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SiRad Easy® / Simple®

(Firmware Version 1.4 and later)

System & Protocol Description

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Version Control

Version	Changed section	Description of change	Reason for change
1.0	all		Initial document
2.0	all	Content and appearance	Hardware & firmware update
2.1	all	Frame descriptions	Protocol update
2.2	1, 3.4, 3.6, 3.7, 4	Frame descriptions	Corrections
2.3	all	Frame descriptions	Firmware & protocol update
2.4	all	Frame descriptions	Corrections

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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 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.

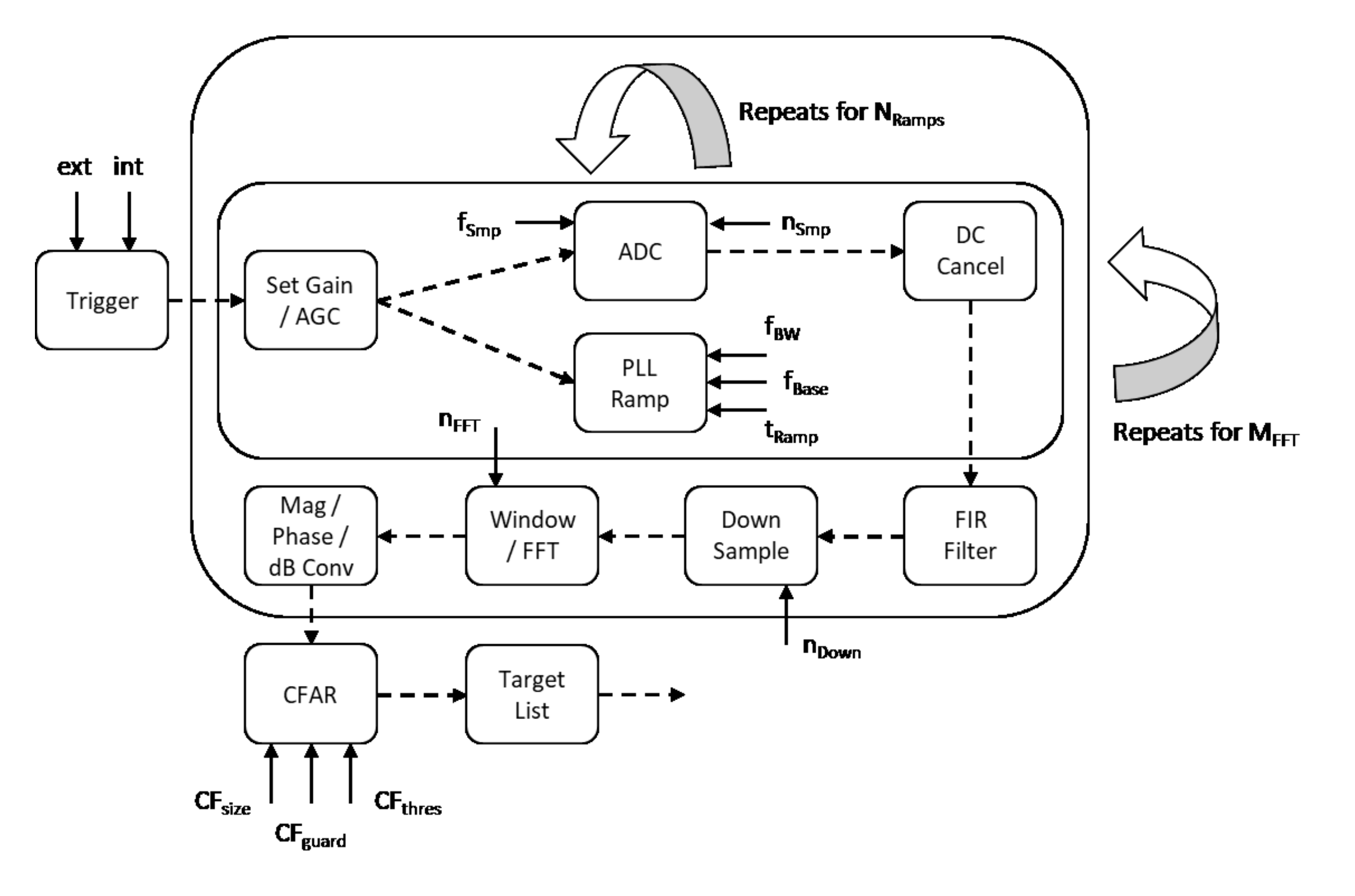


Figure 1 Flow of Radar Measurement on SiRad Evaluation Kits

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.

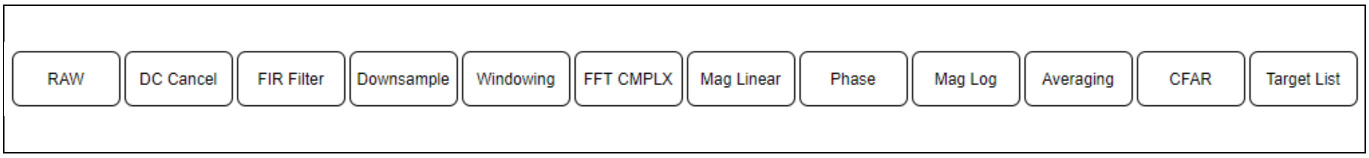


Figure 2 Processing and Data Extraction Steps on SiRad Evaluation Kits

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

Gain	Allowed Values in WebGUI Output Mode	Allowed Values in TSV and Binary Output Mode
8 dB	182	8
21 dB	195	21
43 dB	217	43
56 dB	230	56

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 is enabled, the device triggers each measurement after an internal timer expired (and resets the timer). The manual trigger mode is overridden by the self-trigger mode. When the self-trigger mode is disabled, the system enters manual 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 system when using longer measurement intervals. When using the external trigger options, the pre-trigger can be used to enable the pre-phase before the actual trigger. After the pre-trigger, the system waits for some milliseconds for the main trigger. If the main trigger does not occur within max. 40 ms after the pre-trigger, the system will go back to idle. The pre-trigger option 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
Manual trigger	Device waits for external trigger input for each measurement
Manual trigger with pre-trigger	Device waits for pre-trigger and then for external trigger input for each measurement

Table 3 Trigger Inputs for Manual Trigger and Pre-Trigger

Trigger Input	Description
Trigger button	Blue button on the *SiRad Easy®*
Trigger line	Pin 2 (PC13) of the microcontroller
Trigger command	One of !M\r\n, !N\r\n, or !L\\r\n via UART

A ramp trigger output signal is generated on pin 24 (PC4) of the microcontroller 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

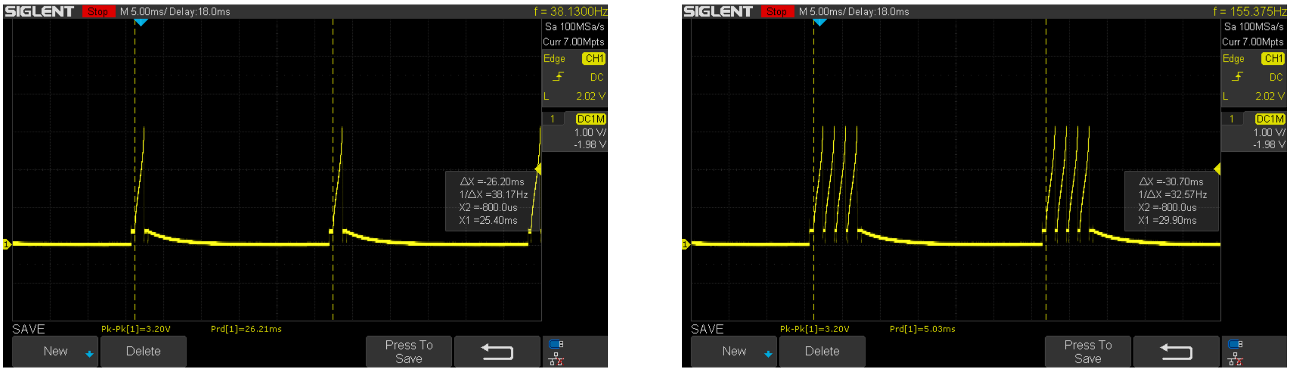
Trigger Output Mode	Description
Ramp trigger	Switches to high with the start of the ramp and to low with the end of the ramp

Table 5 Trigger Outputs

Trigger Output	Description
Trigger line	Pin 24 (PC4) of the microcontroller

1.3 Ramping Modes

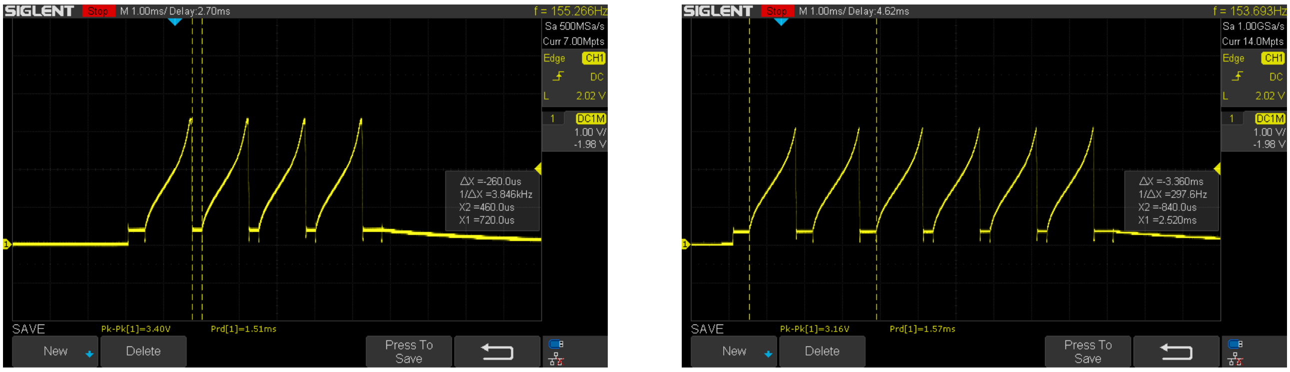
If the Self-Trigger Mode is switched on (default), the device sends a ramp group for each measurement, also shown in Figure 3. The number of ramps can be adjusted and also set to single ramps as shown in Figure 3 (left). The time between the ramp groups or single ramps is time needed for processing and data output and varies with the chosen processing 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

Figure 4 (left) shows the delay between the ramps in a ramp group. This time is needed for pre-processing and cannot be completely 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 evaluation kits support three CFAR algorithms - CA-CFAR, GO-CFAR and SO-CFAR. How to change CFAR operator and its settings is explained in Section 3.3.4. However, 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.

The CA-CFAR operator is explained in Figure 5 as a start into the topic of CFAR operators. The CA-CFAR calculates the average of a number of reference cells as a way to detect targets.

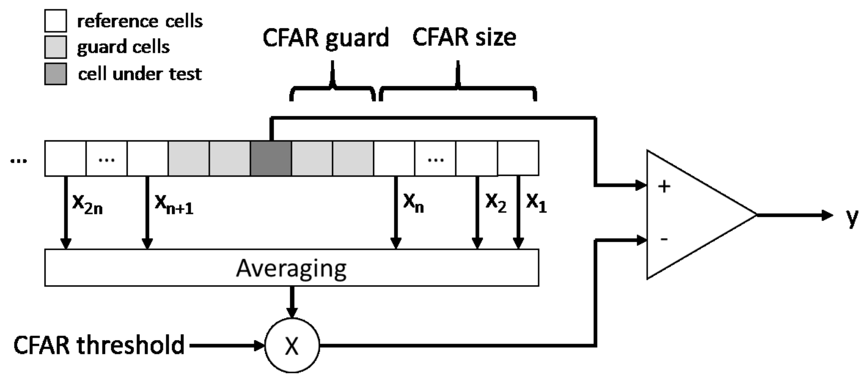


Figure 5 Schematic description of the CA-CFAR operator

1.5 Tuning Options

Please visit our Wiki page about tuning options [1] for tuning and speeding up the evaluation kit. Also find example configurations in our Wiki page about output modes [2].

2 Supported Protocols

The evaluation kit 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 6) but only one way to control the device via input commands, as 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 controllers or devices. The kit always starts up with the WebGUI protocol enabled after powering. 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

This documents applies for firmware version 1.4 or later and is incompatible to firmware version 1.3[1] and below. The following UART settings apply for firmware version 1.4 and later: 230400 baud or 1000000 baud (depending on firmware version), 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 (needs Microsoft Windows)	Terminal programs	Third Party / uC / Own Software
WebGUI	X	X	(X)[2]
TSV	-	X	(X)[3]
Binary	-	X	(X)[4]

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] The baud rate of firmware 1.3 and below is 230400 baud only.
[2] If WebGUI format is implemented.
[3] If data format of tab separated values is supported / implemented.
[4] 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 Section 0 with the terminal program "Realterm[3]" or any other capable terminal program. Put in the UART settings explained in Section 2.1 to the "Port" tab and connect to the kit with "Open". Per default, the kit sends data in the WebGUI output format as shown in Figure 6.

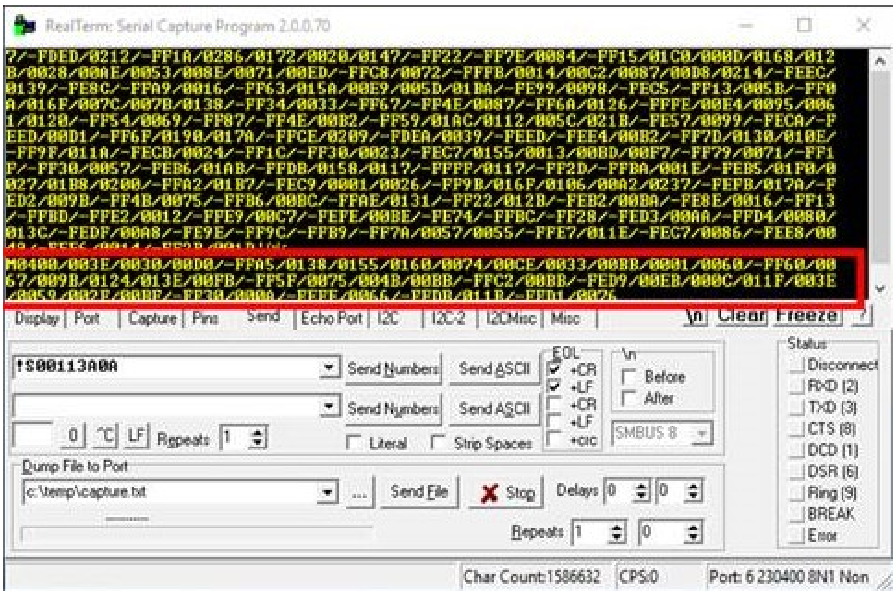


Figure 6 Send and Receive Using a Terminal Program

Calculate command strings by converting the desired command bits into HEX string format. An example command 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	res	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	res	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".

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 1Mbaud or 230400 (depending on firmware version), a correct comport, 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 kit 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 kit

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 kit

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 kit.

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 kit

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 Evaluation Kits and WebGUI

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

3.3 Configuration (Long) Commands

The commands in Table 9 contain data for the configuration of the kit 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
Programming mode	W	-	Used to flash SiRad Simple® without hardware configuration

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 SER connection option is selected, there will be no data displayed on the selected platform. However, *SiRad Easy®* and *SiRad Simple®* always listen on both serial ports, so reconfiguring is possible at any time.

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			res	LOG	FMT	LED		reserved				Protocol			AGC	Gain		SER2	SER1	ERR	ST	TL	C	R	P	CPL	RAW	res	res	SLF	PRE

SelfTrigDelay			
0	0	0	0 ms
0	0	1	2 ms
0	1	0	4 ms
0	1	1	8 ms
1	0	0	16 ms
1	0	1	32 ms
1	1	0	64 ms
1	1	1	128 ms

LED		
0	0	off
0	1	1st target
1	0	reserved
1	1	reserved

Gain		
0	0	8 dB
0	1	21 dB
1	0	43 dB
1	1	56 dB

SER2	
0	output on SER2 off
1	output on SER2 on

SER1	
0	output on SER1 off
1	output on SER1 on

FMT	
0	TL mm distance
1	TL cm distance

LOG	
0	log MAG
1	linear MAG

data frames		off	on
RAW	raw ADC	0	1
CPL	cmplx FFT	0	1
P	phase	0	1
R	magnitude	0	1
C	CFAR	0	1
TL	target list	0	1
ST	status	0	1
ERR	error	0	1

Protocol			
0	0	0	WebGUI
0	0	1	TSV output
0	1	0	BIN output
x	x	x	reserved

SLF	
0	external trig mode
1	standard mode

PRE	
0	standard mode
1	use pre-trigger

AGC	
0	auto gain control off
1	auto gain control on

Figure 10 System Configuration Frame Format

SYS_CONFIG	SelfTrigDelay	res	LOG	FMT	LED	reserved	Protocol	AGC	Gain	SER2	SER1	ERR	ST	TL	C	R	P	CPL	RAW	res	res	SLF	PRE
EASY	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1	1	0	0	0	0	0	1	0
SIMPLE	0	0	0	0	1	0	0	1	0	0	1	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®	!S01012F82
SiRad Simple® 120 GHz	!S01011F82

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**
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	3 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 (depending on whether 'Pre-trigger' is switched on).
Gain	2 bits	Manual gain setting. Overridden by the AGC bit, which enables Auto Gain Control.
SER1	1 bit	UART-USB connection on the Simple, WIFI or header bar on the SiRad Easy®
SER2	1 bit	USB connection on SiRad 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 manual trigger mode)
SLF	1 bit	Switch between self-trigger and manual trigger

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. The SiRad Simple® has a fixed 122 GHz front end onboard.

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	calc	MHz

Figure 12 Radar Front End Configuration Frame Format

RFE_CONFIG	reserved											Radar Frontend Base Frequency [MHz] (21 Bits)																				
EASY 120 GHz	0	0	0	0	0	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	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
SIMPLE	0	0	0	0	0	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

Figure 13 Radar Front End Configuration Default Bit Settings

Table 12 Radar Front End Configuration Default Commands

SYS_CONFIG command for device	Base Frequency	Resulting Command
SiRad Easy® 120 GHz	120000 MHz	!F00075300
SiRad Easy® 24 GHz	24000 MHz	!F00017700
SiRad Simple® 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	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)															

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

PLL_CONFIG	reserved																Bandwidth [MHz] (16 Bits)															
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
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
SIMPLE	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

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

Table 15 PLL Configuration Bits

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

Table 16 Maximum Bandwidth per Radar Front End

Radar Front End	Bandwidth	Resulting Command
TRX_024_006	3000 MHz	!P000005DC
TRX_024_007	3000 MHz	!P000005DC
TRM_060_039	7000 MHz	!P00000DAC
TRX_120_001	6000 MHz	!P00000BB8
TRA_120_002	6000 MHz	!P00000BB8
TRA_120_012/031	24000 MHz	!P00002EE0
TRA_300_030	40000 MHz	!P00004E20

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			Down sample			# 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

Down sample			
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	2,571
0	0	1	2,400
0	1	0	2,118
0	1	1	1,800
1	0	0	1,125
1	0	1	0,487
1	1	0	0,186
1	1	1	0,059

CFAR		
0	0	CA-CFAR
0	1	CFAR_GO
1	0	CFAR_SO
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			Down sample			# Ramps			# Samples			ADC ClkDiv		
EASY&SIMPLE	1	0	1	0	0	0	1	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® 120 GHz	!P000009C4
SiRad Easy® 24 GHz	!P000001F4
SiRad Simple® 120 GHz	!P000009C4

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

Equation 1 Ramp Time

$$t\ [us] = t_{Smp}\ [clock\ cycles] * (n_{Smp} + 85) / (36\ MHz)$$

Accuracy: the width of one distance bin of the sensor after the formula

Equation 2 Accuracy

$$acc = c * (nSmp + 85) / (2 * BW * nFFT * 2ndown)$$

where *c* is the speed of light, *BW* is the bandwidth, n_{Smp} is the number of samples, n_{FFT} is the FFT size, and n_{down} is the downsampling factor.

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

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

Table 19 Sampling time and sample frequency

ADC ClkDiv	ADC sampling time t_{Smp} [clock cycles]	Sample frequency [MS/s]
0	14	2,571
1	15	2,400
2	17	2,118
3	20	1,800
4	32	1,125
5	74	0,487
6	194	0,186
7	614	0,059

3.4 Special Function (Short) Commands

The following short commands do not contain 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
Get detailed error report	E	X	Request detailed error report
Get system info	I	X	Request system info data
Do frequency scan	J	-	Request scan of the min and max frequencies and sets start frequency to min frequency
Set to max. bandwidth	K	-	Set bandwidth to the scanned maximum
Send Pre-Trigger	L	-	Send pre-trigger for an automatic gain measurement (AGC Mode)
Send Trigger	M	-	Send a trigger for a measurement
Send both Triggers (L, M)	N	-	Send pre-trigger and 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 kits, however, the UART receive buffer in the kits 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 kits. 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 evaluation kit is plugged in, 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 19Figure 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.

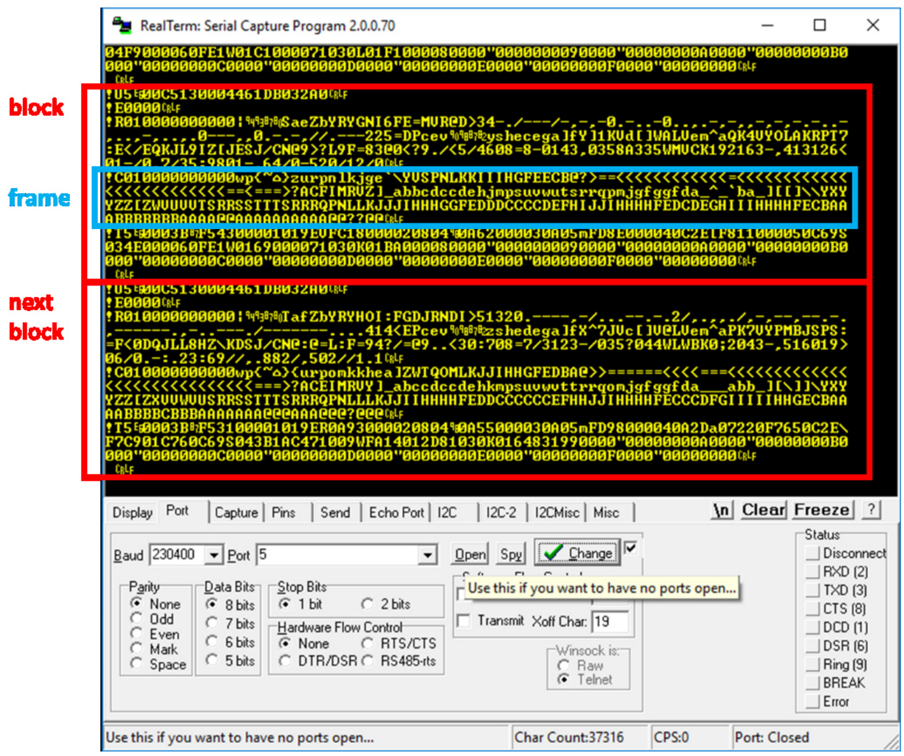


Figure 18 WebGUI Data (Default Communication) in a Terminal Window

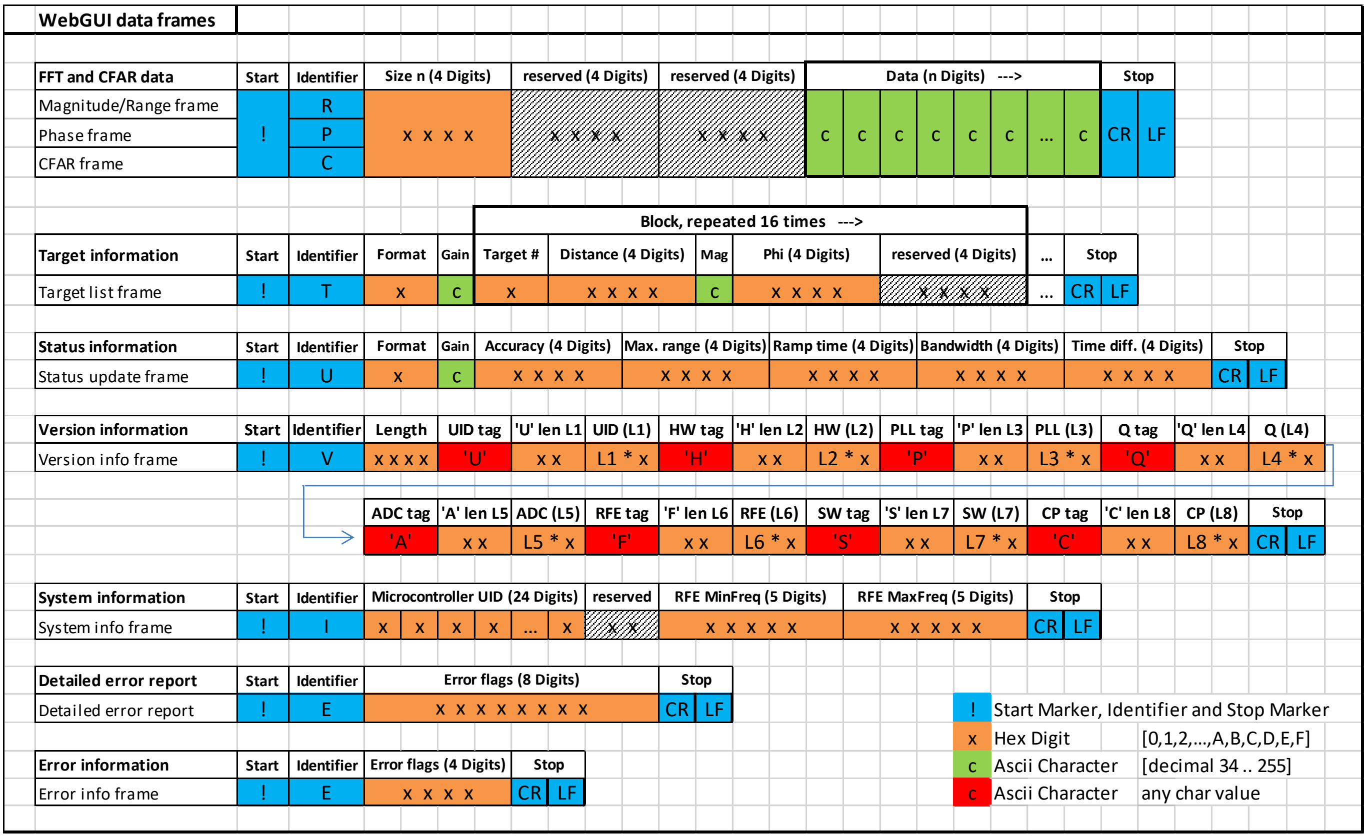


Figure 19 WebGUI Data Frame Formats (Default Communication)

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.

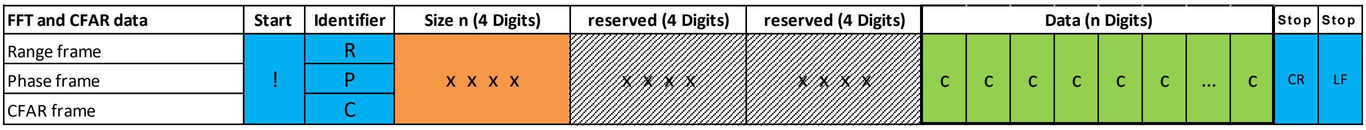


Figure 20 WebGUI Range, Phase and CFAR Data Frame Format

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 (range and CFAR 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 (phase 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	letter 'Z' -> decimal 90	-140 to +80 dB in 220 steps	182, 195, 217, 230
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)	-31416 to +31416
Format	1 digit	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
2 to F	reserved

Table 24 WebGUI Target List Data - Gain Field

Gain (decimal)	Description
8	8 dB gain
21	21 dB gain
43	43 dB gain
56	56 dB gain

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.

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 25 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	letter 'Z' -> decimal 90	-140 to +80 dB in 220 steps	182, 195, 217, 230
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' -> 512	-65536 to 65534 in MHz	'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

Bit	32–25	24–17	16–7	6	5	4	3	2	1
ERROR	reserved	reserved	reserved	FLS	PRC	BB	PLL	RFE	CRC

FLS	
0	no error
1	Flash error

BB	
0	no error
1	Baseband error

RFE	
0	no error
1	Frontend error

PRC	
0	no error
1	Processing error

PLL	
0	no error
1	PLL error

CRC	
0	no error
1	CRC error

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.

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

Error domains:

- CRC: <reserved>
- FLS: <reserved>
- FFT: <reserved>
- ADC: ADC sampling and data buffering errors
- AMP: amplification errors, for example, saturation
- PLL: PLL configuration errors, for example, auto scan of RFE frequency range not successful
- RFE: radar front end configuration errors, for example, operating range exceeded

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

Domain	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 !! 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 26 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'	'74360	119000 MHz	0 to 524287 MHz
RFE MaxFreq	5 digits	HEX string between '00000' and 'FFFFF'	'7A120	125000 MHz	0 to 524287 MHz

4.7 !V Command – Answer: Version Information

The version frame is used to uniquely identify the SiRad evaluation kits 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 27 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®, 'SI' for SiRad Simple®
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 28 WebGUI Version Information - RFE Types

RFE Field	Description
024_006	TRX_024_006
024_007	TRX_024_007
060_039	TRM_060_039
120_00x	TRX_120_001 / TRA_120_002
120_wid	TRA_120_012 / TRA_120_031
300_030	TRA_300_030

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.

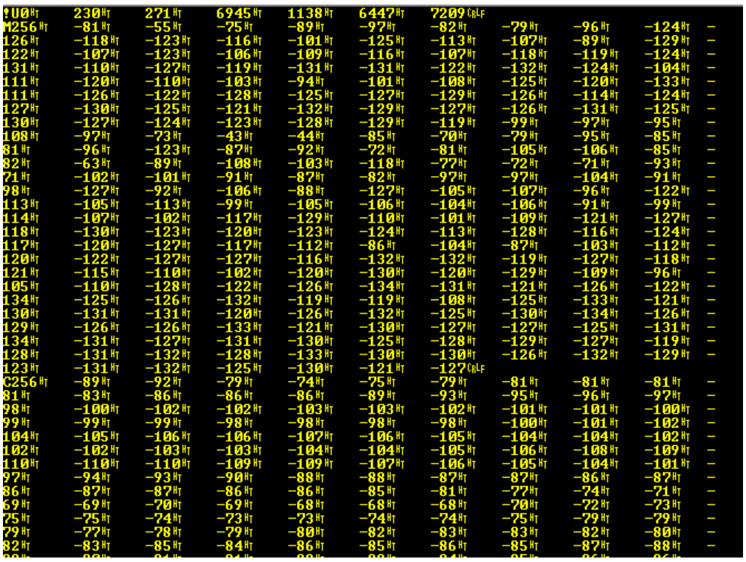


Figure 29 TSV Data Frame (!M Frame) in a Terminal Window

TSV format

Sensor data	Start	Identifier	Delim	Counter	Del	Size	Del	SGN (Size Blocks --->)	Data	Del	Stop	
FFT/Magnitude/Range frame	!	R	/t	n	/t	n	/t	-	n	/t	CR	LF
Phase frame	!	P	/t	n	/t	n	/t	-	n	/t	CR	LF
CFAR frame	!	C	/t	n	/t	n	/t	-	n	/t	CR	LF
Raw Frame	!	M	/t	n	/t	n	/t	-	n	/t	CR	LF

Target information	Start	Identifier	Del	Counter	Del	Format	Del	Gain	Del	Target # (Block, repeated 16 times --->)	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 update frame	Start	Identifier	Del	Counter	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

Symbol	Meaning	Range
!	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
n	String Number	any length

Figure 30 TSV Data Frames Overview

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

After the frame's start marker (1 byte) and identifier 'R', 'P' or 'C' (1 byte) follows a frame counter. The frame counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The frame counter automatically overflows to 0 after reaching the maximum value 65535.

The size field indicates the number of transmitted data points. The value range of the ADC raw data for 1 ramp is 12 bits (0 to 4096).

The size of the ADC raw data output is always 2 * "Number of Samples" when no down sampling is configured.

								Size Blocks --->				
Sensor data	**Start**	**Identifier**	**Delim**	**Counter**	**Del**	**Size**	**Del**	**SGN**	**Data**	**Del**	**Stop**	
FFT/Magnitude/Range frame	!	R	/t	n	/t	n	/t	-	n	/t	CR	LF
Phase frame	!	P										
CFAR frame	!	C										
Raw Frame	!	M										

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

Table 29 TSV ADC Raw Data, Magnitude, Phase and CFAR Data Bits

Format Field	Content	Encoding
Del	Delimiter	\t
Counter	Measurement cycle counter	decimal between 0 to 65535
Size	Size of the transmitted data	decimal between 0 to 65535
Sgn	Sign indicator	
Data	FFT/Magnitude/Range/Phase/CFAR/ Raw Data	decimal between -32768 to +32767

5.2 Target Information

The allowed values for the target Magnitude is between -32768 to +32767, however, the typical value range is between -140 to 0 (dB). The frame counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The frame counter automatically overflows to 0 after reaching the maximum value 65535.

										Block, repeated 16 times --->													
Target information	**Start**	**Identifier**	**Del**	**Counter**	**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 30 TSV Target List Data Bits

Format Field	Content	Encoding
Del	Delimiter	\t
Counter	Measurement cycle counter	decimal between 0 to 65535
Format	Indicates the distance unit	decimal between 0-1
Gain	Indicates the current gain level	decimal 8,21,43 or 56
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 31 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 maximum range is mm, for the ramp time us, and for the bandwidth MHz. To be able to convert accuracy filed into mm, the data should be divided by 10. If the accuracy field says 271, the system accuracy yields to 27.1 mm. The frame counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The frame counter automatically overflows to 0 after reaching the maximum value 65535.

Status update frame		**Start**	**Identifier**	**Del**	**Counter**	**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 32 TSV Status Update Data Bits

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 8,21,43 or 56
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 supported binary format and Figure 35 lists their purpose. The blue parts indicate header and stop markers, purple parts indicate data blocks, length of the data and frame identifier (Chn).

The WebGUI output frames for the version info (!V), system info (!I), and the detailed error report (!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.

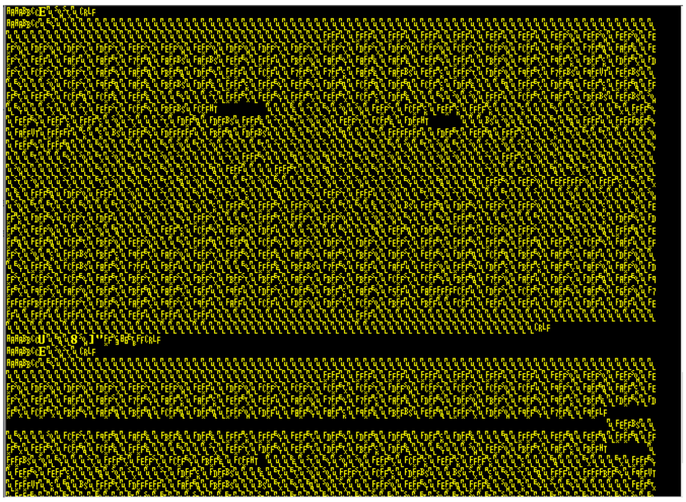


Figure 34 Binary Data in a Terminal Window

Binary output

Sensor data	Header	Chn	Counter	Length	Data (Length * 2 Bytes)	Stop	
ADC data	$AA $AA $BB $CC	M	2 Bytes uint16	Size n uint16	int16	CR	LF
Range/FFT/Mag		R			int16		
Phase frame		P			int16		
CFAR frame		C			int16		

Status Info	Header	Chn	Counter	Format	Gain	Accuracy	Ramp Time	Max. Range	Real Bandwidth	Time Diff	Stop	
System Update	$AA $AA $BB $CC	U	uint16	uint8	uint8	2 Bytes uint16	uint16	uint16	int16	uint16	CR	LF

Error Info	Header	Chn	Counter	Error Flags	Stop	
Error frame	$AA $AA $BB $CC	E	uint16	uint8	CR	LF

						Block, repeated 16 times --->						
Target Information	Header	Chn	Counter	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

Legend: Header, Delimiter, binary Data

Figure 35 Binary Data Frames

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

The binary frame starts with a header and channel indicator, followed by a frame counter. The frame counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The frame counter automatically overflows to 0 after reaching the maximum value 65535. The value range of the ADC raw data for 1 ramp is 12 bits (0 to 4096).

Sensor data	Header	Chn	Counter	Length	Data (Length * 2 Bytes)	Stop	
ADC data	$AA $AA $BB $CC	M	2 Bytes uint16	Size n uint16	int16	CR	LF
Range/FFT/Mag		R			int16		
Phase frame		P			int16		
CFAR frame		C			int16		

Figure 36 Binary Range, Phase and CFAR Data Frame Format

Table 33 Binary Range, Phase and CFAR Data Bits

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

6.2 Target Information

The allowed values for the target Magnitude are between -32768 to +32767, however, the typical value range is between -140 to 0 (dB). The frame counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The frame counter automatically overflows to 0 after reaching the maximum value 65535.

						Block, repeated 16 times --->						
Target Information	Header	Chn	Counter	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 34 Binary Target List Data Bits

Format Field	Field Size	Content	Encoding	Allowed Values
Header		Start of frame	Fixed	Fixed
Identifier	1 byte	Frame identifier	Fixed	Fixed
Counter	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	8, 21, 43 or 56
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 35 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 maximum range is mm, for the ramp time us, and for the bandwidth MHz. To be able to convert accuracy filed into mm, the data should be divided by 10. If the accuracy field says 271, the system accuracy yields to 27.1 mm. The frame counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. The frame counter automatically overflows to 0 after reaching the maximum value 65535.

Status Info	Header	Chn	Counter	Format	Gain	Accuracy	Ramp Time	Max. Range	Real Bandwidth	Time Diff	Stop	
System Update	$AA $AA $BB $CC	U	uint16	uint8	uint8	2 Bytes uint16	uint16	uint16	int16	uint16	CR	LF

Figure 38 Binary Status Update Data Frame Format

Table 36 Binary Status Update Data Bits

Format Field	Field Size	Content	Encoding	Allowed Values
Header		Start of frame	Fixed	Fixed
Identifier	1 byte	Frame identifier	Fixed	Fixed
Counter	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	8, 21, 43 or 56
Accuracy	2 bytes	Device accuracy	Unsigned Integer	0 to 65535
Ramp time	2 bytes	Maximum range of device	Unsigned Integer	0 to 65535
Max. Range	2 bytes	Length of the ramp in us	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 37 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. Error Flags contains the same error bits for error domains as explained in Section 4.4, where the WebGUI error information frame is explained.

Error Info	Header	Chn	Counter	Error Flags	Stop	
Error frame	$AA $AA $BB $CC	E	uint16	uint8	CR	LF

Figure 39 Binary Error Information Data Frame Format

Table 38 Binary Error Information Data Bits

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

References

[1] https://siliconradar.com/wiki/Tuning
[2] https://siliconradar.com/wiki/Output_Modes
[3] https://realterm.sourceforge.io

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