SILICON radar

**is now**

indie SEMICONDUCTOR

indie Semiconductor FFO GmbH

To learn more about indie Semiconductor, please visit our website at www.indiesemi.com

For customer support, please contact us at: dfo.support@indiesemi.com

Support / Wiki:

**Silicon Radar GmbH**
Im Technologiepark 1
15236 Frankfurt (Oder)
Germany

fon +49 (0) 335 228 80 30
fax +49 (0) 335 557 10 50
https://www.siliconradar.com
https://wiki.siliconradar.com

# *SiRad Easy® r4*

## (Firmware 1.5 or higher)

## System & Protocol Description

| Status: | Date: | Author: | Filename: | |
|---|---|---|---|---|
| Release | 16-Nov-2022 | Silicon Radar GmbH | Protocol_Description_SiRad_Easy_r4 | |
| Version: | Product number: | Hardware: | Marking: | Page: |
| 1.1 | *SiRad Easy® r4* | *SiRad Easy® r4* BB v1.0 – v1.3 | | 1 of 36 |
| Document: Annex to VA_U03_01 | | Anlage 8_Template_Datenblatt_RevE | Date: 19-May-2020 | Rev D |

# 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 |
| 1.1 | 7, all | Update in 7, other minor corrections | Binary protocol change |

# Table of Contents

# List of Figures

# List of Tables



# List of Equations

# 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.

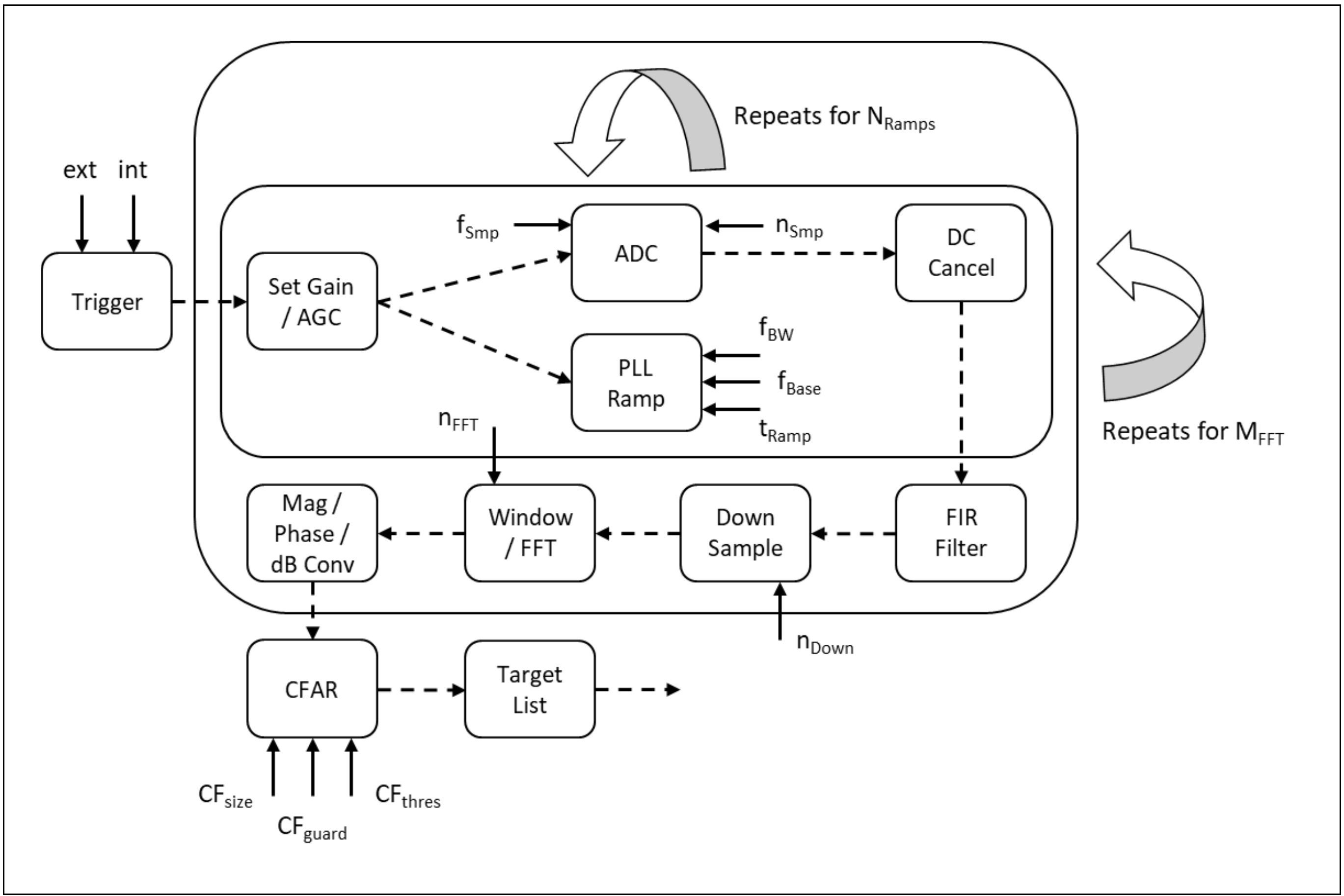



Figure 1 Flow of Radar Measurement

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.

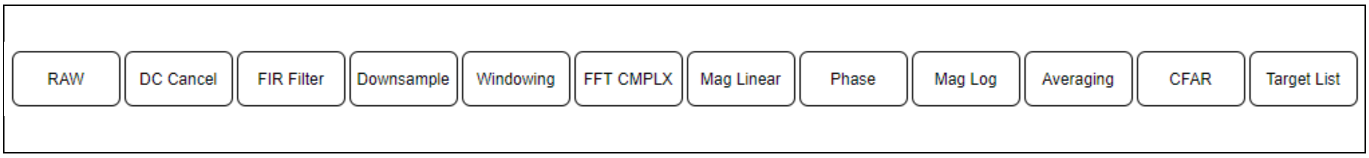



Figure 2 Processing and Data Extraction Steps on SiRad Evaluation Kits

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

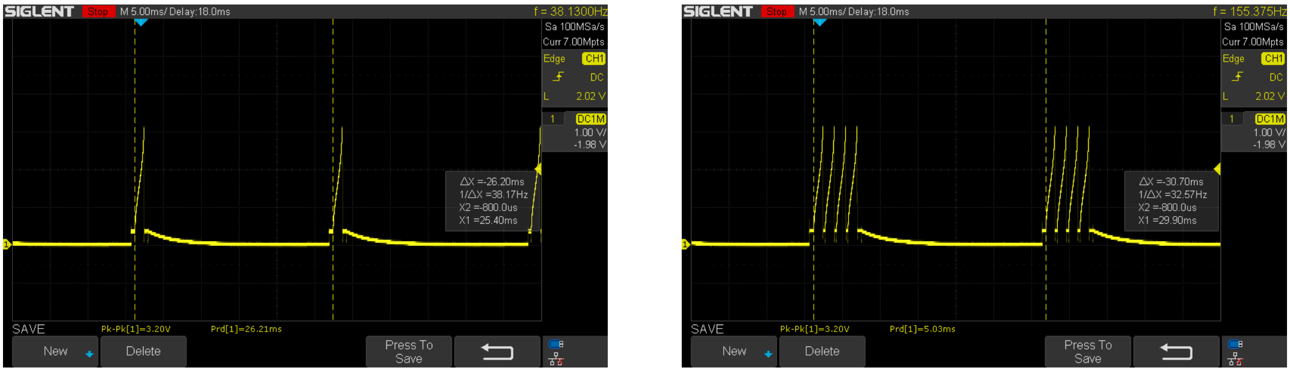
| Trigger Output Mode | Description |
|---|---|
| Ramp trigger | Switches to high with the start of each ramp and to low with the end of each ramp |

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

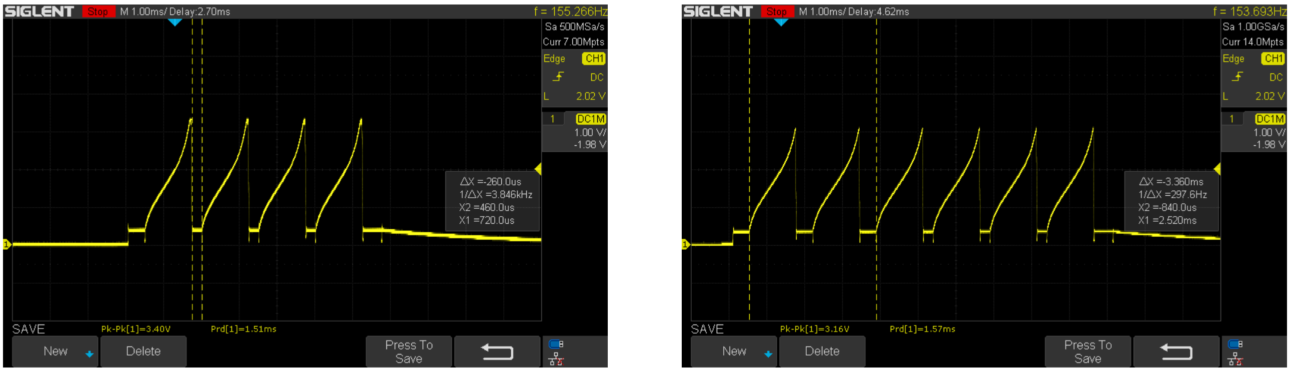
If the Self-Trigger Mode is switched on (default), the device sends a group of ramps for each measurement, also shown in Figure 3 (right). The number of ramps can be adjusted and also set to single ramps as shown in Figure 3 (left). The time between the ramp groups or single ramps is time needed for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

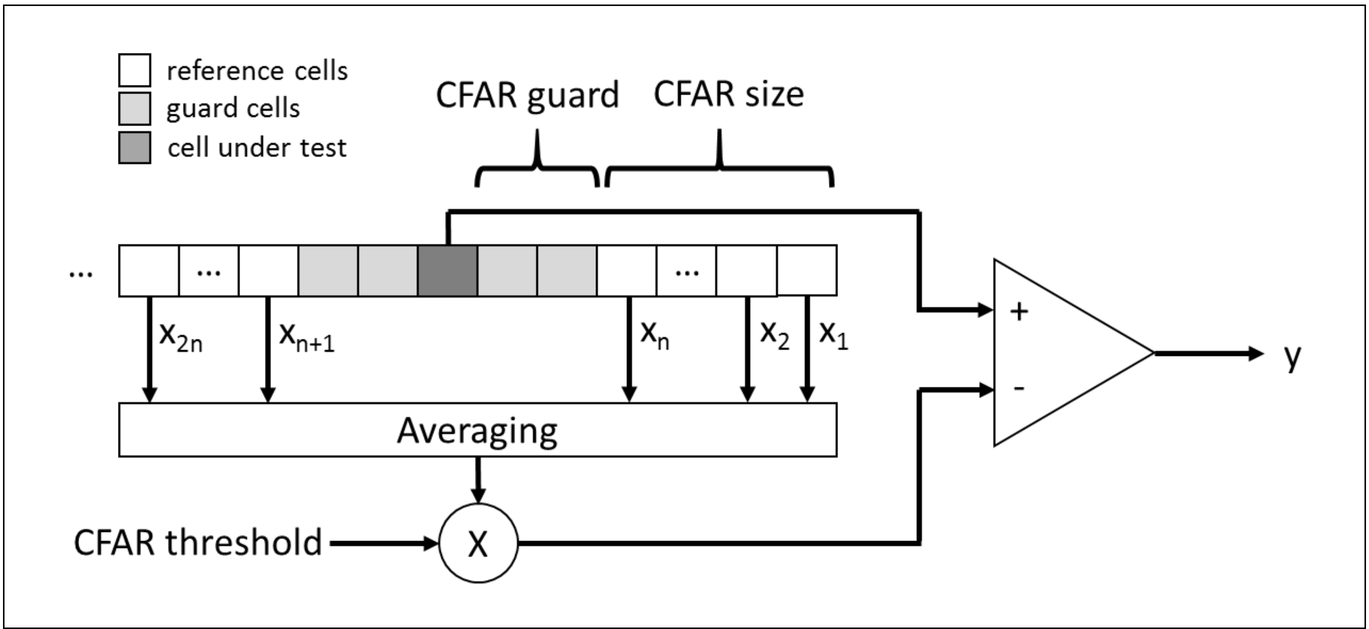



Figure 5 Schematic description of the CACFAR operator

## 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 5 and 7) 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 | - |
| 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 | - | - |
| Info Frame | Contains hardware and firmware information | - | - | X |
| Version info frame | Contains hardware and firmware information | X | - | - |
| Parameter frame | Contains parameters/settings | - | - | 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.

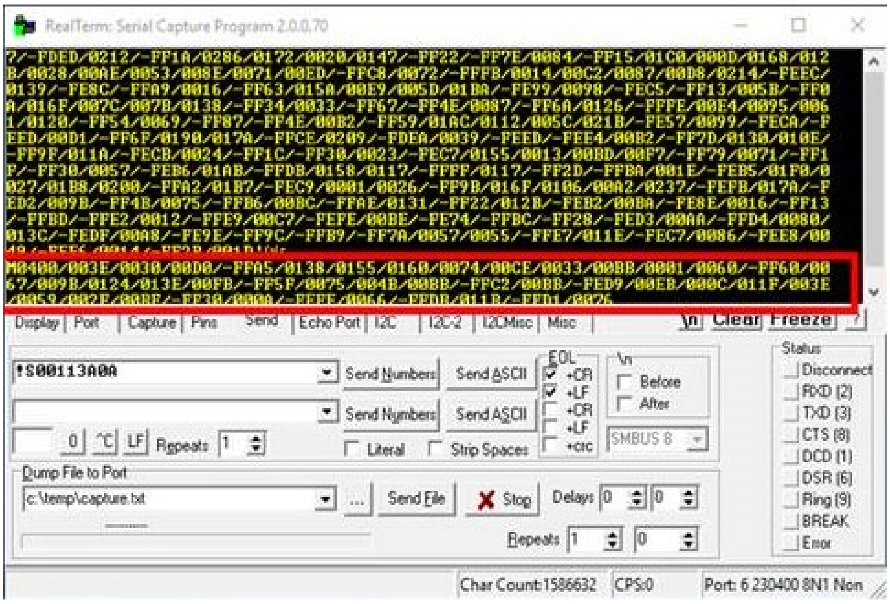


Figure 6 Send and Receive Using a Terminal Program

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 or TSV)

- Open the Com2WebSocket tool, select 230400 baud or 1M baud (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) – WebGUI & TSV Mode

## 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.**

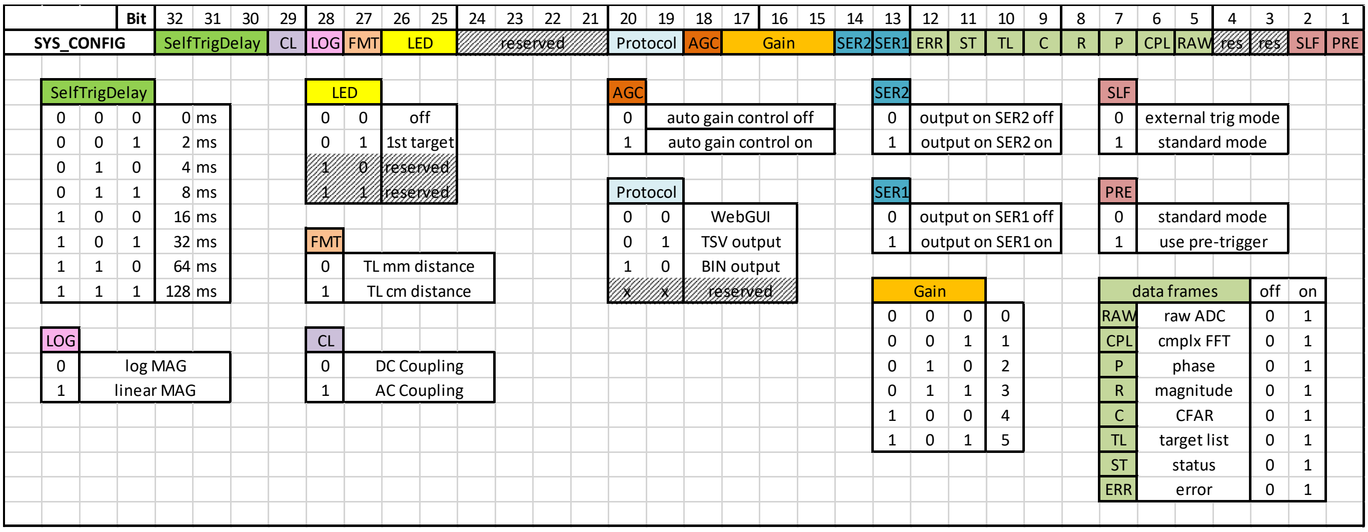


Figure 10 System Configuration Frame Format

| 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 (Examples)

| Radar Front End | Bandwidth | Resulting Command |
|---|---|---|
| TRX_024_046 | 2600 MHz | !P00000514 |
| TRX_120_001 & TRX_120_067 & 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 5 for their formats.

Table 20 Special Function Commands

| Command Frame | Identifier | Answer | Description |
|---|---|---|---|
| Do Front End scan | A | - | Auto detect and pre-configure Front End |
| 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 |
| Programming mode | W | - | Go to programming mode for flashing the device |

## 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 Commands (Input) – Binary Mode

Each parameter that can be set on the kit has a different keyword. The general conventions of setting parameters are:

**PARAM = [value, MAX, MIN, DEF];\r\n** For setting a value and NOT return the set value afterwards.
**PARAM = [value, MAX, MIN, DEF]\r\n** For setting a value and returning the set value afterwards.
**PARAM** For requesting the value of a parameter.

'PARAM' is the specific keyword of a parameter. Sending the command with 'MAX' will set the parameter to its maximum available value, 'MIN' will set it to its minimum available value as well as 'DEF' will set it to its default value. Other than these, command can be sent with number which should be within the possible range. Using semicolon (;) at the end of the command will only affect whether the current value of the parameter is requested. Please note that some parameters can only be set with strings, so 'MIN' and 'MAX' commands are not applicable for these parameters. In below table " indicates a string parameter but the " is to be omitted from commands.

## 4.1 Commands

Table 21 Parameter keywords and values

| Keyword | Allowed Values | Default | Description |
|---|---|---|---|
| AGCMode | "ON", "OFF" | "ON" | Auto Gain Control Mode overrides the manual settings in the 'Gain' field. Uses 2 ramps at the beginning of the measurement to measure the gain. |
| AmpGain | 0 to 5, see Table 1 for dB values | x | Manual gain setting, only effective when AGCM (Auto Gain Control) is off. |
| Bandwidth | 32-bit floating point | x | Bandwidth for the radar front end in MHz |
| Baud | 32-bit unsigned integer | 230400 | Recommended: 115200, 230400, 10000000, other values might not work as good |
| CFARAlgo | "CA", "GO", "SO" | "CA" | Select the type of CFAR operator (CA-CFAR, GO-CFAR, SO-CFAR) |
| CFARGuard | Integer, 0 to 3 | 1 | Number of guard cells left and right of the cell under test |
| CFARSize | Integer, 0 to 15 | 10 | Number of cells left and right of the CFAR guard interval |
| CFARThres | Integer, 0 to 31, in dB | 16 | CFAR threshold value added to average of the CFAR operator |
| Coupling | "AC", "DC" | "AC" | Coupling mode of Baseband amplifier |
| DCCancel | "ON", "OFF" | "ON" | Enables or disables digital de-trending and static offset compensation |
| DownSample | 0, 1, 2, 4, 8, 16, 32, 64 | 0 | Down sampling factor |
| FBase | 32-bit floating point | x | Start (or base) frequency of the radar front end in MHz |
| FFTAvg | Integer, 0 to 3 | 0 | Selects how many FFTs are averaged |
| FFTSize | 32, 64, 128, 256, 512, 1024, 2048 | 512 | Number of FFT points |
| FIRFilter | "ON", "OFF" | "OFF" | Enables or disables FIR Filter |
| FSample | See Table 19 | | Select the sampling frequency |
| LedMode | 0 (Off), 1 (First target rainbow) | 1 | 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. |
| MagScale | "LOG", "LIN" | "LOG" | Sets scaling type of magnitude data; Linear or Log |
| NumRamps | 1, 2, 4, 8, 16, 32, 64, 128 | 16 | Number of ramps used for each measurement |
| NumSamples | 32, 64, 128, 256, 512, 1024, 2048 | 512 | Number of samples used for each measurement |
| OutCFAR | "ON", "OFF" | "ON" | Enables or disables the CFAR Data Frame |
| OutError | "ON", "OFF" | "ON" | Enables or disables the Error Frame |
| OutFFTComplex | "ON", "OFF" | "OFF" | Enables or disables the Complex FFT Data Frame |
| OutMag | "ON", "OFF" | "ON" | Enables or disables the Magnitude/Range Frame |
| OutPhase | "ON", "OFF" | "OFF" | Enables or disables the Phase Data Frame |
| OutTargetList | "ON", "OFF" | "ON" | Enables or disables the Target Data Frame |
| OutTimeDomain | "ON", "OFF" | "OFF" | Enables or disables the ADC Data Frame |
| Protocol | "TSV","BIN","WEBGUI" | "WEBGUI" | Protocol type for data output: TSV (tab separated values), WebGUI and binary |
| TrigMode | "EXT", "SELF" | "SELF" | Selects the triggering mode, External or Self Trigger |
| UARTHeader | "ON", "OFF" | "OFF" | UART connection to the pin header |
| UARTUsb | "ON", "OFF" | "ON" | UART connection to the USB; config can be fed to device using both UARTs at any time |
| Window | "ON", "OFF" | "ON" | Enables or disables windowing on the samples before performing the FFT |

## 4.2 Requests

Some parameters cannot be set, however, be requested from the kit.

| Keyword | Allowed Values | Description |
|---|---|---|
| Accuracy | 32-bit floating point | Returns device accuracy in mm |
| Fscan | No output | Scan true min and max frequency of the RFE and sets start frequency to true min frequency |
| Info | See Section 7.4 | Requests Info frame |
| MaxBandwidth | 32-bit floating point | Sets maximum bandwidth in MHz |
| MaxRange | 32-bit unsigned integer | Returns maximum range of device |
| Params | See Section 7.3 | Requests Parameter frame |
| Reset | No output | Perform software reset |
| RFMax | 32-bit floating point | Returns maximum base frequency |
| RFMin | 32-bit floating point | Returns minimum base frequency |
| SetDefault | No output | Sets default parameters of the kit |
| Trig | Transmits selected output frames | Sends a trigger, only active in External Trigger mode |
| UpdateRate | 16-bit unsigned integer | Returns update rate of device |

# 5 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.

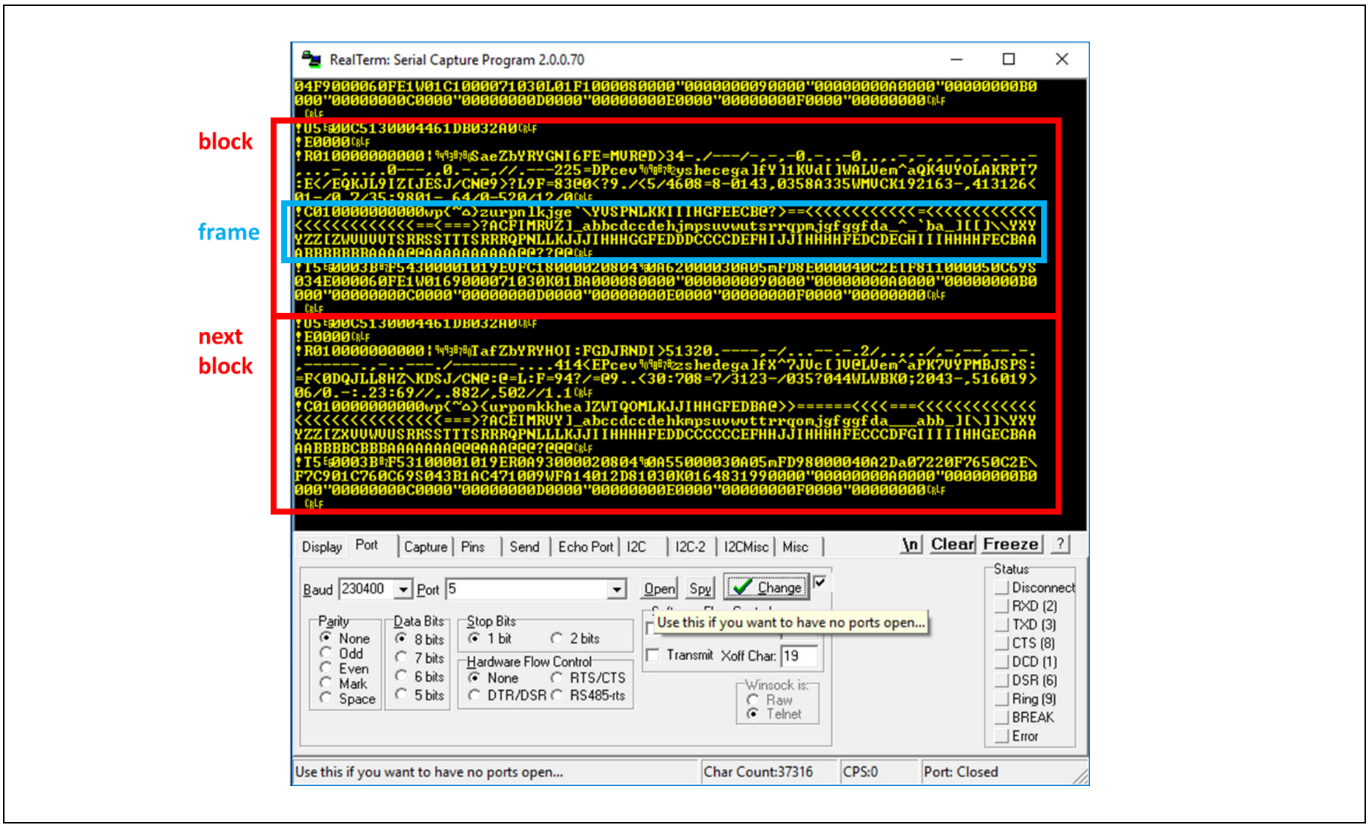



Figure 18 WebGUI Data (Default Communication) in a Terminal Window

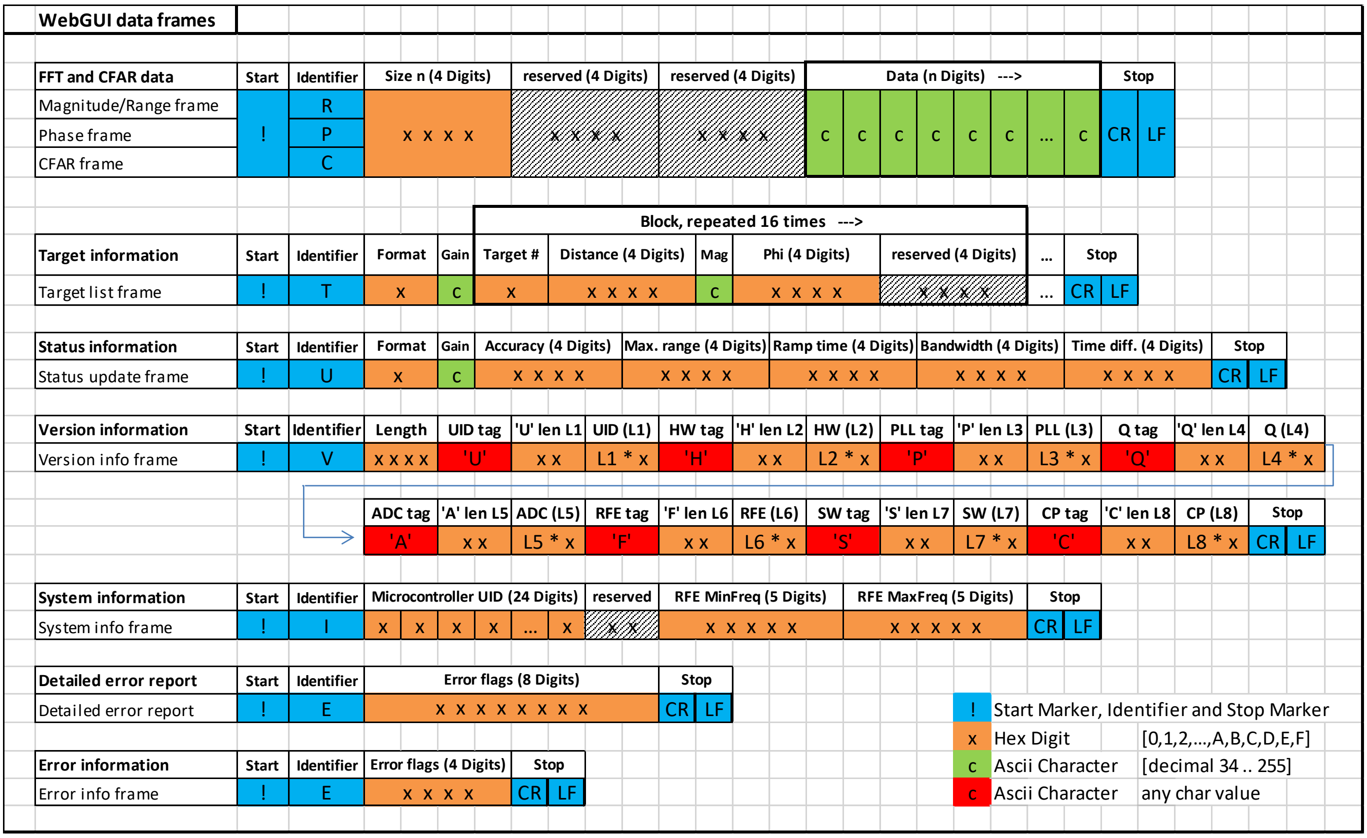



Figure 19 WebGUI Data Frame Formats (Default Communication)

## 5.1 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.

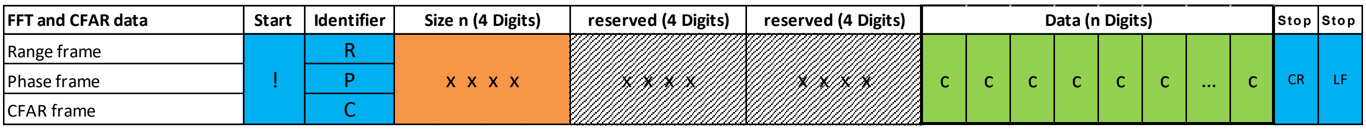



Figure 20 WebGUI Range, Phase and CFAR Data Frame Format

Table 22 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 |

## 5.2 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 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 23 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 24 WebGUI Target List Data - Format Field

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

## 5.3 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 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, 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' |

## 5.4 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 sent 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

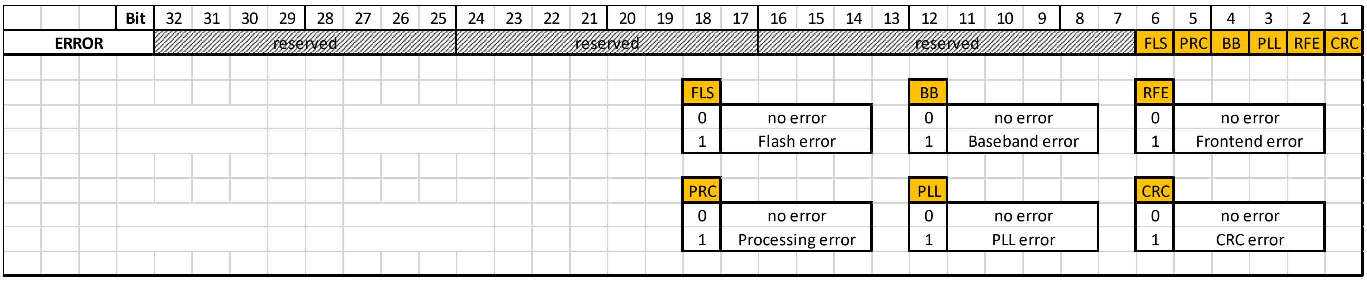



Figure 24 WebGUI Error Information Data Bits

## 5.5 !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 5.4, which reports only the processing domains that experience an error. Also see Section 5.4 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

## 5.6 !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 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' | '07436 | 119000 MHz | 0 to 524287 MHz |
| RFE MaxFreq | 5 digits | HEX string between '00000' and 'FFFFF' | '07A12 | 125000 MHz | 0 to 524287 MHz |

## 5.7 !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 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® |
| 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 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 |
| 120_67 | TRX_120_067 |
| 300_42 | TRA_300_042 |

# 6 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.

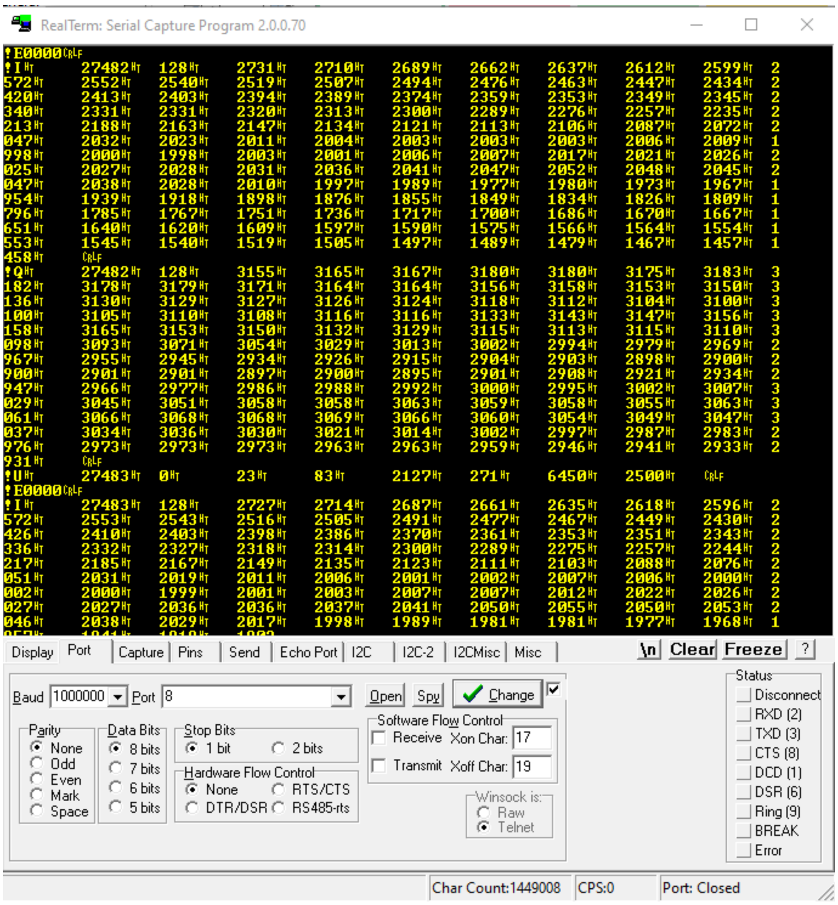



Figure 29 TSV Data Frame (!I and !Q Frame) in a Terminal Window

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**

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

| | | | | | | | | 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 | | | | | | | | | | |

| | | | | | | | | | | 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

## 6.1 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 29 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) |

## 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).

| | | | | | | | | | | 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 30 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 31 TSV Target List Data and Status Update Data - Format Field

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

## 6.3 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 32 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 |

# 7 Binary Output Mode

The Binary Mode has been changed from firmware 1.2 to 1.3, please see Section 4 for Input protocol of Binary Mode.

The binary frames start with a header and a counter (2 byte), followed by a frame identifier (1 byte). The frame counter is a counter that increases with each transmitted frame. The frame length is the total length of data frame. It is followed by Tx and Rx ID, data source and gain. The measurement counter is a 16 bit number starting from 0 and increasing by 1 with each measurement cycle. Both counters automatically overflow to 0 after reaching the maximum value 65535. Sensor data is transmitted as data payload. The type of data and size of data payload are given in data type and No. elements. The frames end with CRC-32 checksum and a stop marker ('CR' and 'LF'). The data order for binary mode is little endian.

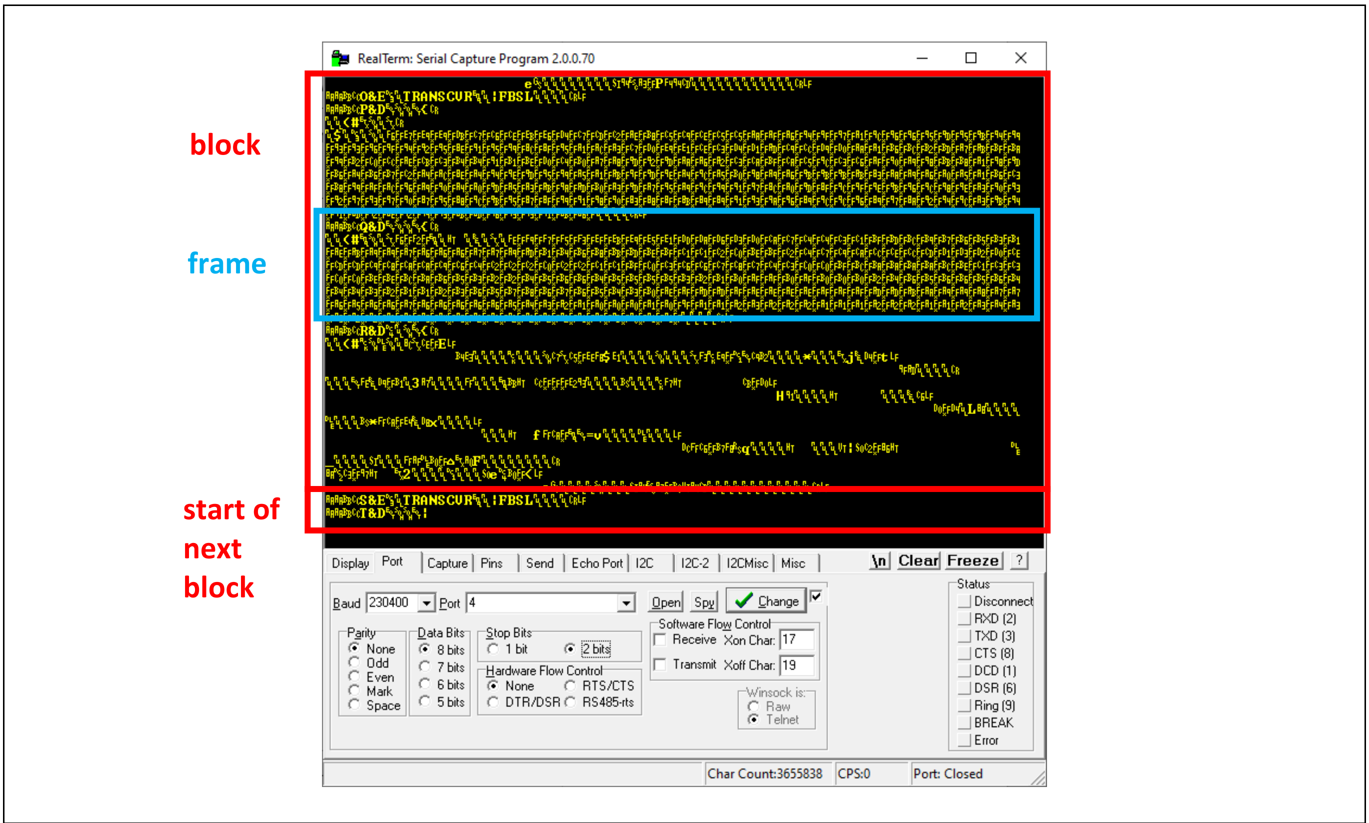



Figure 34 Binary Data in a Terminal Window

**DATA FRAME**

| Header | Frame cnt | Id | Frame Length | Tx ID | Rx ID | Data S. | Gain | Meas. cnt | Stime cnt | Update Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| AA/AA/BB/CC | uint16 | D | uint16 | uint8 | uint8 | uint8 | uint8 | uint16 | uint16 | uint16 |

| Data Type | Variable type | No. elements | Data payload (No. elements digit) | | | | | CRC-32 | Stop |
|---|---|---|---|---|---|---|---|---|---|
| uint8 | uint8 | uint16 | x | x | x | x | x | uint32 | CRLF |

Figure 35 Data Frame

Table 33 Binary Frame Data Values

| Format Field | Field Size | Content | Encoding | Allowed Values |
|---|---|---|---|---|
| Header | 4 bytes | Start of frame | Fixed | AAAABBCC |
| Frame Counter | 2 bytes | Frame counter | Unsigned Integer | 0 to 65535 |
| Frame Identifier | 1 byte | Frame identifier | Fixed | See Table 35 |
| Frame Length | 2 bytes | Total length of ‘data type’, ‘variable type’, ‘no. samples’ and ‘data payload’ fields | Unsigned Integer | 0 to 65535 |
| TxID | 1 byte | Transmit channel ID | Unsigned Integer | 1 |
| RxID | 1 byte | Receive channel ID | Unsigned Integer | 1 |
| Data Source | 1 byte | Data Source | Unsigned Integer | See Table 34 |
| Gain | 1 byte | System Gain in dB | Unsigned Integer | 0 to 256 |
| Measurement Cnt | 2 bytes | Measurement cycle counter | Unsigned Integer | 0 to 65535 |
| Slowtime Cnt | 2 bytes | Slowtime counter | 0 | 0 |
| Update Rate | 2 bytes | Update rate | Unsigned Integer | 0 to 65535 |
| Data Type | 1 byte | Form of data in payload | Unsigned Integer | 0 to 65535 |
| Variable Type | 1 byte | Format of sample points in data payload | Unsigned Integer | 0 to 65535 |
| No. Elements | 2 bytes | Number of sample points in data payload in bytes | Unsigned Integer | 0 to 65535 |
| Data Payload | N bytes | Sensor Data | Variable Type | |
| CRC-32 | 4 bytes | Checksum of Data Frame | Unsigned Integer | 0 to 4294967295 |
| Stop Mark | 2 bytes | Stop mark of Data Frame | Unsigned Integer | \r\n |

Table 34 Data Source

| Data Source | Value |
|---|---|
| I Channel | 1 |
| Q Channel | 2 |
| Interleaved Channel | 3 |
| Summed Channel | 4 |

Table 35 Binary Frame Identifier Overview

| Frame Identifier | Tag | Content |
|---|---|---|
| Data Frame | D | Contains radar signal related data |
| Error Frame | E | Contains basic error information |
| Info Frame | I | Contains hardware and firmware information |
| Parameter Frame | P | Contains radar parameters and their values |

## 7.1 Data Frame; ADC Raw Data (I/Q), Magnitude, Phase and CFAR Output

Table 36 Binary ADC, FFT, Magnitude, Phase and CFAR Data Values

| Format Field | Field Size | Content | Encoding | Allowed Values |
|---|---|---|---|---|
| Data Payload | No. Samples | Magnitude/Range/ CFAR | Signed Integer | -140 to 0 (dB unit) |
| | No. Samples | Phase | Signed Integer | 10000*(-π to +π rad) |
| | No. Samples | ADC/FFT | Unsigned/Signed Integer | decimal between -32768 to +32767 |

## 7.2 Data Frame; Target Information

| Target no. | Distance | Magnitude | Phase | Velocity | Azimuth | Elevation | SNR | Target Age |
|---|---|---|---|---|---|---|---|---|
| uint8 | uint16 | int16 | int16 | int16 | int16 | int16 | uint16 | uint16 |
| No. of detected target / Data Payload | | | | | | | | |

Figure 36 Target information – payload in Data Frame

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

Table 37 Binary Target List Data Values

| Format Field | Field Size | Content | Encoding | Allowed Values |
|---|---|---|---|---|
| Target no. | 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 |
| Velocity | 2 bytes | Velocity of the target | Signed Integer | -32768 to +32767 |
| Azimuth Angle | 2 bytes | Azimuth angle of the target | Signed Integer | 0 |
| Elevation Angle | 2 bytes | Elevation angle of the target | Signed Integer | 0 |
| SNR | 2 bytes | Signal to noise ratio | Unsigned Integer | 0 to 65535 |
| Target Age | 2 bytes | Target age | Unsigned Integer | 0 to 65535 |

## 7.3 Parameters Frame

PARAMETER FRAME

| Header | Frame cnt | Id | Length | Tag | Data Length | Data | Tag | Data Length | Data | CRC-32 | Stop | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AA/AA/BB/CC | uint16 | P | uint16 | uint32 | uint16 | x | uint32 | uint16 | x | uint32 | CR | LF |
| | | | | | | | repeated no of parameter times | | | | | |

Figure 37 Parameter Frame

Parameters Frame contains all the parameters that can be set on the kit, see Table 21. Tag represents the parameter name, data is the values of the parameter.

In the binary parameters 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.

Table 38 Binary Parameters Data Values

| Format Field | Field Size | Description | Encoding | Allowed Values |
|---|---|---|---|---|
| Header | 4 bytes | Start of frame | Fixed | AAAABBCC |
| Frame Counter | 2 bytes | Frame counter | Unsigned Integer | 0 to 65535 |
| Frame Identifier | 1 byte | Frame identifier | Fixed | Table 35 |
| Data Length | 2 bytes | Length of frame excluding start marker, identifier, length field itself, CRC checksum, stop markers | Unsigned Integer | 0 to 65535 |

## 7.4 Info Frame

INFO FRAME

| Header | Frame cnt | Id | Length | Tag | Data Length | Data | Tag | Data Length | Data | CRC-32 | Stop | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AA/AA/BB/CC | uint16 | I | uint16 | x | uint16 | x | x | uint16 | x | uint32 | CR | LF |
| | | | | | | | repeated no of system parameter | | | | | |

Figure 38 Info Frame

Table 39 Binary System Data Values

| Format Field | Field Size | Description | Encoding | Allowed Values |
|---|---|---|---|---|
| Header | 2 bytes | Start of frame | Fixed | AAAABBCC |
| Frame Counter | 2 bytes | Measurement cycle counter | Unsigned Integer | 0 to 65535 |
| Frame Identifier | 1 byte | Frame identifier | Fixed | Fixed |

Table 40 Info Tags

| Format Field | Field Size | Description |
|---|---|---|
| Data Length | 2 bytes | Length of frame excluding start marker, identifier, length field itself, CRC checksum, stop markers |
| UID | 3 bytes | Indicates start of the microcontroller UID info |
| UID length | 2 bytes | Length of the UID field in bytes |
| Data | UID length | The microcontroller UID is a unique unsigned HEX number |
| HW | 2 bytes | Indicates start of the hardware info |
| HW length | 2 bytes | Length of the HW field in bytes |
| Data | HW length | Baseboard hardware identifier |
| RFE | 3 bytes | Indicates start of the radar front end info |
| RFE length | 2 bytes | Length of the RFE field in bytes |
| Data | RFE length | Radar front end chip identifier of firmware |
| FW | 2 bytes | Indicates start of the software / firmware info |
| FW length | 2 bytes | Length of the FW field in bytes |
| Data | FW length | Firmware version in format: <check-in ID >-<date >-<major>.<minor>.<revision> |
| CP | 2 bytes | Indicates start of the communication protocol info |
| CP length | 2 bytes | Length of the CP field in bytes |
| Data | CP length | Protocol version in format: <protocol ID>-<spec date>-<major>.<minor>.<revision> |

## 7.5 Error Frame

| ERROR FRAME | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Header | Frame cnt | Id | Length | Tag | Data Length | Data | Tag | Data Length | Data | CRC-32 | Stop | |
| AA/AA/BB/CC | uint16 | E | uint16 | 8 bytes | uint16 | uint32 | 8 bytes | uint16 | uint32 | uint32 | CR | LF |
| | | | | | | | repeated no of error | | | | | |

Figure 39 Error Frame

The error frame 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 grouped under 4 different fields. If an error is present, first the group name tag and then the error tag comes. Please see Figure 34 for display of Error Frame in a terminal window. When there is no error, the error data blocks (light blue) will not be present in the Error frame.

In Table 42, colored rows represent each error blocks, the bold words in the Format Field sections are error group names and the below tags under the same color are error tags.

Multiple errors that belong to one error group can be raised at the same time, in that case the error tags are separated with '|'. The main errors are separated with comma','.

An example of error data blocks (light blue) in the error frame is given below;
COMMNCTN|CRCE,TRANSCVR|BWUR|FBSH

Table 41 Binary Error Data Values

| Format Field | Field Size | Description | Encoding | Allowed Values |
|---|---|---|---|---|
| Header | 2 bytes | Start of frame | Fixed | AAAABBCC |
| Frame Counter | 2 bytes | Measurement cycle counter | Unsigned Integer | 0 to 65535 |
| Frame Identifier | 1 byte | Frame identifier | Fixed | E |

Table 42 Error Tags

| Format Field | Field Size | Description |
|---|---|---|
| Data Length | 2 bytes | Length of frame excluding header, identifier, length field itself, stop markers |
| **COMMNCTN** | 8 bytes | Indicates the communication errors start point. Communication errors between kit and PC |
| CRCE | 4 bytes | CRC/Protocol error |
| COMP | 4 bytes | Com Port error |
| **TRANSCVR** | 8 bytes | Indicates the transceiver errors start point. Errors are related to RFE and PLL. |
| RFEO | 4 bytes | RFE out of spec |
| BWOR | 4 bytes | BW Overrun |
| BWUR | 4 bytes | BW Underrun |
| FBSH | 4 bytes | Base Frequency too high |
| FBSL | 4 bytes | Base Frequency too low |
| LCKL | 4 bytes | Lock Loss |
| BIST | 4 bytes | BIST Error |
| FMAX | 4 bytes | Maximum Frequency not found |
| FMIN | 4 bytes | Minimum Frequency not found |
| ISME | 4 bytes | ISM error |
| **PROCSSNG** | 8 bytes | Indicates the processing errors start point. Processing errors. |
| FFTP | 4 bytes | FFT Points |
| FFTO | 4 bytes | FFT Overrun - If no of samples > FFT Size |
| GAIN (level) | 4 bytes | Saturation (Software) |
| **SYSTMCON** | 8 bytes | Indicates the system errors start point. General system related errors. |
| FSAMP | 4 bytes | Sampling frequency error |
| STAT | 4 bytes | State Machine error |
| FLSH | 4 bytes | Flashing error |
| STRN | 4 bytes | Saturation (Hardware) |
| SMPO | 4 bytes | Sample Overrun – ADC faster than processing |

# Disclaimer