Passive Radar on fixed and mobile platforms exploiting digital Broadcast signals

Heiner Kuschel

FHG/FHR
Fraunhoferstr. 20, 53343 Wachtberg, Germany

heiner.kuschel@fhr.fraunhofer.de

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Outline of the presentation

- Digital broadcast signals
- DVB-T passive radar model
- DVB-T passive radar processing
- FHR PCL systems
- PCL measurement results
- A multi-band PCL concept
- Conclusions

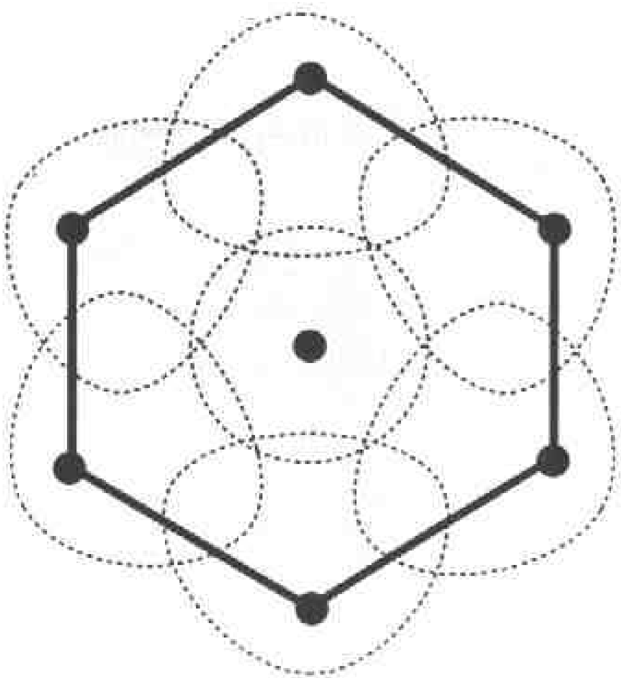
Digital Broadcast Signals (DVB-T, DAB)

- Channel coding by OFDM-technique (Orthogonal Frequency Division Multiplex)
- Spectrum resembles white Gaussian noise within channel band-width.
- Transmission of ‚long‘ sysmbols, separated by guard intervals, to avoid multi-path losses.
- Single or multiple frequency network
- Synchronized to GPS-clock

DAB Digital audio broadcast

- Modulation QPSK
- Single frequency network
- Synchronzation by Null-Symbol and reference symbol
- 4 DAB-channels of 1,5 MHz bandwidth, each, with notches of 0,2 MHz fit into one analogue TV channel of 8 MHz.
- 72 symbols build 1 frame
- In each channel 2,4 Mbit/s is broadcasted with 1536 carrier frequencies.

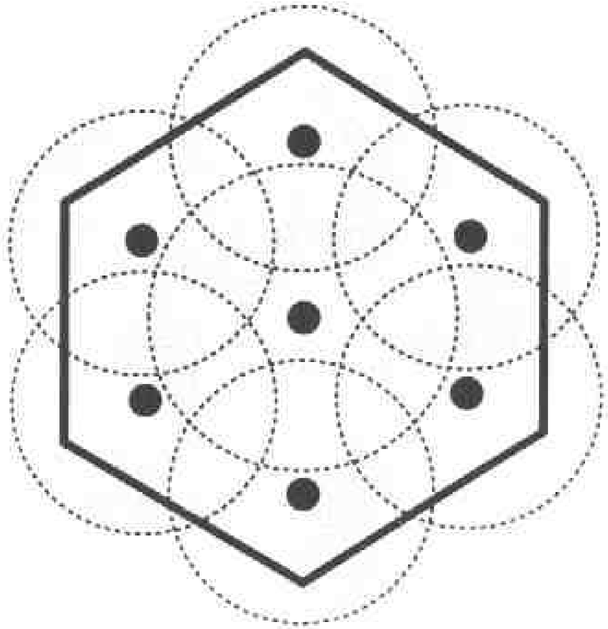
Digital radio   DAB (VHF and L-band)



DAB Reference modell

with closed hexagon (VHF)

(directed antennas)



DAB Reference modell

with open hexagon (L-band)

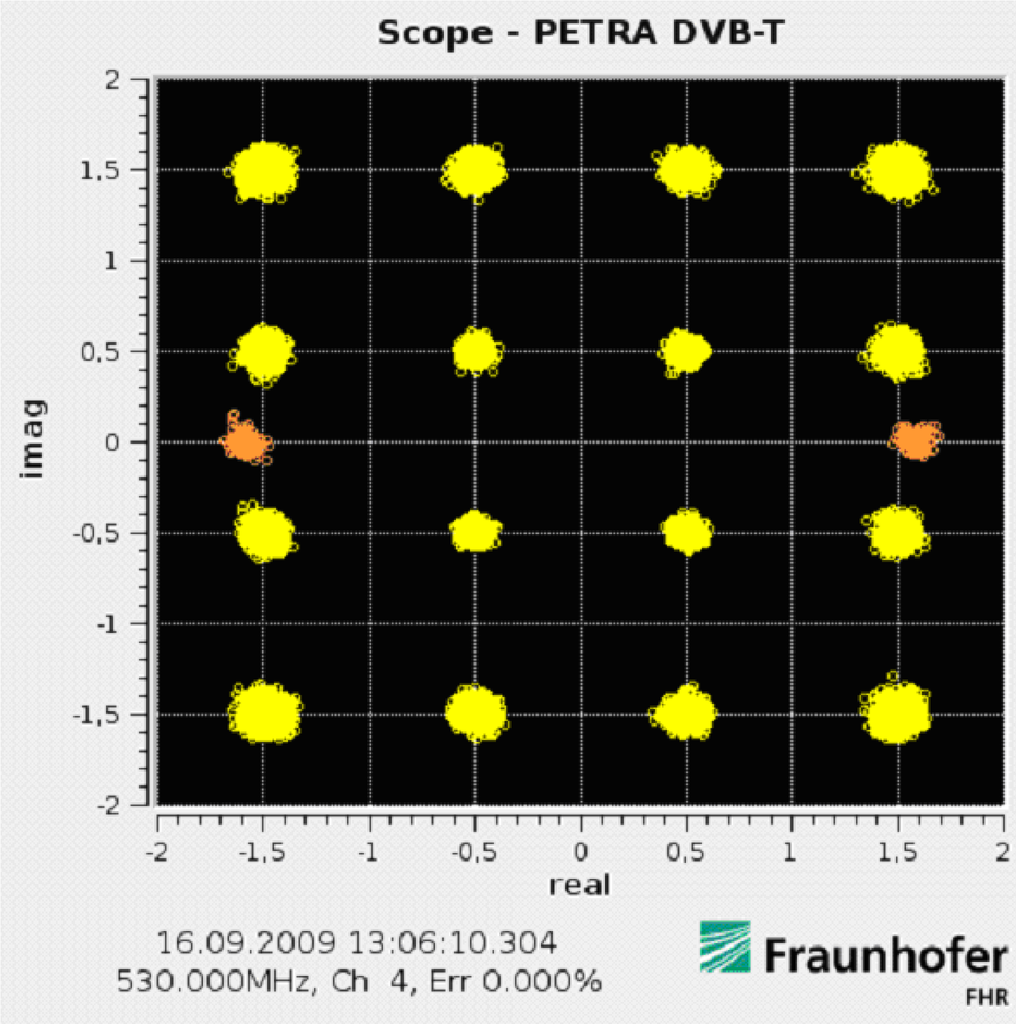
(omni-antennas)

Peripheric transmitters: 1kW

DVB-T Digital television

- modulation QPSK, 16-QAM, 64-QAM.
- 2048, 4096, or 8192 carriers (2k, 4k, 8k mode, respectively)
- 68 blocks form a frame, 4 frames = superframe
- Single frequency network
- Syncronization by specific pilot carriers in sub-frame (4 blocks)
- Tx power ca. 10 dB heigher than for DAB (in Europe)
- Band-width ca. 7.6 MHz (high range resolution)

Measured Constellation map of 16QAM DVB-T signal



DVB-T Passive radar model

direct signal — target echo

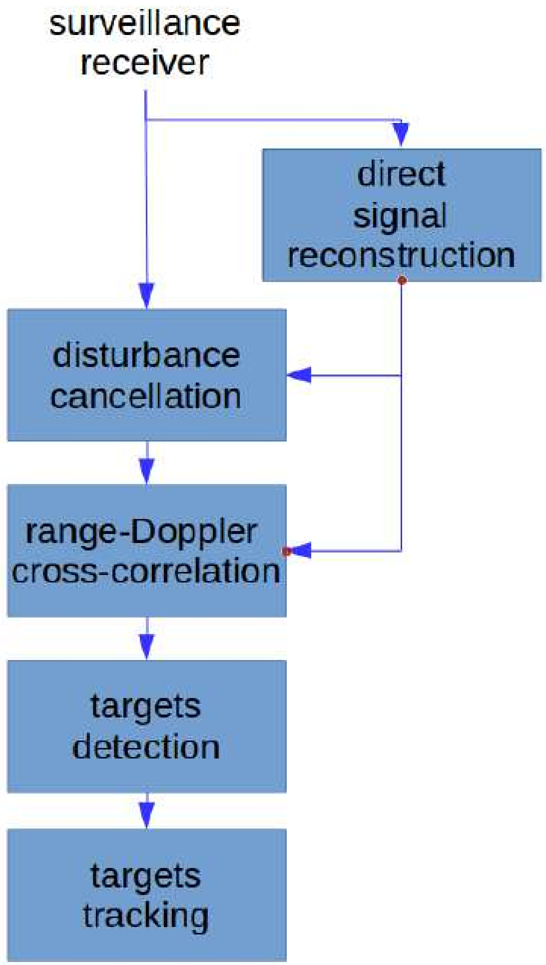
$$r(t) = s(t) * \sum_{i=1}^{I} a_i \cdot \delta(t - t_i) + \sum_{k=1}^{K} \sum_{l=1}^{L} b_{k,l} \cdot s(t - t_{k,l}) \cdot e^{j2\pi f_D t} + n(t)$$

$r(t)$ *received signal*
$s(t)$ *the DVB-signal during one symbol*
i *number of transmitters,*
k *number of targets*
l *number of transmitters contributing to a target echo.*
a_i and $b_{k,l}$ complex factors representing the propagation channel influences depend on the location of the transmitters and targets with respect to the receiver.
t_i and $t_{k,l}$ time delay of the transmitter signals and the target echo signals
$e^{j2\pi f_D t}$ Doppler shift of the target.

DVB-T processing model

- Comparing the received signal with the expected signal by exploiting the reference information (pilots)
- Compensating for the transfer function of the propagation channel
- Reconstruction of the transmitted signal from the direct signal
- Correlating the received signal with the reconstructed clean direct signal (symbol wise)
- Integrating multiple cross-correlation (e.g. FFT)
- Applying CFAR detection and detection clustering
- Tracking in the bistatic range – Doppler domain (R/D)
- Using target bearing information to shift R/D-tracks to the cartesian domain.
- Apply cartesian tracking

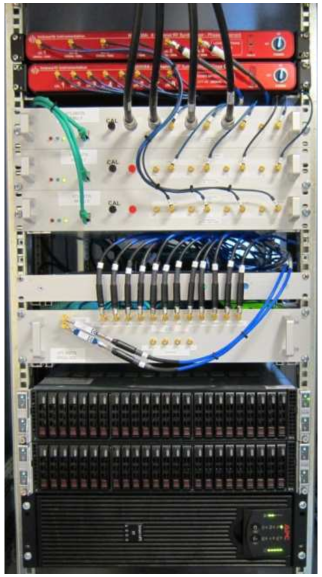
Basic PCL Signal Processing with digital transmissions of opportunities

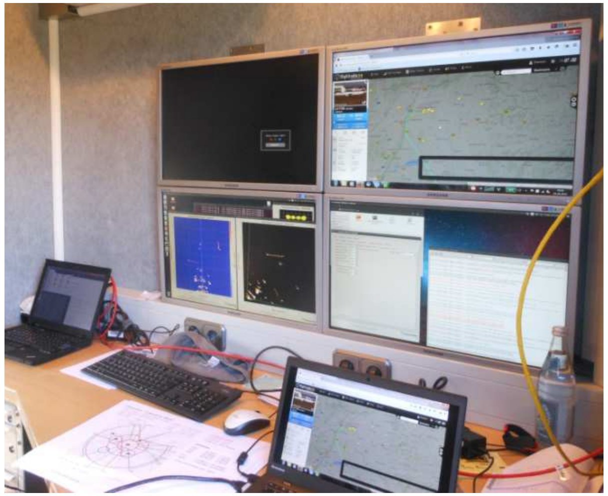


- *Synchronization*
- *Decode of the transmitted signal*
- *Reconstruct the original transmitted signal*
- *Cleaned surveillance signal is cross-correlated in RD domain.*
- *One range-Doppler map per Coherent Integration Interval (CPI)*
- *Target Detection*
- *Detections from multiple CPIS produce tracks*

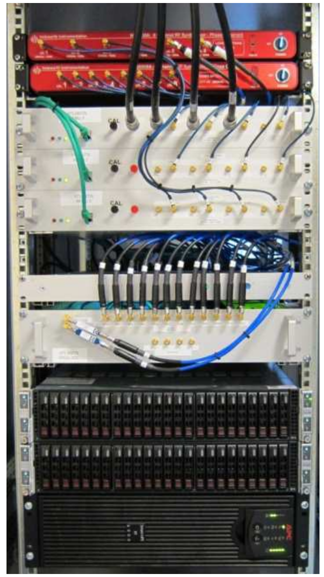
PCL System ATLANTIS (I)

- PCL System for DAB/DVB-T
- 11 RX channels (external calibration)
- 1 Reference channel
- 32 MHz digitized
- (only 8 MHz processed at a time)

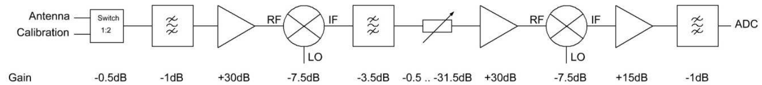




PCL System ATLANTIS (II)



- Multi-channel RF frontend
- Low Phase Noise multi-channel RF synthesizer
- GPSDO as frequency reference and for positioning
- 16-bit data acquisition units
- High-performance computer cluster for data processing and raw data storage
- Instrument Control Center software for remote control of all attached components
- Flexible and high performance signal processing software



LORA11: Uniform Linear Array

- Uniform Linear Array
- From 450 MHz up to 900 MHz
- 11 Discone elements (V-pol)
- Reference antenna on the back
- Adjustable element spacing
- 90° Field of View (Azimuth)
- Calibration via external antenna

- Hydraulic mast
  - up to 15 meters height
  - > 360° mechanical rotation
  - transportable

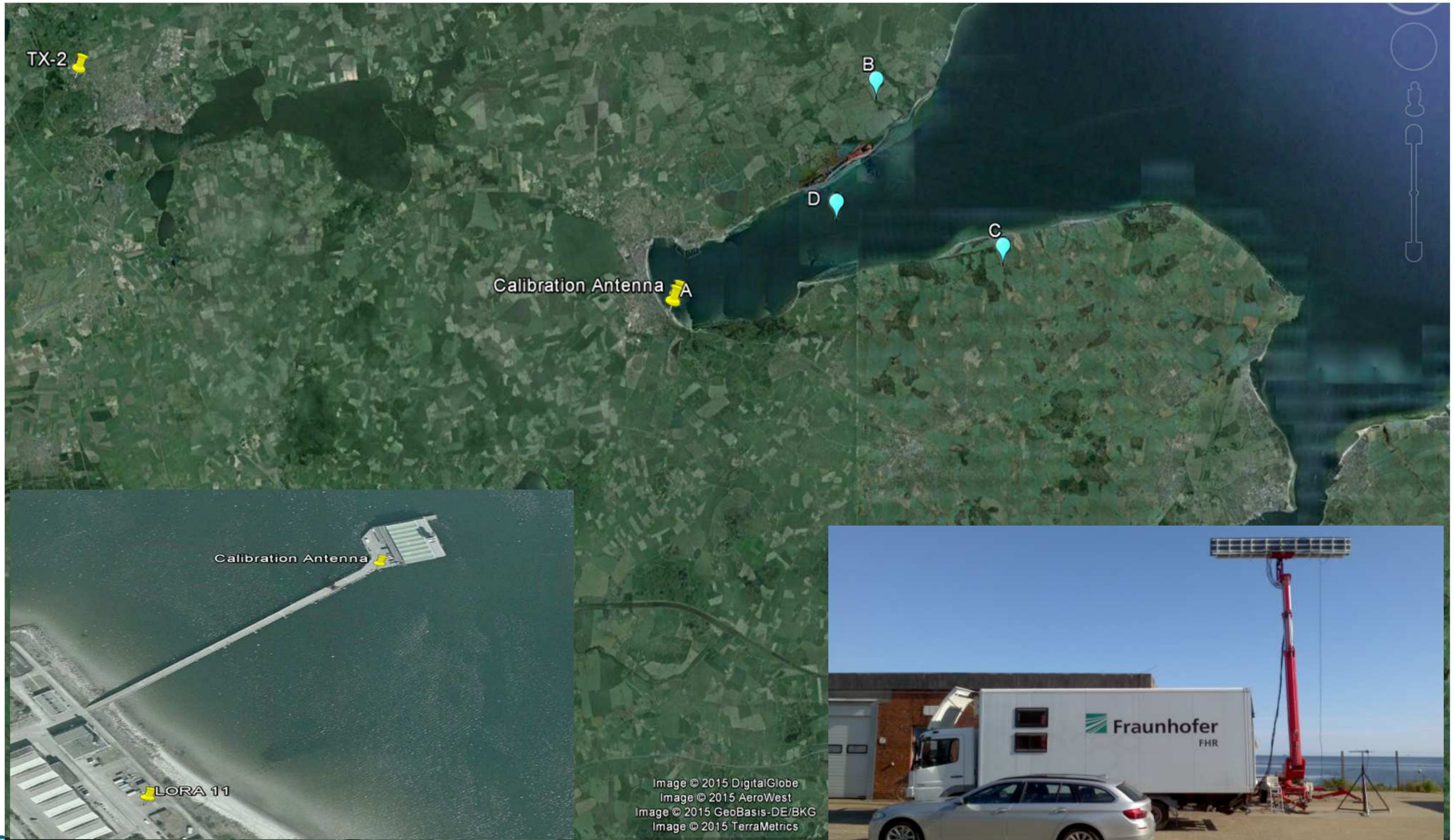
CORA11: Circular Array

- Circular Array
- From 450 MHz up to 900 MHz
- 11 Discone elements (V-pol)
- Calibration antenna in the middle
- Adjustable element spacing
- 360° Field of View (Azimuth)

- Hydraulic mast
  - up to 15 meters height
  - > 360° mechanical rotation
  - transportable

circular array enables azimuth and elevation DOA estimation

Measurement scenario with fixed and mobile PCL platforms

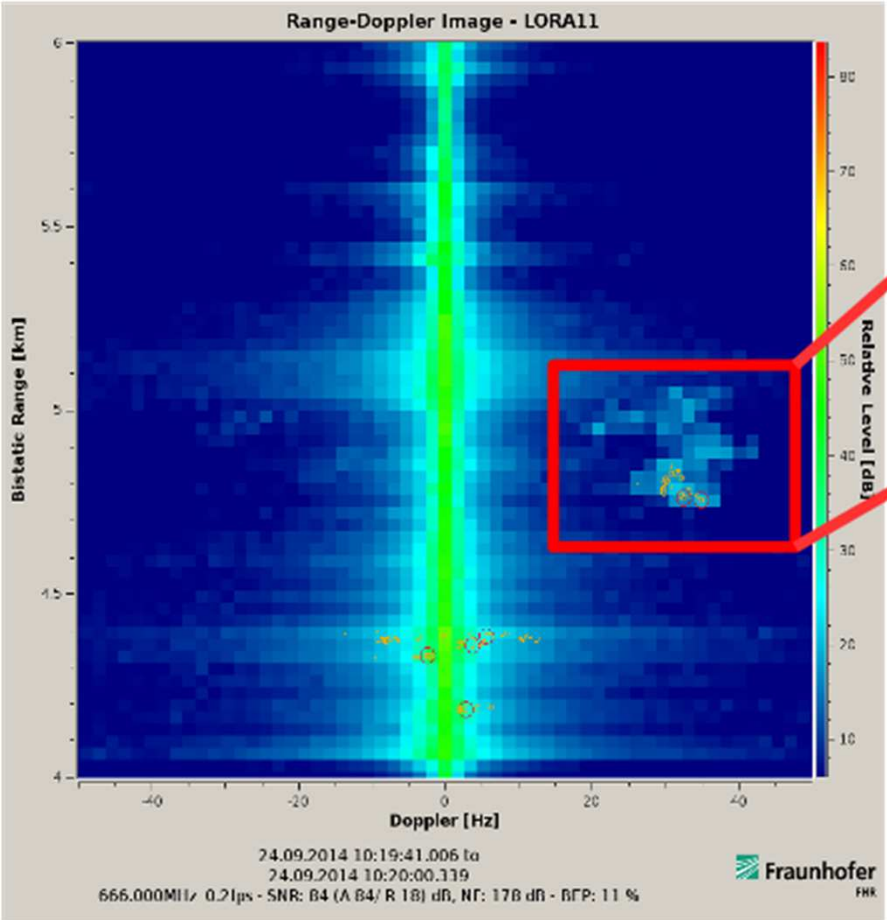


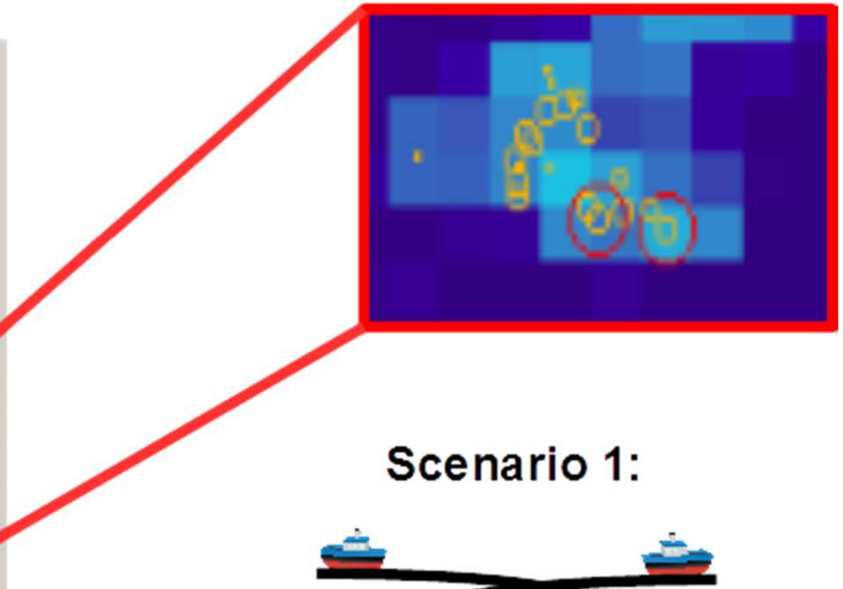
Targets

Ultralight aircraft Delphin of Fraunhofer FHR

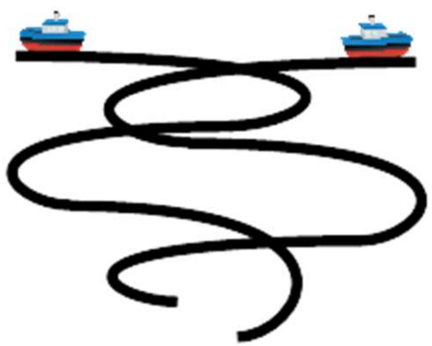
2 speed boats of WTD71

Resolution of two manoeuvring speed boats



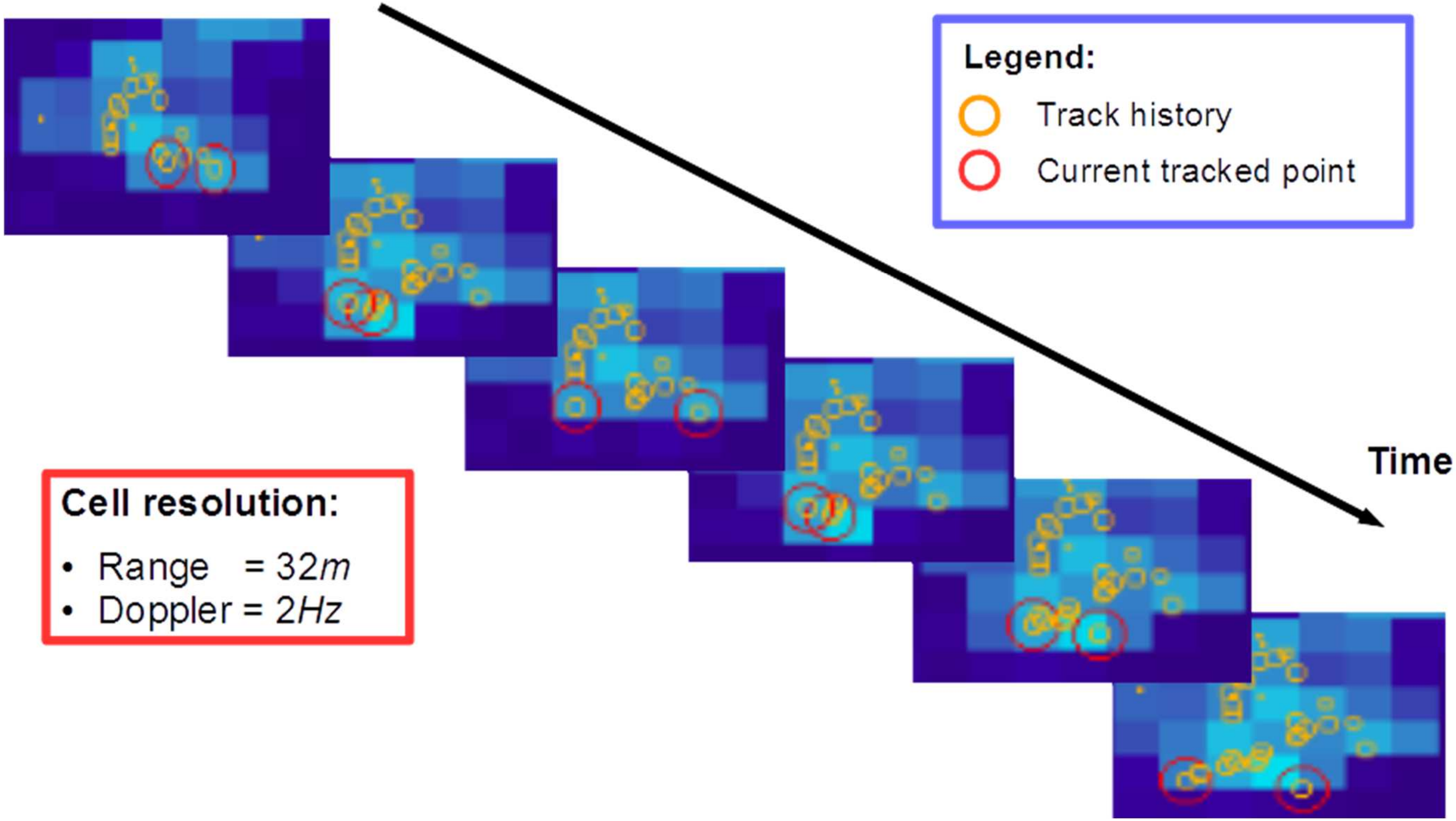


Scenario 1:

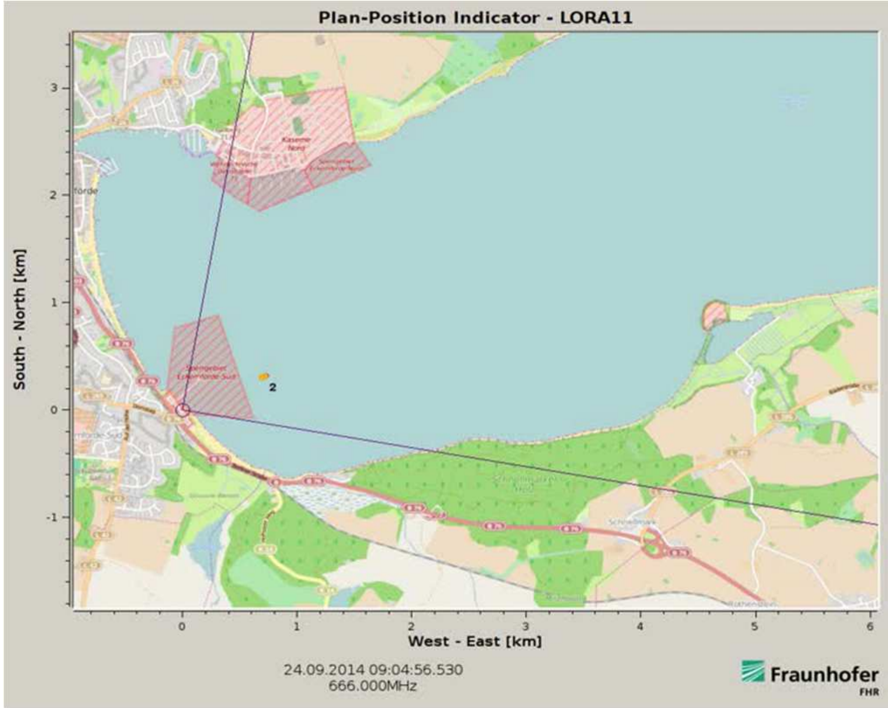


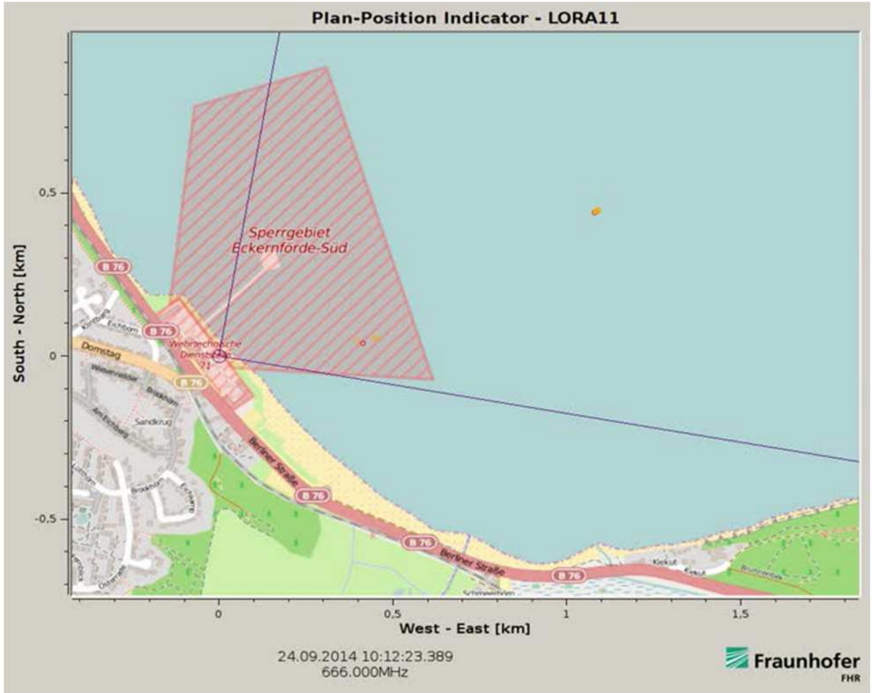
LORA 11

Resolution of two manoeuvring speed boats



videos of measurement





Atlantis on work boat

3 channels:

Reference channel
horizontal channel
vertical channel

DVB-T SAR experimental setup

- Site: Eckernforde harbour, Germany, conducted by FHR
- DVB-T station: “Kiel”, 22km away from receiver
- Receiver: On moving (5m/s) boat- single channel receiver, capturing direct signal+echoes

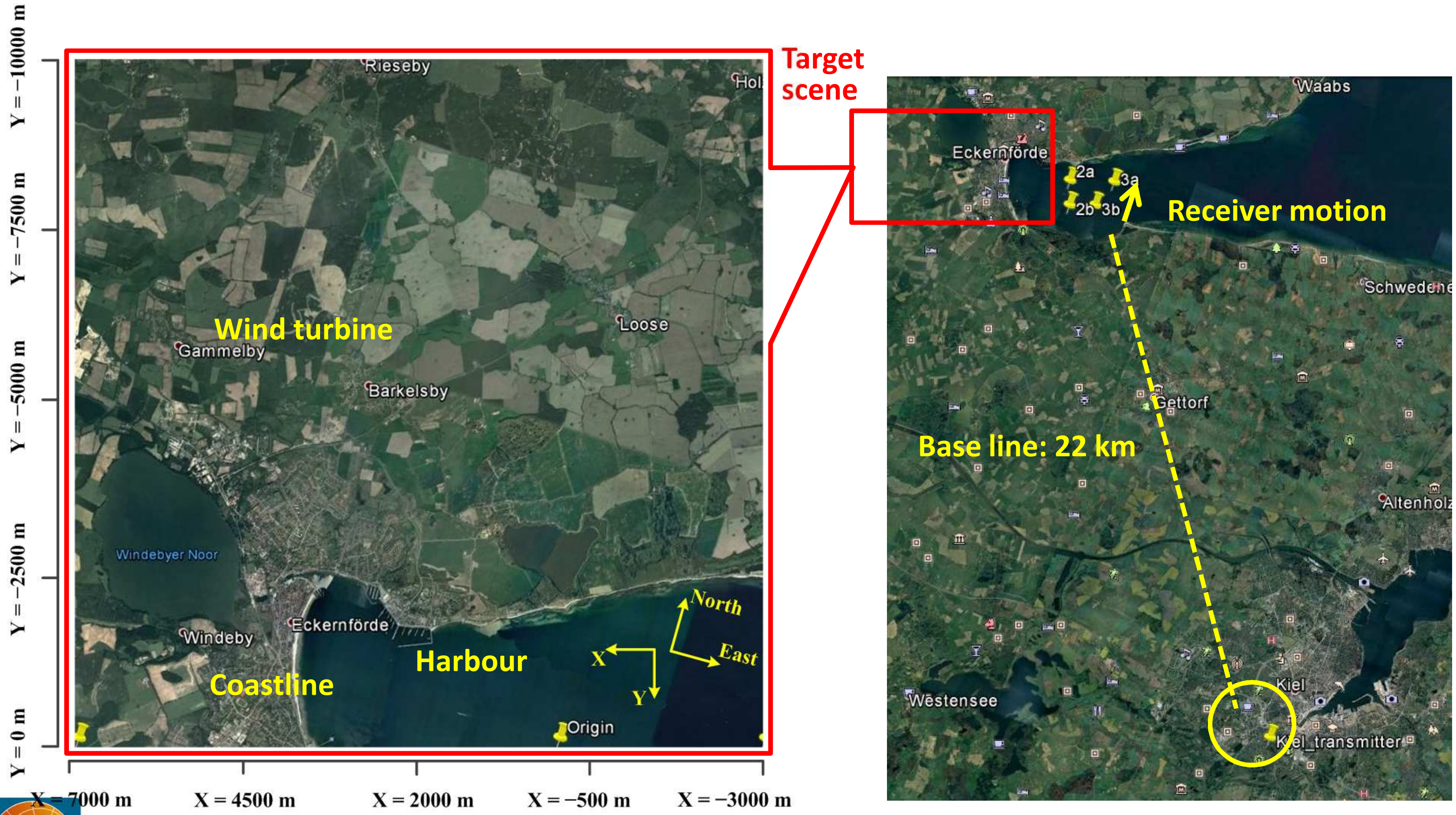
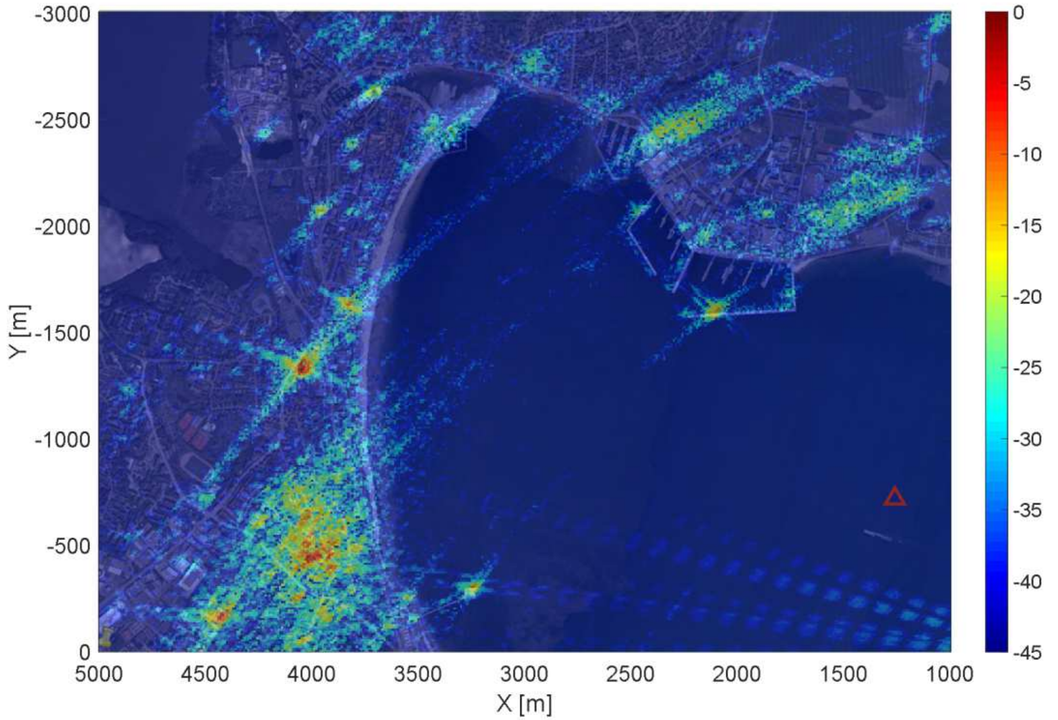
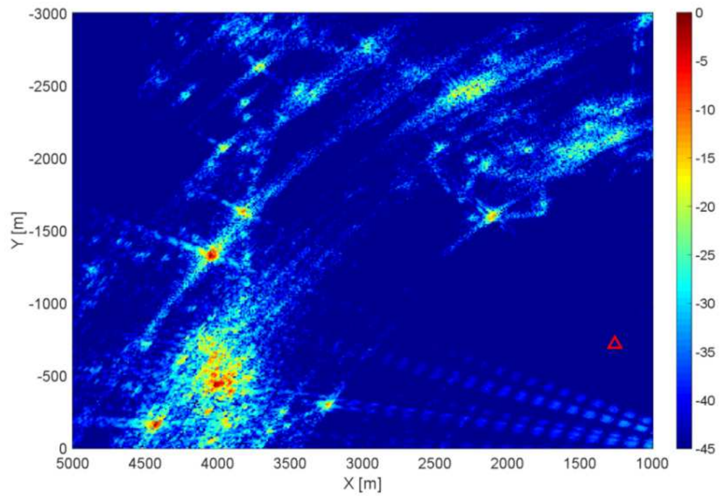
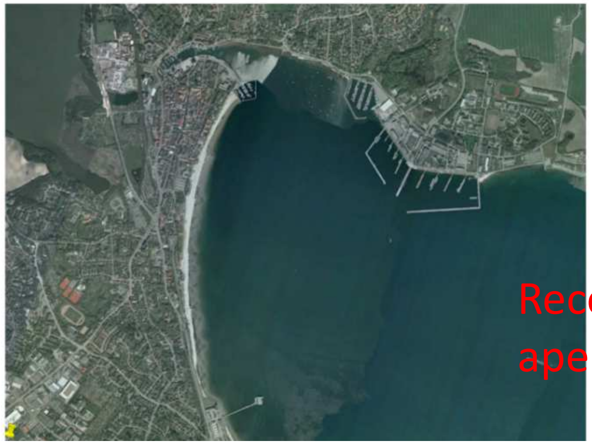


Image detail 1: coastline

- Obtained results with 20s of acquisition
- Back-projection only, no MoComp- full decoding of DVB-T data[1] prior to image formation
- Tx 22km away- ~0.5deg grazing,
- Rx on sea surface- ~0.5 deg grazing
- But image not limited to front face of buildings on shore





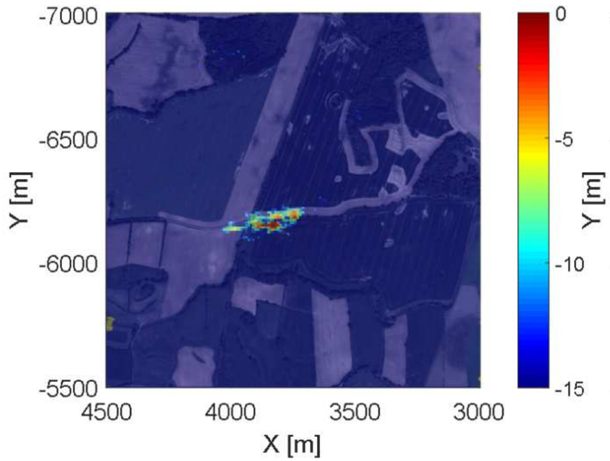


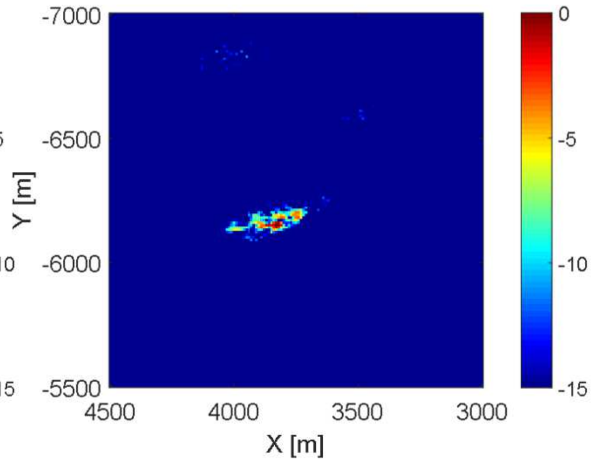
Receiver aperture

1. S. Searle, S. Howard, J. Palmer, "Remodulation of DVB-T signals for use in passive bistatic radar", 44th Asilomar Conf., pp. 1112-1116, 2010.

Image detail 2: wind turbine

- Obtained results with 80s of acquisition
- Target area of interest: a wind turbine around 7 km away from receiver



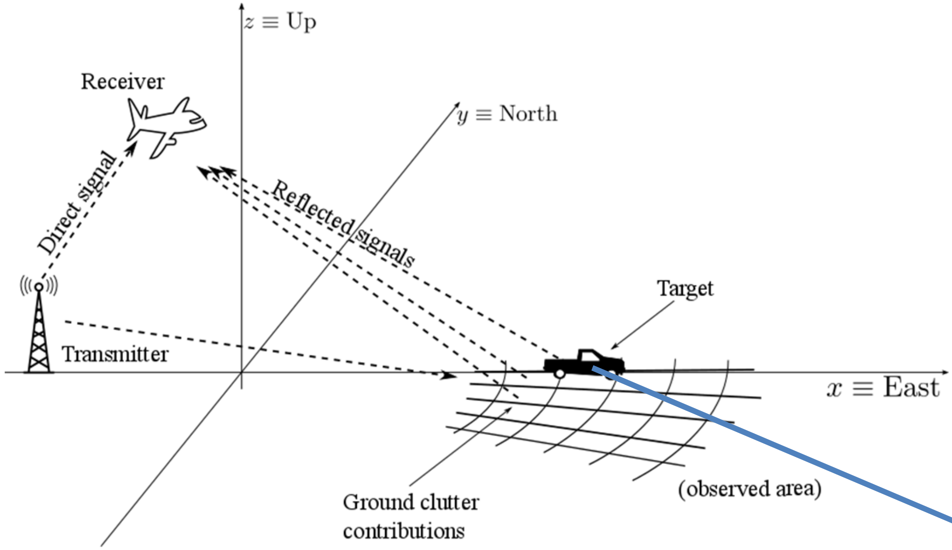


Wind turbine circled in red

Zoomed photo of wind turbine

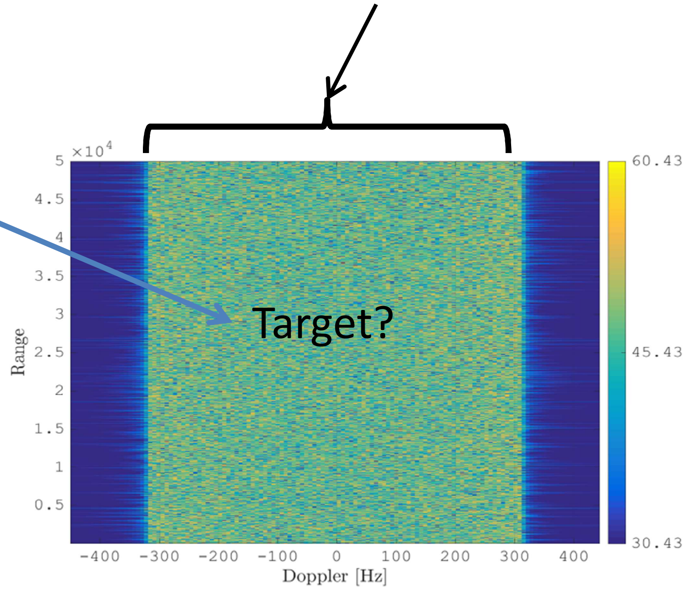
in cooperation with University of Birmingham

Exploiting Reciprocal Filter and DPCA approach for Clutter Removal and Target Detection



Active and passive radar:

- Clutter Doppler spread (due to moving receiver) covers target echoes



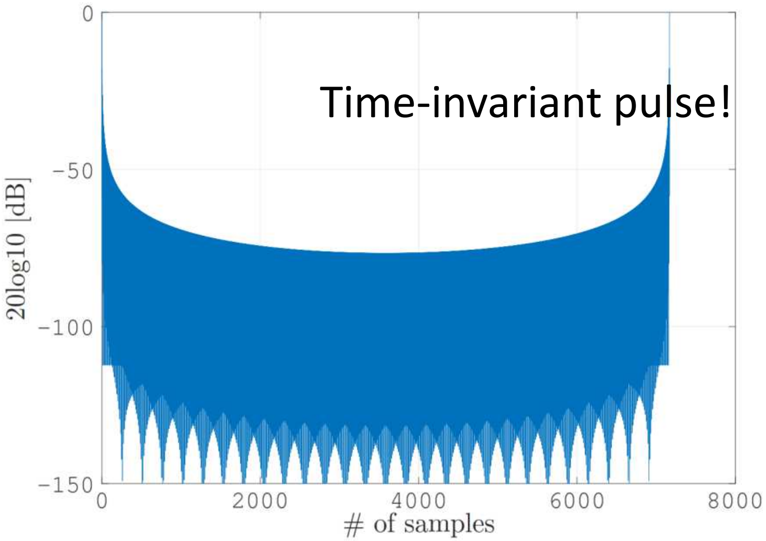
Passive radar:

- Exploitation of communication signals → not created for radar purposes
- Common processing with matched filter does not remove the waveform characteristics

Reciprocal filter versus matched filter

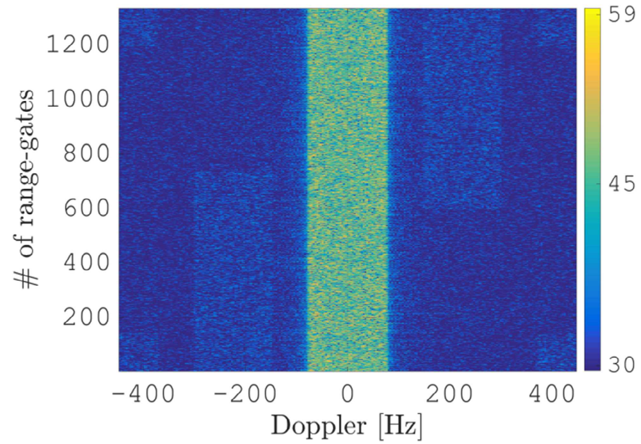
- Matched filter: $Y_M(f) = S_r(f)H_M(f) = S_r(f)S_t(f)^*$
- Reciprocal filter: $H_R(f) = S_t(f)^{-1}$

$$Y_I(f) = S_r(f)H_R(f) = S_r(f)S_t(f)^{-1}$$

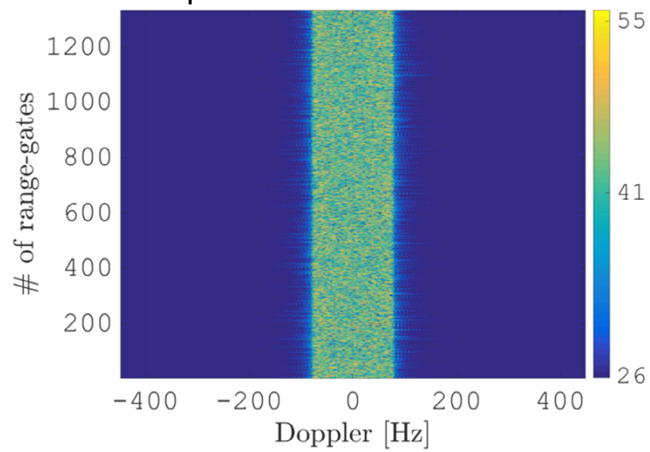


One DVB-T symbol after reciprocal filtering

Ambiguities still present after matched filtering

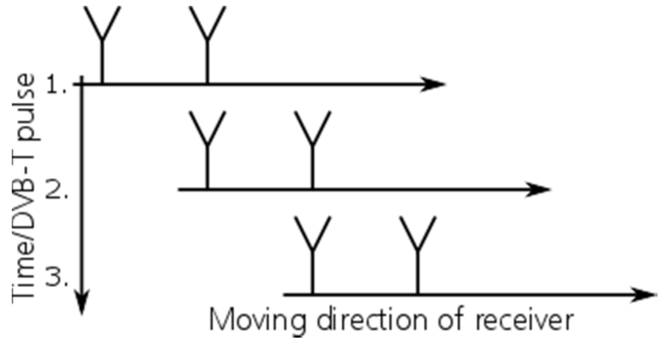


Ambiguities removed with reciprocal filter

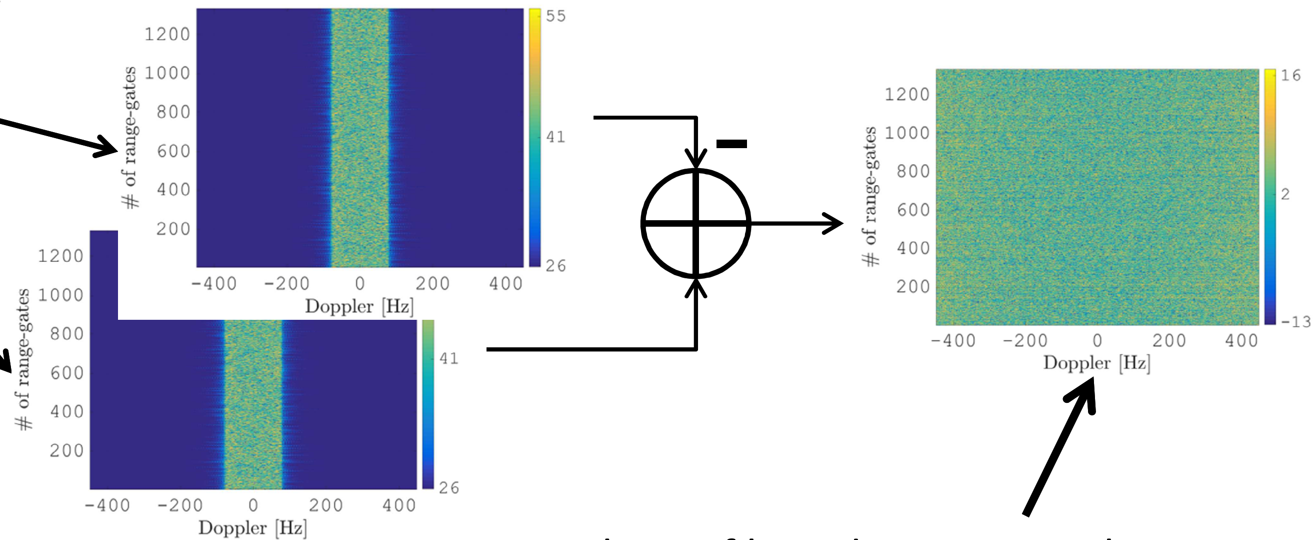


Application of DPCA

Basic principle:



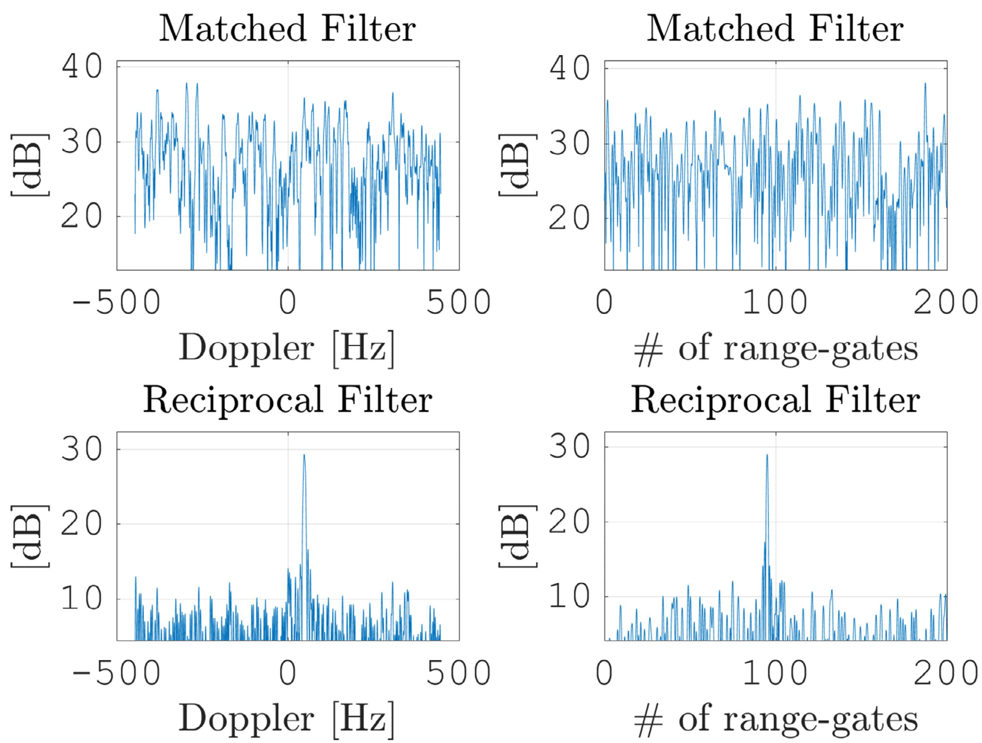
Range-Doppler maps of leading- and trailing antennas



Clutter filtered range-Doppler map

Application of DPCA - Targets

Targets covered by clutter and ambiguities will be found by using reciprocal filtering!



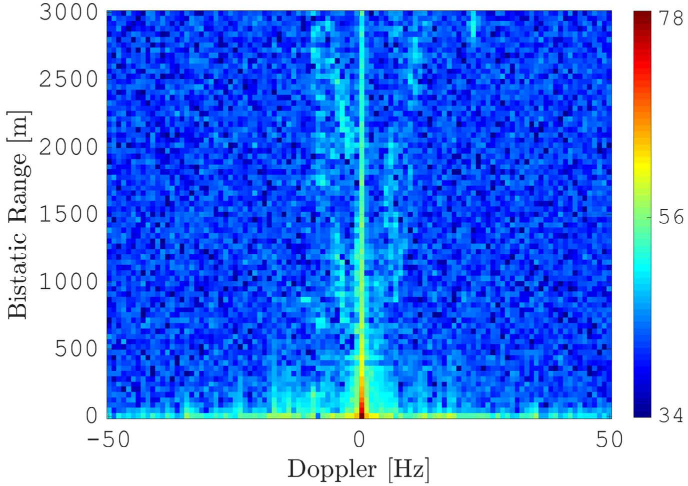
Application on real measurements in cooperation with: Norwegian Defence Research Establishment (FFI)

- Oslofjord, Norway 2016
- DVB-T Transmitter:
  - $f_{Tx} = 650 \text{ MHz}$

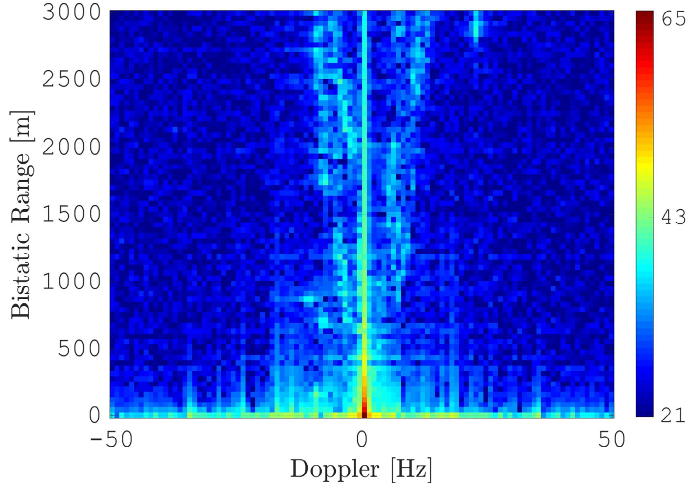
Receiver:

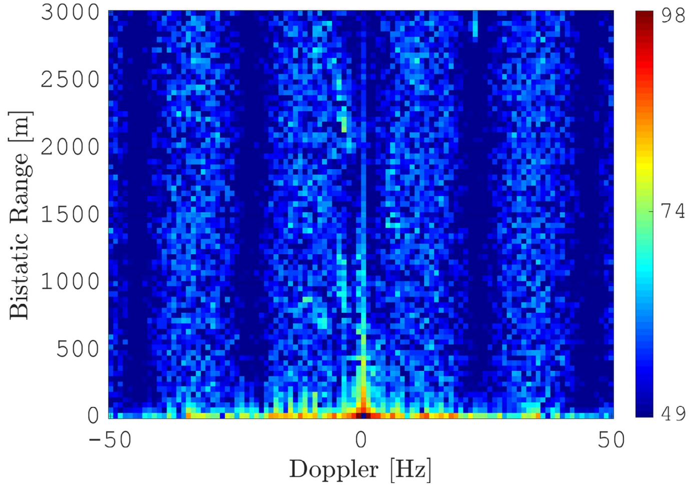
- Receiver system ``Parasol“ on boat.
- Two surveillance antennas.
- $v_{Rx} \approx 9 \text{ m/s}$

Application on real measurements

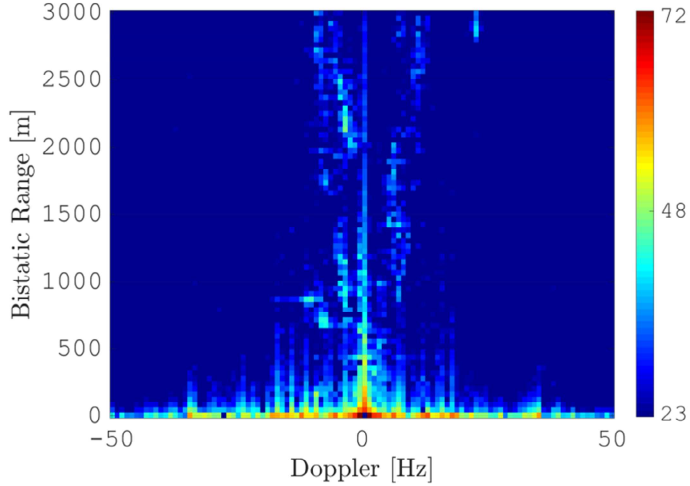


Before DPCA





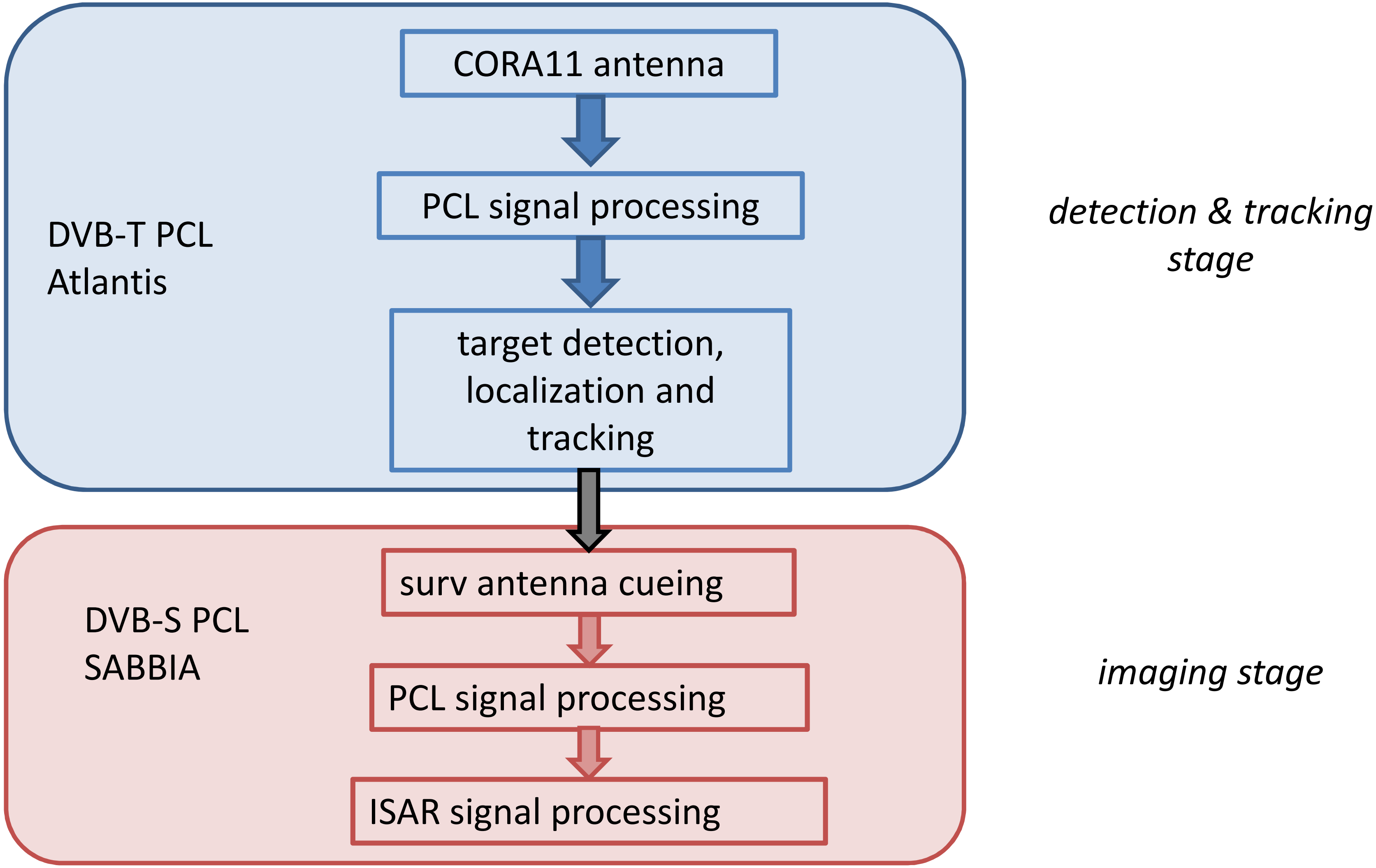
After DPCA



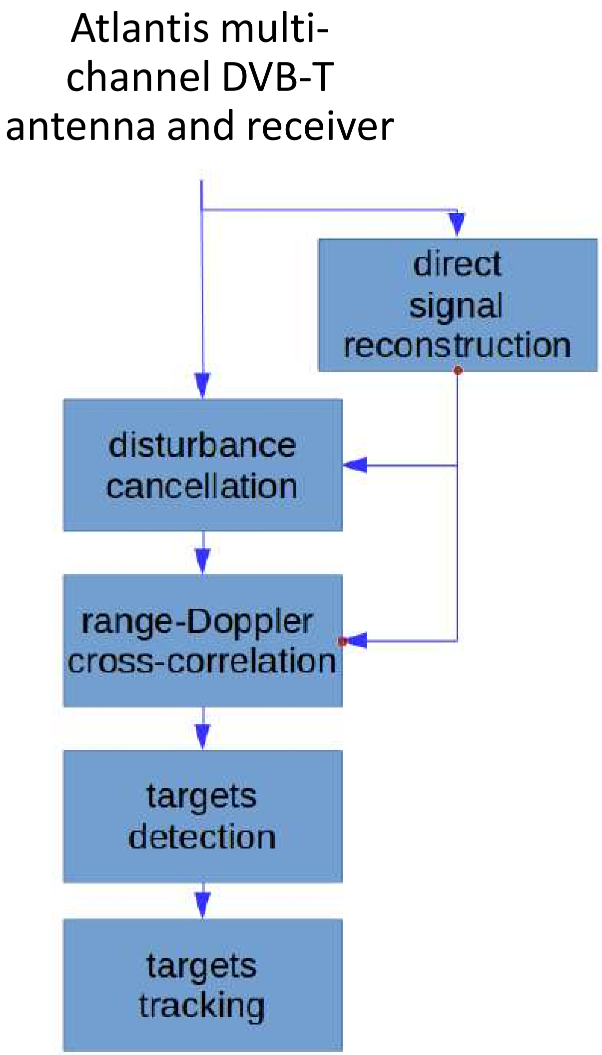
Matched filter

Reciprocal filter

Multi-band PCL concept



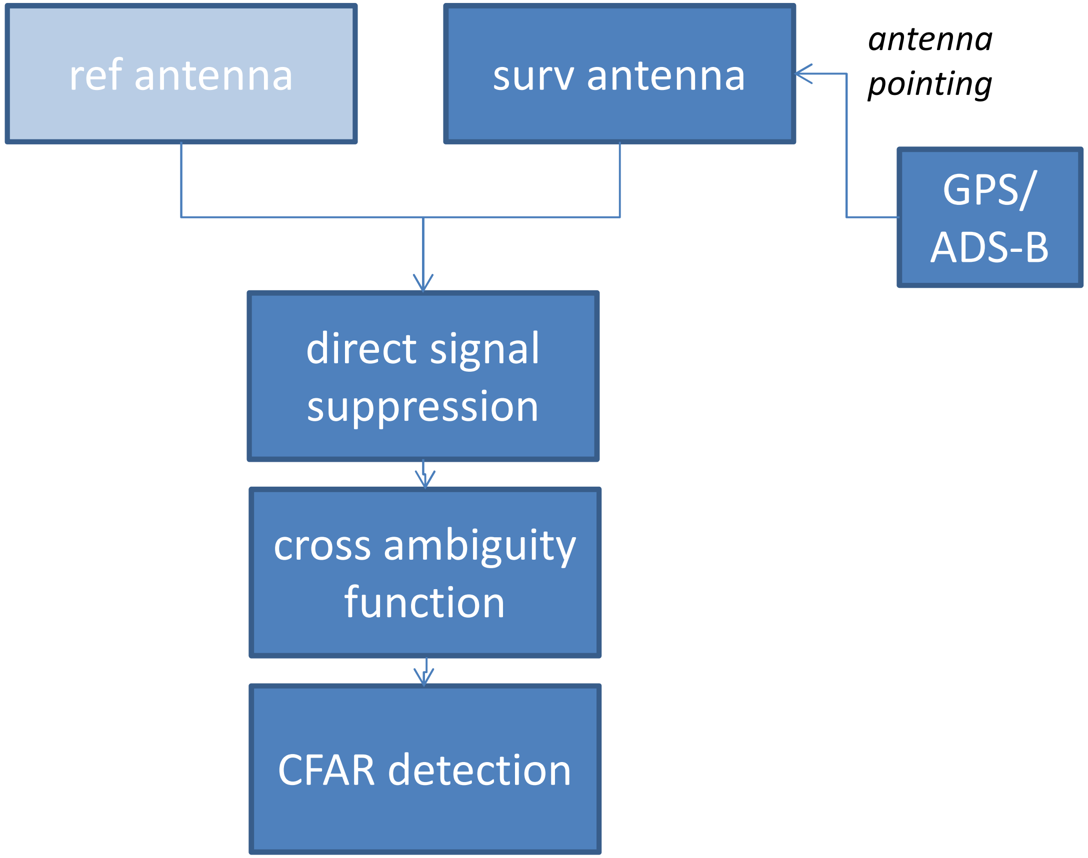
Atlantis signal processing



- Decoding of received signal
- Reconstruction of the original transmitted signal
- Cross-correlation of received signal with clean replica in RD domain.
- Target detection
- Target tracking
- Cueing of DVB-S PCL component

SABBIA: signal processing

- surv antenna pointing via GPS/ADS-B
- „Range compression“ via correlation surv/ref
- Generation of Range/Doppler Map
- CFAR detection in Range/Doppler



SABBIA

- DVB-S based passive radar
- Frequency range: 10,7 GHZ – 12,75 GHz (DVB-S, DVB-S2, DVB-SH)
- Up to 130 MHz bandwidth
- 2 Rx channels (Surv + Ref)
- Automatic antenna alignment (GPS-/ Mode-S-/ AIS-Based)

dish-antenna with 2.2° beamwidth

Conclusions

- The basics of digital broadcast transmissions have been introduced and the processing steps, which are required in order to exploit such signals in passive radar have been highlighted.
- Stationary passive radar radar systems as well as passive radar systems on moving platforms (boats) have been presented.
- Measurement results obtained from fixed and moving platforms were shown.
- Signal processing for clutter removal and target detection has been proposed and evaluated.
- A concept for a multi-band passive radar system, which can be used on moving platforms has been introduced as a future perspective.