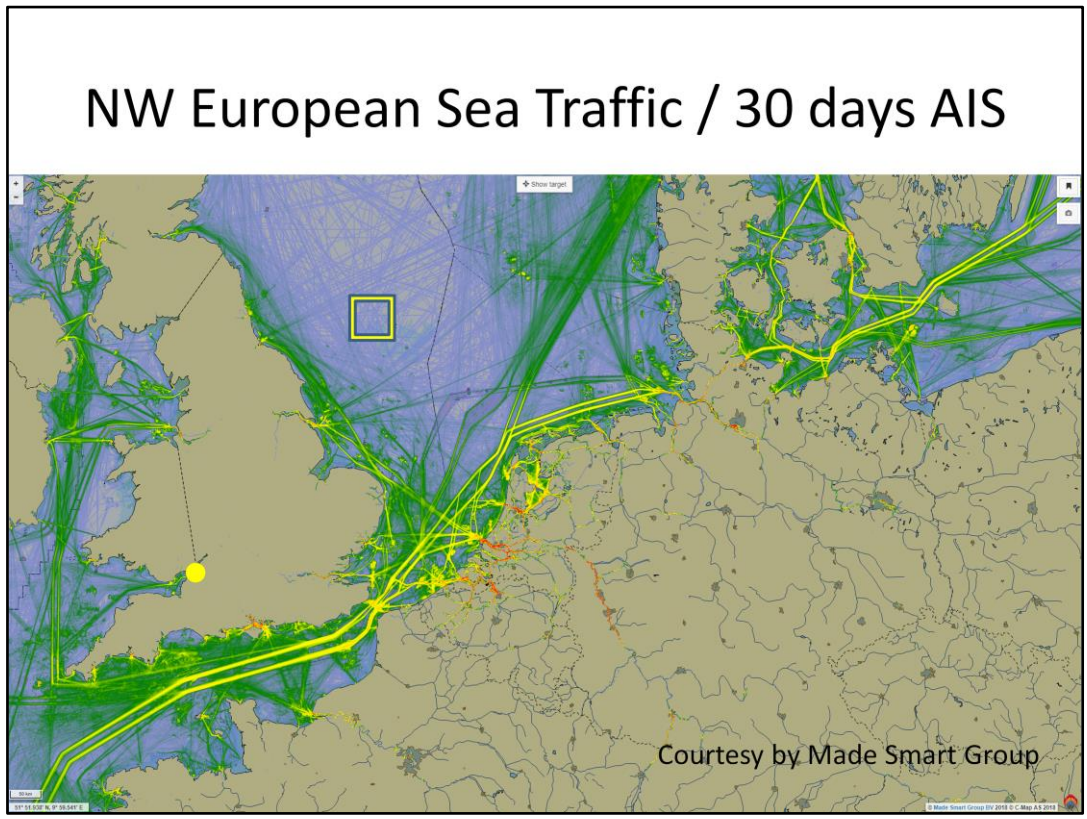
A PNT Epiphany

Durk van Willigen

INC 2018

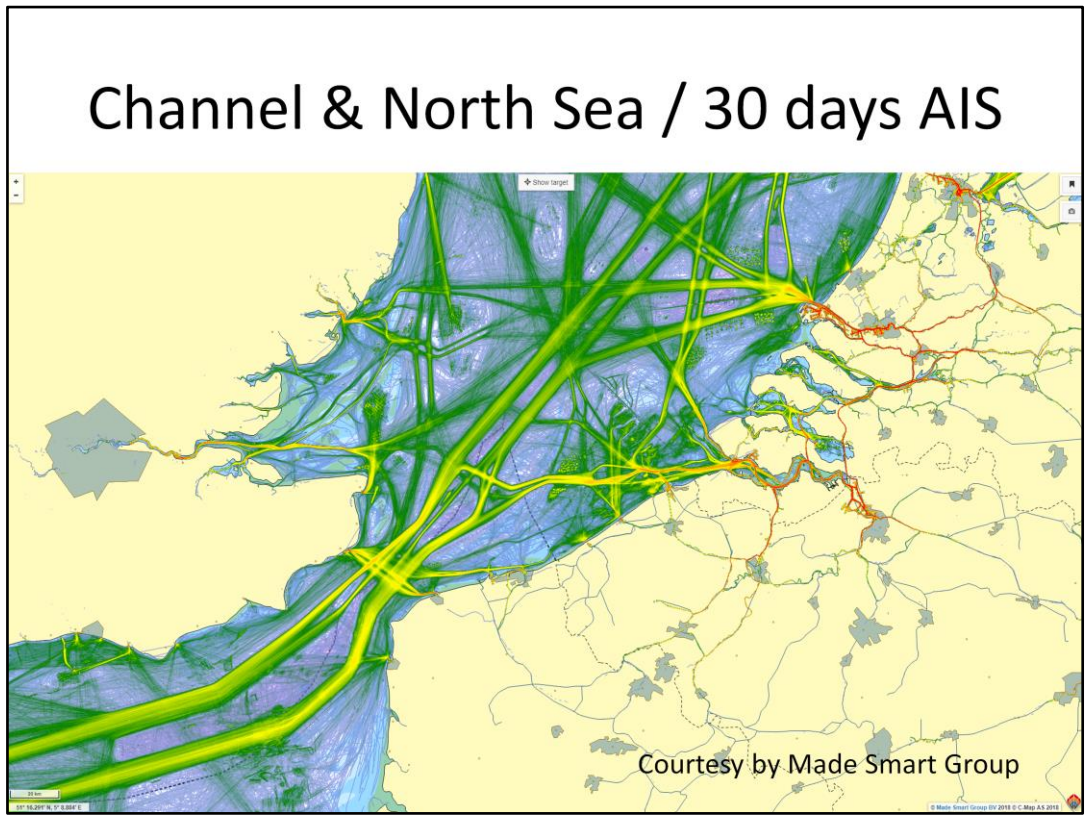
UK, Bristol, 12 November 2018

Good afternoon ladies & gentlemen!



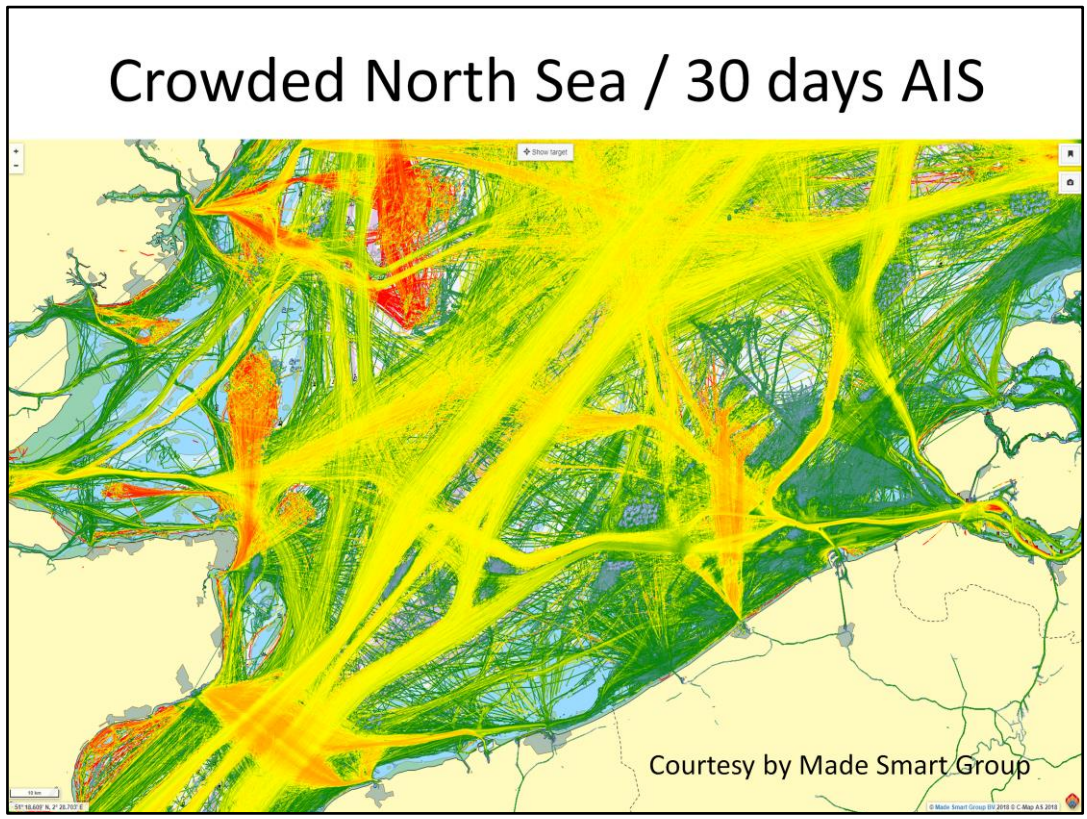
Shipping routes in North-west Europe

AIS = Automatic Identification System



UK and Netherlands are seagoing nations since many centuries. So, the sea is our friend, our enemy, our income and a past battle field! Dutch Navy has lots of experience when we visited the Thames some centuries ago! Ask the British…

Now we are friends, most likely even after March 2019!



Heavy traffic at our highways at sea.

Here VTM is not just for fun; it is an absolute MUST!

GNSS has BFW and Two Enemies?

- **Billion Friends Worldwide**
- **Two potential killing enemies somewhere and sometimes**
  1. **Jamming**
     - Less accurate GNSS performance up to complete destruction of its signals
  2. **Spoofing**
     - Attacking local target up to large area confusing
     - Called Fake Navigation?

These two enemies are most difficult to mitigate. If possible, not suited for mass productions. Ideal weapon for terrorists!

Fake Navigation = modern terms ;-)

A real problem?

- No, because jamming is **forbidden by law!**
- No, because jamming is **very difficult** to do
- No, because jamming is **not fair**
- No, because high-tech receivers will kill both annoying enemies by **mitigation**
- No, because …..
- **But** …..

NOT FAIR, understandable for British only!

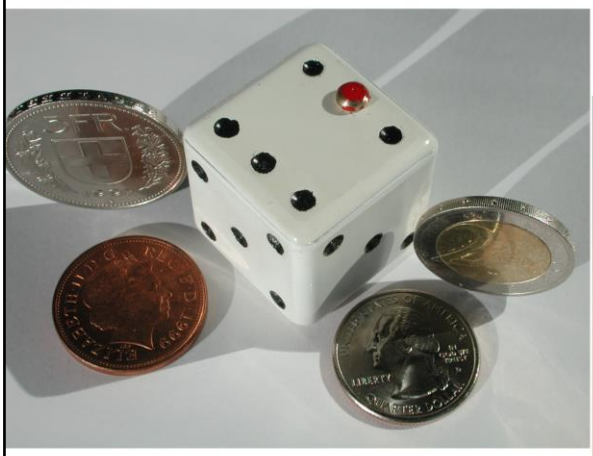
Jamming means here Jamming and Spoofing

Mitigation jamming possible?

- **Smart receivers => battle field in signal domain**
  - High-power jamming prevents GNSS signal processing due to overloading
    - No signals => nothing to process => no PNT
  - Gaussian noise jamming
    - Prevents 'estimate & subtract' techniques
    - Noise cannot be estimated => no subtraction => GNSS signal loss
- **Smart antennas => battle field in spatial domain**
  - Phased-array antennas
    - Beam forming towards SV to increase SNR
      - Where are the signals? Where are north and the vertical?
    - Nulling to reduce jamming signal
      - What to do with 100 jammer directions?

We should learn to think in BATTLE FIELDS and DOMAINS.

Dangerous Dice (2000)



Range 100 metres
Battery for 5 hours

25 x 25 x 25 mm patch
with ground flaps

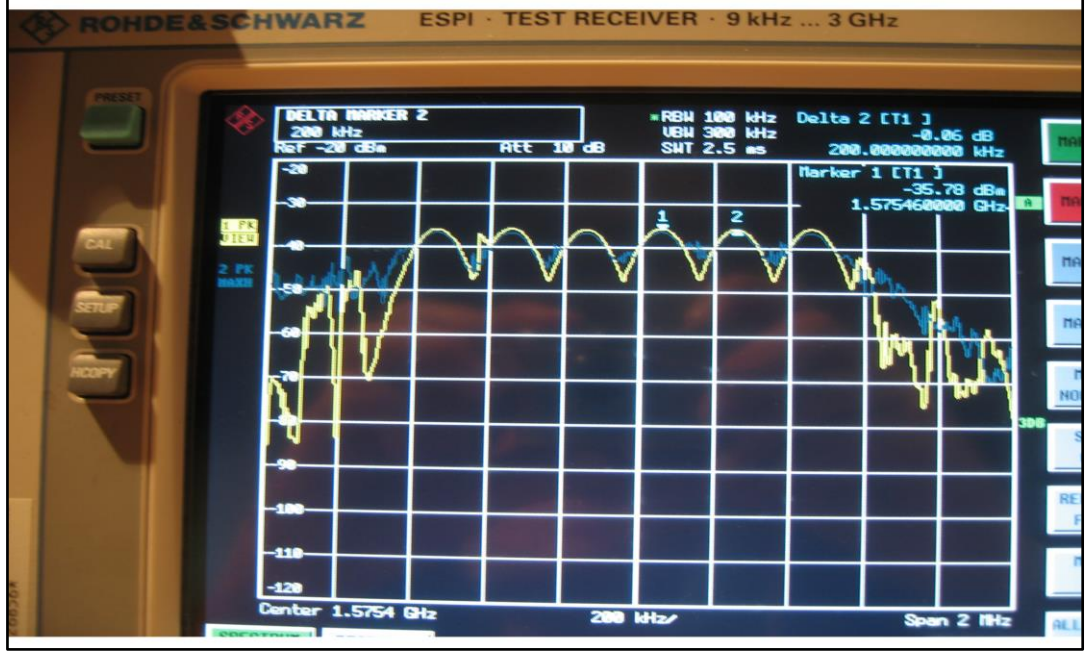
Dice L1 jammer 18-20 years old design

Still not for sale!

Tested by Dutch Police Forces who confirmed 100 metre range

Used at sea for eDLoran tests at Rotterdam Harbour resulted in many red lights and horrible alarm sounds (2013)

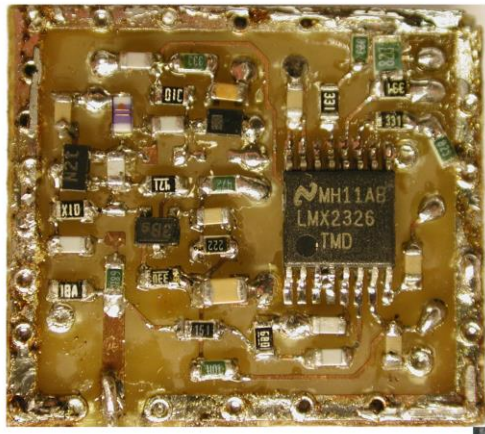
Six-channel Frequency Hopper



Very simple jammer signal structure!

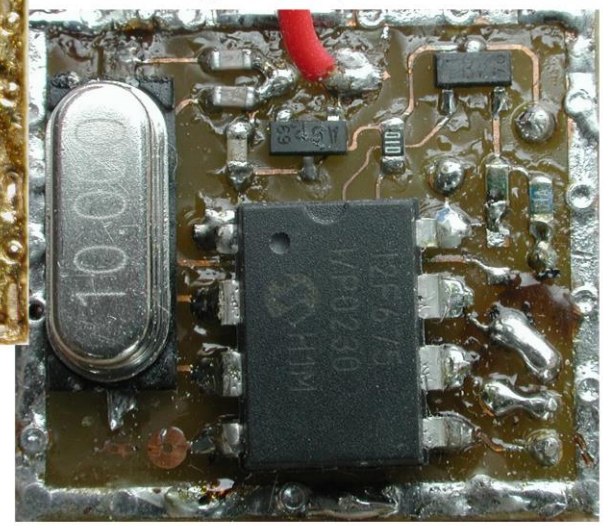
Tested by the Dutch Telecom Authorities.

< 1 mW @ January 2000 !



Analog PCB / 25 x 25 mm

Digital PCB / 25 x 25 mm



Designed and made at Dutch Governmental Lab in 1999.

No series production !

Today, two decades later , software defined radios, open new solutions to design more capable jammers.

Which philosophy could be used?

Just think about a possible example

- GNSS Receivers cannot mitigate strong white noise jamming signals, so:
  - SDR generates Gaussian noise jamming signal
  - Use power amplifier up to the wanted 'killing' range
  - DDoS / Use very many jammers which are silent until?
  - Make jammers remote controlled to allow orchestration
  - Train the orchestra conductors
  - Drones may install jammers at physically safe locations where they are not visible
  - That's all you need to disrupt GNSS!
- **Don't ever dare to implement this**

Gaussian noise not possible to predict like man-made well-defined signals

Package weight mainly depends on battery weight which in turn depends on RF power output and operation time

Miniature power amplifiers have 30+ % efficiency of RF power out/DC power

Use drones with cameras during poor visibility to avoid detection by bad luck. Take your time building up this orchestra.

Software Defined Radios Impact?

- SDR comprises receivers **and** transmitters
- Makes jamming/spoofing **and** mitigation intelligent
- Who will win?
- Think unconventional in multiple domains
  - Signal
  - Physical
  - Psychological
  - Economical
  - Strategical

Jammer/spoofer vs GNSS provider is war game.

Military are more advanced than civil systems, at least I think.

Jammer orchestration is like football

- Confuse and attack the 'mitigators'
  - When / where / range / damage effect / etc….
- If jammer detected it must be found and silenced, but how?
  - Increase time to find
  - Increase time to silence
  - How to silence?
    - Police, military, …

It should be a surprise party.

If detected, then how to silence it? By man, explosives, guns, drones, missiles, etc.

Remote control signals appear randomly to the outsider who doesn't know the remote-control channel and signals configuration.

Economic domain

- Smart receivers/antennas expensive and large
  - Not usable for civil ships, cars and portables
- Ship owners want low-cost GNSS equipment
  - Simple receivers and antennas are not very smart!
  - Average GNSS receiver is very PNT vulnerable
- 'Terrorists' have an exciting business case!
  - Enormous return on investment (1000:1?)
- Keep other three domains proprietary
  (Physically, Psychologically and Strategically)

Initialisation is most difficult part for mitigation. Receiver doesn't know the type of signal and where it comes from and how many there are.

Phased-array antennas need references for elevation and direction to steer the antenna beam and/or nulls.

GPS receivers on-board of sea-going ships are often quite simple and are low cost. So, no phased-array antennas.

Return on Investment larger than 1000-to-1?

But it are real terrorist!

Conclusion?

- Multiple low-cost jammer attack may shut down GNSS in large areas
- Enormous financial impact (London Economics)
- General user seems hypnotized by this threat and accepts it like storm, war, flooding and influenza?
- Nearly all GNSS users just ignore the risks, so do governments and regulators (David Last)!
- Really scaring isn't it?
- **HELP! We need a backup …**

Where are the Backups?

- World talks for decades about backups like
  - Another GNSS
  - Inertial navigation and map matching
  - Atomic clocks
  - Radar
  - Celestial
- **NO real backup GNSS exists for all applications**
- Exceptions:

  Aviation - INS/DME/VOR/Compass/Baro/Radar & ATC
  Cars - Gyros/wheels/map-matching/eLoran

You know why?

- Professional GNSS community accepts the fact of vulnerability
  - Has no solutions for mass GNSS applications
- Policy-makers and governments don't believe it
  - They just ignore it and come up with another GNSS
  - **'To defend one's own high-cost GNSS program resulted in denial of its vulnerability'**, David Last, Coordinates July 2018

Let us be smart and use our Common Sense!

UK - Brexit

- UK faces
  - Galileo PRS denial
  - UK-wide losses due to GNSS denial may rise to £ 5.2B/5 days
- UK discusses UK-owned GNSS
  - Costs multi billions
  - At least one decade to realise
- UK talks about UK-owned eLoran
  - Costs less than £ 100M (equal to one F35)
  - Can be built within 2 years
  - eLoran is not a luxurious cruise ship but still is a very robust PNT lifeboat at a fraction of GNSS costs
  - Brings you home in case of …!

Our British friends have not just an interference mitigation problem, they also have to deal with the upcoming divorce from the European Union. As a result of that they may also face some issues with Galileo.

A really dramatic situation for the UK. eLoran switched off in Europe and Galileo maybe not accessible. What to do now?

Make yourself independent from the Europeans and set up your own GNSS and your own eLoran?

Is that realisable? Yes, it is. See Japan with their QZSS as a GNSS. Quite expensive but possible.

The UK has now 1 eLoran station at the border of England and Scotland. It is broadcasting two signals, the Master at 6731M and one secondary 6731X. It works fine and the whole UK has now a fully independent UTC service.

For navigation at least two or more stations are needed to cover the whole of the UK.

I'll come back on that in a minute!

Current status of GNSS and eLoran receivers

System	GNSS	eLoran
Coverage	3D Global	2D Continental ?
Provider costs	~ £ 5B (UK)	< £ 100M (UK)
Receiver costs	€ 10/module (mass volume)	€ 1k/module (small volume)
Accuracy	0.05/10 m (w/o differential)	10/50 m (w/o differential)
Size	0.25 cc (ublox M8)	15 cc (Loradd++ prototype)
Power	70 mW	500 mW
Data Channel	PRS (public regulated service)	LDC (loran data channel)

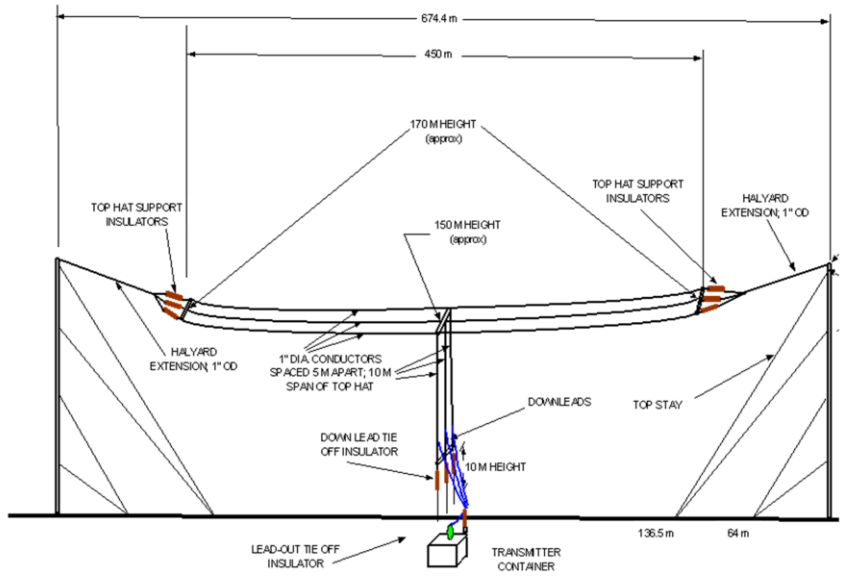
Rough estimates, assumed to install 5 Loran transmitters in the UK.

Using Lessay and Sylt strongly reduces costs and time to build.

Size based on 2010 data

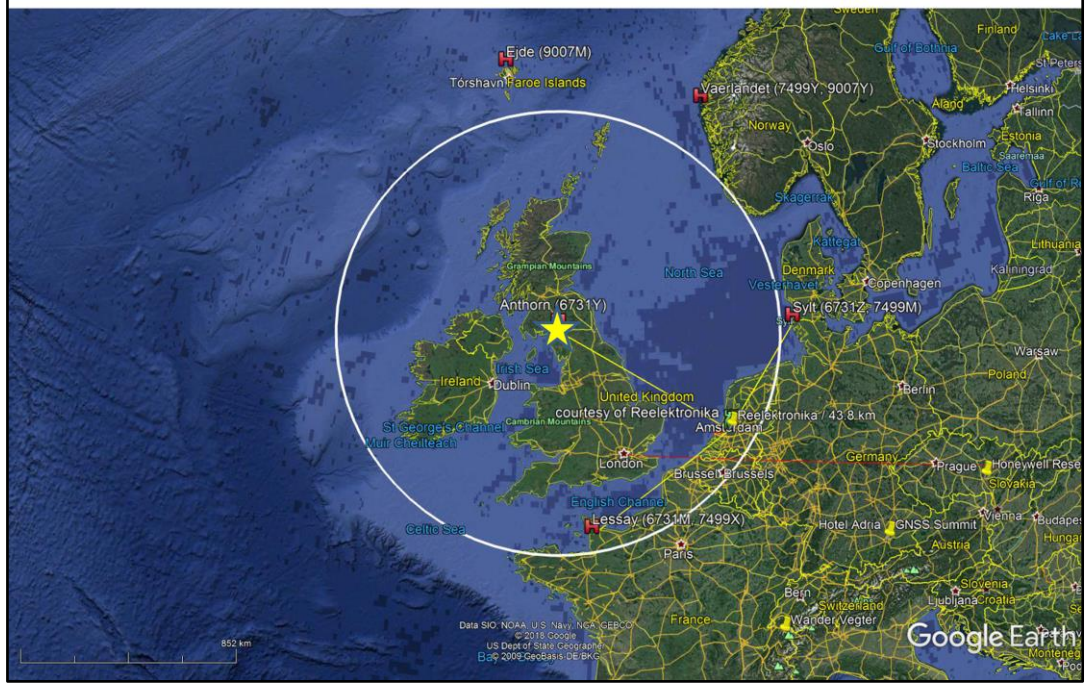
PRS = Public Regulated Service = robust and access-controlled service for government-authorized applications.
Civil institutions will control the access to the encrypted PRS

UK owns Anthorn



2 x 250 kW ERP

Anthorn / 700 km range



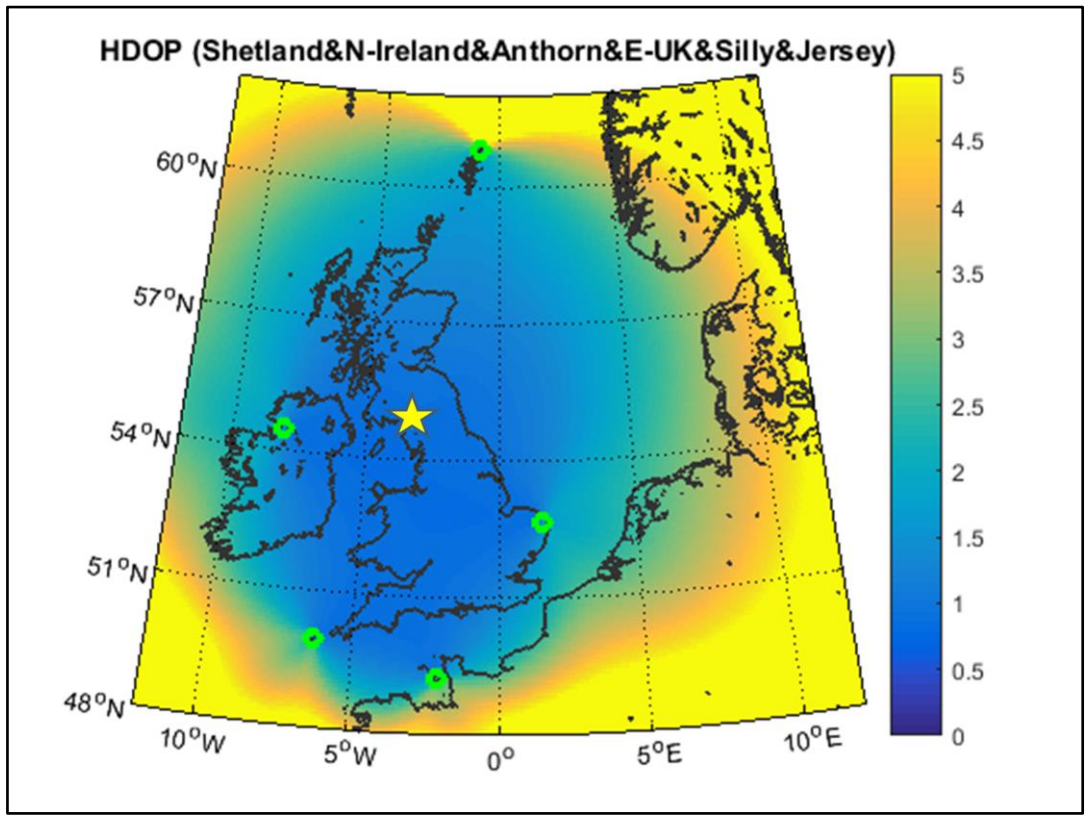
700 Km white circle radius around Anthorn yield good SNR's

Green H's are Loran stations decommissioned at on 1 Jan 2016

Anthorn provides now

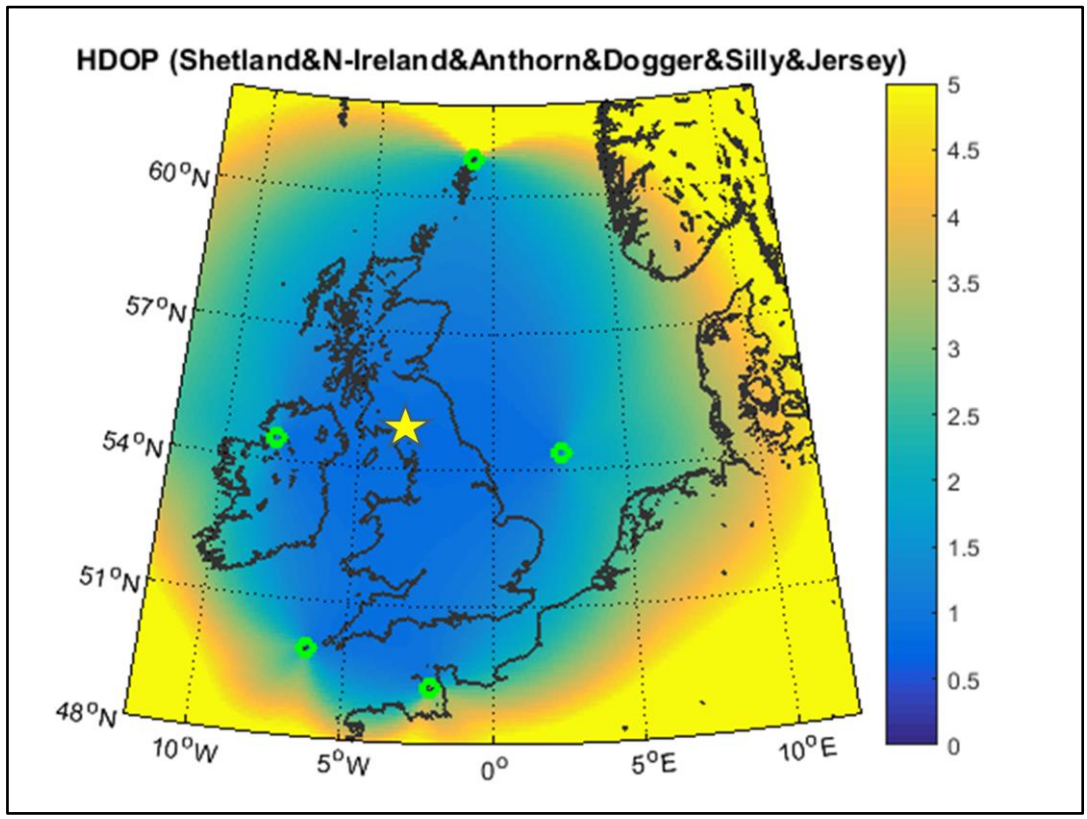
- Two 250 kW eLoran signals
- Two nation-wide eLoran Data Channels
  - UTC via standard Eurofix
  - Encrypted data transmission for UK Government
  - GNSS independent
- Potential Master function for UK eLoran chain
  - Some interesting configurations on next slides

Realise what you have already now. And see what you could achieve in a short time…..

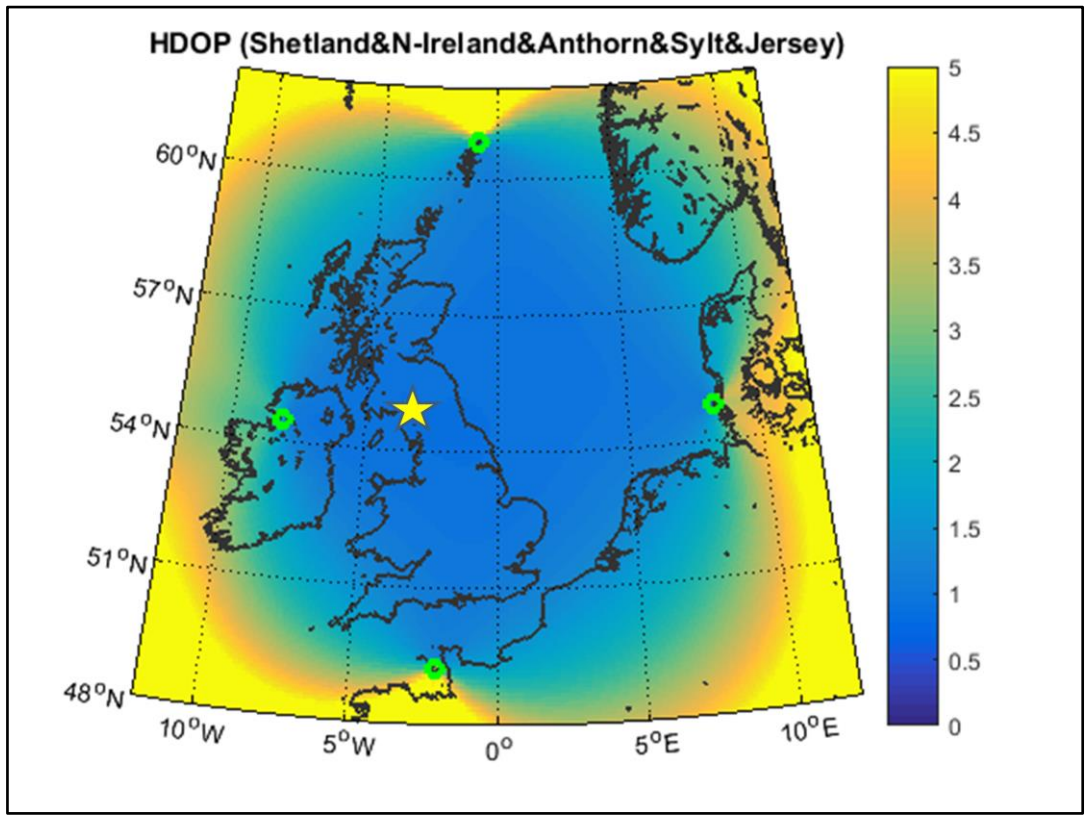


Anthorn station at centre of the UK. Broadcasts UTC to entire UK.

All secondary stations in the UK! Brexit proof!



All stations still in the UK, But somewhat better performance on the southern part of the North Sea.

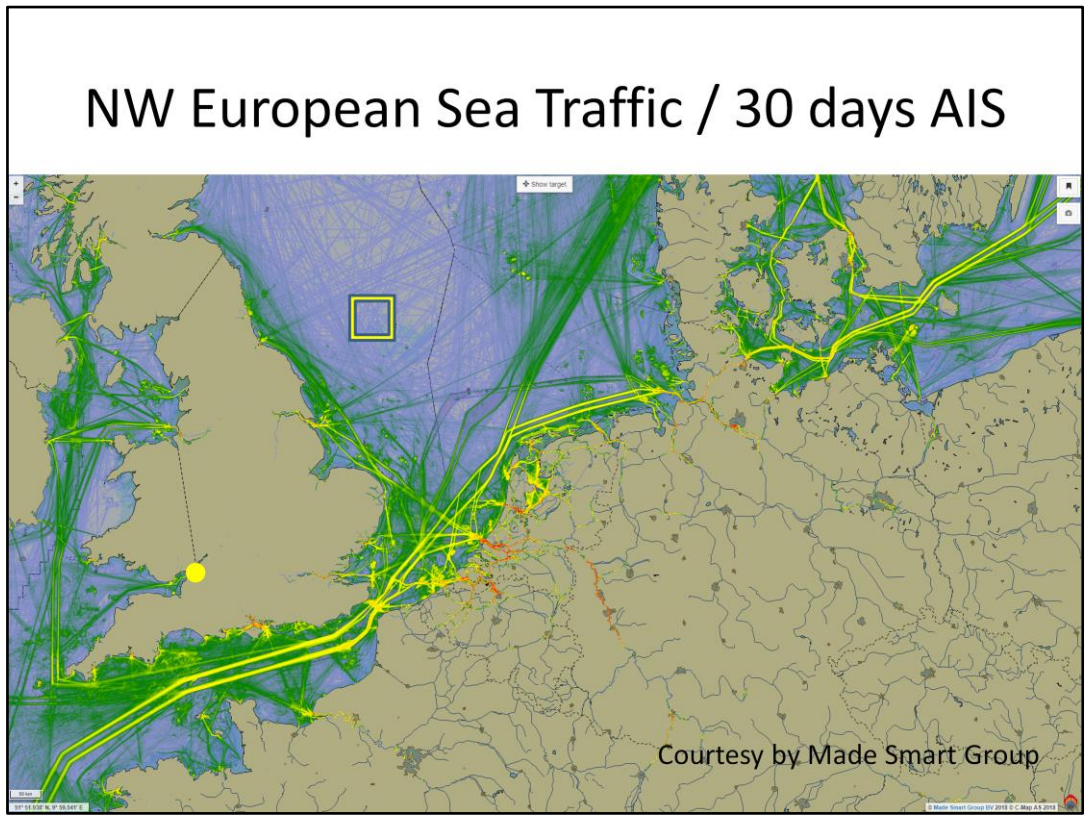


Prof David Last told me that important decisions should be taken by governments and not by ministries. Much more effective!

Do the unexpected thing! Ask Mrs. Theresa May to invite Mrs. Angela Merkel and Mr. Emmanuel Macron for a HIGH TEA to make a deal with your neighbours in post-BREXIT style, so not with the EU!

Suggest to combine the British, French and German eLoran stations and get even better performance for UK, Germany, France and some neighbouring countries. Safe many millions!
Lessay and Sylt are in good condition! Just flip the switch!

British and Dutch scientists demonstrated eLoran capabilities for Harbour and Approach applications.



Very much to win for the German harbours Bremen and Hamburg, and of Le Havre in France.

Epiphany !

- Many self-declared navigation specialists have no clue about practices, costs and laws
- We had Loran for many years on air in Europe but miniature low-cost eLoran receivers were not available. So, the blame is also on me!
- UK needs eLoran, TX & RX manufacturers should make a jump start right now
- GNSS is vulnerable today, so any backup delay means risks!

eLoran users are not interested in coverage diagrams and accuracies. That is just boring tech stuff! They want to know where they are and what time it is at the lowest possible costs. Not tomorrow, but today!

My apologies for this very late EPIPHANY! Our company should have started designing modern receivers much, much earlier. You know, old brains go sometimes somewhat slower!

What to do?

- Governments, regulators and insurance companies shall require operational and proven dissimilar GNSS backups
- Inform high-risks users about GNSS vulnerability and their responsibilities
- Authorities shall guarantee eLoran signals for more than 2 decades
- eLoran transmitters shall be built asap at about £ 3-5M/TX

The risks are today. So act now and not tomorrow!

What to do?, continued

- Only then receiver manufacturers will start developing low-cost miniature receivers which use GNSS **and** eLoran/Chayka signals for robust operations
- If the above is not fulfilled, users will not accept eLoran
- Continental Europe is not a real Brexit fan, but for now **EMBRACE IT!**

UK References

1. ‘The economic impact on the UK of a disruption to GNSS’, London Economics, 19 June 2017
2. ‘5 day disruption to GPS/GNSS services would cost the nation at least £ 5.2B’, ‘The threats of interference, jamming and spoofing are real and serious’, David Last , Coordinates July 2018
3. ‘eLoran Better for UK Than Yet Another Satnav’, Dag Pike, Daily Telegraph, 3 Sep 2018
4. ‘Maritime need for resilient PNT and potential solutions’, Alan Grant, EC Backup workshop, October 5, 2018, Brussels

Thank you