Towards large scale underwater communication networks – miniature, low cost, low power acoustic transceiver design

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Outline

- Background.
- Spread spectrum transmission schemes
- Hardware efficient implementation
- Miniature platforms – Seatrac, Nanotrac
- Positioning capabilities
- The future – EPSRC USMART project

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School of Electrical and Electronic Engineering

SEAlab

Sensors, electromagnetics and acoustics laboratory

Main activities

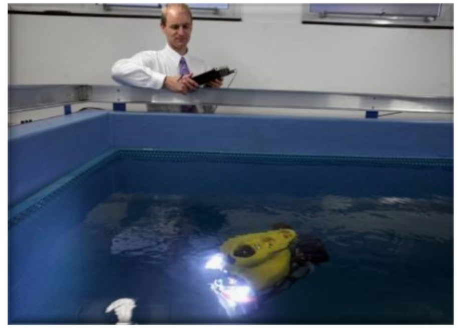
- Acoustic and electromagnetic signal processing.

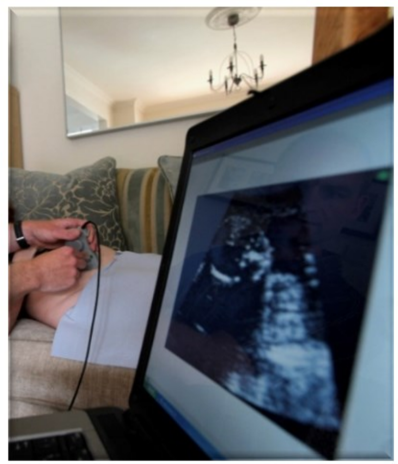
Expertise (20 years +)

- Underwater acoustic communication and navigation.
- Sonar systems and transducer design.
- Low power wireless sensor network development.
- Acoustic and electromagnetic sensor development.
- Through metal communications.
- Medical ultrasound imaging.

Successful commercialisation

- Underwater acoustic modem technology.
- Underwater positioning technology.
- Wireless environmental sensor networks.

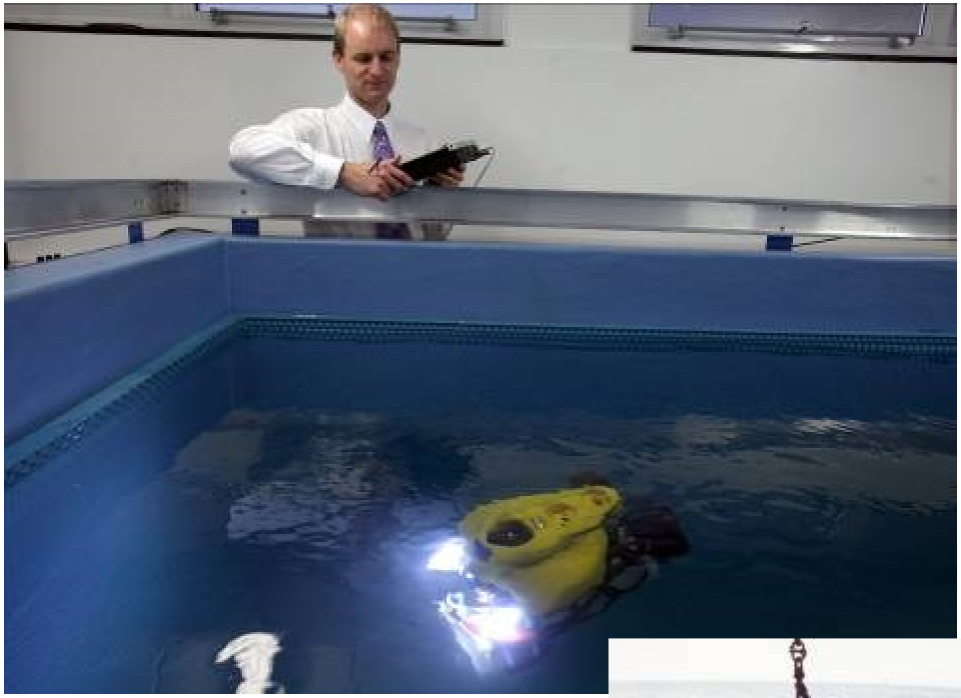


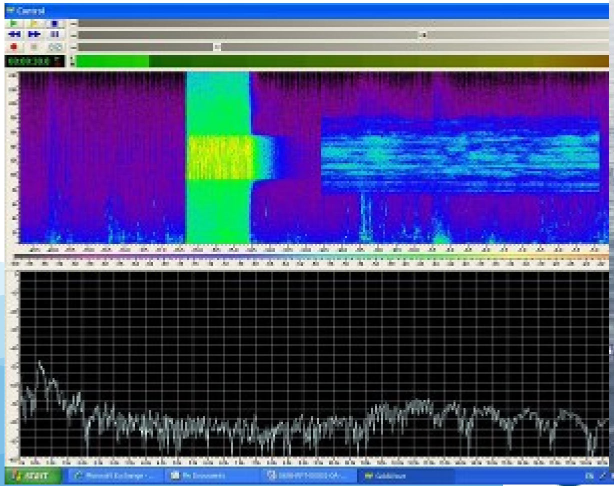


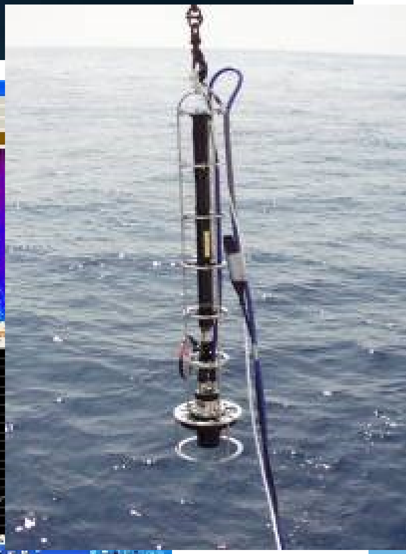
RECENT PROJECTS	
CADDY - Cognitive Autonomous Diving Buddy	FP7-ICT
NEWTON – Novel sensing network for intelligent monitoring	UK - EPSRC
USMART – Underwater smart dust for distributed sensing	EPSRC
Development of affordable ultrasound imaging	CORDAID

Facilities - SEAlab

- Anechoic test tank.
- 3 ROVs
- Acoustic transducers & instrumentation.
- Access to research vessel.



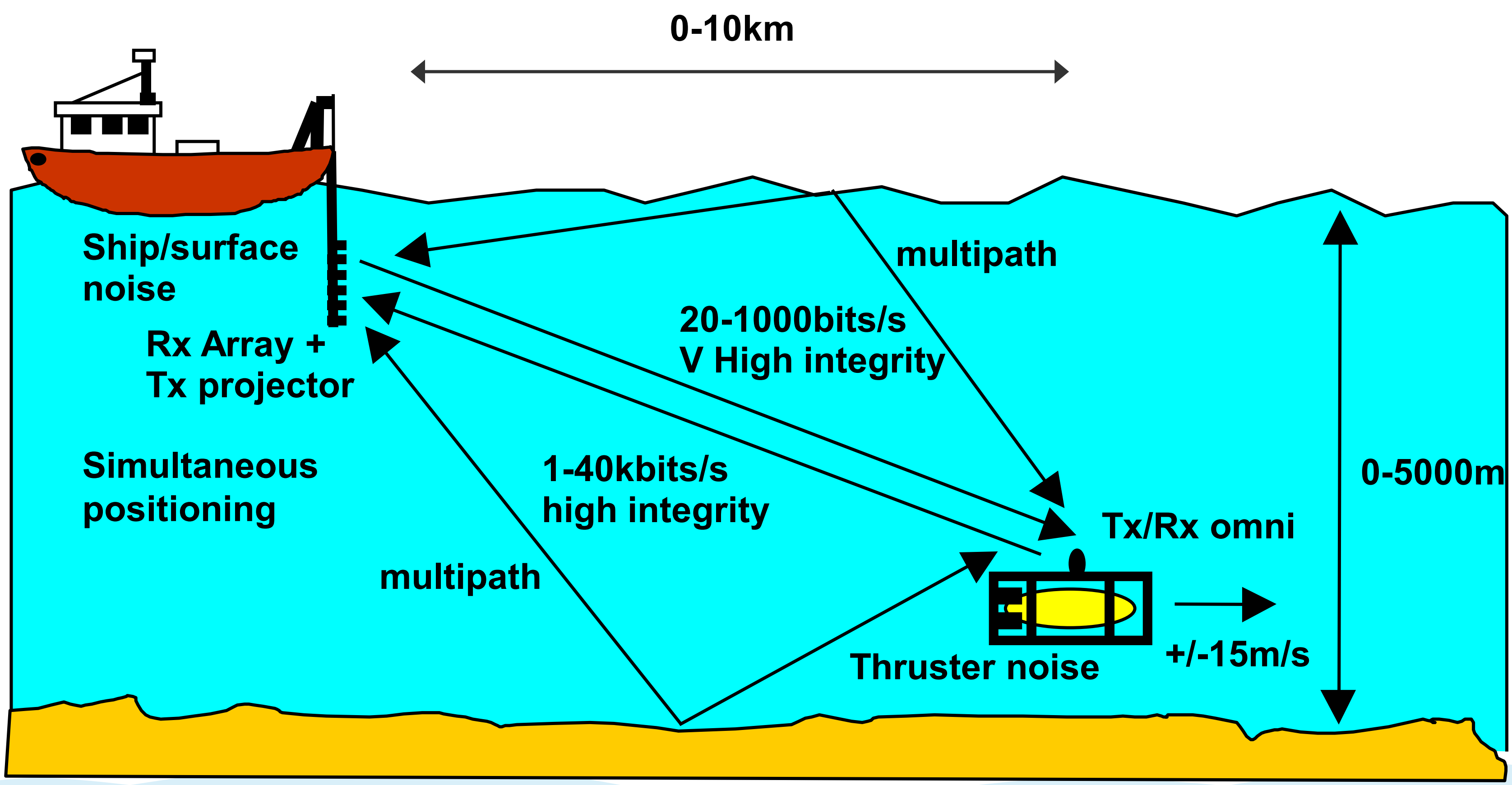




Underwater acoustic communication


- Pioneers in:
  - spatial and frequency diversity
  - adaptive receiver structures
  - advanced Doppler correction techniques
- Licencing technologies to industrial partners e.g. Tritech, Blueprint Subsea, Nautronix.

So what have we achieved?



Van Walree PA, Neasham JA, Schrijver MC. Coherent acoustic communication in a tidal estuary with busy shipping traffic. *Journal of the Acoustical Society of America* 2007, **122**(6), 3495-3506.

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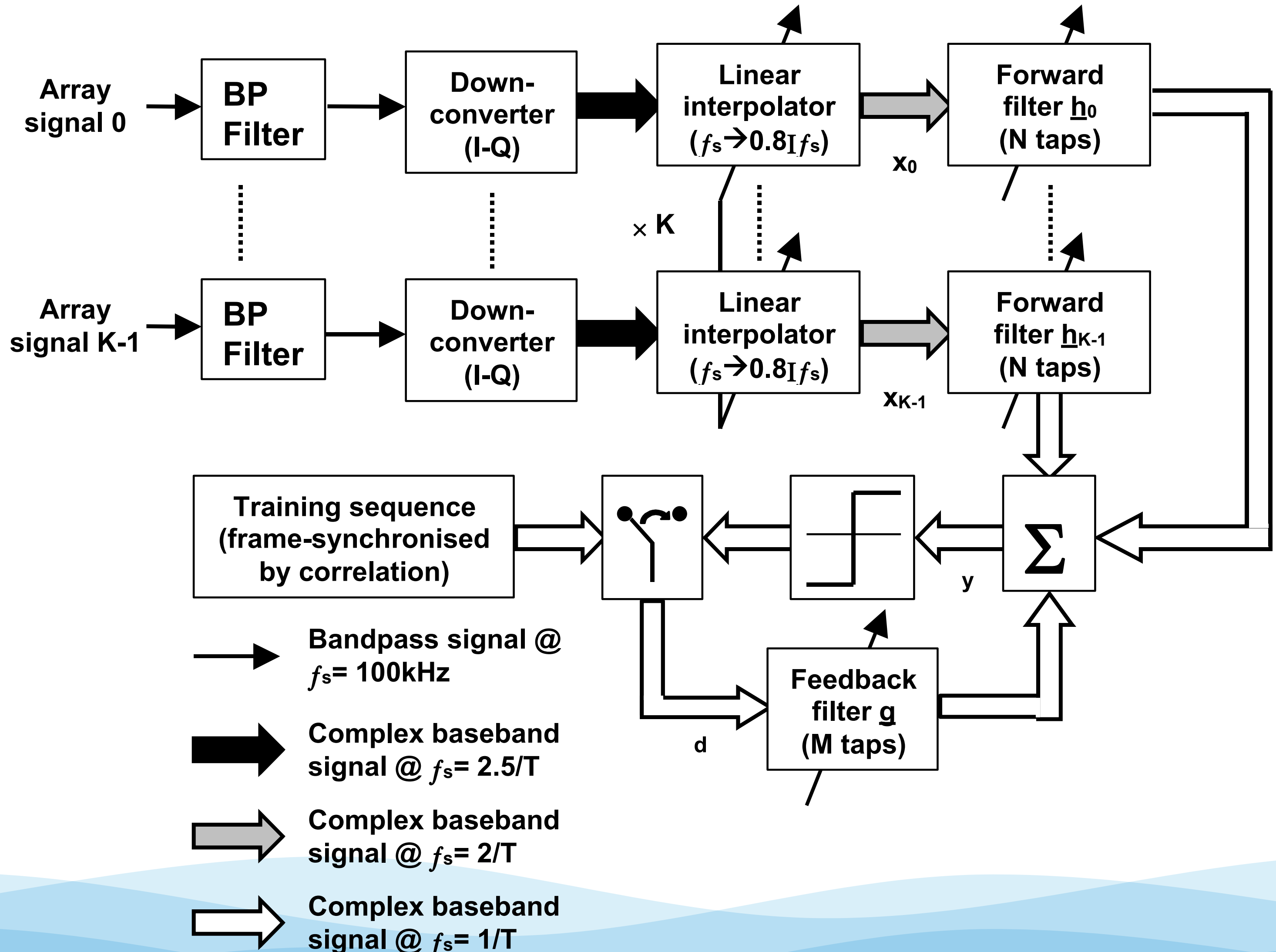
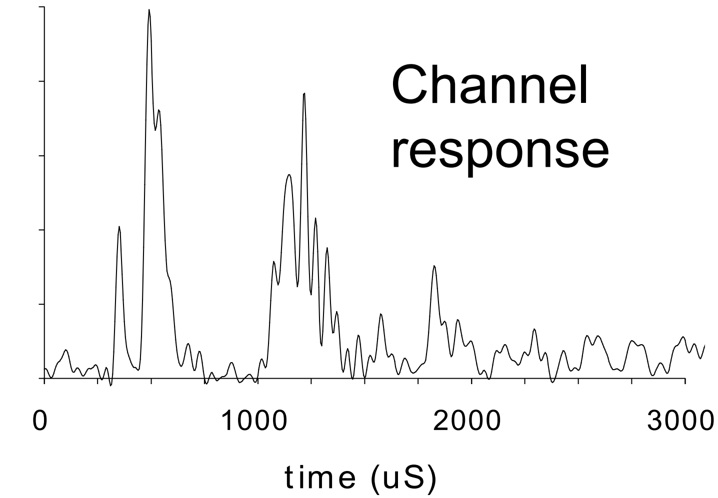
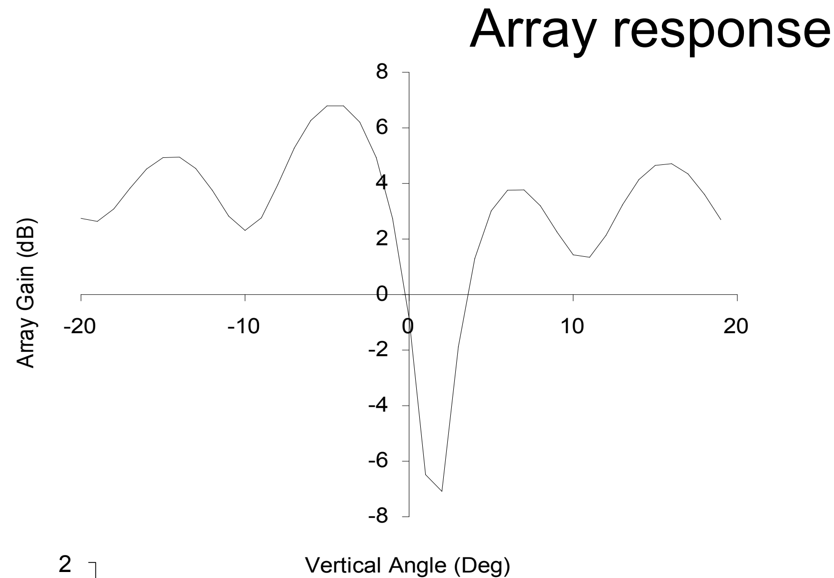
Adaptive multichannel receivers

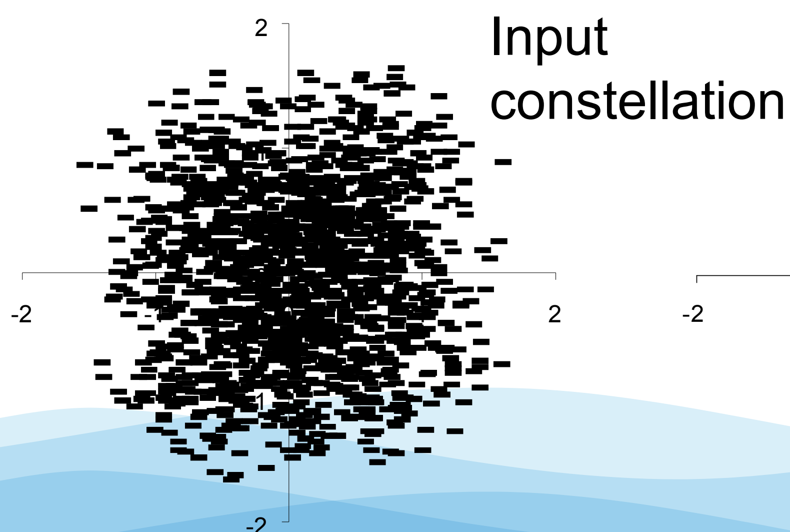


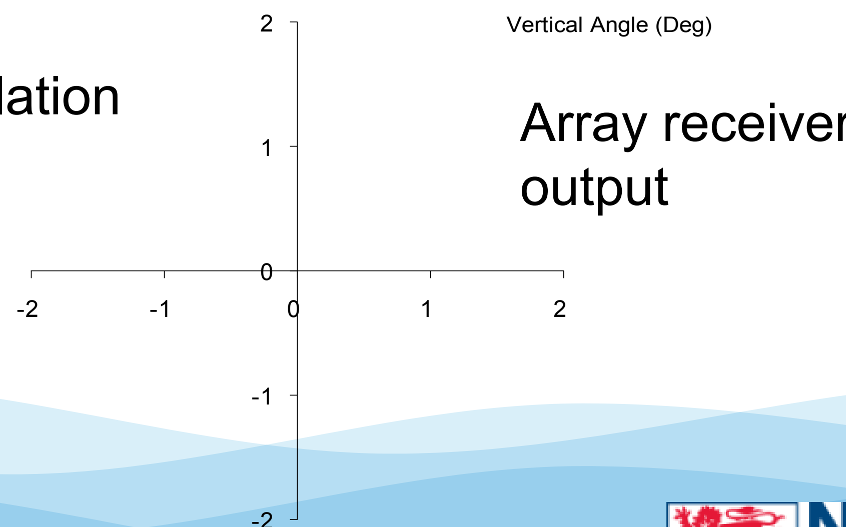
Shah CP, Tsimenidis CC, Sharif BS, Neasham JA. Low Complexity Iterative Receiver Structure for Time Varying Frequency Selective Shallow Underwater Acoustic Channels using BICM-ID: Design and Experimental Results. *IEEE Journal of Oceanic Engineering* 2011, **36**(3), 406-421.

Adaptive multichannel receivers

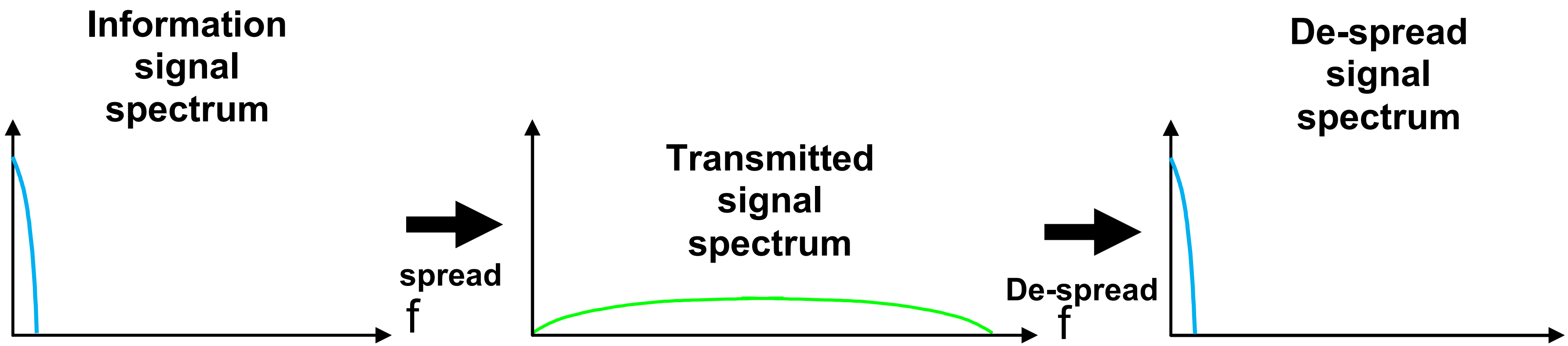




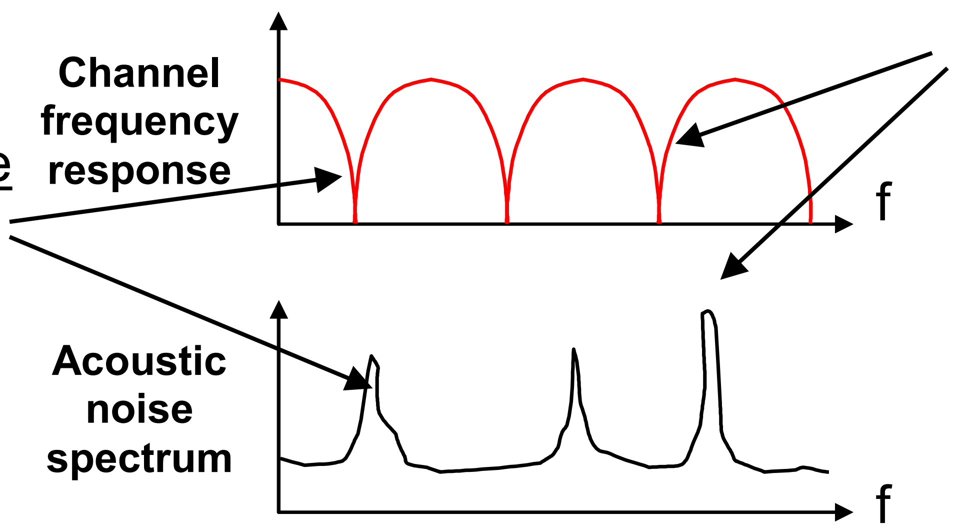




Spread spectrum transmission



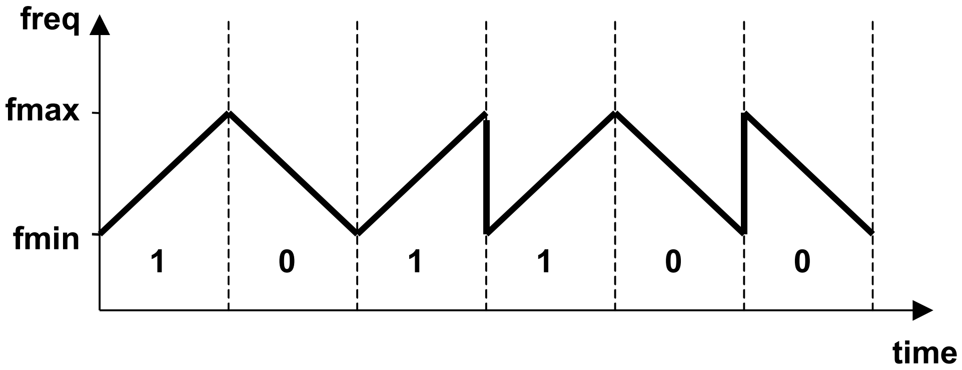
Spreading averages noise and channel effects over wide spectrum



If we transmit a narrow band signal at these frequencies performance will be very poor

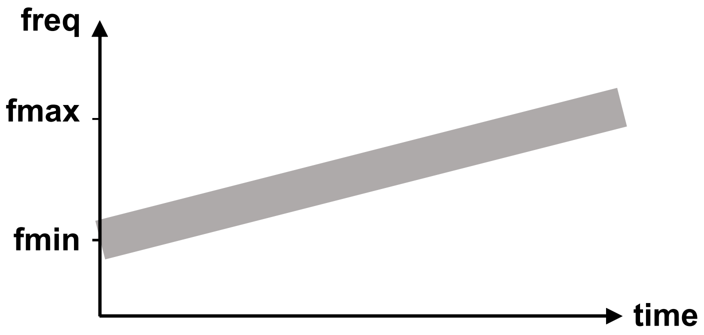
Linear FM (chirp) techniques

Binary orthogonal chirp (BOK)



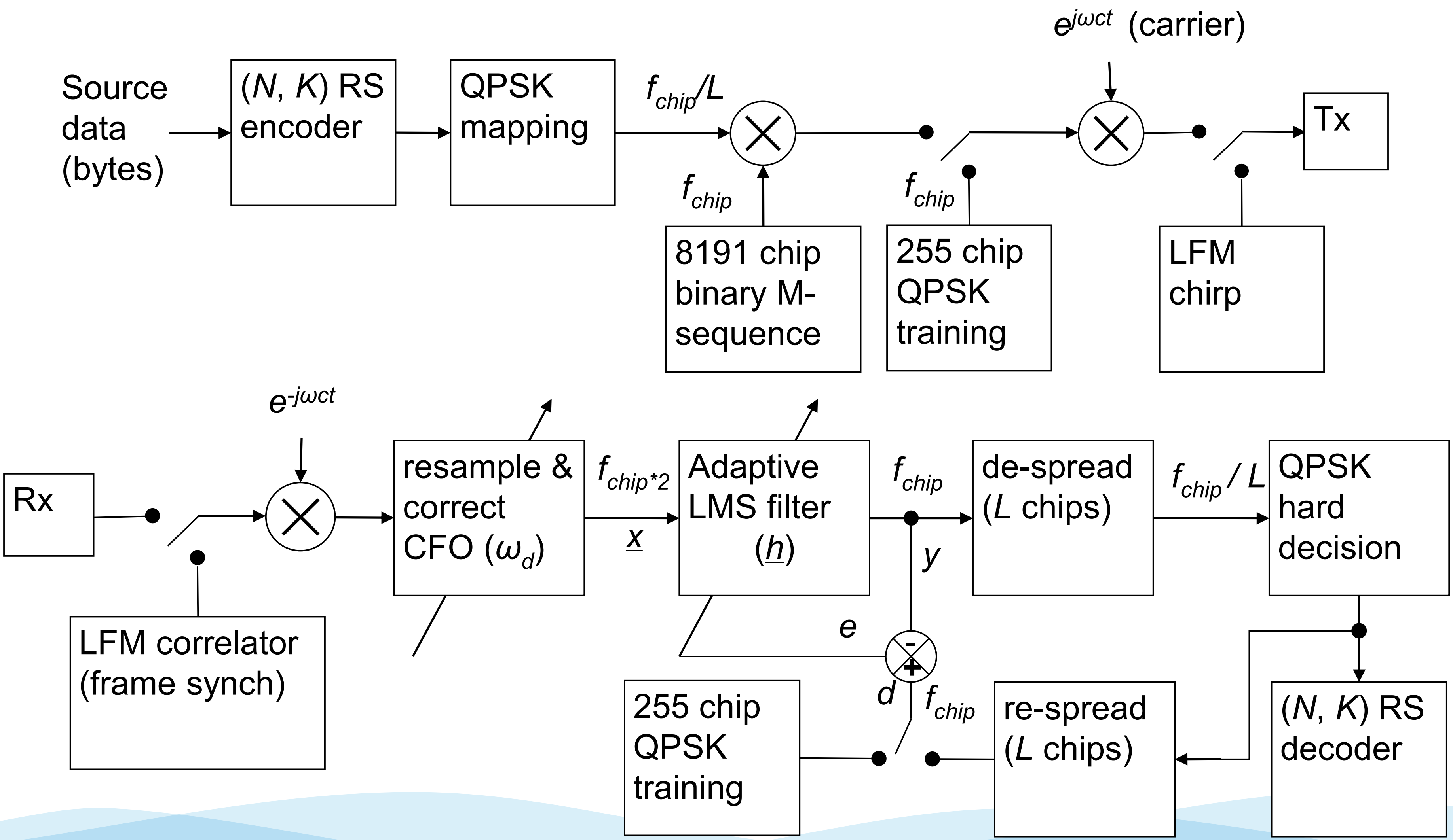
- Simple matched filter receiver.
- Highly multipath & Doppler tolerant.
- Poor bandwidth utilisation (<100bps for B = 8kHz)

Sweep spread carrier

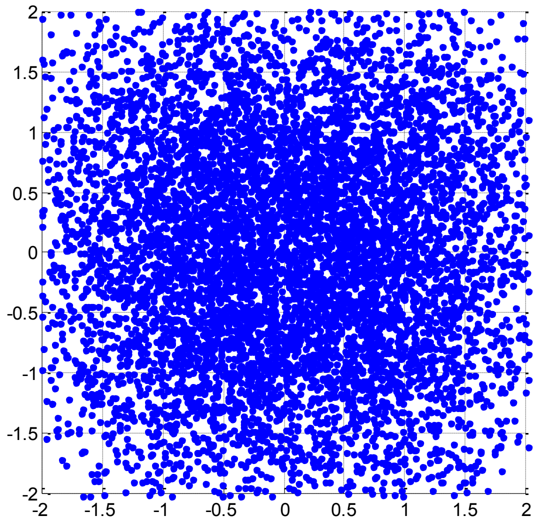


- Swept carrier with PSK / FSK modulation.
- Good multipath tolerance.
- Bandwidth utilisation still low.

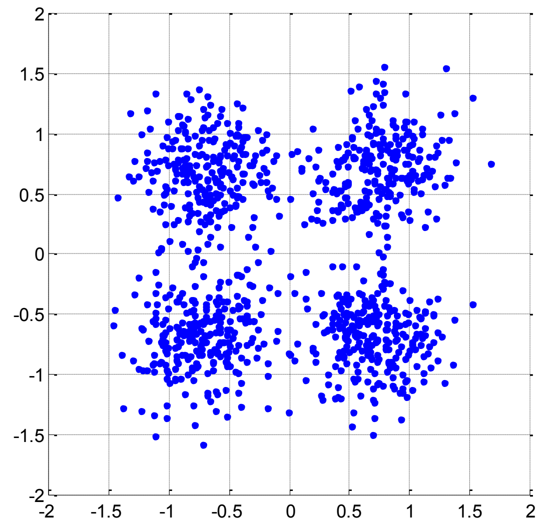
Aperiodic direct sequence spreading



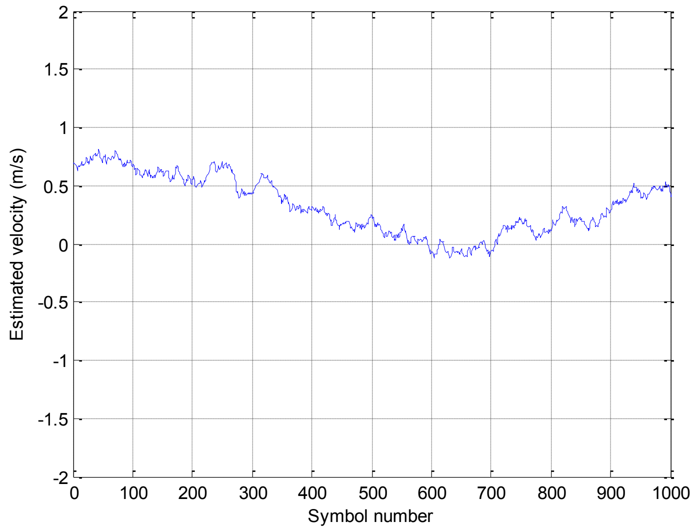
Aperiodic DSSS results (L = 8, 1.5 kbps)



Constellation before de-spreading



Constellation after de-spreading



Estimated velocity from Doppler correction

- Reduction of inter-symbol interference is independent of channel timespread (in this case >100ms).
- Residual symbol errors are corrected by channel code.

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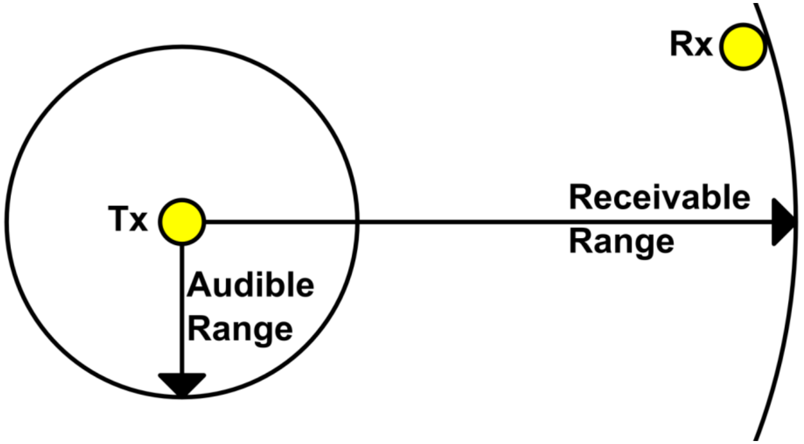
Lower probability of detection communication systems (eco-friendly?)

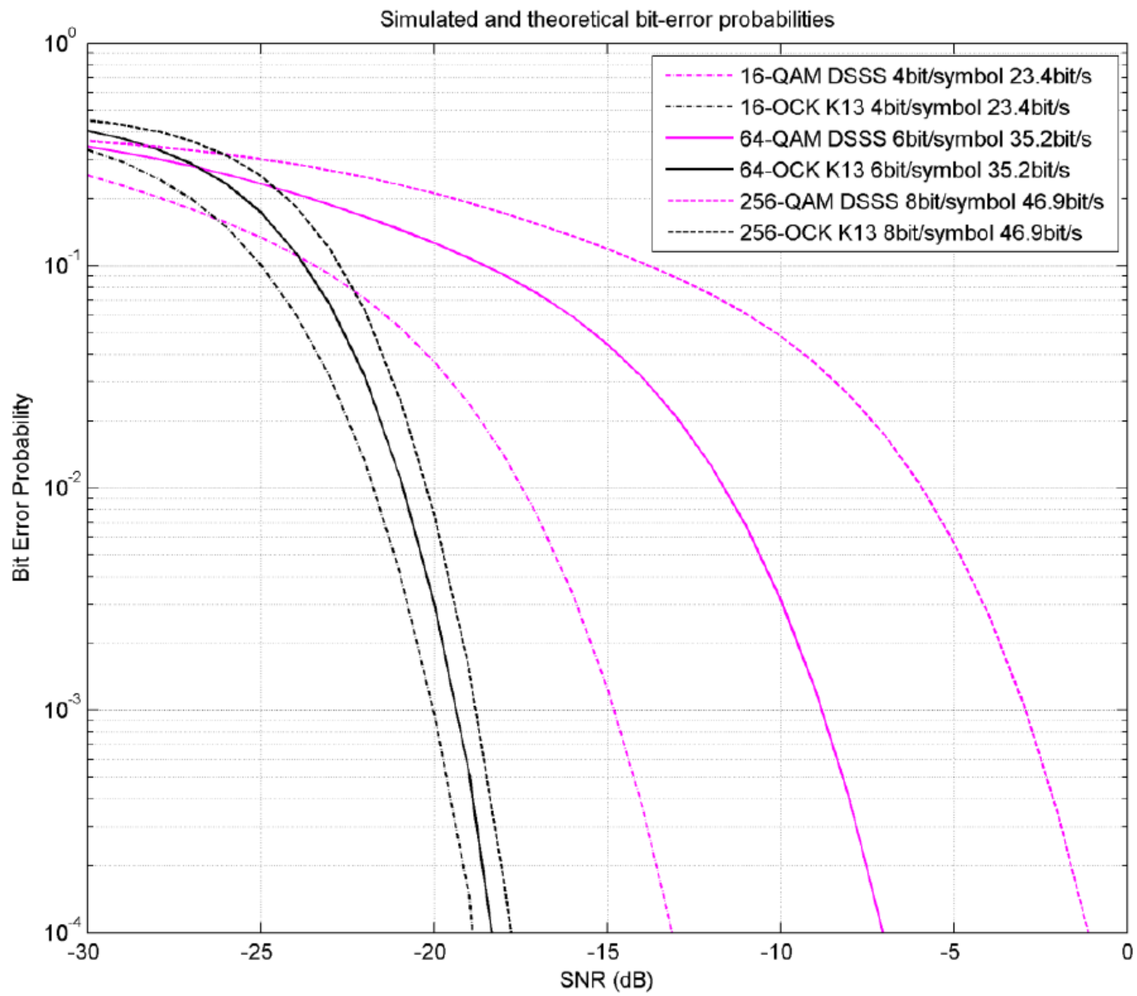
- Using the spread spectrum concept with very high BT product (>1000).
- Received signal-noise ratio as low as -20dB (noise power = 100x signal power).
- Pseudo-noise signals more difficult to discriminate from background noise.



Audible range << receivable range.

M-ary orthogonal code keying

- Data symbols consist of a family of near orthogonal PN codes.
- Vastly outperforms QAM-DSSS for large BT products.
- Receiver complexity high – but simplifications are possible.



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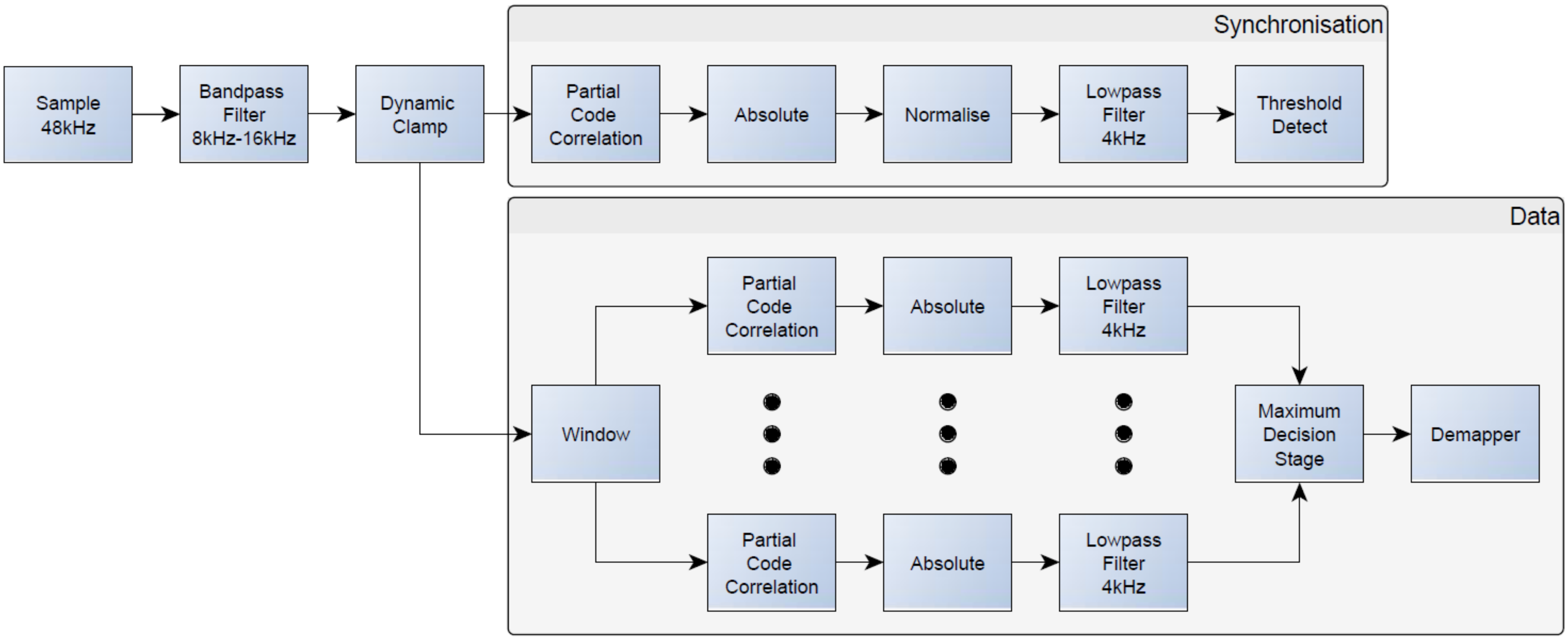
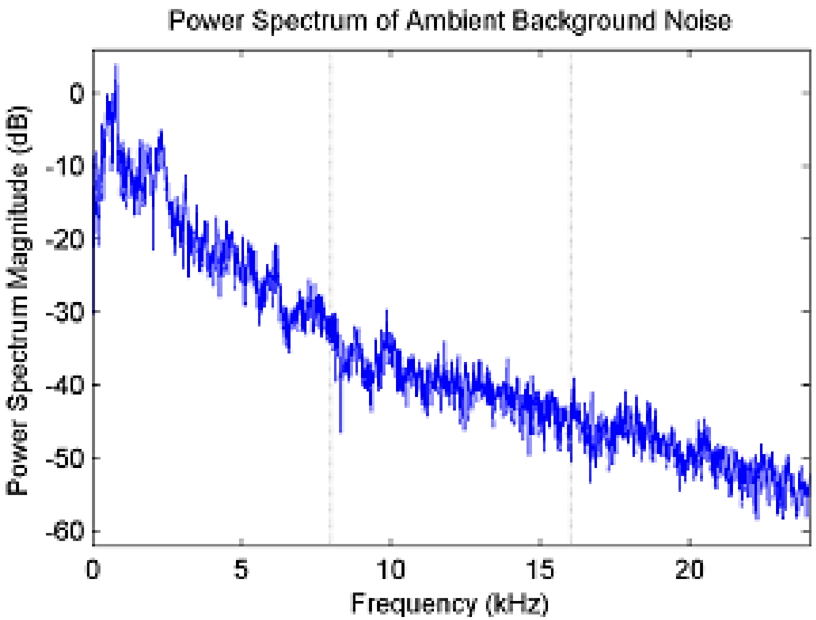
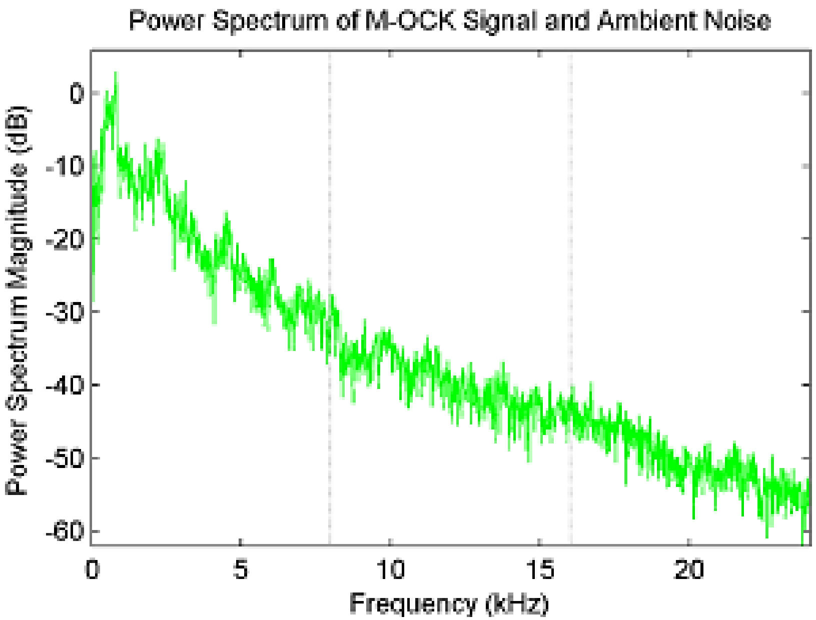
M-OCK receiver structure



Received spectrum during 100bps transmission at 10km (SL < 170dB)





Extremely hard to detect by ear.
Extremely hard to detect signal analysis without entire code family.
Minimises interference with other acoustic systems.

Sherlock B, Tsimenidis CC, Neasham JA. Signal and Receiver Design for Low-Power Acoustic Communications Using M-ary Orthogonal Code Keying. IEEE *OCEANS 2015 - Genova*. 2015.

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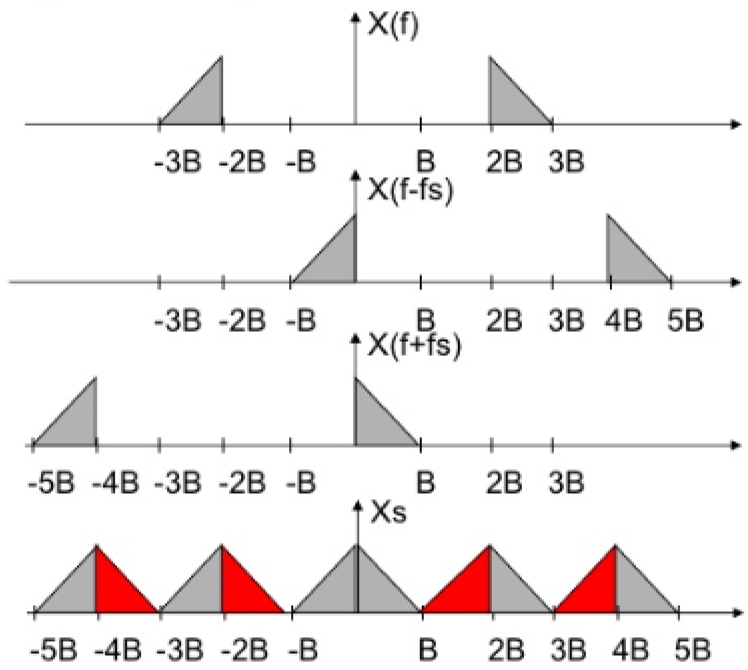
Efficient implementation of spread spectrum receivers

- "Sparse" signal processing is used to reduce computational load of correlation receiver.
- Bandpass sampling - reduces sampling rate.
- Simplified arithmetic – 1xN bit and 1x1 bit convolution eliminate multipliers.
- Overall much lower processor power and cost.



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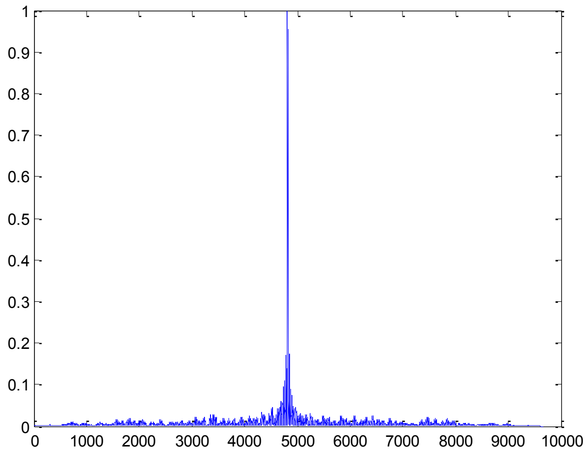
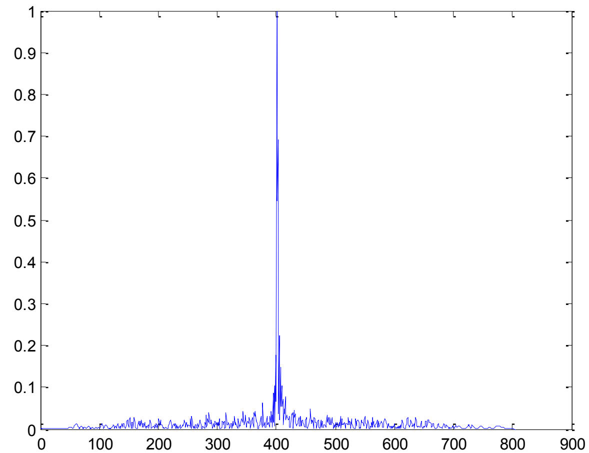
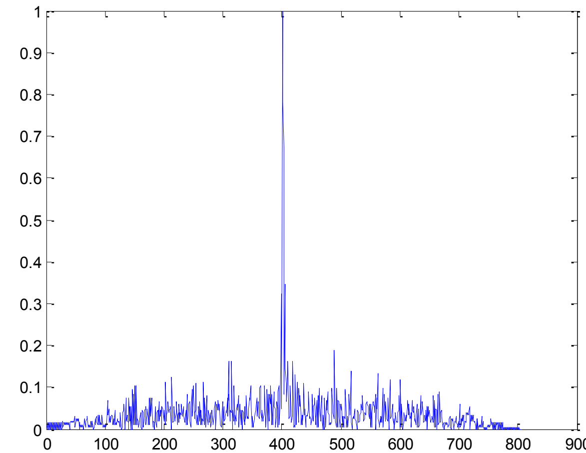
What is the performance penalty?



f_s = 96kHz, 16-bit, 16 x16 MAC



f_s = 8kHz, 16-bit, 1 x16 MAC



f_s = 8kHz, 1-bit, binary MAC

- 1 x 16 bit correlator has almost no penalty in PN code detection.
- Binary (1x1) correlator only starts to degrade severely as SNR approaches 0 dB (due to hard-limiting effect).

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Seatrac miniature hardware platform

- Miniature transponder with integrated USBL array (160mm x 50mm)
- Simultaneous positioning and data exchange.
- Spread spectrum data rates from 100 – 1500 bits/s (chirp and DSSS).
- Reliable operation to 2km range in hostile multipath channels.

Licensed to Blueprint Subsea:
http://www.blueprintsubsea.com/

Neasham JA, Goodfellow G, Sharphouse R. Development of the "Seatrac" miniature acoustic modem and USBL positioning units for subsea robotics and diver applications, IEEE *OCEANS 2015 - Genova*. 2015.

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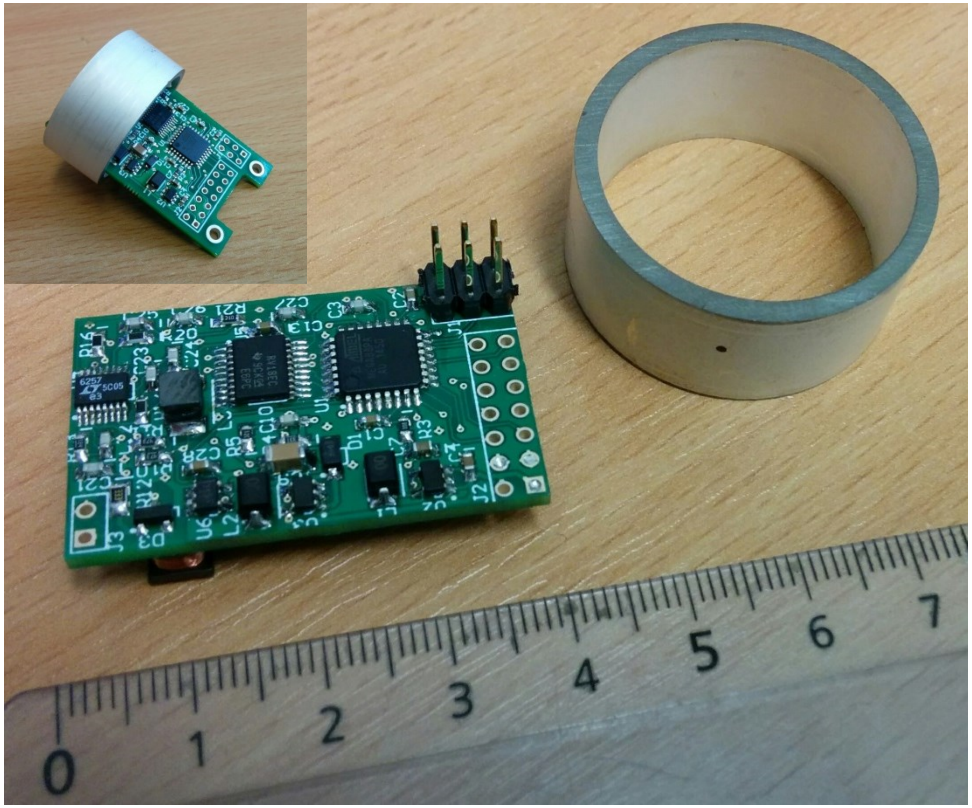
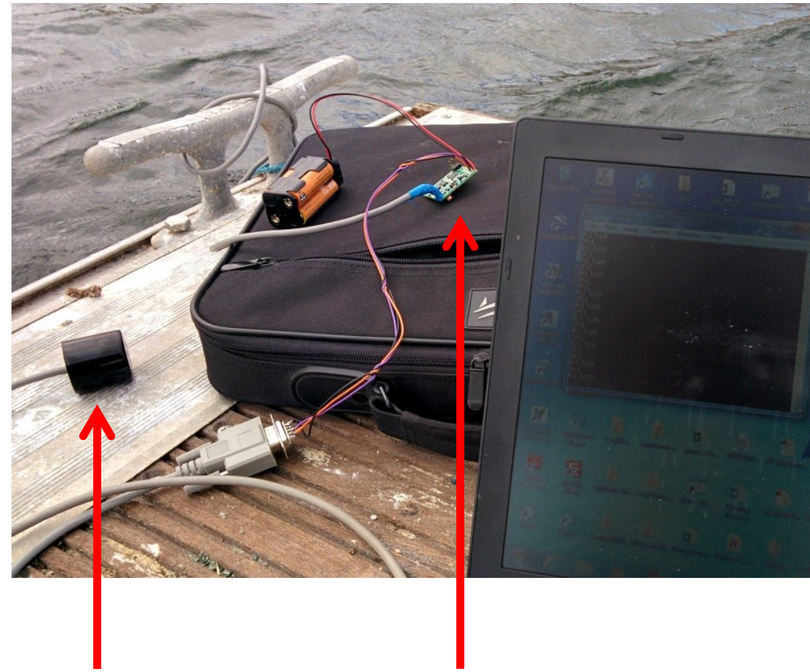
Ultra low cost/power – “Nanomodems”





Transducer and electronics can be separated by cable or encapsulated together (inset)

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Nanomodem specification

Supply voltage	3 – 6.5V dc
Supply current (5V supply)	Receiving: < 2mA Transmitting: ~ 300mA
Acoustic signals	24-28kHz, SPL = 168 dB
Acoustic data rate	40–160 bps BOK, unicast and broadcast messages.
Addressing	up to 255 nodes (programmable)
Ranging (ping command)	9.375 cm (c=1500m/s) increment, ~20 cm variance
Maximum Range	2 km
RS232 interface	9600 Baud, 8-bit, no parity, 1 stop bit, no flow control
Manufacturing cost	<£40 for assembled PCB and transducer

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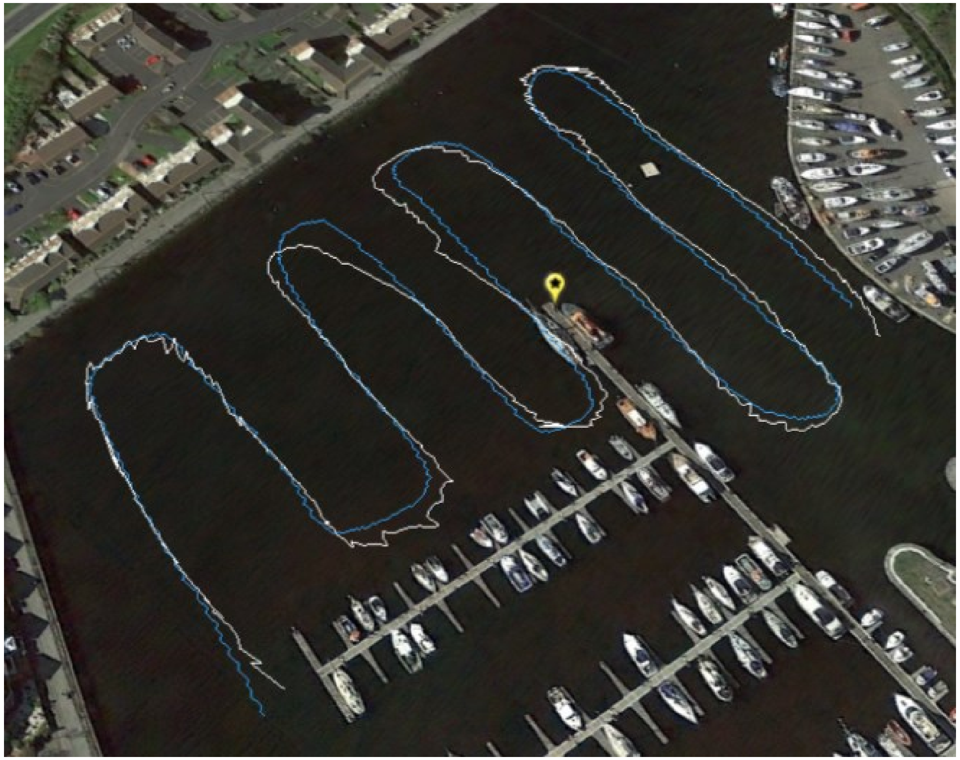
USBL positioning (Seatrac platform)

- Tiny in-built USBL array (20mm spacing).
- Repeatability of bearing < 1 deg, absolute accuracy < 5 deg.
- Ranging within 20cm given accurate VOS.



White = USBL fix, blue = GPS, USBL fixed at yellow marker

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LBL positioning with Nanomodems

- Multiple nanomodems in known reference locations.
- Position calculated by long baseline method (white) and compared to GPS (red).

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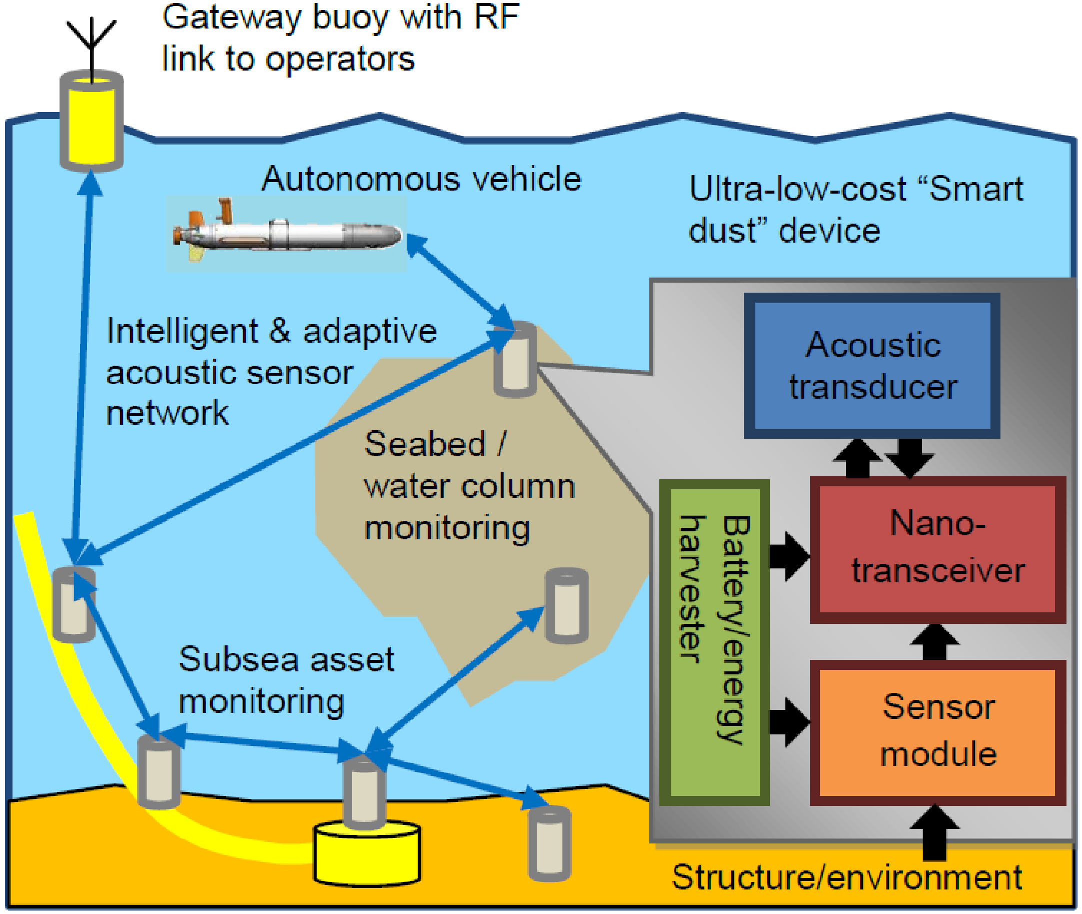
EPSRC USMART (£1.3M, 06/17 – 05/20)

- Step change in efficiency/cost of subsea data gathering.
- Enhanced Nanomodems up to 500bps using MOK/DSSS.
- Smart distributed sensing algorithms + efficient network protocols



Thank you for listening

Any questions?

Email: jeff.neasham@ncl.ac.uk

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