

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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Outline

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

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

Lecture 5

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

Lecture 5: Angle estimation with MIMO radar xWR6843ISK

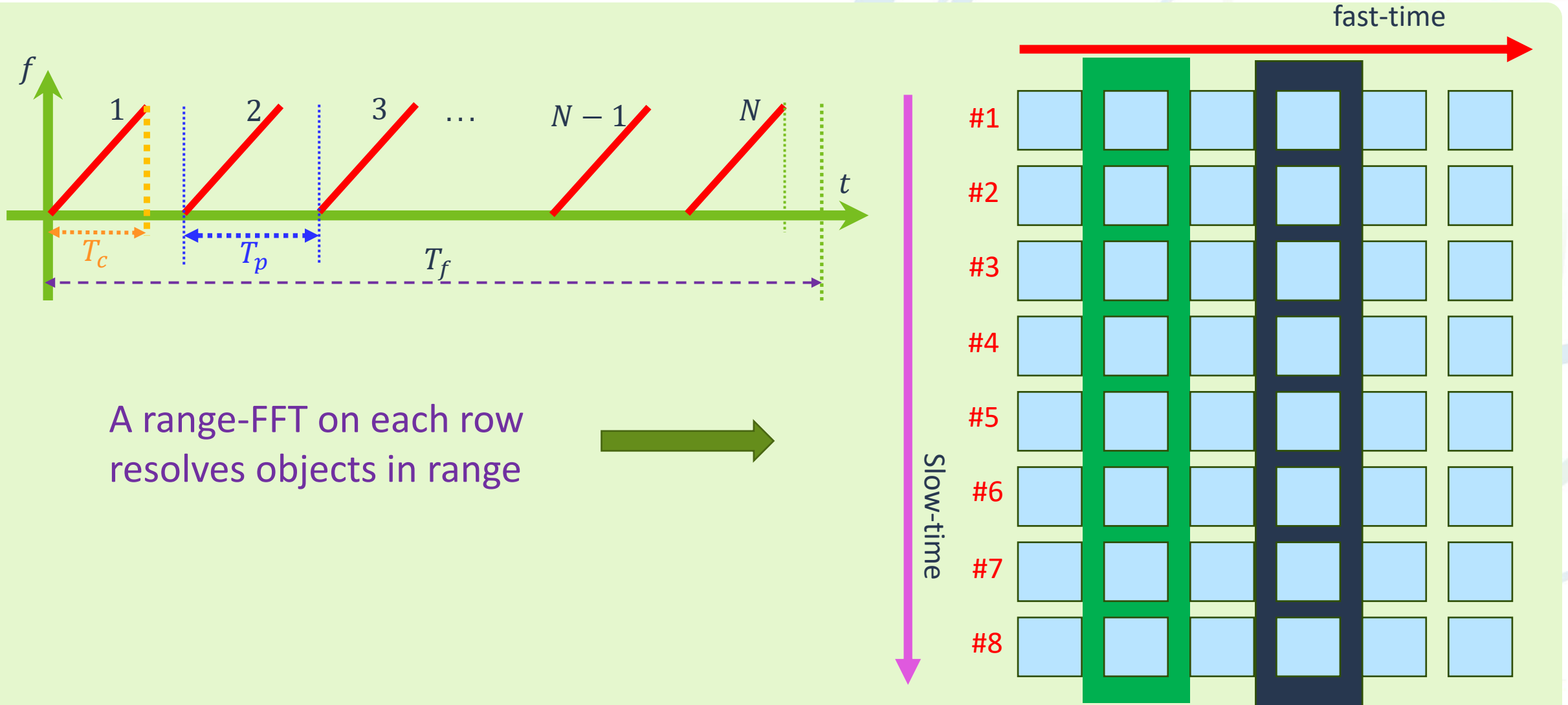
What we learn in Lecture 5

- 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

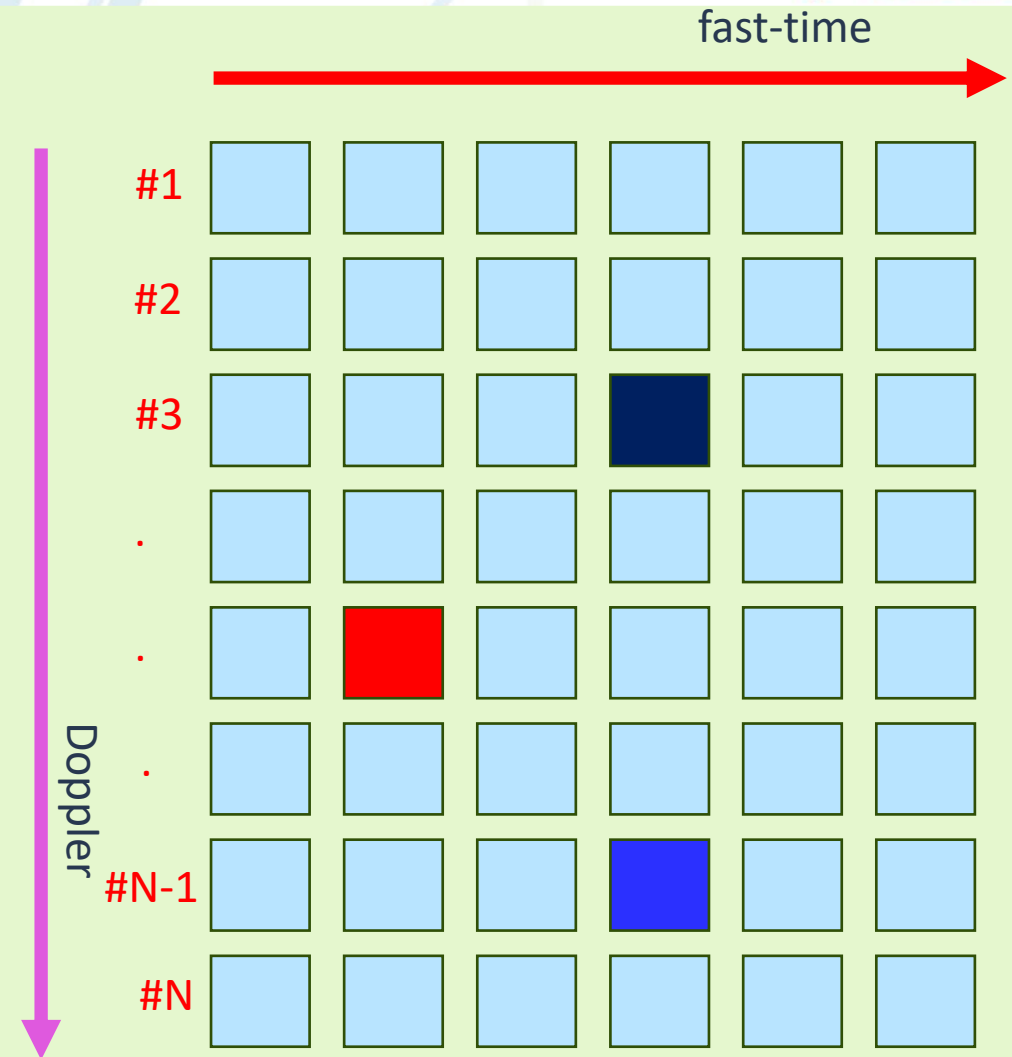
FMCW Radar



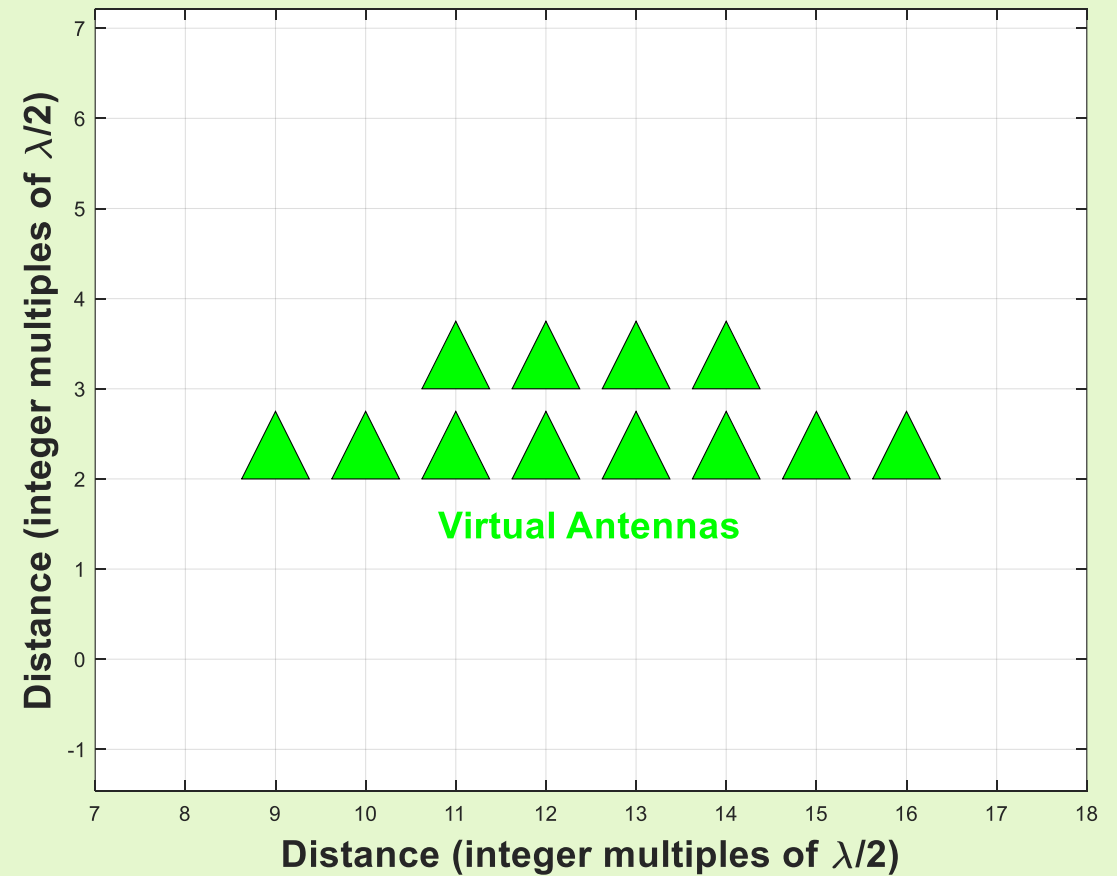
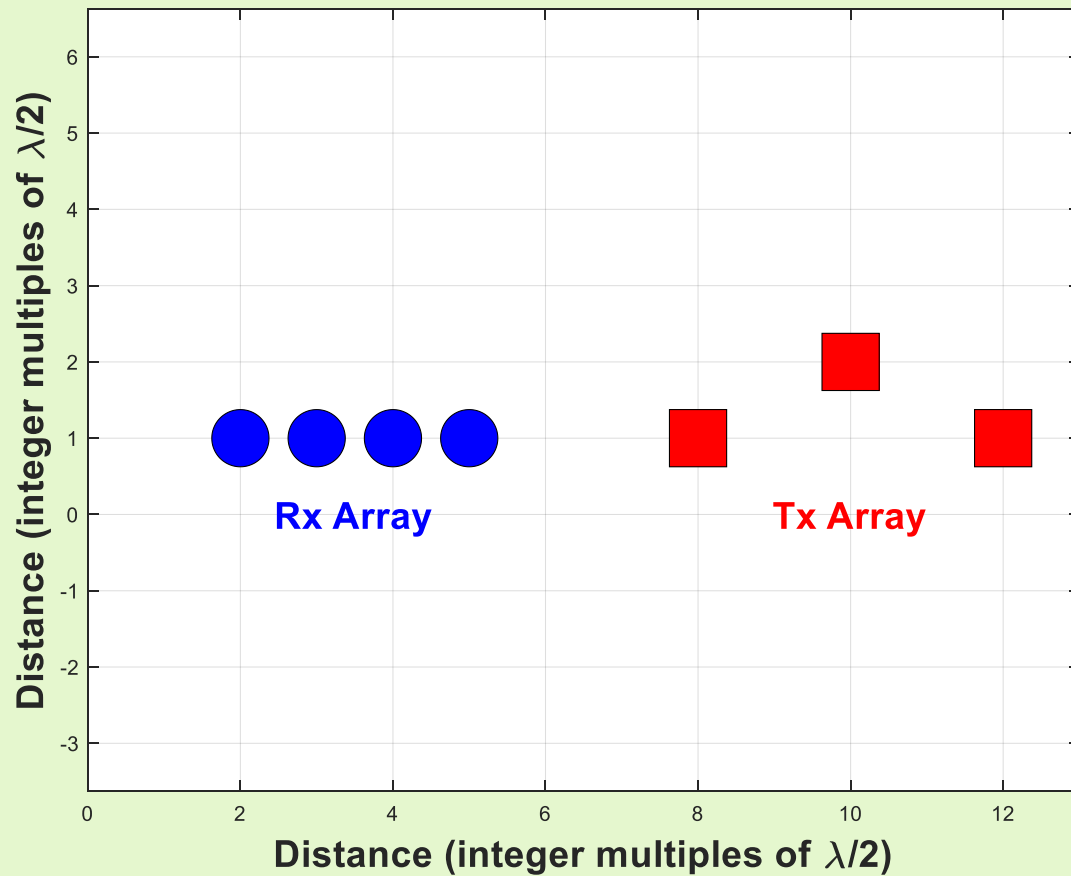
FMCW MIMO Radar

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

This is for one receive channel !

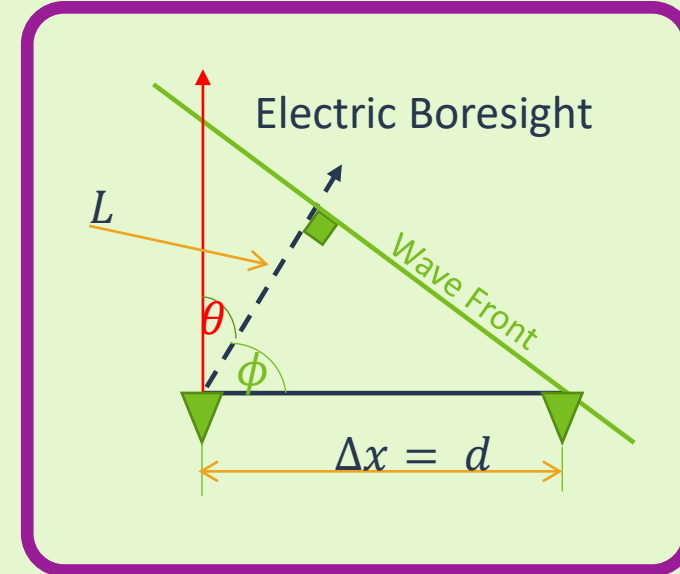
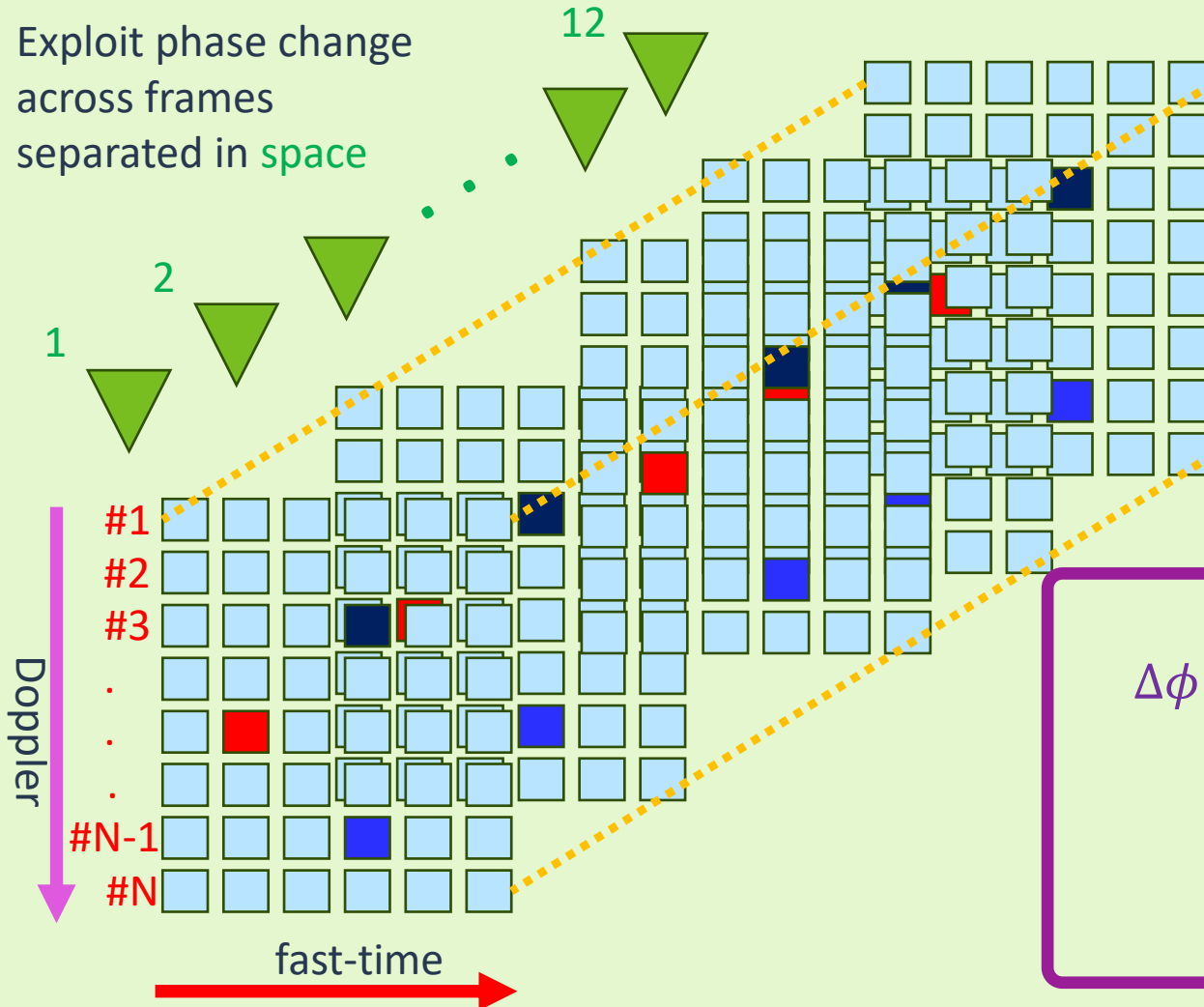


Virtual Array in FMCW MIMO Radar



Lect5_example1.m

Angle Estimation in FMCW MIMO Radar



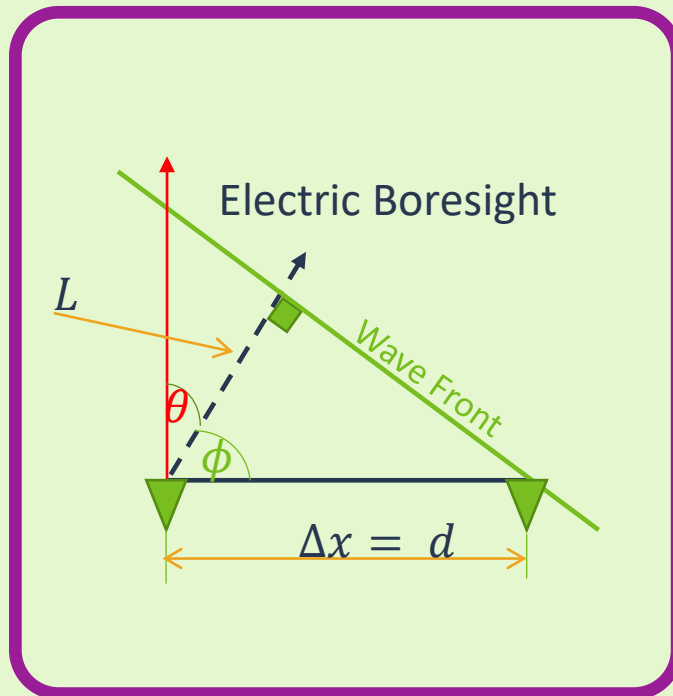
$$\Delta\phi = \frac{2\pi\Delta d}{\lambda} = \frac{2\pi d \sin \theta}{\lambda}$$

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

a non-linear relationship!

Angular Resolution in FMCW MIMO Radar

How much is **angular resolution** in a MIMO radar system?



Angular Field of View

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

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

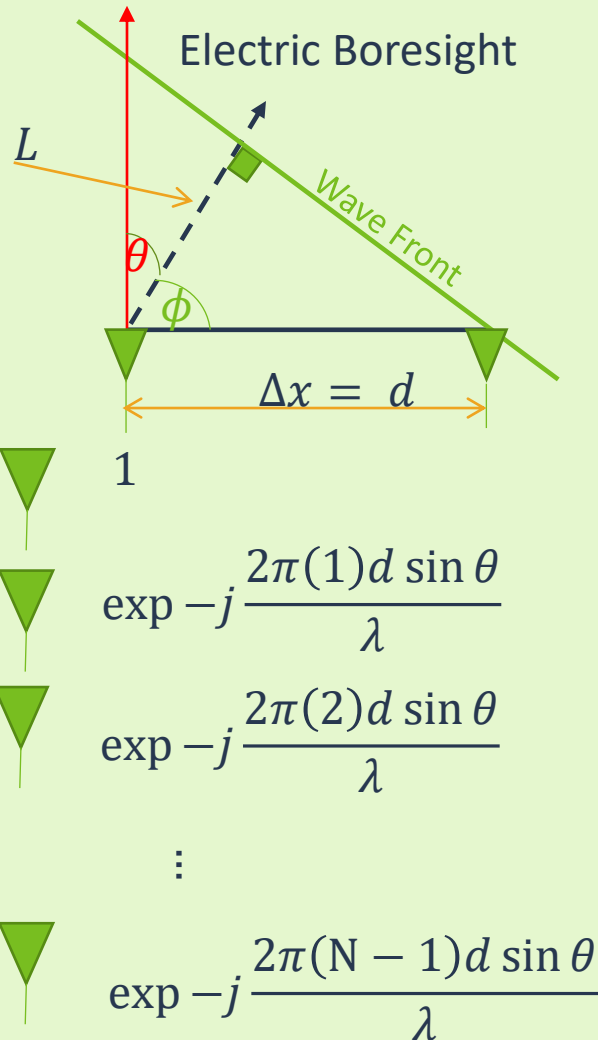
The virtual array has inter-element space of $\frac{\lambda}{2}$



No grating lobe!

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

Angular Resolution in FMCW MIMO Radar



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

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

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

Since derivative of $\sin(\theta)$ is $\cos(\theta)$

$$\frac{\sin(\theta + \Delta \theta) - \sin(\theta)}{\Delta \theta} \approx \cos \theta$$

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

best resolution at $\theta = 0$

assuming $d = \lambda/2$ and $\theta = 0$

$$\theta_{res} = \frac{2}{N_{VA}}$$

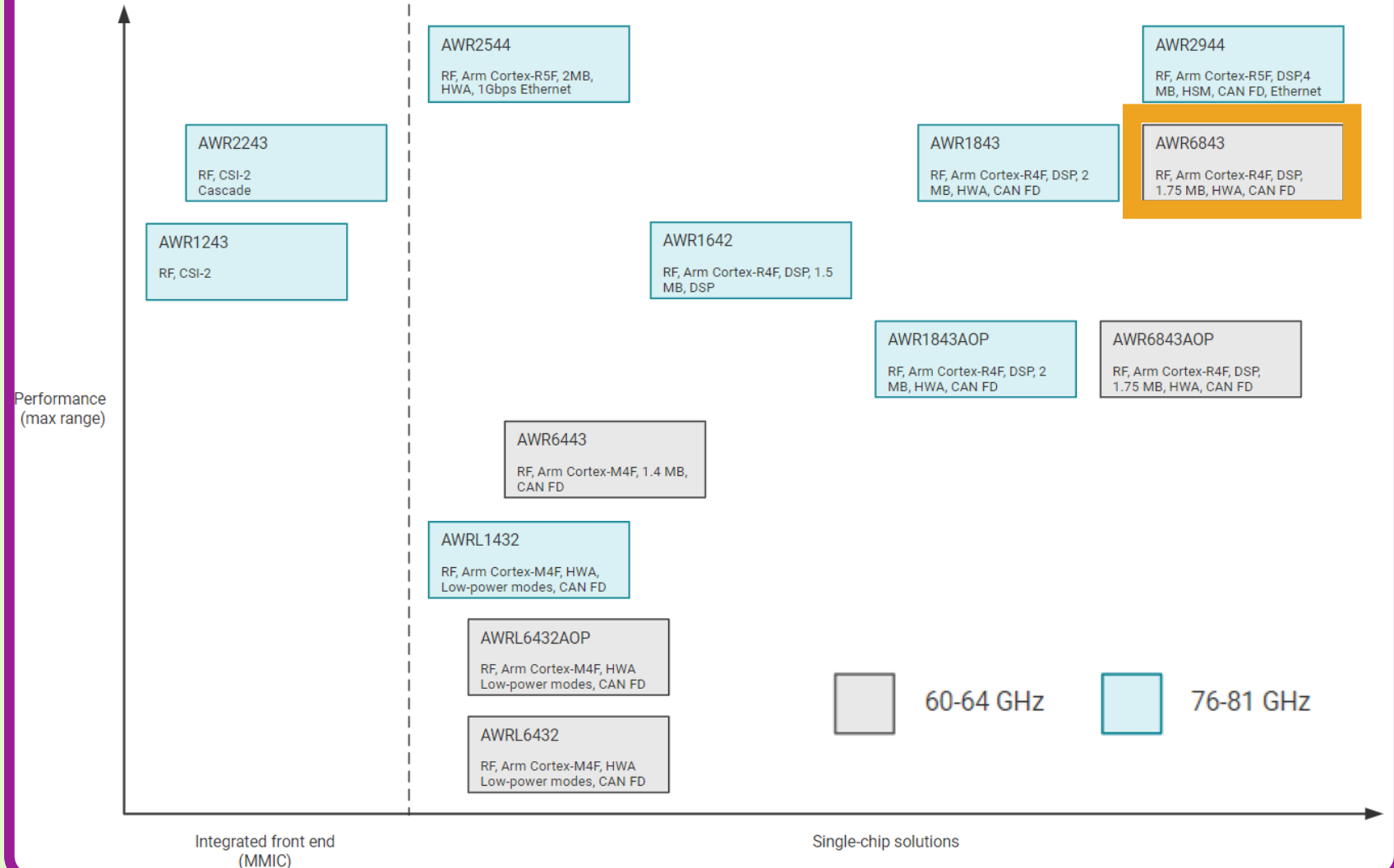
mmWave radar sensors at Texas instruments

•FMCW transceiver

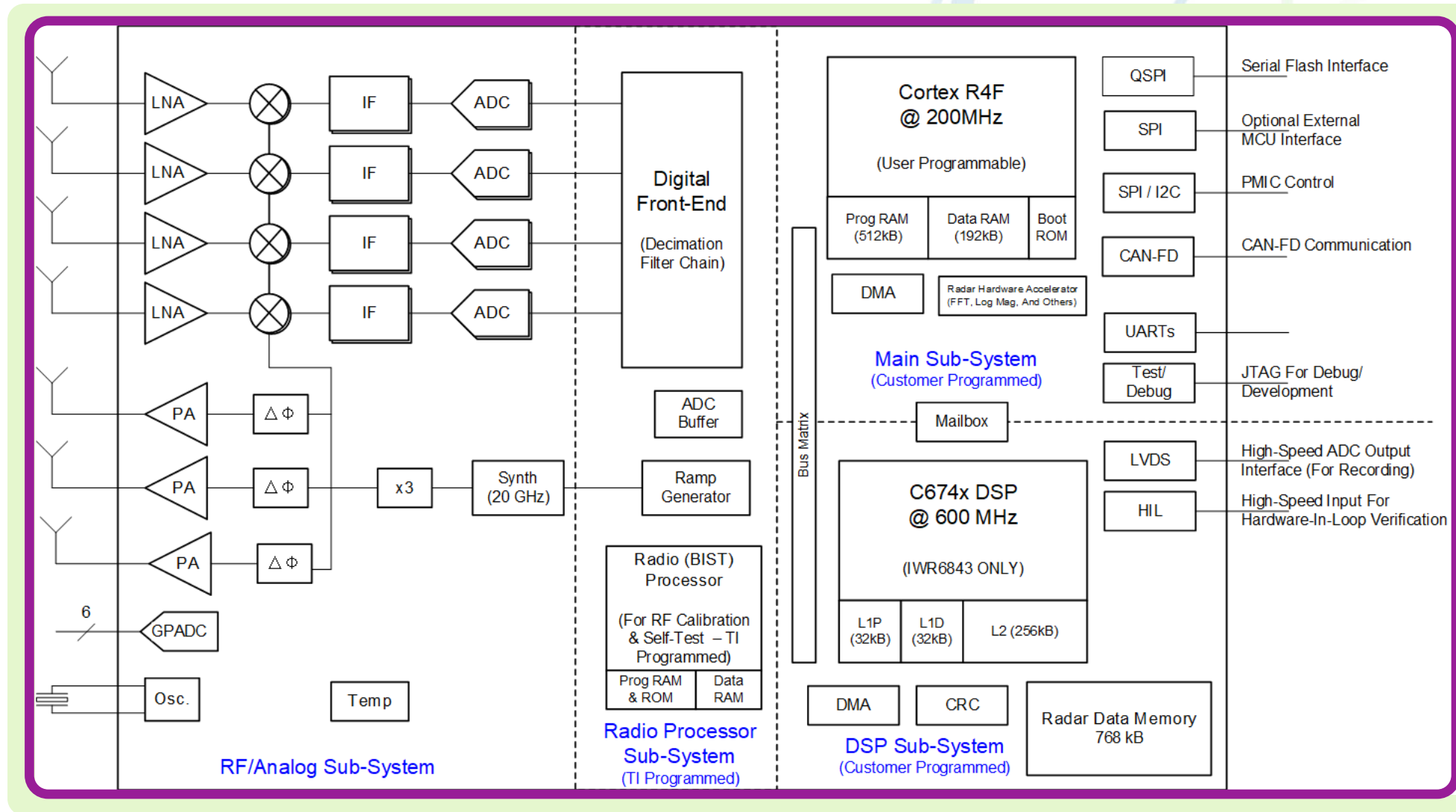
- Integrated PLL, transmitter, receiver, Baseband, and ADC
- 60- to 64-GHz coverage with 4-GHz continuous bandwidth
- Four receive channels
- Three transmit channels
- Supports 6-bit phase shifter
- Ultra-accurate chirp engine based on fractional-N PLL
- TX power: 12 dBm
- RX noise figure:
 - 12 dB
- 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

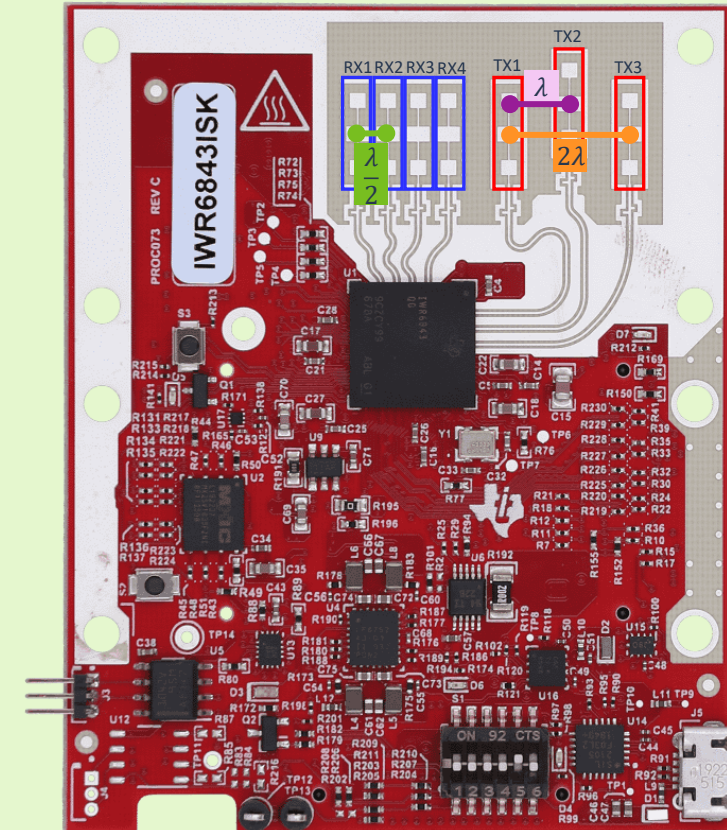


xWR6843ISK evaluation module - Texas instruments

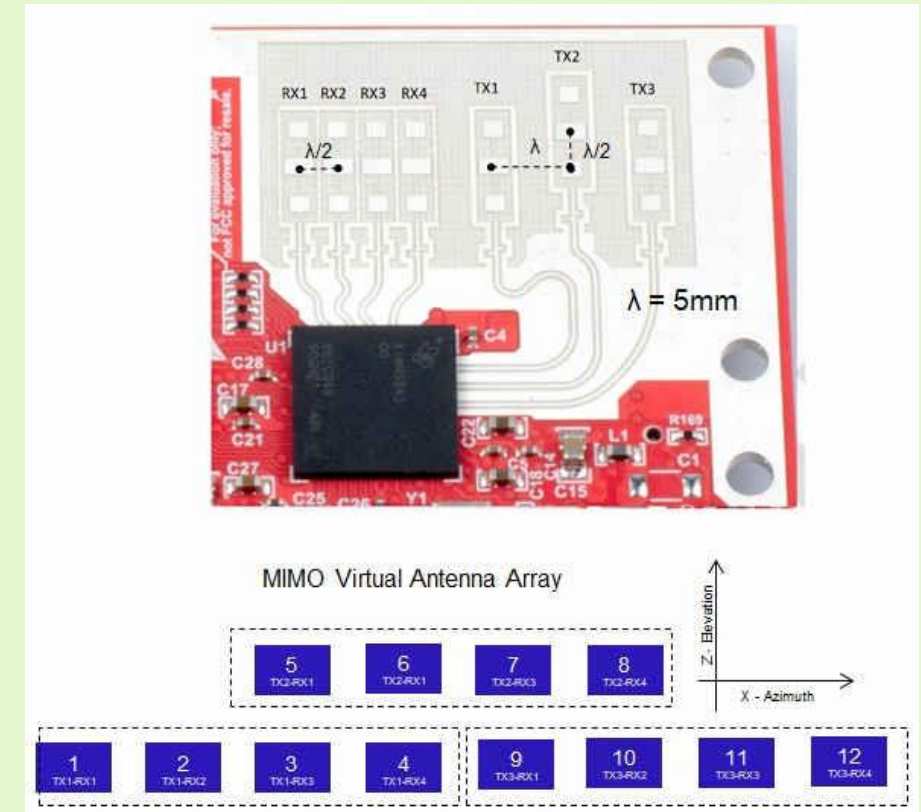
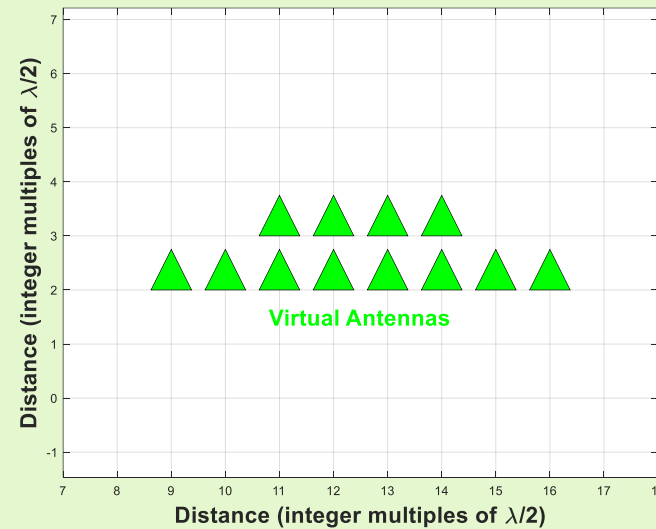
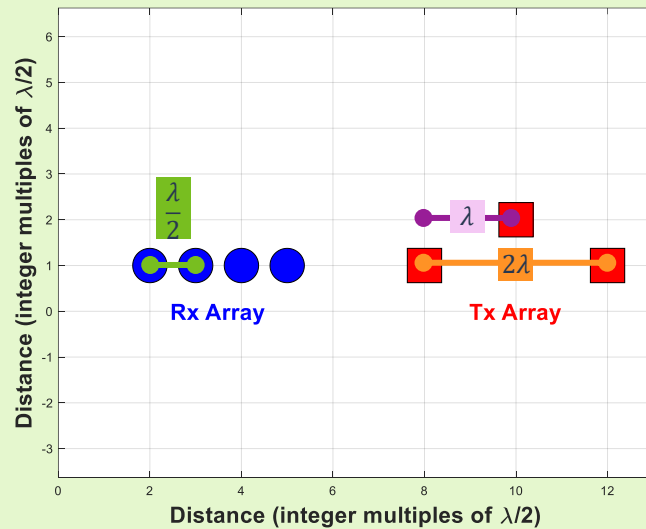


IWR6843ISK evaluation module - Texas instruments

	Integrated 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



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

Get started with running application demos on IWR6843

Explore mmWave sensor capabilities of IWR6843 by running various application demonstration examples using a PC GUI and EVM.

	<p>EVALUATION BOARD</p> <p>IWR6843ISK – IWR6843 intelligent mmWave sensor standard antenna plug-in module</p> <p>Required Why do I need this? ⓘ</p>	<div>Enter quantity</div> <div>Add to cart</div> <p>€159.73 (EUR)</p> <p>In stock</p> <p>Limit: 9</p> <p>Buy from a distributor</p>
	<p>SOFTWARE PROGRAMMING TOOL</p> <p>UNIFLASH – UniFlash for most TI microcontrollers (MCUs) and mmWave sensors</p> <p>Required if Needing additional end equipment demonstration applications. Why do I need this? ⓘ</p> <p>Supported products & hardware</p>	<div>Launch</div> <div>Download options</div>
	<p>GUI FOR EVALUATION MODULE (EVM)</p> <p>MMWAVE-SENSING-ESTIMATOR-CLOUD – mmWave sensing estimator cloud development on TI Resource Explorer</p> <p>Required Why do I need this? ⓘ</p> <p>Supported products & hardware</p>	<div>Launch</div>

MMWAVE-SENSING-ESTIMATOR-CLOUD

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

Serial Port Configuration

mmWave:User/Application Port (CLI CFG_port)	mmWave:Auxillary Data port (Demo output DATA_port)
Ports: <input type="text"/>	<input type="text"/>
Baud Rates: 115200 (recommended) <input type="text"/>	921600 (recommended) <input type="text"/>
<input type="button" value="REFRESH"/>	<input type="button" value="OK"/> <input type="button" value="CANCEL"/>

mmWave Demo Visualizer

Configure

Desirable Configuration

Best Range Resolution

Frequency Band (GHz) 60-64

Calibration Data Save/Restore None 0x1F0000

Scene Selection

Frame Rate (fps) 10

Range Resolution (m) 0.039 0.047

Maximum Unambiguous Range (m) 3.95 21.61

Maximum Radial Velocity (m/s) 0.61 9.59

Radial Velocity Resolution (m/s) 0.13 0.13

Plot Selection

☒ Scatter Plot ☐ Range Azimuth Heat Map

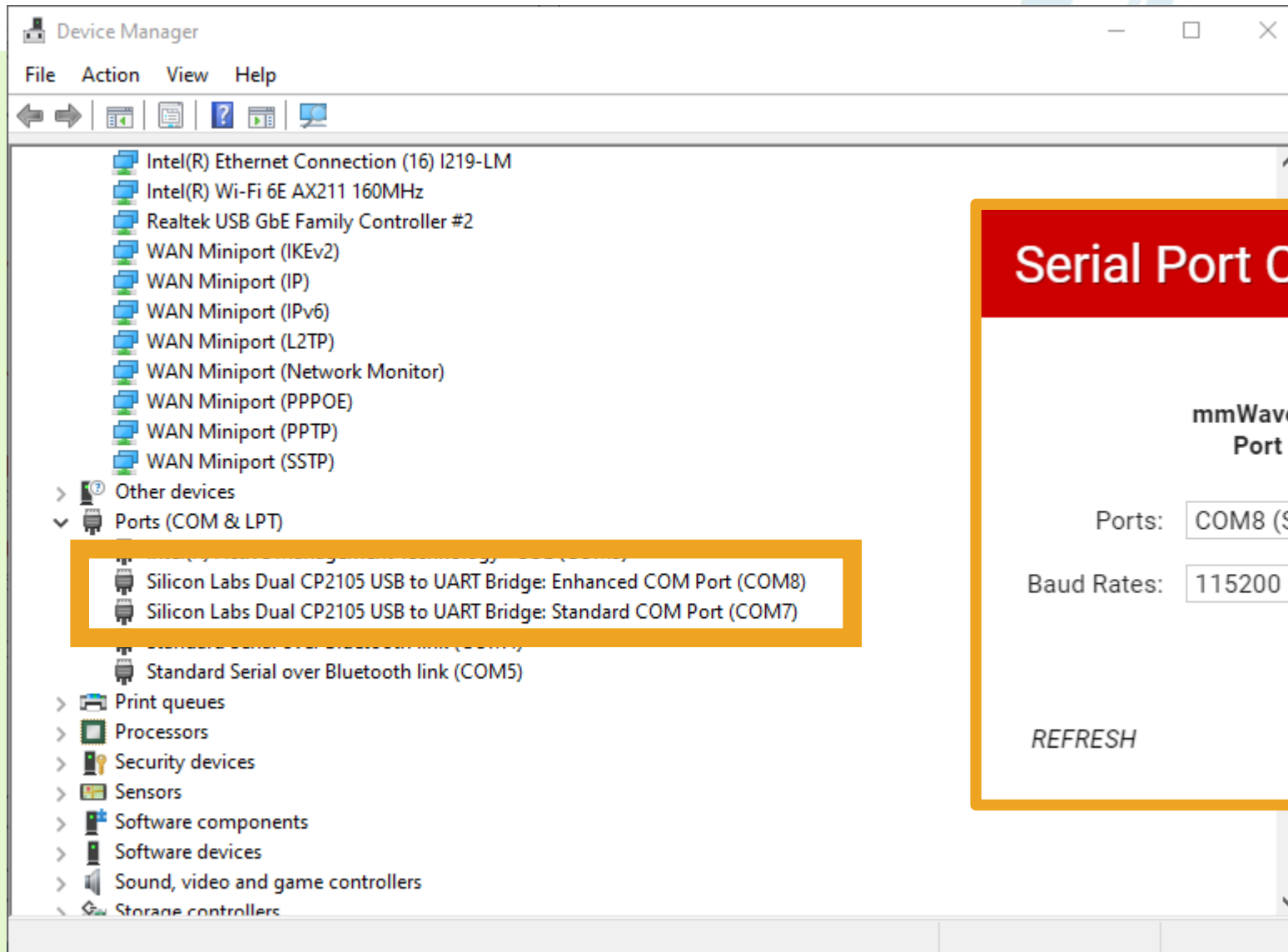
☒ Range Profile ☐ Range Doppler Heat Map

☐ Noise Profile ☒ Statistics

Console Messages

(*) For SDK 2.1 LTS release, please use this link: https://dev.ti.com/gallery/view/mmwave/mmWave_Demo_Visualizer/ver/3.6.0/

MMWAVE-SENSING-ESTIMATOR-CLOUD



Serial Port Configuration

mmWave:User/Application
Port (CLI CFG_port)

mmWave:Auxillary Data
port (Demo output
DATA_port)

Ports: COM8 (Silicon Labs) ▼

COM7 (Silicon Labs) ▼

Baud Rates: 115200 (recommended) ▼

921600 (recommended) ▼

REFRESH

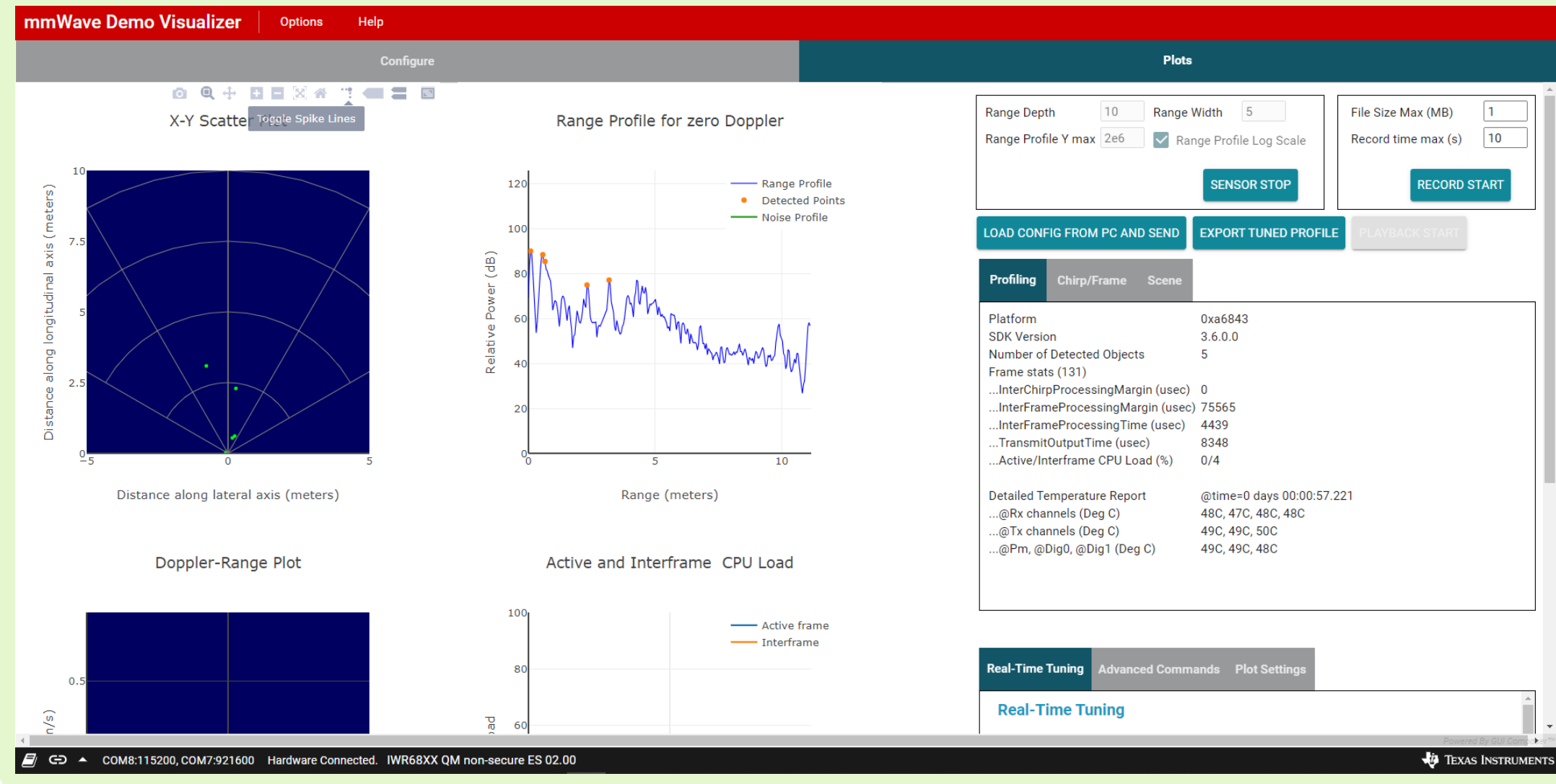
OK

CANCEL

Angle estimation with MMWAVE-SENSING-ESTIMATOR-CLOUD

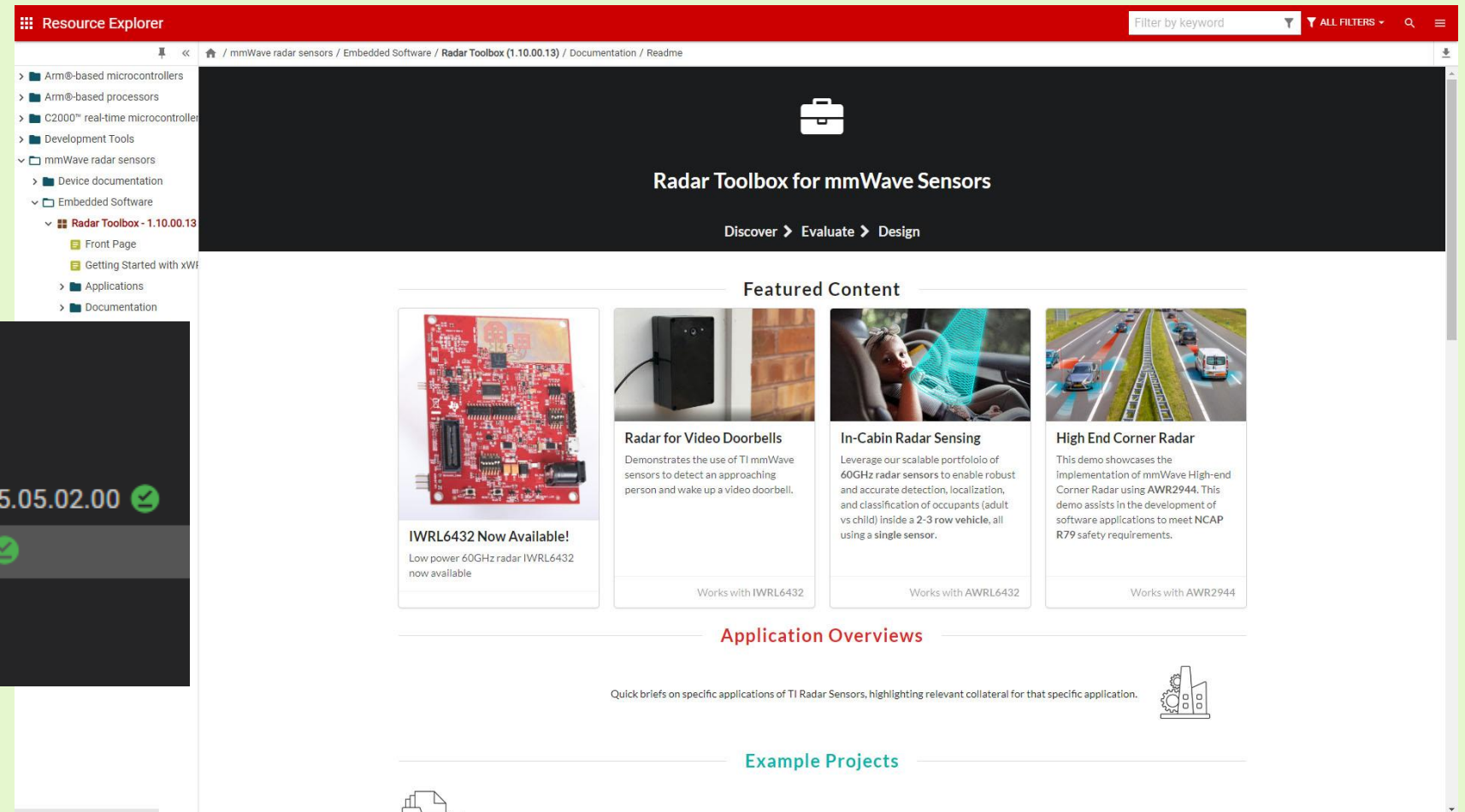
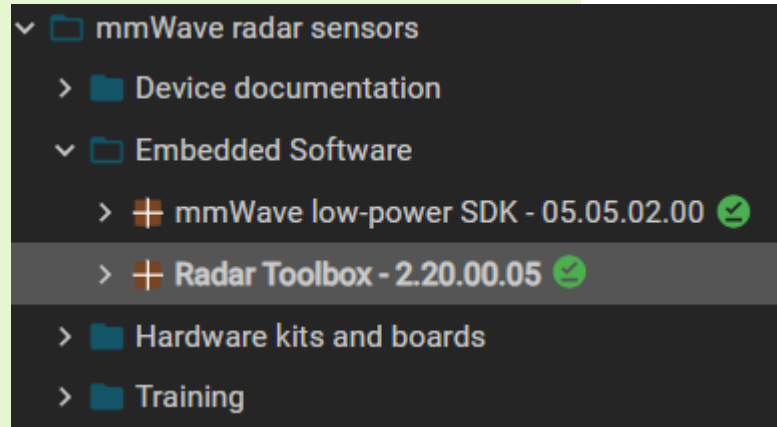


https://dev.ti.com/gallery/view/mmwave/mmWave_Demo_Visualizer/ver/3.6.0/



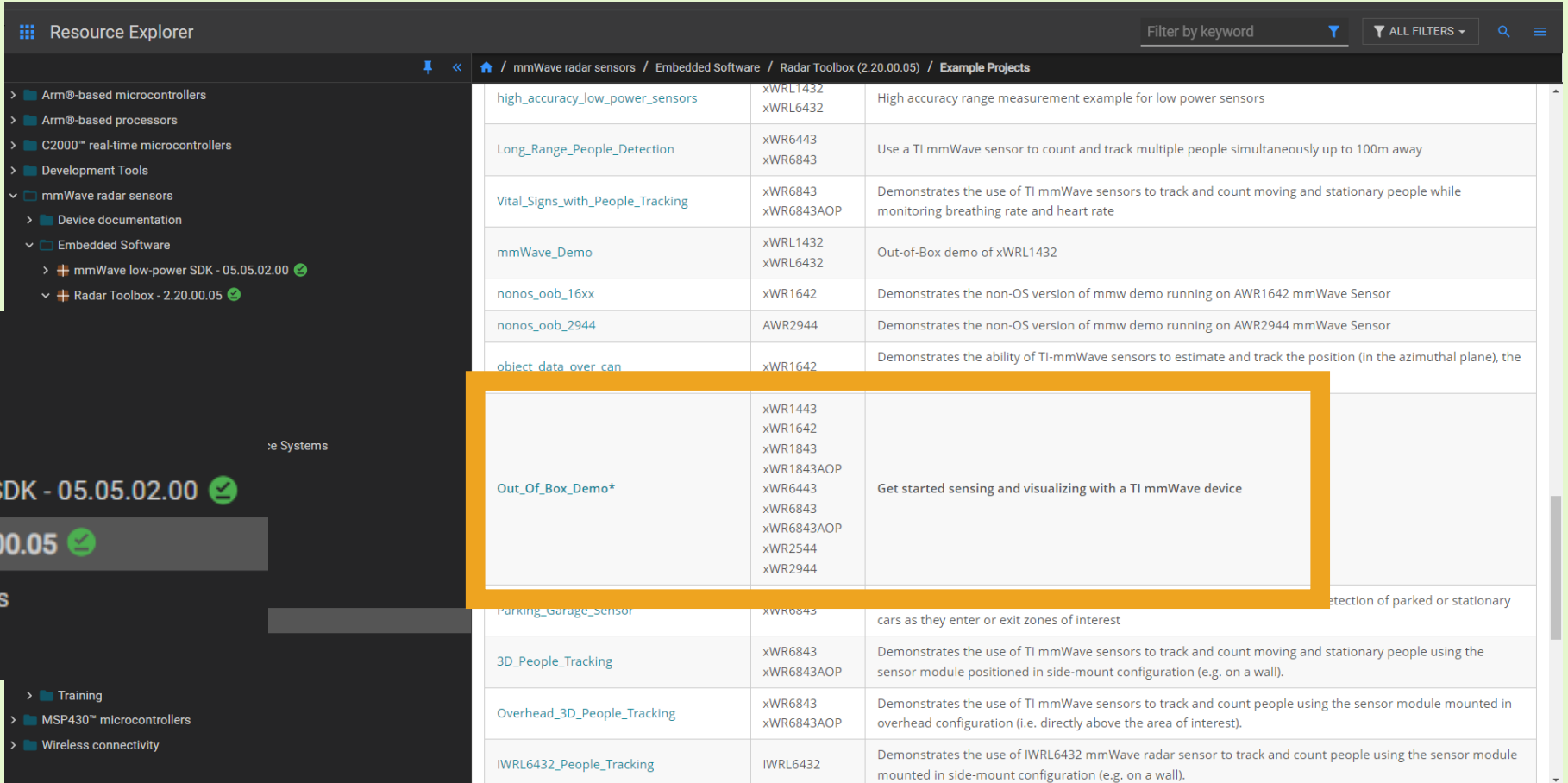
TI Resource Explorer – Radar Toolbox

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



TI Resource Explorer – Radar Toolbox

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



Resource Explorer

Filter by keyword ALL FILTERS

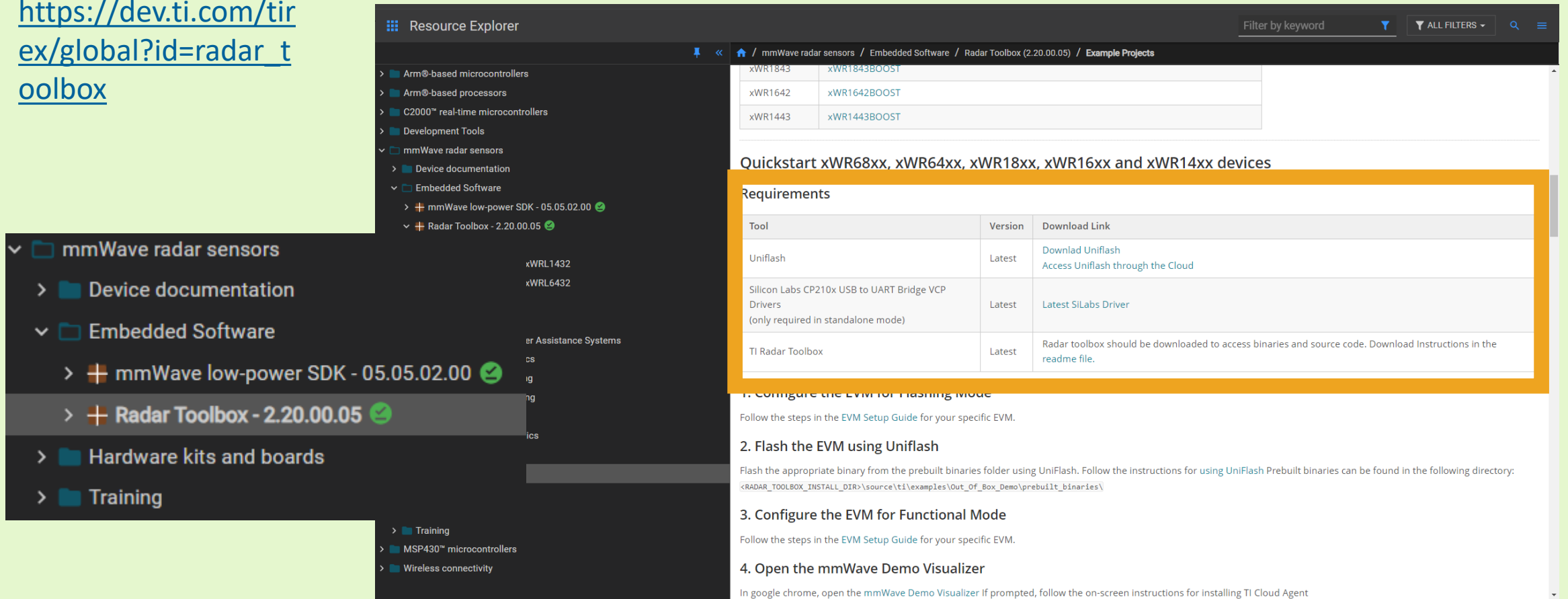
mmWave radar sensors / Embedded Software / Radar Toolbox (2.20.00.05) / Example Projects

- Arm®-based microcontrollers
- Arm®-based processors
- C2000™ real-time microcontrollers
- Development Tools
- mmWave radar sensors
 - Device documentation
 - Embedded Software
 - mmWave low-power SDK - 05.05.02.00
 - Radar Toolbox - 2.20.00.05**
- Hardware kits and boards
- Training

high_accuracy_low_power_sensors	xWRL1432 xWRL6432	High accuracy range measurement example for low power sensors
Long_Range_People_Detection	xWR6443 xWR6843	Use a TI mmWave sensor to count and track multiple people simultaneously up to 100m away
Vital_Signs_with_People_Tracking	xWR6843 xWR6843AOP	Demonstrates the use of TI mmWave sensors to track and count moving and stationary people while monitoring breathing rate and heart rate
mmWave_Demo	xWRL1432 xWRL6432	Out-of-Box demo of xWRL1432
nonos_oob_16xx	xWR1642	Demonstrates the non-OS version of mmw demo running on AWR1642 mmWave Sensor
nonos_oob_2944	AWR2944	Demonstrates the non-OS version of mmw demo running on AWR2944 mmWave Sensor
object_data_over_can	xWR1642	Demonstrates the ability of TI-mmWave sensors to estimate and track the position (in the azimuthal plane), the
Out_Of_Box_Demo*	xWR1443 xWR1642 xWR1843 xWR1843AOP xWR6443 xWR6843 xWR6843AOP xWR2544 xWR2944	Get started sensing and visualizing with a TI mmWave device
Parking_Garage_Sensor	xWR6843	Demonstrates the use of TI mmWave sensors to detect and track the position of parked or stationary cars as they enter or exit zones of interest
3D_People_Tracking	xWR6843 xWR6843AOP	Demonstrates the use of TI mmWave sensors to track and count moving and stationary people using the sensor module positioned in side-mount configuration (e.g. on a wall).
Overhead_3D_People_Tracking	xWR6843 xWR6843AOP	Demonstrates the use of TI mmWave sensors to track and count people using the sensor module mounted in overhead configuration (i.e. directly above the area of interest).
IWRL6432_People_Tracking	IWRL6432	Demonstrates the use of IWRL6432 mmWave radar sensor to track and count people using the sensor module mounted in side-mount configuration (e.g. on a wall).

TI Resource Explorer – Radar Toolbox

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



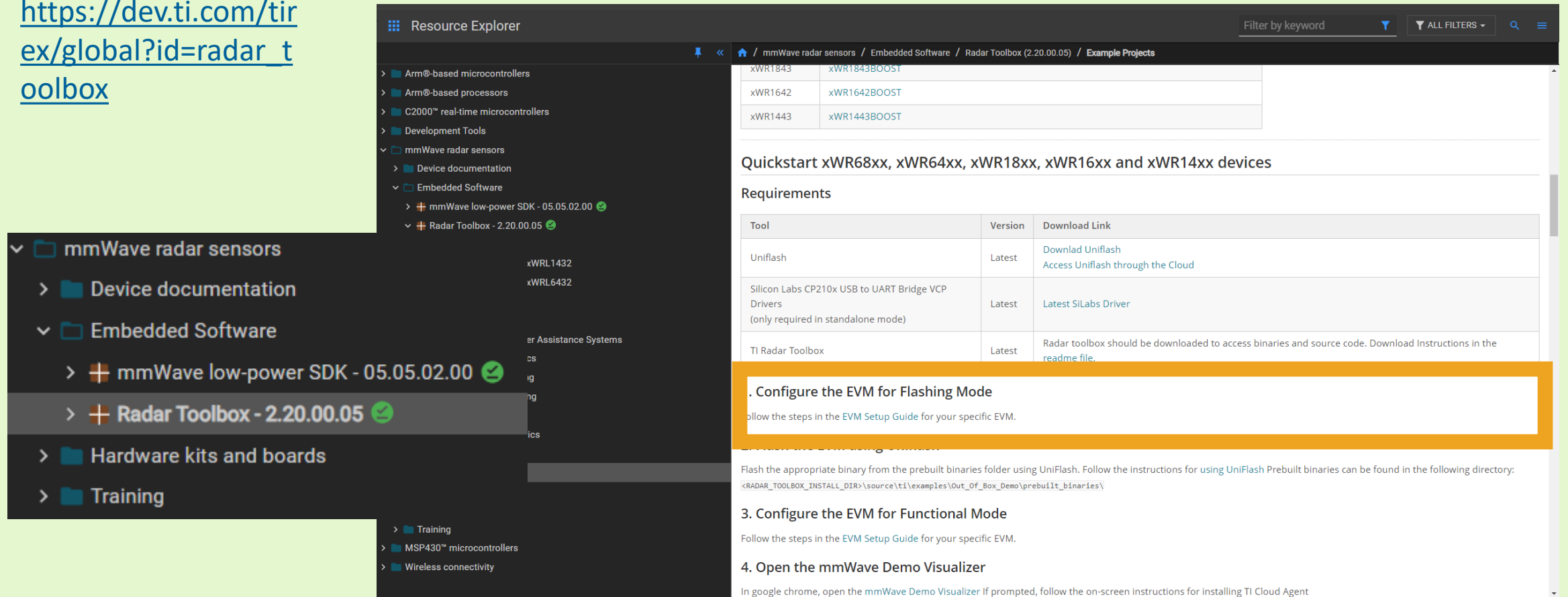
The screenshot displays the TI Resource Explorer interface. On the left, a sidebar shows a tree view of resources, with 'mmWave radar sensors' expanded. Under 'Embedded Software', 'Radar Toolbox - 2.20.00.05' is selected. The main content area shows the 'Quickstart' page for xWR68xx, xWR64xx, xWR18xx, xWR16xx, and xWR14xx devices. A table lists requirements for the toolbox, and a list of steps guides the user through EVM configuration and flashing.

Tool	Version	Download Link
Uniflash	Latest	Download Uniflash Access Uniflash through the Cloud
Silicon Labs CP210x USB to UART Bridge VCP Drivers (only required in standalone mode)	Latest	Latest SiLabs Driver
TI Radar Toolbox	Latest	Radar toolbox should be downloaded to access binaries and source code. Download Instructions in the readme file .

1. Configure the EVM for Flashing Mode
Follow the steps in the EVM Setup Guide for your specific EVM.
2. Flash the EVM using Uniflash
Flash the appropriate binary from the prebuilt binaries folder using UniFlash. Follow the instructions for using UniFlash Prebuilt binaries can be found in the following directory:
<RADAR_TOOLBOX_INSTALL_DIR>\source\ti\examples\Out_Of_Box_Demo\prebuilt_binaries\
3. Configure the EVM for Functional Mode
Follow the steps in the EVM Setup Guide for your specific EVM.
4. Open the mmWave Demo Visualizer
In google chrome, open the [mmWave Demo Visualizer](#) If prompted, follow the on-screen instructions for installing TI Cloud Agent

Configure sensor to the Flash mode

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



The screenshot displays the TI Resource Explorer interface. On the left, the 'Resource Explorer' sidebar shows the navigation tree with 'mmWave radar sensors' expanded, leading to 'Embedded Software' and then 'Radar Toolbox - 2.20.00.05'. The main content area shows the 'Quickstart xWR68xx, xWR64xx, xWR18xx, xWR16xx and xWR14xx devices' page. This page includes a 'Requirements' table and a section titled '2. Configure the EVM for Flashing Mode' which is highlighted with an orange border.

Tool	Version	Download Link
Uniflash	Latest	Download Uniflash Access Uniflash through the Cloud
Silicon Labs CP210x USB to UART Bridge VCP Drivers (only required in standalone mode)	Latest	Latest SiLabs Driver
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<RADAR_TOOLBOX_INSTALL_DIR>\source\ti\examples\Out_Of_Box_Demo\prebuilt_binaries\

3. Configure the EVM for Functional Mode

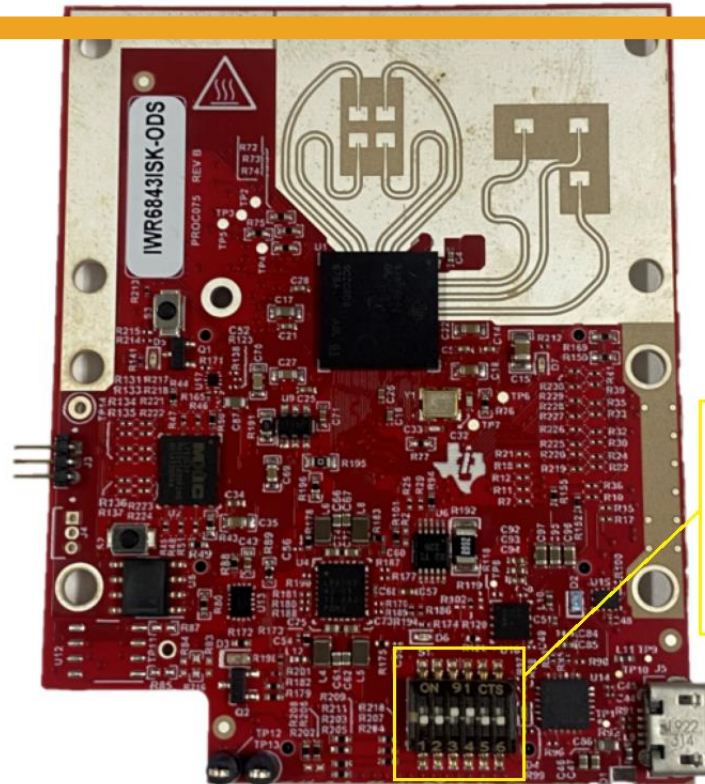
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4. Open the mmWave Demo Visualizer

In google chrome, open the [mmWave Demo Visualizer](#) If prompted, follow the on-screen instructions for installing TI Cloud Agent

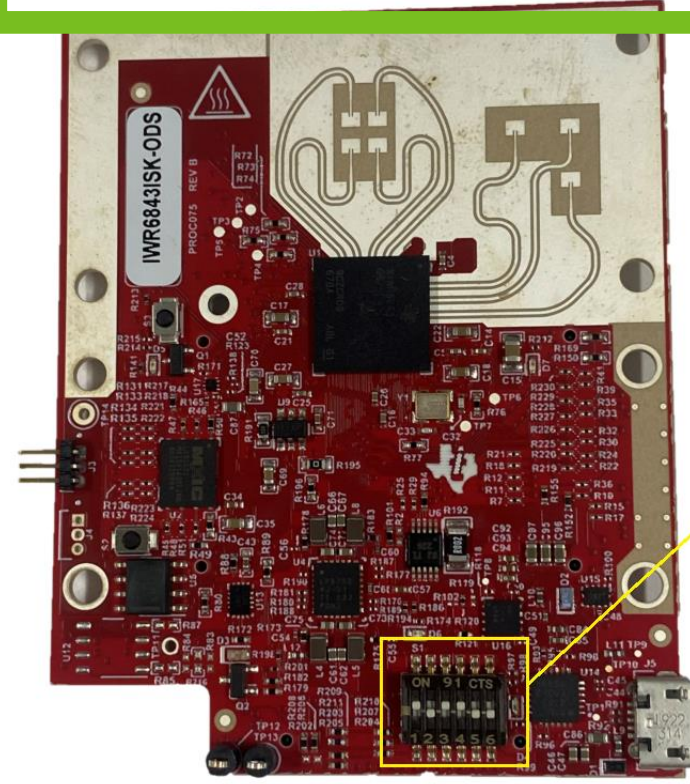
Configure sensor to the Flash mode

Functional Mode



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

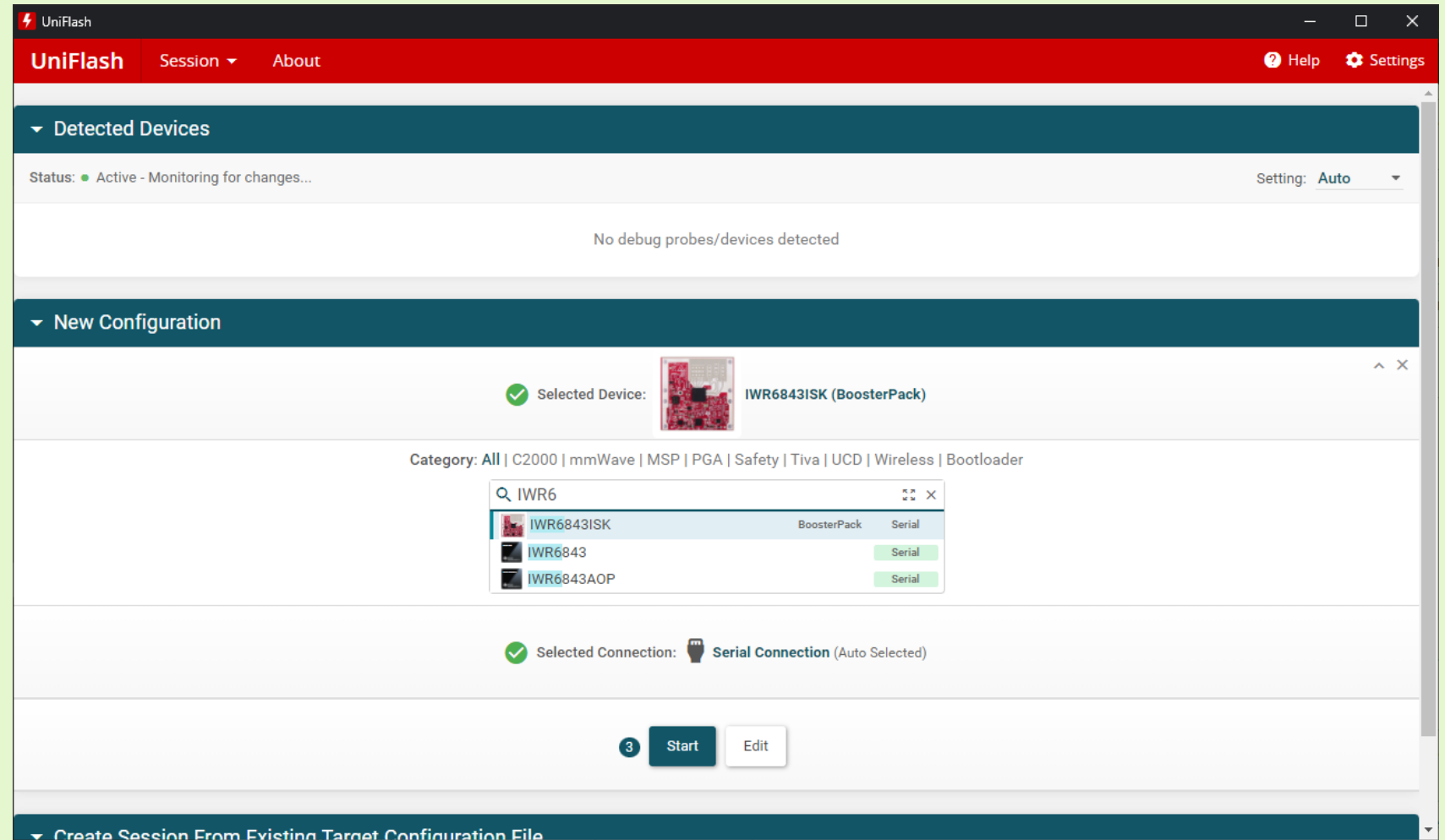
Flash Mode



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

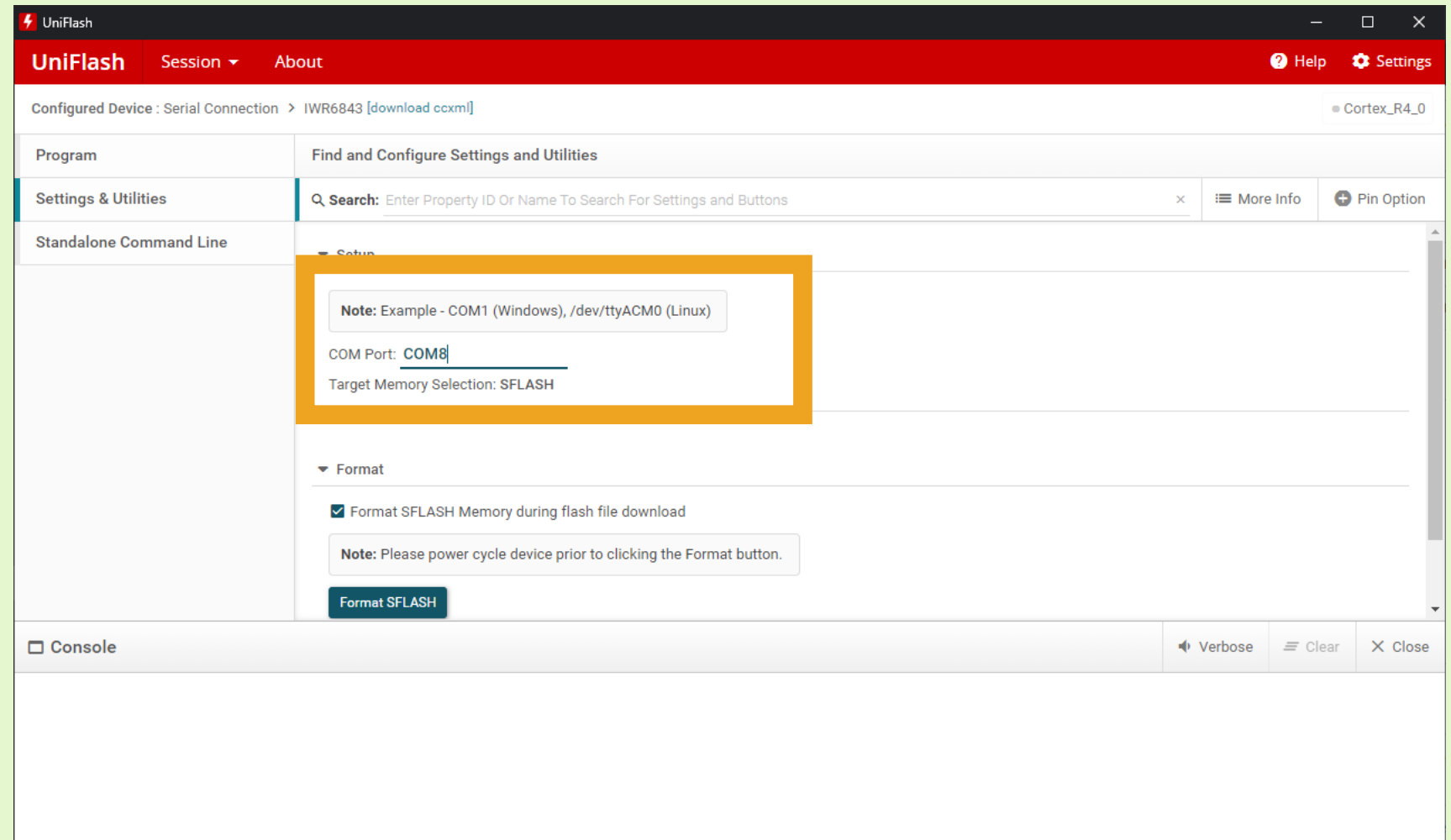
Programming the binary

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



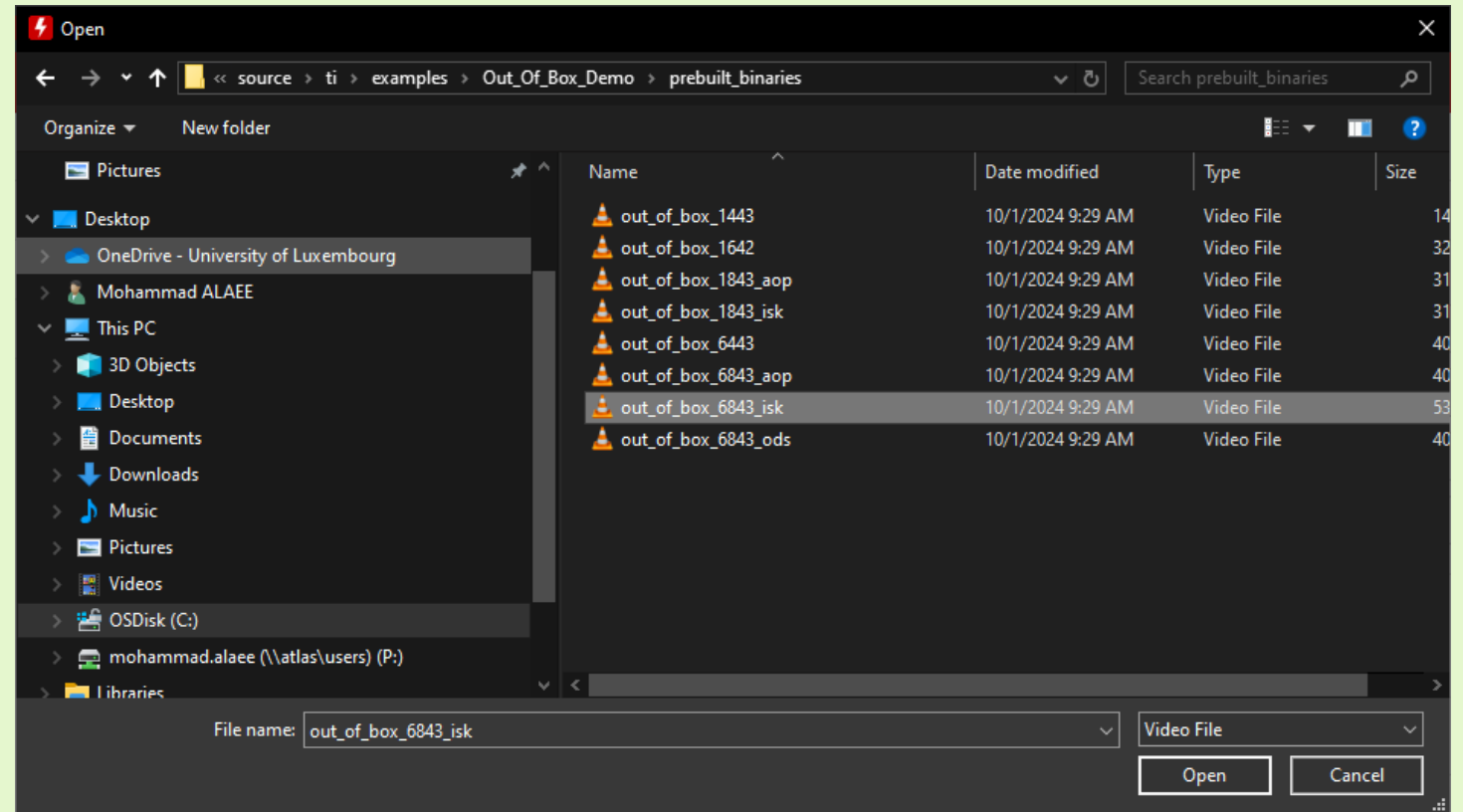
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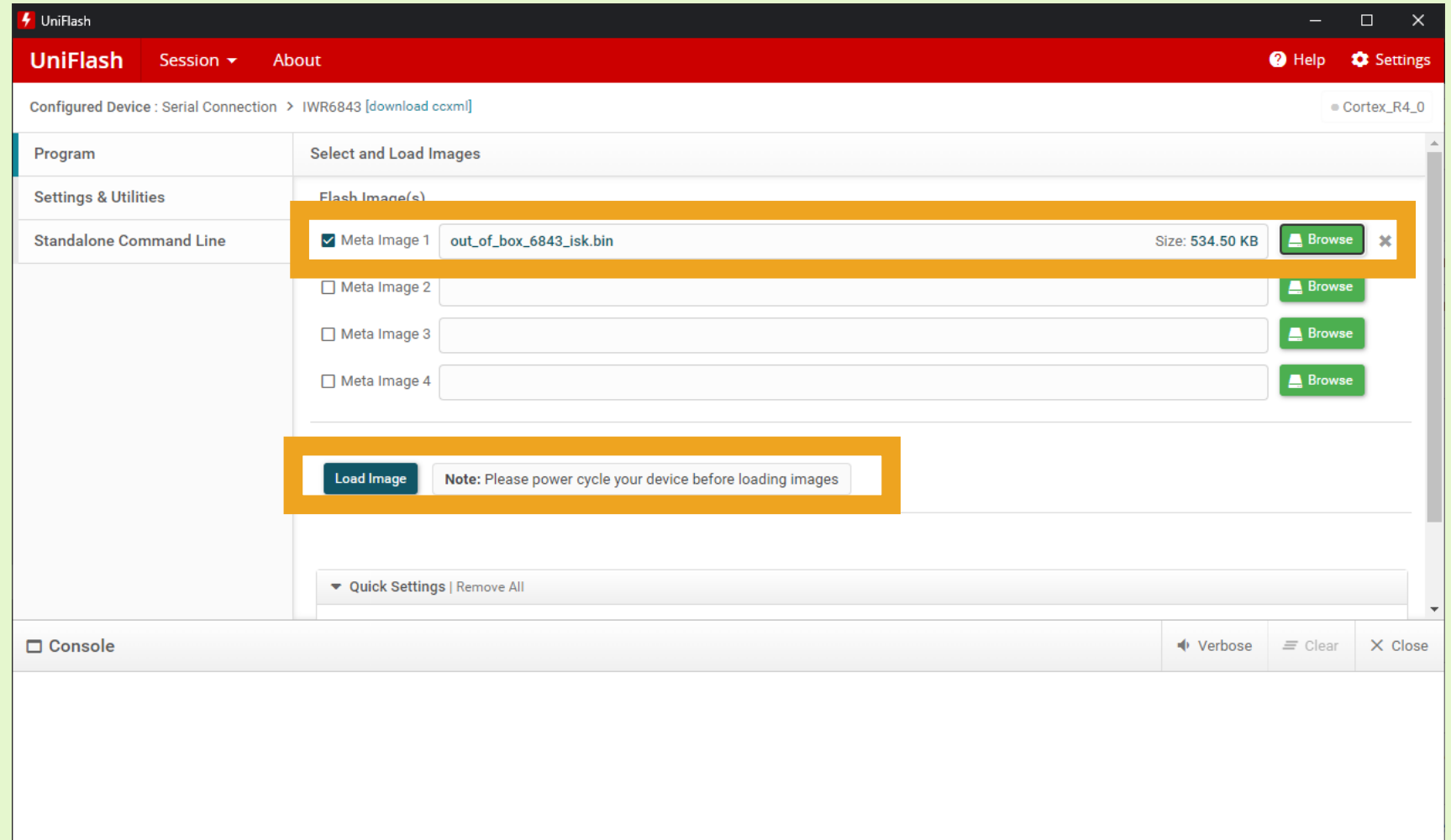
Programming the binary

C:\ti\radar_toolbox_2_20_0
0_05\source\ti\examples\Ou
t_Of_Box_Demo\prebuilt_bi
naries



Programming the binary

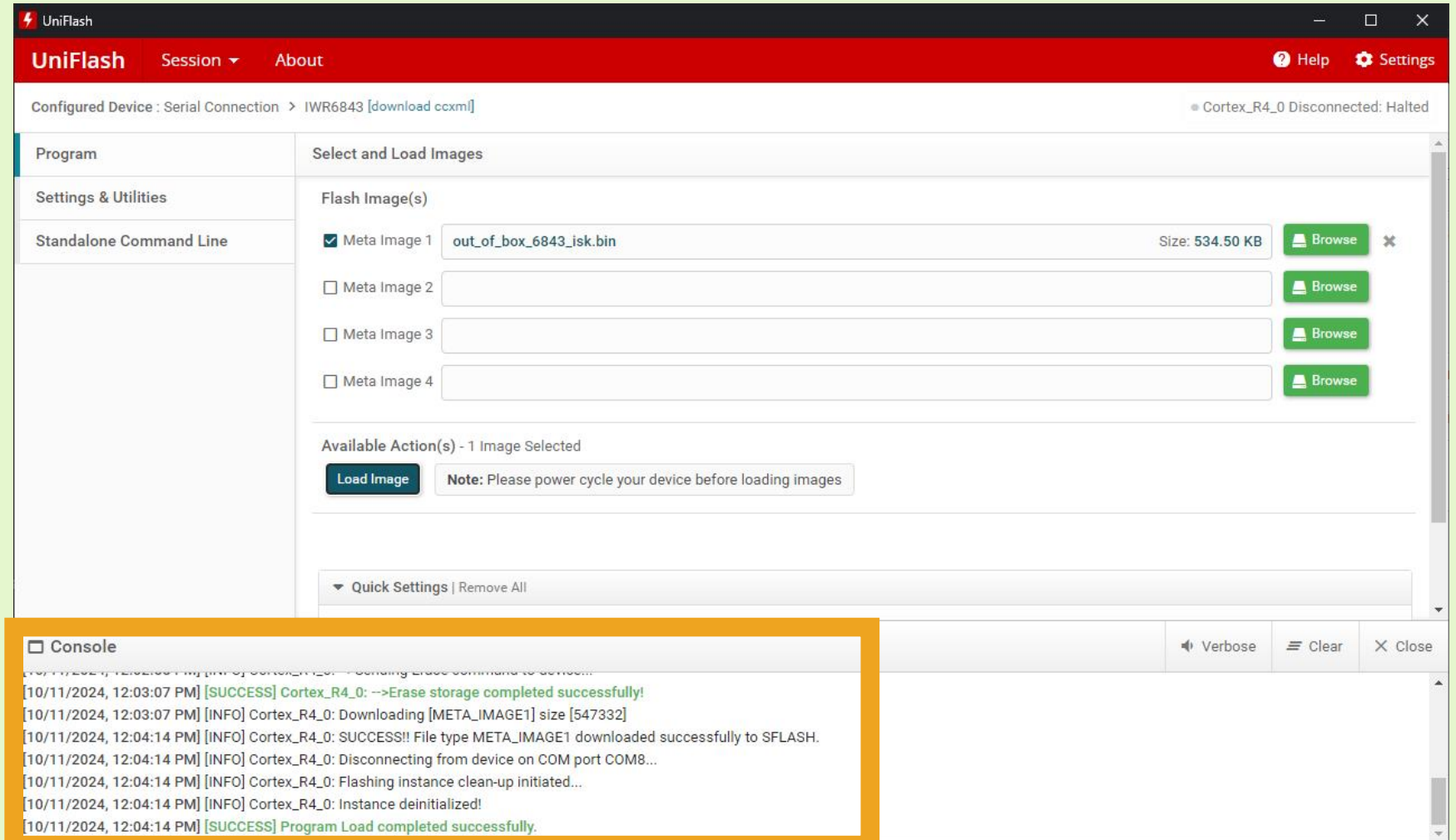
UNIFLASH – UniFlash
for most TI
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sensors



Programming the binary

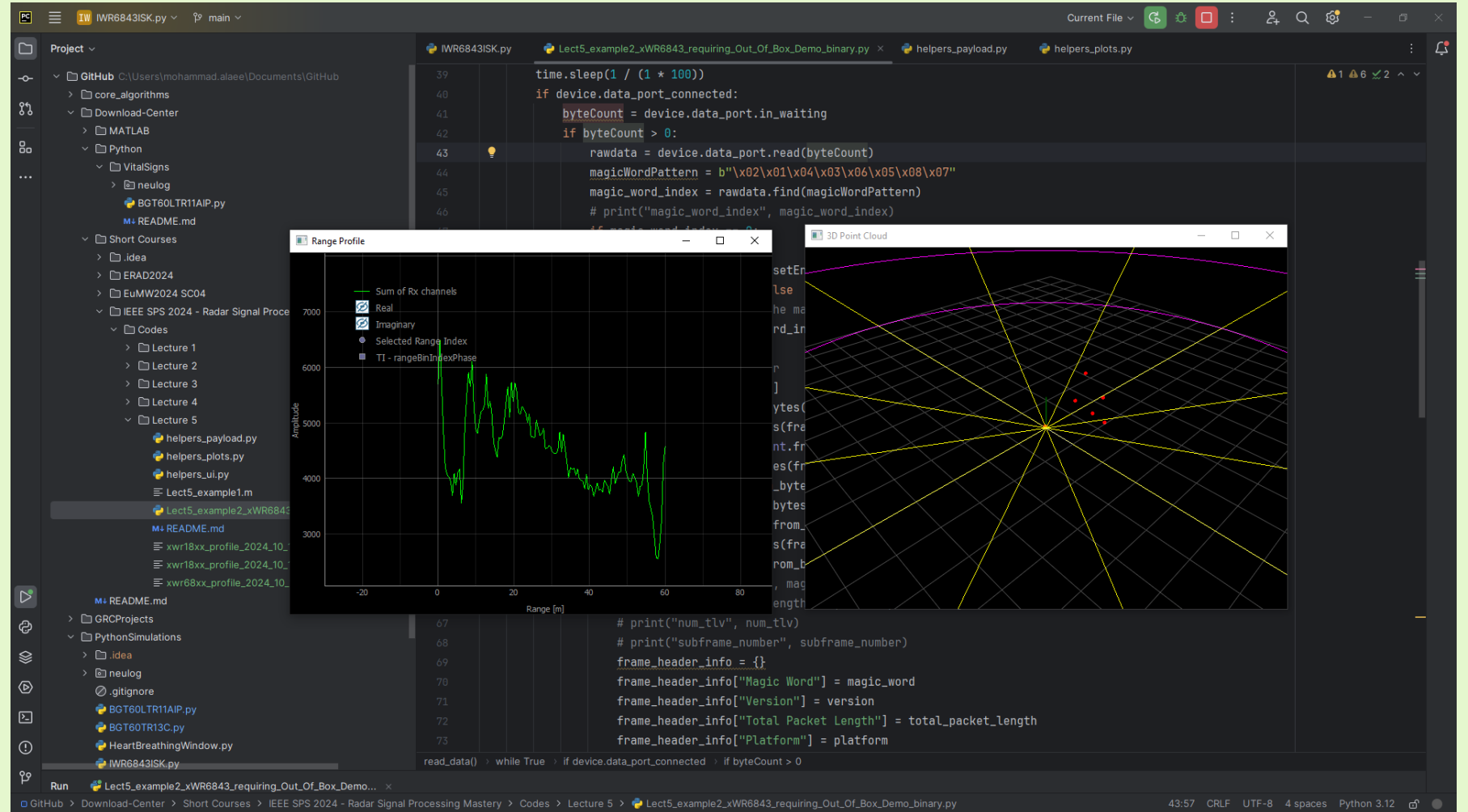
UNIFLASH – UniFlash
for most TI
microcontrollers
(MCUs) and mmWave
sensors

Unplug sensor, and set
it back to the
functional mode



Self programming with xWR6843, xWR1843, xWR1642, xWR1443

Lect5_example2_xWR6843_requiring_Out_Of_Box_Demo_binary.py



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