USER MANUAL

3D-MIMO-RADAR

Devices: *iSYS-5010*

Revision: *3*

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Table of content

History

Document revision	Date	Change log	Author
1	2016-08-25	First release	TP
2	2016-12-01	Function description added	TP
3	2017-11-30	Detection sensitivity added (2.2.4)	JW

Documents

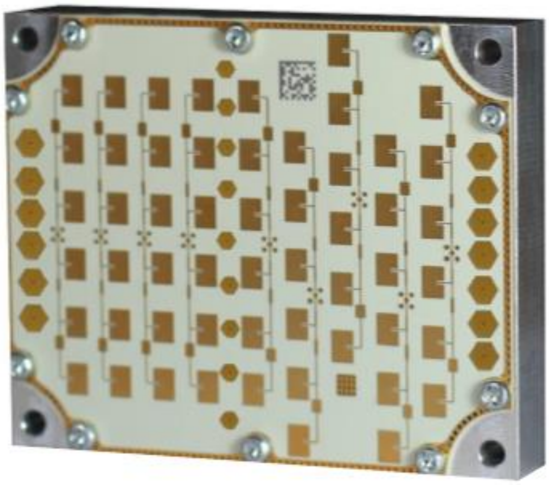
[1] iSYS serial interface protocol rev14.pdf

[2] serial radarSDK readMe rev12.pdf

[3] target viewer manual rev4.pdf

1. Brief description

The iSYS-5010 is a 24 GHz MIMO (multiple input multiple output) RADAR system with integrated signal processing for security applications.



Features:

- Simultaneous capture of speed, range and angle information for up to 256 targets
- Detection range up to 54.9 m
- Velocity measurement up to 34.9km/h
- Field of view 150° (±75°) in azimuth with a resolution of 16°
- Target list output on SPI
- UART communication for RADAR sensor configuration
- Temperature range from -40°C to +85°C
- Different frequency channels available to avoid interference

2. Technical specifications

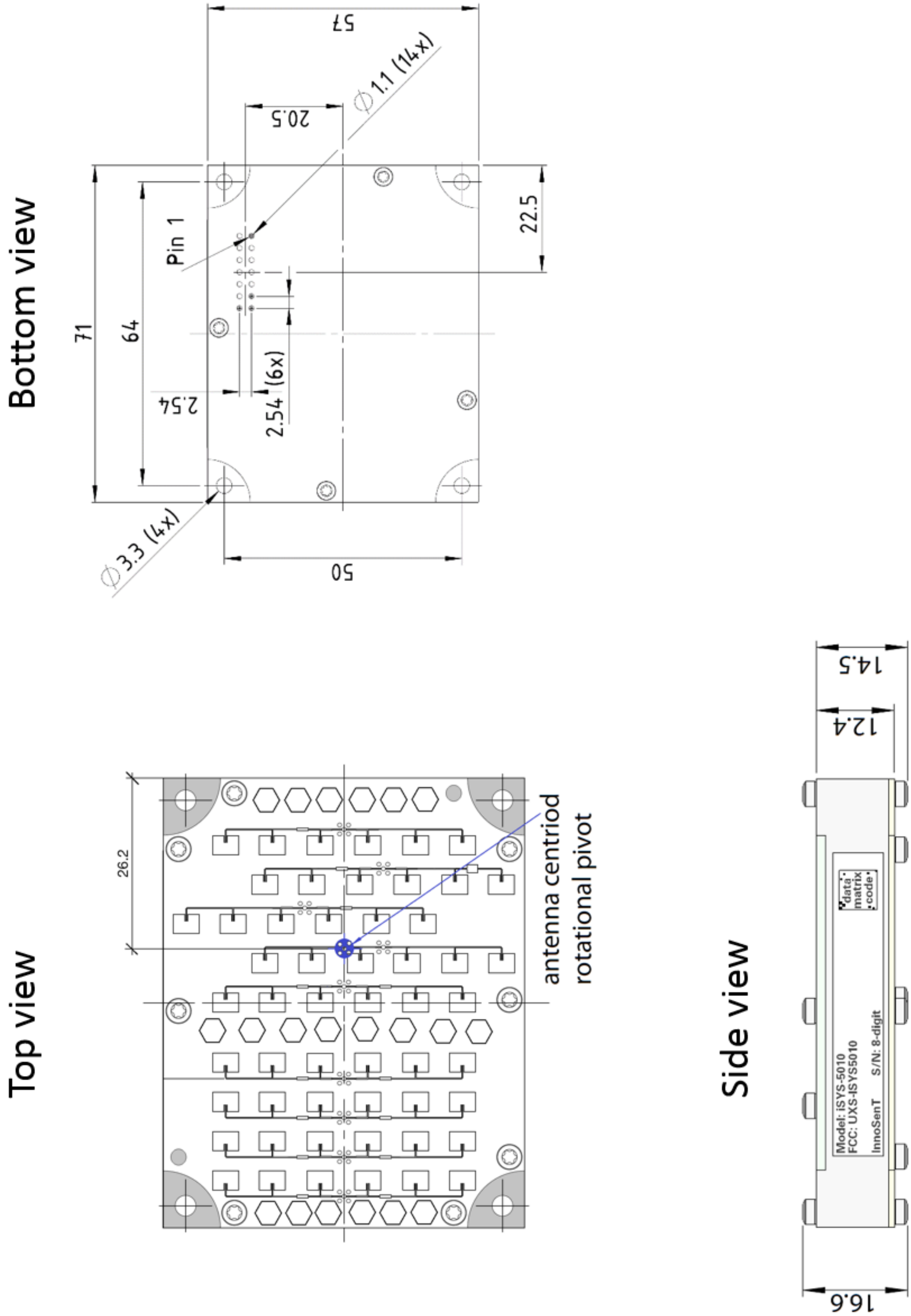


Figure 1: Mechanical schematic

2.1. System parameters

2.1.1. Antenna specification

The antenna patterns for the transmitters and the receivers are shown below:

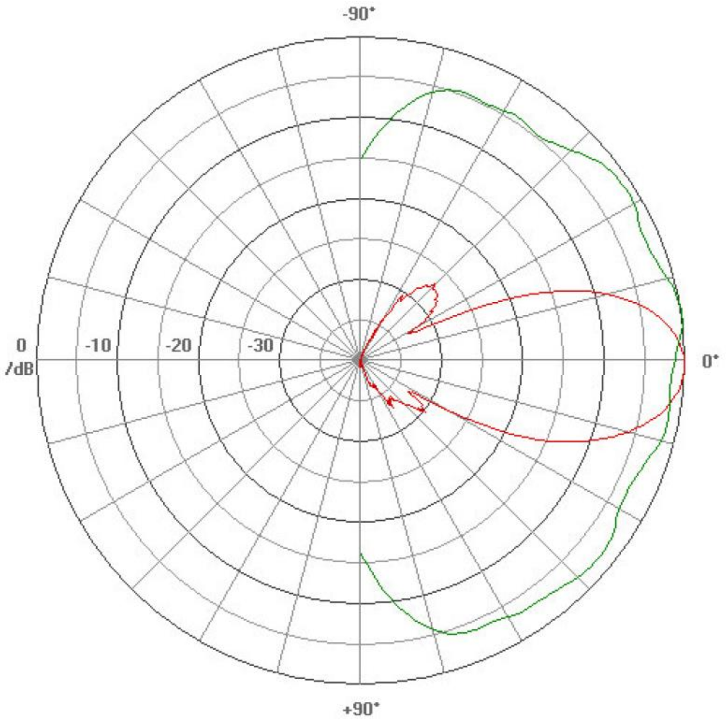


Figure 2: Transmitters and receivers antenna pattern

	● Red graph ELEVATION ANGLE	● Green graph AZIMUZH ANGLE
3 dB – Width [°]	20	97
10 dB – Width [°]	36	166

Table 1: Transmitters – Receivers Antenna Pattern

2.1.2. Angle measurement

The iSYS-5010 is specified with the following angle characteristics:

Measurement range	Resolution	Error
± 55 °	16 ° (@ 0° azimuth)	- 1.0 ° … +1.0°
± 75 °	16 ° (@ 0° azimuth)	not specified

Table 2: Angle measurement

The measurement precision is ensured in the range of -55 ° to +55 °.

2.1.3. Range measurement

The iSYS-5010 RADAR sensor is specified for the range:

Measurement range	Resolution	Error
1 m ... 54.9 m	0.93 m	± 1 m

Table 3: Range measurement

The measurement precision is ensured in the range of 1 m to 50 m.

2.1.4. Range ambiguity detection scheme

To ensure the range limitations, two different modulations (shown in Table 4) are used to detect targets that are over the unambiguous range.

If only one modulation is used, a target which moves over the maximum range is detected as an approaching target. This target's distance will be the same distance as the mirrored target that moves from the maximum range to the RADAR sensor. The velocity value of this ambiguous target does not change.

<u>Example</u>: A target moves away from the sensor and is located at a distance of 70 m. By using modulation 1, this target will be detected at a distance of 39.8 m.

(70 m – 54.9 m = 15.1 m → 54.9 m – 15.1 m = 39.8 m)

By using two interleaved modulations for two consecutive frames, two different range resolutions and maximum unambiguous ranges are available. Thus, it is possible to distinguish between targets within the unambiguous range and targets located in the ambiguous range. Indeed, an ambiguous target will not be detected at the same range for the two modulations. This target will jump between two different ranges, which allows it to be detected as an over-range target.

<u>Example</u>: A target moves away from the sensor and is located at a distance of 70 m.
With modulation 1, this target will be detected at a distance of 39.8 m.
(70 m – 54.9 m = 15.1 m → 54.9 m – 15.1 m = 39.8 m)
With modulation 2, it is detected at a distance of 48.2 m.
(70 m – 59.1 m = 10.9 m → 59.1 m – 10.9 m = 48.2 m)

Modulation	Unambiguous range	Resolution
1	1 m ... 54.9 m	0.8721 m
2	1 m ... 59.1 m	0.9375 m

Table 4: Modulation for unambiguous range and resolution

2.2. Functions

The iSYS-5010 radar sensor allows the possibility to be configured through the UART communication port. Three functions are available and can be activated or deactivated by commands:

- Frequency channels: to enable the use of more iSYS-5010 simultaneously without interference
- Clustering: to enable an easy reading of the target list
- RCS calculation: to choose between the signal strength information and the RCS information of the targets

2.2.1. Frequency channels

To allow two RADAR sensors functioning at the same time without creating interference between them, the iSYS-5010 is set with two different frequency channels coupled with interference suppression algorithm. The two frequency channels have been designed to produce a specific type of interference that can be detected and easily removed by the signal processing algorithm.

On each RADAR sensor, it is possible to choose and switch between the two frequency channels.

2.2.2. Clustering

To allow an easy reading of the target list, the iSYS-5010 provides a target clustering feature. This feature allows to regroup the targets located in an area around a reference target into a new clustered target. The position of this new clustered target is the barycentric of all original target positions. Its signal strength and velocity refer to the target with the strongest signal strength. The clustering effect is shown in Figure 3.

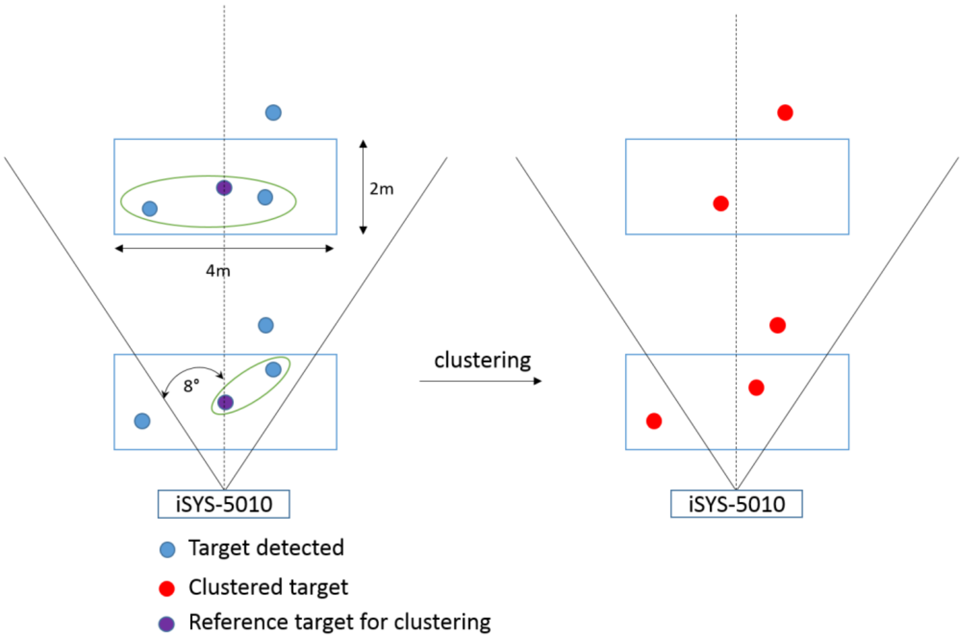


Figure 3: Clustering effect

2.2.3. RCS calculation

In order to discriminate the targets of the scene, the iSYS-5010 gives the signal strength of each target contained in the target list or its equivalent RCS value.

The signal strength, in [dB], of the targets is measured after the Fast Fourier Transformation (FFT) in range and velocity. This signal strength is a scaled information from the real signal strength. The RCS value is calculated from signal strength where the range effect, scaling effect and the azimuth antenna pattern effect have been corrected. However, the RCS values obtained have not been corrected by the elevation pattern effect. Thus, it is only correct in the elevation boresight (0° in elevation).

2.2.4. Detection sensitivity

The detection sensitivity can be used to adapt the device due rain interference.

The iSYS-5010 allows to customize the detection sensitivity for three ranges. These parameters determine how sensitive the sensor is for detections in a specific radial range areas. A lower value means that the threshold is more sensitive in this range area (more targets) and a higher values sets a lower sensitivity (fewer targets) for the detection of moving targets.

The default values and applicable range areas for these parameters are shown below in Table 5. Values $\pm 2dB$ around the default values are recommended. Higher or lower values are also supported by the iSYS-5010 RADAR sensor, but they will generate too much noise targets or no targets in the target list.

Parameter	Radial Range area	Default value	Recommended values
Near range sensitivity	Up to 2.7m	2.5dB	0.5dB to 4.5dB
Main range sensitivity	2.7m to 40.7m	3.6dB	1.6 dB to 5.6dB
Long range sensitivity	Above 40.7m	3.5dB	1.5 dB to 5.5dB

Table 5: moving target threshold sensitivity paramters

3. Installation

The test installation is shown below in Figure 4. Typically, the responses of the targets of interest for the RADAR are considered to be at least at 1m in height. This reference height corresponds to the torso, for a person, or the mean response height for a car. In Table 6, several installation configurations are suggested. At InnoSenT, the RADAR sensor is typically installed on a pole at a height h of 3m and an angle position α of 3°. This configuration has been chosen in order to optimize the maximum range of the iSYS-5010 RADAR sensor.

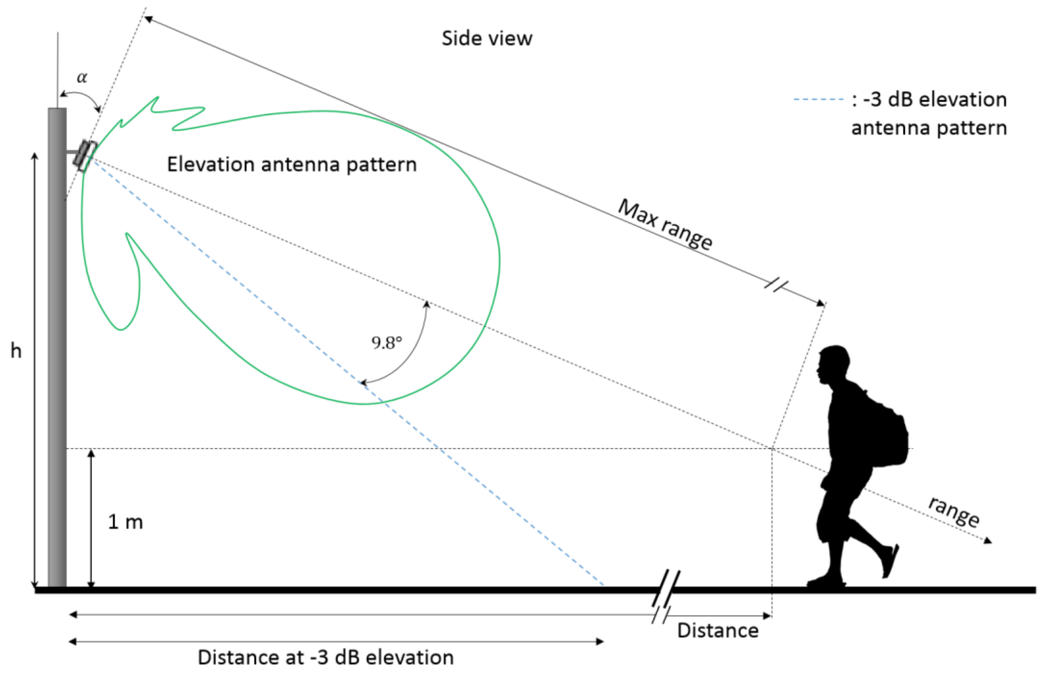


Figure 4: Installation example

Height h	Angle α	Max range	distance	Distance at – 3 dB elevation
2 m	1.2°	47.7 m	47.7 m	5.1 m
2.5 m	1.7°	50.5 m	50.5 m	7.3 m
3 m	3°	45.8 m	45.8 m	9.1 m
3 m	2.5°	38.2 m	38.1 m	8.8 m
3.5 m	3°	47.7 m	47.7 m	11 m

Table 6: Installation parameters

The proper functionality of the iSYS-5010 RADAR sensor can only be achieved if all installation parameters are set correctly. Thus, please ensure that the complete field of view is clear without any obstructions. Otherwise, shadowing effects may occur that limit the detection performance.

4. Connection

4.1. Connector placement

The iSYS-5010 provides a 14 Pin 2.54 mm pitch female header. This connector (W+P 3492-14-3-00-00) is a dual entry type and is mounted on the inner side of the DSP-board. InnoSenT uses a gold-plated connector. The length of the mating connector should be 5.5mm ± 0.5mm (e.g. W+P 3132-12-14-00-0-ST). The pin description is given in Table 7.

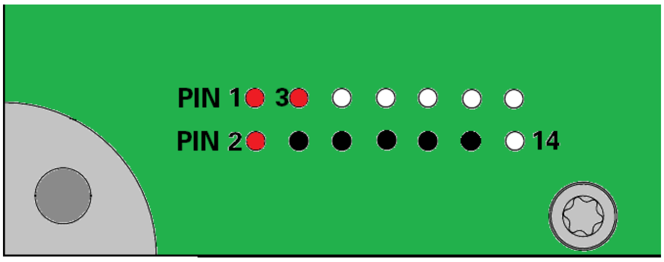


Figure 5: iSYS-5010 connector

PIN	NAME	DESCRIPTION
#1 ●	6V2_IN	Power Supply, 900mA max.
#2 ●	6V2_IN	
#3 ●	6V2_IN	
#4 ●	GND	
#5	SPI_CLK	SPI → interface for target list output, CLK 5 MHz max.
#6 ●	GND	
#7	SPI_CS	SPI → interface for target list output
#8 ●	GND	
#9	SPI_MOSI	SPI → interface for target list output
#10 ●	GND	
#11	SPI_MISO	SPI → interface for target list output
#12 ●	GND	
#13	UART_RX	UART → command interface for configuration
#14	UART_TX	

Table 7: Connector Pin-out

4.2. Power supply

	Comment	Symbol	min.	typ.	max.	Unit
Supply voltage		V_{CC}	6.1	6.25	6.4	V
Ripple		V_{ripple}			10	mV
Current		I		600	900	mA

Table 8: Power supply parameters

5. Communication

The iSYS-5010 has two interfaces:

- UART command interface (bidirectional)
- SPI target list output interface

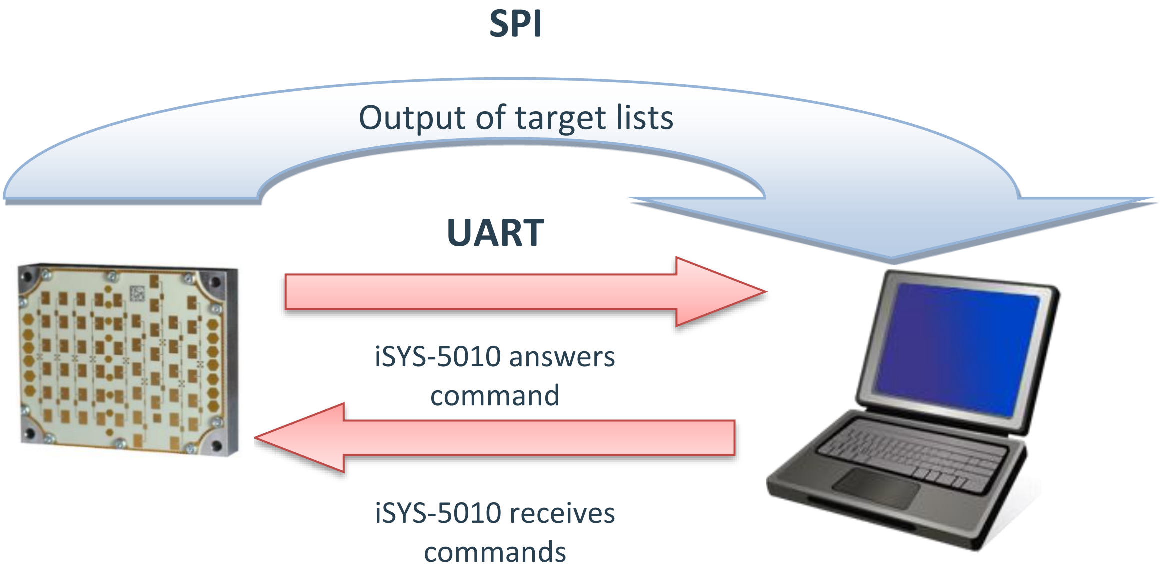


Figure 6: UART and SPI communication

5.1. UART command interface

The UART interface is available for device configuration and firmware update purposes.

There are two different ways for implementation served by InnoSenT:

- serial protocol description including commands for self-implementation
- serial RadarAPI with C++ example project

5.1.1. UART configuration

	value	comment
Transmission direction	full duplex	
Baudrate	115200	Baud
Data	8	
Stop-bits	1	
Parity	none	
Voltage level	3.3	V, CMOS

Table 9: UART configuration

5.1.2. Serial protocol description

InnoSenT uses a companywide serial protocol for all iSYS devices with serial interface. The iSYS serial interface protocol document [1] describes this protocol and all commands.

But remark that each device uses only a small subset of this commands. The supported commands are listed in the appendix of the document [1].

5.1.3. Serial RadarAPI description

InnoSenT provides a C++ serial RadarAPI. This API contains the functions for the whole InnoSenT serial interface protocol. The serial RadarAPI is explained in detail in document [2].

The iSYS-5010 supports following commands from the serial RadarAPI:

- iSYS_ReadDeviceName
- iSYS_getDeviceAddress
- iSYS_StartAcquisition / iSYS_StopAcquisition
- iSYS_setFrequencyChannel / iSYS_getFrequencyChannel
- iSYS_setProcessingRcsCalibrationEnable / iSYS_getProcessingRcsCalibrationEnable
- iSYS_setTargetClusteringEnable / iSYS_getTargetClusteringEnable
- iSYS_setThresholdMovingTargetsNearRangeMargin / iSYS_getThresholdMovingTargetsNearRangeMargin
- iSYS_setThresholdMovingTargetsMainRangeMargin / iSYS_getThresholdMovingTargetsMainRangeMargin
- iSYS_setThresholdMovingTargetsLongRangeMargin / iSYS_getThresholdMovingTargetsLongRangeMargin
- iSYS_getFirmwareVersion
- iSYS_getSerialNumber
- iSYS_getDspHardwareVersion
- iSYS_getRfeHardwareVersion
- iSYS_getProductInfo

5.2. SPI target list interface

The iSYS-5010 processes the radar signals due to a target list which will be send via SPI interface. One complete target list will be send within one frame every measurement cycle. Each frame consists of a sum of sub-frames (start/end sub frame, target sub frame). Each sub-frame will be send within one chip-select signal. A schematic SPI target list transmission is shown in Figure 7 below.

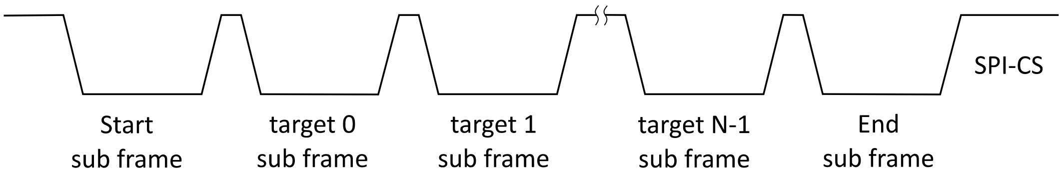


Figure 7: schematic example of SPI target list frame

The target list of each measurement is transmitted after processing of the sampled data is finished. This leads to a delay of at least 64ms up to 100ms between the detection of a target and the transmission. This delay is not constant, because the number of detections influences the processing time. The figure below shows the timing of the measurement and the target list output.

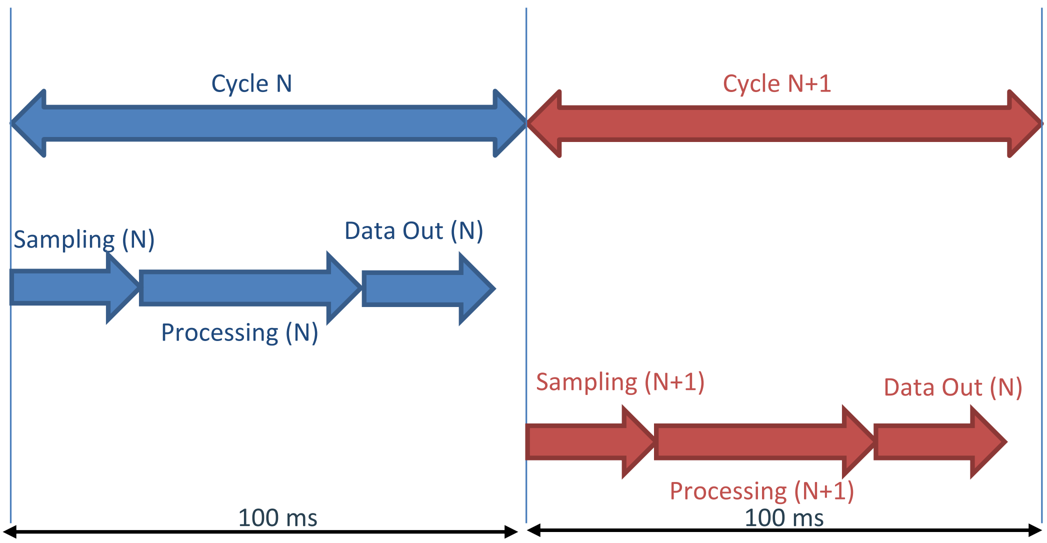


Figure 8: Timing of sampling, processing and target list output

5.2.1. SPI configuration

	value	comment
Transmission direction	simplex, Master	**iSYS-5010 is Master device**
Bit order		MSB first
SCLK frequency	5	MHz
Data word size	32	Bit
CS		Chip select active low
CPOL	0	Clock idle low
CPHA	1	Falling edge
Voltage level	3.3	V, CMOS
Max number of targets	256	

Figure 9: SPI communication parameter

Frame transmission time for maximum number of targets:

The needed transmission time for the maximum target list with 256 targets can be calculated with the formula below. The factor 1.01 is used for the overhead caused by inter sub frame chip selects.

$$\frac{(256\,targets \cdot 6\,DWORD + 4\,DWORD) \cdot 32\frac{Bit}{DWORD}}{5\,MHz} \cdot 1.01 = 9.95\,ms \approx 10ms$$

5.2.2. Target-List information content definitions

The target list consists of up to 256 targets. For each target the signal strength / RCS, range, velocity and angle is transmitted. The signal strength regards to the scaled FFT magnitude calculated during signal processing. It is also possible to transmit the RCS instead of the signal strength. For changing the output between signal strength and RCS (RADAR cross section) refer to the serial RadarAPI [2] or the serial interface protocol [1]. The definition of the sign for the transmitted velocity and angle value is shown in Figure 10:

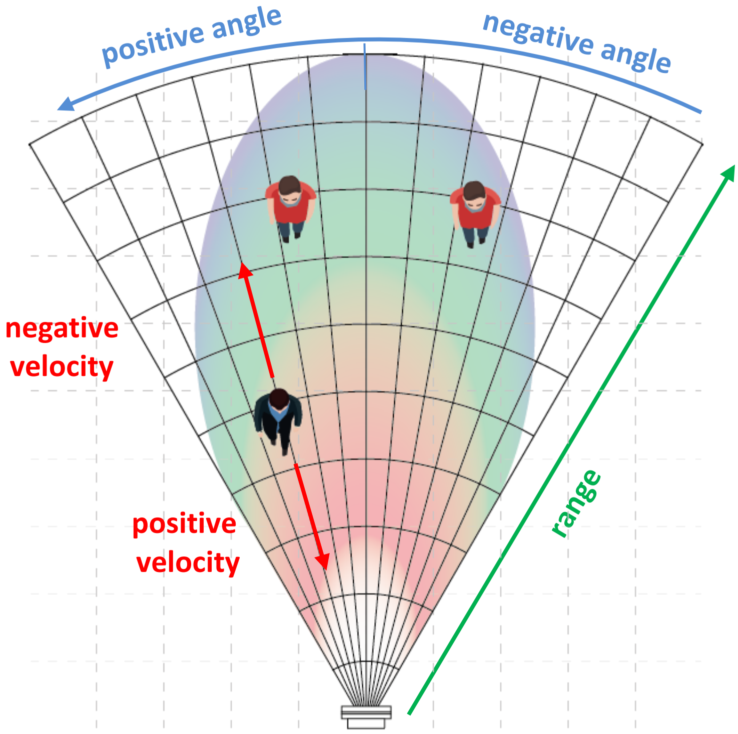


Figure 10: target information contained in target sub frame

5.2.2.1. Target list frame

The SPI target list uses three different sub frame types:

- **Start sub frame**

This sub frame is used to mark the start of a target list frame.

Double word number	Data type	description
0	Uint32_t	Start identifier 0xFEED5010
1	Uint32_t	number of targets N

Table 10: SPI target list start sub frame

- **Target sub frame**

This sub frames contain the information for one of the N targets. For each target one target sub frame is transmitted.

Double word number	**Data type**	**description**
0	Float32_t	Signal strength in dB or RCS in m^2
1	Float32_t	Range in m
2	Float32_t	Velocity in m/s
3	Float32_t	Angle azimuth in degree
4	Float32_t	Reserved 1
5	Float32_t	Reserved 2

Table 11: SPI target list target sub frame

- **End sub frame**

This sub frame is used to mark the end of a target list frame. It contains the checksum of the target list frame. The checksum is the sum of the bytes over all target sub frames.

Double word number	**Data type**	**description**
0	Uint32_t	End identifier 0xFEED0000
1	Uint32_t	Target list checksum

Table 12: SPI target list end sub frame

Example for SPI target list

The following example show a possible target list with two targets. An example for calculation the target list checksum is also included below

Sub frame	Sub frame content		
Start frame	Start identifier	0xFEED5010	
	Target number	0x00000002	
Target frame 0	RCS	0x41200000	Data used for checksum calculation
	Range	0x41c9999a	
	Velocity	0x3f800000	
	Angle azimuth	0x4121eb85	
	Reserved 1	0x00000000	
	Reserved 2	0x00000000	
Target frame 1	RCS	0x40a00000	
	Range	0x420e6666	
	Velocity	0x3dcccccd	
	Angle azimuth	0xc1700000	
	Reserved 1	0x00000000	
	Reserved 2	0x00000000	
End frame	End identifier	0xFEED0000	
	Target list checksum	0x00000AFE	

Table 13: Example target list

Calculation of the frame checksum:

$$CKSUM = 0x41 + 0x20 + 0x41 + 0xc9 + 0x99 + 0x9a + 0x3f + 0x80 + 0x41 + 0x21 + 0xeb + 0x85 + 0x40 + 0xa0 + 0x42 + 0x0e + 0x66 + 0x66 + 0x3d + 0xcc + 0xcc + 0xcd + 0xc1 + 0x70 = 0xAFE$$

5.2.3. Decoding a target list sub frame

Following code can be used to decode the target sub frame

```
inputArray[0] = static_cast<float32_t>( ((rxArray[0] BIT_AND 0x000000FF) << 24) BIT_OR  /* signal strength  or rcs*/
                ((rxArray[1] BIT_AND 0x000000FF) << 16) BIT_OR
                ((rxArray[2] BIT_AND 0x000000FF) << 8)  BIT_OR
                (rxArray[3] BIT_AND 0x000000FF) );

inputArray[1] = static_cast<float32_t>( ((rxArray[4] BIT_AND 0x000000FF) << 24) BIT_OR  /* range */
                ((rxArray[5] BIT_AND 0x000000FF) << 16) BIT_OR
                ((rxArray[6] BIT_AND 0x000000FF) << 8)  BIT_OR
                (rxArray[7] BIT_AND 0x000000FF) );

inputArray[2] = static_cast<float32_t>( ((rxArray[8] BIT_AND 0x000000FF) << 24) BIT_OR  /* velocity */
                ((rxArray[9] BIT_AND 0x000000FF) << 16) BIT_OR
                ((rxArray[10] BIT_AND 0x000000FF) << 8)  BIT_OR
                (rxArray[11] BIT_AND 0x000000FF) );

inputArray[3] = static_cast<float32_t>( ((rxArray[12] BIT_AND 0x000000FF) << 24) BIT_OR /* angle azimuth*/
                ((rxArray[13] BIT_AND 0x000000FF) << 16) BIT_OR
                ((rxArray[14] BIT_AND 0x000000FF) << 8)  BIT_OR
                (rxArray[15] BIT_AND 0x000000FF) );

inputArray[4] = static_cast<float32_t>( ((rxArray[16] BIT_AND 0x000000FF) << 24) BIT_OR /* reserved1 */
                ((rxArray[17] BIT_AND 0x000000FF) << 16) BIT_OR
                ((rxArray[18] BIT_AND 0x000000FF) << 8)  BIT_OR
                (rxArray[19] BIT_AND 0x000000FF) );

inputArray[5] = static_cast<float32_t>( ((rxArray[20] BIT_AND 0x000000FF) << 24) BIT_OR /* reserved2*/
                ((rxArray[21] BIT_AND 0x000000FF) << 16) BIT_OR
                ((rxArray[22] BIT_AND 0x000000FF) << 8)  BIT_OR
(rxArray[23] BIT_AND 0x000000FF) );
```

Table 14: Decode target information of a target sub-frame

5.3. Target-Viewer

InnoSenT provides a graphical user interface called Target-Viewer for displaying the targets and configuring the iSYS-5010 by UART communication.

The Target-Viewer works only with the Beagle SPI Protocol-Analyzer from Total-Phase. For further information regard document [3].

InnoSenT GmbH
Am Roedertor 30
97499 Donnersdorf
GERMANY
Tel.: +49 95289518-0
E-Mail: info@innosent.de
www.innosent.de