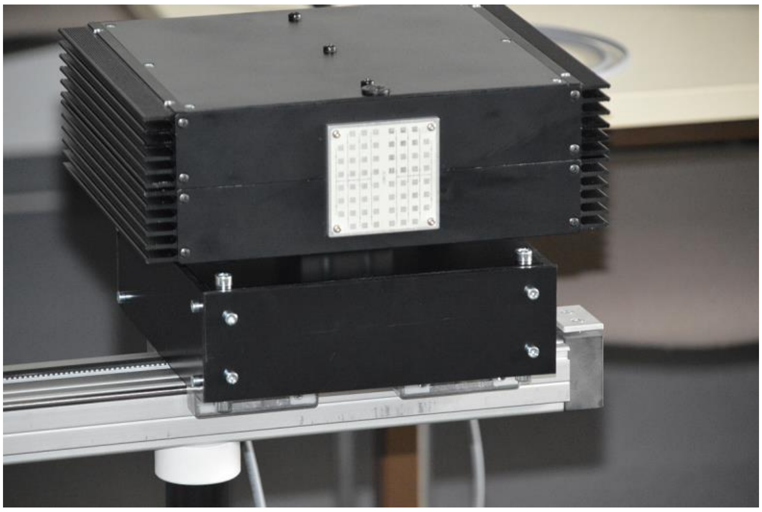
SkyRadar
Modular Radar Training System
FMCW and SAR



23.06.2014

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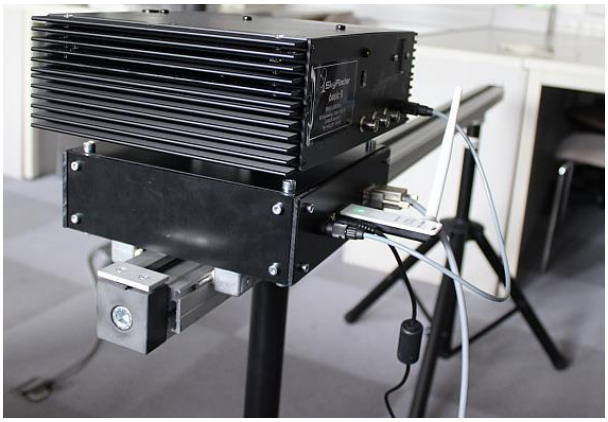
Catalog: SkyRadar FMCW 5.0
This catalog describes the product release 5.0



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SkyRadar Modular Radar Training System FMCW and SAR

1 Release notes

This document describes the FMCW and SAR module of product suite SkyRadar „Modular Radar Training System“. This data sheet has the release number 5.0. The product has been developed for didactical and research purposes, targeting Aviation Academies, Military Academies as well as Universities. It is not released for any operational Air Traffic Management functions. Indoor and outside operations may be subject to national telecommunication laws and regulations. The inside operation of this system is perfectly safe due to its low power technology.

2 Introduction

SkyRadar's modular radar training system FMCW and SAR is a high resolution close range ground radar developed as radar training system. It is perfectly safe for human users and supports apart from the Frequency Modulated Constant Wave (FMCW) functionality also Doppler, mono-pulse and Frequency Shift Keying (FSK). Together with its dc-motor piloted Synthetic Aperture Radar application it provides the most accurate SAR training radar for indoor and outdoor application that exists in the market.

The remainder of this document first introduces the FMCW module. Then it presents the SAR module which is actually an extension of the FMCW module.

A FMCW Base

Part #: SkyRadar PSR-FMCW-Ver.5.0

Description

Similar to the SkyRadar Base Module, the FMCW base is the core of a range of applications. It operates with an Phased Array antenna and provides applications as FMCW mode, Doppler, Frequency Shift Keying etc. The FMCW Base software allows for comfortable control of the system, providing multiple ways of visualization such as FMCW Fast Fourier Transform, Doppler, IF Signals or the VCO Ramp.

Parts

The FMCW Module consists of:

- one (1) phased array antenna
- one (1) base unit, including
  - one (1) digital signal processing unit (DSP)
  - one (1) transceiver
  - one (1) motor control unit (only activated when rotary unit is added)
- One (1) Visualization and Control Software for the FMCW module
- One (1) Laptop Computer (responding to current state-of-the-art)
- One (1) cable set.

Prerequisites

- none

Extensions

- SkyRadar SAR

3 General Description

3.1 Technical Features

- Supports Doppler, FMCW, FSK, Monopulse
- USB Interface to Host Computer
- Onboard Low Noise Power Supplies
- Connectors for Different Radar Devices
- Amplifiers for Native Doppler Transceivers
- High Performance 16Bit Data Processing
- 250kSamples/s ADC and DAC
- Compact and Rugged Construction
- Powerful Signal Explorer PC Software
- NI LabVIEW ® DAQmx USB Interface

3.2 Applications

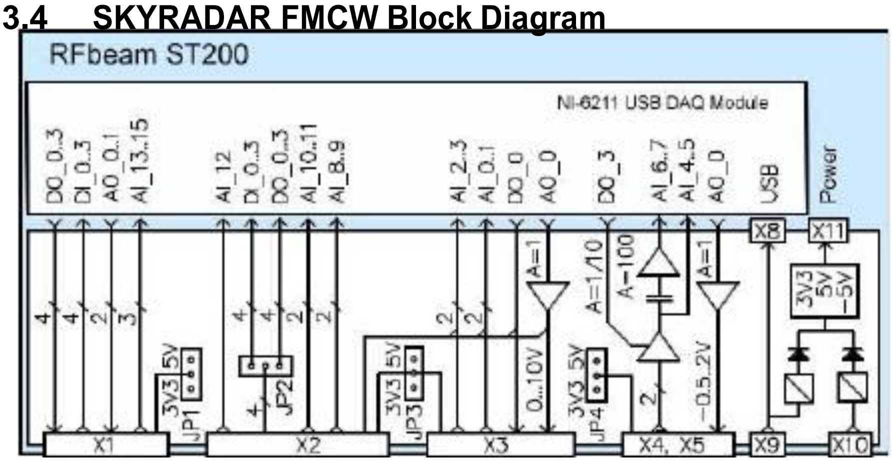
- Radar Training and Research System
- Evaluation of Advanced Shortrange Radar Applications
- Development of Own Data Processing Algorithms
- Signal Analysis and Logging

3.3 Description

SKYRADAR FMCW is a 16Bit data acquisition and processing system with a total 250k/s sampling rate. It contains all hardware necessary for acquiring Radar signals of SkyRadar Transceivers. SKYRADAR FMCW contains a motherboard with power supply, amplifiers and I/O connectors. Data acquisition is performed by a NI-USB-6211 16Bit multifunction DAQ module from National Instruments mounted on the backside.

The easy to handle SkyRadar Signal Explorer software features many basic Radar functions including an exciting FSK (Frequency Shift Keying) operation mode for high resolution distance measurements of moving objects.

3.4 SKYRADAR FMCW Block Diagram



Radar Connectors:
X1: General purpose I/O
X2: Mixed I/O
X3: 4 Channel An. Inputs
X4: 2 Channel An. Inputs
X5: 2 Channel An. Inputs

Computer Interface:
X9: USB PC Port

Power:
X10: Optional DC In
X11: Low Noise DC Out

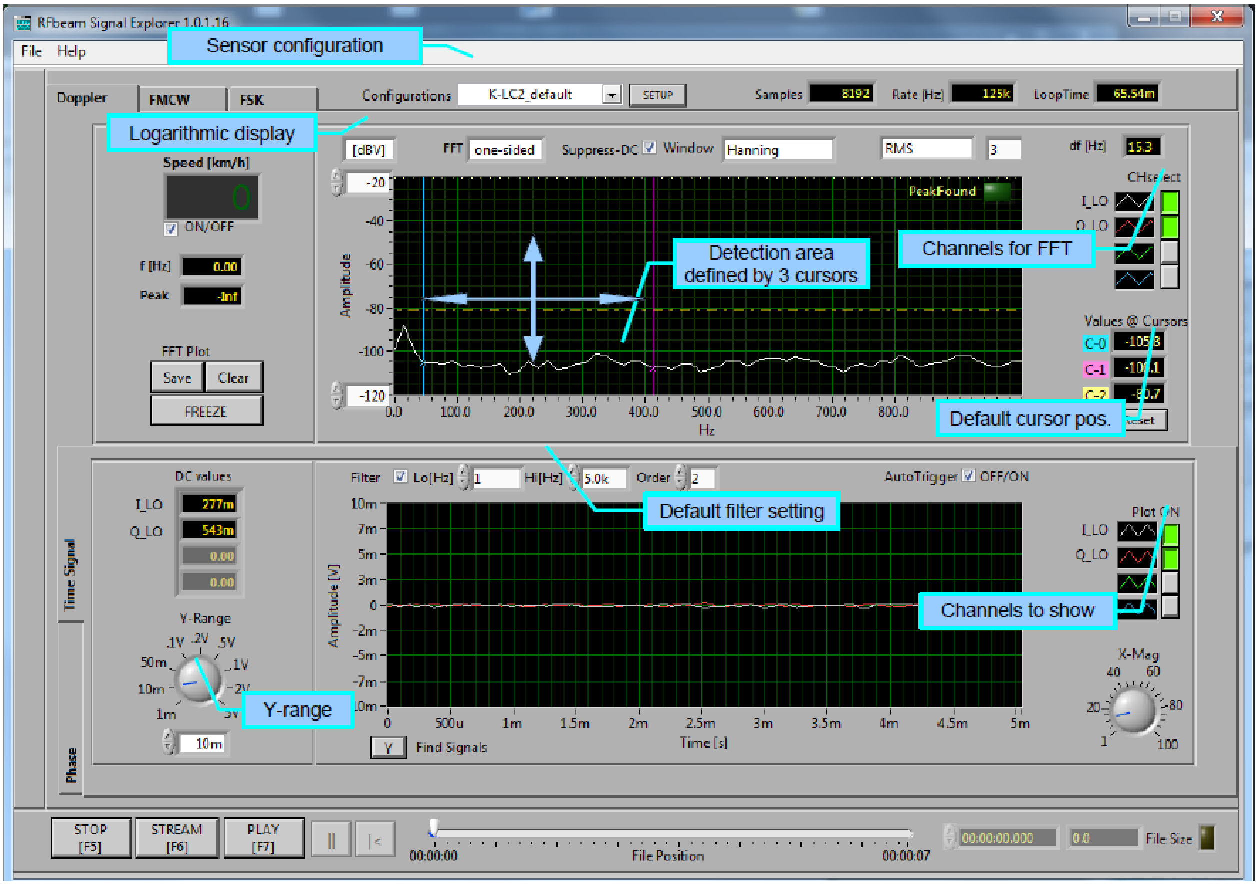
3.5 Components included in the system SkyRadar FMCW

- SKYRADAR FMCW Hardware
- SKYRADAR-FMCW Signal Explorer Software Installer on CD, USB stick or downloaded on HD
- USB cable
- K-LC2 sensor connected to connector X5
- PC running on Windows xp or never

3.6 Signal Explorer Software

SKYRADAR FMCW software comes with a setup procedure containing all necessary components into one single package:

- SkyRadar SKYRADAR FMCW
  Signal Explorer Software
- National Instruments DAQmx
  driver software
- National Instruments LabVIEW
  runtime systerm


RFbeam Signal Explorer 1.0.1.16
File Help
Sensor configuration
Doppler
FMCW
FSK
Configurations
K-LC2_default
SETUP
Samples
8192
Rate [Hz]
125k
LoopTime
65.54m
Logarithmic display
Speed [km/h]
ON/OFF
f [Hz]
0.00
Peak
-Inf
FFT Plot
Save
Clear
FREEZE
[dBV]
FFT
one-sided
Suppress-DC
Window
Hanning
RMS
3
df [Hz]
15.3
PeakFound
Amplitude
Hz
Detection area defined by 3 cursors
Channels for FFT
CHselect
I_LO
Q_LO
Values @ Cursors
C-0
C-1
C-2
Default cursor pos.
DC values
I_LO
Q_LO
277m
543m
0.00
0.00
Y-Range
Y-range
10m
Time Signal
Phase
Filter
Lo[Hz]
Hi[Hz]
5.0k
Order
2
AutoTrigger
OFF/ON
Default filter setting
Amplitude [V]
Time [s]
Find Signals
Plot ON
Channels to show
X-Mag
STOP [F5]
STREAM [F6]
PLAY [F7]
00:00:00
File Position
00:00:07
00:00:00.000
File Size

4 SKYRADAR FMCW Hardware

SKYRADAR FMCW consists of a mother board and a 16 Bit USB data acquisition system with 250kHz sampling rate. The mother board contains 5V and 3.3V low noise power supplies and analog buffers and amplifiers.

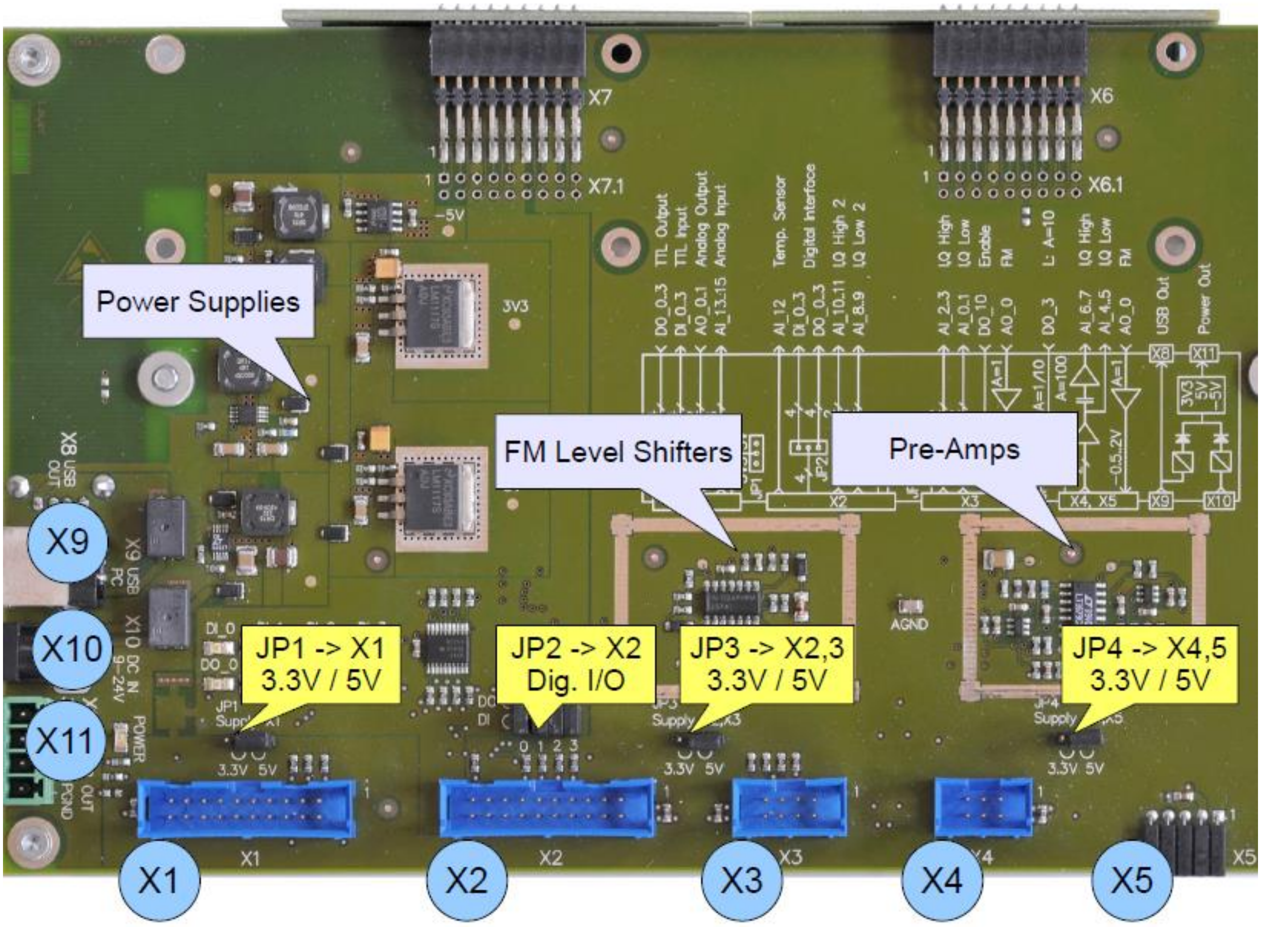
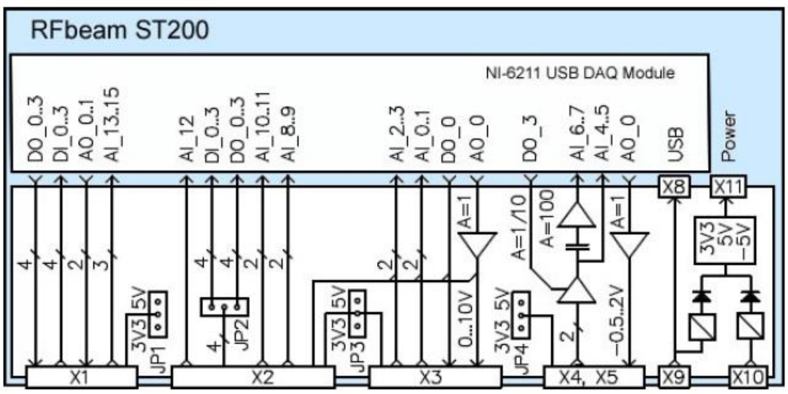


Fig 2: Connector Arrangement



Sensor Connectors:
X1: General purpose I/O
X2: Mixed I/O
X3: 4 Channel An. Inputs
X4: 2 Channel An. Inputs
X5: 2 Channel An. Inputs

Computer Interface:
X9: USB PC Port

Power:
X10: Optional DC In
X11: Low Noise DC Out

Fig. 3: Block Diagram

4.1 Typical Sensor Connections

Please refer to Fig. 3 and to chapter Sensor Connectors for more details on the connectors.

Sensors with higher current consumption (>120mA like K-MC4) need more power than USB can deliver. An external DC 12V power supply with >0.5A should be plugged into X10 of the SKYRADAR FMCW system.

5 Signal Explorer Software

5.1 Overview

SKYRADAR FMCW Signal Explorer provides 3 main operation modes:

- Doppler Mode: Speed and direction measurements
- FMCW Mode: Distance measurements of statical and moving objects
- FSK Mode: Distance measurements with high resolution for moving objets

User interface includes selecting of operation modes and sensor types, setting of filter types and bandwidth, sampling rates, graphical representation of signals in time and frequency.

The following figure describes the user inteface screen is devided into 3 sections:

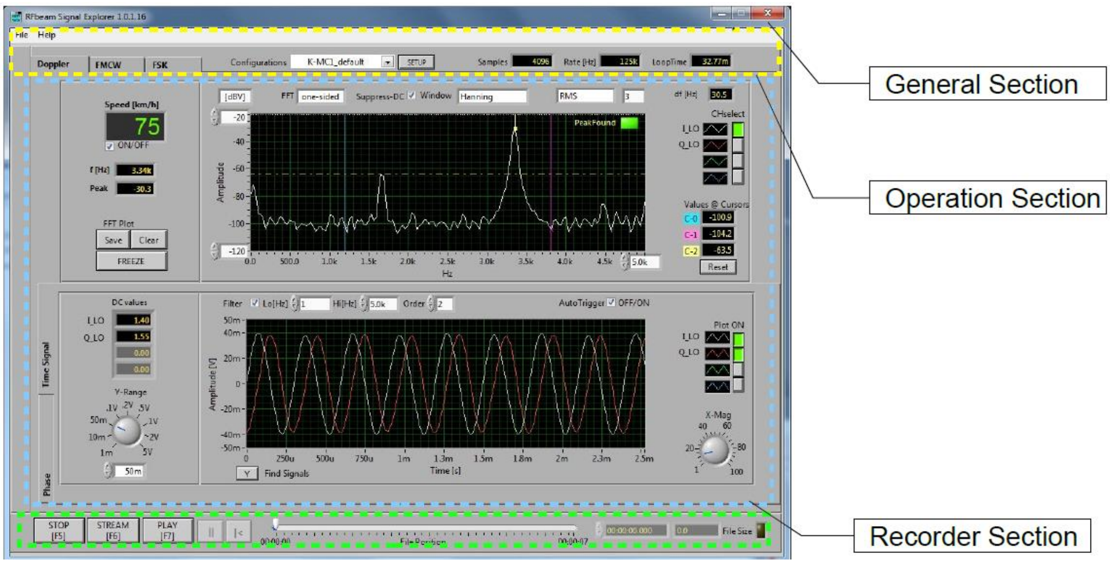


Fig. 4: Screen Sections

5.1.1 General Section

Settings and readouts in the general screen section (see Fig. 4) are accessible in all operation modes.

Readouts

- Samples:Number of samples per channel as input for the signal processing (FFT).
- Rate: ADC sampling rate per channel.
- Loop Time: Time to read the samples defined in the selected configuration.

5.1.2 Configurations Selector

Many key settings are stored as so called configurations. Existing configurations may be selected at any time. After selecting, Signal Explorer jumps back into operation mode Doppler.

Configuration naming convention:

```
K-LC2_X4-5_IQH.cfg
   |       |   |_connector inputs
   |       |____ connector name(s)
   |___________ sensor type
```

5.1.3 Operation Section

This is the real time signal section (see Fig. 4). Select the operation mode with the horizontal tabs on the top. Some modes allow selecting sub-modes by the vertical tabs in the bottom left part of the operation section

5.1.4 Recorder Section

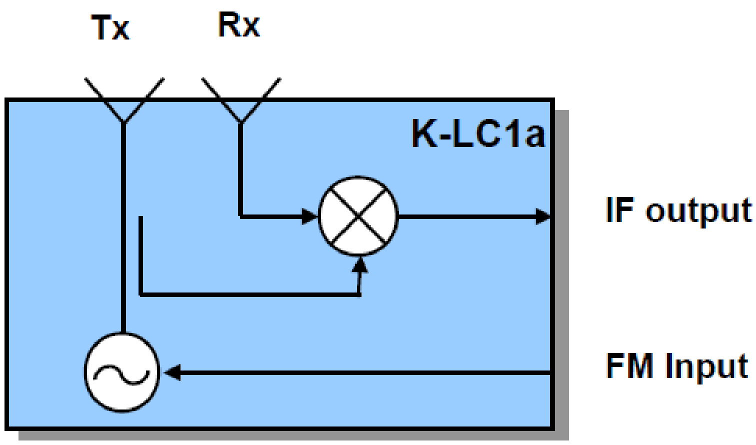
The Signal Explorer allows real time recording and playback of signals captured in the Doppler and in the FSK mode.

6 Modes

6.1 Doppler Mode

A more precise tiltle would be 'CW (Continuous Wave) Doppler Radar', when using SkyRadar Radar sensors. These sensors do not produce pulses, but send continuously in the K-band (24.125 GHz). The sensors are also called Radar transceivers, because they include a Transmitter and a Receiver. Doppler Radar is used to detect moving objects and evaluate their velocity.

RFbeam Radar transceivers return a so called IF signal, that is a mixing product of the transmitted (Tx) and the received (Rx) frequency. An moving object generates a slightly higher or lower frequency at the receiver. The IF signal is the absolute value of the difference between transmitted and received frequency. These transceivers operate in the CW (Continuous Wave) mode as opposed to the pulse radars that measure time of flight. CW radars can operate with very low transmit power (< 20dBm resp. 100mW).



.

Note the difference between logarithmic (upper figure) and linear (bottom figure) FFT display. Smaller peaks in logarithmic display disappear in linear display.

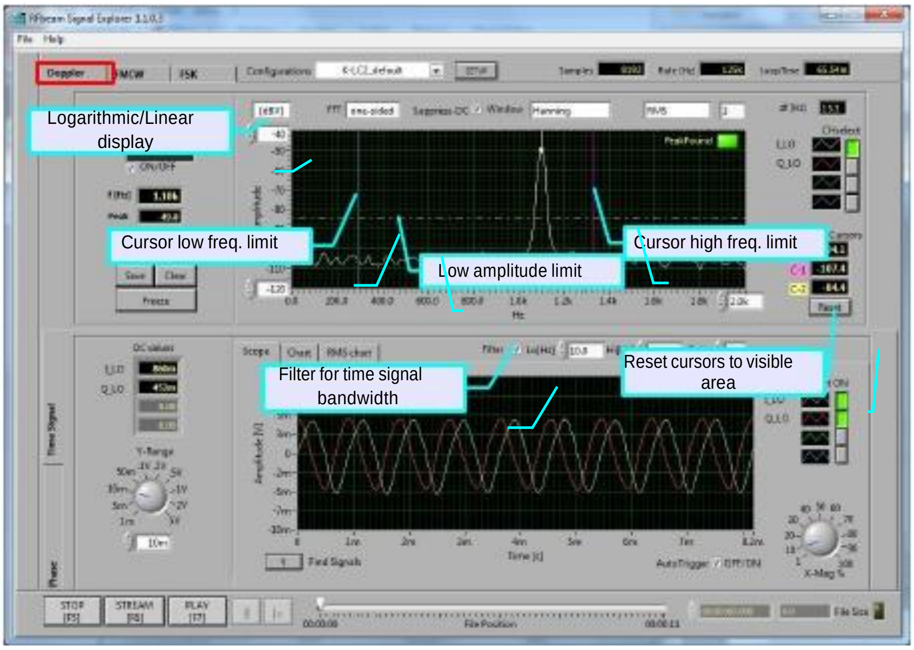


Fig. 7: Logarithmic FFT scale

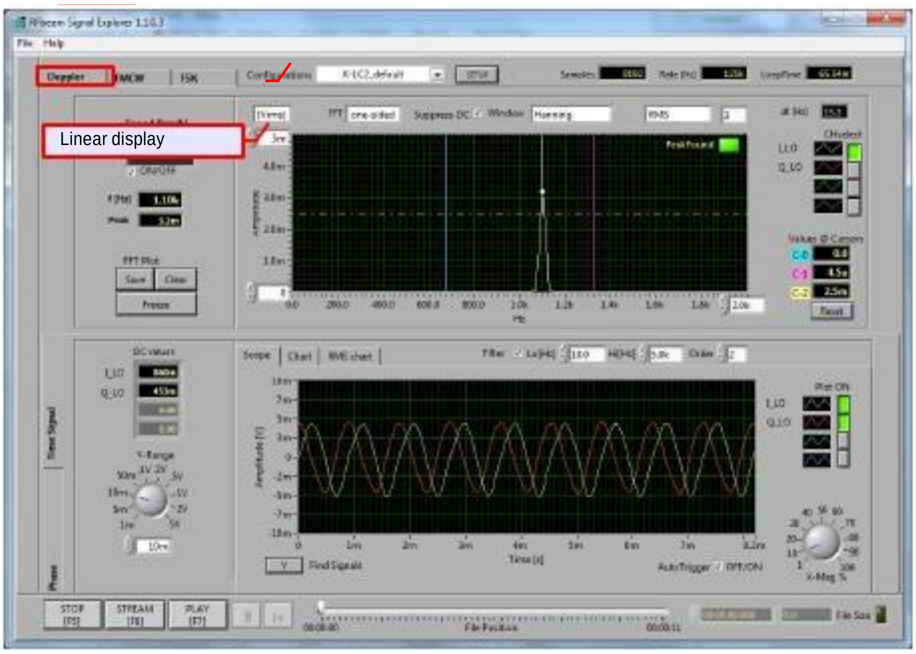


Fig. 8: Linear FFT scale

6.2 Chart Modes

Besides the classical scope modes, SKYRADAR FMCW allows “chart” modes for viewing slow signals.

Data for the charts come from the signal buffer. Scaling is performed on display level and not on signal level. This allows scrolling and zooming. Charts may be zoomed by changing the Y range and/or by changing the horizontal chart speed. Charts may be “freezed”. Freezed charts may be horizontally scrolled over a history of around 1 million samples.

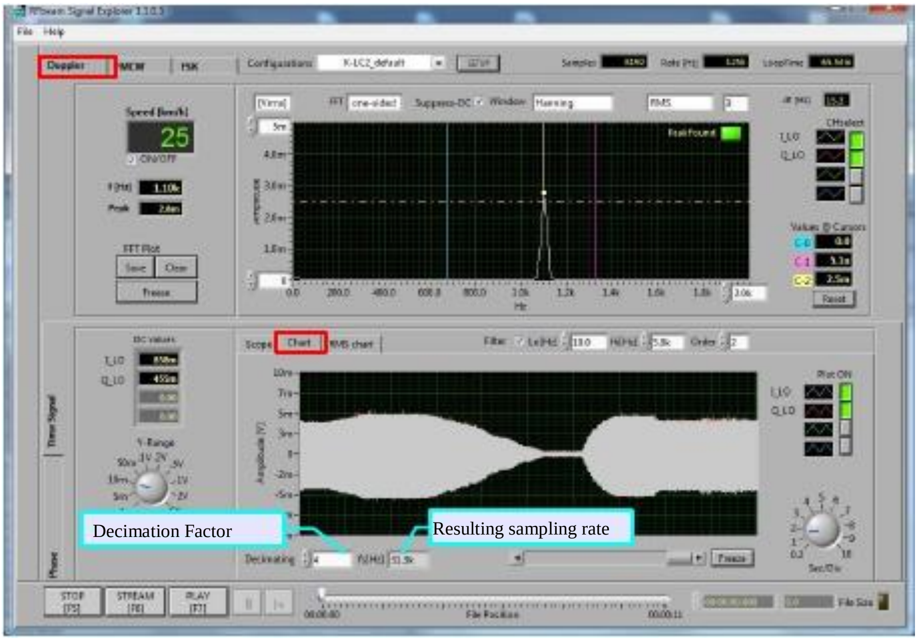


Fig. 9: Signal chart mode. Slow chart, high frequency → Envelope chart

You may (and should) down-sample the signal, so that not all the signal buffer will be written to the chart. Set the decimation factor to the highest possible value, but smaller than the number of samples (in this example 8192) defined in the configuration. This process is called decimation or resampling.

6.2.1 Signal chart mode - very slow signals

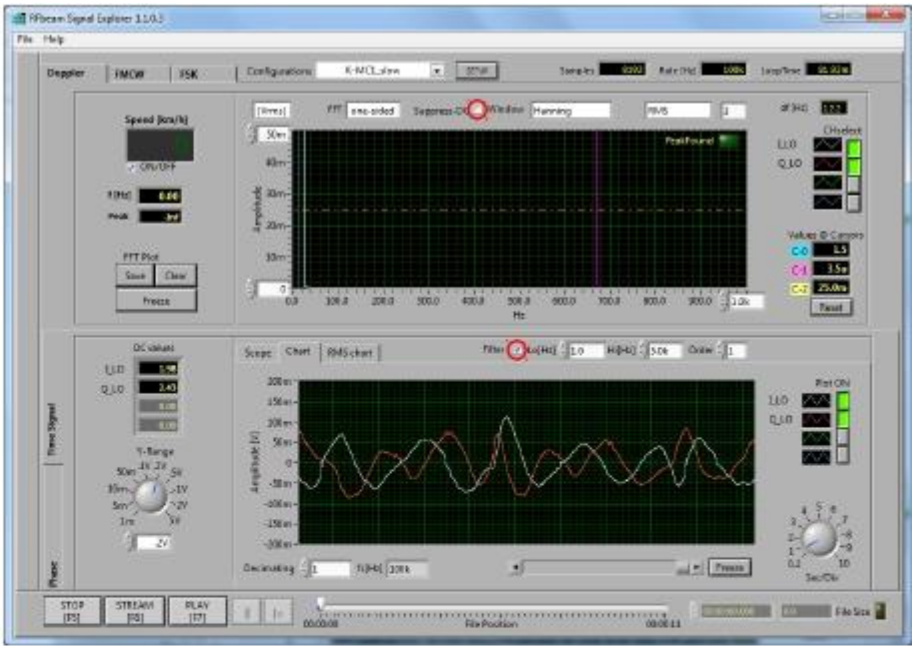


Fig. 10: Signal chart mode, very low frequency (record of human breathing)

6.2.2 RMS chart Mode

The “RMS chart mode” traces the RMS amplitude of the selected peak in a chart.

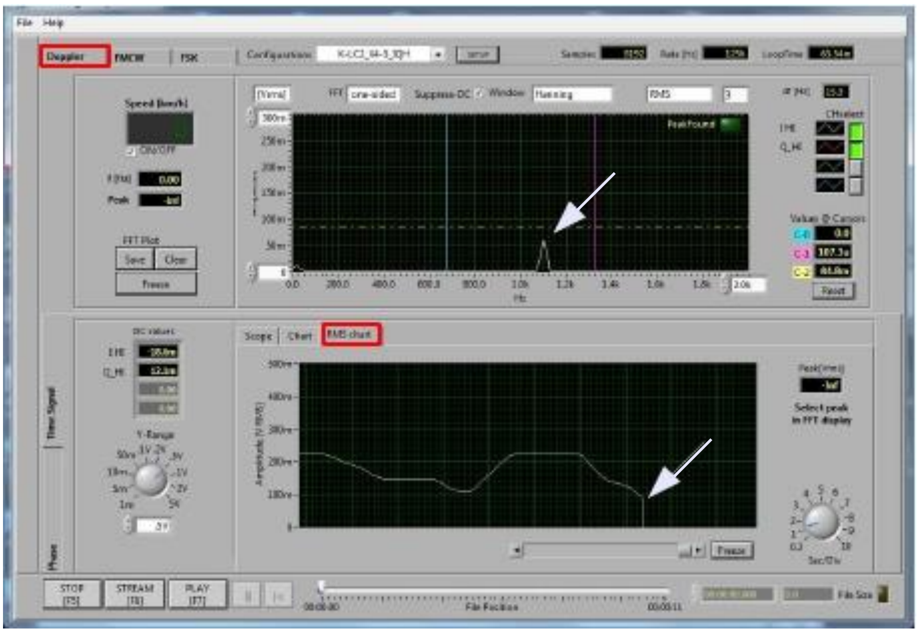


Fig. 11: RMS chart mode. Traces the selected peak's RMS amplitude

6.2.3 Exploring phase relation

The phase relation between two channels can be evaluated by using "cross FFT" algorithms (Fig. 12) or by using "complex FFT" (Fig. 13).

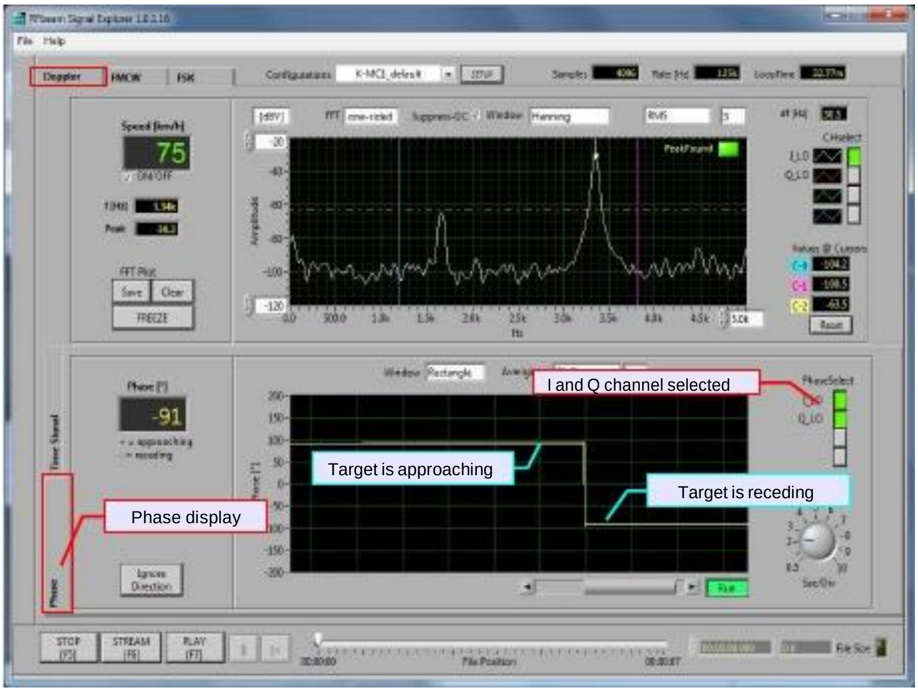


Fig. 12: Display I and Q phase relation to evaluate moving direction

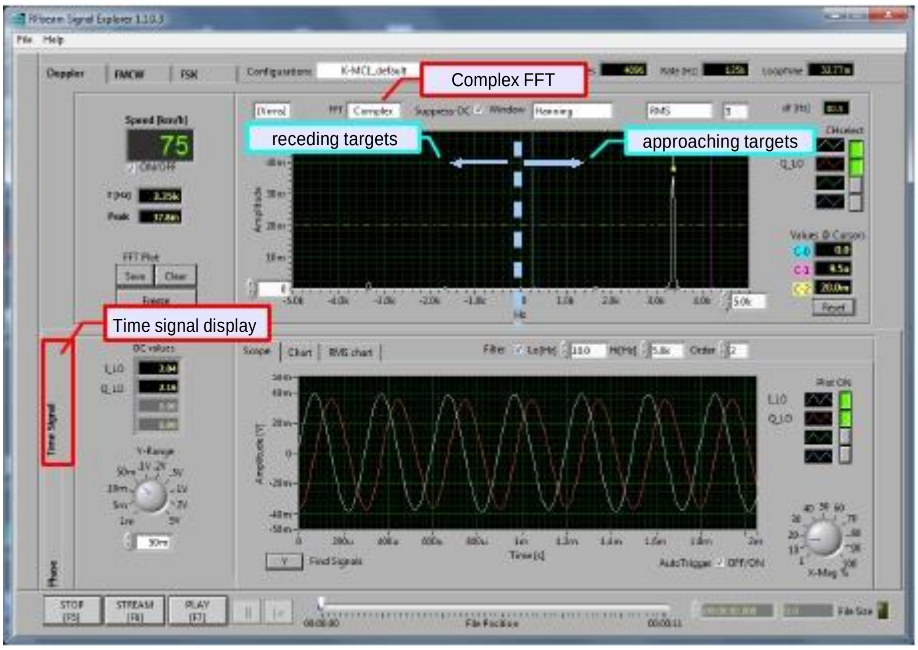


Fig. 13: Complex FFT with one approaching target: peak on right side

6.3 FMCW Mode

6.3.1 Introduction into FMCW

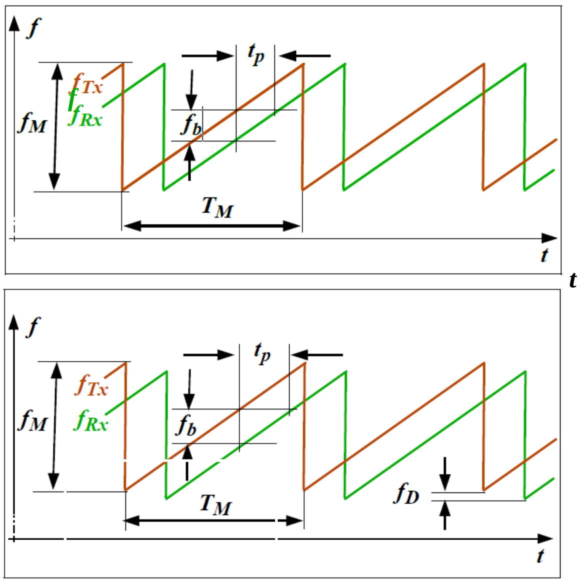
FMCW stands for Frequency Modulated Continuous Wave. This technique allows detection of stationary objects. FMCW needs Radar sensors with an FM input. This input accepts a voltage that causes a frequency change. There are also sensors with digital frequency control based on digital PLL designs. Modulation depth is normally a very small amount of the carrier frequency. In the K-band, most countries allow a maximum frequency range of 250MHz. Description of many effects such as velocity-range un-ambiguities go beyond the scope of this paper. Please refer to Radar literature for more detailed explanations of FMCW and FSK techniques.

6.3.2 Sawtooth Modulation

Transmit frequency is modulated by a linear ramp. Fig. 14 shows a typical signal fRx returned by stationary and constantly moving objects. Note, that the difference frequency fb is constant throughout nearly the whole ramp time. At the output of the Radar transceiver we get the low frequency signal fb called beat frequency. This is the result of mixing (=multiplying) transmitted and received frequencies (refer to Fig. 5).

Sawtooth modulation has important disadvantages:

- It is very difficult to get reliable results for moving objects
- The very sharp down ramp can disturb the amplified signals (ringing, saturation)



Returned echo from stationary object

f_M Modulation depth
T_M Modulation period
f_{Tx} Transmitted frequency
f_{Rx} Received frequency
t_p Signal propagation time (time of flight)
f_b Beat frequency f_{Tx} - f_{Rx}
f_D Doppler shift frequency

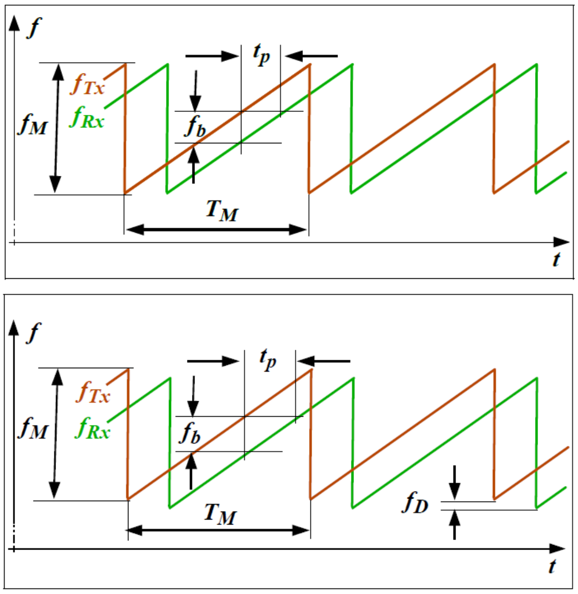
Returned echo from moving object

Received frequency f_{Rx} is shifted by f_D.
This is the Doppler frequency caused by a receding object moving at a constant speed.

Fig. 14: Sawtooth modulation
Above: Stationary object, Below: Moving object

6.3.3 Triangle Modulation

Transmit frequency is modulated by a linear up and down ramp. Fig. 15 shows a typical signal fRx returned by stationary and constantly moving objects. Note, that the difference frequency fb is constant throughout nearly the whole ramp time.
At the output of the Radar transceiver we get the a low frequency signal fb called beat frequency. This is the result of mixing (=multiplying) transmitted and received frequencies (refer to Fig. 5).



Returned echo from stationary object

f_M Modulation depth
T_M Modulation period
f_{Tx} Transmitted frequency
f_{Rx} Received frequency
t_p Signal propagation time (time of flight)
f_b Beat frequency f_{Tx} - f_{Rx}
f_D Doppler shift frequency

Returned echo from moving object

Received frequency f_{Rx} is shifted by f_D .
This is the Doppler frequency caused by a receding object moving at a constant speed.

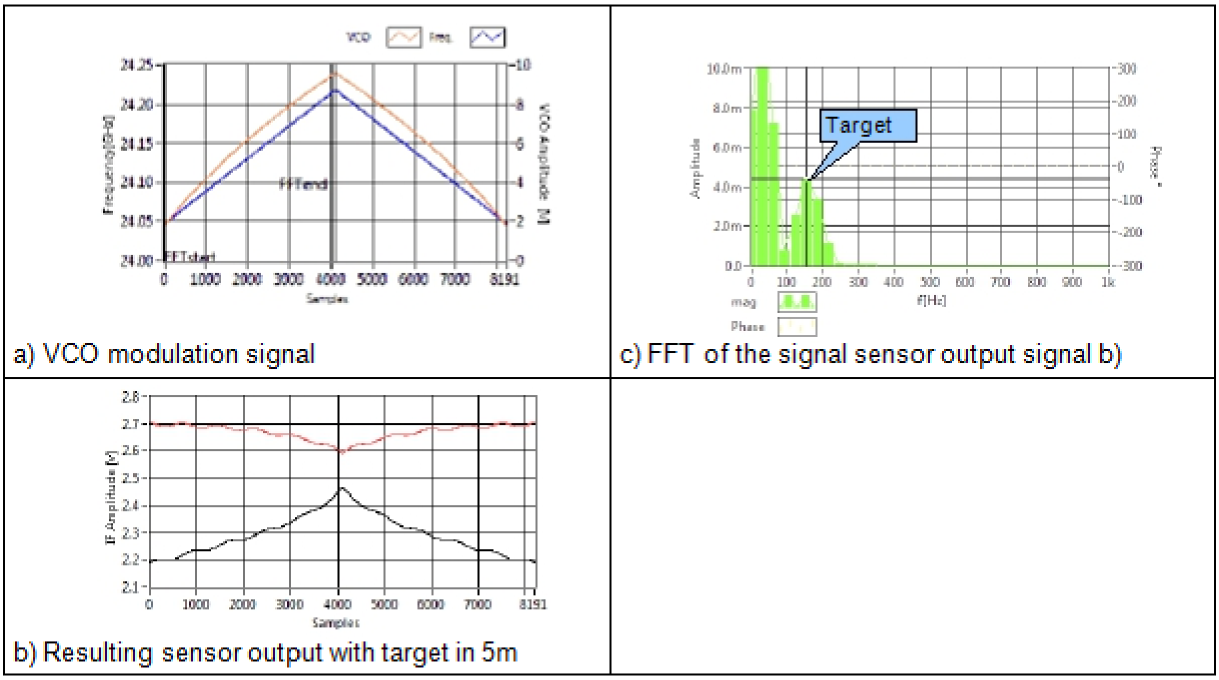
By measuring during up and down ramp, Doppler frequency f_D is the diffence between f_{b1} and f_{b2}

Fig. 15: Triangle modulation

Above: Stationary object, Below: Moving object

6.3.4 Advanced FMCW Modulation Techniques

Triangle modulation may be extended with phase of constant frequency to allow Doppler detection. You find examples in chapter Exploring FMCW.



a) VCO modulation signal
c) FFT of the signal sensor output signal b)
b) Resulting sensor output with target in 5m

Fig. 16: The left picture b) shows the I and Q signals of a SKYRADAR sensor. The target has a distance of 5m. Self-mixing signal is much higher than the reflected sinus signal of the target. FFT in picture c) shows that target signal is very close to the self-mixing signal.

6.3.5 Exploring FMCW

SkyRadar FMCW Module offers a comfortable tool for FMCW exploration in the context of teaching and research alike. The implemented sensors have enough sensitivity and beam focusing to demonstrate FMCW for many applications. Best experience can be obtained by placing the Radar sensor outdoor. Fig. 17 shows an example of a signal from a sensor placed outside an office window. Please note that some window types may absorb Radar signals, if they contain metallic components.

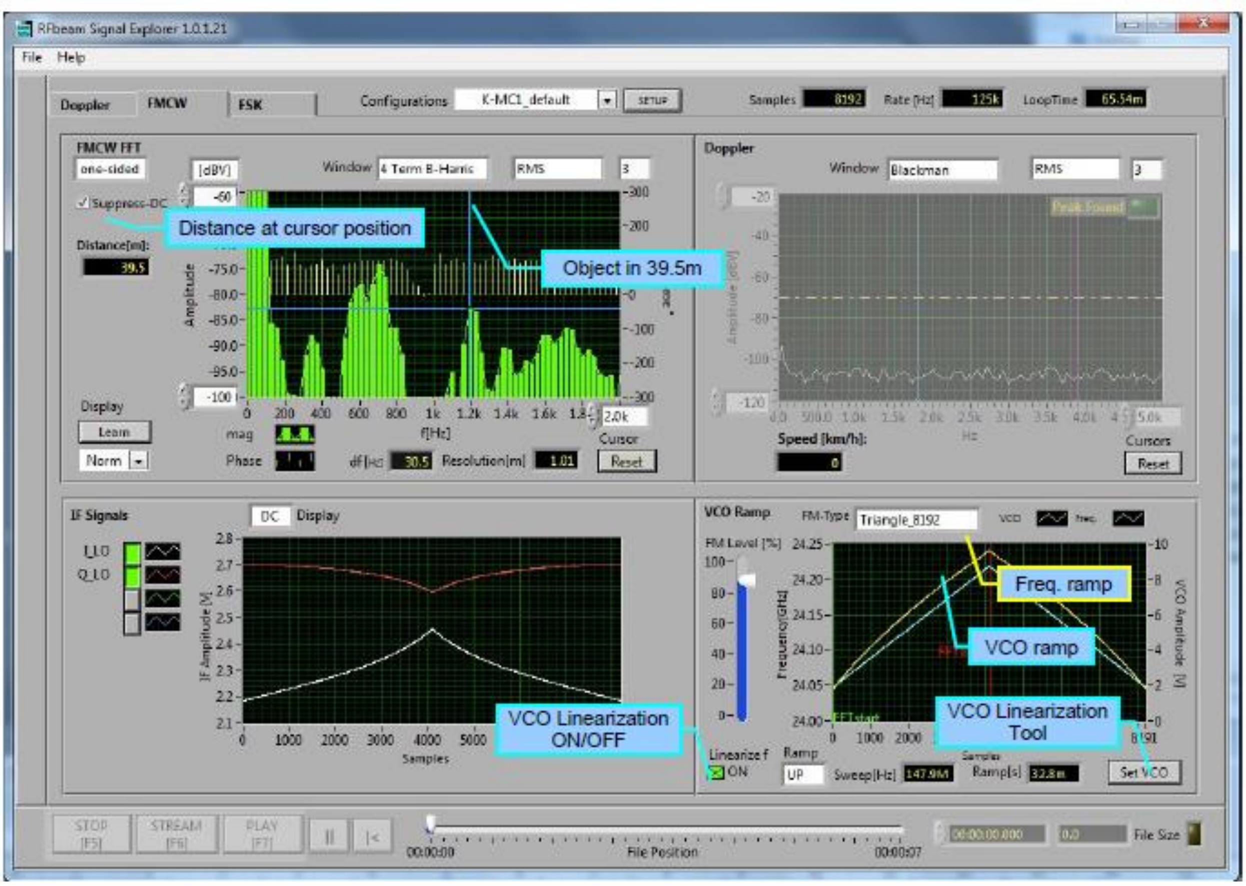


Fig. 17: SKYRADAR FMCW Screen Overview.

Bottom right graph in Fig. 17 demonstrates a calculated VCO ramp (yellow) to get a linear frequency ramp (blue. Doppler FFT is displayed only, if VCO ramp contains a third, constant frequency block (called "3- blocks" FM Type).

6.4 FSK Mode

FSK stands for Frequency Shift Keying. FSK uses two discrete carrier frequencies fa and fb, (Fig. 18) while FMCW uses linear ramps. For each carrier frequency, separate IF signals must be sampled in order to get 2 buffers for separate FFT processing. Due to the very small step fa - fb a moving target will apear at the nearly the same Doppler frequency at both carriers, but with a different phase (Fig. 19). Phase shift due to the modulation timing and sampling must also be taken into account.

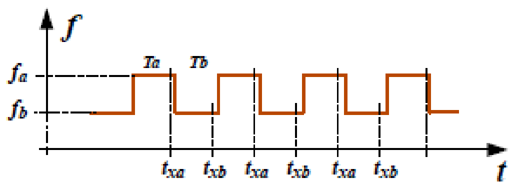
<table>
<tr>
<td>

Fig 18: FSK modulation scheme</td>
<td>f_a Carrier Frequency a
f_b Carrier Frequency b
t_{xa} Sampling point for Doppler a
t_{xb} Sampling point for Doppler b

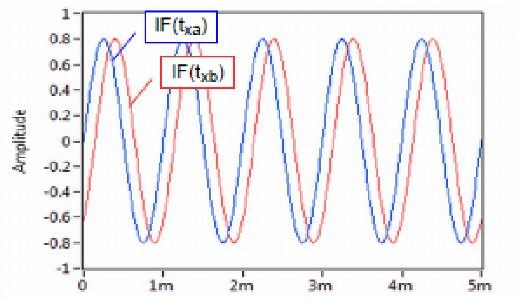
Switching must be performed at a sampling rate high enough to meeting the Nyquist criteria for the Doppler signal acquisition.</td>
</tr>
<tr>
<td>

Fig 19: Resulting Doppler Frequencies</td>
<td>$IF(t_{xa})$ Sensor output signal at Carrier Frequency f_a
$IF(t_{xb})$ Sensor output signal at Carrier Frequency f_b

Doppler signals of the same moving target have same frequency, but are phase shifted by $\Delta\varphi$

For both IF signals, phase must be determined at the spectral peak of the object.</td>
</tr>
</table>

6.4.1 Exploring FSK

The power of FSK may be best explored by using the FMCW radar series sensors. You may check the functionality by walking around in front of these sensors. SKYRADAR FMCW generates a continuous rectangular signal stream at the VCO input of the Radar sensor. With a strict and jitter free clock, two signal buffers, one for fa, one for fb. (see Fig. 18), are generated from the sensor IF output. Sampling rate of each buffer is normally ¼ of the sampling rate of the analog output. This rate may be changed using the setup feature described in chapter Configurations Setup. Both buffers are fed into the 2 inputs of a cross FFT, that allows measuring the phase for each spectral line. Phase (=distance) is displayed on Signal Explorer for the highest level spectral peak only. But FSK would allow detecting distances of many targets with different speeds.

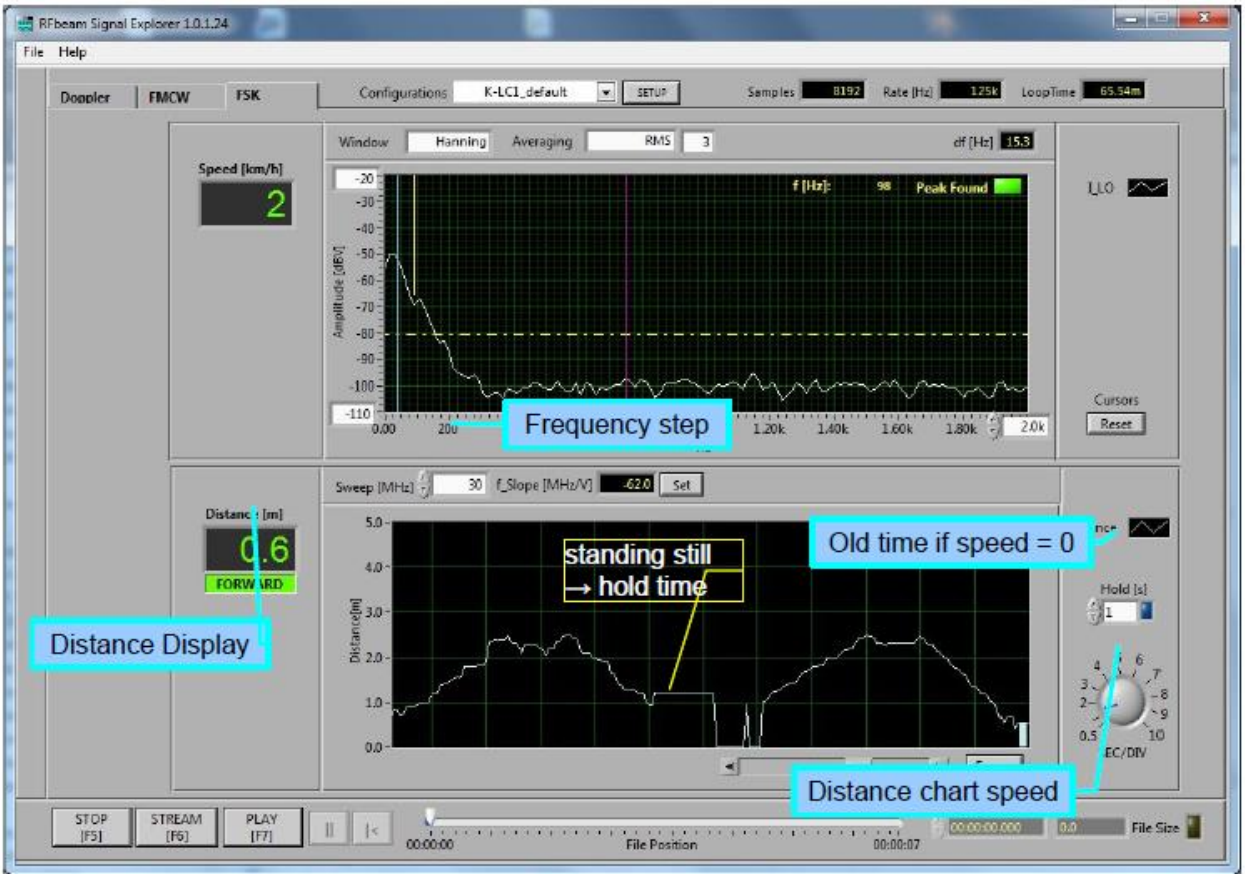


Fig. 20: FSK: moving person, stopping for 1 second

7 Recording and Playback

ST100 allows recording and playing back Radar signals. Data is stored in multichannel TDMS files according to the National Instruments ® standard. There is no compression. Sampling rate in the file corresponds to the main sampling rate. Following items are stored in the TDMS file:

- Channel related:
  - Channel (= Signal) Name
  - Data length
  - Samples/cycle
  - Date/time of recording start
- Administration:
  - Sensor Name
  - Author (user name of PC)
  - Notes (not used yet)
  - Configuration Name
  - System Mode (Doppler, FSK)

FMCW recording is not supported in the current Signal Explorer version. Recording produces very long filels, depending on sampling rate, number of channels and recording duration.

8 Technical Data FMCW Radar Transceiver

8.1 Features

- 24 GHz short range transceiver
- 180 MHz sweep FM input
- High sensitivity, with integrated RF/IF amplifier
- Dual 30 patch antenna
- Buffered I/Q IF outputs
- Additional DC IF outputs
- Beam aperture 25°/12°
- RSW Rapid Sleep Wakeup
- Slim 6mm thickness construction

8.2 Applications

- Doppler and FSK
- Object speed measurement systems
- Ranging and distance detection
- SAR Application

8.3 Description

The Transceiver is a 60 patch doppler module with an asymmetrical narrow beam. Thismodule includes a RF low noise amplifier and two 47dB IF preamplifiers for both I and Q channels. This greatly improves flexibility in FSK ranging applications.

8.4 Technical Data

Parameter	Conditions / Notes	Sym-bol	Min	Typi-cal	Max	Unit
Operating conditions						
Supply voltage		V_{cc}	4.75	5.0	5.25	V
Supply current	Module enabled (Pin 1 = VIL)	I_{cc}		70	100	mA
	Module RSW mode (Pin 1 = VIH)			7	10	mA
VCO input voltage		U_{vco}	1		10	V
VCO pin resistance	Internal pulldown 10k	R_{vco}		10k		Ω
Operating temperature		T_{op}	-20		+80	°C
Storage temperature		T_{st}	-20		+80	°C
Power down/Enable						
Module power down	Input tied high with pullup 10k	V_{IH}	-0.7		+0.3	V_{cc}
Module enable	VIL		-0.2		2	V
Minimum enable time	Sample&Hold capacitor charged	t_{on}	4			µs
Maximum hold time	S&H error <10%	t_{off}	2			ms
Hold Step	Charge injection visible at DC output	V_{step}		6		mV
Transmitter						
Transmitter frequency	UVCO= 5V, Tamb=-20°C .. +60°C	f_{TX}	24.050	24.150	24.250	GHz
Frequency drift vs temp.	Vcc=5.0V, -20°C .. +60°C	Δf_{TX}		-1		MHz/°C
Frequency tuning range	Δf_{vco}			180		MHz/°C
VCO sensitivity	S_{vco}			18		MHz/V
VCO Modulation Bandwidth	Δf=20MHz	BVCO		3		MHz
Output power	EIRP	PTX	+16	+18	+20	dBm
Output power deviation	Full VCO tuning range	Δ PTX		+/- 1		dBm
Spurious emission	According to ETSI 300 440	Pspur		-30		dBm
Receiver						
Antenna gain	F_{TX}=24.125GHz	G_{Ant}		18.5		dBi
LNA gain	F_{RX}=24.125GHz	G_{LNA}		16		dB
Mixer Conversion loss	f_{IF} =500Hz	D_{mixer}		-6		dB
Receiver sensitivity	f_{IF} =500Hz, B=1kHz, S/N=6dB	P_{RX}		-123		dBm
Overall sensitivity	f_{IF} =500Hz, B=1kHz, S/N=6dB	D_{system}		-141		dBc
IF output						
IF output impedance	_AC outputs	R_{IF_AC}		100		Ω
	_DC outputs	R_{IF_DC}		101		Ω
IF Amplifier gain	_AC outputs	G_{IF_AC}		47		dB
	_DC outputs	G_{IF_DC}		15		dB
I/Q amplitude balance	fIF =500Hz, UIF=100mVpp (_AC outputs)	ΔUIF		3		dB
I/Q phase shift	fIF =500Hz, UIF=100mVpp (_AC outputs)	φ	80	90	100	°
IF frequency range	-3dB Bandwidth (_AC outputs)	f_{IF_AC}	40		15k	Hz

Parameter	Conditions / Notes	Symbol	Min	Typical	Max	Unit
IF output (continued)						
IF noise voltage	f_{IF} =500Hz	UIF-noise		22		µV/√Hz
fIF =500Hz	$U_{IFnoise}$			-93		dBV/Hz
IF output offset voltage	V_{cc} = 5V, _AC outputs	Uos_AC	2.0	2.5	3.0	V
	no object in range,VCO pin open ,_ DC outputs	U_{os_DC}	0.5	2.0	2.5	V
Supply rejection	supply pins to _AC outputs, 500Hz	Dsupply		-24		dB
Antenna						
Horizontal -3dB beamwidth	E-Plane	Wϕ		12		°
Vertical -3dB beamwidth	H-Plane	Wθ		25		°
Horiz. sidelobe suppression		Dϕ		-20		dB
Vert. sidelobe suppression		Dθ		-18		dB
Body						
Outline Dimensions	connector left unconnected			65*65*6		mm3
Weight				50		g
Connector	Module side: AMP X-338069-8			8		pins

8.5 Antenna System Diagram

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

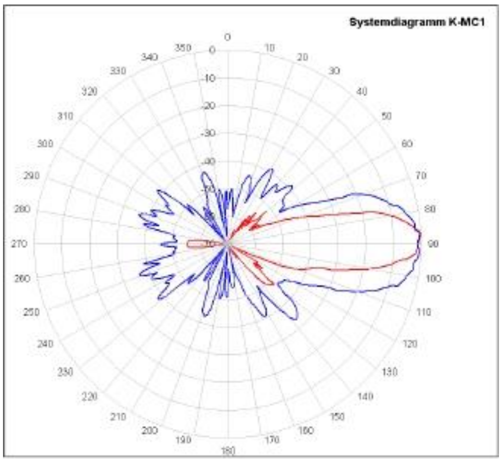


Fig. 21: Antenna System Diagram

8.6 FM Characteristics

Carrier frequency can be modulated by means of a voltage applied to the VCO input.

This feature can be used for ranging applications using FMCW or FSK techniques. FMCW needs good linearity in the frequency ramp. SkyRadar provides a downloadable tool "VCO-Lin" that allows calculating the non-linearity using 3 known frequency versus VCO voltage points.

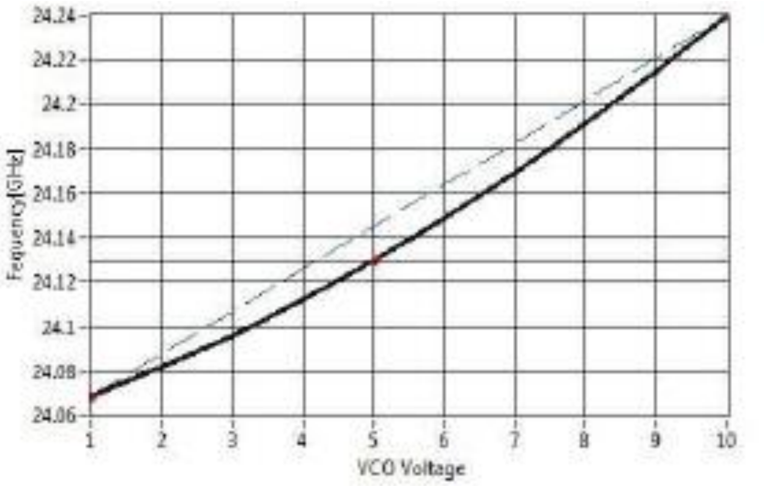


Fig. 22: FM Characteristics

B SAR-Module

Part #: SkyRadar PSR-SAR-Ver.5.0

Description

The SAR Module is an extension of the FMCW base. A servo-controlled linear axis allows movement of the antenna and thus produces radar images with defined time-stamps and positions for SAR operations. SAR aggregates the data in a time-multiplex approach. SAR allows producing resolutions which go far beyond results of a normal antenna.

Parts

The SAR Module consists of:

- one (1) linear axis driven by a DC motor
- one (1) control unit providing
  - motor control
  - Wireless LAN connection with the Laptop Computer
- One (1) cable set.

Prerequisites

- FMCW Base

Extensions

- none

9 General Description

A Synthetic Aperture Radar (SAR), is a mostly airborne or space-borne side-looking radar system which utilizes the flight path of the platform to simulate an extremely large antenna or aperture electronically, and that generates high-resolution remote sensing imagery. Over time, individual transmit/receive cycles (PRT's) are completed with the data from each cycle being stored electronically. The signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture. After a given number of cycles, the stored data is recombined (taking into account the Doppler effects inherent in the different transmitter to target geometry in each succeeding cycle) to create a high resolution image of the terrain being over flown.

SAR works similarly to a phased-array radar, but in deviation to the large number of the parallel antenna elements of a phased array, SAR uses one antenna in a time-multiplex approach. The different geometric positions of the antenna elements are result of the moving platform now.

The SAR-processor stores all the radar returned signals, as amplitudes and phases, for the time period T from position A to D. Now it is possible to reconstruct the signal which would have been obtained by an antenna of length v • T, where v is the platform speed. As the line of sight direction changes along the radar platform trajectory, a synthetic aperture is produced by signal processing that has the effect of lengthening the antenna. Making T large makes the „synthetic aperture" large and hence a higher resolution can be achieved.

When a target first enters the radar beam, the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam some time later, determines the length of the simulated or synthesized antenna. The synthesized expanding beamwidth, combined with the increased time a target is within the beam as ground range increases, balance each other, such that the resolution remains constant across the entire swath.

The achievable azimuth resolution of a SAR is approximately equal to one-half the length of the actual (real) antenna and does not depend on platform altitude (distance).

The system consists of modular parts. The linar axis is the moving part of the system. The Antenna and the case with the included embedded hardware is mounted to the linear axis. The Antenna focuses the electromagnetic radio beam. The transceiver emits and receives the radio beam. An internal logic do the conversion from analog signals into digital signals. The embedded hardware is receiving this signal which also controls the linear axis.

9.1 Technical Features

The SAR system works as an extension of the FMCW module. All its technical features apply. Namely:

- Supports Doppler, FMCW, FSK, Monopulse
- USB Interface to Host Computer
- Onboard Low Noise Power Supplies
- Connectors for Different Radar Devices
- Amplifiers for Native Doppler Transceivers
- High Performance 16Bit Data Processing
- 250kSamples/s ADC and DAC
- Compact and Rugged Construction
- Powerful Signal Explorer PC Software
- NI LabVIEW ® DAQmx USB Interface

9.2 Applications

- Radar Training and Research System in the context of high resolution images
- Development of Own Data Processing Algorithms
- Signal Analysis and Logging
- Research in the fields of air traffic control, architectue, defense, naval applications, geological imaging of terrains through airbone sidelobe radars etc.

9.3 Hardware

The SkyRadar SAR module is combined with a Radar Transceiver from the SkyRadar FMCW module. The data acquisition is done with a NI-USB-6211 multi-purpose IO module.

9.4 Functionality

The functionality in general is as follows:

A target (reflector) is positioned somewhere in the target field (e.g. 100m x 20m) as shown in Figure 1: Measurement setup.

The radar antenna is then placed at predetermined positions here marked p1 trough p8. At each position a measurement is performed resulting is a waveform capture. Through signal analysis it is then possible to determine the range at which the reflection was found. Then by combining the separate measurement results from the positions p1 trough p8 it is possible to determine the exact location of the reflector.

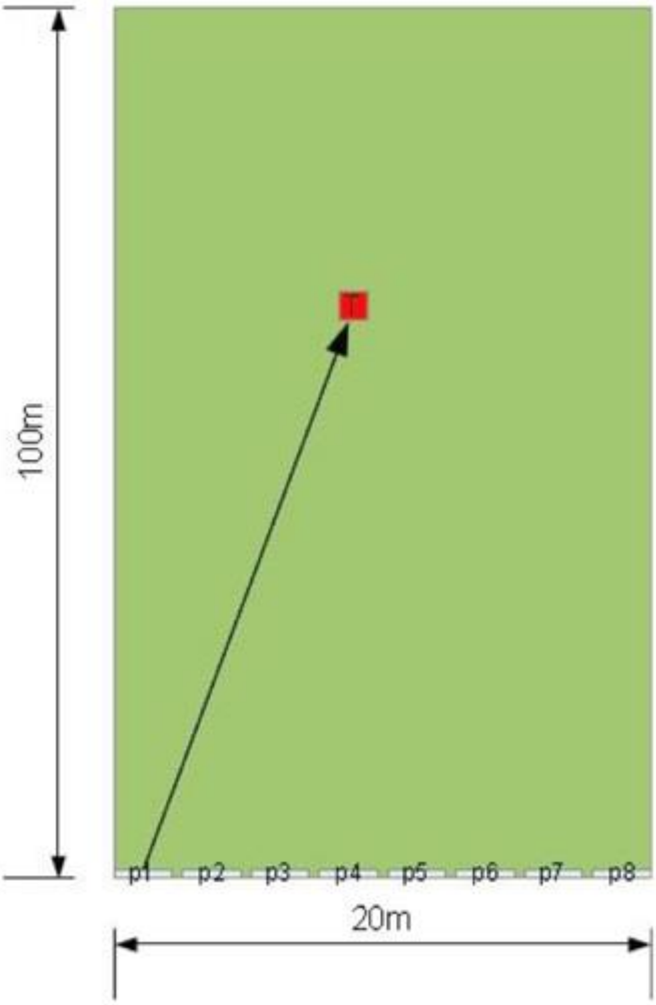


Figure 23: Measurement Setup

9.5 Measurement principle

A frequency modulated continuous wave radar (FMCW) is placed on a horizontal axis and captures images in a time multiplex approach. Based on the Synthetic Aperture Radar algorithms, the gained images are integrated to generate one high resolution image. To accomplish the spatially off-set measurements, a linear axis swivels the radar antenna and transceiver.

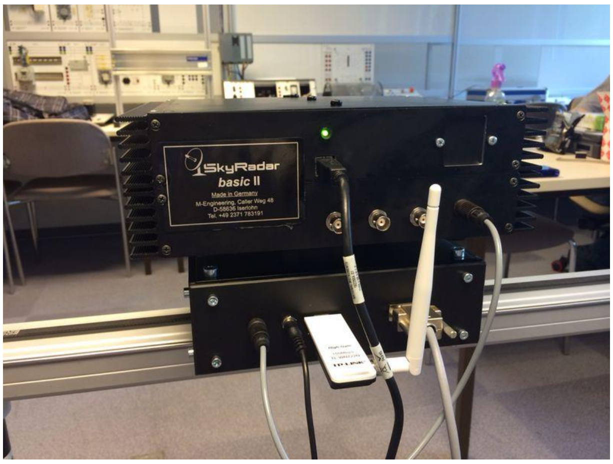


Figure 24: SAR measurement on a DC-motor controlled linear axis.

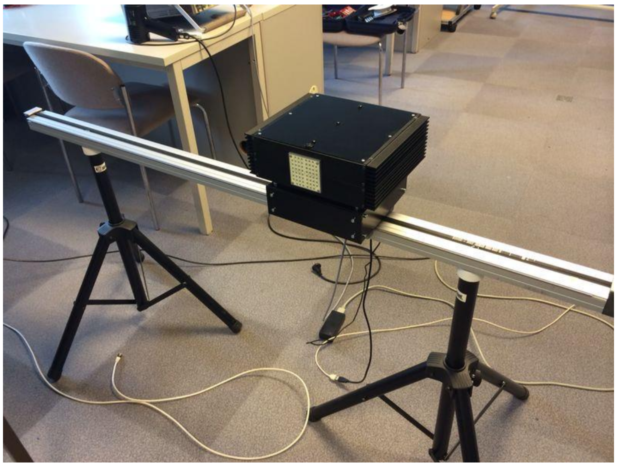


Figure 25: SAR measurement on a DC-motor controlled linear axis.

10 Technical Principles

10.1 Generation of signals

The radar equation is enables to generate track the signal.. This is to determine the power returned from our test reflector and thus the amplitude and frequency of the test signal.

$$P_r = \frac{P_t G^2 \lambda^2 \phi}{(4\pi)^3 R^4 L_s L_a(R)}$$

A calculation example follows:

Using the SkyRadar Receiver FMCW and the figures from its data-sheet Pt = Transmitted Power 18dBm (.063watt) G = Antenna Gain (18.5 dBi + 47dB amplifier gain) (3 500 000 times) Lambda = wavelength = c/Tfreq = 299792458 / 24125000000 = 0.0124 m Fi = reflection cross section = 1m2 R = Range at which the reflector is positioned as seen from the antenna, 40m Ls & La set to 1 Assuming negligible atmospheric losses the received power is: .024 Watt At a input impedance of 100 ohm = 0.015 V

The frequency of the signal is determined by the modulation depth (150MHz and modulation period 0.066 sec (15Hz))

Using the range formula solved for Fb we can determine the signal frequency.

$$R = \frac{c_0}{2} \cdot \frac{f_b}{f_M} \cdot \frac{T_M}{2} \qquad\qquad F_b = \frac{4R \cdot f_M}{c_0 \cdot T_M}$$

For a range of 40m: 1213 Hz

The generated signal is depicted in the following figure: 40m target return signal

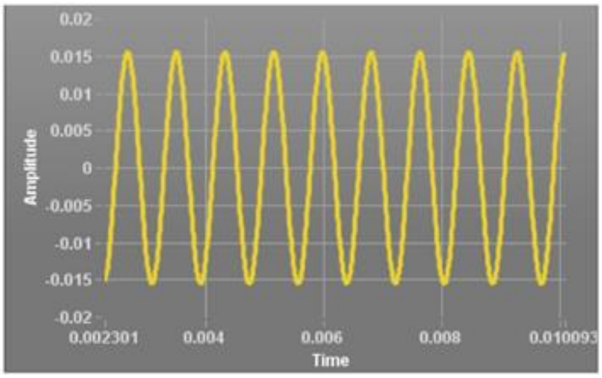


Figure 26: Generated signal

The next step is to determine the distance of the reflection from this signal In order to make the test more realistic a second signal at 25 meters is added together with some noise

The resulting signal is shown here:

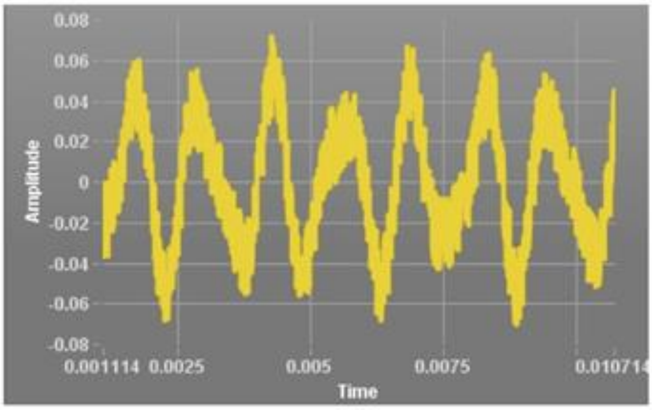


Figure 27: Resulting signal

10.2 Analysis

The signal analysis is done via a Power Spectral Density function, the result is show here:

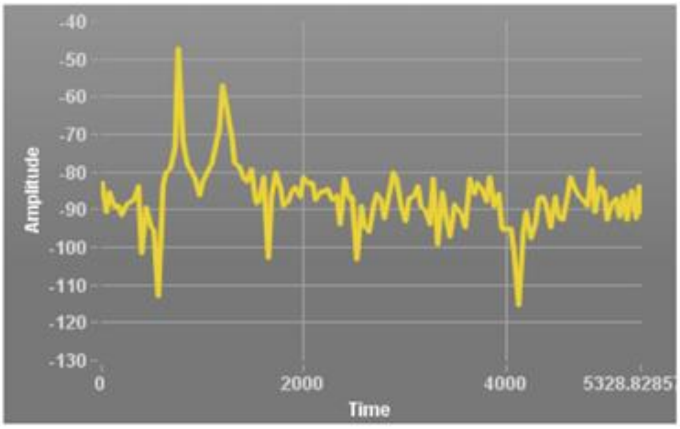


Figure 28: Power Spectral Density function

Two peaks are detected one at 760 Hz and one at 1205 Hz resulting in a distance of : 25 and 39.75 meters.

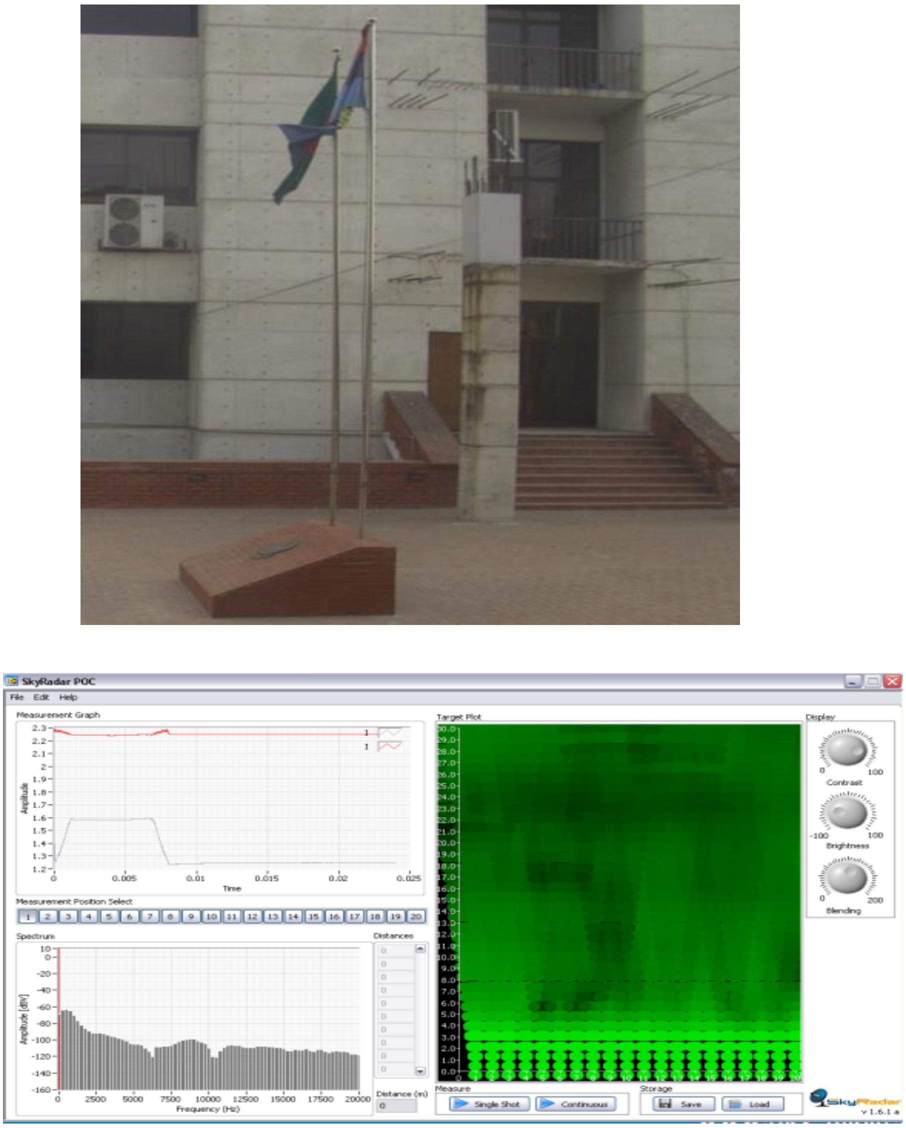


Figure 29: SAR based image processing. Above: two flags. Below on the right: radar image of the same flag, measured through a window (Measurement graph, spectrum and target plot).