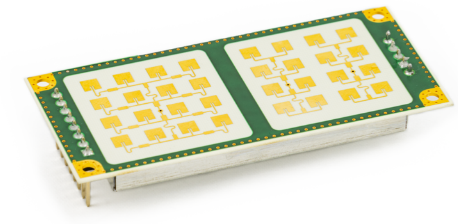
RFbeam Microwave

K-MD7

digital radar transceiver



Features

- Small and low cost digital 24 GHz traffic radar sensor
- Measures speed, direction, distance and angle of moving objects
- Perfect for speed signs or simple traffic counting applications
- Maximum speed range of 200 km/h and distance range of 300m
- Typical detection distance of 50m for persons and 150m for cars
- Multi-target tracking for up to 8 moving objects
- Target list output over serial UART interface
- Pulsed FSK signal processing to lower power consumption
- Integrated bootloader for firmware update
- Wide operating voltage range of 3.2 to 5.5V
- 34 x 30 degree antenna beam pattern

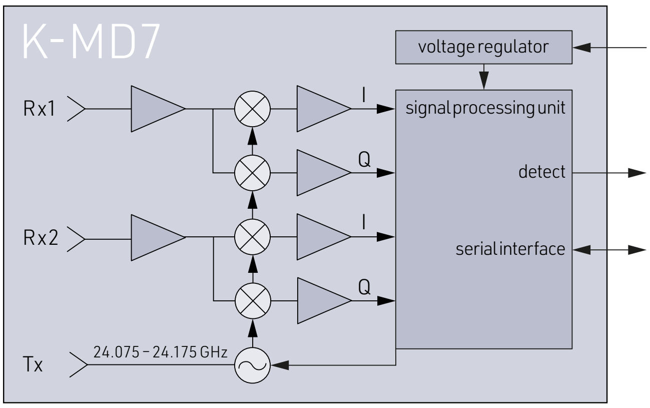
Description

The K-MD7 is an evolution of the successful K-LD7 with a narrower antenna beam and enhanced processing power. This allows for higher detection distances and tracking of up to 8 objects to a maximum unambiguous range of 300m. The serial interface features the possibility to read out a target list with speed, direction, distance and angle information of all moving objects in front of the sensor or to digitally configure the sensors detection parameters.

There is no need to write own signal processing algorithms or handle small and noisy signals. A small footprint of 70 x 32 x 13.5 mm gives maximum flexibility in the product development process. For fast prototyping an evaluation kit (K-MD7-EVAL) is available which features powerful signal visualization on a PC.

Block Diagram

Figure 1: **Block diagram**



Characteristics

Parameter	Conditions / Notes	Symbol	Min	Typ	Max	Unit
Operating conditions						
Supply voltage		V_{cc}	3.2		5.5	V
RMS current	Depending on speed range setting	I_{cc}	55		105	mA
Peak current		I_{pp}		180	250	mA
Operating temperature		T_{Op}	-40		+85	°C
Storage temperature		T_{St}	-40		+105	°C
Transmitter						
Transmitter frequency	T_{amb}=-40°C .. +85°C	f_{TX}	24.075		24.175	GHz
Frequency drift vs. temperature		Δf_{TX}		0.6		MHz/°C
Antenna gain	f_{TX}=24.125GHz	G_{TXAnt}		12.2		dBi
Output power	EIRP	P_{TX}			20	dBm
Spurious emissions	According to ETSI 300 440	P_{Spur}		-30		dBm
Receiver						
LNA gain		G_{LNA}		19		dB
Mixer conversion loss	f_{IF}=1kHz	D_{mixer}		10		dB
Antenna gain	f_{TX}=24.125GHz	G_{RXAnt}		9.8		dBi
Receiver sensitivity	f_{IF}=500Hz, B=1kHz, S/N=6dB	P_{RX}		-104.2		dBm
Overall sensitivity	f_{IF}=500Hz, B=1kHz, S/N=6dB	D_{system}		-148.8		dBc
Detection distance	σ=1 m^2 (Person)	R		50		m
Signal Processing						
Modulation				FSK		
Velocity processing				512 point complex FFT		
Speed range	Max value adjustable	r_{speed}	0.5		200	km/h
Speed resolution	Depending on speed range setting	Δr_{speed}	0.2		0.8	km/h
Distance range	Max value adjustable	$r_{distance}$	1		300	m
Distance resolution	Depending on distance range setting	$\Delta r_{distance}$	1		3	m
Angular resolution		Δr_{angle}		1		deg
Tracking range		$r_{tracking}$	1		300	m
Antenna						
TX Horizontal -3dB beam width	E-Plane	$W_{\varphi TX}$		30		°
TX Vertical -3dB beam width	H-Plane	$W_{\theta TX}$		30		°
RX Horizontal -3dB beam width	E-Plane	$W_{\varphi RX}$		46		°
RX Vertical -3dB beam width	H-Plane	$W_{\theta RX}$		30		°
Horiz. side lobe suppression		D_{φ}	-12	-20		dB
Vertical side lobe suppression		D_{θ}	-12	-20		dB
Rx1 / Rx2 spacing		l		12.446		mm
Interface						
Digital output high level voltage		$V_{OH@8mA}$	2.4		3	V
Digital output low level voltage		$V_{OL@8mA}$	0		0.4	V
Digital output high level voltage		$V_{OH@20mA}$	1.7		3	V
Digital output low level voltage		$V_{OL@20mA}$	0		1.3	V
Digital input high level voltage		V_{IH}	1.7		4	V
Digital input low level voltage		V_{IL}	-0.3		1.3	V
Digital I/O source/sink current		I_{OH}, I_{OL}	-20		20	mA
Body						
Outline dimensions				70 × 32 × 13.5		mm^3
Weight				11		g
Connector				3pin 2.54mm / 8pin 2.54mm		
ESD rating						
Electrostatic discharge	Human body model class 2	V_{ESD}			2000	V

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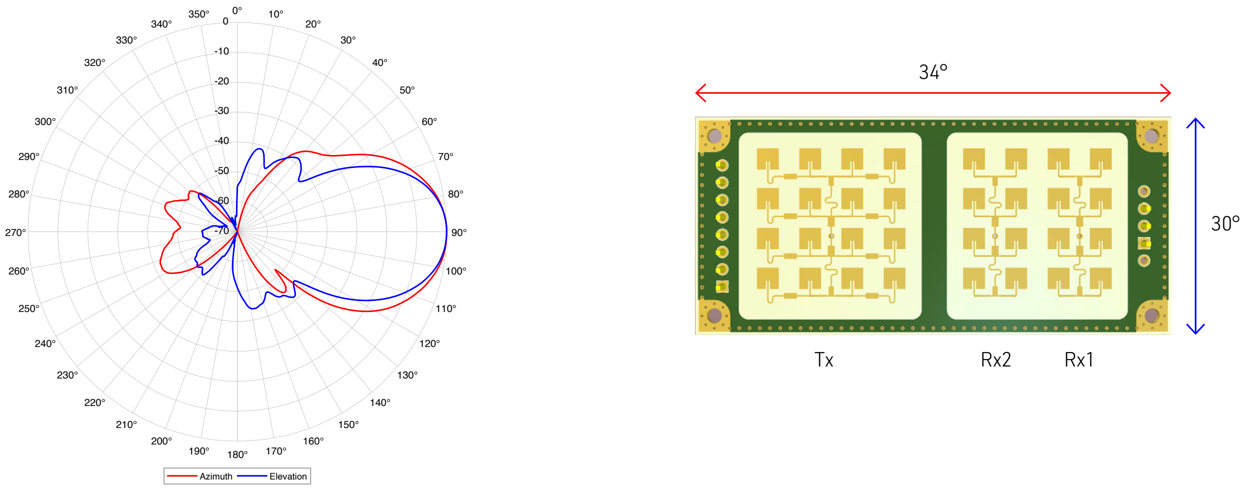
1 Antenna Diagram Characteristics

This diagram shows module sensitivity in both azimuth and elevation directions. It incorporates the transmitter and receiver antenna characteristics.

Figure 2: **Overall antenna diagram**



2 Pin Configurations and Functions

Figure 3: **Pin configuration**

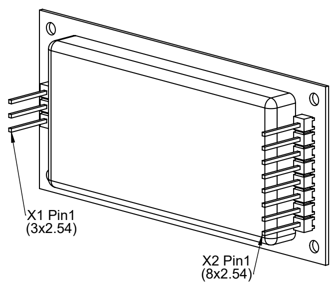


Table 1: **Pin function description**

Connector	Pin. No.	Name	Description
X1	1 – 3	Mounting	These pins are for mounting only. ⚠ Leave these pins floating and do not connect them to any potential.
X2	1	GND	Ground pin
	2	Detection out	Digital detection output. Goes to high if in minimum one tracked target is inside of the defined detection zone. ✎ The detection area and other parameters of the detection algorithm can be easily changed over the instruction set.
	3	VCC	Power supply pin (3.2 to 5.5V)
	4	RX	Serial interface RX input
	5	TX	Serial interface TX output
	6	Digital IO 1	Reserved for future use, do not connect
	7	Digital IO 2	Reserved for future use, do not connect
	8	Digital IO 3	Reserved for future use, do not connect

3 Theory of Operation

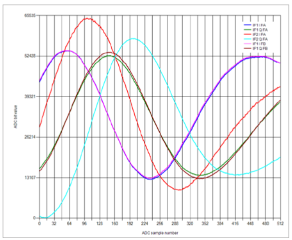
3.1 Overview

The K-MD7 is a Doppler radar sensor and consists of an analogue RF frontend and a powerful signal processor with tracking and a fully digital serial interface. The RF frontend features one transmitter with a modulation input and two I/Q receivers. The signal processing unit modulates the frontend with a frequency step (FSK modulation) and samples the analogue I/Q Doppler signals for both transmit frequencies and for both receiving antennas. The processing of this sampled data allows the measurement and tracking of speed, direction, distance and angle of moving objects in the front of the sensor.

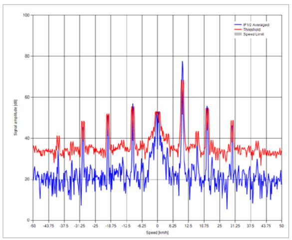
3.2 Processing

The processing of the K-MD7 uses different processing stages to measure and track the speed, direction, distance and angle of moving targets. The last stage implements a configurable detection zone which signals a detection over a digital output. To get the full control in an application it is possible to read out the data of each processing step over the serial interface.

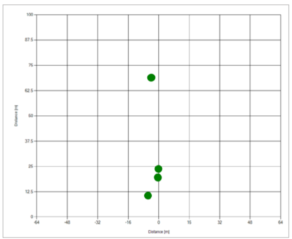
Table 4: **Signal processing workflow**



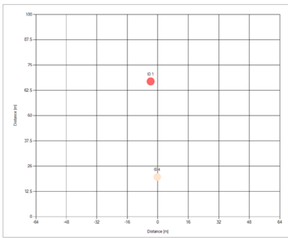
Raw ADC data (RADC)
- Samples I/Q ADC data of receiver Rx1 and Rx2 for frequency A
- Samples I/Q ADC data of receiver Rx1 for frequency B



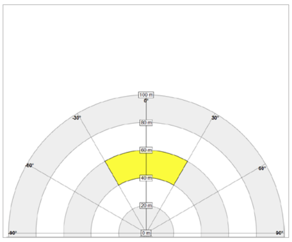
Raw FFT data (RFFT)
- Calculates the complex FFT from the I/Q ADC data of Rx1 and Rx2 for frequency A
- Averages the two complex FFT's
- Adds the threshold line to the RFFT data
- Includes speed and direction filters



Raw ADC data (RADC)
- Samples I/Q ADC data of receiver Rx1 and Rx2 for frequency A
- Samples I/Q ADC data of receiver Rx1 for frequency B



Tracking data (TDAT)
- Cluster and track the dominant raw targets
- Filter out interferences
- Predicts temporary lost objects
- Can track up to 8 different targets



Detection zone
- Generates a detection if in minimum one tracked target is in a detection zone
- Size of detection zone is configurable

3.3 Speed and direction measurement

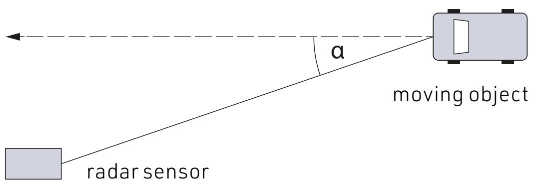
Every moving object in front of the sensor generates a Doppler frequency at the analogue outputs of the RF frontend. This Doppler frequency is proportional to the speed of the object. Moving direction is defined by the phase shift between the I/Q signals.

The K-MD7 calculates the speed and the direction for all raw targets. The direction is represented by the sign of the speed. A positive speed represents a receding and a negative speed an approaching movement.

The calculated speed is only correct if the movement of the object is radial to the sensor. If the movement is tangential the speed needs to be compensated by the angle of the movement compared to the sensor.

$$v_{real} = \frac{v_{measured}}{\cos(\alpha)} \qquad [km/h]$$

Figure 5: **Tangential speed compensation**



3.4 Distance measurement

The distance measurement is based on the FSK principle. The signal processing unit quickly changes between two discrete RF frequencies and measures the ADC values for both transmitting frequencies. After the detection of all raw targets above the threshold, the distance for each target is calculated based on the phase difference in both ADC signals.

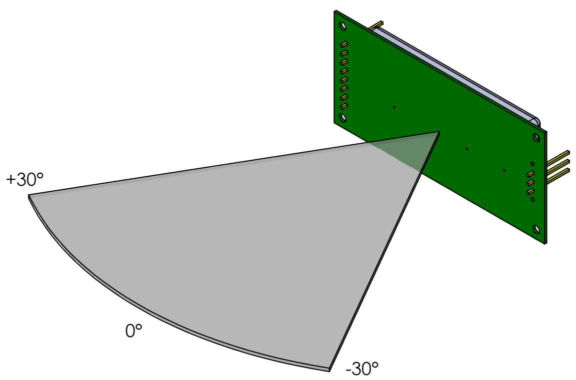
3.5 Angle measurement

The angle measurement is based on the angle of arrival principle. After the detection of all raw targets above the threshold, the angle for each target is calculated based on the phase difference between the two receiving channels.

The angle is calculated in degree and valid between +/- 30°. If an object has an angle of zero it is directly in front of the sensor. A positive or negative angle defines if the target is more on the right or left side of the sensor.

> ⚠ Any objects outside the valid angular range will be attenuated due to the narrow antenna beam of the sensor. If a strong reflector is in the near field of the sensor, but outside the unambiguous angle range, it may produce a RAW target with incorrect angle information.

Figure 6: **Positive and negative angle definition**



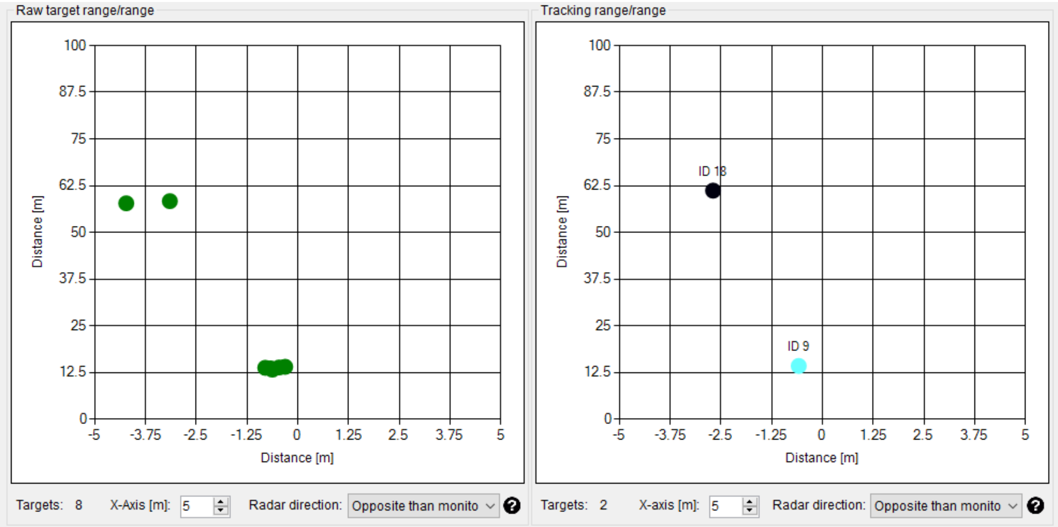
3.6 Raw targets and tracking filter

A real object generates not only one raw target point. A car for example generates several raw target points with different speeds and different distances created by the size of the car and the wheels. This generates a so called point cloud of different raw targets from one object. Depending on the environment where the sensor is used it will also see more or less reflexions generated by the moving object. The number of raw targets can be controlled by adjusting the threshold offset which is described in more detail in chapter Threshold offset on page 9 or by using a speed or direction filter.

To get a more usable output the sensor features a tracking filter to cluster and track the dominant targets based on the raw targets. The filter includes a suppression of reflexions, vibrations and interferences and can also predict temporary lost targets which generates a smooth output.

The tracking filter can be adapted to various applications via the parameters Tracking filter type which is described in more detail in chapter Tracking on page 9.
information.

Figure 7: **RAW targets vs. tracked targets**

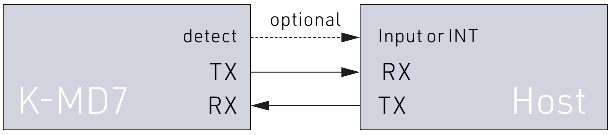


4 Application Information

4.1 Host driven operation

With a connection of the serial interface to a host (for example MCU or PC) it is possible to read out the processing data (RADC, RFFT, PDAT and TDAT) and control all the parameters of the sensor. Optionally it is possible to connect the digital output of the sensor to an input on the host to trigger the host if the sensor generates a valid detection. This is the recommended use case and allows the user to optimize the sensor easily for different applications.

Figure 8: **MCU or PC connection example**



4.2 Radar settings

The K-MD7 features different parameters to adjust the functionality of the sensor to the needs of different applications. All parameters are stored in the radar parameter structure which can be read out and written over the serial interface. The structure and the serial protocol are described in the chapter Instruction Set Description on page 11.

It is very important to set the distance and speed range settings to values which are matching with the distance and speed of the expected targets in the detection area of the sensor.

For example, if the goal is to measure objects in the 100m distance and 50km/h speed range, but cars are moving at 150m with 150km/h, the 200m distance range and 200km/h speed range setting must be used or the threshold offset needs to be increased until the cars are no longer visible in the raw targets.

⚠ Wrong settings can generate false sensor outputs. It is possible that strong targets outside the configured distance or speed range can create faulty targets.

4.2.1 Distance range

The distance range parameter defines the maximum unambiguous distance measurement of the sensor. For a lower maximal distance range, the range resolution is better but if the distance of a measured target is higher than the current distance range setting it can generate wrong measurements. Hence it is very important to set the distance range to a setting where targets are expected.

Table 2: **Distance range settings**

Max. range [m]	Range resolution [m]
100	1
200	2
300	3

An approach to work with a lower maximum distance range is to change the sensor orientation to get a field of view without moving objects above the maximal distance range or to increase the threshold offset (described in the chapter Threshold offset on page 9) to reduce the sensitivity of the sensor.

4.2.2 Speed range

The speed range parameter defines the maximum unambiguous speed measurement of the sensor. For a lower maximal speed range, the speed resolution is better and the current consumption is smaller but if the speed of a measured target is higher than the current speed range setting it can generate wrong measurements. Therefore it is very important to set the speed range to a setting where targets are expected.

Table 3: **Speed range settings**

Max. speed [km/h]	Speed resolution [km/h]	Typ. frame duration [ms]	Typ. Supply current [mA]
50	0.2	114	55
100	0.4	57	72
200	0.8	29	105

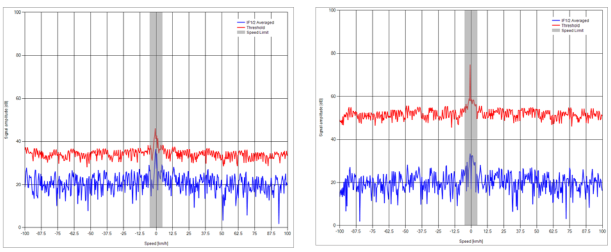
An approach to work with a lower maximum speed is to change the sensor orientation to get a field of view without moving objects above the maximal speed range or to increase the threshold offset (described in the chapter Threshold offset on page 9) to reduce the sensitivity of the sensor.

> To read out data intensive messages like RADC and RFFT it is recommended to work with the highest baud rate. If the readout time of the requested data is higher than the typical frame duration it is not possible to read out the frames in real time. By checking the frame number in the DONE message, it is possible to validate real time readout.

4.2.3 Threshold offset

The threshold offset is adjustable and defines the distance in dB between the noise floor of the raw FFT data and the threshold line. The processing in the K-MD7 searches for raw targets that are above this threshold line. The smaller the offset the more sensitive the sensor will be. A higher offset will reduce the sensitivity.

Figure 9: **Low vs. high threshold offset**



4.2.4 Tracking filter

The tracking filter can track up to 8 different targets and has the option to change its behaviour over a parameter in the instruction set.

> The implemented tracking filter is optimized for traffic applications and hence the output does potentially not match your application requirements. RFbeam offers the possibility to customize the tracker to your needs. Do not hesitate to contact us for an appropriate quote.

Table 4: **Tracking filter types**

Filter type	Description
Standard	Standard filter type to track multiple cars on a street
Fast detection	Enables a faster detection of the target with the disadvantage to reduce the immunity against reflexions and other interferences.
Long visibility	Filter with a high immunity against interferences and a high prediction of temporary lost targets

4.2.5 Base frequency

There are three channels available to adjust the base transmit frequency of the sensor. This can be useful if multiple sensors are transmitting in the same area with the same base frequency to suppress the generated interferences that can occur in such an environment

4.3 Detection settings

4.3.1 Target generation filter

The generation of targets in the K-MD7 can be filtered based on a set of adjustable parameters to optimize the sensor for different applications. The parameters are all located in the radar parameter structure which is described in detail in chapter Parameter structure on page 14.

Table 5: **Target generation filter parameters**

Parameter name	Description
Min. / max. detection speed	Used to filter out slow or fast targets. PDAT Raw targets are only generated if the speed of the object is between the minimum and maximum detection speed limit.
Detection direction	Used to limit the target generation by its direction. It is possible to filter out approaching or receding targets or allow a detection for both directions.

4.3.2 Detection zone filter

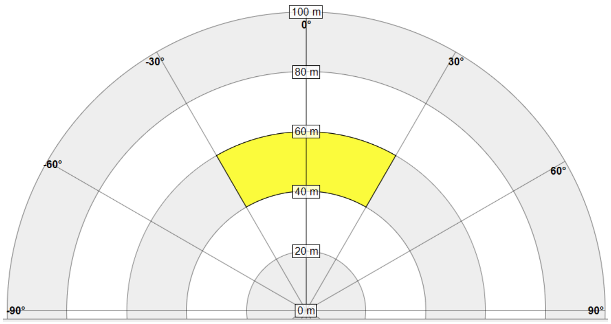
The K-MD7 features a configurable detection zone filter which switches the detection output to high as soon as at least one TDAT target is within the defined zone. This function can be used, for example, to wake up the host or an external display when a valid target is detected.

Table 6: **Detection zone filter parameters**

Parameter name	Description
Min. / max. detection zone distance	Used to limit the detection zone to a minimum and maximum distance.
Min. / max. detection zone angle	Used to limit the detection zone to a minimum and maximum angle.

> ⚠ The detection zone is only adjustable inside of the unambiguous angle range of +/- 30°.

Figure 10: **Detection zone visualisation**



5.3.3 Digital output

The sensor features four digital IO's on its connector. One output is used to signal if there is in minimum one tracked target within the detection zone. The remaining 3 IO's are reserved for future use or customer specific functions.

Table 7: **Functionality of detection output**

Function	Description
Detection output	Signals if there is a moving object inside of the detection zone Low -> No valid target inside the detection zone High -> In minimum one TDAT target inside the detection zone

5 Instruction Set Description

5.1 Hardware Layer

The hardware layer is based on a simple UART connection with a configurable baud rate. The sensor always starts up with its default baud rate. The default baud rate can be changed over the INIT command as described in the chapter Connection on page 12.

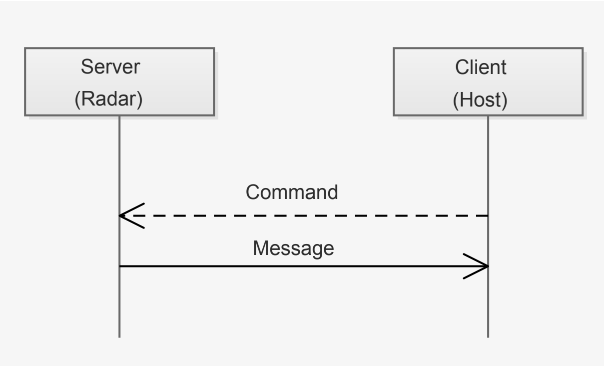
Table 8: **Default serial connection settings**

Parameter	Configuration
Baud rate	115200
Data bits	8
Parity	Even
Stop bits	1
Flow control	None

5.2 Communication Layer

5.2.1 Client-Server

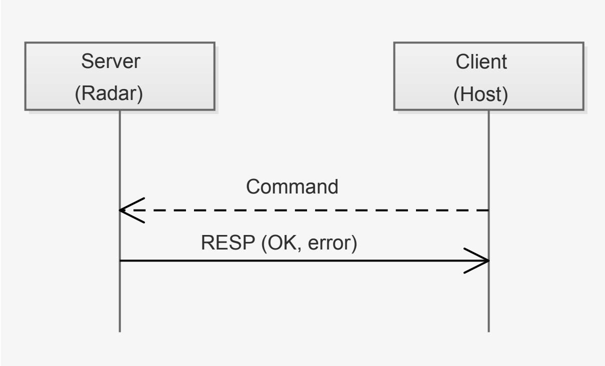
Figure 11: **Client-Server model**



The communication is based on a client-server model. There are two types of packets transmitted. Commands are sent from client to server and messages are sent from server to client.

5.2.2 Handshaking

Figure 12: **Handshaking**



Every command sent by the client is acknowledged by the server with a response message (RESP). The response message includes an error code what delivers information data about the success or failure of the received command.