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SiRad Easy® r4

(Firmware 1.2 or higher)

System & Protocol Description

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Version Control

Version	Changed section	Description of change	Reason for change
0.9	all		Initial document
1.0	all	Minor corrections	Protocol adjustments Firmware 1.2

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1 Measurement Flow

This section describes the measurement flow of the evaluation kit with its most important parameters. The settings as well as the kind and amount of transmitted data can be modified by the communication protocol described in the following sections.

After start up, the evaluation kit scans for the minimum and maximum frequencies that the mounted radar front end can use and the start- or base-frequency f_{Base} is set to minimum frequency as a result of the frequency scan. The evaluation kit also determines the maximum usable bandwidth f_{BW} from the result of the frequency scan and sets this bandwidth after the frequency scan was performed. The frequency scan (fscan) and set to maximum bandwidth (max BW) functions are repeatable using protocol commands, please also see Section 3.4. Individual base-frequencies and bandwidths can be set after startup, please also see Section 3.3.2 and Section 3.3.3.

The workflow of the radar measurement is shown in Figure 1. Each measurement cycle is initiated by either an internal self-trigger (int) or an external / manual trigger (ext). Continuous measurements can be triggered with a certain trigger frequency, also see Section 1.2 for the trigger options.

Once a trigger is received, the PLL is started and drives a frequency ramp from the base-frequency f_{Base} to f_{Base} + f_{BW} for each ramp in the number of ramps N_{Ramps} with the ramp time t_{Ramp}. The radar front end starts its detection in this frequency range during each ramp. The ideal ramp time t_{Ramp} is around 1 ms for achieving good initial SNR with the baseband of the evaluation kit, unless it is modified.

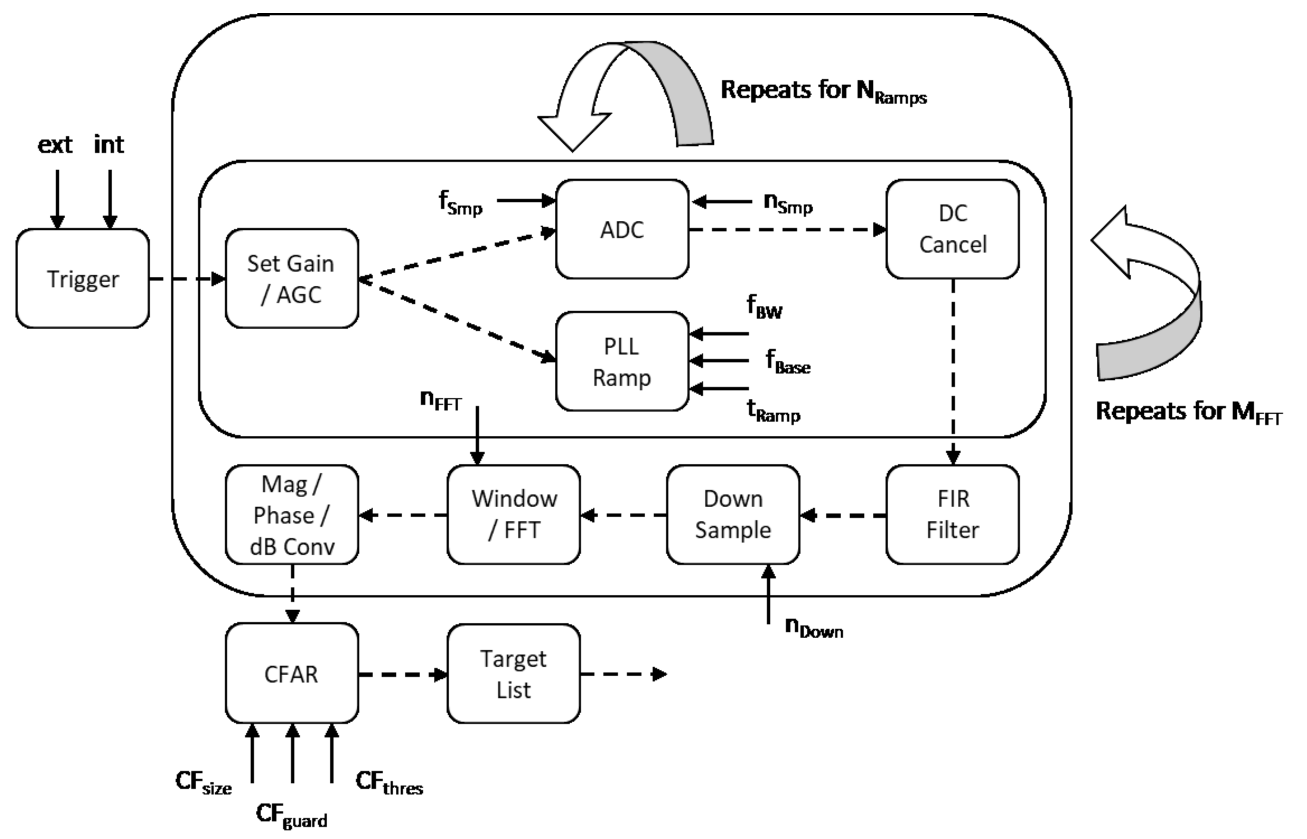


Figure 1 Flow of Radar Measurement

The AD converter (ADC) begins sampling the number of samples n_{Smp} with a certain sample frequency f_{Smp}. The current measurement is repeated for the number of ramps N_{Ramps}, further called ramp group. Depending on the processing settings, there can be a smaller or larger delay between each ramp in the ramp group due to the processing of previous ramp data while the next ramp is driving.

The baseband amplification factor is adjusted by a manually chosen gain value or by a continuously recalculated automatically acquired gain value, further named Auto Gain Control (AGC) Mode, also see Section 1.1. If Auto Gain Control (AGC) Mode is switched on, the kit drives two additional ramps in the beginning of the ramp group to determine optimum gain settings for the environment. Otherwise, the gain factor is set according to the manual gain setting.

The DC cancelation is a standard mean subtraction and is performed on each ramp separately, if switched on. The IQ data acquired during each ramp of the ramp group is summed up and scaled to increase the SNR. Depending on the processing settings, FIR filtering, down sampling, and windowing are performed on the measured data and then transformed by an FFT with n_{FFT} points. Figure 2 shows the order of processing and data extraction steps.

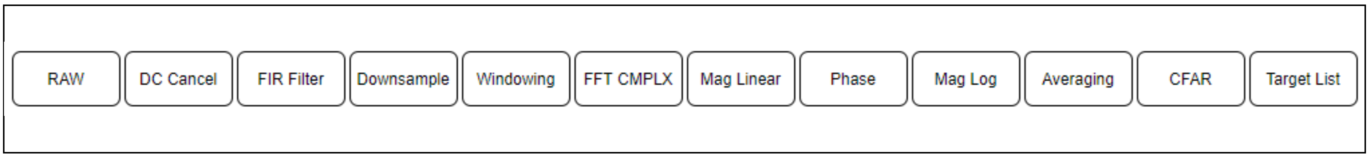


Figure 2 Processing and Data Extraction Steps on SiRad Evaluation Kits

Magnitude, phase and other information is extracted from the FFT. The output data of a number M_{FFT} of FFTs can be averaged. The targets in the FFT output data are detected by the CFAR operator (with its parameters CFsize, CFguard and CFthres). There are 3 different available CFAR operators - CA-CFAR, GO-CFAR and SO-CFAR. The Target List is then created from the CFAR output and the data extracted from the FFT. The kind and amount of output data is selectable and can have different data formats: WebGUI output (standard), Tab Separated Values (TSV) and Binary output. The resulting data is always transferred immediately after a measurement (full ramp group) took place.

1.1 Auto Gain Control (AGC) Mode

A measurement is divided into two parts: pre-measurement and measurement. The pre-phase is used to detect the maximum gain setting of the device so that no saturation occurs. It uses two frequency ramps to do that (if the Auto Gain Control Mode is switched on). The actual measurement is started after the pre-measurement phase and consists of a chosen number of frequency ramps.

The device uses the manual gain setting when the AGC Mode is disabled. When AGC Mode is switched on, the device may switch between two gain modes during measurements, depending on the environment conditions. In this case, it is recommended to switch AGC Mode off and set the gain manually, so that no gain switching occurs between measurements.

Table 1 Manual Gain Modes

RFE Board TRX_120_001						
Gain	0	1	2	3	4	5
SPI Control Value	0	1	2	4	6	7
1st Stage Gain	20 dB					
2nd Stage Gain	1 dB	2 dB	4 dB	8 dB	16 dB	32 dB
Combined Gain	21 dB	22 dB	24 dB	28 dB	36 dB	52 dB
Allowed Values in WebGUI Output Mode	195	196	198	202	210	226
Allowed Values in TSV and Binary Output Mode	21	22	24	28	36	52

…
<continued on next page>

RFE Board TRA_120_002 / TRX_024_046						
Gain	0	1	2	3	4	5
SPI Control Value	0	1	2	4	6	7
1st Stage Gain	12 dB					
2nd Stage Gain	1 dB	2 dB	4 dB	8 dB	16 dB	32 dB
Combined Gain	13 dB	14 dB	16 dB	20 dB	28 dB	44 dB
Allowed Values in WebGUI Output Mode	187	188	190	197	202	218
Allowed Values in TSV and Binary Output Mode	13	14	16	20	28	44

RFE Board TRA_120_045						
Gain	0	1	2	3	4	5
SPI Control Value	0	1	2	3	4	5
IC Gain	1 dB	10 dB	20 dB	30 dB	40 dB	60 dB
Combined Gain	6 dB	19 dB	29 dB	39 dB	49 dB	69 dB
Allowed Values in WebGUI Output Mode	180	193	203	213	223	243
Allowed Values in TSV and Binary Output Mode	6	19	29	39	49	69

1.2 Trigger Options

After the pre-measurement phase (please see Section 1.1) the actual measurement is started and consists of a chosen number of frequency ramps (ramp group). A measurement can be triggered either manually (externally) or internally via a timer (self-trigger).

When the Self-Trigger Mode is enabled, the device triggers each measurement after an internal timer expired (and resets the timer). The External Trigger Mode is overridden by the Self-Trigger Mode. When the Self-Trigger Mode is disabled, the device enters External Trigger Mode and goes to idle until it was triggered externally. After the measurement, the device transmits the data and waits for the next external trigger. This is useful to minimize power consumption of the device when using longer measurement intervals. When using the external trigger options, the Pre-Trigger Mode can be used to enable the pre-phase before the actual trigger. After the pre-trigger, the device waits for some milliseconds for the main trigger. If the main trigger does not occur within max. 40 ms after the pre-trigger, the device will go back to idle. The Pre-Trigger Mode can be also useful to synchronize a number of devices and start their measurements simultaneously or at a defined time.

Table 2 Trigger Input Modes

Trigger Input Mode	Description
Self-Trigger	Device triggers itself for measurements; continuous transmission of measurement data / ramp group
External Trigger	Device waits for external trigger input for each measurement / ramp group
External Trigger with Pre-Trigger	Device waits for external pre-trigger and then for main trigger input for each measurement / ramp group

Table 3 Trigger Inputs for External Trigger and Pre-Trigger

Trigger Input	Description
Trigger command	One of !M\r\n, !N\r\n, or !L\\r\n via UART
Trigger input line	Pin 16 on connector PX2 of the baseboard, pin 60 (PD_13) of processor

A ramp trigger output signal is generated with each ramp. The trigger signal switches to high with the start of the ramp and to low with the end of the ramp.

Table 4 Trigger Output Modes

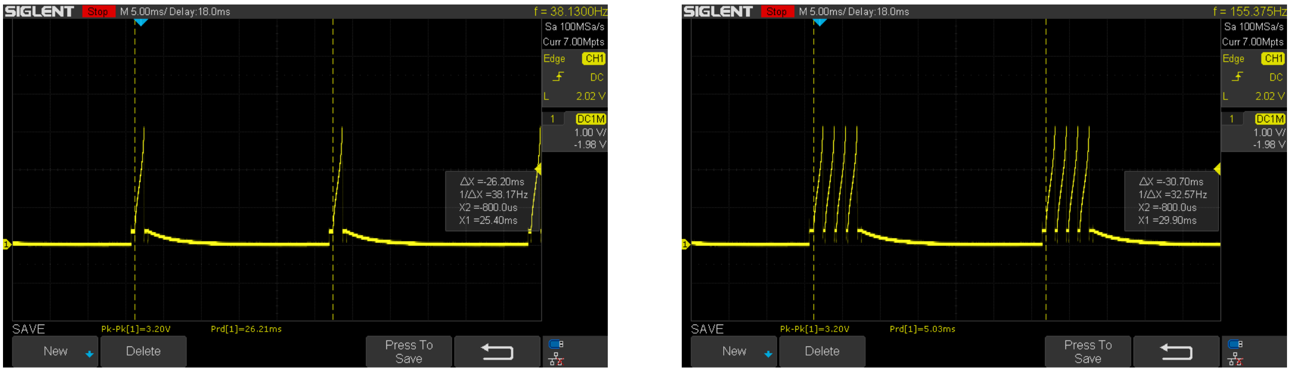
Trigger Output Mode	Description
Ramp trigger	Switches to high with the start of each ramp and to low with the end of each ramp

Table 5 Trigger Outputs

Trigger Output	Description
Trigger output line	Pin 14 on connector PX2 of the baseboard, pin 59 (PD_12) of processor

1.3 Ramp Modes

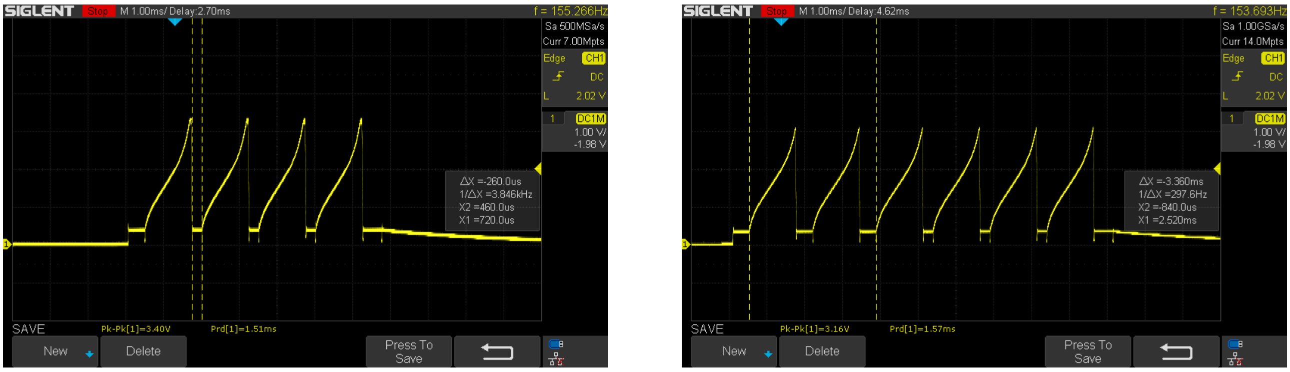
If the Self-Trigger Mode is switched on (default), the device sends a group of ramps for each measurement, also shown in Figure 3 (right). The number of ramps can be adjusted and also set to single ramps as shown in Figure 3 (left). The time between the ramp groups or single ramps is time needed for processing and data output and varies with the chosen device settings. The time can be minimized by switching off unnecessary data output and choosing less complex computation and measurement settings. Figure 3 shows the ramping with AGC Mode switched off.



Single Ramps Ramp Groups of 4 Ramps Each

Figure 3 Single Ramp vs. Ramp Group (Set of Ramps)

Figure 4 (left) shows the time between the ramps in a ramp group is time needed for pre-processing and cannot be minimized or removed. Figure 4 (right) shows an example of the ramping with AGC Mode switched on. The first two ramps are used for determining the gain and not for the measurement itself vs. Figure 4 (left) with the AGC Mode turned off (increases the update rate of the device).



Processing Time between Ramps of Ramp Group AGC Mode On, 1st Two Ramps of Ramp Group

Figure 4 Ramps Group Details

1.4 CFAR Operator

Constant false alarm rate (CFAR) operators are used to calculate an adaptive threshold above the noise floor. Due to the characteristics of usual target spectra, it can be used as an efficient way to achieve a guaranteed detection threshold and reduce false alarms.

The *SiRad Easy® r4* supports three CFAR algorithms (CA-CFAR, CFAR-GO and CFAR-SO). Section 3.3.4 explains how to change the CFAR operator and its settings. As an example, a standard CA-CFAR operator that calculates the average from reference cells for the CFAR is explained in Figure 5. The CA-CFAR calculates the average of a number of reference cells as a way to detect targets. However, such a standard CFAR operator might not be ideal in every target situation or for every application. It should be optimized for the specific measurement task. Therefore, the *SiRad Easy® r4* has options to output the FFT data before the target detection took place, for third-party processing tuned to the intended target application.

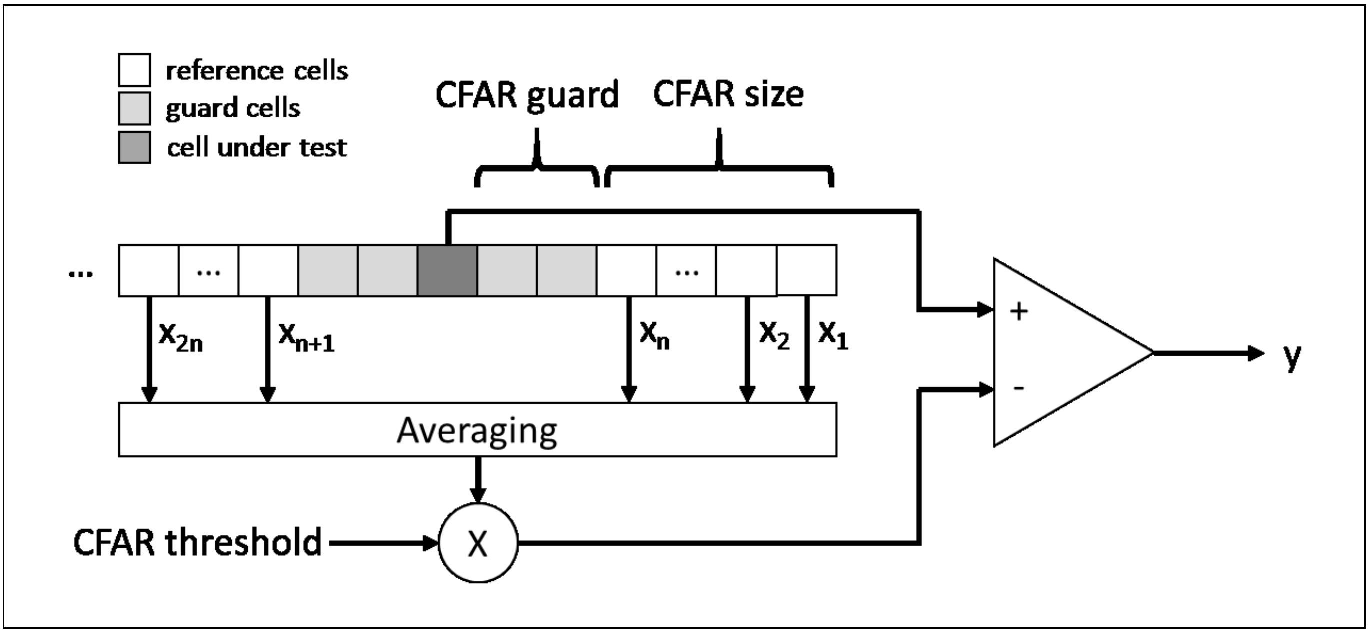


Figure 5 Schematic description of the CACFAR operator

1.5 Tuning Options

How to tune and speed up the SiRad Evaluation Kits, please visit our Wiki Tuning page. For example configuration please see our Wiki Output Modes page.

2 Supported Protocols

The *SiRad Easy® r4* communicates via UART. The UART protocol is (extended) ASCII based and supports communication to any PC / microcontroller / device that supports the UART settings in Section 2.1 and that implements the communication protocol described in this document. There are three output modes (WebGUI, TSV, Binary; explained in Section 4 to 0) but only one way to control the device via input commands, explained in Section 3. The kit supports the Silicon Radar WebGUI for graphical control but also terminal programs, TSV output (Tab Separated Values) for import into spreadsheet / third party software or logging to text files and binary output for faster communication to other microcontrollers. The kit always starts up with the WebGUI protocol enabled after power on. The output modes can be switched in the WebGUI or using the protocol commands described in this document from a terminal program or a third party control software. The TSV and binary output modes are not supported by the WebGUI.

2.1 UART Settings

The following UART settings apply: 230400 baud or 1 Mbaud - depending on flashed firmware, 8 data bits, 1 start bit, 1 stop bit, no parity, no flow control.

2.2 Software Compatibility

Table 6 Compatibility of WebGUI and Third-Party Software

Protocol	SiRad WebGUI	Terminal programs	Third Party / uC / Own Software
WebGUI	X	X	(X)[1]
TSV	-	X	(X)[2]
Binary	-	X	(X)[3]

2.3 Supported Data Frames per Output Mode

You can find the supported data frames by each protocol in Table 7. Data frames that are not supported by TSV or binary output modes can still be sent while using TSV or binary mode, but the data format of these frames will be in the WebGUI format.

Table 7 Supported Data Frames per Output Mode (WebGUI vs. TSV vs. Binary)

Data Frame	Description	WebGUI	TSV	Binary
ADC raw data frame	Contains ADC raw data (I/Q)	-	X	X
Range frame	Contains distance data extracted from the FFT	X	X	X
Phase frame	Contains phase information extracted from the FFT	X	X	X
CFAR frame	Contains the output of the CFAR operators	X	X	X
Target list frame	Contains the target list with the detected targets	X	X	X
Status update frame	Contains status data updates	X	X	X
Error info frame	Contains basic error information	X	-	X
Detailed error info frame	Contains detailed error information	X	-	-
System info frame	Contains hardware information	X	-	-
Version info frame	Contains hardware and firmware information	X	-	-

[1] If WebGUI format is implemented.
[2] If data format of tab separated values is supported / implemented.
[3] If binary data format is supported / implemented.

2.4 Terminal Program (Send / Receive)

You can use a terminal program to receive data and send command strings as, for example, shown in Figure 6 with the terminal program "Realterm". Put in the UART settings explained in Section 2.1 to the "Port" tab and connect to the system with "Open". Per default, the system sends data in the WebGUI output format as shown in Figure 6.

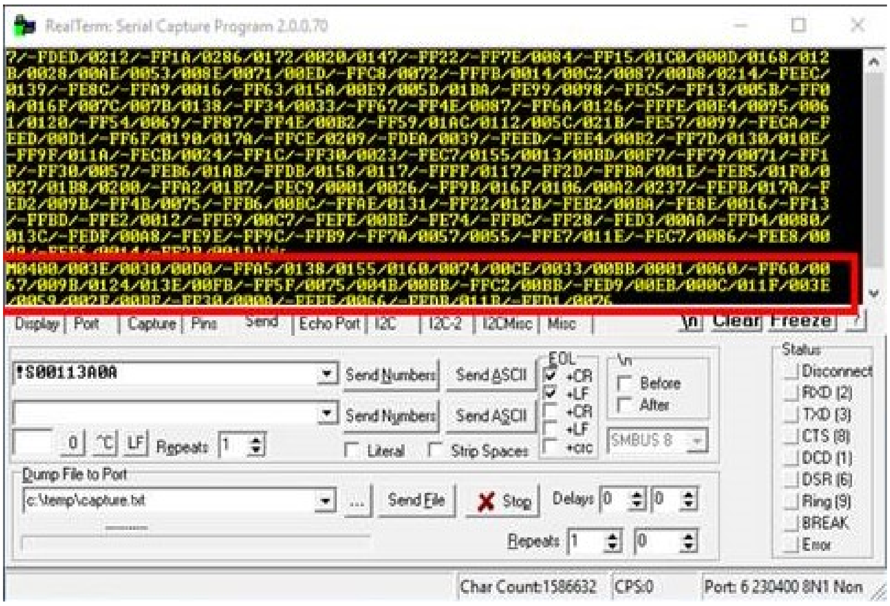


Figure 6 Send and Receive Using a Terminal Program

Calculate command strings by converting the desired command bits into HEX string format. An example command[4] is shown in Figure 7, the resulting HEX string is shown in Figure 8. Use zeros for any RESERVED (grey) fields.

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
SYS_CONFIG	SelfTrigDelay			reserved			LED		reserved							RAW	resl	AGC	Gain		SER2	SER1	EXT	ST	TL	P	C	R	DC	res	SLF	PRE
Binary	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**

Figure 7 Example: System Configuration Bits Settings

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
SYS_CONFIG	SelfTrigDelay			reserved			LED		reserved							RAW	resl	AGC	Gain		SER2	SER1	EXT	ST	TL	P	C	R	DC	res	SLF	PRE
HEX	**0**				**0**				**0**				**0**				**4**				**9**				**B**				**A**			

Figure 8 Example: System Configuration in HEX String Format

Add the start marker '!' and the frame identifier to the front of the HEX string command to form the command string. The command formats are explained in Section 3. For the example in Figure 8, you would get the command string

!S000049BA\r\n

Paste the command string into your terminal program and send it to the device. In "Realterm", the command can be pasted into the "Send" tab as shown in Figure 6. Then activate CR and LF, depending on if you already added "\r\n" to the command or not, to let "Realterm" add the stop markers to the string automatically, and then click "Send ASCII".

[4] Please refer to the relevant sections below for the actual command.

2.5 Output Mode Configuration (Examples)

Some examples of how to change the output modes are given in the following sub sections.

2.5.1 Change Output Mode and Data from the WebGUI (WebGUI, TSV or Binary)

- Open the Com2WebSocket tool, select 230400 baud or 1Mbaud (depending on the flashed firmware version), the correct COM port assigned to the kit by the OS, and connect to the kit
- Open the WebGUI and connect to the WebSocket provided by the Com2WebSocket tool
- (Optional) Set any desired RF, processing and target recognition parameters
- Change to the “Output Data” tab
- Chose the protocol type with the “Protocol Type” slider
- Select the desired output data checkboxes

From that moment on, the system transmits the selected data frames and it can be disconnected from the WebGUI and the Com2WebSocket tool, if needed.

2.5.2 Change to TSV Output Mode from a Terminal Program

- Find your desired bit settings in the “System Configuration” command, Section 3.3.1
- Set the “Protocol” bits in the “System Configuration” command to “001” (TSV)
- Send the command to the system

The output should change to the desired output mode.

2.5.3 Change to Binary Output Mode from a Terminal Program

- Find your desired bit settings in the “System Configuration” command, Section 3.3.1
- Set the “Protocol” bits in the “System Configuration” command to “010” (BIN)
- Send the command to the system

The output should change to the desired output mode.

2.5.4 Activate ADC Raw Data (I/Q) Output from a Terminal Program

- Use the “System Configuration” command settings from 2.5.2 or 2.5.3
- Find your desired bit settings in the “Baseband Configuration” command, Section 3.3.4

To enable un-windowed ADC raw data output:

- Set the “RAW” bit in the “System Configuration” command
- Unset the “WIN” bit in the “Baseband Configuration” command

To enable windowed ADC raw data output:

- Set the “RAW” bit in the “System Configuration” command
- Set the “WIN” bit in the “Baseband Configuration” command

To enable/disable DC cancellation:

- Set the “DC” bit in the “Baseband Configuration” command accordingly

Then send both commands to the device.

2.5.5 Activate Complex FFT Data Output from a Terminal Program

- Use the settings from 2.5.2 or 2.5.3
- Set the “CPL” bit in the “System Configuration” command
- Send the command to the device

3 Commands (Input)

3.1 Command Frames

Each command frame starts with ASCII value 33 (‘!’) as start marker and ends with two ASCII command characters (‘CR’ and ‘LF’) as stop marker, also see the blue parts in Figure 9. Orange parts indicate data parts (explained later in this section).

Command frames

Configuration command	Start	Identifier	Command settings (8 Digits)	Stop	
System configuration	!	S	SYS_CONFIG	CR	LF
Radar frontend config.		F	RFE_CONFIG		
PLL configuration		P	PLL_CONFIG		
Baseband configuration		B	BB_CONFIG		
Programming mode		W	ProgMode (fixed)		

Short command	Start	Identifier	Stop	
Get full error report	!	E	CR	LF
Get system info		I		
Do frequency scan		J		
Set to max. bandwidth		K		
Send Pre-Trigger		L		
Send Trigger		M		
Send both Triggers (L, M)		N		
Get version info		V		

!	Start Marker, Identifier and Stop Marker	
x	Hex Digit	[0,1,2,...,A,B,C,D,E,F]
c	Ascii Character	[decimal 34 .. 255]

Figure 9 Command Frames

3.2 Hardware and Software Compatibility

Table 8 Command Frames Compatibility with *SiRad Easy® r4* and WebGUI

Command Frame	Identifier	*SiRad Easy® r4*	WebGUI
System configuration	S	X	X
Radar front end configuration	F	X	X
PLL configuration	P	X	X
Baseband configuration	B	X	X
Programming mode	W	-	-
Get full error report	E	X	X
Get system info	I	X	X
Do frequency scan	J	X	X
Set to max. bandwidth	K	X	X
Send pre-trigger (optional)	L	X	-
Send (main) trigger	M	X	-
Send both triggers (L, M)	N	X	-
Get version info	V	X	X

3.3 Configuration (Long) Commands

The commands in Table 9 contains data for the configuration of the device and are explained in the following sections. The configuration commands are available in all output modes.

Table 9 Configuration Commands

Command Frame	Identifier	Answer	Description
System configuration	S	X	Configure basic functions of the system
Radar front end configuration	F	X	Configure front end base-frequency
PLL configuration	P	X	Configure the bandwidth of the frequency ramp
Baseband configuration	B	X	Configure baseband and processing related parameters

3.3.1 System Configuration

The system configuration command configures basic functions of the system, including triggering, LED, data output, and gain. When the ERR, ST, TL, P, C, R, CPL, or RAW bits are enabled, the according frame will be output after each measurement. Use these bits to switch the transmission of these frames on or off. Switching unnecessary frames off can increase the update rate of the device significantly.

Please note that, if the wrong connection option is selected, there will be no data displayed in the WebGUI. However, *SiRad Easy® r4* always listens on both serial ports, so reconfiguration is possible any time.

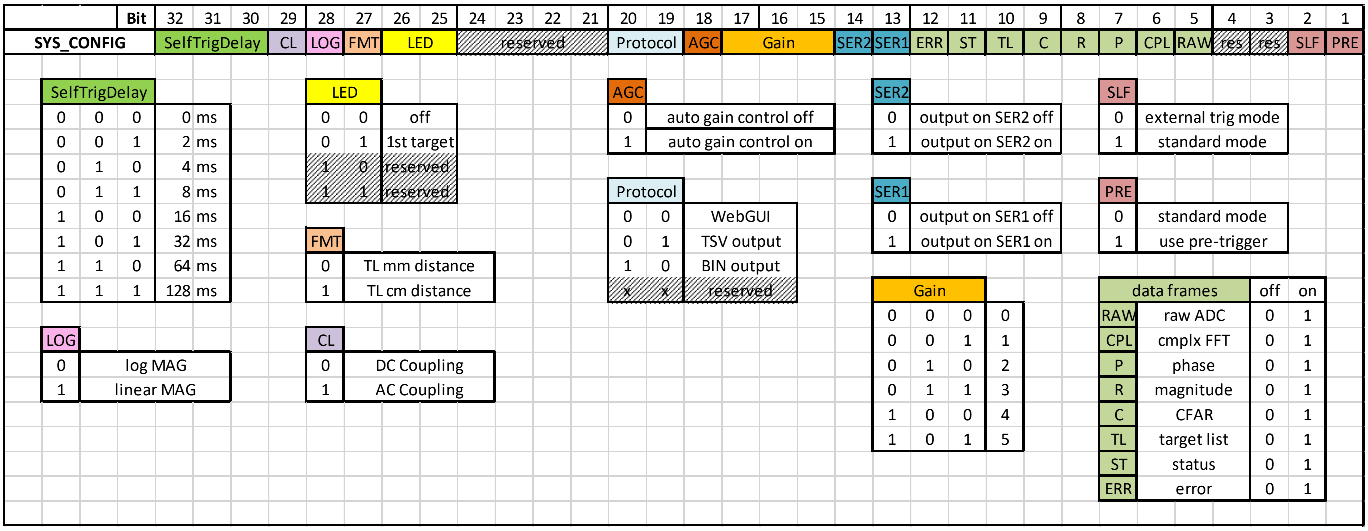


Figure 10 System Configuration Frame Format

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
SYS_CONFIG	SelfTrigDelay			CL	LOG	FMT	LED		reserved				Protocol		AGC	Gain			SER2	SER1	ERR	ST	TL	C	R	P	CPL	RAW	res	res	SLF	PRE
EASY 120 GHz	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	1	0
EASY 24 GHz	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	1	0

Figure 11 System Configuration Default Bit Settings

Table 10 System Configuration Default Commands

SYS_CONFIG command for device	Resulting command
SiRad Easy®	!S11022F82

Table 11 System Configuration Bits

Format Field	Field Size	Description
SelfTrigDelay	3 bits	Sets a delay time between Self-Trigger events
LOG	1 bit	Sets scaling type of magnitude data; when set to 0, magnitude data is in dB; **linear scaled magnitude outputs are ONLY useful for TSV or binary output format**
CL	1 bit	Coupling mode of Baseband amplifier
FMT	1 bit	Select the data output format: mm / cm
LED	2 bits	When set to 1st target rainbow, the LED displays the distance of the first recognized target as a color from blue (far) over green (medium range) to red (close). The current maximum range is used as a reference.
Protocol	2 bits	Protocol type for data output: WebGUI, TSV (tab separated values) and binary; **TSV and binary outputs are NOT displayed in the WebGUI**
AGC	1 bit	Auto Gain Control Mode: overrides the manual settings in the ‘Gain’ field. Uses 2 ramps at the beginning of the measurement or the pre-trigger phase for gain measurement (if ‘Pre-Trigger’ Mode is switched on).
Gain	3 bits	Manual gain setting; overridden by the AGC bit, which enables Auto Gain Control. See Table 1 for dB gain values
SER1	1 bit	UART connection to the pin header
SER2	1 bit	USB connection on the Easy; configuration data can be fed to the device using both UARTs at any time
ERR	1 bit	Enables the Error Information frame
ST	1 bit	Enables the Status Information frame
TL	1 bit	Enables the Target List frame
P	1 bit	Enables the Phase frame
C	1 bit	Enables the CFAR frame
R	1 bit	Enables the Magnitude / Range frame
CPL	1 bit	Enables the Complex FFT data frame; **NOT displayed in the WebGUI**
RAW	1 bit	Enables the ADC raw data (I/Q) frame; **NOT displayed in the WebGUI**
PRE	1 bit	Enable pre-trigger (applies only in External Trigger Mode)
SLF	1 bit	Switch between Self-Trigger and External Trigger Mode

3.3.2 Radar Front End Configuration

The radar front end configuration command configures the start (or base) frequency for the front end. The base frequency can be set in 250 kHz steps. Each front end has a slightly different minimum and maximum operating frequency due to production tolerances.

IMPORTANT:
The radar front ends are able to use a larger bandwidth than what is allowed in the ISM bands. In most countries, the bandwidth is limited to 1 GHz between 122 GHz and 123 GHz for production purposes by law. Please check your local regulations. It remains the customer’s responsibility to assure the operation of the front end according to local regulations, especially applying to frequency band allocations outside of the laboratory environment. Silicon Radar and its distributors will not accept any responsibility for consequences resulting from the disregard of these instructions and warnings.

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
RFE_CONFIG	reserved											Radar Frontend Base Frequency [MHz] (21 Bits)																				

Radar Frontend Base Frequency [MHz] (21 Bits)																						
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	kHz
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	250	kHz
…																					…	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	524287	MHz

Figure 12 Radar Front End Configuration Frame Format

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
RFE_CONFIG	reserved											Radar Frontend Base Frequency [MHz] (21 Bits)																				
EASY 120 GHz	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0
EASY 24 GHz	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0

Figure 13 Radar Front End Configuration Default Bit Settings

Table 12 Radar Front End Configuration Default Commands

RFE_CONFIG command for device	Base Frequency	Resulting Command
SiRad Easy® @24 GHz	24000 MHz	!F00017700
SiRad Easy® @120 GHz	120000 MHz	!F00075300

Table 13 Radar Front End Configuration Bits

Format Field	Field Size	Description
RF Base frequency	21 bits	The base-frequency plus chosen bandwidth should not exceed the maximum operating frequency

3.3.3 PLL Configuration

The PLL configuration command sets the bandwidth for the radar front end. The bandwidth can be configured in 2 MHz steps. A negative bandwidth can be set as well, the charge pump output of the PLL will be inverted.

IMPORTANT:
The radar front ends are able to use a larger bandwidth than what is allowed in the ISM bands. In most countries, the bandwidth is limited to 1 GHz between 122 GHz and 123 GHz for production purposes by law. Please check your local regulations. It remains the customer's responsibility to assure the operation of the front end according to local regulations, especially applying to frequency band allocations outside of the laboratory environment. Silicon Radar and its distributors will not accept any responsibility for consequences resulting from the disregard of these instructions and warnings.

Bit	32–17	16–1
PLL_CONFIG	reserved	Bandwidth [MHz] (16 Bits)

Bandwidth [MHz] (16 Bits)																
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-2 MHz
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	-4 MHz
...																...
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-65536 MHz
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 MHz
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2 MHz
...																...
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	+65534 MHz

Figure 14 PLL Configuration Frame Format

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
PLL_CONFIG	reserved																Bandwidth [MHz] (16 Bits)															
EASY 24 GHz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	0	0
EASY 120 GHz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	1	0	0

Figure 15 PLL Configuration Default Bit Settings

Table 14 PLL Configuration Default Commands

PLL_CONFIG command for device	Bandwidth	Resulting Command
SiRad Easy® @24 GHz	1000 MHz	!P000001F4
SiRad Easy® @120 GHz	5000 MHz	!P000009C4

Table 15 PLL Configuration Bits

Format Field	Field Size	Description
Bandwidth	16 bits	Negative values result in falling ramp slope, positive values in a rising saw tooth; representation in two's complement

Table 16 Minimum Full Bandwidth per Radar Front End

Radar Front End	Bandwidth	Resulting Command
TRX_120_046	2600 MHz	!P00000514
TRX_120_001	5500 MHz	!P00000ABE
TRA_120_002	5500 MHz	!P00000ABE
TRA_120_045	14200 MHz	!P00001BBC

3.3.4 Baseband Configuration

The baseband configuration command configures baseband and processing related parameters: sampling parameters, DC cancellation, windowing, down sampling, FIR Filter, FFT parameters, and CFAR parameters.

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
BB_CONFIG	WIN	FIR	DC	CFAR		CFAR Threshold [dB]				CFAR Size				CFAR Grd		Average n		FFT Size			Downsampling			# Ramps			# Samples			ADC ClkDiv		

WIN	
0	windowing off
1	windowing on

FIR	
0	FIR filter off
1	FIR filter on

DC	
0	DC cancellation off
1	DC cancellation on

FFT Size			
0	0	0	32
0	0	1	64
0	1	0	128
0	1	1	256
1	0	0	512
1	0	1	1024
1	1	0	2048
1	1	1	reserved

Downsampling			
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	4
1	0	0	8
1	0	1	16
1	1	0	32
1	1	1	64

# Ramps			
0	0	0	1
0	0	1	2
0	1	0	4
0	1	1	8
1	0	0	16
1	0	1	32
1	1	0	64
1	1	1	128

# Samples			
0	0	0	32
0	0	1	64
0	1	0	128
0	1	1	256
1	0	0	512
1	0	1	1024
1	1	0	2048
1	1	1	reserved

ADC ClkDiv			MS/s
0	0	0	1.800
0	0	1	1.000
0	1	0	0.675
0	1	1	0.397
1	0	0	0.28125
1	0	1	0.218
1	1	0	0.173
1	1	1	0.055

CFAR		
0	0	CA-CFAR
0	1	GO-CFAR
1	0	SO-CFAR
1	1	reserved

CFAR Threshold [dB]				dB
0	0	0	0	0
0	0	0	1	2
				...
1	1	1	1	30

CFAR Size				
0	0	0	0	0
0	0	0	1	1
...				
1	1	1	1	15

CFAR Grd		
0	0	0
0	1	1
1	0	2
1	1	3

Average n		
0	0	0
0	1	1
1	0	2
1	1	3

Figure 16 Baseband Setup Frame Format

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
BB_CONFIG	WIN	FIR	DC	CFAR		CFAR Threshold [dB]				CFAR Size				CFAR Grd		Average n		FFT Size			Downsampling			# Ramps			# Samples			ADC ClkDiv		
EASY	1	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	1	1	0	0	0	0	0	1	0	0	1	0	0	1	0	1

Figure 17 Baseband Setup Default Bit Settings

Table 17 Baseband Setup Default Commands

BB_CONFIG command for device	Resulting Command
SiRad Easy®	!BA452C122

Table 18 Baseband Setup Bits

Format Field	Field Size	Description
WIN	1 bit	Enables Windowing on the samples before performing the FFT
FIR	1 bit	Enables the FIR filter
DC	1 bit	Enables digital de-trending and static offset compensation
CFAR	2 bits	Select the CFAR operator
CFAR Threshold	4 bits	CFAR threshold value added to average of the CFAR operator; value range is 0 to 30 in step size of 2
CFAR Size	4 bits	Number of cells left and right of the CFAR guard interval; value range is 0 to 15
CFAR Guard	2 bits	Number of guard cells left and right of the cell under test; value range is 0 to 3
Average n	2 bits	Selects how many FFTs are averaged
FFT Size	3 bits	Number of FFT points
Down Sample	3 bits	Down sampling factor
#Ramps	3 bits	Number of ramps used for each measurement
#Samples	3 bits	Number of samples used for each measurement
ADC ClkDiv	3 bits	Select the sampling frequency

Ramp time: The ramp time t is calculated using the selected sampling time t_{Smp} according to Table 19, the number of samples n_{Smp} and the set clock frequency of the ADCs according to Figure 16 / Table 19, like

Equation 1 Ramp Time

$$t\ [us] = t_{Smp}\ [clock\ cycles] * (n_{Smp} + 55) / (27\ MHz),$$

where 55 samples is a fixed overhead and 27 MHz the set sampling speed of the ADC.

Table 19 Sampling time and sample frequency

ADC ClkDiv	ADC sampling time t_{Smp} [clock cycles]	Sample frequency [MS/s]
0	15	1.800
1	27	1.000
2	40	0.675
3	68	0.397
4	96	0.28125
5	124	0.218
6	156	0.173
7	492	0.055

Accuracy: the width of one distance bin according to

Equation 2 Accuracy

$$acc = c * (n_{Smp} + 55) / (2 * BW * n_{FFT} * 2^{ndown})$$

where c is the speed of light, BW the bandwidth, n_{Smp} the number of samples, 55 samples a fixed overhead, n_{FFT} the FFT size, and n_{down} the down sampling factor.

Downsampling: determines how many samples are averaged after sampling. Higher down sampling values improve the accuracy but reduce the maximum range. Voids are filled with zeroes when down sampling. A down sampling factor of 0 means no down sampling, 1 means average of 2 values, 2 means average of 4 values, etc.

3.4 Special Function (Short) Commands

The following short commands do not contain any data and perform a single request or action only. They are available in all output modes but their answers are only sent in WebGUI output format. Please see Section 4 for their formats.

Table 20 Special Function Commands

Command Frame	Identifier	Answer	Description
Programming mode	W	-	Go to programming mode for flashing the device
Get detailed error report	E	X	Request detailed error report
Get system info	I	X	Request system info data
Do frequency scan	J	-	Scan true min and max frequency of the RFE and sets start frequency to true min frequency
Set to max. bandwidth	K	-	Set bandwidth according to the scanned true min and max frequencies of the RFE
Send pre-trigger (optional)	L	-	Send pre-trigger for an automatic gain measurement (AGC Mode)
Send (main) trigger	M	-	Send a trigger for a measurement
Send both triggers (L, M)	N	-	Send pre-trigger and main trigger in one command
Get version info	V	X	Request version info data

3.5 Timing and UART Receive Buffer

There are no timing constraints when sending commands to the device, however, the UART receive buffer in the device has a limited size of 128 bytes, which limits the number of commands that can be send in a row. This has to be taken into consideration when sending commands to the device. Commands are processed after each measurement cycle. If multiple commands need to be sent in a row and their total size exceeds 128 bytes, they have to be split and a part of them has to be sent after the next measurement cycle.

4 WebGUI Output Mode (Default)

Once the devices is plugged to the USB, it begins sending WebGUI data. Figure 18 shows some of the supported WebGUI data frames and Figure 19 lists their purpose. The data is transmitted in blocks of certain data frames that are tied together in a single transmission, as highlighted in Figure 18. In the figure, two data blocks are marked red. Each data block ends with ASCII value 32 (‘ ‘, space) and additional stop marker and can contain multiple data frames of different size. In the example in Figure 18, the data blocks contain 5 data frames each. One data frame in the upper block is marked blue. Each data frame starts with ASCII value 33 (‘!’) as start marker and ends with two ASCII command characters (‘CR’ and ‘LF’) as stop marker.

The blue parts in Figure 19 indicate start and stop markers and the frame identifier, orange and green parts indicate data parts and grey parts indicate reserved parts that should not be used. Each frame type is recognized by a unique identifier (a certain letter) following the start marker of the frame. The frame types are of different size.

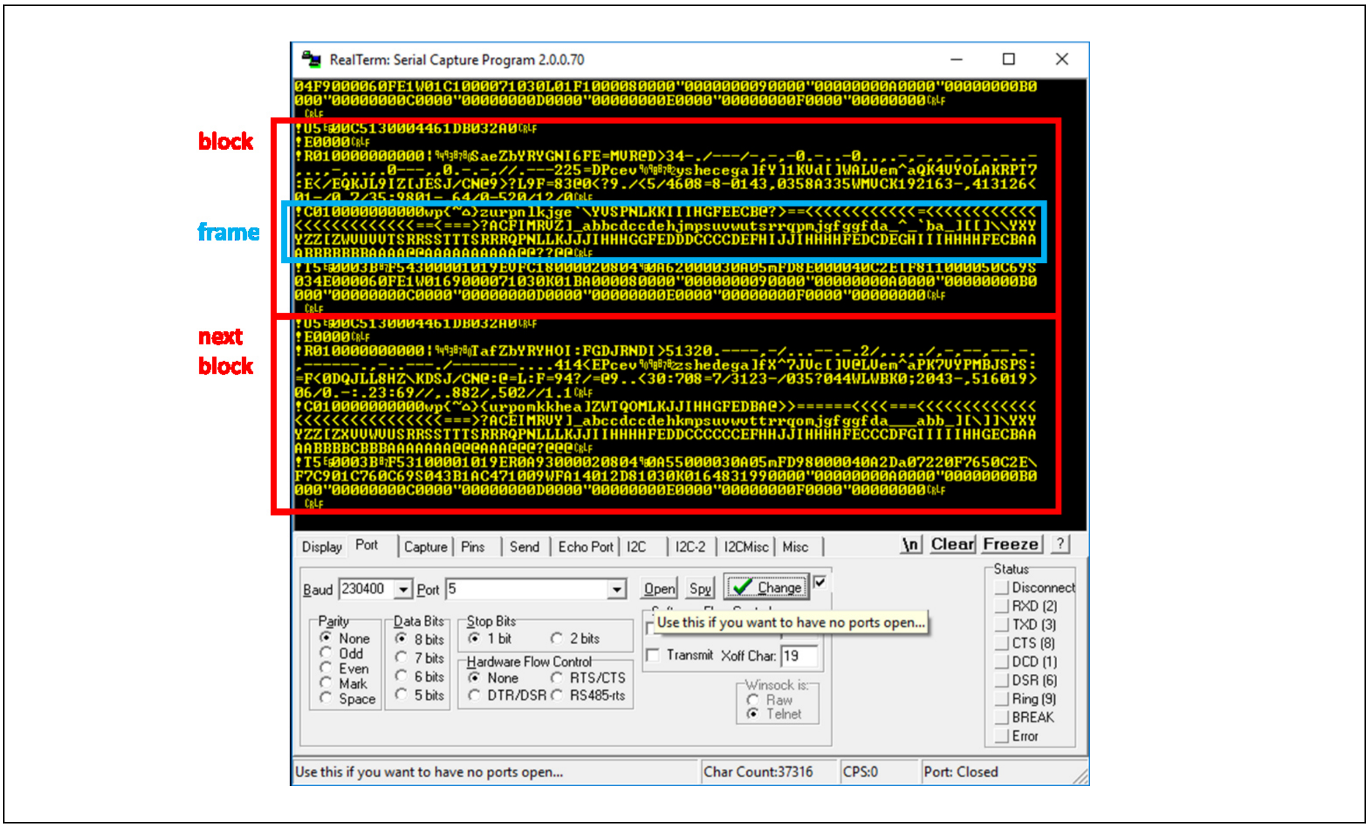


Figure 18 WebGUI Data (Default Communication) in a Terminal Window

WebGUI data frames

FFT and CFAR data	Start	Identifier	Size n (4 Digits)	reserved (4 Digits)	reserved (4 Digits)	Data (n Digits) --->	Stop
Magnitude/Range frame	!	R	x x x x	x x x x	x x x x	c c c c c c ... c	CR LF
Phase frame		P					
CFAR frame		C					

Target information	Start	Identifier	Format	Gain	Target #	Distance (4 Digits)	Mag	Phi (4 Digits)	reserved (4 Digits)	...	Stop
					Block, repeated 16 times --->						
Target list frame	!	T	x	c	x	x x x x	c	x x x x	x x x x	...	CR LF

Status information	Start	Identifier	Format	Gain	Accuracy (4 Digits)	Max. range (4 Digits)	Ramp time (4 Digits)	Bandwidth (4 Digits)	Time diff. (4 Digits)	Stop
Status update frame	!	U	x	c	x x x x	x x x x	x x x x	x x x x	x x x x	CR LF

Version information	Start	Identifier	Length	UID tag	'U' len L1	UID (L1)	HW tag	'H' len L2	HW (L2)	PLL tag	'P' len L3	PLL (L3)	Q tag	'Q' len L4	Q (L4)
Version info frame	!	V	x x x x	'U'	x x	L1 * x	'H'	x x	L2 * x	'P'	x x	L3 * x	'Q'	x x	L4 * x

ADC tag	'A' len L5	ADC (L5)	RFE tag	'F' len L6	RFE (L6)	SW tag	'S' len L7	SW (L7)	CP tag	'C' len L8	CP (L8)	Stop
'A'	x x	L5 * x	'F'	x x	L6 * x	'S'	x x	L7 * x	'C'	x x	L8 * x	CR LF

System information	Start	Identifier	Microcontroller UID (24 Digits)	reserved	RFE MinFreq (5 Digits)	RFE MaxFreq (5 Digits)	Stop
System info frame	!	I	x x x x ... x	x x	x x x x x	x x x x x	CR LF

Detailed error report	Start	Identifier	Error flags (8 Digits)	Stop
Detailed error report	!	E	x x x x x x x x	CR LF

Error information	Start	Identifier	Error flags (4 Digits)	Stop
Error info frame	!	E	x x x x	CR LF

!	Start Marker, Identifier and Stop Marker	
x	Hex Digit	[0,1,2,...,A,B,C,D,E,F]
c	Ascii Character	[decimal 34 .. 255]
c	Ascii Character	any char value

Figure 19 WebGUI Data Frame Formats (Default Communication)

4.1 Magnitude/Range, Phase and CFAR Output

The range frame contains the magnitude output of the FFT, the phase frame contains the argument or phase of the FFT. The CFAR frame contains the output of the CFAR operator that is used to detect targets. The range frame, phase frame and CFAR frame share the same frame formats, please see Figure 20. The start and stop markers and frame identifiers are highlighted in blue, data parts in orange and green color, reserved parts with grey stripes.

The size of this frame depends on the chosen FFT size. A certain FFT size will lead to half of the size of the FFT in the 'Size' field only. The FFT output is mirrored along the magnitude axis, so both parts are added together before the transmission and the length of the transmitted data is only half of the FFT output. The phase scaling factor is 110 for the WebGUI protocol.

FFT and CFAR data	Start	Identifier	Size n (4 Digits)	reserved (4 Digits)	reserved (4 Digits)	Data (n Digits)	Stop	Stop
Range frame	!	R	x x x x	x x x x	x x x x	c c c c c c ... c	CR	LF
Phase frame		P						
CFAR frame		C						

Figure 20 WebGUI Range, Phase and CFAR Data Frame Format

Table 21 WebGUI Range, Phase and CFAR Data Bits

Format Field	Field Size	Encoding	Example	Interpretation	Allowed Values
Size	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 512	0 to 65535	'0010', '0020', '0040', '0080', '0100', ...
Data (R and C frame)	n digits	characters between decimal value 34 and 254	letter 'Z' -> decimal 90	-140 to +80 dB in 220 steps	34 to 254
Data (P frame)	n digits	characters between decimal value 34 and 254	letter 'Z' -> decimal 90	-π to +π rad (-180° to +180°) in 220 steps	34 to 254

4.2 Target Information

The target list contains the targets recognized by the CFAR operator. A target is detected whenever the magnitude of the FFT exceeds the CFAR operator's threshold. The local maximum of that area is marked as a target. The target list's frame format is shown in Figure 21.

The target information is repeated 16 times in the target list. All 16 target information blocks are sent, regardless whether the target blocks are filled with detected targets or not. Empty target information blocks of the list are filled with zeros. Each target information block consists of the 'Target #', 'Distance', 'Magnitude', and 'Phase' fields.

					repeated 16x							
Target information	**Start**	**Identifier**	**Format**	**Gain**	**Target #**	**Distance (4 Digits**	**Mag**	**Phi (4 Digits)**	**reserved (4 Digits)**	**...**	**Stop**	**Stop**
Target list frame	!	T	x	c	x	x x x x	c	x x x x	x x x x	...	CR	LF

Figure 21 WebGUI Target List Data Frame Format

Table 22 WebGUI Target List Data Bits

Format Field	Field Size	Encoding	Example	Interpretation	Allowed Values
Format	1 digit	unsigned HEX between '0' and 'F'	'F' -> 15	0 to 15	'0,1'
Gain	1 digit	character between decimal value 34 and 254, also see Table 1	letter 'Z' -> decimal 90	-140 to +80 dB in 220 steps	See Table 1
Target #	1 digit	unsigned HEX between '0' and 'F'	'F' -> 15	0 to 15	'0' to 'F'
Distance	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 512	0 to 65535 in chosen unit	'0000' to 'FFFF'
Magnitude	1 digit	character between decimal value 34 and 254	letter 'Z' -> decimal 90	-140 to +80 dB in 220 steps	34 to 254
Phase	4 digits	signed HEX between '0000' and 'FFFF'	'0200' -> 512	-32768 to +32767 (-π to +π rad)	110*(-π to +π rad)
Format	4 digits	unsigned HEX between '0' and 'F'	'F' -> 15	0 to 15	'0,1'

Table 23 WebGUI Target List Data - Format Field

Format (HEX)	Description
0	distance in mm
1	distance in cm

4.3 Status Update

The status update frame in Figure 22 is a feedback of the current accuracy, range, ramp time, and ramp bandwidth and also returns the time difference since the last measurement. The time difference data is interpreted as values between 0 and 65535, which translates to 0 to 0.65535 seconds in 10 ms steps. For example, 'Time diff.' = 0200 is interpreted as 0x0200, which is 512 in decimal range. The time difference counter runs at 100 kHz and is configured as an overflowing 16-bit counter. Each tick lasts 10 ms and the counter overflows at 0.65535 seconds. Therefore, the minimum unambiguous measurement frequency is 1.5 Hz.

Status information	**Start**	**Identifier**	**Format**	**Gain**	**Accuracy (4 Digits)**	**Max. range (4 Digits)**	**Ramp time (4 Digits)**	**Bandwidth (4 Digits)**	**Time diff. (4 Digits)**	**Stop**	**Stop**
Status update frame	!	U	x	c	x x x x	x x x x	x x x x	x x x x	x x x x	CR	LF

Figure 22 WebGUI Status Update Data Frame Format

Table 24 WebGUI Status Update Data Bits

Format Field	Field Size	Encoding	Example	Interpretation	Allowed Values
Format	1 digit	unsigned HEX digit between '0' and 'F'	'F' -> 15	0 to 15	'0, 1'
Gain	1 digit	character between decimal value 34 and 254, also see Table 1	letter 'Z' -> decimal 90	-140 to +80 dB in 220 steps	See Table 1
Accuracy	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 512	0 to 65535 (0 to 6553.5 mm)	'0000' to 'FFFF'
Max. Range	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 512	0 to 65535 in chosen unit	'0000' to 'FFFF'
Ramp time	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 512	0 to 65535 in us	'0000' to 'FFFF'
Bandwidth	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 1024, in 2 MHz steps	-32768 to +32767, Interpretation = -65536 to 65534 in MHz (2 MHz steps)	'0000' to 'FFFF'
Time diff.	4 digits	unsigned HEX between '0000' and 'FFFF'	'0200' -> 512	0 to 65535 (0 to 0.65535 s)	'0000' to 'FFFF'

4.4 Error Information

The error info frame includes error bits that may be raised temporarily during the signal processing of the radar data and may be removed when changing the settings. This frame will be send by default and can be deactivated by setting 0 to the "ERR" bit in the system configuration command. The 'Error flags' field is transmitted as a 4 byte unsigned HEX number (marked with 'x' in Figure 23). Figure 24 shows the error bits in the 'Error flags' field.

Error information	Start	Identifier	Error flags (4 Digits)	Stop	Stop
Error info frame	!	E	x x x x	CR	LF

Figure 23 WebGUI Error Information Data Frame Format

Error domains:

- FLS: <reserved>
- PRC: temporary errors in the signal processing
- BB: temporary baseband processing errors
- PLL: temporary PLL configuration errors
- RFE: temporary radar front end configuration errors
- CRC: temporary errors in the UART transmission or CRC checksum

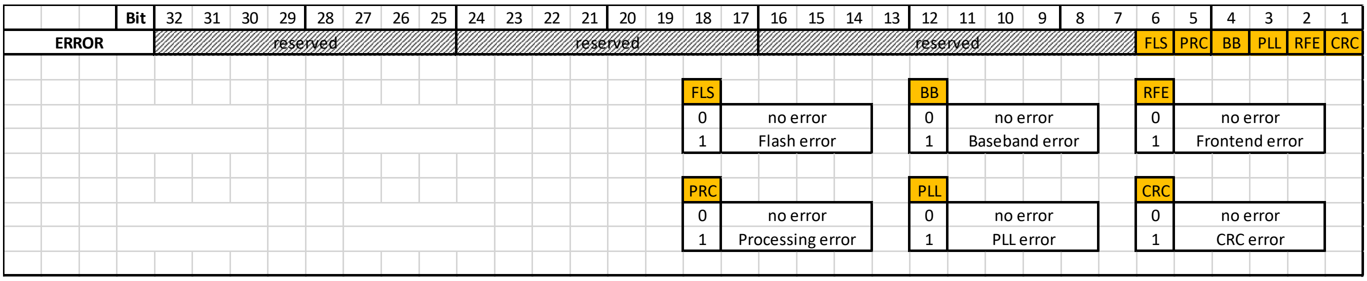


Figure 24 WebGUI Error Information Data Bits

4.5 !E Command – Answer: Detailed Error Report

The detailed error report contains error bits that may be raised temporarily during the signal processing of the radar data and may be removed when changing the settings. This frame contains specific error information, other than the standard Error Information frame explained in Section 4.4, which reports only the processing domains that experience an error. Also see Section 4.4 for on overview of the Error domains.

Detailed error report	Start	Identifier	Error flags (8 Digits)	Stop	
Detailed error frame	!	E	x x x x x x x x	CR	LF

Figure 25 WebGUI Detailed Error Report Frame Format

Bit	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
ERROR_DETAILED	CRC	CRC	CRC	CRC	FLS	FLS	FLS	FLS	FFT	FFT	FFT	FFT	ADC	ADC	ADC	ADC	AMP	AMP	AMP	AMP	PLL	PLL	PLL	PLL	RFE	RFE	RFE	RFE	RFE	RFE	RFE	RFE

Group	Label	0	1
CRC		no error	reserved
CRC		no error	reserved
CRC		no error	reserved
CRC		no error	reserved
FLS		no error	reserved
FLS		no error	reserved
FLS		no error	reserved
FLS		no error	reserved
FFT		no error	reserved
FFT		no error	reserved
FFT		no error	reserved
FFT		no error	reserved
ADC		no error	reserved
ADC		no error	reserved
ADC	bit number 18	no error	DC error
ADC	bit number 17	no error	Sample overrun
AMP		no error	reserved
AMP		no error	reserved
AMP		no error	reserved
AMP	bit number 13	no error	Saturation
PLL		no error	reserved
PLL	bit number 11	no error	Lock loss
PLL	bit number 10	no error	Fmax not found
PLL	bit number 9	no error	Fmin not found
RFE		no error	reserved
RFE		no error	reserved
RFE	bit number 6	no error	RFE out of spec
RFE	bit number 5	no error	reserved
RFE	bit number 4	no error	BW overrun
RFE	bit number 3	no error	BW underrun
RFE	bit number 2	no error	Fbase high
RFE	bit number 1	no error	Fbase low

Figure 26 WebGUI Detailed Error Report Bits

4.6 !I Command – Answer: System Information

The system info frame is used to uniquely identify SiRad Evaluation Kits and return Firmware information.

System information	Start	Identifier	Microcontroller UID (24 Digits)	reserved	RFE MinFreq (5 Digits)	RFE MaxFreq (5 Digits)	Stop	
System info frame	!	I	x x x x x x x x x x ... x	x x	x x x x x	x x x x x	CR	LF

Figure 27 WebGUI System Information Data Frame Format

Table 25 WebGUI System Information Bits

Format Field	Field Size	Encoding	Example	Interpretation	Allowed Values
Microcontroller UID	24 digits	HEX string	'800F0011570A 463332322039'	-	-
RFE MinFreq	5 digits	HEX string between '00000' and 'FFFFF'	'07436	119000 MHz	0 to 524287 MHz
RFE MaxFreq	5 digits	HEX string between '00000' and 'FFFFF'	'07A12	125000 MHz	0 to 524287 MHz

4.7 !V Command – Answer: Version Information

The version frame is used to uniquely identify the evaluation kit and returns information about the hardware and firmware.

Version information	Start	Identifier	Length	UID tag	'U' len L1	UID (L1)	HW tag	'H' len L2	HW (L2)	PLL tag	'P' len L3	PLL (L3)	Q tag	'Q' len L4	Q (L4)
Version info frame	!	V	x x x x	'U'	x x	L1 * x	'H'	x x	L2 * x	'P'	x x	L3 * x	'Q'	x x	L4 * x
			ADC tag	'A' len L5	ADC (L5)	RFE tag	'F' len L6	RFE (L6)	SW tag	'S' len L7	SW (L7)	CP tag	'C' len L8	CP (L8)	Stop
			'A'	x x	L5 * x	'F'	x x	L6 * x	'S'	x x	L7 * x	'C'	x x	L8 * x	CR LF

Figure 28 WebGUI Version Information Data Frame Format (WebGUI Output Format Only)

Table 26 WebGUI Version Information Bits

Format Field	Field Size	Description
Length	4 HEX digits	Length of frame excluding start marker, identifier, length field itself, stop markers
UID tag	1 digit	Indicates start of the microcontroller UID info
UID length	2 HEX digits	Length of the UID field
UID	variable	The microcontroller UID is a unique unsigned HEX number
HW tag	1 digit	Indicates start of the hardware info
HW length	2 HEX digits	Length of the HW field
HW	variable	Baseboard hardware identifier, 'EA' for SiRad Easy®
PLL tag	1 digit	Indicates start of the PLL info
PLL length	2 HEX digits	Length of the PLL field
PLL	variable	PLL chip identifier, '59' for the ADF4159
Q tag	1 digit	Indicates start of the clock info
Q length	2 HEX digits	Length of the Q field
Q	variable	CLK chip identifier
ADC tag	1 digit	Indicates start of the ADC info
ADC length	2 HEX digits	Length of the ADC field
ADC	variable	Operating mode of the ADC, 'I' for interleaved, 'N' non-interleaved
RFE tag	1 digit	Indicates start of the radar front end info
RFE length	2 HEX digits	Length of the RFE field
RFE	variable	Radar front end chip identifier of firmware
SW tag	1 digit	Indicates start of the software / firmware info
SW length	2 HEX digits	Length of the SW field
SW	variable	Firmware version in format: <check-in ID >-<date >-<major>.<minor>.<revision>
CP tag	1 digit	Indicates start of the communication protocol info
CP length	2 HEX digits	Length of the CP field
CP	variable	Protocol version in format: <protocol ID>-<spec date>-<major>.<minor>.<revision>

Table 27 RFE Types

RFE Field	Description
024_x6	TRX_024_046
120_01	TRX_120_001
120_02	TRA_120_002
120_45	TRA_120_045

5 TSV Output Mode

Figure 29 shows the supported TSV output frames and Figure 30 lists their purpose. The TSV protocol has a limited set of data frames. When the TSV output is activated, the data is in decimal range. Therefore, the TSV data frames can be configured to transmit the raw data of the ADC. The blue parts in Figure 30 indicate start and stop markers, frame identifiers and delimiters as well as signs, yellow indicates data parts with string numbers of variable length.

The WebGUI output frames for the version info (!V), system info (!I), and the error frames (!E), can be used together with the TSV output mode but there is no TSV representation of these frames. They will be transmitted in WebGUI format, if requested.

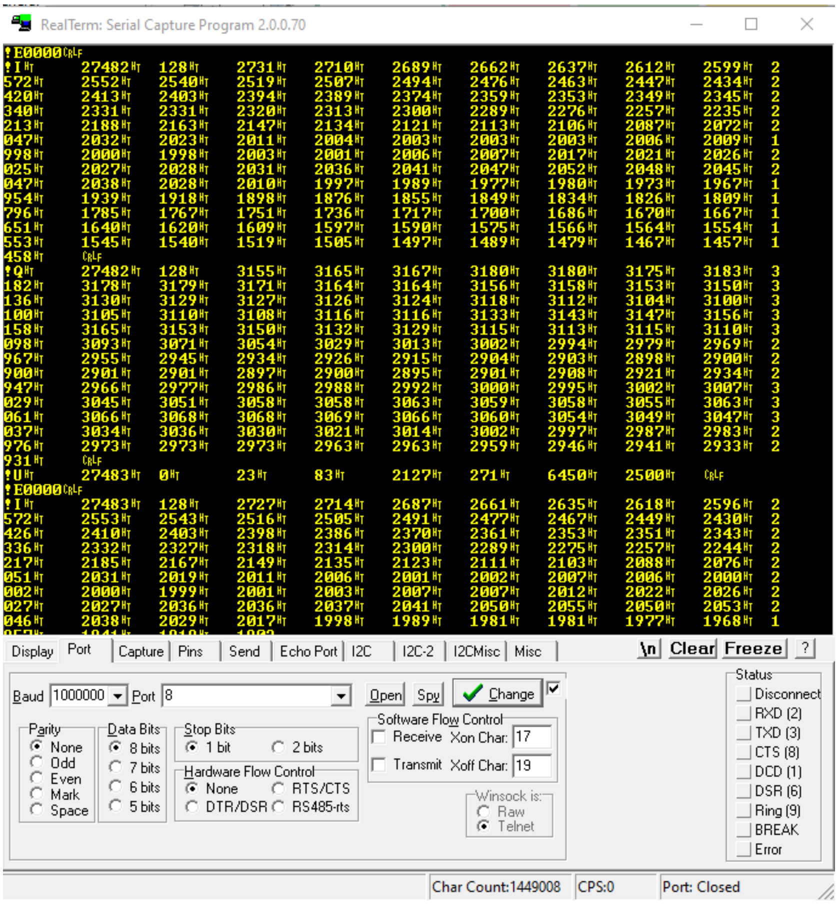


Figure 29 TSV Data Frame (!I and !Q Frame) in a Terminal Window

All TSV frames begin with a start marker (1 byte) and identifier (1 byte) followed by a counter (2 byte). The counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The counter automatically overflows to 0 after reaching the maximum value 65535. Values are separated by a tab delimiter. Frames end with a stop marker (‘CR’ and ‘LF’).

TSV data frames

								Block, repeated 'Size' times --->				
ADC, FFT and CFAR data	**Start**	**Identifier**	**Del**	**Cnt**	**Del**	**Size**	**Del**	**Sgn**	**Data**	**Del**	**Stop**	
Magnitude/Range frame		R										
Phase frame		P										
CFAR frame	!	C	/t	n	/t	n	/t	-	n	/t	CR	LF
ADC data frame (I)		MI										
ADC data frame (Q)		MQ										

! Start Marker, Identifier and Stop Marker
n String Number any length

										Block, repeated 16 times --->													
Target information	**Start**	**Identifier**	**Del**	**Cnt**	**Del**	**Format**	**Del**	**Gain**	**Del**	**Target #**	**Del**	**Distance**	**Del**	**Sgn**	**Mag**	**Del**	**Sgn**	**Phase**	**Del**	**res.**	**Del**	**Stop**	
Target list frame	!	T	/t	n	/t	n	/t	c	/t	n	/t	n	/t	-	n	/t	-	n	/t	n	/t	CR	LF

Status information	**Start**	**Identifier**	**Del**	**Cnt**	**Del**	**Format**	**Del**	**Gain**	**Del**	**Accuracy**	**Del**	**Max. range**	**Del**	**Ramp time**	**Del**	**Sgn**	**Bandwidth**	**Del**	**Time diff.**	**Del**	**Stop**	
Status update frame	!	U	/t	n	/t	n	/t	c	/t	n	/t	n	/t	n	/t	-	n	/t	n	/t	CR	LF

Figure 30 TSV Data Frame Formats

5.1 ADC, Magnitude/Range, Phase and CFAR Output

The 'Size' field indicates the number of transmitted data points. The value range of the data differs with the content of the frame. The value range of ADC/Magnitude/Range, Phase, and CFAR data is -32768 to +32767. The value range of the raw ADC data for 1 ramp is 12 bits (0 to 4096).

The size of the ADC data is always 2 times the number of samples, when no down sampling is configured.

								Block, repeated 'Size' times --->				
ADC, FFT and CFAR data	**Start**	**Identifier**	**Del**	**Cnt**	**Del**	**Size**	**Del**	**Sgn**	**Data**	**Del**	**Stop**	
Magnitude/Range frame		R										
Phase frame		P										
CFAR frame	!	C	/t	n	/t	n	/t	-	n	/t	CR	LF
ADC data frame (I)		MI										
ADC data frame (Q)		MQ										

Figure 31 TSV ADC, Magnitude, Phase and CFAR Data Frame Format

Table 28 TSV ADC, Magnitude, Phase and CFAR Data Values

Format Field	Content	Encoding	
Del	Delimiter	\t	
Cnt	Measurement cycle counter	decimal between 0 to 65535	decimal between 0 to 65535
Size	Size of the transmitted data	decimal between 0 to 65535	
Sgn	Sign indicator		
Data	FFT/ Raw Data/ADC	decimal between -32768 to +32767	decimal between -32768 to +32767
	Magnitude/ Range/ CFAR	decimal between -32768 to +32767	-140 to 0 (dB unit)
	Phase	decimal between -32768 to +32767	100000*(-π to +π rad)

5.2 Target Information

The theoretical value range of the target Magnitude is -32768 to +32767, however, the typical value range is -140 to 0 (dB).

										Block, repeated 16 times --->													
Target information	**Start**	**Identifier**	**Del**	**Cnt**	**Del**	**Format**	**Del**	**Gain**	**Del**	**Target #**	**Del**	**Distance**	**Del**	**Sgn**	**Mag**	**Del**	**Sgn**	**Phase**	**Del**	**res.**	**Del**	**Stop**	
Target list frame	!	T	/t	n	/t	n	/t	c	/t	n	/t	n	/t	-	n	/t	-	n	/t	n	/t	CR	LF

Figure 32 TSV Target List Data Frame Format

Table 29 TSV Target List Data Values

Format Field	Content	Encoding
Del	Delimiter	\t
Cnt	Measurement cycle counter	decimal between 0 to 65535
Format	Indicates the distance unit	decimal between 0-1
Gain	Indicates the current gain level	decimal dB values, see Table 1
Target #	Indicates the target number	decimal between 0-15
Distance	Target distance	decimal between 0 to 65535
Sgn	Sign indicator	
Magnitude	Magnitude of the target	decimal between -32768 to +32767
Phase	Phase value of the target	decimal between -32768 to +32767

Table 30 TSV Target List Data and Status Update Data - Format Field

Format (HEX)	Description
0	distance in mm
1	distance in cm

5.3 Status Update

In the TSV status update frame, the unit for the ramp time is us and for the bandwidth MHz. To convert the accuracy into mm, the data should be divided by 10. If the accuracy field says 271, the system accuracy is 27.1 mm. The time difference field indicates the time since the last measurement. The time difference data is interpreted as values between 0 and 65535, which translates to 0 to 0.65535 seconds in 10 ms steps. For example, 'Time diff.' = 0200 is interpreted as 0x0200, which is 512 in decimal range. The time difference counter runs at 100 kHz and is configured as an overflowing 16-bit counter. Each tick lasts 10 ms and the counter overflows at 0.65535 seconds. Therefore, the minimum unambiguous measurement frequency is 1.5 Hz.

Status information	Start	Identifier	Del	Cnt	Del	Format	Del	Gain	Del	Accuracy	Del	Max. range	Del	Ramp time	Del	Sgn	Bandwidth	Del	Time diff.	Del	Stop	
Status update frame	!	U	/t	n	/t	n	/t	c	/t	n	/t	n	/t	n	/t	-	n	/t	n	/t	CR	LF

Figure 33 TSV Status Update Data Frame Format

Table 31 TSV Status Update Data Values

Format Field	Content	Encoding
Del	Delimiter	\t
Cnt	Measurement cycle counter	decimal between 0 to 65535
Format	Indicates the distance unit	decimal between 0-1
Gain	Indicates the current gain level	decimal dB values, see Table 1
Accuracy	Device accuracy	decimal between 0 to 65535
Max. range	Maximum range of device	decimal between 0 to 65535
Ramp time	Length of the ramp in us	decimal between 0 to 65535
Bandwidth	Bandwidth in MHz	decimal between-32768 to +32767, Interpretation = -65536 to 65534 in MHz (2 MHz steps)
Time difference	Indictor for update rate	decimal between 0 to 65535

6 Binary Output Mode

Figure 34 shows the binary output format and Figure 35 lists the binary output frames and their purpose. The blue parts indicate header and stop markers, purple parts indicate data blocks, length of the data and frame identifier.

The WebGUI output frames for the version info (!V), system info (!I), and the detailed error report (!E), can be used together with the binary output mode but there is no binary representation of these frames. They will be transmitted in WebGUI format, if requested. The data order for binary mode is little endian.

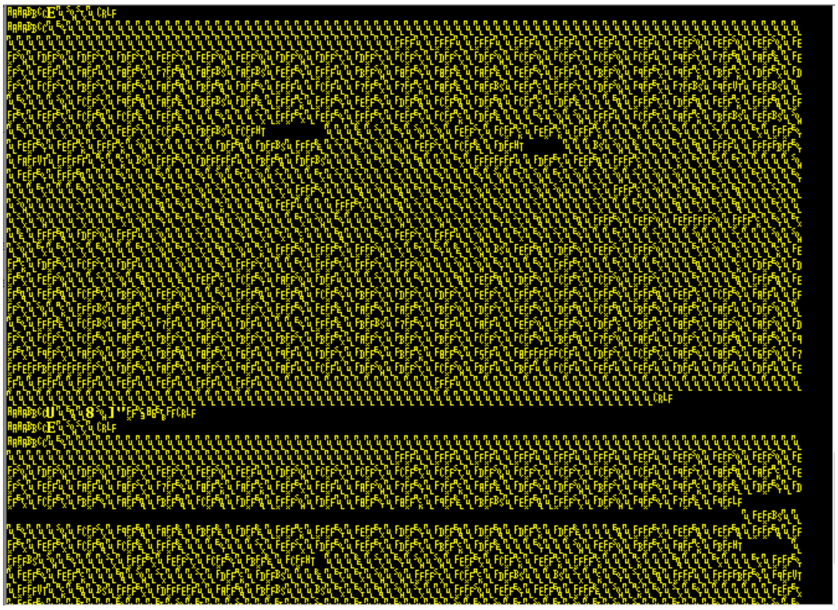


Figure 34 Binary Data in a Terminal Window

Binary data frames

ADC, FFT and CFAR data	Header	Identifier	Cnt	Size	Data (Size * 2 Bytes)	Stop	
FFT/Magnitude frame	$AA $AA $BB $CC	R	uint16	uint16	int16 / uint15	CR	LF
Phase frame		P			int16 / uint15		
CFAR frame		C			int16		
ADC data frame (I)		I			int16		
ADC data frame (Q)		Q			int16		

!	Header, Identifier and Stop Marker
n	Binary data fixed length

					Block, repeated 16 times --->						
Target information	Header	Identifier	Cnt	Format	Gain	Target #	Distance	Magnitude	Phase	Reserved int16	Stop	
Target list frame	$AA $AA $BB $CC	T	uint16	uint8	uint8	uint8	uint16	int16	int16		CR	LF

Status information	Header	Identifier	Size	Cnt	Format	Gain	Accuracy	Ramp Time	Max. Range	Real Bandwidth	Time Diff	Stop	
Status update frame	$AA $AA $BB $CC	U	uint16	uint16	uint8	uint8	uint16	uint16	uint16	int16	uint16	CR	LF

Error information	Header	Identifier	Size	Cnt	Error Flags	Stop	
Error info frame	$AA $AA $BB $CC	E	uint16	uint16	uint8	CR	LF

Figure 35 Binary Data Frames

The binary frames start with a header and frame identifier (1 byte), followed by a counter (2 byte). The counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The counter automatically overflows to 0 after reaching the maximum value 65535. The frames end with a stop marker ('CR' and 'LF').

6.1 ADC Raw Data (I/Q), Magnitude, Phase and CFAR Output

The 'Size' field indicates the number of transmitted data points. The value range of the data differs with the content of the frame. The value range of ADC, FFT, Magnitude, Phase, and CFAR data is -32768 to +32767. The ADC data value range differs depending on the selected processing parameters. The value range of the raw ADC data for 1 ramp is 12 bits (0 to 4096). The data order for binary mode is little endian.

ADC, FFT and CFAR data	Header	Identifier	Cnt	Size	Data (Size * 2 Bytes)	Stop	
FFT/Magnitude frame	$AA $AA $BB $CC	R	uint16	uint16	int16 / uint15	CR	LF
Phase frame		P			int16 / uint15		
CFAR frame		C			int16		
ADC data frame (I)		I			int16		
ADC data frame (Q)		Q			int16		

Figure 36 Binary ADC, FFT, Magnitude, Phase and CFAR Data Frame Format

Table 32 Binary ADC, FFT, Magnitude, Phase and CFAR Data Values

Format Field	Field Size	Content	Encoding	Allowed Values
Header		Start of frame	Fixed	Fixed
Identifier	1 byte	Frame identifier	Fixed	Fixed
Cnt	2 bytes	Measurement cycle counter	Unsigned Integer	decimal between 0 to 65535
Size	2 bytes	Size of the transmitted data	Unsigned Integer	decimal between 0 to 65535
Data	Length * 2 bytes	Magnitude/Range/ CFAR	Signed Integer	100000*(-π to +π rad)
	Length * 2 bytes	Phase	Signed Integer	-140 to 0 (dB unit)
	Length * 2 bytes	ADC/FFT	Signed Integer	decimal between -32768 to +32767

6.2 Target Information

The theoretical value range of the target Magnitude is -32768 to +32767, however, the typical value range is -140 to 0 (dB). The data order for binary mode is little endian.

						Block, repeated 16 times --->						
Target information	Header	Identifier	Cnt	Format	Gain	Target #	Distance	Magnitude	Phase	Reserved int16	Stop	
Target list frame	$AA $AA $BB $CC	T	uint16	uint8	uint8	uint8	uint16	int16	int16		CR	LF

Figure 37 Binary Target List Data Frame Format

Table 33 Binary Target List Data Values

Format Field	Field Size	Content	Encoding	Allowed Values
Header		Start of frame	Fixed	Fixed
Identifier	1 byte	Frame identifier	Fixed	Fixed
Cnt	2 bytes	Measurement cycle counter	Unsigned Integer	0 to 65535
Format	1 byte	Indicates the distance unit	Unsigned Integer	0 to 1
Gain	1 byte	Indicates the current gain level	Unsigned Integer	decimal dB values, see Table 1
Target #	1 byte	Indicates the target number	Unsigned Integer	0 to 15
Distance	2 bytes	Target distance	Unsigned Integer	0 to 65535
Magnitude	2 bytes	Magnitude of the target	Signed Integer	-32768 to +32767
Phase	2 bytes	Phase value of the target	Signed Integer	-32768 to +32767

Table 34 Binary Target List Data - Format Field

Format (HEX)	Description
0	distance in mm
1	distance in cm

6.3 Status Update

In the binary status update frame, the unit for the ramp time us and for the bandwidth MHz. To convert the accuracy into mm, the data should be divided by 10. If the accuracy field says 271, the system accuracy is 27.1 mm. The time difference field indicates the time since the last measurement. The time difference data is interpreted as values between 0 and 65535, which translates to 0 to 0.65535 seconds in 10 ms steps. For example, 'Time diff.' = 0200 is interpreted as 0x0200, which is 512 in decimal range. The time difference counter runs at 100 kHz and is configured as an overflowing 16-bit counter. Each tick lasts 10 ms and the counter overflows at 0.65535 seconds. Therefore, the minimum unambiguous measurement frequency is 1.5 Hz. The data order for binary mode is little endian.

Status information	Header	Identifier	Size	Cnt	Format	Gain	Accuracy	Ramp Time	Max. Range	Real Bandwidth	Time Diff	Stop	
Status update frame	$AA $AA $BB $CC	U	uint16	uint16	uint8	uint8	uint16	uint16	uint16	int16	uint16	CR	LF

Figure 38 Binary Status Update Data Frame Format

Table 35 Binary Status Update Data Values

Format Field	Field Size	Content	Encoding	Allowed Values
Header		Start of frame	Fixed	Fixed
Identifier	1 byte	Frame identifier	Fixed	Fixed
Cnt	2 bytes	Measurement cycle counter	Unsigned Integer	0 to 65535
Format	1 byte	Indicates the distance unit	Unsigned Integer	0 to 1
Gain	1 byte	Indicates the current gain level	Unsigned Integer	decimal dB values, see Table 1
Accuracy	2 bytes	Device accuracy	Unsigned Integer	0 to 65535
Ramp time	2 bytes	Length of the ramp in us	Unsigned Integer	0 to 65535
Max. range	2 bytes	Maximum range of device	Unsigned Integer	0 to 65535
Bandwidth	2 bytes	Bandwidth in MHz	Signed Integer	-32768 to +32767, Interpretation = -65536 to 65534 in MHz (2 MHz steps)
Time diff.	2 bytes	Indictor for update rate	Unsigned Integer	0 to 65535

Table 36 Binary Status Update Data - Format Field

Format (HEX)	Description
0	distance in mm
1	distance in cm

6.4 Error Information

The error info frame includes error bits that may be raised temporarily during the signal processing of the radar data and may be removed when changing the settings. This frame will be send by default and can be deactivated by setting 0 to the "ERR" bit in the system configuration command. The 'Error flags' field contains the same error bits for error domains as explained in Section 4.4. The data order for binary mode is little endian.

Error information	Header	Identifier	Size	Cnt	Error Flags	Stop	
Error info frame	$AA $AA $BB $CC	E	uint16	uint16	uint8	CR	LF

Figure 39 Binary Error Information Data Frame Format

Table 37 Binary Error Information Data Values

Format Field	Field Size	Content	Encoding	Allowed Values
Header		Start of frame	Fixed	Fixed
Identifier	1 byte	Frame identifier	Fixed	Fixed
Cnt	2 bytes	Measurement cycle counter	Unsigned Integer	0 to 65535
Error Flags	1 byte	Temporary error flags	Unsigned Integer	0 to 255

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