+/- 60	+/- 60	+/- 60
Azimuth Angular Resolution (deg)1	29	15	29
Elevation FOV (deg)2	+/- 60	+/- 15	+/- 60
Elevation Angular Resolution (deg)1	29	58	29
Gain	5dBi	7dBi	5dBi
Modular Mode	• Requires mmWaveICBOOSTfor debugging and DCA1000• Flashing and functionalmode available withoutmmWaveICBOOST	• Requires mmWaveICBOOSTfor debugging• Flashing and functionalmode available withoutmmWaveICBOOST	• Requires mmWaveICBOOSTfor debugging• Flashing and functionalmode available withoutmmWaveICBOOST
Raw ADC Data Capture	Yes – requires mmWaveICBOOST + DCA1000	Yes – requires DCA1000	Yes – requires DCA1000



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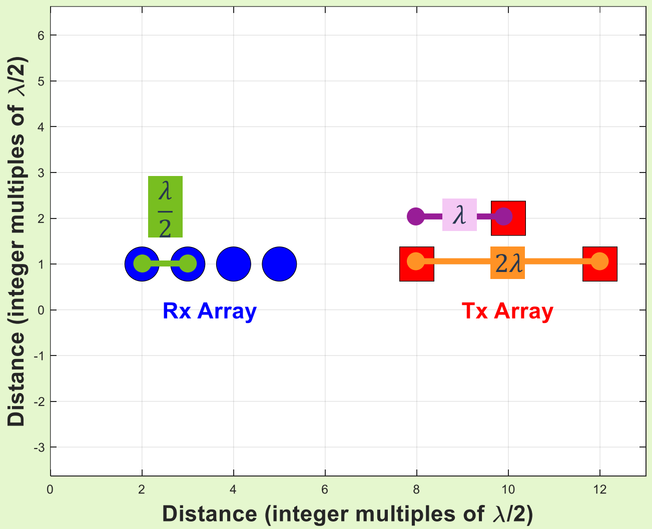
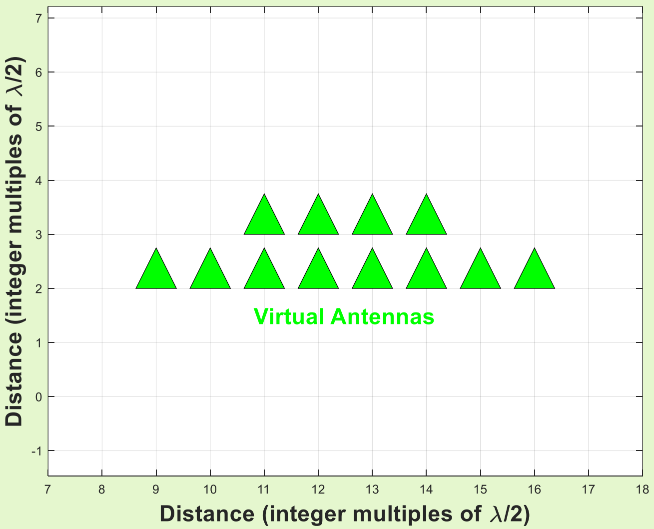
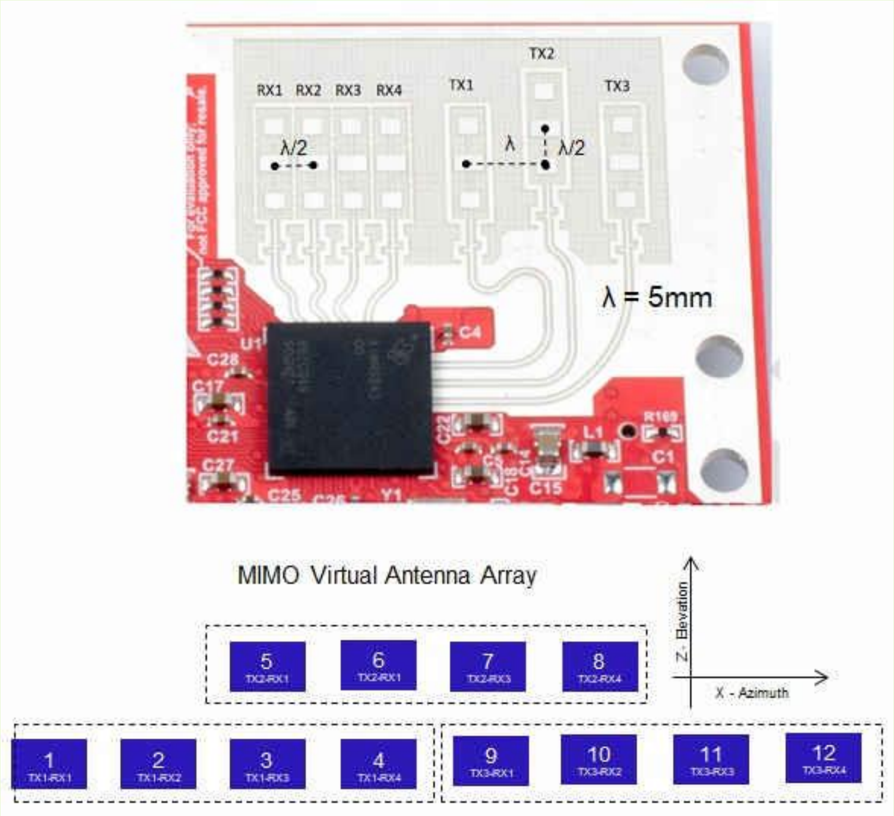
Virtual Array in IWR6843ISK evaluation module







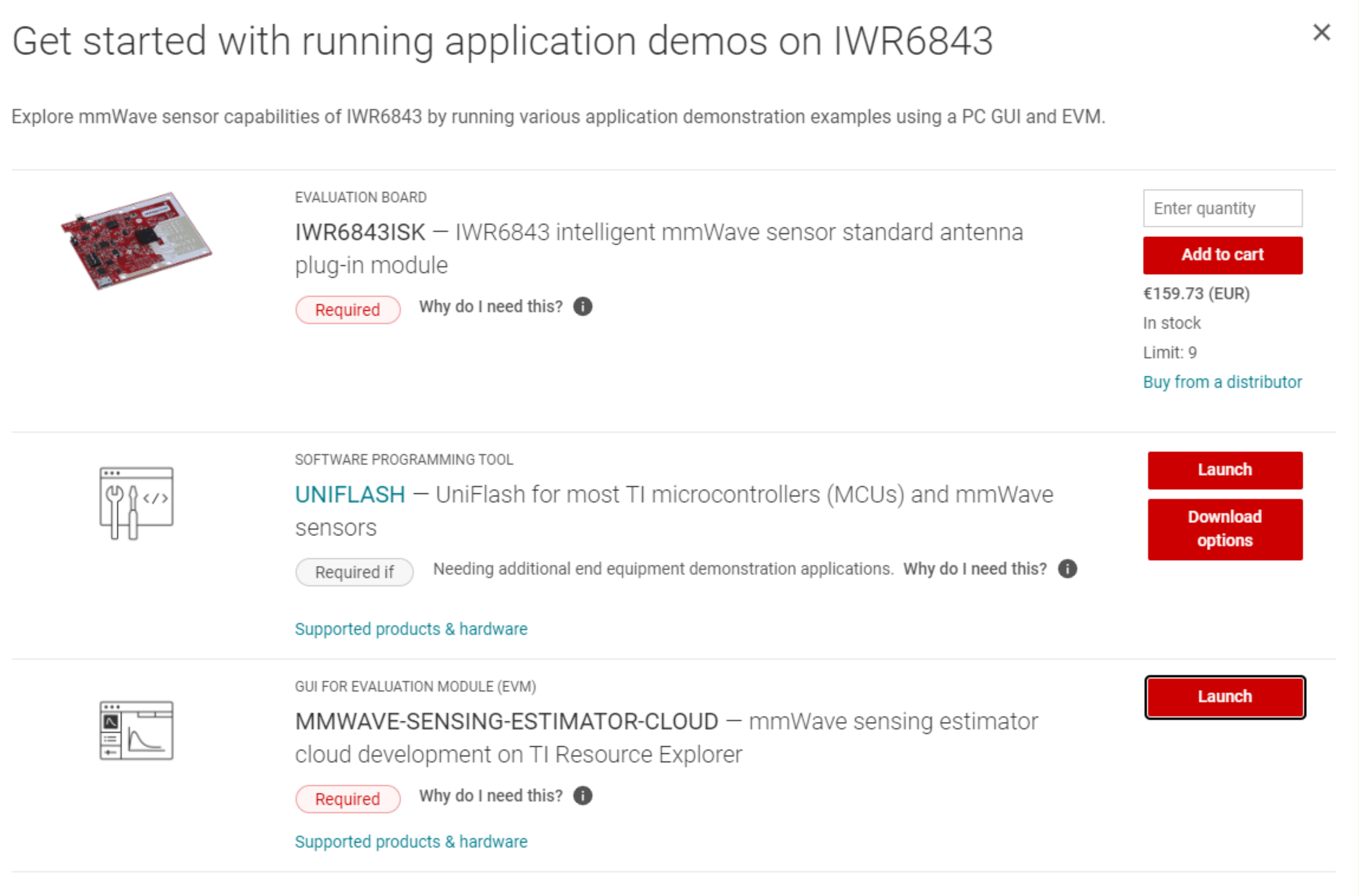
Lect5_example1.m

Getting started with xWR6843-ISK

https://www.ti.com/tool/IWR6843ISK

UNIFLASH — UniFlash for most TI microcontrollers (MCUs) and mmWave sensors

MMWAVE-SENSING-ESTIMATOR-CLOUD — mmWave sensing estimator cloud development on TI Resource Explorer



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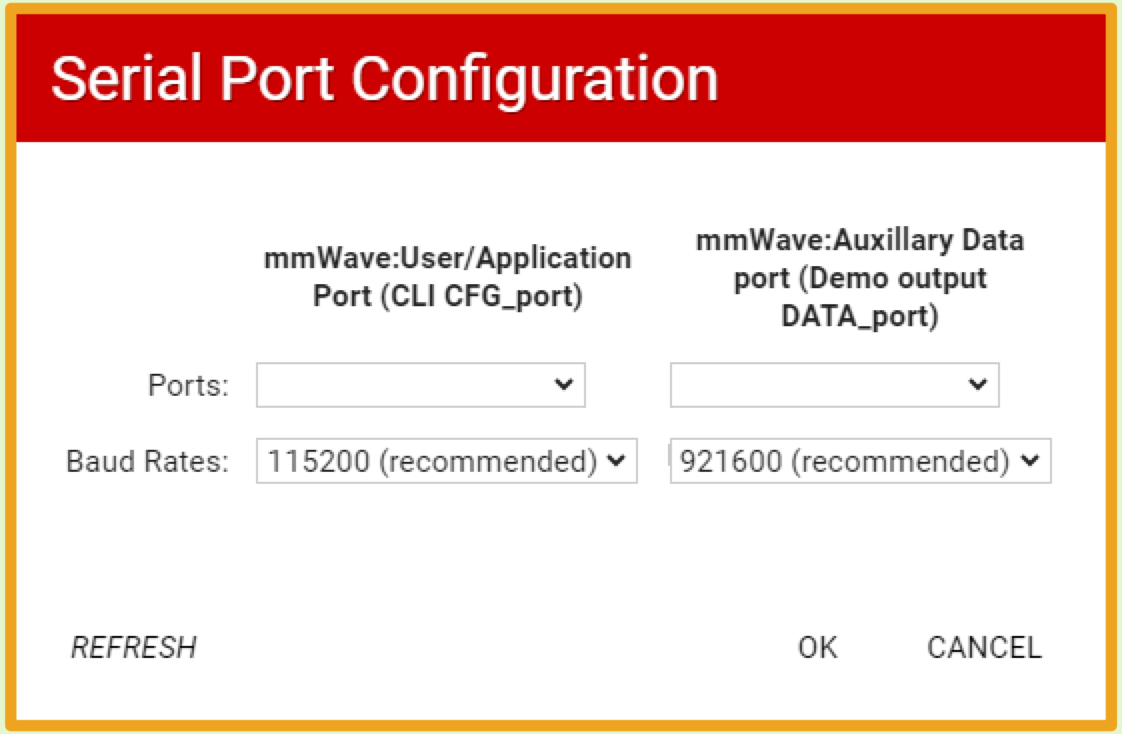
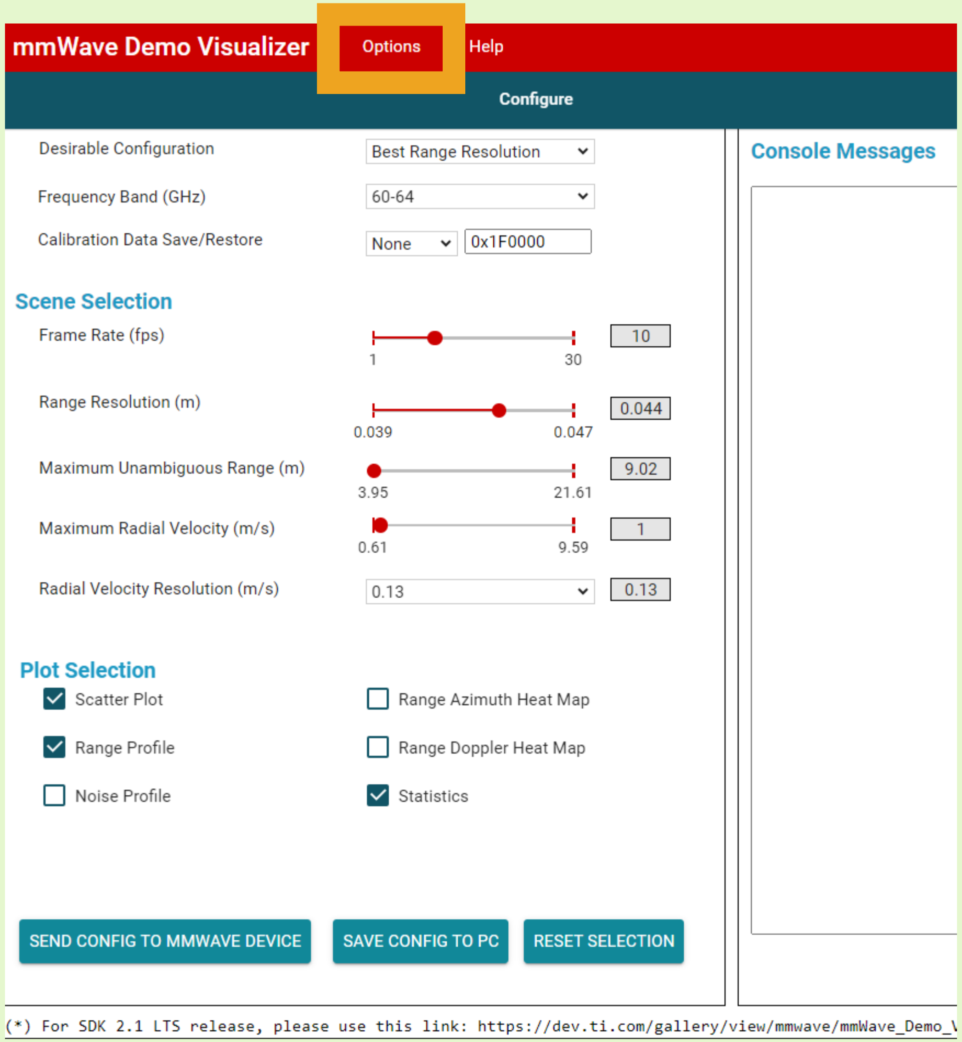
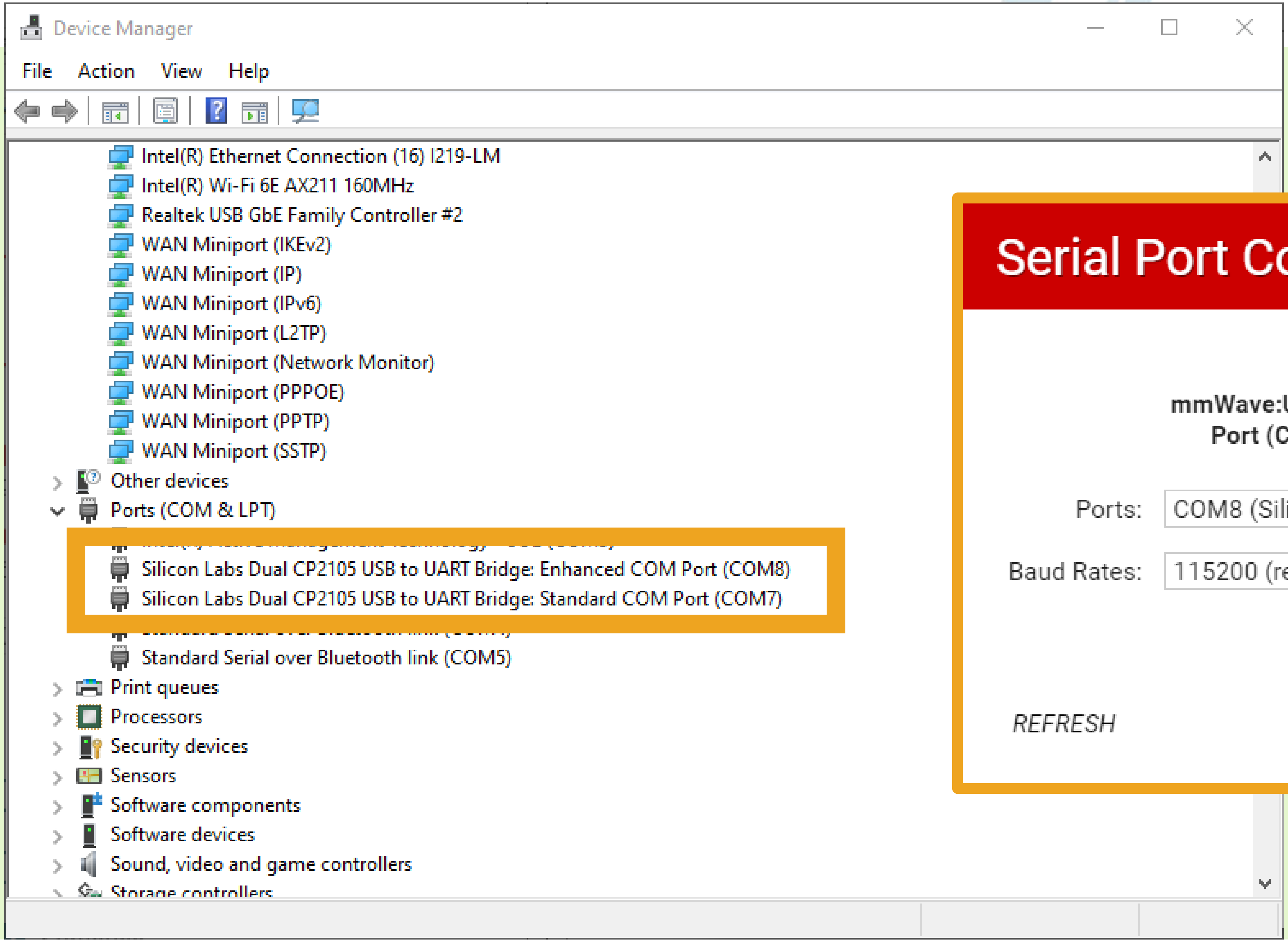
MMWAVE-SENSING-ESTIMATOR-CLOUD

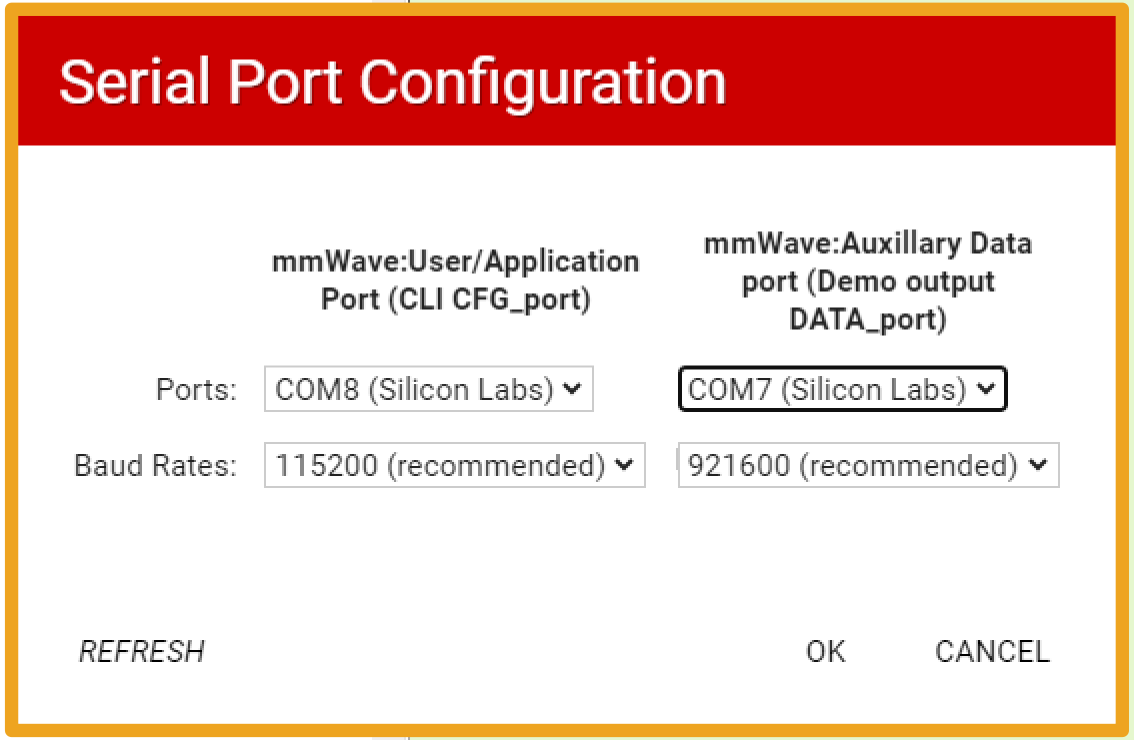
https://dev.ti.com/gallery/view/mmwave/mmWave_Demo_Visualizer/ver/3.6.0/





MMWAVE-SENSING-ESTIMATOR-CLOUD





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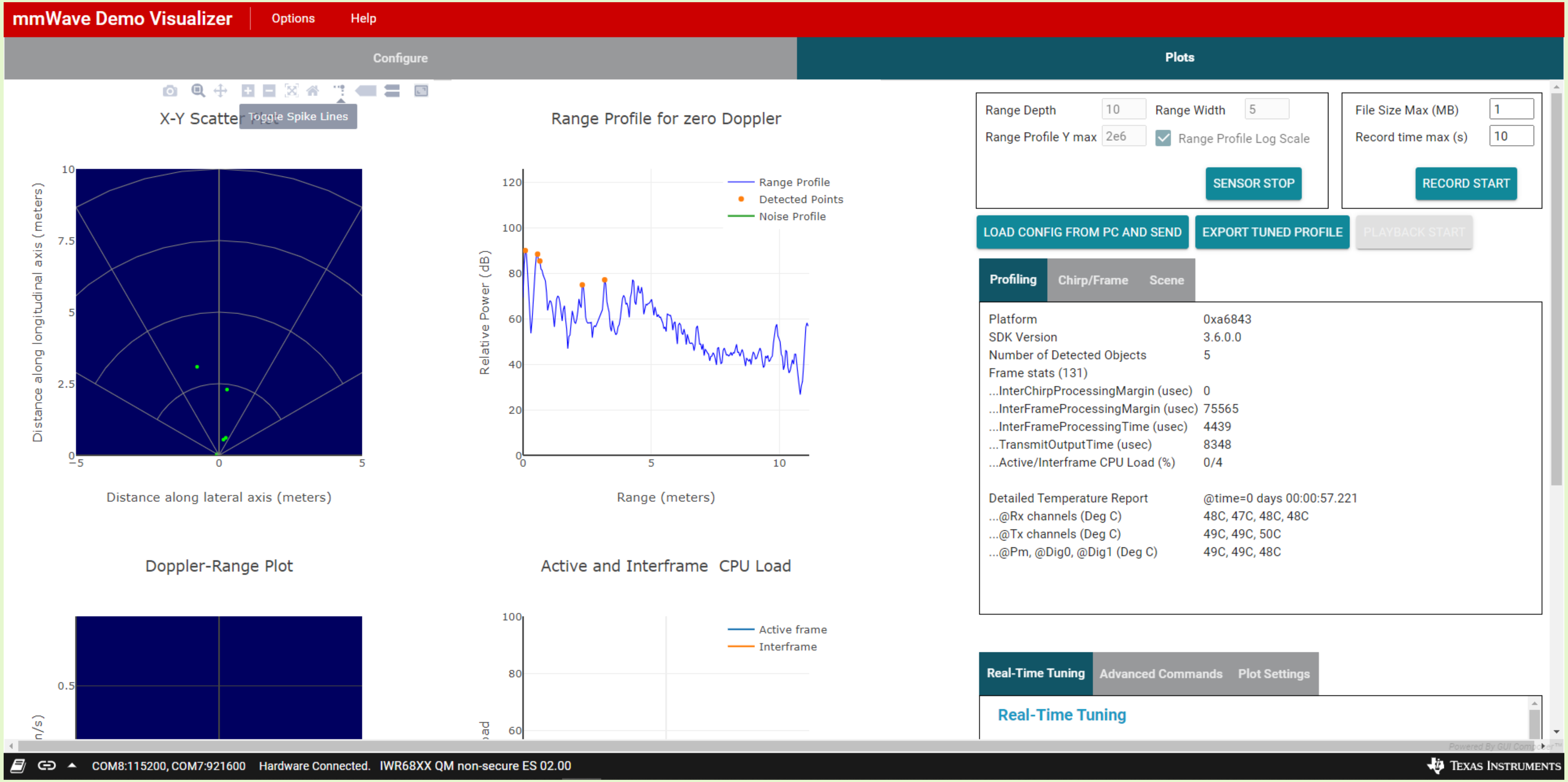
Angle estimation with MMWAVE-SENSING-ESTIMATOR-CLOUD

https://dev.ti.com/gallery/view/mmwave/mmWave_Demo_Visualizer/ver/3.6.0/



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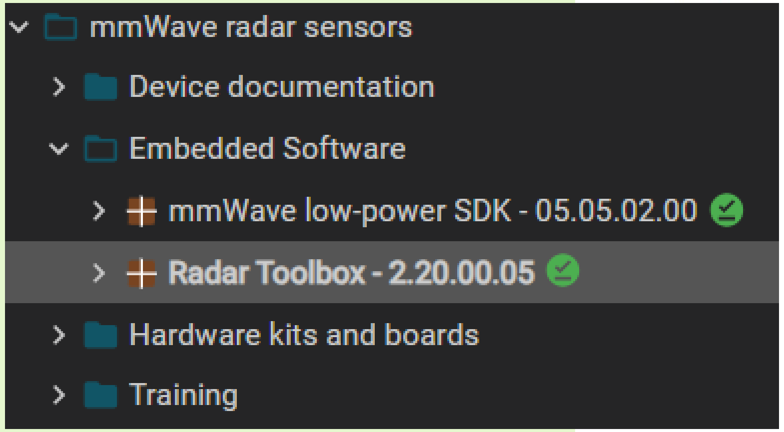
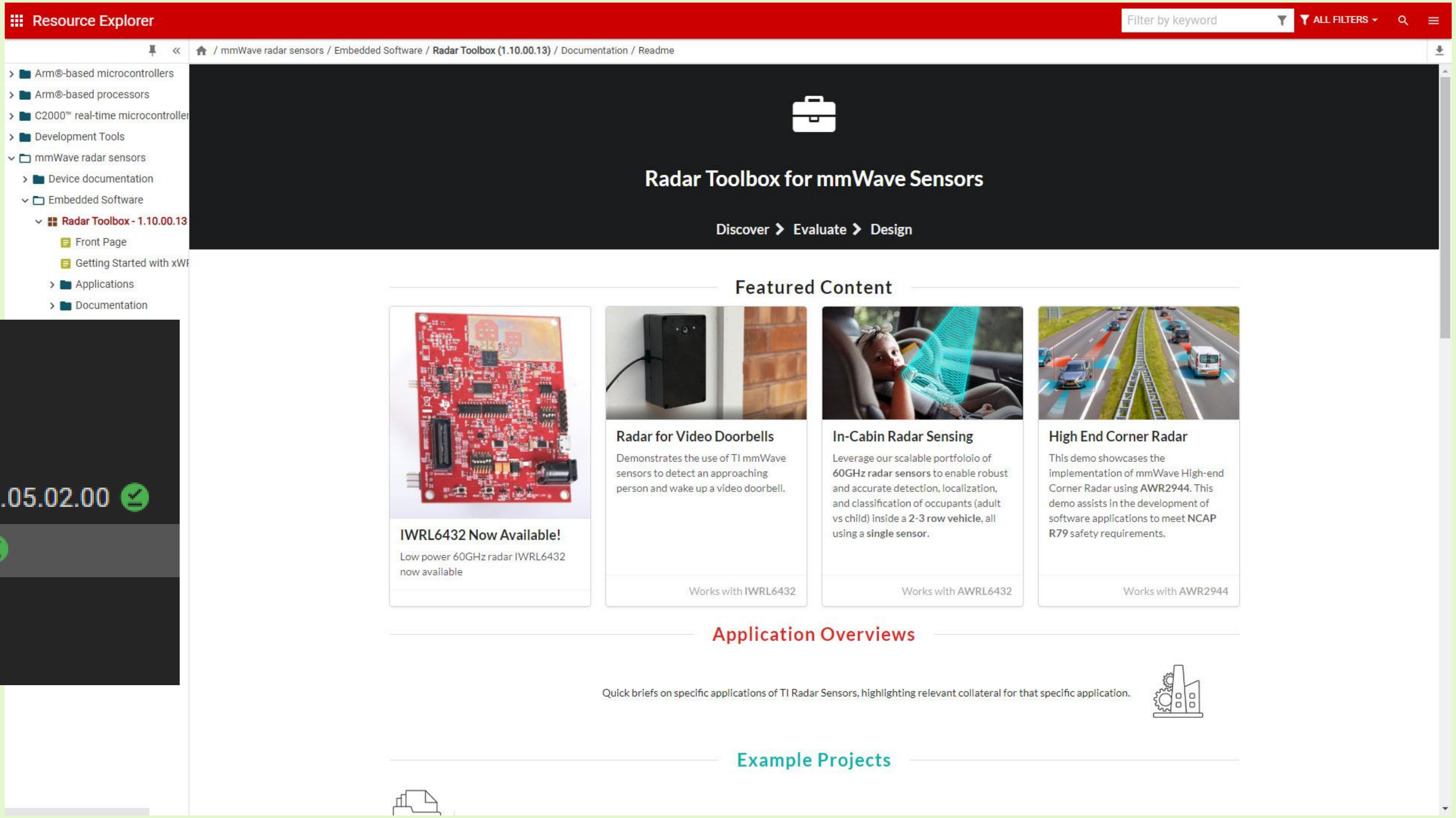
TI Resource Explorer – Radar Toolbox

https://dev.ti.com/tirex/global?id=radar_toolbox





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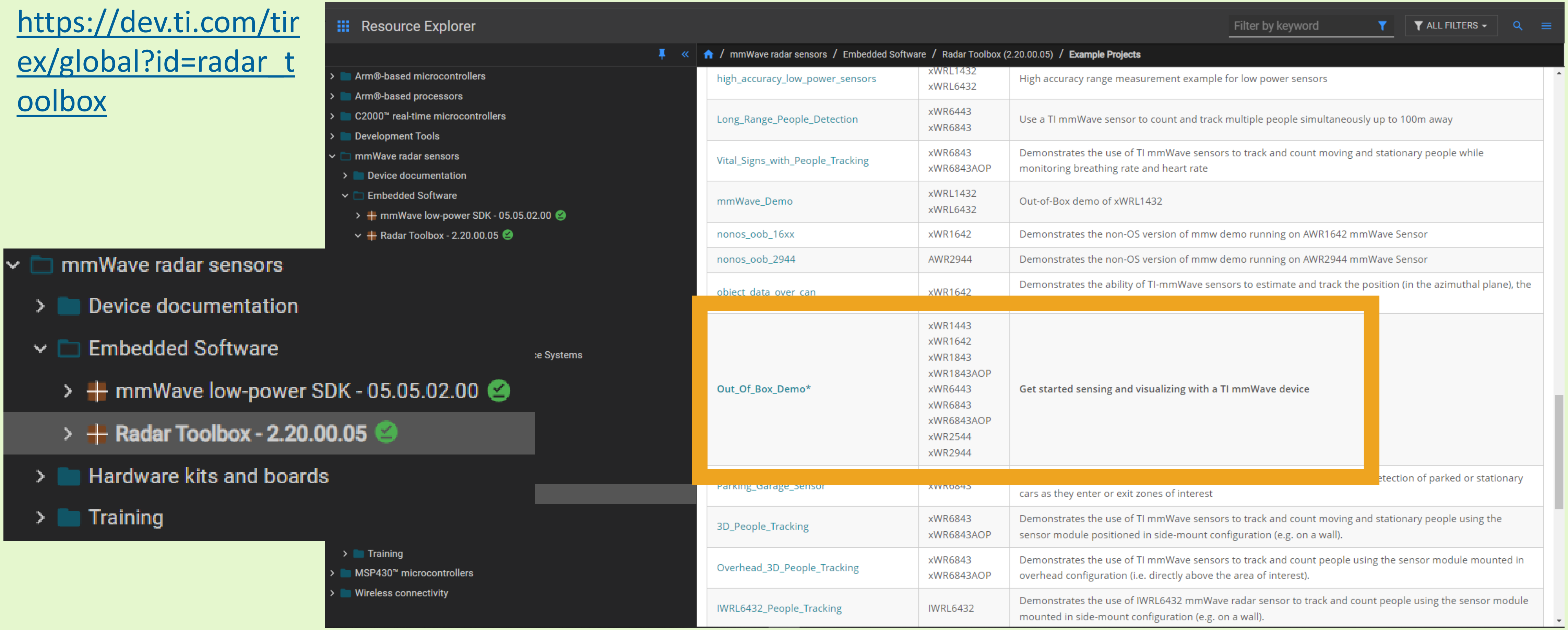

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TI Resource Explorer – Radar Toolbox

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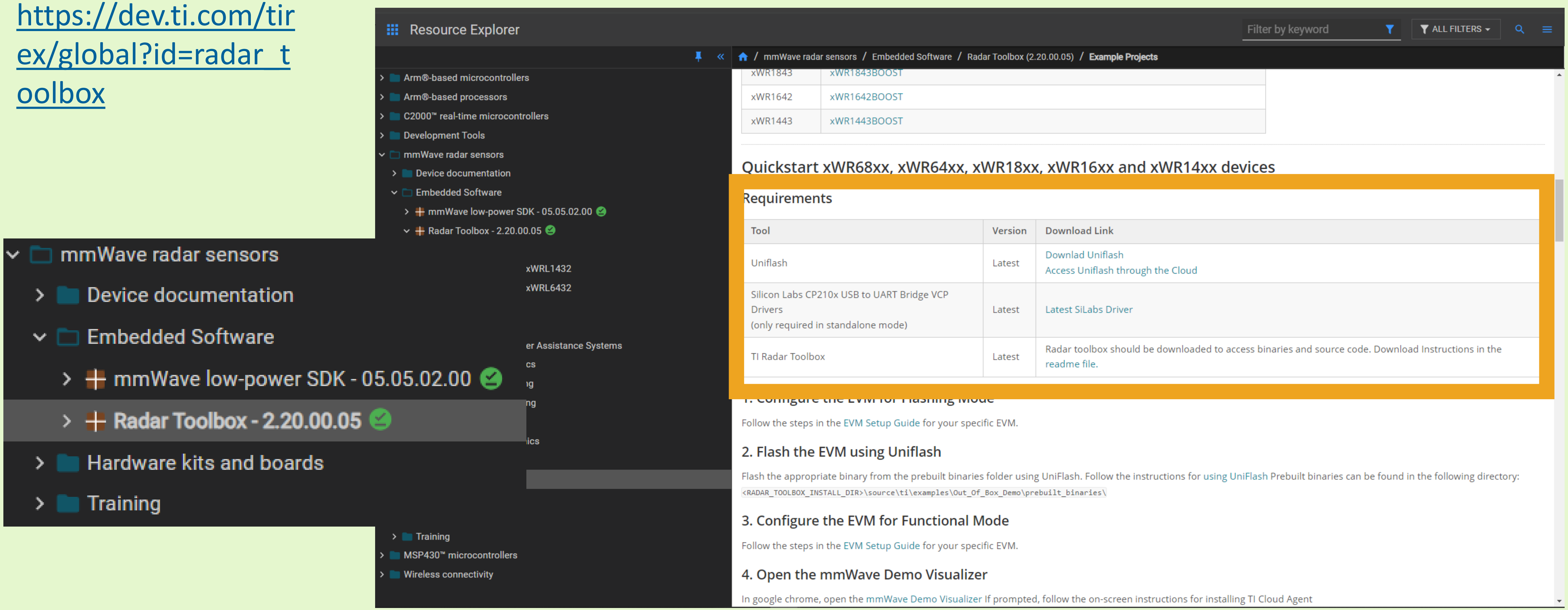
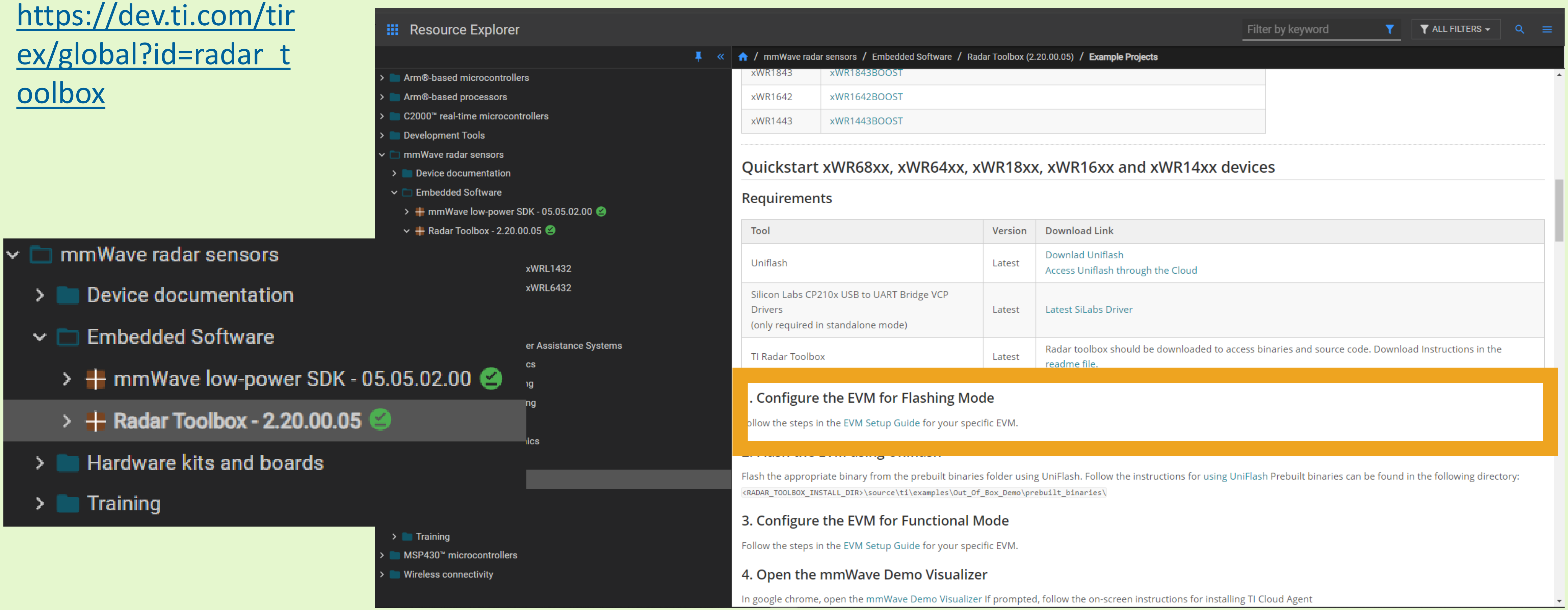


Configure sensor to the Flash mode

https://dev.ti.com/tirex/global?id=radar_toolbox



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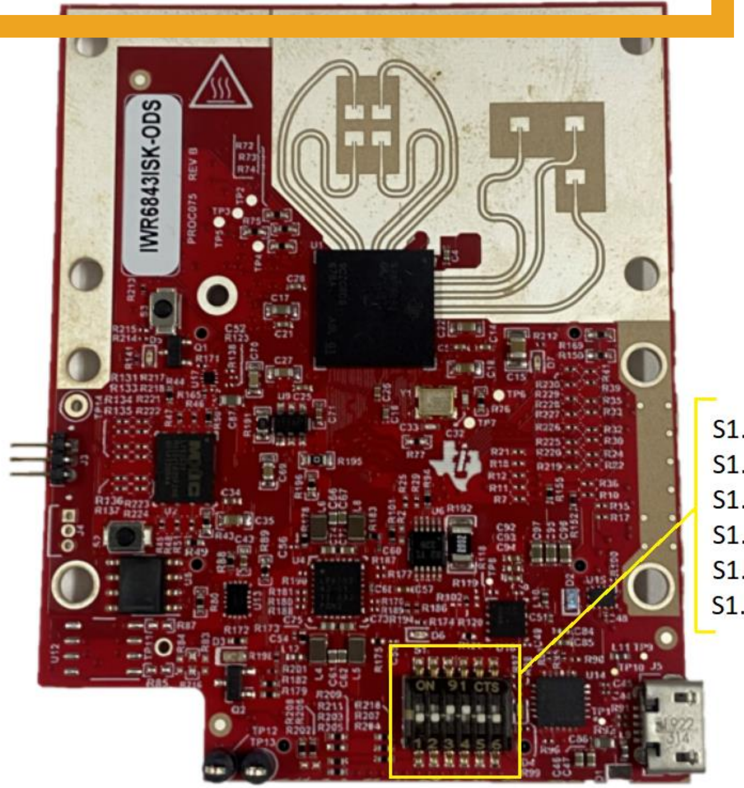
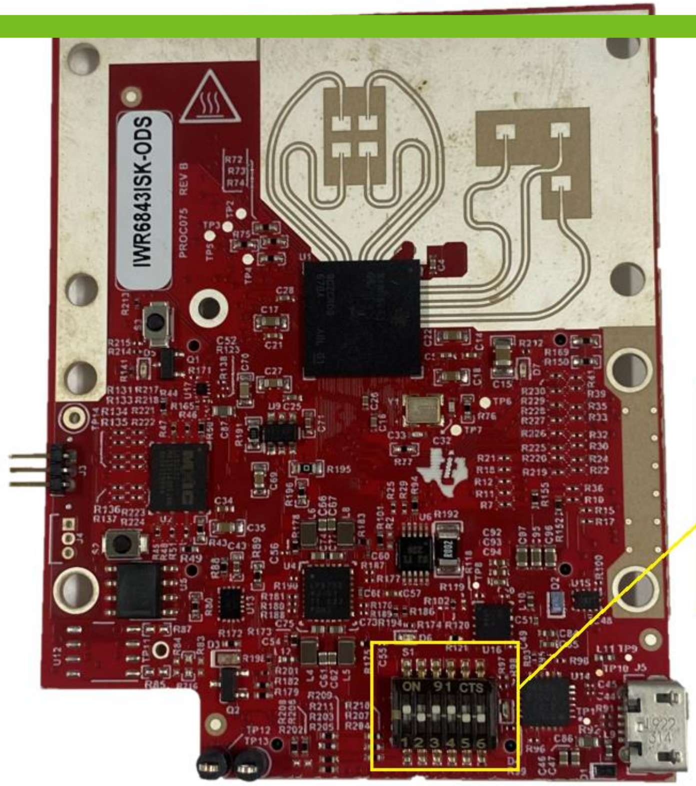
Configure sensor to the Flash mode

Functional Mode



S1.1: Off
S1.2: Off
S1.3: On
S1.4: On
S1.5: Off
S1.6: N/A

Flash Mode



S1.1: On
S1.2: Off
S1.3: On
S1.4: On
S1.5: Off
S1.6: N/A

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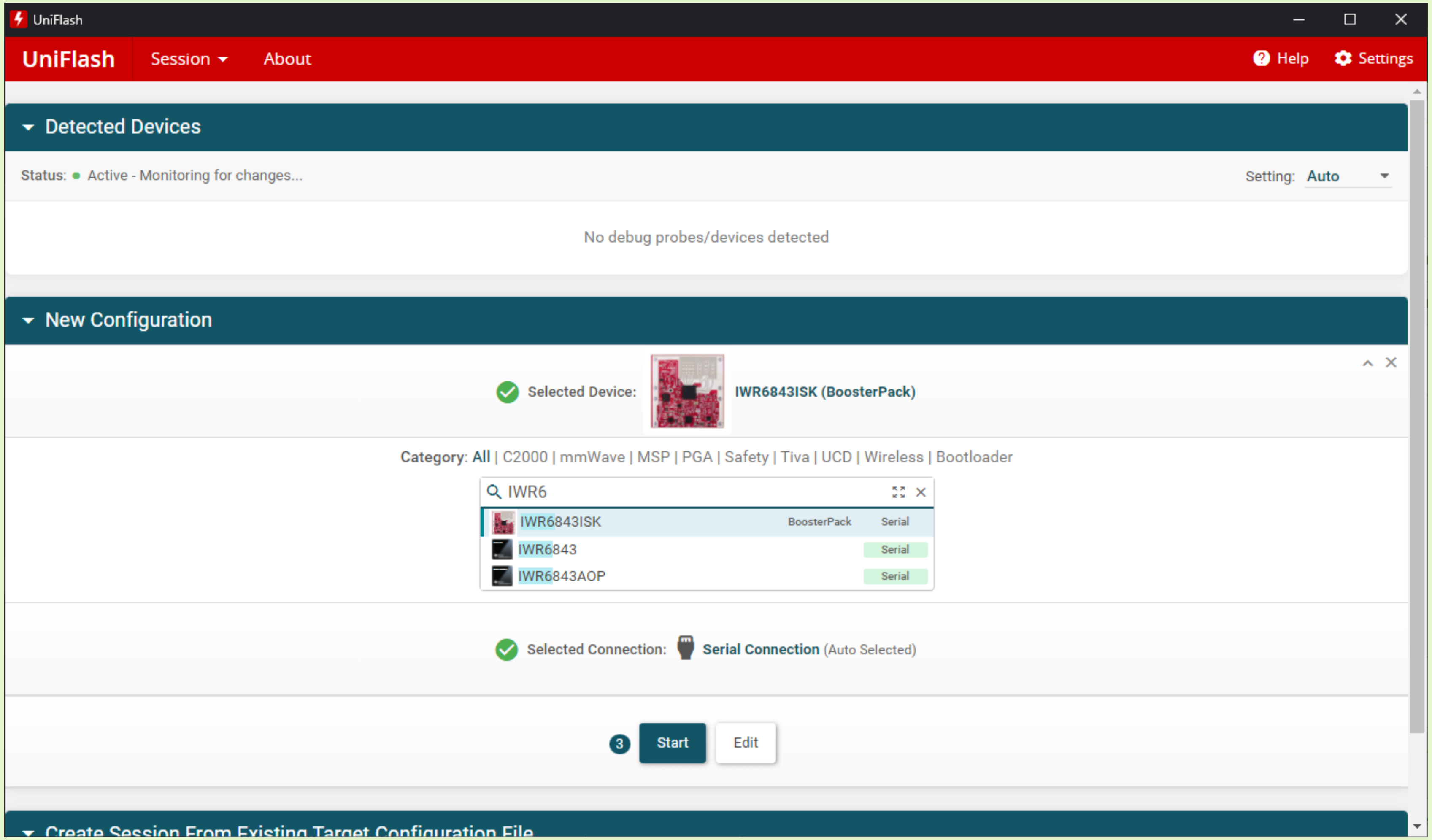
Programming the binary

[UNIFLASH](#) — UniFlash for most TI microcontrollers (MCUs) and mmWave sensors



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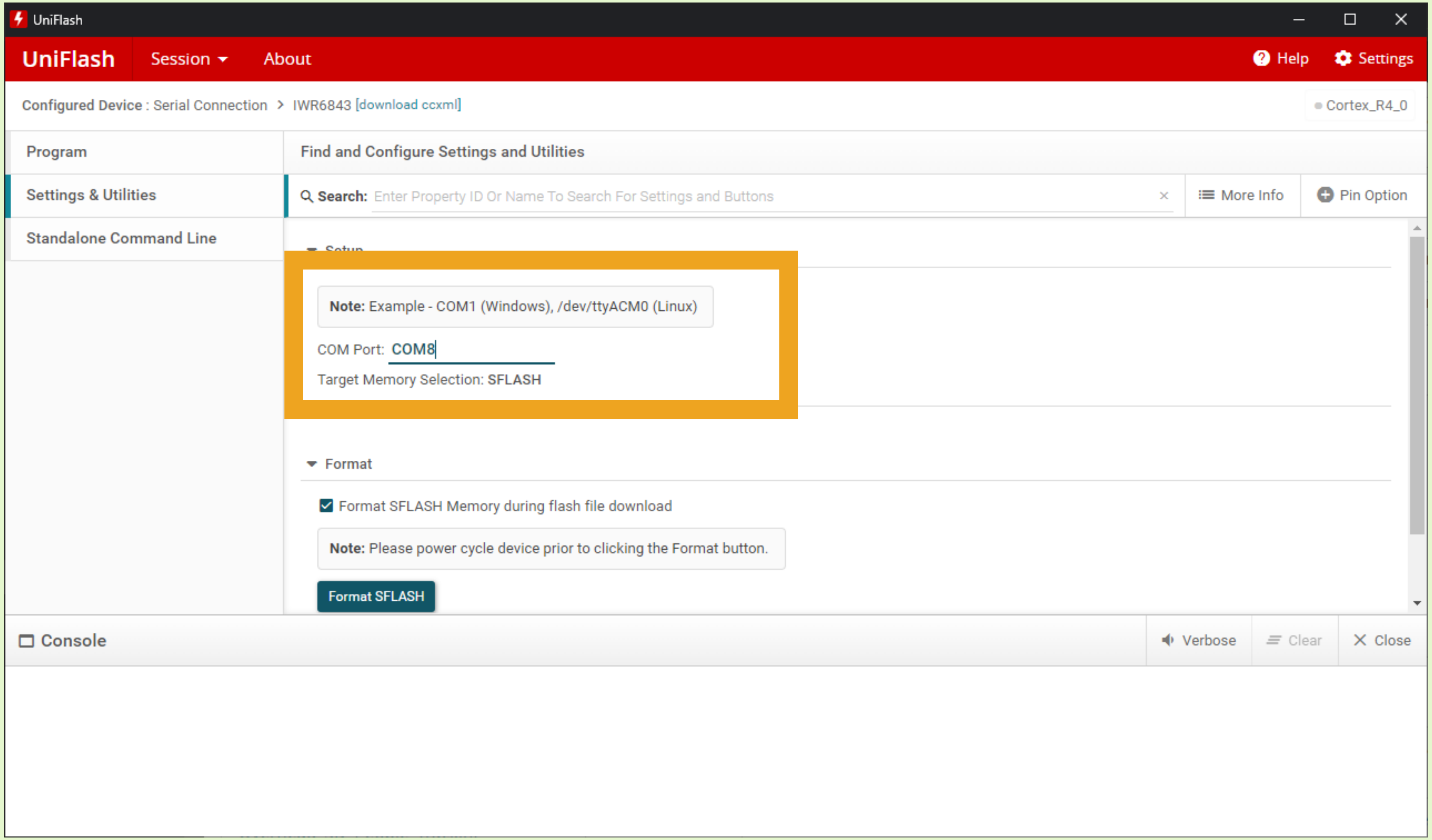

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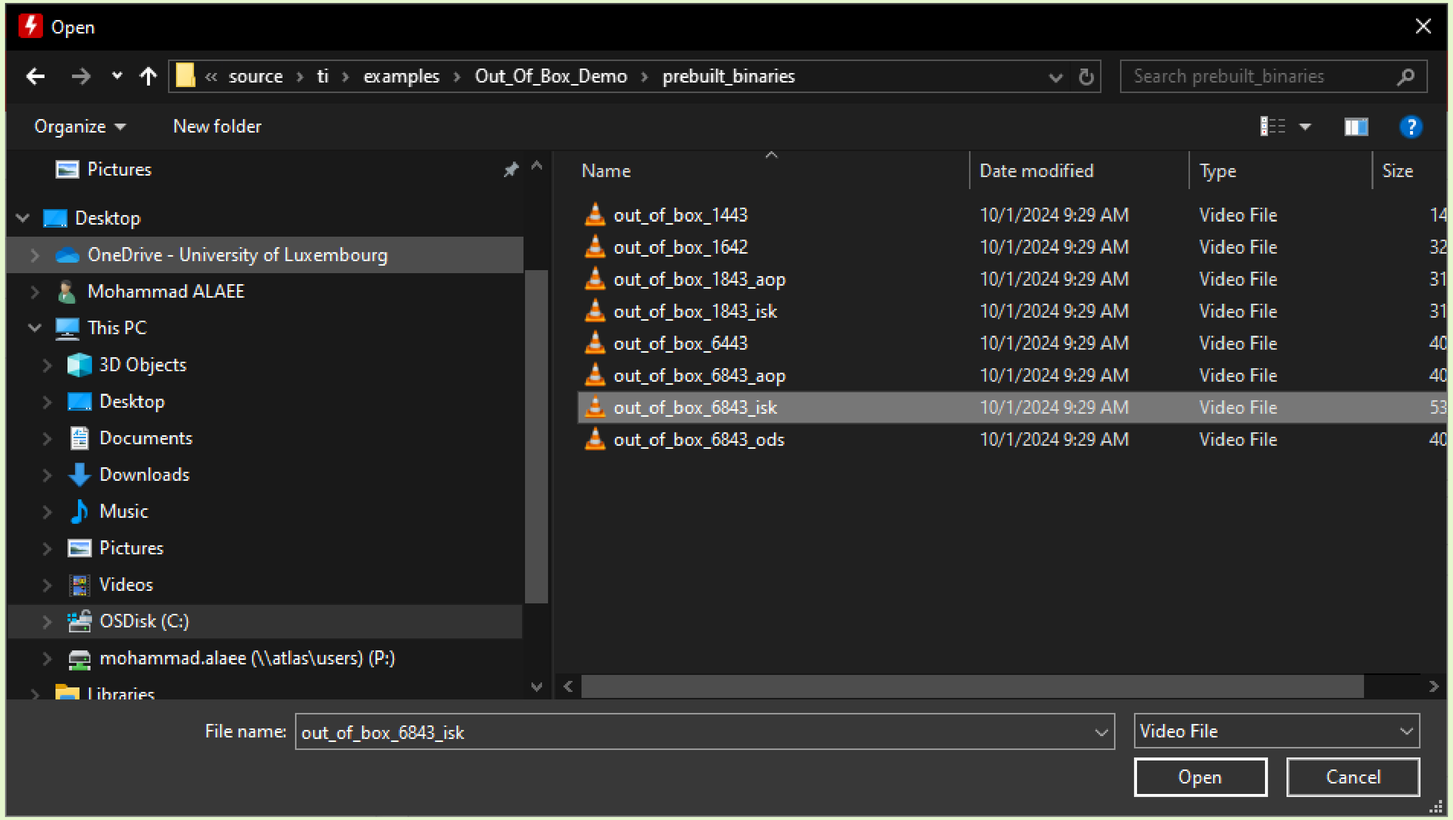
Programming the binary

C:\ti\radar_toolbox_2_20_00_05\source\ti\examples\Out_Of_Box_Demo\prebuilt_binaries



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Programming the binary

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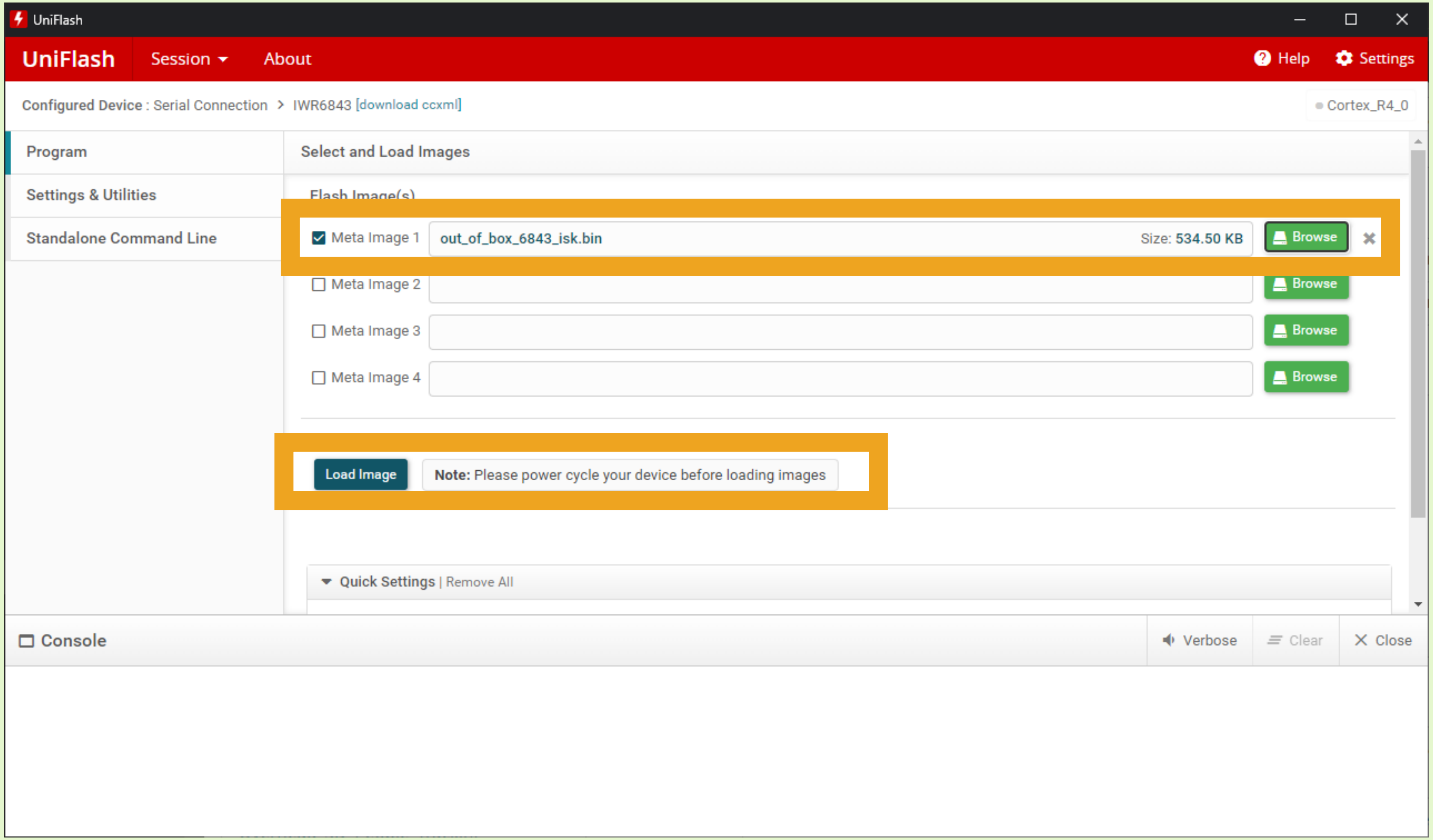

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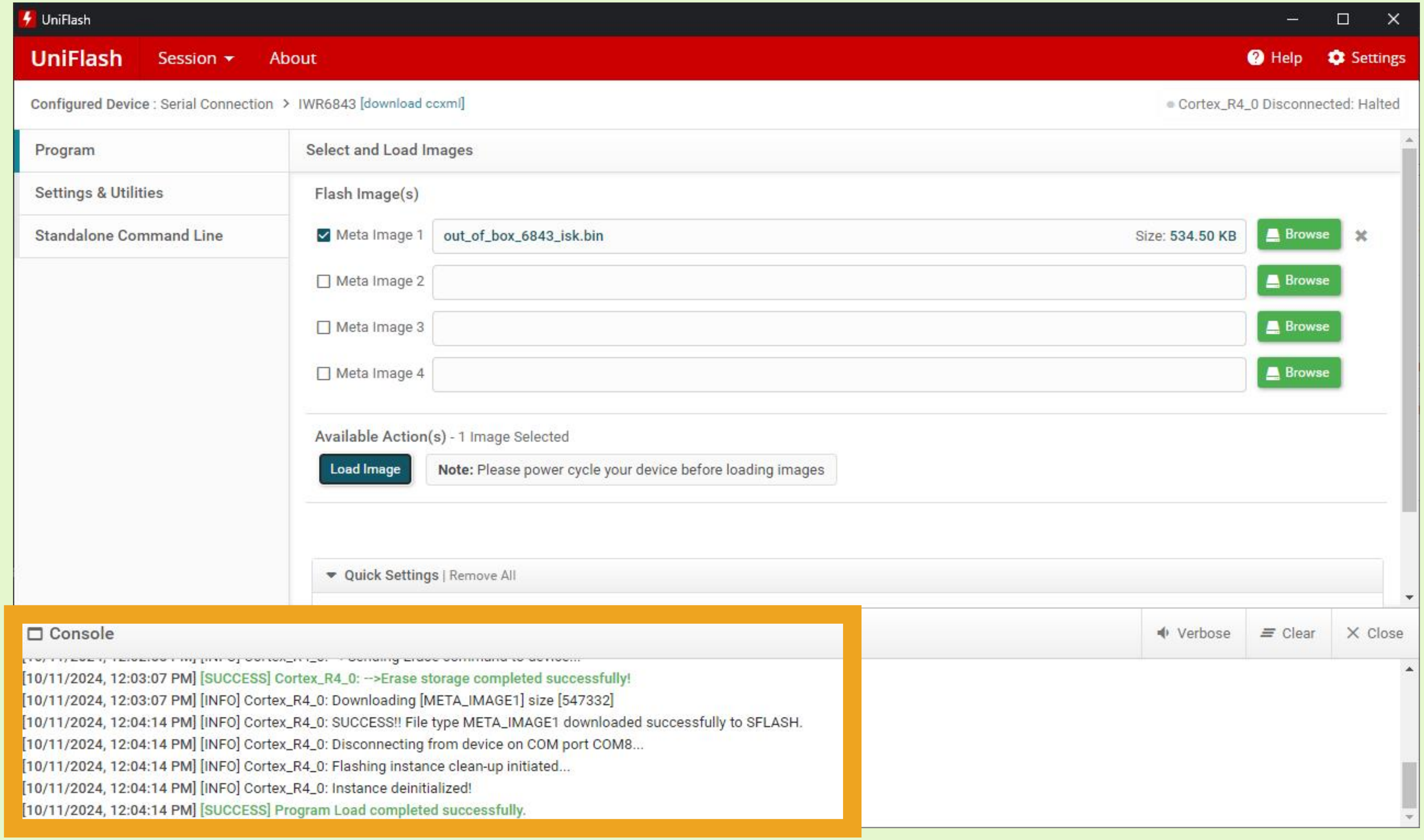
Programming the binary

[UNIFLASH](#) – UniFlash for most TI microcontrollers (MCUs) and mmWave sensors

Unplug sensor, and set it back to the functional mode



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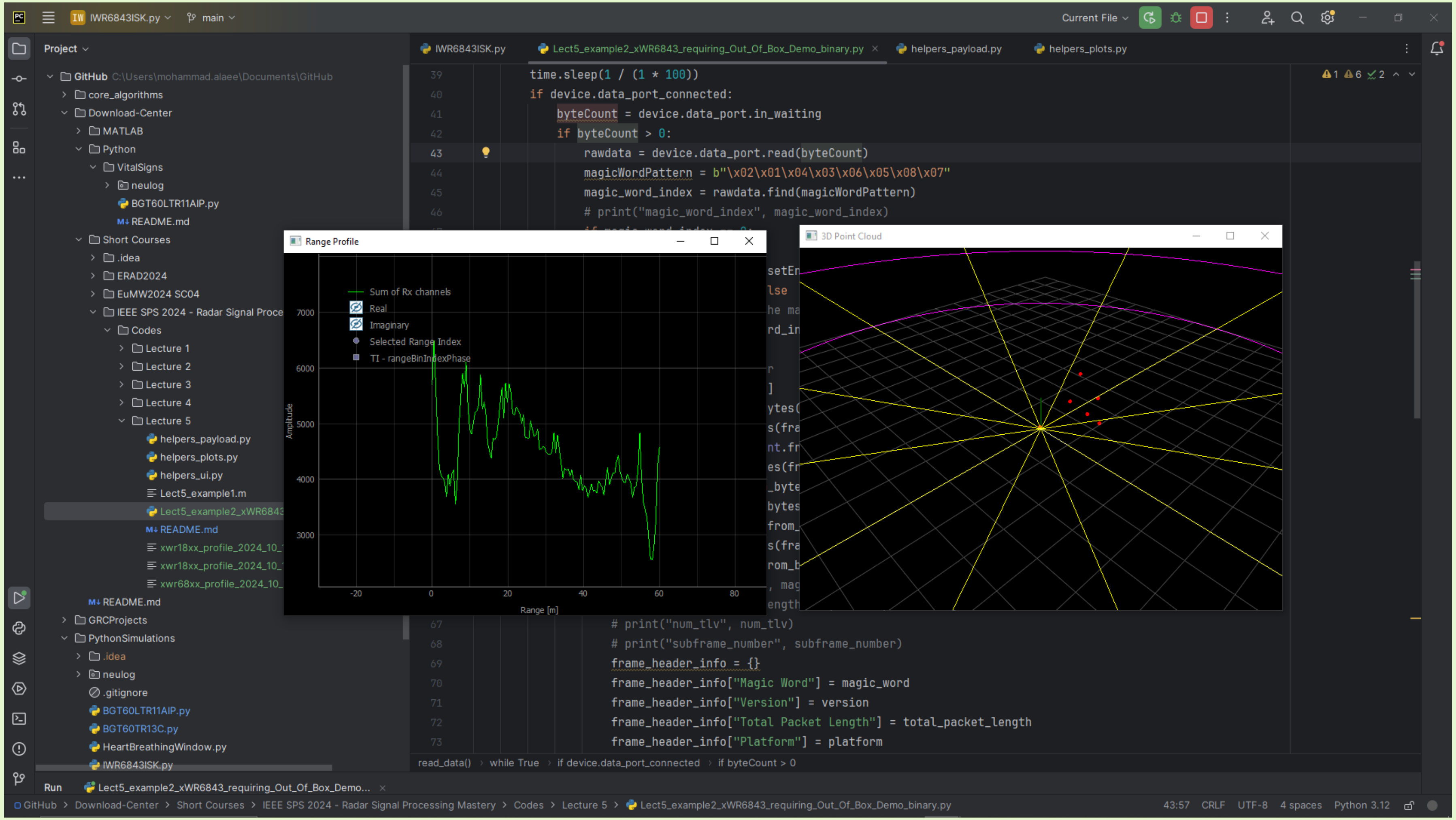
Self programming with xWR6843, xWR1843, xWR1642, xWR1443

Lect5_example2_xWR6843_requiring_Out_Of_Box_Demo_binary.py



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What we learned from Lecture 5

- In Lecture 5 we used IWR6843 to capture real data and processed it. 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

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