UNIVERSITY OF BIRMINGHAM

Cognitive Real-Time System for Autonomous Vehicles

(104268-CORTEX)

Data Repository Description

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Date: TBD

1 Introduction

This report describes the data that has been collected by the University of Birmingham and is stored in the Repository along with this document.

Along with this document the following document should also be read, explaining the structure of the collected data files

- Data Structure Description (Document Number 104268 – UoBDataStruct1)

2 Data Scenarios

2.1 Sidelobe Measurements with Corner Reflector

2.1.1 Description

Date	21-11-19
Location	University of Birmingham, Munrow Carpark
Purpose	To measure sidelobe performance of NXP radar and Inras radar

This measurement is intended to serve as a reference measurement to evaluate the beamforming performance of the NXP Dolphin and Inras Radarbook sensors, principally the azimuth beamwidth and sidelobe level. Sidelobe levels are of particular concern due to their performance limitation which results from the effective one-way propagation inherent to MIMO operation.

For this measurement a corner cube was placed in a carpark at various angles with respect to the radar position, at a slant range of about 5m. The setup of the radars is shown in Figure 1, and the scene with the corner reflector is shown in Figure 2

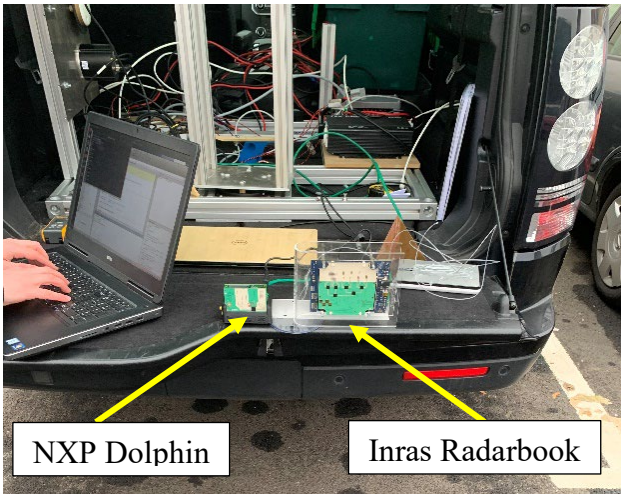

Figure 1: Picture of radar setup at back of Land Rover during data collection for side-lobe measurements

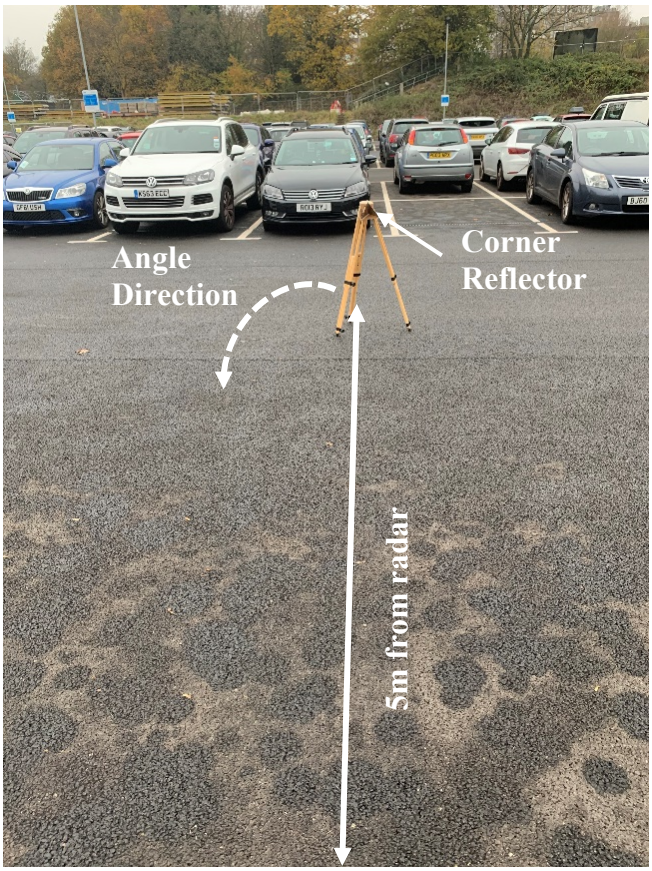

Figure 2: Picture of scene during data collection for side-lobe measurements with corner reflector

2.1.2 Operating Parameters

2.1.2.1 Inras Radarbook Specific

The Inras Radarbook, with four transmit elements at 3.5λ spacing and eight receive elements at $\lambda/2$ spacing, was configured in MIMO mode. The active transmitters cycle from chirp-to-chirp in the order: TX1-TX2-TX3-TX4. With four transmit elements and eight receive elements the Radarbook would produce a virtual array of 32-elements, but the spatial configuration of the antennas on the Radarbook, would give three overlapping virtual elements. Removing these overlapping elements would emulate an equivalent of a 29-element $\lambda/2$ spaced antenna array (one-way only). Removal of the overlapping elements is usually done before MIMO processing of the radar signals from the Radarbook.

The operating parameters used for the Radarbook, in this scenario, are given in Table 1. These have been determined to give the optimal range resolution, and negligible data transfer loss to the computer, available from the Inras Radarbook. The mapping of the settings, given by the symbol in the Table 1, to the transmit timing of the radarbook is shown in Figure 3.

Table 1: Settings for the Inras radarbook for the side-lobe measurements.

Parameter	Symbol	Value	Unit
Radarbook Setting			
Centre Frequency	f_{centre}	77	GHz
Bandwidth	f_{BW}	2.0	GHz
Number of samples recieved	$n_{samples}$	2048	
Chirp Ramp-Up time	$TrampUp$	204.8	us
Chirp Ramp-Down time	$TrampDo$	10	us
Chirp interval time	Tp	250	us
MIMO interval time (Effective MIMO PRI)	$TInt$	10	ms
Resulting Performance			
Range Resolution	R_{res}	7.5	cm
Maximum unambiguous range[1]	R_{unamb}	76.8	m
Doppler Resolution	$v_{DoppRes}$	1.95	ms^{-1}
Maximum unambiguous range	v_{unamb}	0.1	ms^{-1}
Note 1: Due to the low-pass anti-aliasing filter, with a cut-off of 3.25MHz, within the radarbook, the effective maximum unambiguous range is 49.9m.			

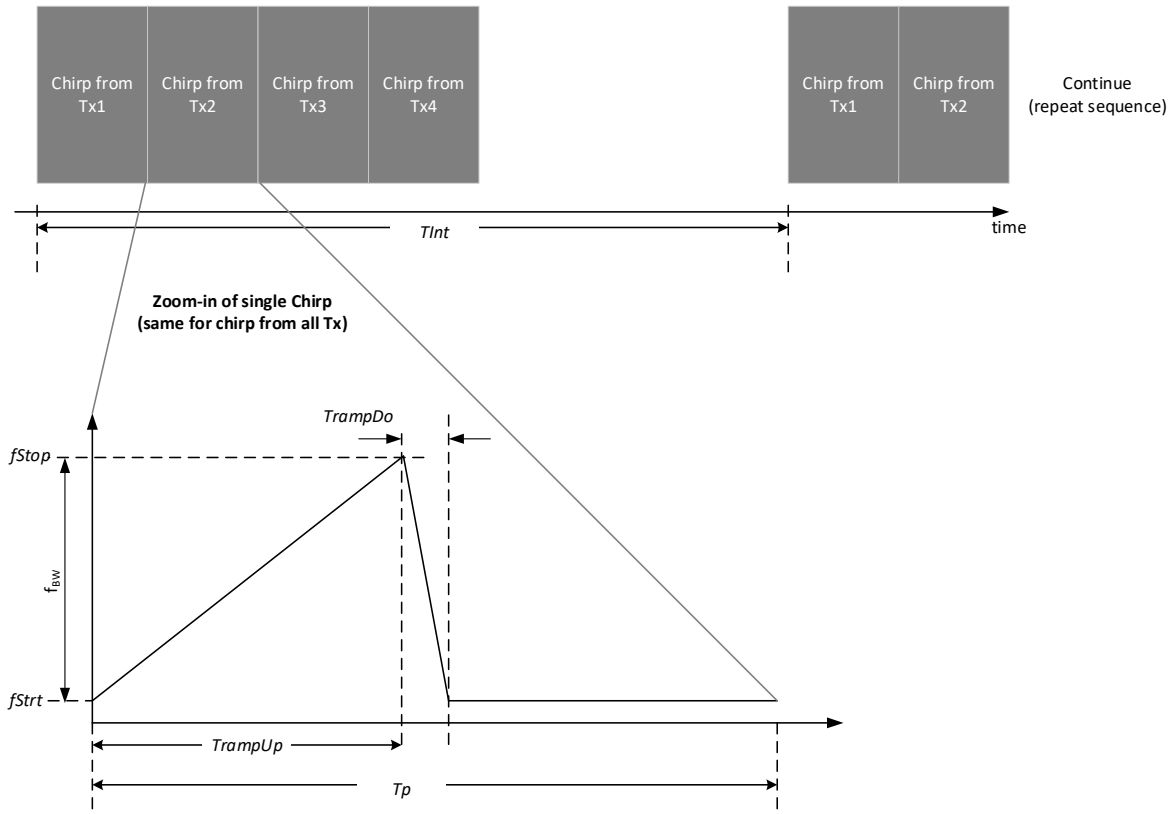

Figure 3: MIMO timing and settings of Inras radarbook.

2.1.2.2 NXP Dolphin Specific

The NXP Dolphin was configured in TD-MIMO mode. The active transmitter, each separated by 2λ, cycles from chirp-to-chirp: TX1-TX2-TX3. There are four receive elements with λ/2 spacing. Therefore, this mode provides a twelve element λ/2 spaced receive array. For clarity, parameters will be defined as follows:

- **Chirp duration:** active duration of chirp during which time data is recorded
- **Pulse repetition interval (PRI):** time from the start of one chirp until the start of the next chirp (i.e. includes both active and non-active period). This interval determines maximum unambiguous Doppler value.
- **Chirps per Doppler interval:** number of individual chirps which are incorporated into a single coherent Doppler processing interval. This is equal to the number of Doppler bins after Doppler DFT.
- **Doppler processing interval:** active period during which a number of chirps are gathered. This interval determines Doppler resolution.
- **Doppler repetition interval:** time from the start of one Doppler interval to the start of the next Doppler interval. This includes both the Doppler Processing interval itself, and an inactive period between each Doppler interval during which data is still being transferred to the computer.
- **Doppler overlap factor:** Ratio between the Doppler processing interval and the Doppler repetition interval.

Operating parameters used for measurement are as follows:

Table 2: Settings for the NXP Dolphin for the side-lobe measurements.

Parameter	Value	Units
Bandwidth	2.0	GHz
Chirp duration	25.6	µs
PRI	86.6	µs
Chirps per Doppler interval	126	-
Doppler processing interval	10.9	ms
Doppler repetition interval	16	ms
Doppler overlap factor	0.68	-
Range resolution	7.5	cm
Max unambiguous range	19.2	m
Velocity resolution	0.174	ms^{-1}
Max unambiguous velocity (RX-BF)	±3.7	ms^{-1}

2.1.3 Data Files

The following are the data files for this scenario

- Scene with no corner reflector
  - Inras: //cornerReflector_None_MIMOmode_21-11-2019/data_Inras_MimoMode.mat
  - NXP: //cc_measurements_td-mimo/cc_bg.mat
- Scene with corner reflector at 0deg
  - Inras: // cornerReflector_0deg_MIMOmode_21-11-2019/data_Inras_MimoMode.mat
  - NXP: //cc_measurements_td-mimo/cc_0deg.mat
- Scene with corner reflector at 15deg
  - Inras: // cornerReflector_15deg_MIMOmode_21-11-2019/data_Inras_MimoMode.mat
  - NXP: //cc_measurements_td-mimo/cc_15deg.mat
- Scene with corner reflector at 30deg
  - Inras: // cornerReflector_30deg_MIMOmode_21-11-2019/data_Inras_MimoMode.mat
  - NXP: //cc_measurements_td-mimo/cc_30deg.mat
- Scene with corner reflector at 45deg
  - Inras: // cornerReflector_45deg_MIMOmode_21-11-2019/data_Inras_MimoMode.mat
  - NXP: //cc_measurements_td-mimo/cc_45deg.mat

2.2 Inras MIMO Measurements for MTI in Carpark

2.2.1 Description

Date	21-11-19
Location	University of Birmingham, Munrow Carpark
Purpose	To make measurements for MTI with Inras radar in MIMO mode

The use of the MIMO mode in the Inras radarbook has a very low unambiguous Doppler, due to the larger repetition interval required for its MIMO sequences, as each transmitter, of a MIMO frame, pulses consecutively in time. So, identification of moving targets, and their speed, is not possible via Doppler processing. Another method to identify moving targets, and their speed, is via moving target indicator (MTI). This measurement uses the Inras radarbook in its MIMO mode of operation to view a pedestrian moving up-and-down a cluttered carpark scene, which will then be processed using MTI.

For this measurement a person was walking up and down a carpark within the scene shown in Figure 4.

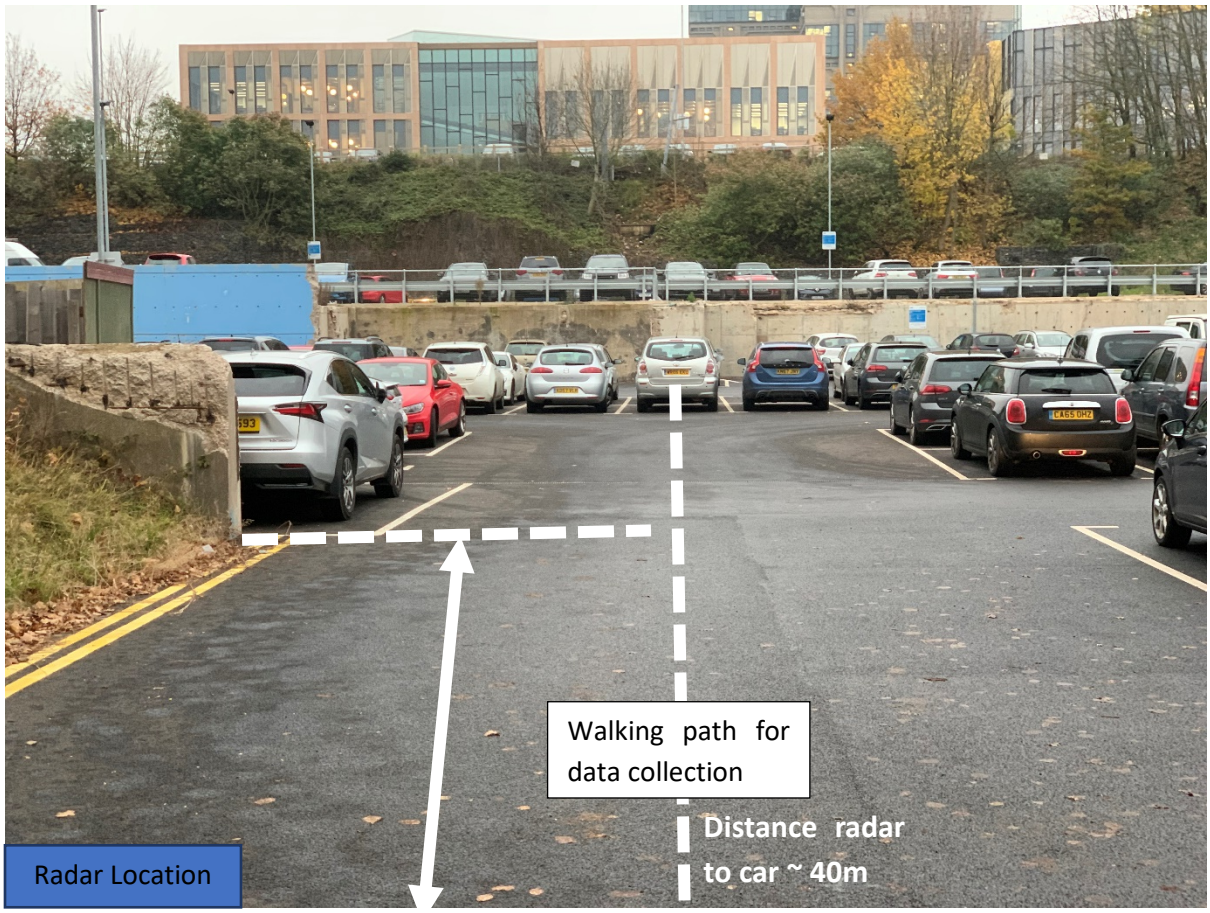

Figure 4: Scene for MTI data collection in Munrow carpark, of person walking up and down indicated path

2.2.2 Inras Radarbook Operating Parameters

The Inras Radarbook, with four transmit elements at 3.5λ spacing and eight receive elements at $\lambda/2$ spacing, was configured in MIMO mode. The active transmitters cycle from chirp-to-chirp in the order: TX1-TX2-TX3-TX4. With four transmit elements and eight receive elements the Radarbook would produce a virtual array of 32-elements, but the spatial configuration of the antennas on the Radarbook, would have three overlapping virtual elements. Removing these overlapping elements would emulate an equivalent of a 29-element $\lambda/2$ spaced antenna array (one-way only), which is usually done before MIMO processing of the radar signals from the Radarbook.

The operating parameters used for the Radarbook, in this scenario, are given in Table 3. These have been determined to give the optimal range resolution, and negligible data transfer loss to the computer, available from the Inras Radarbook. The mapping of the settings, given by the symbol in the Table 1, to the transmit timing of the radarbook is in Figure 3, shown earlier.

Table 3: Settings for the Inras radarbook for the side-lobe measurements.

Parameter	Symbol	Value	Unit
Radarbook Setting			
Centre Frequency	f_{centre}	77	GHz
Bandwidth	f_{BW}	2.0	GHz
Number of samples recieved	$n_{samples}$	2048	
Chirp Ramp-Up time	$TrampUp$	204.8	us
Chirp Ramp-Down time	$TrampDo$	10	us
Chirp interval time	Tp	250	us
MIMO interval time (Effective MIMO PRI)	$TInt$	10	ms
Resulting Performance			
Range Resolution	R_{res}	7.5	cm
Maximum unambiguous range[1]	R_{unamb}	76.8	m
Doppler Resolution	$v_{DoppRes}$	1.95	ms^{-1}
Maximum unambiguous range	v_{unamb}	0.1	ms^{-1}
Note 1: Due to the low-pass anti-aliasing filter, with a cut-off of 3.25MHz, within the radarbook, the effective maximum unambiguous range is 49.9m.			

2.2.3 Data Files

The following are the data files for this scenario

- \\ personWalking_InrasMIMOmode_21-11-2019\ data_Inras_MimoMode.mat

2.3 NXP Dolphin non-MIMO Measurements at 2GHz Bandwidth with Two Walking Pedestrians

2.3.1 Description

Date	21-11-19
Location	University of Birmingham, Gisbert Kapp basement
Purpose	Tracking of moving pedestrian targets and extraction of micro-Doppler

This measurement is intended to evaluate performance of the NXP Dolphin sensor, for tracking moving pedestrian targets from a static platform. The radar was operated in a non-MIMO mode in order to maximise Doppler performance at the expense of azimuthal resolution. This configuration is designed to allow the NXP Dolphin to complement the Inras Radarbook sensor, which in contrast provides much greater azimuth resolution but effectively no Doppler information. This measurement was designed to demonstrate the separation of two closely passing targets, which cannot be separated in azimuth alone, using the additional Doppler dimension.

For this measurement two pedestrian targets were walking up and down in opposite directions in the basement area of Gisbert Kapp within the scene shown in Figure 5. The wall visible adjacent to the target is at a range of approximately 20 m.

Camera data is supplied as an H.264 encoded video file in an MP4 container and is timestamped to allow for co-registration. However, there is some degree of error due to latency.

Figure 5: Scene for NXP Dolphin data collection in Gisbert Kapp basement, of two pedestrian targets walking and passing each other

2.3.2 NXP Dolphin Radar Operating Parameters

The NXP Dolphin was configured with a single active transmitter and four active receivers in order to maximise Doppler performance. For clarity, parameters will be defined as follows:

- **Chirp duration:** active duration of chirp during which time data is recorded
- **Pulse repetition interval (PRI):** time from the start of one chirp until the start of the next chirp (i.e. includes both active and non-active period). This interval determines maximum unambiguous Doppler value.
- **Chirps per Doppler interval:** number of individual chirps which are incorporated into a single coherent Doppler processing interval. This is equal to the number of Doppler bins after Doppler DFT.
- **Doppler processing interval:** active period during which a number of chirps are gathered. This interval determines Doppler resolution.
- **Doppler repetition interval:** time from the start of one Doppler interval to the start of the next Doppler interval. This includes both the Doppler Processing interval itself, and an inactive period between each Doppler interval during which data is still being transferred to the computer.
- **Doppler overlap factor:** Ratio between the Doppler processing interval and the Doppler repetition interval.

Operating parameters used for the measurement are as follows:

Table 4: Settings for the NXP Dolphin for the non-MIMO measurements in the Gisbert Kapp basement.

Parameter	**NXP Dolphin**	**Units**
Bandwidth	2.0	GHz
Chirp duration	25.6	µs
PRI	86.6	µs
Chirps per Doppler interval	128	-
Doppler processing interval	11.1	ms
Doppler repetition interval	16	ms
Doppler overlap factor	0.69	-
Range resolution	7.5	cm
Max unambiguous range	19.2	m
Velocity resolution	0.174	ms^{-1}
Max unambiguous velocity (RX-BF)	±11.1	ms^{-1}

2.3.3 Data Files

The following are the data files for this scenario

- two_persons_walking_passing_2ghz_non-mimo/test_nxp.mat
- two_persons_walking_passing_2ghz_non-mimo/video.mp4
- two_persons_walking_passing_2ghz_non-mimo/video_timestamp.mat

2.4 NXP Dolphin non-MIMO Measurements at 0.5GHz Bandwidth with Single Walking Pedestrian

2.4.1 Description

Date	29-10-19
Location	University of Birmingham, Munrow car park
Purpose	Tracking of moving pedestrian target and extraction of micro-Doppler

This measurement is intended to evaluate the micro-Doppler performance of the NXP Dolphin sensor for a moving pedestrian target. The radar was operated in a non-MIMO mode in order to maximise Doppler performance at the expense of azimuthal resolution. As the target moves away from the radar, the signal-to-noise ratio (SNR) of the target bulk return and micro-motion will decrease. This measurement scenario is designed to assess micro-Doppler signature quality as a function of range to target in order to identify maximum target range for which performance is acceptable.

For this measurement a single pedestrian target was walking away from the radar on-boresight in the Munrow car park at the University of Birmingham, as shown in Figure 6.

Camera data is supplied as an H.264 encoded video file in an MP4 container and is timestamped to allow for co-registration. However, there is some degree of error due to latency.

Figure 6: Scene for NXP Dolphin data collection in Gisbert Kapp basement, of two pedestrian targets walking and passing each other

2.4.2 NXP Dolphin Radar operating parameters

The NXP Dolphin was configured with a single active transmitter and four active receivers in order to maximise Doppler performance. For clarity, parameters will be defined as follows:

- **Chirp duration:** active duration of chirp during which time data is recorded
- **Pulse repetition interval (PRI):** time from the start of one chirp until the start of the next chirp (i.e. includes both active and non-active period). This interval determines maximum unambiguous Doppler value.
- **Chirps per Doppler interval:** number of individual chirps which are incorporated into a single coherent Doppler processing interval. This is equal to the number of Doppler bins after Doppler DFT.
- **Doppler processing interval:** active period during which a number of chirps are gathered. This interval determines Doppler resolution.
- **Doppler repetition interval:** time from the start of one Doppler interval to the start of the next Doppler interval. This includes both the Doppler Processing interval itself, and an inactive period between each Doppler interval during which data is still being transferred to the computer.
- **Doppler overlap factor:** Ratio between the Doppler processing interval and the Doppler repetition interval.

Operating parameters used for the measurement are as follows:

Table 5: Settings for the NXP Dolphin for the non-MIMO measurements in the Munrow car park.

Parameter	NXP Dolphin	Units
Bandwidth	0.5	GHz
Chirp duration	25.6	µs
PRI	86.6	µs
Chirps per Doppler interval	128	-
Doppler processing interval	11.1	ms
Doppler repetition interval	16	ms
Doppler overlap factor	0.69	-
Range resolution	30.0	cm
Max unambiguous range	76.8	m
Velocity resolution	0.174	ms^{-1}
Max unambiguous velocity (RX-BF)	±11.1	ms^{-1}

2.4.3 Data Files

The following are the data files for this scenario

- single_person_walking_0.5ghz_non-mimo/test_nxp.mat
- single_person_walking_0.5ghz_non-mimo/video.mp4
- single_person_walking_0.5ghz_non-mimo/video_timestamp.mat