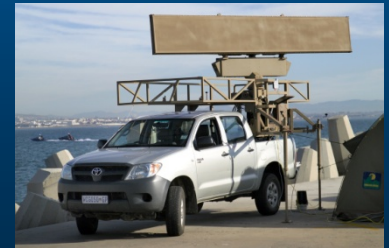
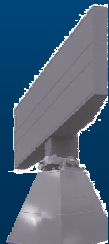


FMCW in a (slightly) maritime Context

Pieter-Jan Wolfaardt



1. Introduction
2. Comparison between pulse and FMCW radar
3. Differences between pulse and FMCW and radar
4. Issues with FMCW radar
5. Some FMCW radar examples
6. Some activities on FMCW radar at RRS

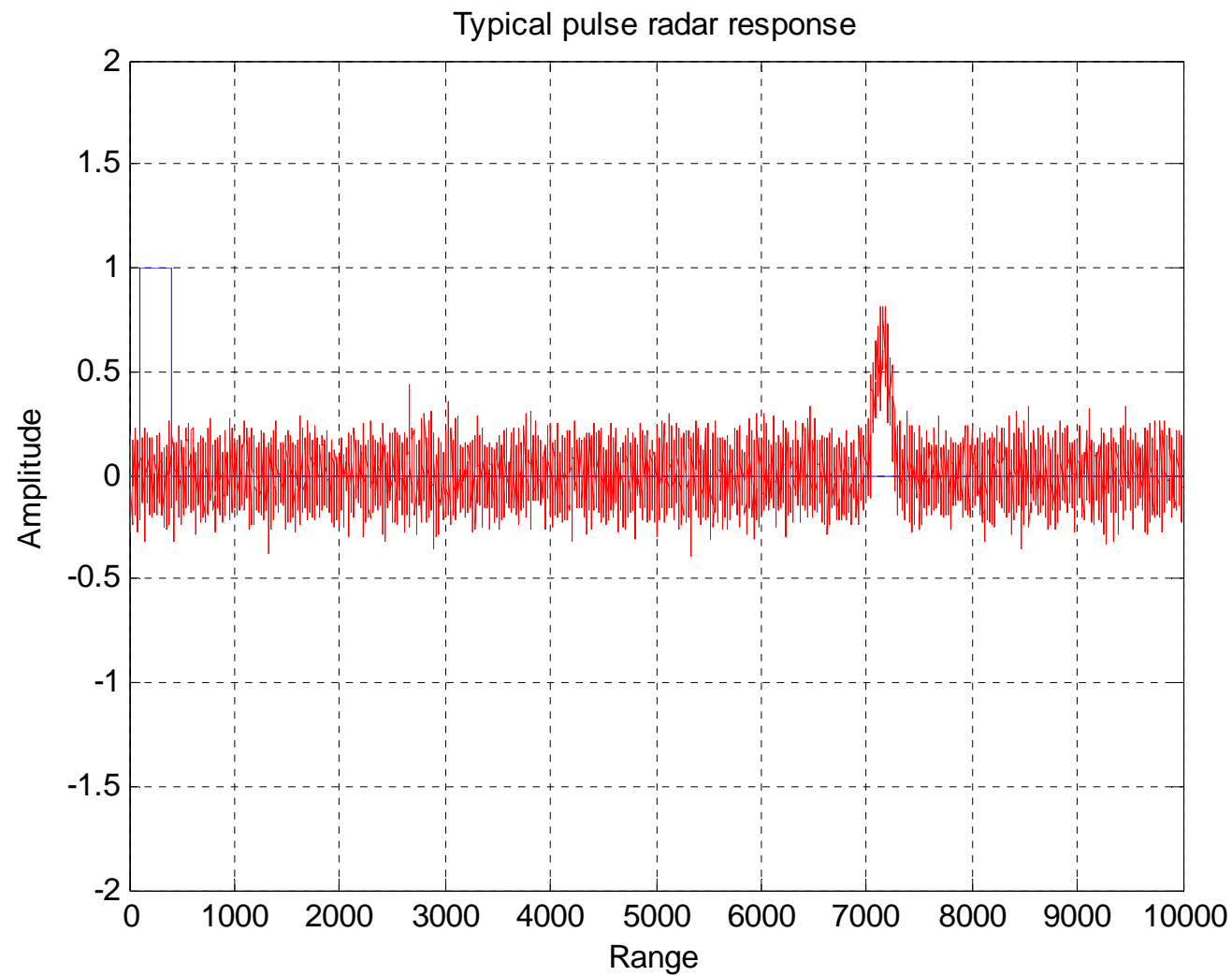


Introduction

REUTECH
RADAR SYSTEMS

- FMCW started to be known in early 80's.
- Interesting because of low radiated power.
- Initially limited interest from the radar/ew community
- Followed by optimistic claims of very long detection ranges at very low (milliwatt) power level
- Sanity sets in
- Skolnik->Most FMCW radar fail to achieve performance within 20 predicted performance
- Since then much better understanding of the advantages and disadvantages of FMCW radar

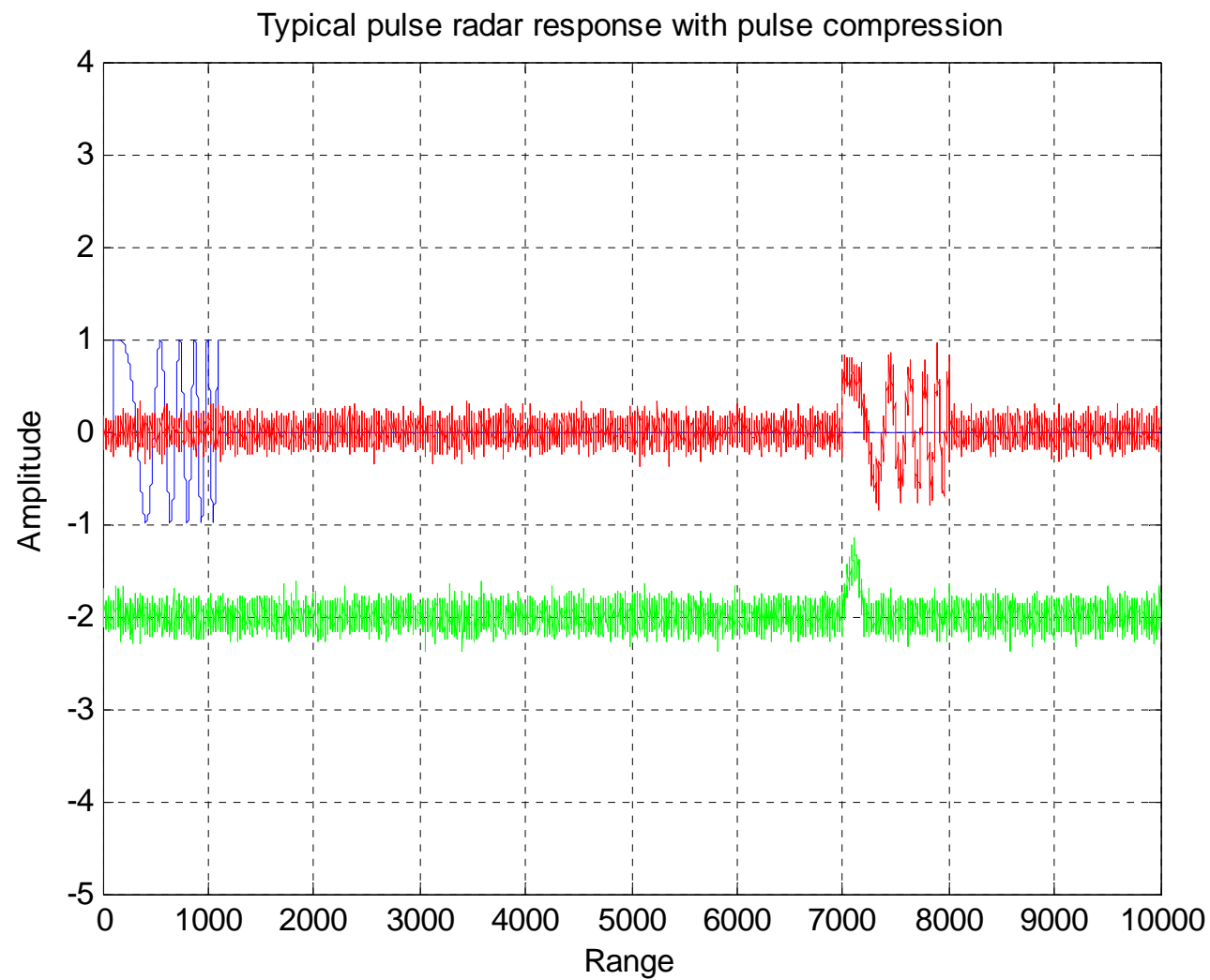
Simple Pulse Radar Response



Lat: -33.958 °
Long: 18.806 °
Alt: 343.8 °
Range: 981 m
X: -708 m
Y: 679 m

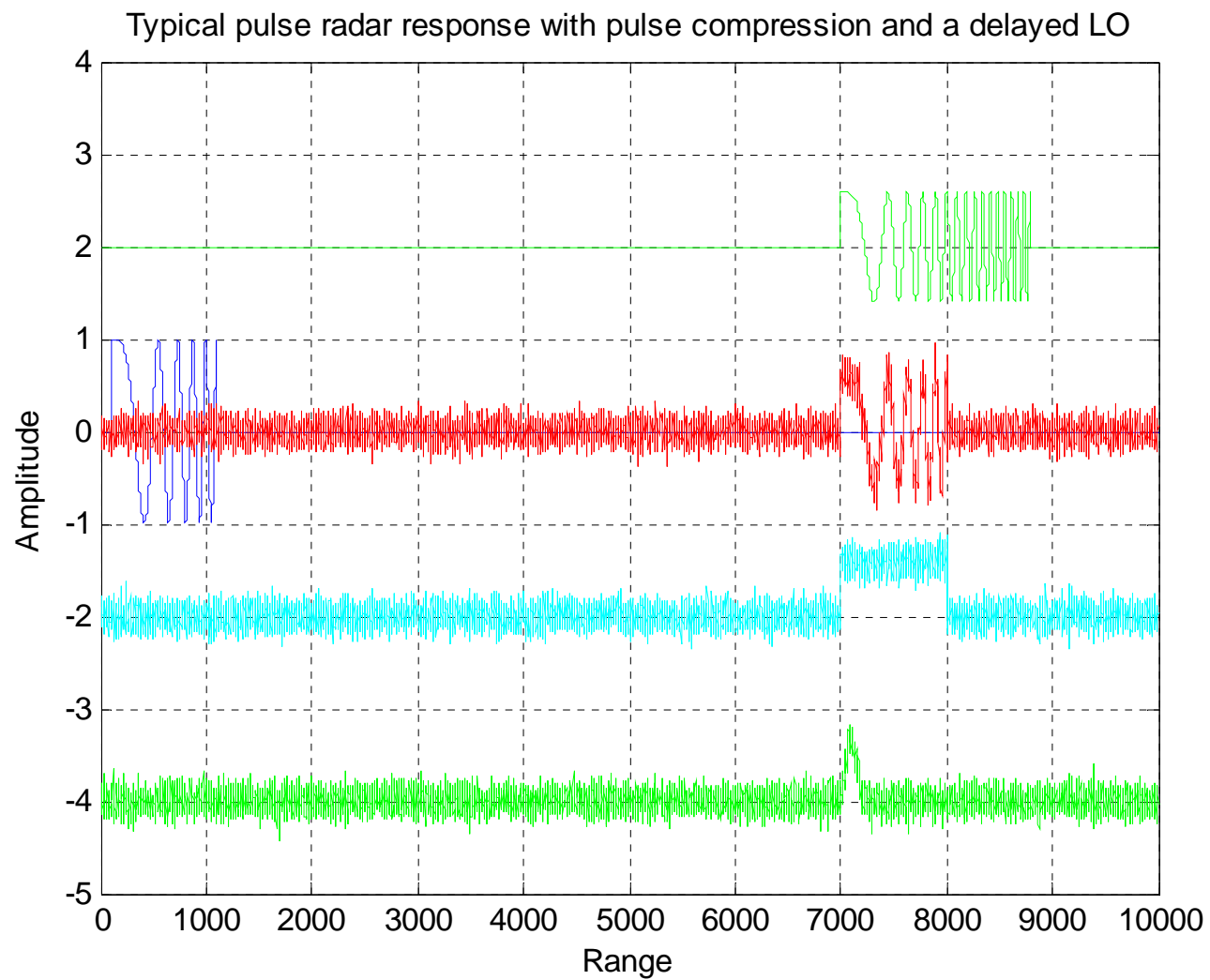
Pulse Compression Radar Response

REUTECH
RADAR SYSTEMS



Relation to FMCW

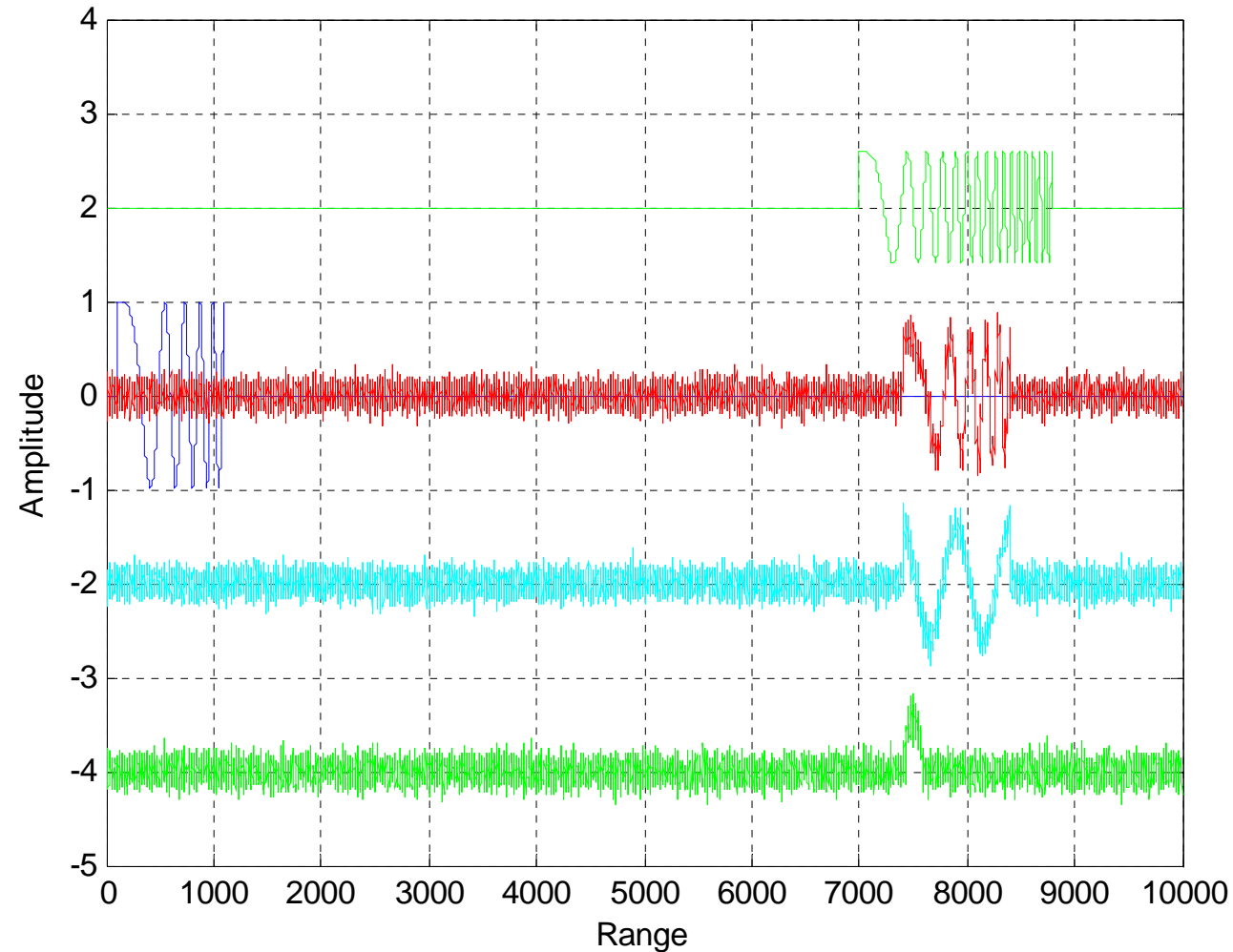
REUTECH
RADAR SYSTEMS



Relation to FMCW with delayed target

REUTECH
RADAR SYSTEMS

Typical pulse radar response with pulse compression and a delayed LO Target moved



Similarities between FMCW and Pulsed Radar

REUTECH
RADAR SYSTEMS

- Theoretically
 - FMCW and pulsed radar produce identical results
 - Except for a quadratic phase term which is known and predictable (Residual Phase)
 - Requires the same power budget
 - Requires similar detection strategies
 - Adhere to the same physical laws!

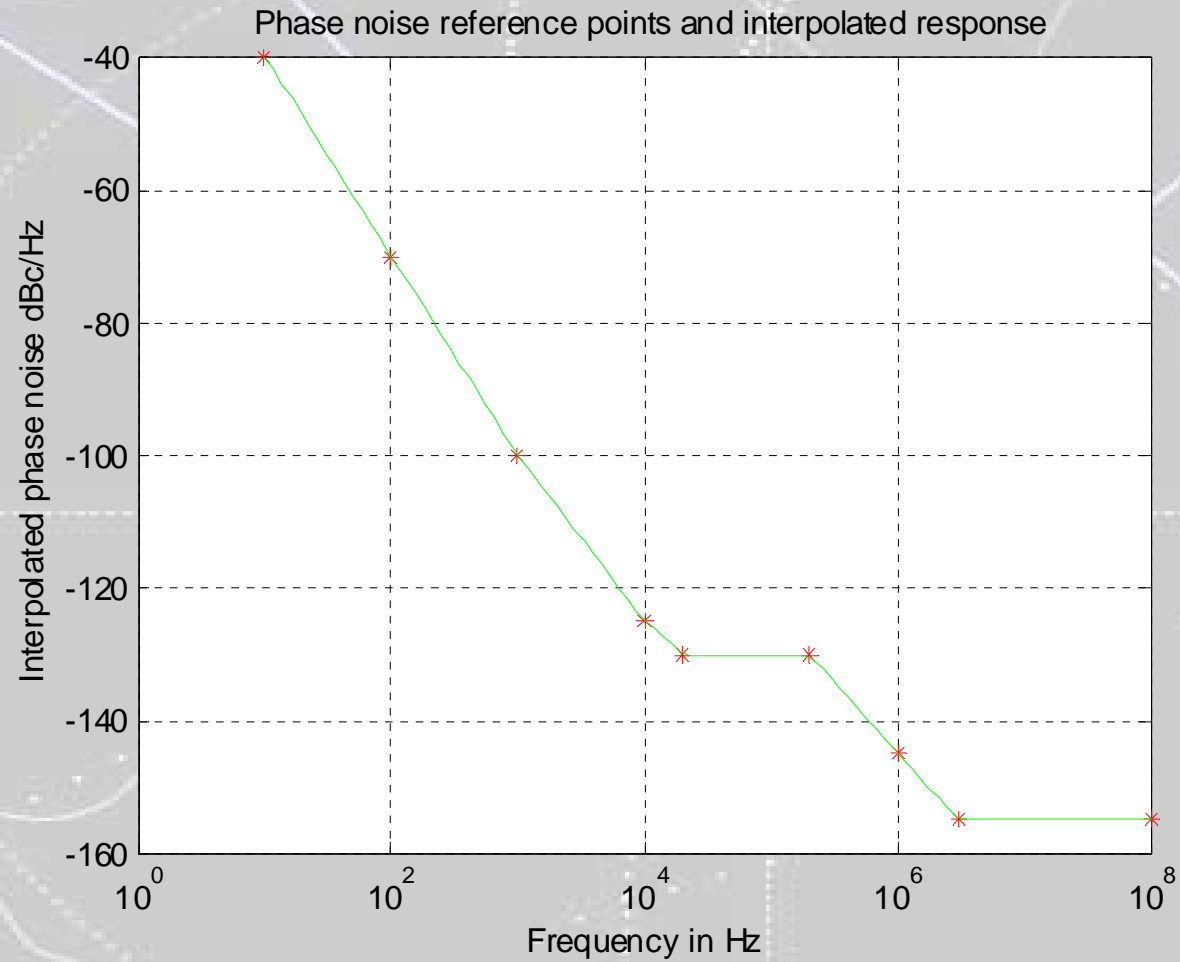
Differences

- Practical differences
 - Receiver is on while transmitting
 - Physical radar parameters differ significantly to accommodate differences in implementation strategies
 - FMCW approach large duty cycles
 - Much slower sweep rates than pulse-compression
 - Range-Doppler coupling is a bigger problem
 - Potentially much reduced hardware
 - Often require separate transmit and receive antennas

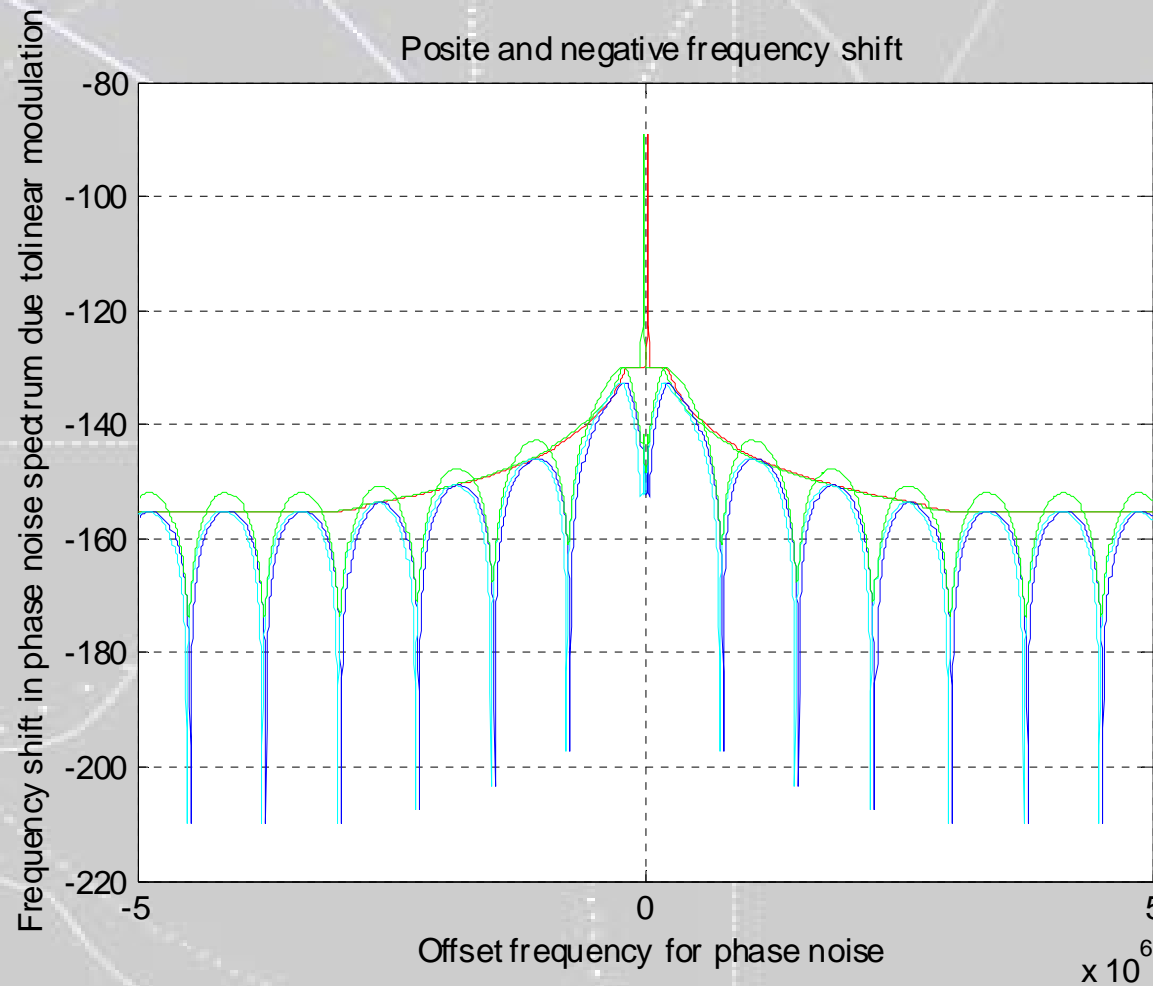
What are the implications

- Transmit/Receive leakage
 - Limits the maximum available power
 - Can be controlled by proper design
 - Can be cancelled by active cancellers
- Wideband transmitter noise
 - Amplitude noise relatively under control by proper design.
 - Phase noise can be a major problem.

Phase Noise Effect

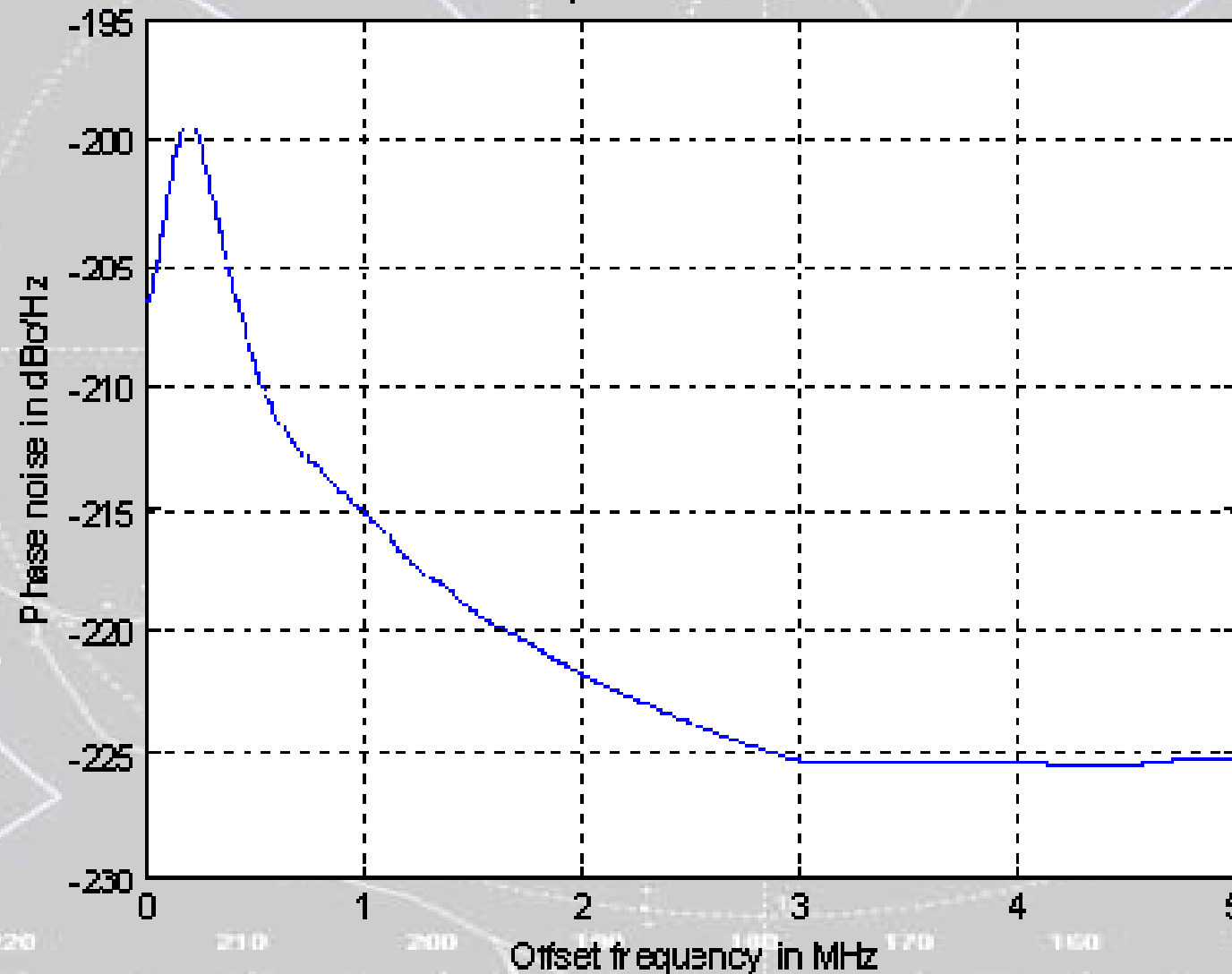


Phase noise effect of a single target at fixed range



Cumulative Phase noise

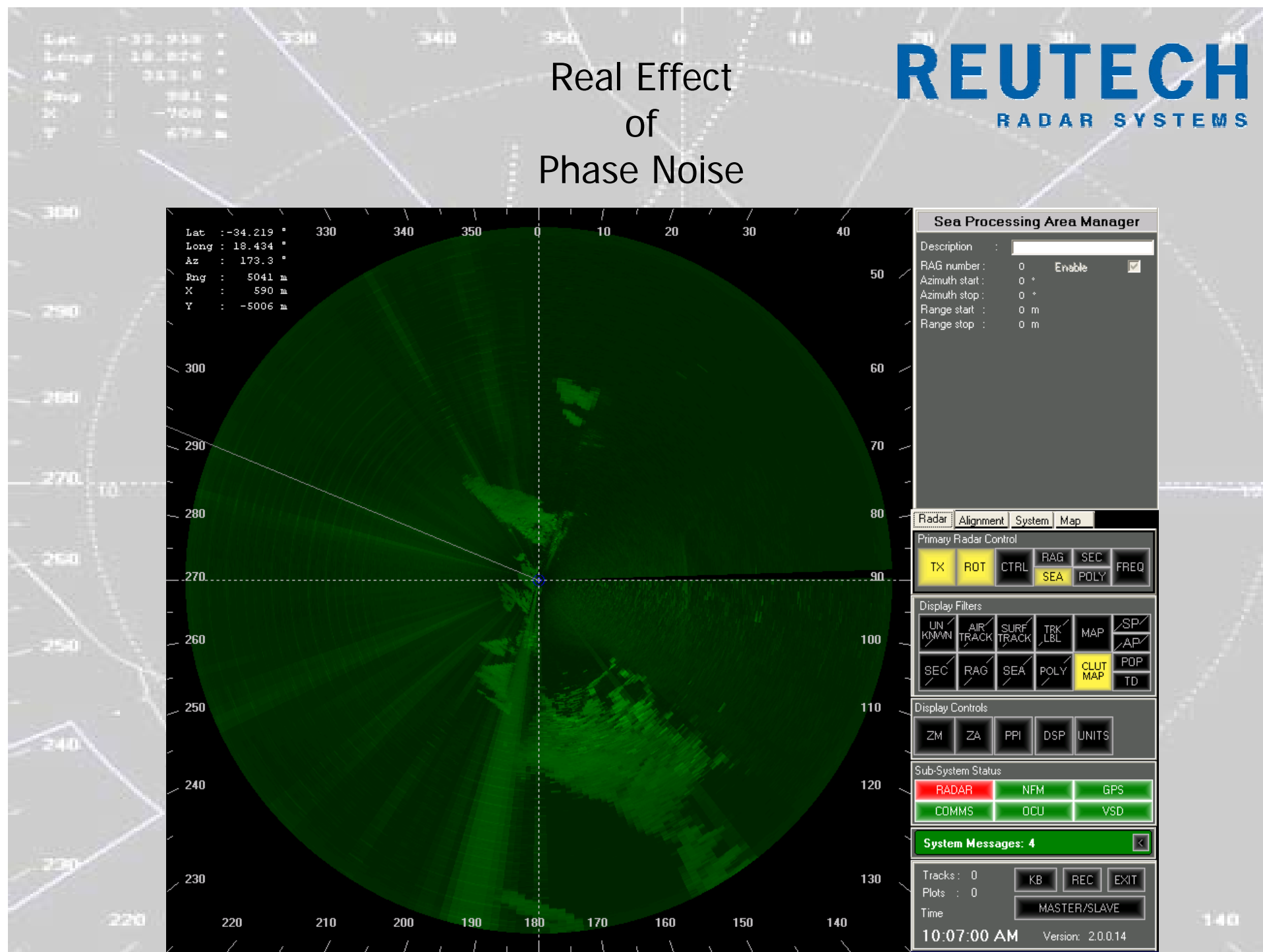
Summed phase noise due to clutter





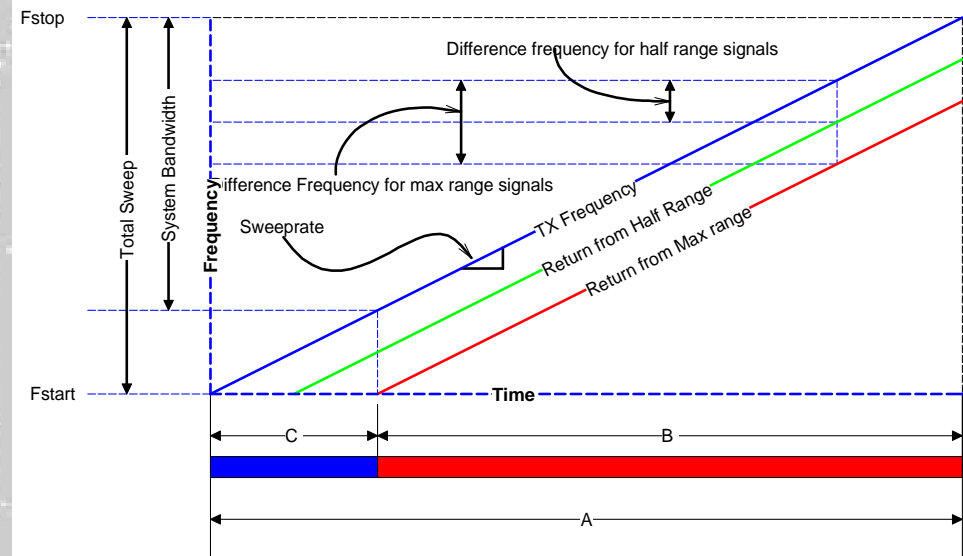
Real Effect of Phase Noise

REUTECH
RADAR SYSTEMS



Other practical issues

- Never as efficient as a pulse radar
- Effective duty cycle sometimes as low as 50%
- Rest of power is wasted
- Lower effective SRF (sweep repetition time)
- Range-Doppler coupling in longer range systems
- Front-end dynamic range
- Limited to shorter ranges due to phase noise effects



Other practical issues

REUTECH
RADAR SYSTEMS

- High processing gain
 - Typically 50 dB or more coherent processing gain
 - Susceptible to impulse interference
 - Can be eliminated by design against impulse interference
- Simple to very simple system architecture
- Very adaptable even dynamically
- High (or very high) range resolution is easily achievable
 - Complete pulse-doppler radar with 2.5 meter range resolution





Lower North Deployment

Bayview Village

Simonstown Harbour

Simon's Town Simon's Town

Mount Pleasant

Image © 2009 DigitalGlobe
Image © 2009 TerraMetrics

© 2009 Tele Atlas

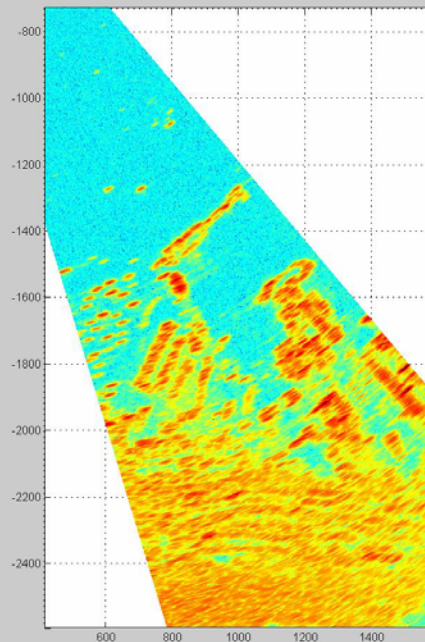
34°10'58.10" S 18°26'22.58" E elev 0 ft

©200

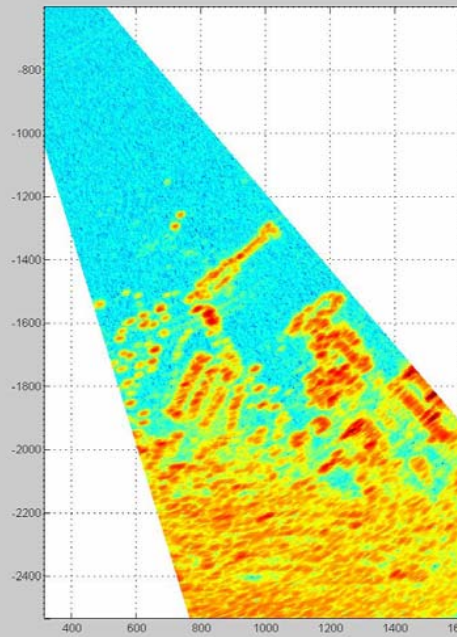
StealthRad™ Resolution modes

REUTECH
RADAR SYSTEMS

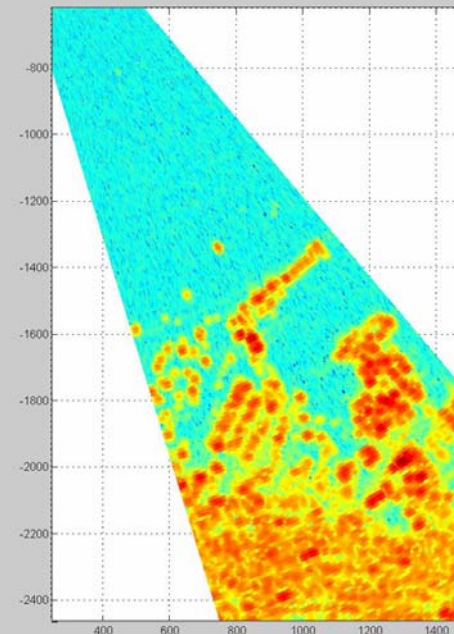
Simon's Town Harbour captures:



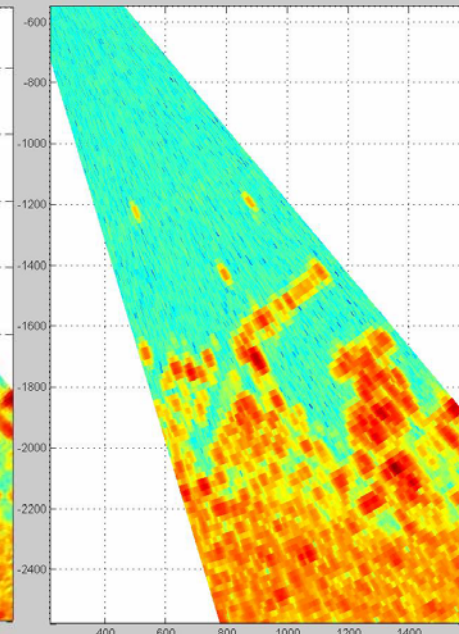
5 km mode: 2.5 m



10 km mode: 5 m



20 km mode: 10 m



40 km mode: 20 m

...Situational awareness through persistent surveillance...

List of FMCW Sensors



Ship Based

Pilot Mk I~III	SAAB Group, Sweden
RSR 960	Reutech Radar Systems, South Africa
Scout Mk 2~3	Thales Nederland
MSSC	
Scouter	Thales Nederland
Smart-L	Thales Nederland
Sure	Thales Nederland
Variant	Thales Nederland
Aries	Indra, Spain
Prymara	Kvant, Ukraine (may be on a submarine)

List of FMCW Sensors



Landbased Fixed

Landbased static:

Aries	Indra, Spain
RSR 952	Reutech Radar Systems
SIRS77	SAAB Group
Close	SAAB Group
GB-Scout	Thales Nederland
(MSSC	Magnavox & Signaal) now Thales Nederland
Page Variant	African Defence Systems
RSR 940	Reutech Radar Systems
RSR 942	Reutech Radar Systems
Scout Mk 2	Thales Nederland
CS	
SL-520M	Weibel, Germany
ASC-10	PIT WZR Radwar, Poland
Struna-1	Nizhno Novgorodsky Radio Eng. Research Inst. Russia
ALG	BAE Systems, UK
Boeing	Boeing, USA
MMWR	

List of FMCW Sensors



Landbased mobile / semi-mobile:

Raven	Indra, Spain
RSR 970	Reutech Radar Systems
Squire	Thales
Traq-TT	Electronic House Development, South Africa
Ground	Thales
Alerter 1, 10, 20	
5N62 Square Pair	Almaz, Russia
5N66/76N6 Clam Shell	Lianozovo Electromechanical Plant, Russia
9S35M/9S36	Tikhonmirov NIIP, Russia
Fire Dome	
RSRA-201	PIT WZR Radwar
Owl	CNPEP Radwar SA, Poland
PSNR-6	Strela Reserch Institute, Russia
AN/MPQ-48	Raytheon Electronic Systems, US

List of FMCW Sensors



Manportable:

GR-05	BATS, Belgium
Page	Thales Nederland
RSR 950	Reutech Radar Systems
Squire	Thales
Olifant II	Thomson-CSF (now Thales)
BAL-607	Chinese
FARA	Kintex, Bulgaria
FARA-1/PV/U	Strela/Almaz-Antey, Russia
AN/PPS-11	Martin-Marietta, USA
SR Hawk	Syracuse Research Corporation, USA
HP-100M	Tcherno More, Bulgaria
PGSR-2	Pro Patria Electronics, Hungary
PSF-2	Pro Patria Electronics
QW-1A	Chinese
Blighter 202, 400 series	Plextek Ltd, UK
Blighter 200	TRW & Magnavox, USA
DSMR-800	Advanced Aviation Technology Ltd, UK
STAR S-90	Samel, Bulgaria

StealthRad™

REUTECH
RADAR SYSTEMS



...Situational awareness through persistent surveillance...

Page Variant in SA

REUTECH
RADAR SYSTEMS

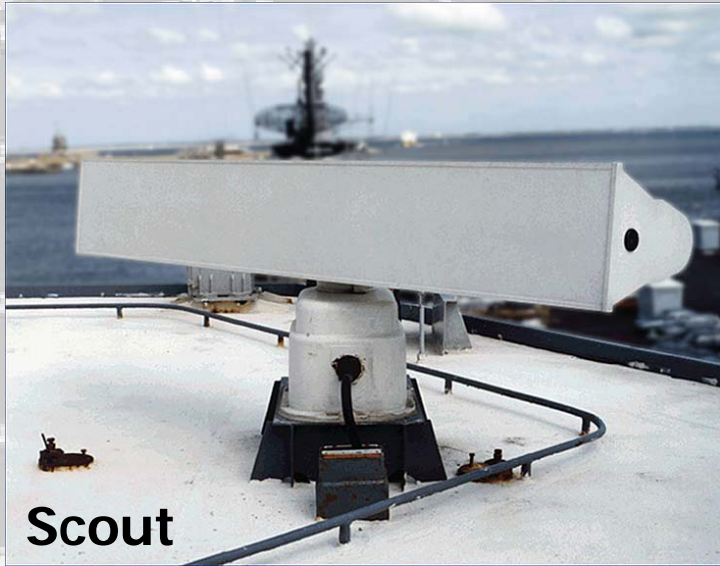


Examples of FMCW Radar



Blighter™ 202 Radar





Scout



**Smart-L with fitted FMCW
sensor**



Varian

1.4kW average power

S Band

90 km on 0.02 sqm target

Low level designation

Anti-Air

12 s / rev

Vertical/Horizontal polarisation

Low max IF frequency

CLAMSHELL





StealthRad™

REUTECH
RADAR SYSTEMS



...Situational awareness through persistent surveillance...

StealthRad™ - Continuous scan

REUTECH
RADAR SYSTEMS

Radar operational & performance characteristics

Parameter	Specification
Operating frequency range	X Band 700 MHz instantaneous BW
Modulation type	LFM CW
Instrumented range	Variable up to 40 km
Minimum Range	≤ 10 m
Range accuracy	From < 2 to 8 m
Beamwidth	0.6°
Azimuth accuracy	1°
Range resolution	6 to 20 m
Azimuth resolution	1.8°
Average transmitted RF power	< 20 W (43 dBm)



...Situational awareness through persistent surveillance...

StealthRad™ - Continuous scan

REUTECH
RADAR SYSTEMS

Detection Range – Air targets

Target description	Typical RCS	Detection range (no ducting)	Detection range (typical ducting)
Based on swerling-1 targets with frequency agility, radially inbound at height 2000 m, with 80% single scan probability of detection			

Light aircraft

2 m²

25 km

N/A

Private Jet

5 m²

32 km

N/A

Helicopter

10 m²

37 km

N/A

...Situational awareness through persistent surveillance...

StealthRad™ - Sector scan

REUTECH
RADAR SYSTEMS

Detection Range – Land based targets

Target description	Typical RCS	Detection range
Based on 50% single scan probability of detection, deployed 10m above the surrounding terrain with a 5° tilt angle		
Instrumented Range 25km for small targets and 50km for bigger ($RSC \geq 5 \text{ m}^2$) targets, Scan rate 10°/s and Scan Sector 40°		

Person walking $\approx 1.5 \text{ m}$ above ground	1 m^2	20 km
Motorcycle $\approx 1.5 \text{ m}$ above ground	1 m^2	20 km
Small Vehicle $\approx 1.5 \text{ m}$ above ground	5 m^2	26 km
Helicopter, identified $\approx 10 \text{ m}$ above ground (0.3 m^2 for rotor hub)	5 m^2	25 km
Armoured Vehicle $\approx 2 \text{ m}$ above ground	10 m^2	32 km
Main battle tank $\approx 2 \text{ m}$ above ground	50 m^2	40 km

...Situational awareness through persistent surveillance...

StealthRad™ - Sector scan

REUTECH
RADAR SYSTEMS

Detection Range – Marine surface targets

Target description	Typical RCS	Detection range
Based on 50% single scan probability of detection, deployed 10m above the surrounding terrain with a 5° tilt angle, assuming normal evaporation ducting.		
Instrumented Range 25km for small targets and 50km for bigger ($RSC \geq 5 \text{ m}^2$) targets, Scan rate 10°/s and Scan Sector 40°		

Inflatable Rubber boat with engine and crew $\approx 1 \text{ m}$ above surface

1 m^2

17 km

Helicopter, identified $\approx 10 \text{ m}$ above sea

5 m^2
(0.3 m^2 for rotor hub)

25 km

Power boat $\approx 2 \text{ m}$ above surface

5 m^2

30 km

Fishing vessel $\approx 5 \text{ m}$ above ground

100 m^2

Instrumented range

...Situational awareness through persistent surveillance...

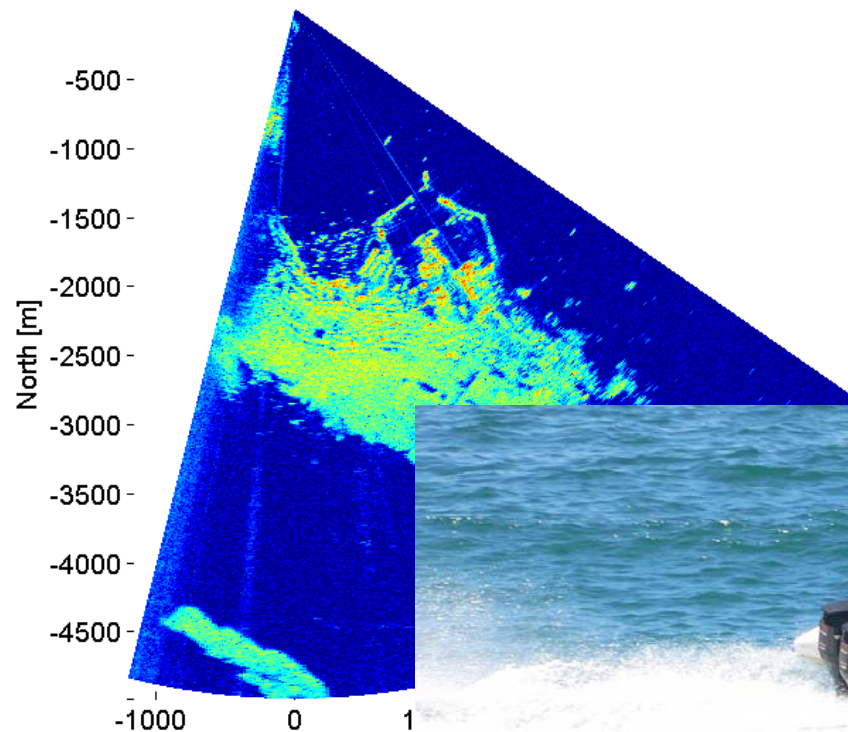
Small Boat Detection

REUTECH
RADAR SYSTEMS

Detection of small boats in calm conditions

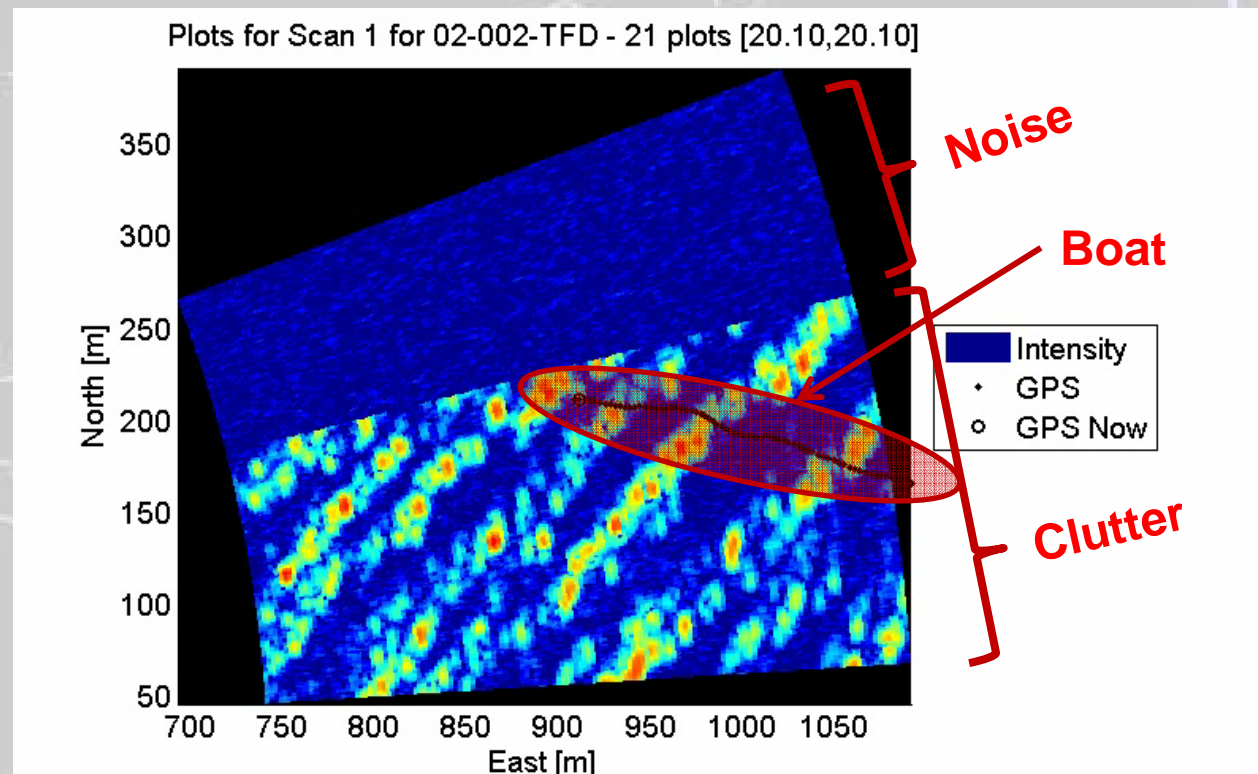
- High resolution, low grazing angle, HH pol. antenna
- RIB's of 4 – 5 m length out to km's

Radar intensity display from Lower North



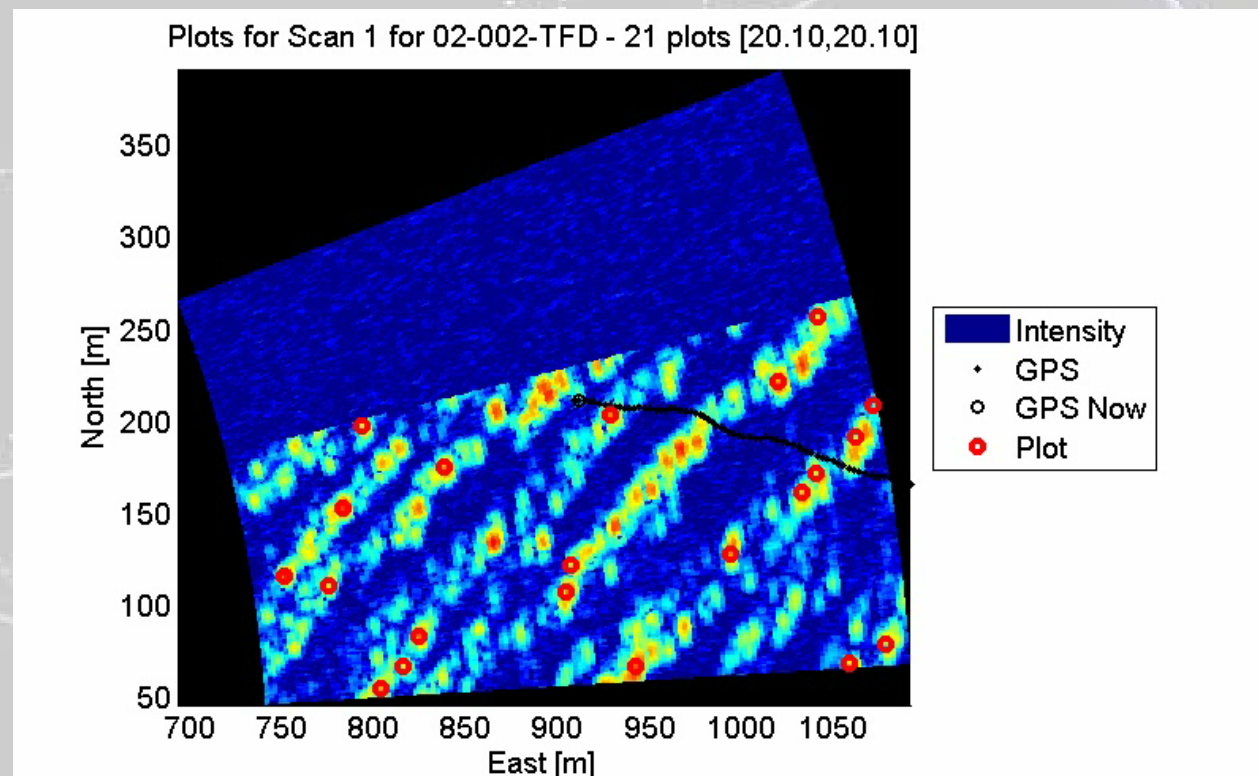
Small Boat Detection

- Raw radar data captured at Lower North
 - Track of boat indicated with black line
 - Black circle indicates current boat location
 - Virtually impossible to discern target from the clutter



Small Boat Detection

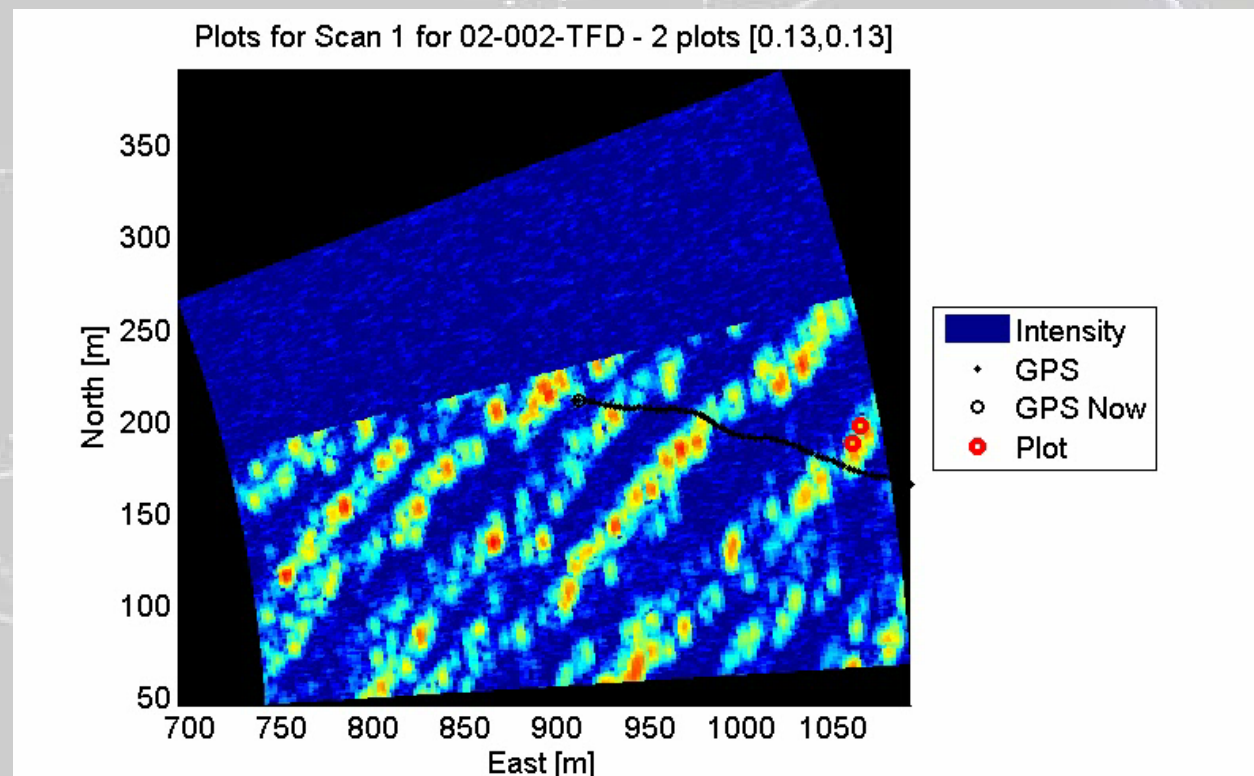
- Detections using a standard CFAR detector
 - Increased sensitivity to give 50 % Pd
 - Unacceptable number of false alarms



...Situational awareness through persistent surveillance...

Small Boat Detection

- Detections using a standard CFAR detector
 - Desensitized to give acceptable false alarms
 - Zero detections on the target

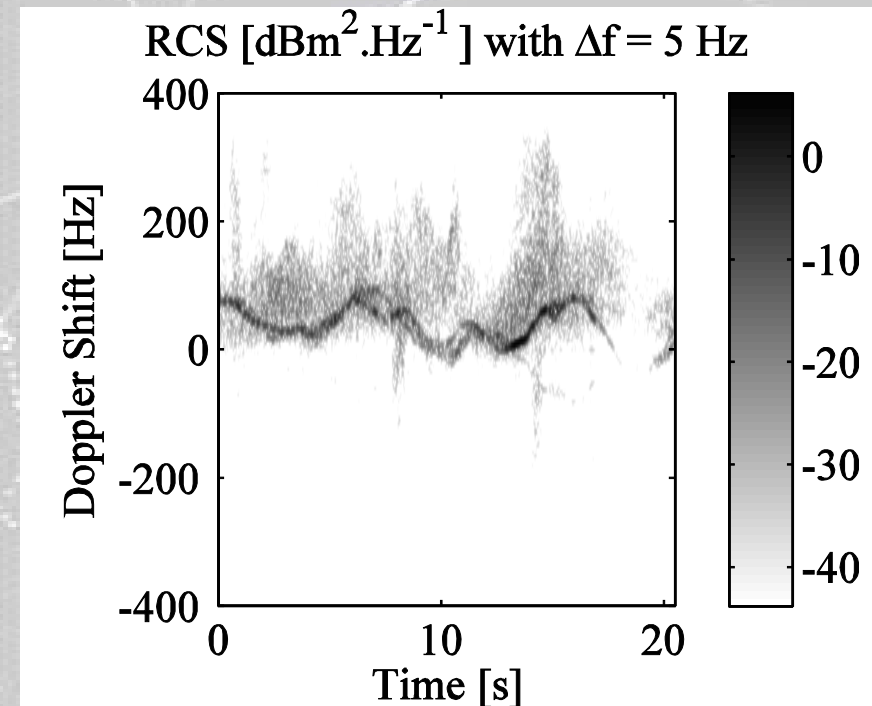


...Situational awareness through persistent surveillance...

Small Boat Detection

REUTECH
RADAR SYSTEMS

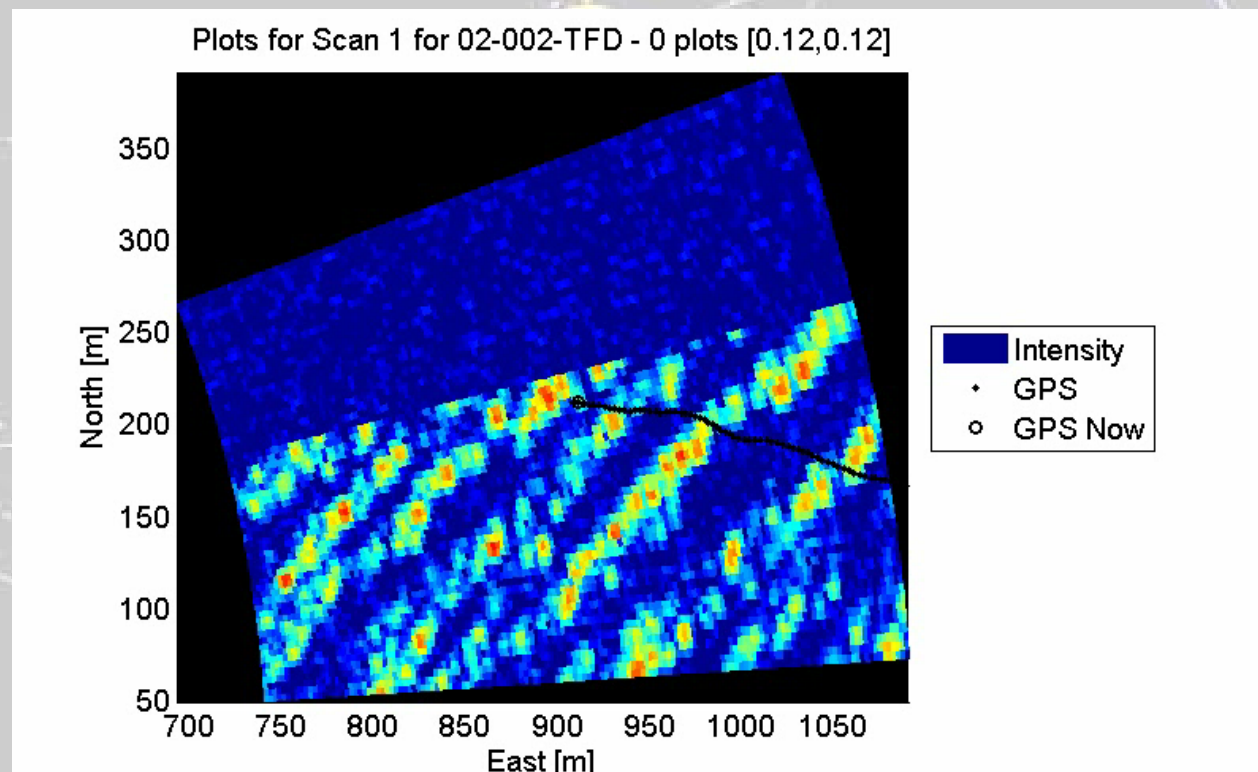
- Doppler processing
 - Separate target from clutter at different f_d
 - Adaptive CFAR that changes to the changing clutter environment
 - Automatic estimation of the clutter environment
 - Complimented by a clutter suppression filter



...Situational awareness through persistent surveillance...

Small Boat Detection

- Detections using a Range Doppler Adaptive CFAR detector
 - Same false alarms as the standard CFAR detector
 - Increases Pd up to 90 %



...Situational awareness through persistent surveillance...

Mine Wall Radar

REUTECH
RADAR SYSTEMS



TATS

REUTECH
RADAR SYSTEMS



TATS FMCW 3D Sensor

TATS FMCW 3D Sensor

Multiple receivers

Doppler Processing

FMCW Phased array

High FMCW SRT (>50 KHz)

Wide bandwidth(<0.5 meter range uncertainty).

High difference frequency

Establish 3D track in less than 5 ms

80 degree elevation cover

90 degree azimuth cover

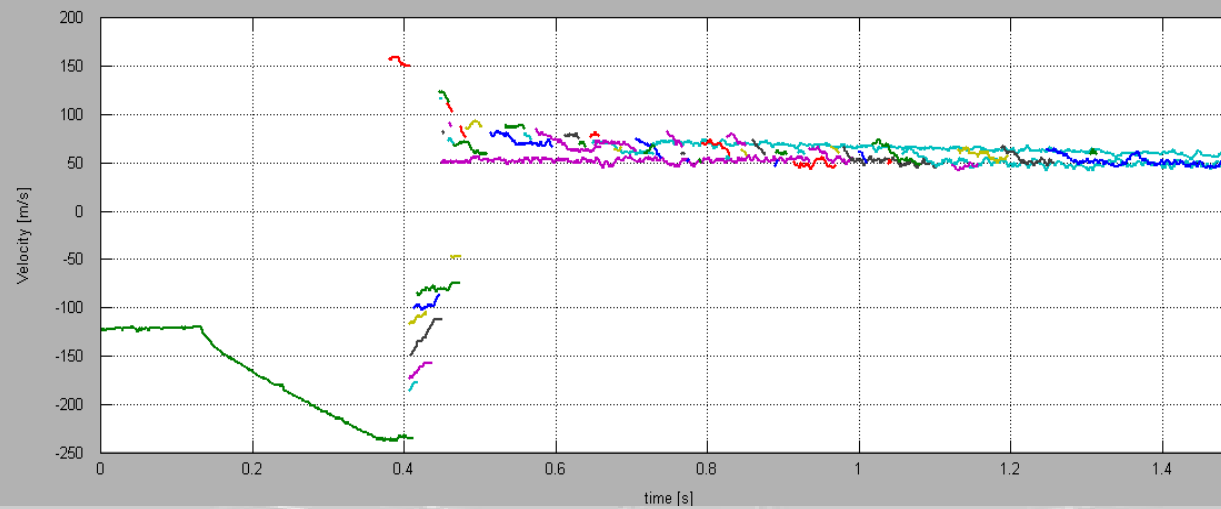
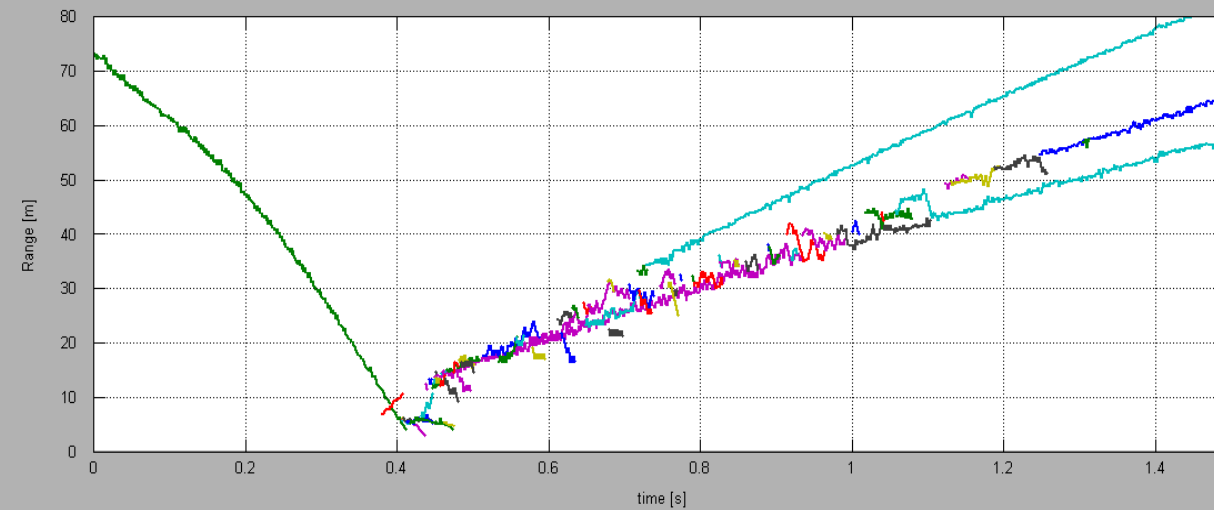
Detect RPG >250 meter

9 mm round >100 meter

Paintball>25 meter

TATS results

REUTECH
RADAR SYSTEMS



● Thank You
questions