Interreg Baltic Sea Region

EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

Webinar about R-Mode for the Baltic Sea Region

Medium Frequency (MF) R-Mode

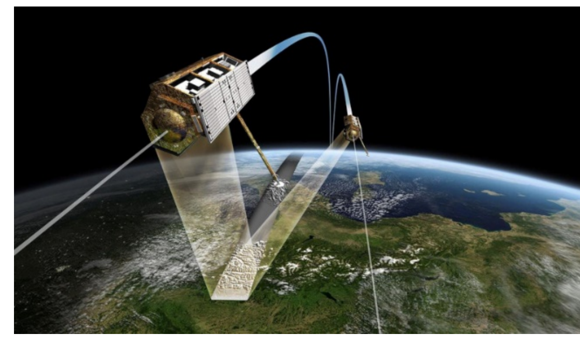
Stefan Gewies, Lars Grundhöfer,

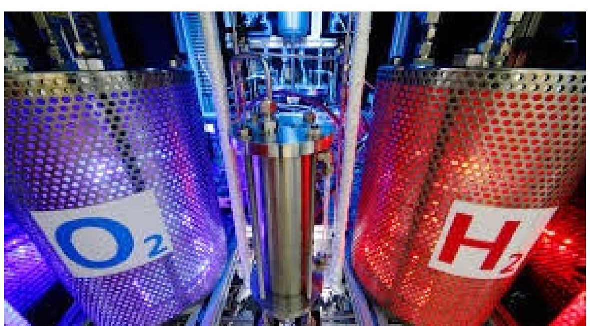
Filippo Giacomo Rizzi, Niklas Hehenkamp

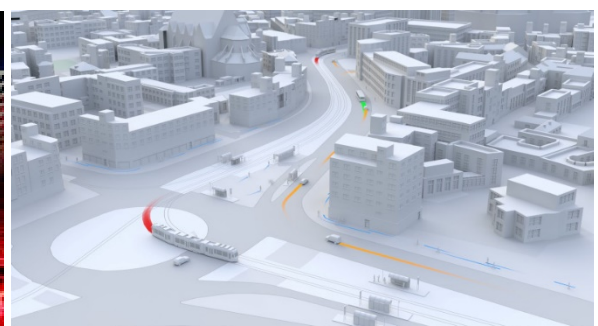
DLR

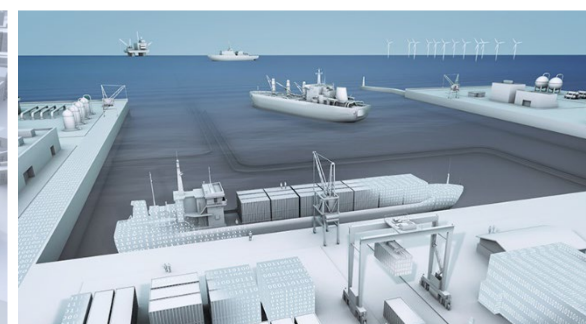
German Aerospace Center (DLR) at a glance

- DLR is the Federal Republic of Germany’s research centre for aeronautics and space
- Research and development activities in the fields of aeronautics, space, energy, transport, security and digitalization
- German Space Agency at DLR plans and implements the national space programme on behalf of the federal government
- DLR: 55 research institutes and facilities & approx. 10,000 employees
- DLR mission: explore Earth and space and develop technologies for a sustainable future

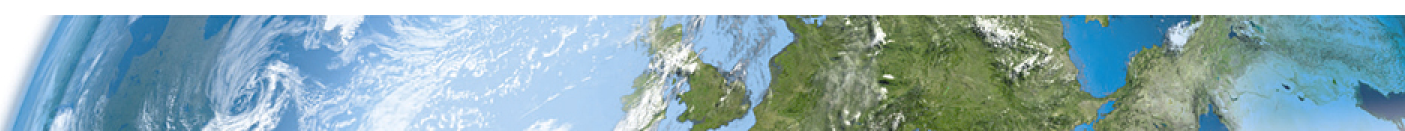








DLR

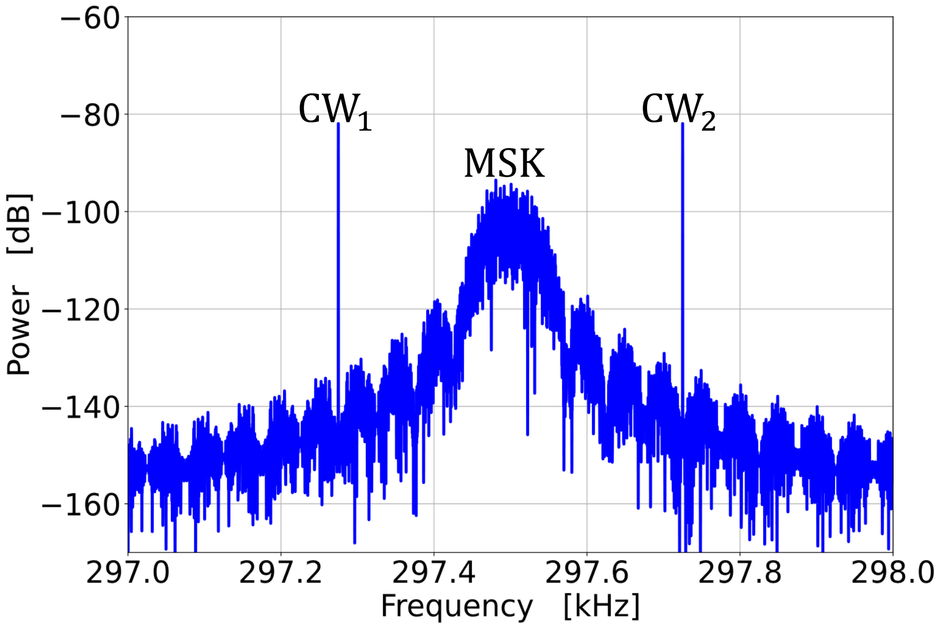


Outlook

- Overview Medium Frequency (MF) R-Mode
- Theoretical performance of MF R-Mode testbed in the Baltic
- MF R-Mode experiments
- MF R-Mode hardware
- Summary and conclusions
- Live demonstration MF R-Mode receiver (Lars Grundhöfer)

Medium Frequency (MF) R-Mode principle

- Modification of radio beacon signal
  - Two aided carriers (CW) 225Hz beside beacon carrier
  - Well known phase of CW
- Ranging
  - Measure phase of CWs
  - Solve ambiguities of CW with beat signal of both CW
  - Track signal
- Positioning
  - Use 3 received signals to estimate longitude, latitude and time



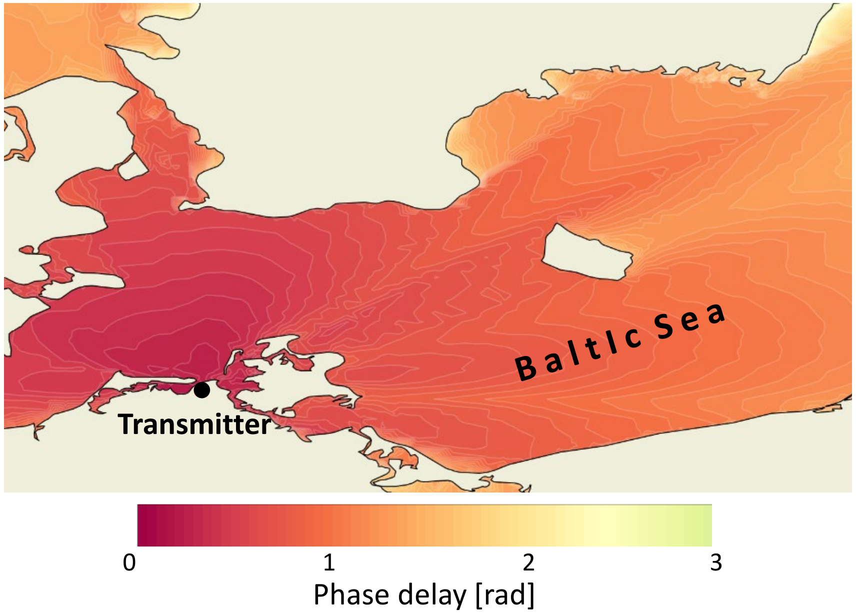
Power spectrum of simulated MF R-Mode signal

MF R-Mode propagation error sources

- Sky-wave
  - Multipath effect
  - Night-time ionosphere reflection
  - Neglectable at short distances
- ➢ Suppression of the fading is under investigation

- Ground propagation
  - Ground conductivity depended propagation speed
  - Delay has to be considered
- ➢ Possible approaches to mitigate path related phase delay:
  - Work with phase correction maps
  - Measure phase delay for known position and keep it
  - Differential R-Mode

Phase delay of Groß Mohrdorf signal (ground-wave) compared to vacuum propagation



Challenge R-Mode transmitter

- Current radio beacon transmitter chain optimized for MSK modulated signal
- Problems identified
  - Jumps and drifts in CW phases
  - Intermodulations (class D amplifier)

➢ Each transmitter has to be analysed separately
  - Signal distortions and delays
  - Static and dynamic calibration necessary

- R-Mode Baltic and R-Mode Baltic 2 developed concepts

○ At the moment not clearly defined signals are transmitted in the Baltic testbed

Source: Swedish Maritime Administration

MF R-Mode navigation information

- Essential information defined
  - Status
  - Provide position of transmitter
  - Provide corrections
  - Interoperability of systems
  - In accordance with VDES R-Mode
- Ongoing design of RTCM2 messages
- Transmission together with DGNSS messages planned
- MF R-Mode navigation information are not provided by transmitters in the testbed

IALA Guideline on Implementation of R-Mode on MF and VHF frequencies (Draft)

Parameter	Definition	Bits	Scale factor	Unit
A_0	Constant term of polynomial	32^{*}	2^{-30}	s
A_1	1st order term of polynomial	24^{*}	2^{-50}	s/s
Δt_{LS}	Leap Second count before leap second adjustment	8^{*}	1	s
t_{0t}	UTC data reference Time of Week	8	3600	s
WN_{0t}	UTC data reference Week Number	8	1	Week
WN_{LSF}	Week Number of leap second adjustment	8	1	Week
DN	Day Number at the end of which a leap second adjustment becomes effective	3^{**}	1	Day
Δt_{LSF}	Leap Second count after leap second adjustment	8^{*}	1	s

CLOCK AND DELAY CORRECTIONS

The clock of the base station provides offset of transmission of VDE ranging message, and other delays as offset to the RMST. The clock error is given by an offset (CO) and its uncertainty (CU) as 1σ confidence level. The parameters CO and CU are defined in Table ....

Parameter	unit	Bits	scale	range min	range max	Notice
Clock offset (CO)	ns	9	1/3	-85.33	85.0	Offset of local clock to RMST (0.1m = 3*10^8 m/s * 1/3 ns)
Clock uncertainty (CU)	ns	5	exponential	0	1008.74	Uncertainty u=k^n-1 and k=1.25 in ns (series: 0, 0.25, 0.56, 0.95, ..., 1008.74) u = 0 means out of range
Delay CW (low)	ns	14	1/3	0	5461	delay of lower CW
Delay CW (high)	ns	14	1/3	0	5461	delay of higher CW
Delay MSK	ns	14	1/3	0	5461	delay of MSK component (limited to one period)
Phase of MSK signal	π rad	2	0.5	0	2	phase of the MSK signal component at the beginning of message (preamble); possible values are 0, 1/2 π, π, 3/2 π

The 5 bits of CU offer 32 levels n of uncertainty, using u = kn-1 and k=1.25. It describes uncertainties ranging from 0 to about 1008 ns. The value 0 defines out of range or overflow.

Coordinates of transmitter antenna / frequency offset CW

- Coordinates of MF transmitter antenna given in WGS 84
- Provide information about used MSK minima for CW transmission

Parameter	unit	Bits	scale	range min	range max	Notice

DLR R-Mode receiver

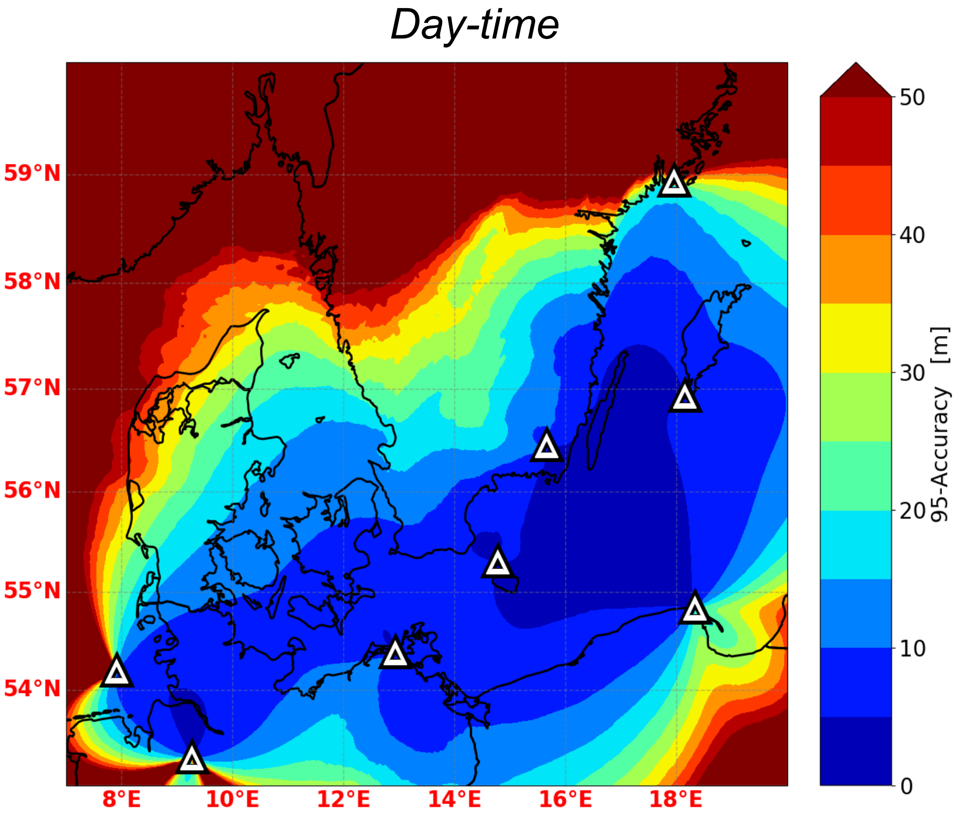
- SDR based receiver platform
- GPS stabilized Rubidium atomic clock for accurate timing
- Maximum likelihood approach for estimation of Time Of Arrival
- All in view receiver
- Least Square Single Point Positioning
- Calibration in the testbed based on known GNSS position
    - Estimates: clock biases, phase correction propagation path, delays and signal distortions transmitter chain

➢MF R-Mode receiver for static and dynamic measurements

Prediction of MF R-Mode positioning performance of Baltic testbed

Assumptions

- Considers beacon range of IALA list
- ITU models for noise and propagation attenuation
- Clock accuracy 10 ns
- Perfect signals transmitted
- No phase error from propagation path
- Ambiguities of CW were solved



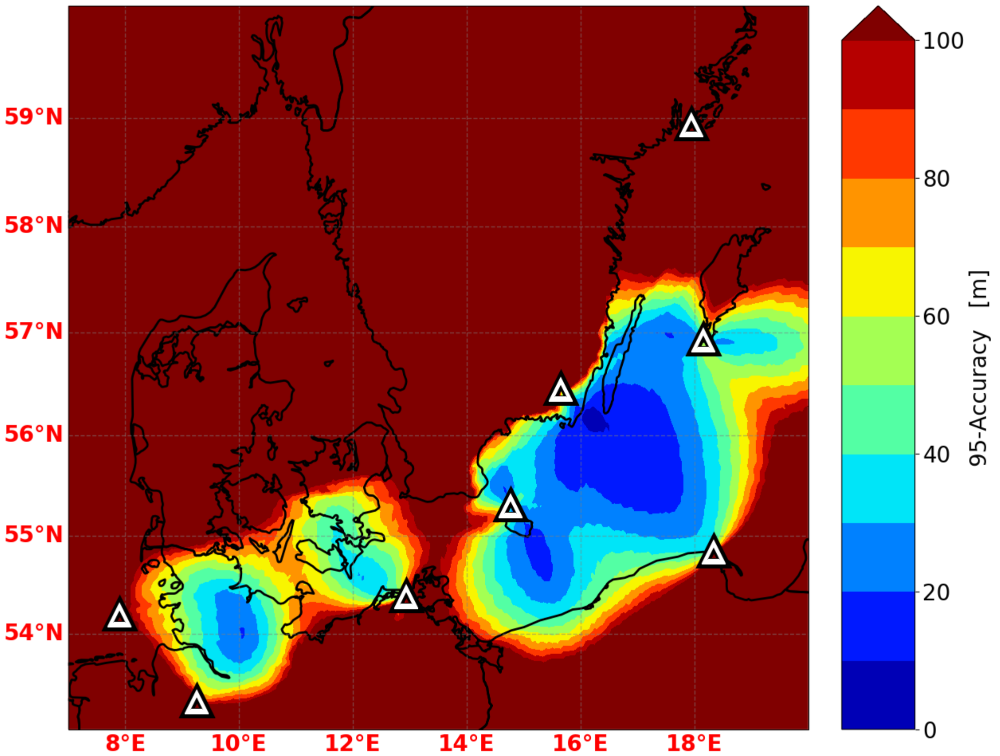
➢10 m positioning accuracy theoretical achievable between the R-Mode beacons

Prediction of MF R-Mode positioning performance of Baltic testbed

Assumptions

- Skywave interferes with certain probability and signal strength, [1]
- Different models for skywave interference exists
- Research has to show, how to describe best performance degradation in the night

Night-time

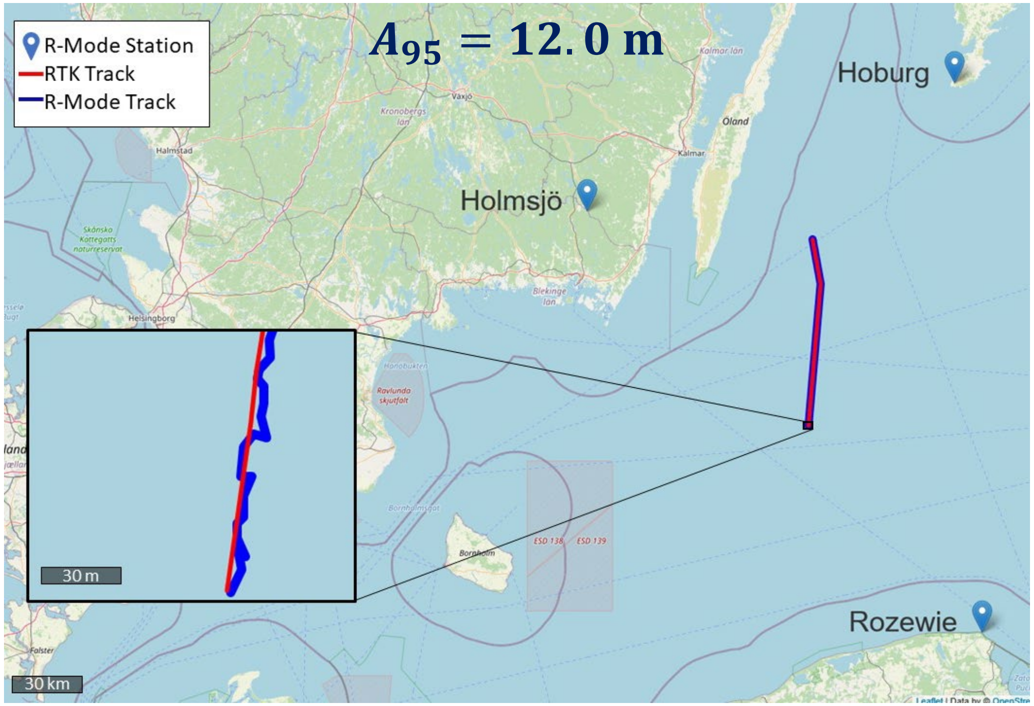


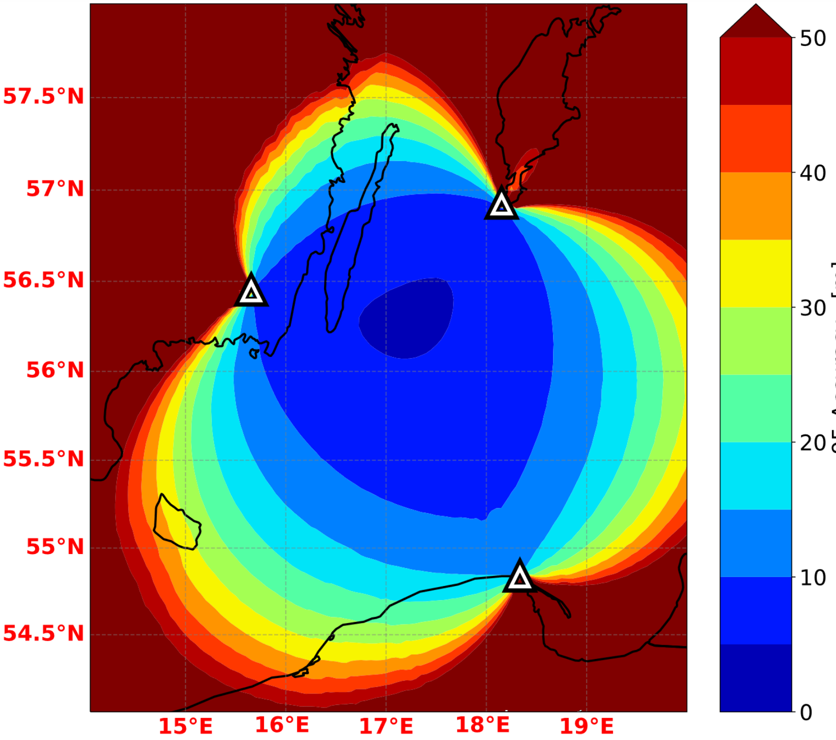
➢Clear degradation compared to day-time: for good geometry error few 10 m

[1] MF/VDES R-Mode Coverage Prediction and Accuracy Estimation, GRAD, RPT-39-JSa-20, December 2020.

Dynamic day-time measurement in the Baltic testbed

- Use only nearest MF R-Mode transmitters
- Here less impact of change of propagation path on ranging

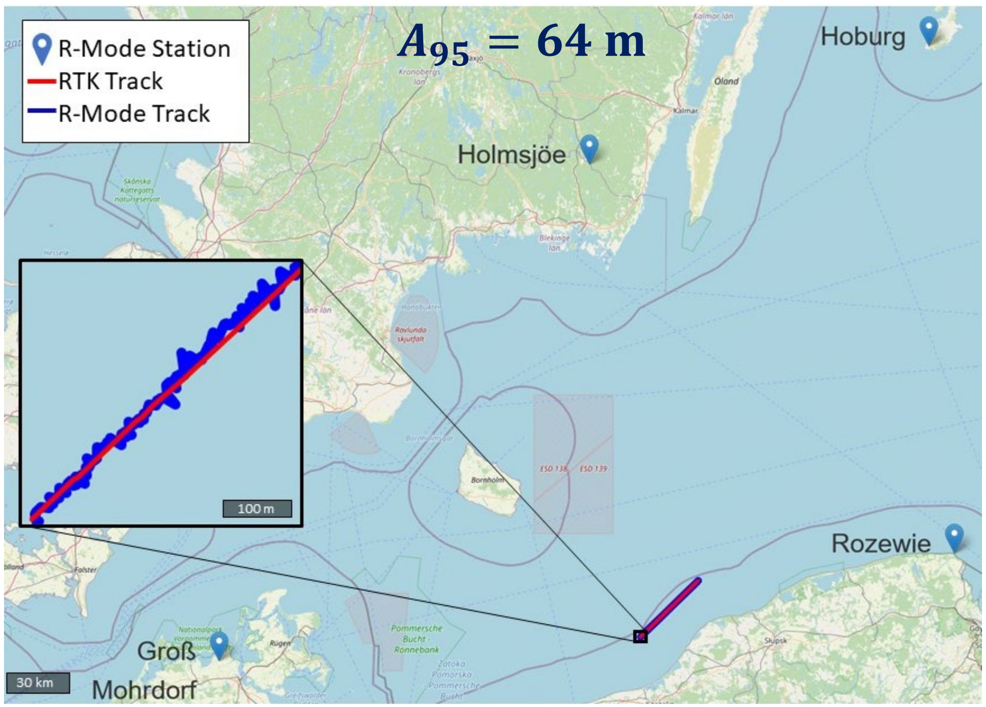


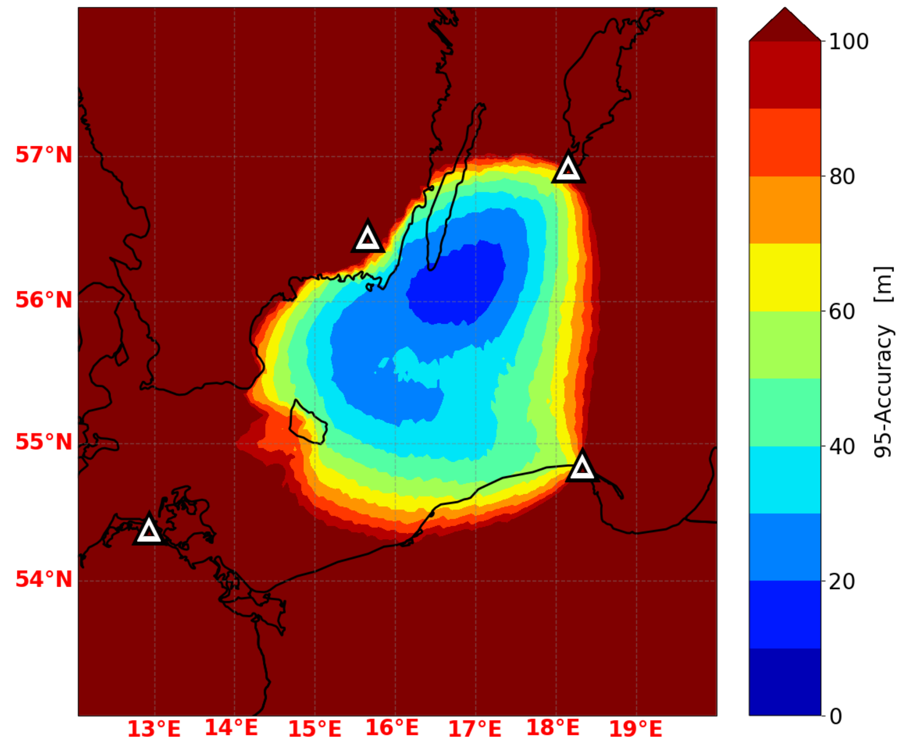


➢Experiment slightly lower performance than theory

Dynamic night-time measurement in the Baltic testbed

- Use only nearest MF R-Mode transmitters
- Here less impact of change of propagation path on ranging





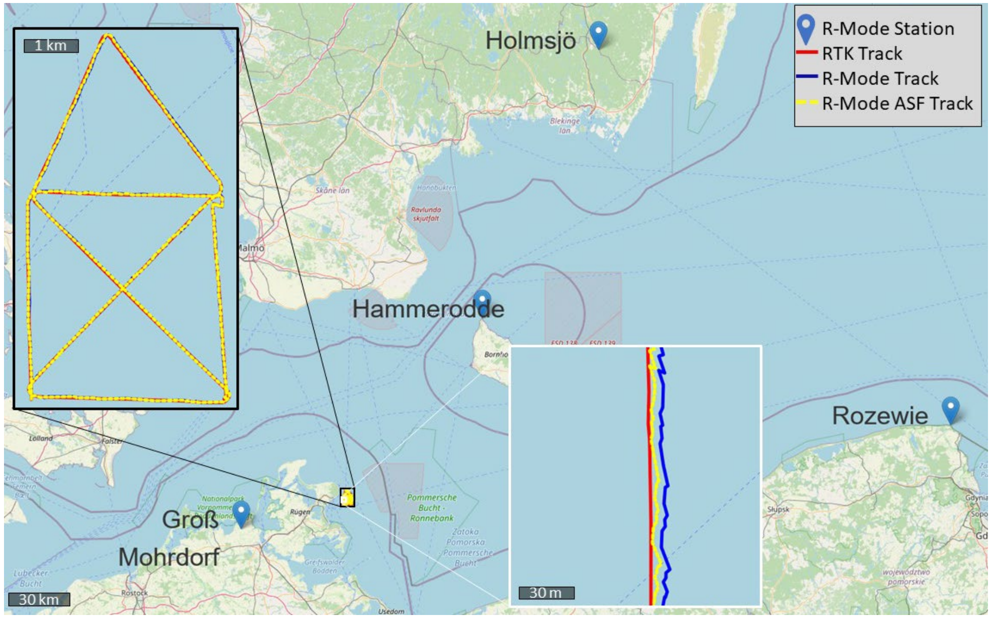
➢Experiment in agreement with theory

Dynamic day-time measurement with compensation of propagation path

- Phase Corrections Maps (PCM) based on ground conductivity map of Germany (ITU)
- Signal instabilities at two transmitter sites
- Positioning performance
  - Uncorrected (95%): 31 m
  - Corrected (95%): 22 m

➢ Compensation of propagation delay is crucial

- Increase performance
  - Static: better PCM
  - Dynamic: D-R-Mode

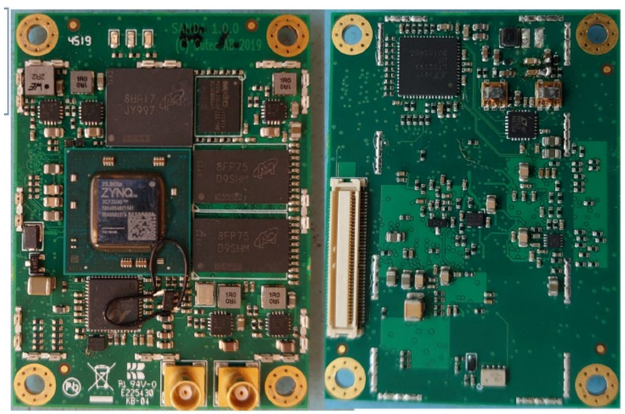


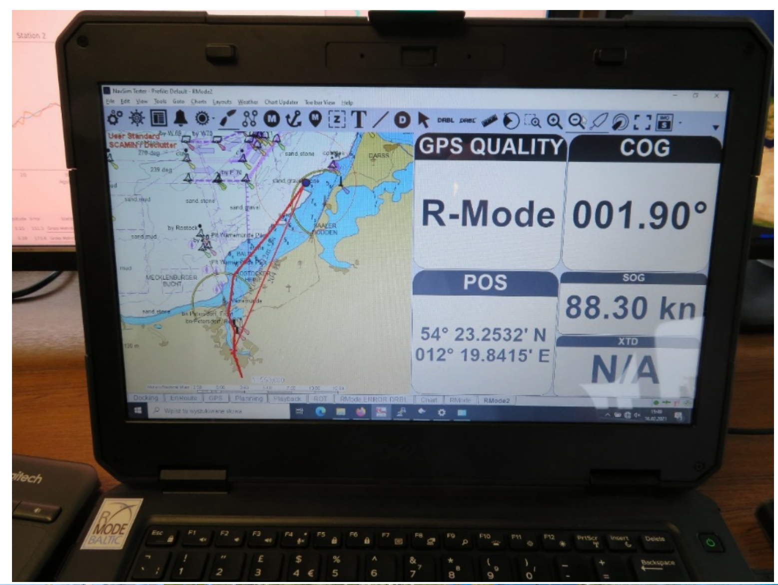
R-Mode hardware developments

Saab TransponderTech: MF concept prototype receiver

NavSim: Portable Pilot Unit

Gutec AB, navXperience GmbH: MF + VHF concept prototype receiver





MF R-Mode modulator from Novator (before R-Mode Baltic projects)

Summary and conclusions MF R-Mode

- R-Mode performance depends on
    - measurements process of the phase of a carrier,
    - on propagation path effects and
    - signal distortions at transmitter site.
- Theory predict for the Baltic testbed for defined signals an MF R-Mode positioning performance
    - Day-time: 10 m accuracy between transmitter sites
    - Night-time: better than 100 m accuracy possible
- Experiments support theory for good conditions.
- MF R-Mode performance can be increased with improve quality of the transmitted signal and better phase correction maps.
- R-Mode capable hardware is available to perform monitoring, dynamic measurements, and application development.

Life demonstration R-Mode receiver

- R-Mode dynamic measurement with Fyrbyggaren

Contact

Stefan Gewies
Project Manager
DLR
Institute of Communications and Navigation
Phone: +49 3981 480187
E-mail: Stefan.Gewies@dlr.de
https://www.r-mode-baltic.eu

Project partner