A Pseudolite-Based Maritime Navigation System: Concept through to Demonstration

Dr. Charles S. Dixon and Mr. Russell G. Morrison

EADS Astrium, Anchorage Road, Portsmouth, PO3 5PU, United Kingdom

Abstract

GPS alone will be unable to meet emerging performance requirements for maritime applications with respect to service robustness, accuracy, integrity and availability. Even when Galileo (or indeed other nascent GNSS) eventually become operational there will be performance gaps. In particular, identified applications in port areas (for example automated docking) and in inland waterways, have very stringent performance requirements.

EADS Astrium Ltd has developed a Test Environment for a Maritime Navigation System in order to perform demonstrations for the maritime community. This includes a number of Transmit Stations mounted on existing structures and terrain at accurately known locations overlooking a navigation zone (such as a maritime harbour). These continuously transmit replica GNSS signals. Another key component of the Navigation System is the single Monitoring and Control Station. This monitors each transmitter's signal, calculates clock corrections and provides each Transmit Station with the contents of its navigation messages, emulating the function of the Galileo central control facility. It also controls and monitors any demonstration signal scenarios.

This paper presents details of Astrium's Pseudolite-based Navigation System that is the foundation of a Maritime Test Environment. As well as design details, the paper presents outcomes from a public demonstration undertaken in Oban, on the West Coast of Scotland in March 2008.

Key words: Pseudolite, Maritime navigation system, Transition station, GNSS

1. Introduction

The EC 6th Framework Project "MARUSE" was led by Kongsberg Seatex AS and managed by the GNSS Supervisory Authority. MARUSE has been described in a number of earlier publications and the interested reader is referred to those [1, 2, 3, 4]. This paper is based upon an earlier publication [5] but additionally presents specifics and findings from demonstrations undertaken in Oban, on the West Coast of Scotland in March 2008.

Maritime User Requirements are presented based on an analysis of emerging user needs conducted as part of project MARUSE. The Maritime Test Environment, completed by EADS Astrium, is then described in detail. This includes the critical Transmit stations and the Monitor and Control Station. Signal transmissions are also described and an outline of the demonstrations undertaken.

EADS Astrium the industrial Prime Contractor for development of the Navigation Payload of the Galileo Satellites. Navigation payload efforts at EADS Astrium are now focused on the development of four "In Orbit Validation" (IOV) spacecraft payloads that will prove all significant elements of the Galileo system. In parallel, development of ground-based GNSS transmitters, known as pseudolites has been taking place to augment GNSS coverage for technically challenging or difficult domains. Such domains include the infamous "urban canyon" and similar domains where GNSS signals may be partially or completely blocked by buildings or other obstructions.

A particular domain of interest is Maritime, where augmentation of GNSS coverage for certain harbour operations is seen as important to support efficient future operations, including automated harbour approach and automated docking. Emerging performance requirements for maritime applications with respect to accuracy,

integrity and availability require more from a GNSS System than can be supplied by GPS alone. Once it is fully operational, Galileo will greatly enhance performance. In order to guarantee uninterrupted high-accuracy and high-integrity navigation, further augmentation to GNSS may be necessary, for example through the use of pseudolites.

2. Maritime User Requirements

Emerging performance requirements for maritime applications with respect to accuracy, integrity, availability, and continuity are rather demanding, and indeed are considered beyond the capabilities of a GNSS System to support. Identified applications in port areas (for example automated docking) and in inland waterways, have very stringent performance requirements as shown in Table 1. The figures are based on an analysis prepared by the General Lighthouse Authorities of the United Kingdom and Ireland, contracting through the Corporation of Trinity House within Project MARUSE [6].

Table 1 Maritime Application Requirements (extract from [6])

	Navigation Phase			
	Ocean	Coastal	Port	Inland Waterways
Requirement	Ship-to-ship coordination	AtoN Management[1]	Automatic Docking	Law Enforcement
Accuracy	H: 10 m V: N/A	H: 1 m V: 1 m	H: 0.1 m V: 0.1 m	H: 1 m V: 1 m
Availability	99.8%	99.8%	99.8%	99.8%
Continuity	99.97%	N/A	99.97%	99.97%
Integrity	Yes	Yes	Yes	Yes

3. MARUSE Maritime Test Environment

EADS Astrium has developed a transportable Test Environment in which to perform navigation demonstrations as part of the MARUSE demonstrations for the maritime community. This includes:

- A number of Transmit Stations mounted on existing structures (cranes/gantries, berths, buildings, hills) at accurately known locations overlooking the

---

[1] AtoN Management means management of Aids to Navigation (placement of buoys, etc.)

demonstration zone (several kilometres in extent). These continuously transmit Galileo-like signals and also have the capability to transmit pulsed pseudolite signals.

- A single Monitoring and Control Station with line of sight visibility of each Transmit Station. This monitors each transmitter's signal, calculates clock corrections and provides each Transmit Station with the contents of its navigation messages, emulating the function of the real Galileo central control facility. It also controls and monitors demonstration signal scenarios.

The Test Environment is designed to facilitate demonstration of Galileo differentiators, such as accuracy, integrity, and availability in an environment that is realistic for the maritime application groups as considered in Table 1. In Figure 1 the configuration of the Test Environment is illustrated. This includes several synchronised Transmit Stations, a Monitor and Control Station, and the WLAN interconnecting them.
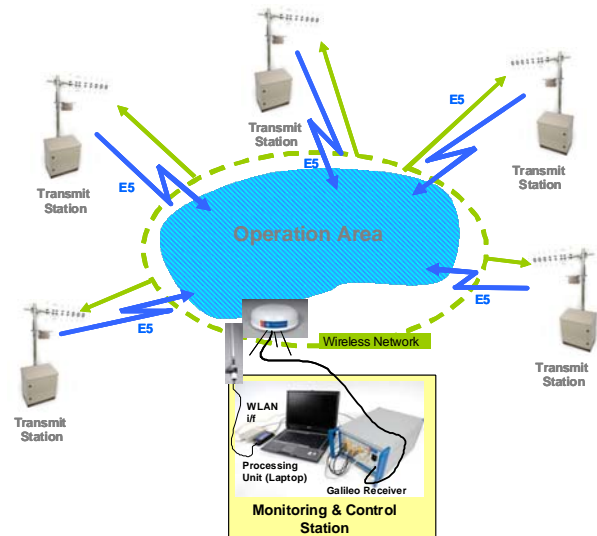

Fig. 1 Maritime Navigation Test Environment Configuration

A navigation solution may be obtained at a user receiver from a mixture of GPS and Pseudolite or Galileo signals by introducing a second time variable (i.e. local receiver clock offset from both GPS time and Galileo time). With the Test Environment Master Clock standing in for Galileo Time, there is an advantage in its synchronisation to GPS Time (i.e. removal of the second time variable in the receiver solution) but this is not strictly necessary for user navigation. A minimum of 5 signal measurements are required to obtain a user navigation solution with

unsynchronised System Times, or 4 measurements with synchronised System Times. The Test Environment's Master Clock will for demonstration purposes be synchronised to GPS time.

The demonstration environment requires, in addition to the Transmitters, a minimum of two GNSS receivers, one for on-vessel applications and one to provide references to the M&C facility. These receivers will use conventional GPS L1 transmissions as well as the Test Environment signals.

The chosen Test Environment signal has characteristics as close to Galileo E5 Alt-BOC signal as possible. The navigation message content and receiver functionality have been adapted to cope with the Transmit Stations being stationary, rather than in a MEO orbit. In addition the Transmit Stations will be mounted at low elevations. This will limit the accuracy of any height determination and may result in multipath effects that must be handled by the receiver. The close transmit-receive range will result in larger than normal received power level variations although this will be minimised by care in setting the output power levels, and in positioning of the transmitters in relation to the demonstration zone.

For any service provision demonstration to be realistic, navigation solutions obtained from the Test Environment must contain errors representative of those expected from the true Galileo system. Operational Galileo errors are expected to originate primarily from spacecraft orbit and clock prediction errors (ephemeris), and from ionosphere and troposphere propagation variation not corrected by the use of two frequencies or imperfectly modelled. Orbit errors are effectively eliminated from the test environment transmissions through precise survey of each of the transmitter locations. Residual uncertainties should be at the centimetre level. In addition, propagation errors will be minimal because of the small spatial extent of the covered area. Clock errors will however be somewhat larger than their Galileo equivalents since the Test Environment uses ovenised crystal oscillators (OCXO) instead of the atomic clocks used in GPS (Rubidium and Caesium) and Galileo (Hydrogen Maser and Rubidium). The update rate for clock corrections parameters in the test environment system will therefore be necessarily higher than for GNSS systems. A baseline rate of once per 50 seconds has been established, this value maximising correspondence with the Galileo message frame structure [6] on the E5a and E5b carriers.

All of the types of error discussed above lead only to bias and uncertainty in pseudorange measurements at user level, so their origin does not alter their impact. The combined impact of such errors can thus be simulated by the M&C facility introducing deliberate errors in the clock correction parameters sent to each transmitter for inclusion in the navigation data. The testbed can also emulate changes in which "Spacecraft" are visible by changing the PRN code used by a particular transmitter. The M&C facility can similarly emulate "Spacecraft" degradation or outage.

3.1   Transmit Stations

The Transmit Stations are a variation of Pseudolite technology. The Transmit Stations generate and broadcast navigation signals based on those planned for use by the future Galileo System.

Transmit Stations are compact and self-contained, and produce continuous GNSS satellite-like transmissions at a source level that is preset and maintained constant for the duration of any demonstration. Transmitters can either work independently, or can be synchronised in groups to work together as a single, coherent system. The design places few restrictions on the location of their deployment, ensuring that demonstration planners have the freedom to create optimal signal environments for maritime or other sector application demonstrations.

Figure 2 illustrates the Transmit Station architecture. It comprises four distinct parts: a timing and frequency generation section, a radio frequency (RF) section, a real-time firmware section including an FPGA device and control and a "soft real-time" software section hosted on a central processing unit (CPU).
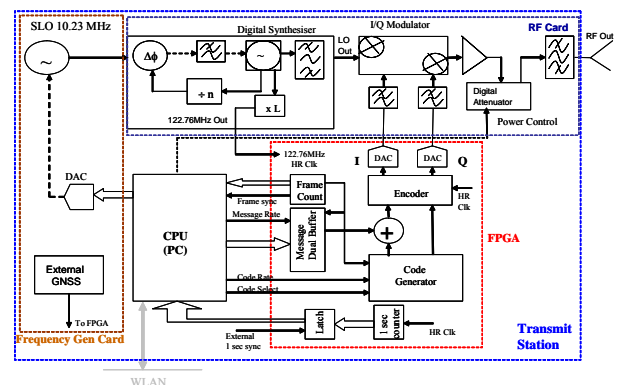

Fig. 2 Transmit Station Architecture

Each of the Transmit Stations within the Demonstration Test Environment is designed to perform the following functions:

- Accept commands from remote source (M&C Station) via wireless network, and continue to operate usefully in absence of external commands;
- Maintain stable local timing reference, and synchronise to external standard when available;
- Generate coherent broadcast carrier frequency;
- Generate PRN spread spectrum code and modulate carrier;
- Generate navigation message and modulate the PRN frames;
- Amplify, filter and broadcast resultant Galileo-like navigation signal at required source level;
- Restrict out-of-band transmissions;
- Maintain physical security and protect system from external environment;
- Be capable of working from internal power supply;
- Record status data.

Hardware Implementation

To minimise risk, commercial off-the-shelf (COTS) hardware was used where possible. The RF circuitry is based on an existing Astrium modulator/upconverer, with modified filters to meet the required RF performance.This module has a cPCI format, which dictated the form of the other equipments. The CPU and FPGA are PMC modules, mounted on a dual PMC/cPCI carrier. The FPGA module has a dual high-speed DAC interface card fitted. All are commercial modules, selected for performance and minimum power requirements.

The modules are mounted in a commercial 2-slot 19-inch cPCI rack, with a 12v dc power supply. An internal Ethernet LAN provides system connectivity. Figure 3 illustrates the Transmit Station main electronics package as realised in hardware.
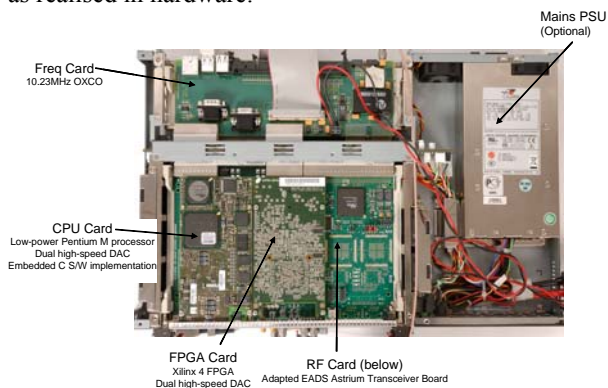

Fig. 3 Transmit Station Main Electronics

Two boards were designed specifically for the EADS Astrium Pseudolite. These connect to the rear of the cPCI rack, using existing connections. They contain the oven-controlled crystal oscillator (OCXO), plus circuitry to adjust its frequency; test interfaces and interconnection between the RF board and the processor. Various test/debug interfaces are also fitted.

The designated "master" pseudolite also has an EGNOS receiver fitted to one of the boards, to provide a low-jitter 1pps reference for oscillator frequency control.

External to the 19-inch rack are the wireless LAN components (RF Modem and Ethernet Bridge) and power-switching components (relays and switches for manual control, plus an iBoot switch controlled by the Ethernet Bridge).

The system is powered by a commercial 12v lead-acid battery, and optionally by a mains power supply.

The electrical equipment is housed in a weatherproof cabinet, providing protection to IP66 (powerful water jets).

The RF Navigation antenna is a corner reflector mono-pole, and the WLAN communications antenna is a Yagi. Both are mounted externally.
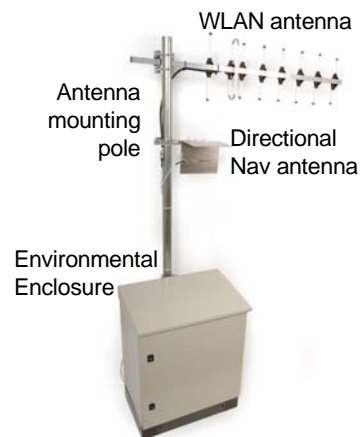

Fig. 4 Transmit Station Physical Realisation
Pseudolite RF Transmitter

The Pseudolite transmitter is based on a single stage single sideband up-conversion process and attractive, particularly in comparison with alternative double sideband schemes incorporating filters and frequently comprising multiple stages. Although of greater

complexity such schemes are well tried and can consistently deliver high spectral performance.

Fig. 5 PSL RF Transmitter Output Spectrum

The SSB output is generated by means of a single chip complex up-converter. This device incorporates two single stage double sideband suppressed carrier mixers whose local oscillators are in phase quadrature. The baseband input signals, also in phase quadrature, are up-converted by these mixers. Their outputs are combined to produce either an upper or lower sideband signal depending on the lead/lag relationship between the baseband inputs. The remainder of the circuitry is concerned with the creation and control of these baseband signals which will maximize the up-conversion process.

The main characteristics of the Pseudolite RF transmitter are tabled below:

Table 2 (Astrium) Pseudolite RF Transmitter Characteristics

Characteristic	Value	Units
Transmit Power Range	0 to -55	dBm
Programmable Synthesiser	1191.795	MHz
Programmable Attenuation Range	55	dB
Input Frequency Reference (Fref)	10.23	MHz
Synchronised Output Clock Facility (HR Clk)	12x Fref = 122.76	MHz
Output Clock Level	14 ± 1dB	dBm

3.2   Monitor and Control Station

The overall role of the Monitoring & Control (M&C) Station is to coordinate the operation of the Transmit / PSL Stations so that they form a coherent navigation system.

The Monitor and Control Station (M&C) Station within the Demonstration Test Environment is designed to perform a number of key functions.

At the heart of the M&C is a processing element which provides the ability to accept and process data from the GNSS Reference Receiver via a data link. The data being received from the GNSS Reference Receiver will include measurements of Pseudorange, Carrier Phase, Doppler, C/No and lock time; data such as raw Navigation symbols and tracking & receiver status.

The M&C processing element also provides the mechanism for generating commands for dissemination over the communications link to each Transmit Station for passing of navigation parameters and miscellaneous data. Linked with this is the mechanism for accepting and processing acknowledgements and other health & status data from each of the transmit stations received via the communications link.

A User interface is provided to enable inputting of parameters, obtaining system status general system housekeeping as well as functionality for storage of Status data on appropriate media. An example M&C screen is given in Figure 6 below.

The M&C processing element also provides the low-level algorithms for timing within the system. It maintains the master timing reference, by synchronising to external standard. Also included are the algorithms for determining timing offsets (ΔT) to be sent to each Transmit Station. Timing algorithms were described in a previous paper [5].
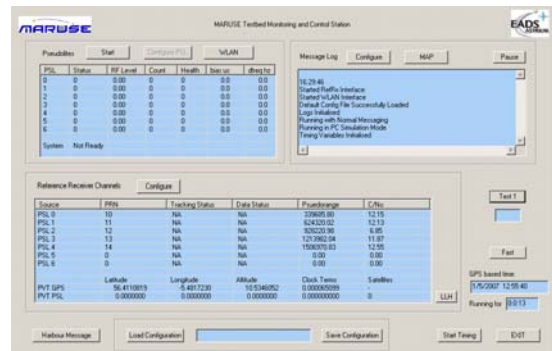

Fig. 6 M&C Screen User Interface

3.3   Galileo Reference Receiver

A Septentrio GeneRx Receiver is used as the Pseudolite Reference Receiver for this work. This unit is capable of tracking GPS satellites as well as the Galileo-like transmissions of the pseudolites. Its main functions are to measure Pseudoranges from the transmit stations, to collect the transmitted Navigation Data, to time-stamp this

data and to relay it to the M&C via a dedicated RS-232 serial link.

3.4 Communications Link

The Communications Link interconnects the M&C Station with each of the Transmit Stations at there remote locations. The communications link utilises medium to long range Wireless Local Area Network (WLAN) capabilities. For the prototype equipment in Project MARUSE, X8200 Radio Modems are used. These RF modems can achieve a range of up to 20km in free space and the RF power can be varied from 5mW to 500mW. Serial data can be transmitted by X8200 with baud rates from 1.2K to 115.2K over distances of 10km to 20km line of sight, and can operate in both license-exempt and licensed bands. Antennas used are 10dB Yagi at the Transmit Stations and 0dB omnidirectional antenna at the M&C.

For an operational system this link type might be appropriate, although for many applications communications links may already exist which could meet the relatively modest communications demands of the system.

4. Test Environment Signals

The Signals transmitted by the Transmit stations are replica Galileo signals based on the E5A and E5B AltBOC-modulated transmissions [7]. Differences from the Galileo transmissions are described below.

In the Test Environment, there will be no ionosphere between the Transmit Stations and the Receivers; it is therefore of limited value to use multiple transmission frequencies in a terrestrial pseudolite environment. The transmissions used for project MARUSE are identical in terms of frequency and modulation to the Galileo transmissions. This comprising two pairs of I&Q components referred to as E5A and E5B, which are AltBOC modulated onto an RF carrier centred at 1191.795 MHz.

The wide band E5 signal shall be generated with the AltBOC modulation of side-band sub-carrier rate $R_{S,E5} = 1/T_{S,E5} = 15.345$ MHz (15 x 1.023 MHz) according to the expression [7]:

$$s_{E5}(t) = \frac{1}{2 \cdot \sqrt{2}} \cdot (e_{E5a-I}(t) + j \cdot e_{E5a-Q}(t)) \cdot [sc_{ES-S}(t) - j \cdot sc_{ES-S}(t - T_{s,E5}/4)] +$$

$$\frac{1}{2 \cdot \sqrt{2}} \cdot (e_{E5b-I}(t) + j \cdot e_{E5b-Q}(t)) \cdot [sc_{ES-S}(t) + j \cdot sc_{ES-S}(t - T_{s,E5}/4)] +$$

$$\frac{1}{2 \cdot \sqrt{2}} \cdot (\bar{e}_{E5a-I}(t) + j \cdot \bar{e}_{E5a-Q}(t)) \cdot [sc_{ES-P}(t) - j \cdot sc_{ES-P}(t - T_{s,E5}/4)] +$$

$$\frac{1}{2 \cdot \sqrt{2}} \cdot (\bar{e}_{E5b-I}(t) + j \cdot \bar{e}_{E5b-Q}(t)) \cdot [sc_{ES-P}(t) + j \cdot sc_{ES-P}(t - T_{s,E5}/4)] \ .$$

with the binary signal components e_{E5a-I}, e_{E5a-Q}, e_{E5b-I} and e_{E5b-Q} (consisting of the BPSK modulated ranging codes multiplied with the respective navigation data stream for the data-channels).

The main characteristics of the MARUSE E5 transmitted signal are highlighted in the table 3.

Table 3 Signal Characteristics

Characteristic	Details
TX Signal Bandwidth	92 MHz
TX Centre Frequency	1191.795 MHz
Signal	E5 (E5a & E5b)
Service	I/NAV, F/NAV
Modulation	AltBOC
E5A Chip rate	10.230 MChip / s
E5B Chip rate	10.230 MChip / s
E5A-I Symbol Rate	50 symbols / s
E5B-I Symbol Rate	250 symbols / s
E5A-I Code period	20 ms
E5A-I Primary Code length	10230 (chips)
E5A-I Secondary Code length	20 (chips)
E5A-Q Code period	100 ms
E5A-Q Primary Code length	10230 (chips)
E5A-Q Secondary Code length	100 (chips)
E5B-I Code period	4 ms
E5B-I Primary Code length	10230 (chips)
E5B-I Secondary Code length	4 (chips)
E5B-QCode period	100 ms
E5B-Q Primary Code length	10230 (chips)
E5B-Q Secondary Code length	100 (chips)
Adapted for TX Stations:	
Navigation Framing	
Navigation Messages	Almanac
	Ephemeris
	Timing
	GPS Offset
Other Message Types	Low Bit Rate Communications message

5. Oban Demonstrations

Tests and live demonstrations took place in Oban on the West coast of Scotland, on 4th March 2008. Observers from around Europe saw the NLV Pharos undertake a variety of precision manoeuvres in the bay. These

included placement of a new wreck-marking buoy. Crucial to the success of the demonstration were a number of new systems developed under the MARUSE project, including innovative onboard dynamic positioning technologies and an array of EADS Astrium pseudolites which mimicked GALILEO satellite signals. The pseudolites were placed in various locations around Oban Bay, enabling a vessel to use GALILEO-like signals for the first time to navigate in British waters.

The demonstration in Oban was the fourth in a series undertaken by MARUSE. Participants watched the NLV Pharos in real time via closed-circuit television as it manoeuvred using the EADS Astrium pseudolites. The demonstration was hosted by the Research and Radionavigation Directorate of the General Lighthouse Authorities of the UK and Northern Ireland (GLAs), which include the Northern Lighthouse Board, the Commissioners' of Irish Lights and Trinity House.

Major aims of the demonstrations are summarised in Table 4, and these included demonstration of Galileo-based navigation in advance of Galileo deployment, accuracy characterisation of the equipment, and interoperability confirmation, both of GPS and Galileo, and of these systems interoperating with pseudolite augmentation.

Table 4: Demonstration Technical Items

ITEM	DETAIL
Navigation using Galileo-like signals	E5a, E5b, E5 AltBOC Code-phase solution
Accuracy	Required <5m; Desirable ~1m
Interoperability	(a) Galileo + GPS (b) Interoperability + PSL

5.1   Demonstration Scenario

The public demonstration undertaken in Oban was based on the concept of a vessel blocking a busy waterway. It used a combination of Pseudolites, GPS and Virtual Aids to Navigation (AtoN) (making use of AIS and Electronic chart displays (ECDIS)). The demonstration also used NLV Pharos vessel from Northern Lighthouse Board to undertake the physical demonstrations within Oban bay. The scenario for the demonstration was as follows:

- A simulation of a vessel entering the Oban waterway (using AIS to show its position) is shown on an ECDIS electronic chart display.
- The simulated vessel suffers a failure causing it to remain in the waterway as an obstruction

- The position of this vessel is marked by the General Lighthouse Authorities (GLAs) using the virtual AtoN (AIS, ECDIS) and its position is broadcast via AIS to all nearby vessels.
- The NLV Pharos is deployed to physically mark the vessel with a Buoy, over the same location as that provided by the Virtual AtoN, using the enhanced positioning from the EADS Astrium Pseudolites.

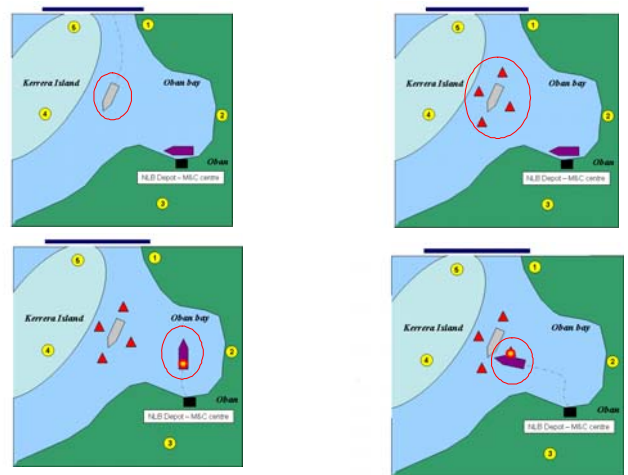The demonstration scenario is shown in following figure:

Fig. 7 Demonstration Scenario (courtesy of Dr Alan Grant General Lighthouse Authorities of the United Kingdom and Ireland)

Fig. 8 NLV Pharos deploying a wreck marker buoy during Oban Demonstration

6. Mission accomplished

The MARUSE demonstrations undertaken in Oban, which involved the placement of virtual buoys and the retrieval and placement of a real emergency buoy over a simulated wreck in Oban Bay, were considered a success by the GSA.

The role of the MARUSE pseudolites in this demonstration was to mimic future GALILEO signals, but they can also serve as stand-alone infrastructure elements. "These pseudolites can be very useful in filling gaps in current GNSS services," said MARUSE project manager Stig Erik Christiansen of Norway's Kongsberg Seatex, "especially in problem areas like 'urban canyons' or deep locks in our inland waterways. And, at sea, this kind of technology can help to reduce the potentially terrible risk of collision between tankers, for example, ultimately reducing operating costs by increasing the precision and efficiency of navigation."

7. Conclusions

A Maritime Navigation Test Environment has been created by EADS Astrium and its partners as part of Project MARUSE. This will facilitate testing and demonstration of two distinct benefits to future shipping. Firstly, Galileo differentiators (more visible sources of transmission, higher accuracy, integrity) have been demonstrated in advance of full operation of the Galileo System. This has helped to introduce the benefits of GNSS in general, and Galileo in particular to the Maritime domain, whilst simultaneously soliciting feedback that can be used to modify the final implementation of Galileo.

Secondly, pseudolite operation has been demonstrated. Pseudolites may be appropriate to augment GNSS performance in critical situations or difficult environments. Critical situations include those where safety of life and/or continuity of high-quality system performance are paramount. Difficult environments include situations where GNSS signals may become blocked by local obstructions such as harbour gantry cranes and other local obstructions.

The EADS Astrium approach has been to produce a sophisticated yet low-cost Test Environment within which Galileo receivers and other user equipment and applications can be tested. The Environment is focused on the demands of the maritime domain, but is also flexible and moveable facilitating re-use for other applications and domains.

Demonstrations have been undertaken in Oban on the West Coast of Scotland in spring 2008 as part of Project MARUSE. This used the pseudolite transmission stations and M&C equipment developed by EADS Astrium and described in this article, Receivers from Septentrio, User Terminals from Kongsberg Seatex, and Vessels from Trinity House Lighthouse Authority.

8. Future Work

Future adaptations of the Pseudolite and M&C Equipment for other domains are foreseen. This may include Emergency Management, Rail, Road, and Security-related domains.

The Pseudolite-based Transmit Stations and M&C Equipment have been added to the EADS Astrium product range. These can augment GNSS performance in critical situations or difficult environments. Critical situations include those where safety of life and/or continuity of high-quality system performance are paramount. Difficult environments include situations where GNSS signals may become blocked by local obstructions, and encompass urban canyons and indoor operations among other environments.

References

[1] Grant, A.J., N. Ward, S.E. Christiansen, C.S. Dixon, A. Suskind; ***MARUSE Demonstrating the use of Maritime Galileo Pseudolites***. Accepted for ION GNSS 2007 Conference, 25-28 September, 2007 – Fort Worth, TX, USA

[2] Christiansen, S.E., C.Amlacher, G.Burden, C.S. Dixon, A.J. Grant, S Mazzeo, A. Suskind; ***Introduction of Galileo in Maritime and Inland Waterway Applications***. ENC GNSS'07 / TimeNav'07, 29-31 May 2007, Geneva, Switzerland

[3] Dixon, C.S., R.G. Morrison; ***Maritime Demonstration Testbed for Galileo***. ION GNSS 2006 Conference, 26-29 September 2006, Fort Worth TX, USA

[4] Dixon, C.S., R.G. Morrison and S.E. Christiansen; ***Testbed for Galileo Maritime Demonstration***. ENC GNSS 2006 Conference, 7-10 May 2006, Manchester, United Kingdom.

[5] Dixon, C.S., Bolt, M., Helliwell, A., Lau Semedo, P., Morrison, R.G., Parks, M., Whittaker, A., Williams, M. ***Demonstration of a Galileo Based Maritime Navigation System*** RIN NAV 07 30th October – 1st November 2007

[6] ***MARUSE Application Group Consolidation – Project Document: MARUSE-DD06-THL-AGC-R000***, Final Version dated 17th February 2007.

[7] ***Galileo Open Service Signal-In-Space Interface Control Document (SIS ICD).*** GAL OS ICD/D.0 Issued 2006 Draft 0

[8] Dixon, CS and RG Morrison; ***Demonstration of a Galileo-Based Maritime Navigation System: First Demonstration Results***. ENC GNSS 2008 Toulouse, April 2008