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| IALA Guideline |

g-R-Mode

VDES R-Mode

Edition 0.7

10/10/2019

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|  |  |  |

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# Introduction and Scope

## Identification

This document describes the system requirements and goals for a VDES R-Mode System to be developed by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA). The document is intended to be used as the basis for design, development, verification and acceptance of the system.

## Intended Use of the VDES R-Mode System

IALA members intend to establish the VDES R-Mode System as a contingency or backup Positioning, Navigation and Timing (PNT) system for maritime shipping. The operational concept is that, when there is a disruption to Global Navigation Satellite System (GNSS) services on-board a ship, the VDES R-Mode system (possibly together with other terrestrial PNT systems such as MF R-Mode and eLoran) provides ranging measurements to an on-board navigation system so that the impact of the GNSS service outage on the ship’s ability to navigate safely is minimised.

Additional information on the intended use of the system can be found in reference (IALA, 2019).

## System Overview

The VDES R-Mode System will send accurately timed VHF transmissions from a network of land-based and, possibly, offshore Base Stations (BS). A shipborne VDES R-Mode Sensor (VRMS) will measure the timing (and other) parameters of the received signals and output the signal observables to an external PNT processor, such as the Multi-system Shipborne Radionavigation Receiver (MSR) described in reference (IMO-MSC.401(95)). The PNT processor will then use the observables to determine the user’s position, speed over ground and other navigation parameters.

VDES R-Mode should, as far as possible, use pre-existing shore side infrastructure, including shore stations and Monitoring and Control Centres (MCC’), and pre-existing AIS/VDES shipborne installations. Monitoring and control data is likely to be carried between the Base Stations, Far-field Monitoring Stations (FMS’) and one or more Monitoring and Control Stations (MCS’) via pre-existing Wide Area Networks.

VDES R-Mode will be synchronised to an external Time Source traceable to a common time scale in order to facilitate interoperability with other PNT systems.

# Reference Documents

The following documents are referred to in this document:

1. IMO-MSC.401(95), ’IMO Resolution MSC.401(95)’, Performance Standards for Multi-system Shipborne Radionavigation Receivers.
2. RMB-B&P-1v0, ’R-Mode Baltic - Baseline and Priorities’, Issue 1.0, March 2019.
3. IALA, 2019, ‘Stakeholder Requirements for R-Mode’, Input document no. ENAV24-6.1.17.3, ENAV24.
4. ‘System Requirements for VDES R-Mode’, 18/06/2019, v0.2

# Definitions and Acronyms

## Definitions

The definitions of terms used in this IALA document can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at <http://www.iala-aism.org/wiki/dictionary> and were checked as correct at the time of going to print. In addition, the terms below are defined. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

*Accuracy* means the degree of conformance between the estimated value of a parameter at a given time and its true value at that time.

*Availability* means the percentage of time that a system (or a system element) is performing a required function under stated conditions. Non-availability can be caused by scheduled or unscheduled interruptions.

*Continuity* means the probability that a system (or a system element) remains available over a specified Continuity Time Interval, assuming it was available at the beginning of the interval.

*Continuity Risk* is calculated as one minus the Continuity requirement; for example, the Continuity requirement of 99.97% per 15 minutes is equivalent to a Continuity Risk of 3e-4 per 15 minutes.

*Continuity Time Interval* means the time-period required to complete an operation during which continuous availability of a system (or a system component) is required.

*DRMS Accuracy* means the Root Mean Square value of the Horizontal Position Error.

*Global Navigation Satellite System(s)* means any combination of one or more of the following systems: GPS; GLONASS; BeiDou; Galileo.

*Hazardously Misleading Information* means the occurrence of a position fix with Horizontal Position Error larger than the Horizontal Alert Limit without an alarm being raised within the Time to Alarm.

*Horizontal Alert Limit* means the maximum tolerable Horizontal Position Error for a given application / phase of voyage. Typically, this is set as 2.5 times the corresponding R95 Accuracy requirement for the application.

*Horizontal Position Error* means the distance between the true position of a sensor at a given time and the projection of the estimated position onto the local tangent plane containing the true position at that time.

*May* expresses permissive guidance.

*Multisystem Shipborne Radionavigation Unit* means a multisystem shipborne radionavigation receiver / transceiver.

*Passive Ranging Service* means the provision of VDES R-Mode navigation data and passive ranging observables.

*Positioning Availability* means the percentage of all positioning epochs in any given time period for which an external PNT processor has a position fix and can guarantee its integrity. Non-availability can be caused by a range of factors such as: loss of navigation data; insufficient number of visible ranging signals; receiver fault; inability to perform integrity monitoring (due to insufficient number of visible ranging signals or poor HDOP); fixes which are determined by the integrity monitor to represent a risk; and fixes for which the determined level of integrity is not sufficient to meet the requirements.

*Positioning Continuity* means the probability that a user will be able to determine position with specified Accuracy and is able to monitor the Integrity of the determined position over a specified Continuity Time Interval applicable for a particular operation. It is assumed that, at the beginning of the operation, the user equipment is fault-free and the system is available. Events which cause loss of Continuity are the same ones which cause loss of Positioning Availability with the exception of events which can be forecast, such as poor HDOP or announced down-time of some aspect of the system.

*Positioning Integrity* means the ability of a system to provide timely warnings to users when the system should not be used for navigation. It is usually specified in terms of an Integrity Risk, a Horizontal Alert Limit and a Time to Alarm.

*Positioning Integrity Risk* means the probability of the user being presented with Hazardously Misleading Information at any time during a stated operation window.

*R95 Accuracy* means the Horizontal Position Error not exceeded with a probability of 95%.

*Radio Station* means one or more transmitters or receivers or a combination of transmitters and receivers, including the accessory equipment, necessary at one location for carrying on communication via radio waves.

*Service Area* means a geographical area designated by the VDES R-Mode system provider within which the system is expected to meet all requirements applicable to the Navigation Data Output Function and Passive Ranging Observables Function as specified in this document.

*Service Availability* means the percentage of time a given service meets all requirements applicable to that service stated herein.

*Shall* expresses a characteristic which is to be present in the item which is the subject of the specification, i.e. 'shall' expresses a binding requirement.

*Should* expresses a target or goal to be pursued, but not necessarily achieved.

*Station* means a facility in which one or more Radio Stations can be installed.

*Time of Arrival* TBD

*Time of Transmission* TBD

*User* means a machine (such as the Multi-system Shipborne Radionavigation Receiver or similar) that makes use of the navigation data and observables produced by the VDES R-Mode System to determine position, speed over ground, coarse over ground and time.

*User Range Accuracy* means an estimate of the one-sigma range error to a Base Station due to the intrinsic Base Station and reference Time Source errors.

*VDES R-Mode Base Station (also Base Station)* means a Radio Station installed at a fixed, known location, capable of being used by a VDES R-Mode Sensor as a reference object for ranging or pseudoranging.

*VDES R-Mode Sensor* means a Radio Station, typically installed on a ship, capable of using VDES to obtain range or pseudorange measurements to VDES R-Mode Base Stations.

*Will* expresses a declaration of intent on the part of IALA. 'Will' does not express a binding requirement. 'Will' may also be used to express simple futurity.

## Acronyms

|  |  |
| --- | --- |
| 1PPS | One Pulse Per Second |
| ARAIM | Advanced Receiver Autonomous Integrity Monitoring |
| BS | VDES R-Mode Base Station (also Base Station) |
| CRC | Cyclic Redundancy Check |
| CTI | Continuity Time Interval |
| EIRP | Effective Isotropic Radiated Power |
| FMS | Far-field Monitoring Station |
| GNSS | Global Navigation Satellite System(s) |
| HAL | Horizontal Alert Limit |
| HMI | Hazardously Misleading Information |
| HPE | Horizontal Position Error |
| IALA | International Association of Marine Aids to Navigation and Lighthouse Authorities |
| IR | Integrity Risk |
| MCC | Monitoring and Control Centre |
| MCS | Monitoring and Control Station |
| MRAIM | Maritime RAIM |
| MSR | Multisystem Shipborne Radionavigation Receiver |
| MSRU | Multisystem Shipborne Radionavigation Unit |
| PKI | Public Key Infrastructure |
| PNT | Positioning, Navigation and Timing |
| RF | Radio Frequency |
| RMS | Root Mean Square |
| SA | Service Area |
| SINR | Signal-to-Noise-and-Interference Ratio |
| TBC | To Be Confirmed |
| TBD | To Be Defined / Determined |
| TOA | Time of Arrival |
| TOT | Time of Transmission |
| TTA | Time to Alarm |
| URA | User Range Accuracy |
| VDES | VHF Data Exchange System |
| VRM | VDES R-Mode |
| VRMS | VDES R-Mode Sensor |
| WAN | Wide Area Network |

# System Architecture

The R-Mode system with its service to provide synchronised ranging signals is part of the overall PNT supporting e-Navigation architecture as shown in Figure 1.



1. R-Mode embedded in the overarching IMO e-Navigation architecture

## Architecture Overview

The R-Mode system consists in general of the following components (shown in Figure 2and Figure 3 ):

* R-Mode transmitter station: A station that provides R-Mode service. It is intended to use existing VDES and maritime radio beacon land based stations.
* R-Mode monitor: Station that monitors broadcasted signals of R-Mode transmitter.
* R-Mode reference time: Time distribution infrastructure that provides in a region the R-Mode reference time which is used for R-Mode service provision.
* Command and control, Security center: Central infrastructure of a region that is used to control and command the complete network. It provides a security services for the R-Mode system and service.
* R-Mode user: User of R-Mode service.



1. Logical R-Mode architecture



1. Synchronization of R-Mode transmitter and monitor with R-Mode reference time

## R-Mode System Functional Architecture

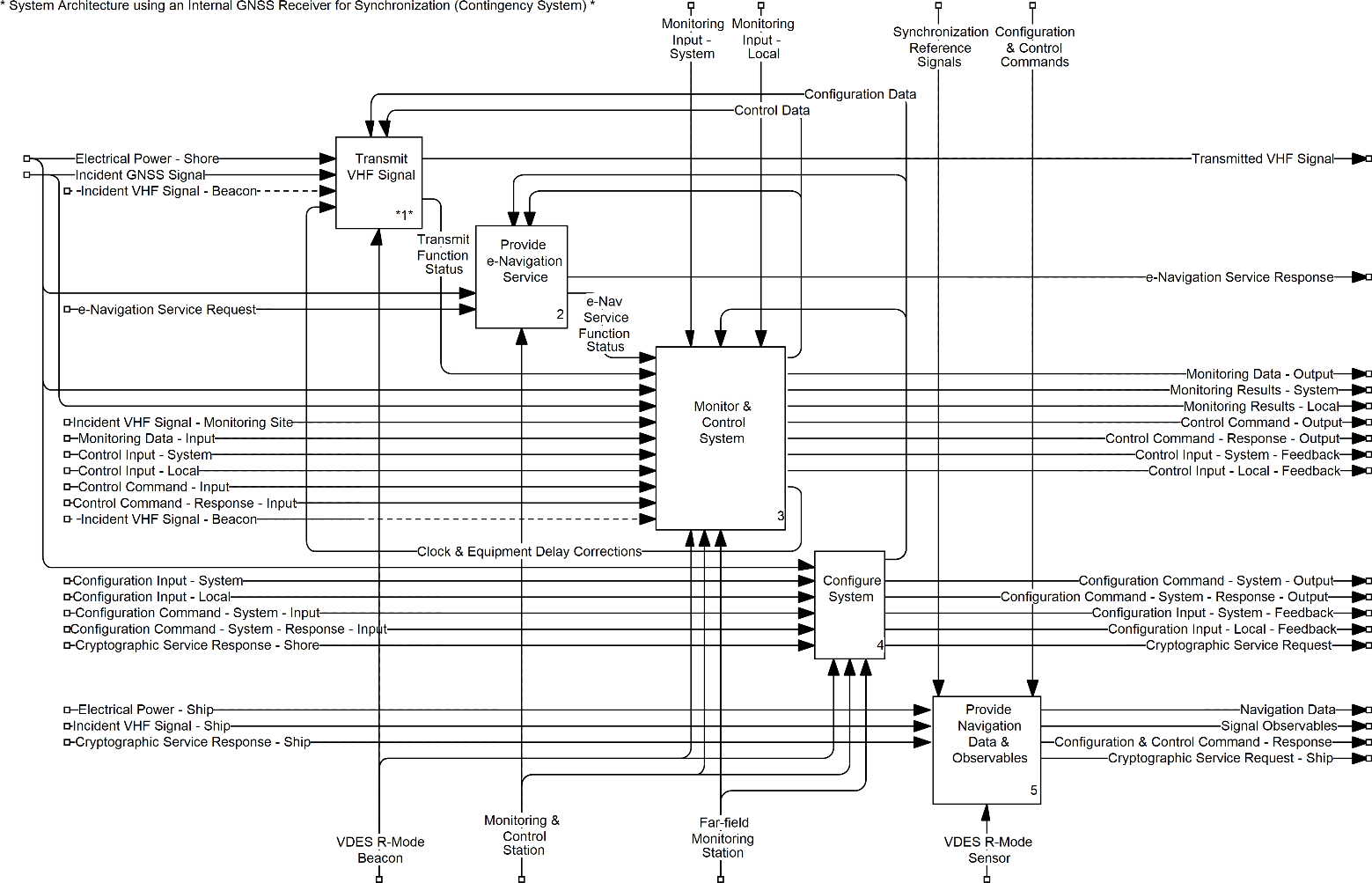
The IDEF0 modelling approach is used here to outline a functional architecture for VDES R-Mode. For an introduction to IDEF0 please see Section 8.4.1. The architectural diagrams shown here are consistent with the External System Diagrams for the VDES R-Mode System contained in the Stakeholder Requirements Document (IALA, 2019).

Section 4.2.1 presents an architecture for a VDES R-Mode System using GNSS in conjunction with high-stability local oscillators for base station synchronization, thus representing a contingency system*[[1]](#footnote-1)* with a holdover time dependent on the (in)stability of the local oscillator. The architecture uses outputs from the base station’s internal GNSS receiver to calibrate the local oscillator and estimate parameters of a clock error model, which can then be used during a (short-term) GNSS service outage to discipline the base station’s clock.

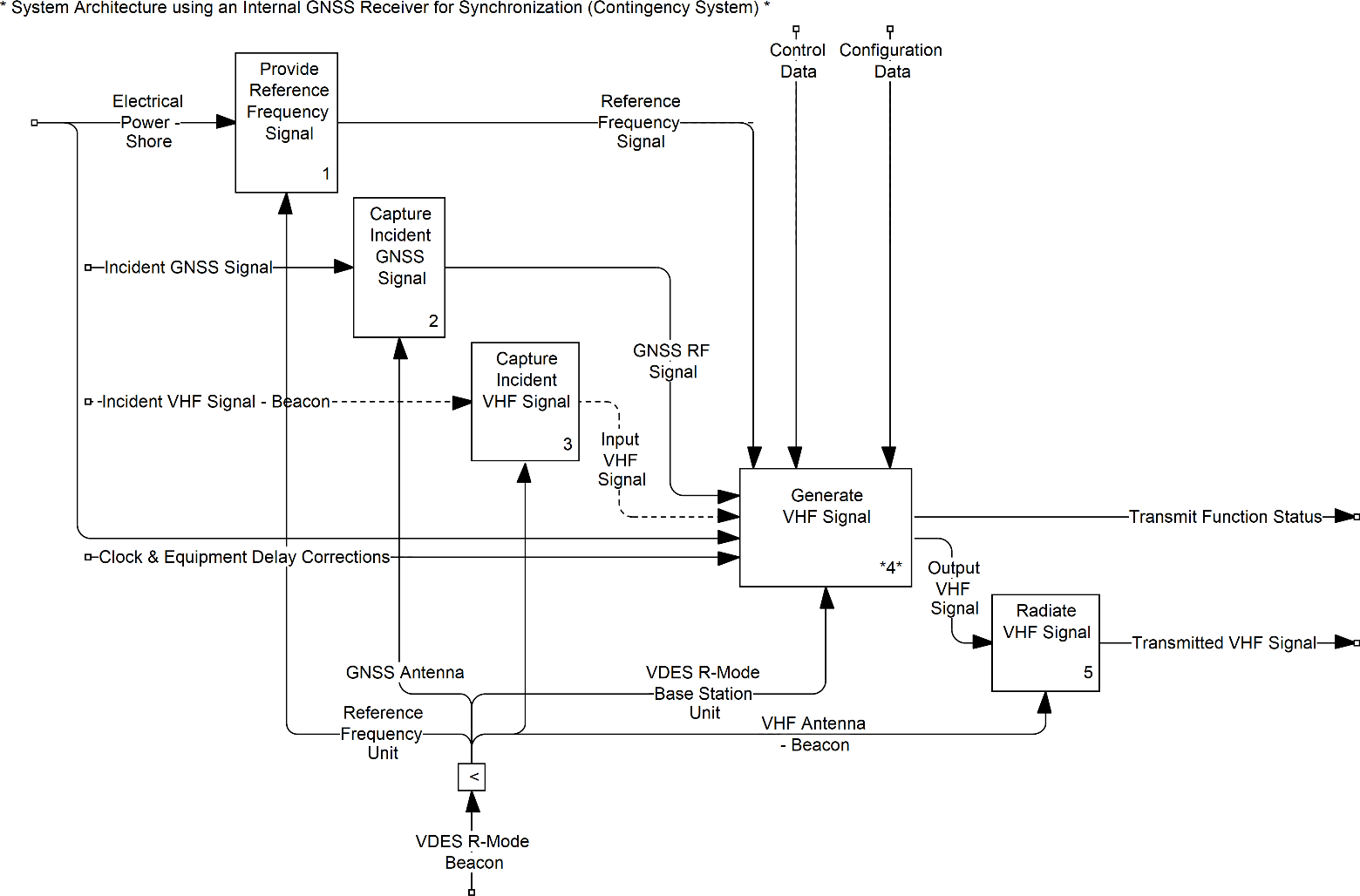
Section 4.2.2 presents an alternative system architecture using a timing device external to the VDES base station unit. Assuming this device operates independently of GNSS, this architecture represents a backup system*[[2]](#footnote-2)*.

Figure 4 and Figure 7 in the following sections show the top-level functional breakdown, data flows and key system elements for the two system architectures, respectively. Of particular relevance to this specification is the Transmit VHF Signal Function, which is expanded in Figure 5 and Figure 8, and further in Figure 6 and Figure 9, respectively. Descriptions of the data flows and key system elements shown in the diagrams are provided (in an alphabetical order) in Table 1 in Section 4.2.3.

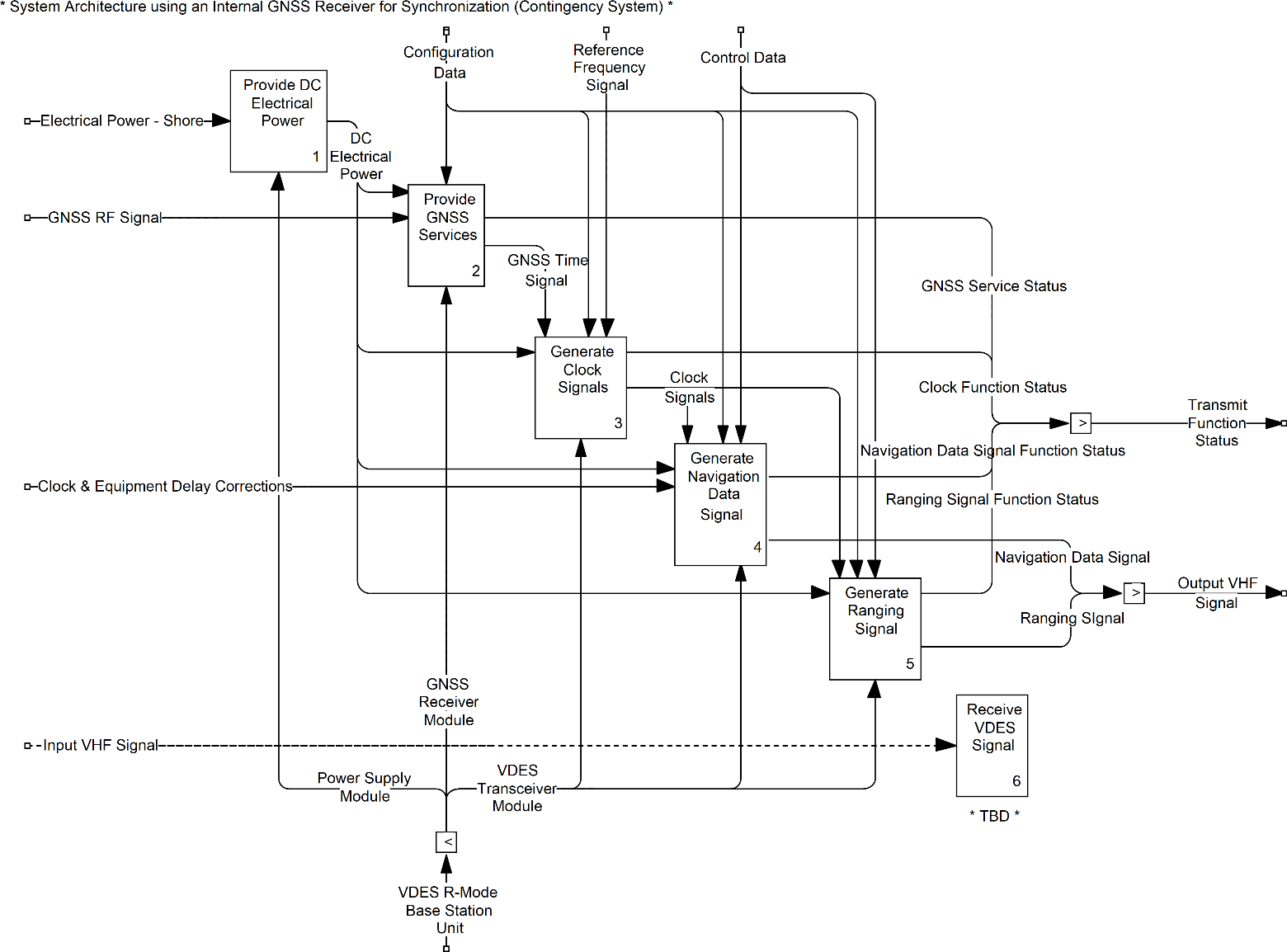
### System Architecture Using GNSS for Synchronization



1. Top-level functional breakdown for a VDES R-Mode System using GNSS for synchronization (contingency system configuration)

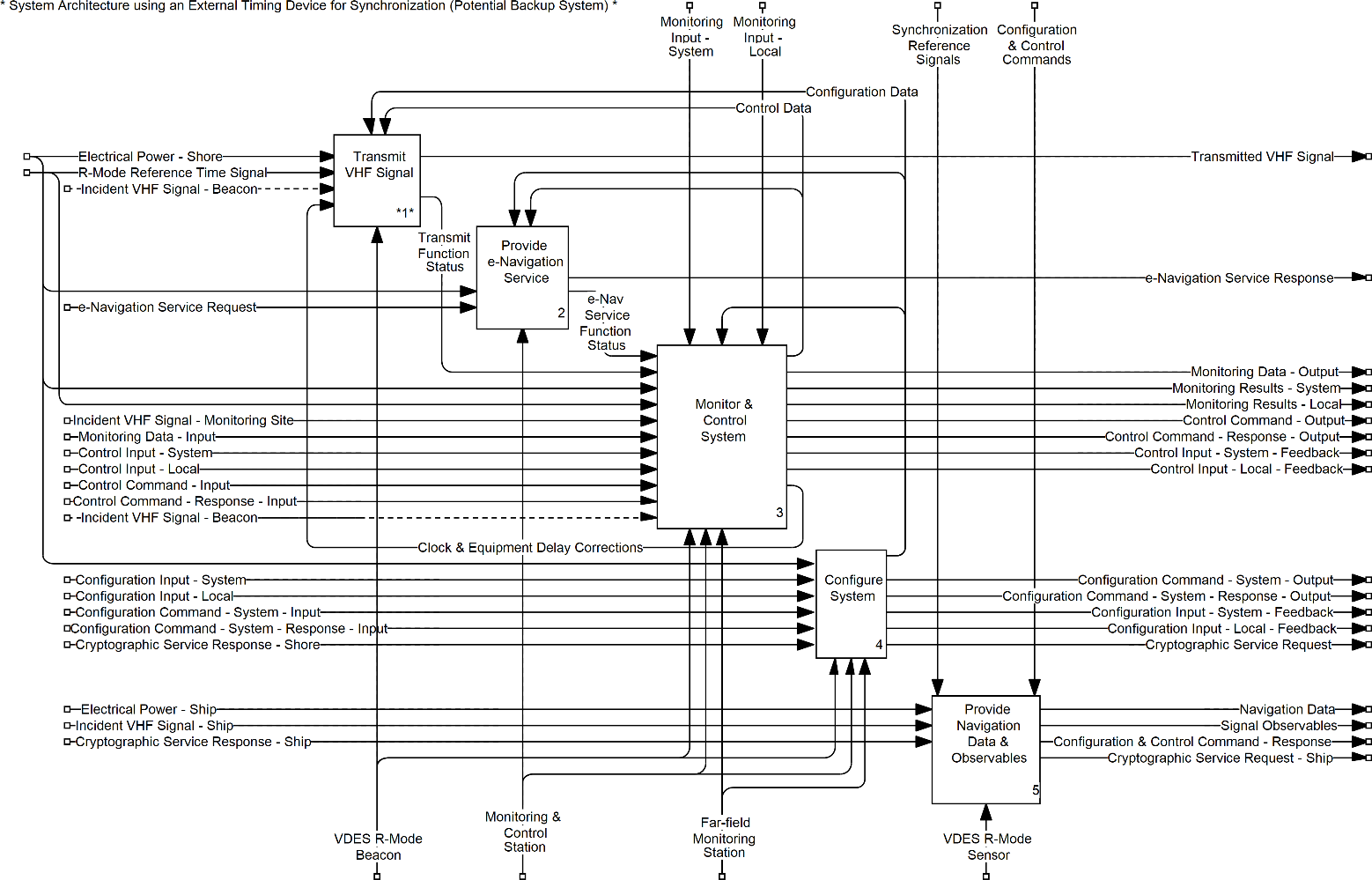


1. Transmit VHF Signal Function (contingency system configuration)

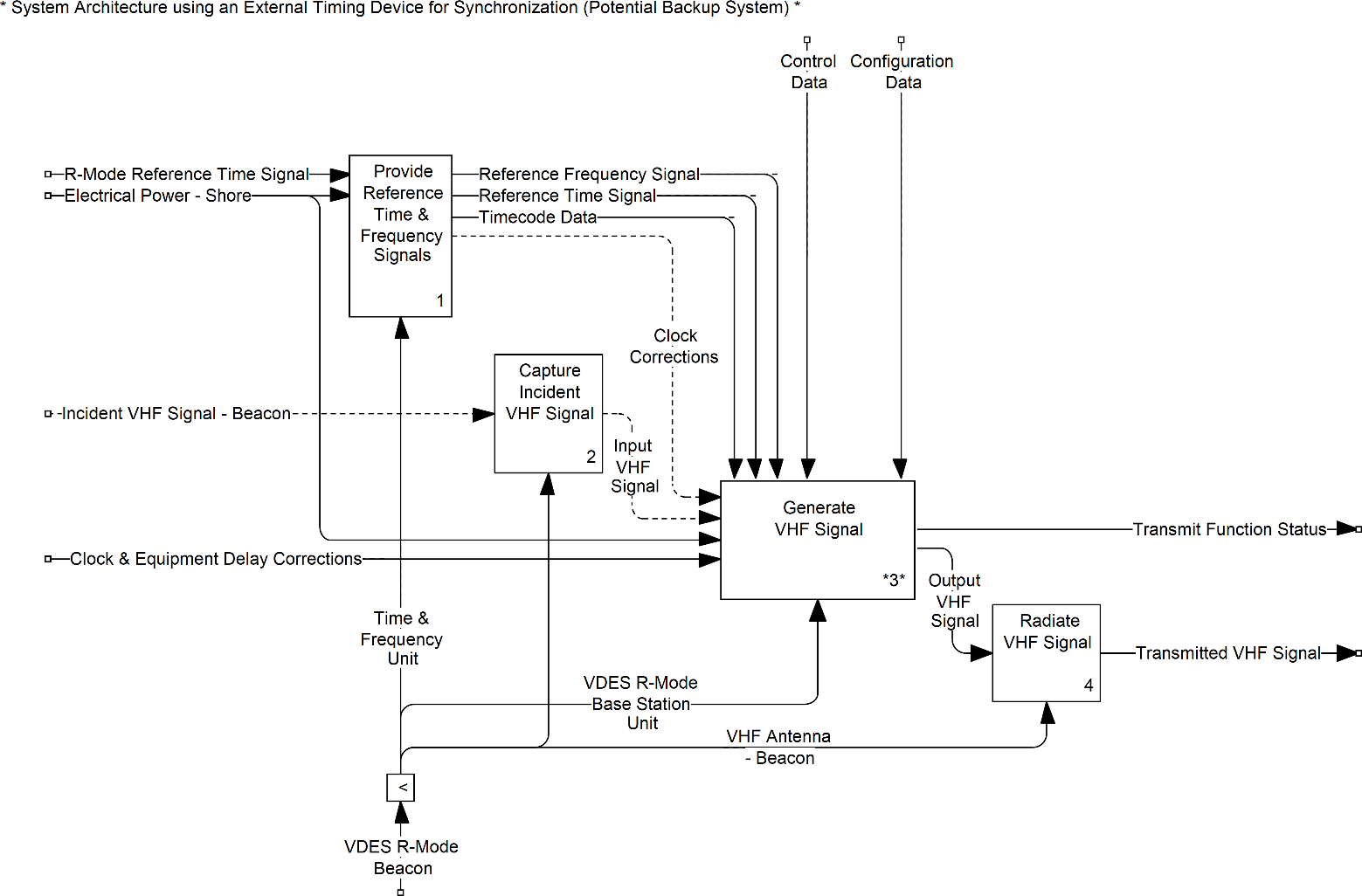


1. Generate VHF Signal Function (contingency system configuration)

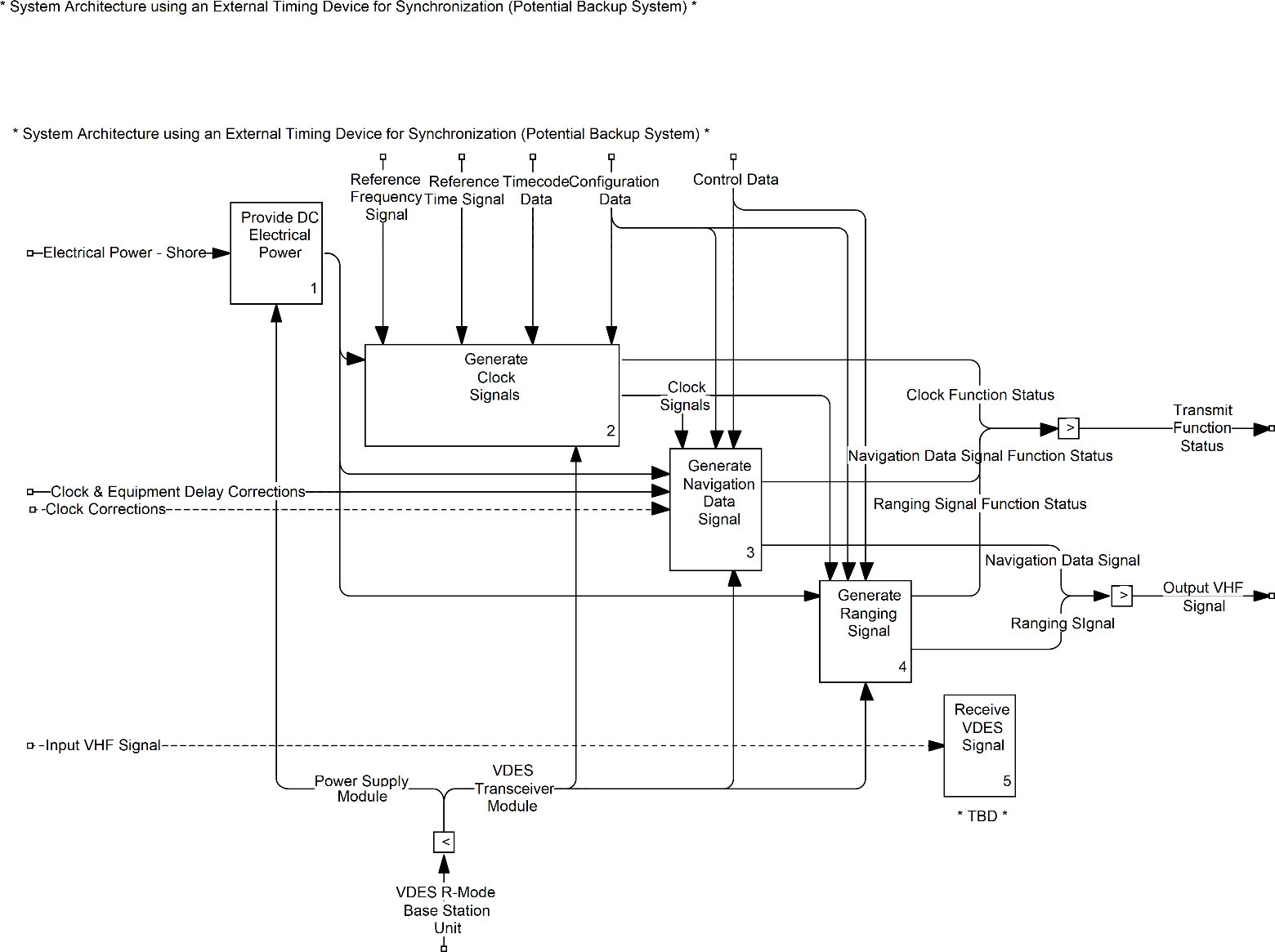
### System Architecture Using a Non-Gnss Source for Synchronization



1. Top-level functional breakdown for a VDES R-Mode System using a non-GNSS source for synchronization (backup system configuration)



1. Transmit VHF Signal Function (backup system configuration)



1. Generate VHF Signal Function (backup system configuration)

### Data Flow and System Element Descriptions

1. Data flows and key system elements in a VDES R-Mode System

| Data Flow / System Element | Description |
| --- | --- |
| Clock & Equipment Delay Corrections | (Near) real-time signal timing corrections produced by the Monitor & Control System Function in order to compensate for changes in the signal time of transmission due to changing environmental parameters |
| Clock Corrections | Parameters of a clock error model produced by the Time & Frequency Unit |
| Clock Function Status | Status of the Generate Clock Signals Function |
| Clock Signals | Internal clock signals used within VDES R-Mode Base Station Unit |
| Configuration & Control Command - Response | Response to a Configuration & Control Command received from a Multi-system Shipborne Radionavigation Unit |
| Configuration & Control Commands | Configuration & Control Commands received from a Multi-system Shipborne Radionavigation Unit |
| Configuration Command - System - Input | Configuration commands sent from the Monitoring & Control Station via a Wide Area Network to other shore side system elements |
| Configuration Command - System - Output | Remote configuration command to be sent to a shore side system element via a Wide Area Network |
| Configuration Command - System - Response - Input | Response from a shore side system element to configuration commands sent from the Monitoring & Control Station via a Wide Area Network |
| Configuration Command - System - Response - Output | Response to a configuration command sent via a Wide Area Network |
| Configuration Data | Configuration data for the Transmit VHF Signal Function, Provide e-Navigation Service Function and Monitor & Control System Function |
| Configuration Input - Local | Enables an operator - system administrator to configure a shore side system element via a local human-machine interface |
| Configuration Input - Local - Feedback | Feedback to an operator - system administrator on whether a configuration operation requested via a local human-machine interface has been successfully completed |
| Configuration Input - System | Enables an operator - system administrator to configure the shore side system elements using commands sent via a Wide Area Network |
| Configuration Input - System - Feedback | Feedback to an operator - system administrator on whether a previously requested remote configuration operation has been successfully completed |
| Control Command - Input | Control commands sent from the Monitoring & Control Station via a Wide Area Network to other shore side system elements |
| Control Command - Output | Control Commands to be sent from a Monitoring and Control Station via a Wide Area Network to other shore side system elements |
| Control Command - Response - Input | Response from a shore side system element to a control command sent from the Monitoring & Control Station via a Wide Area Network |
| Control Command - Response - Output | Response to a control command received via a Wide Area Network |
| Control Data | Control data for the Transmit VHF Signal Function and Provide e-Navigation Service Function |
| Control Input - Local | Enables an operator to control the operation of a shoreside system element via a local human-machine interface |
| Control Input - Local - Feedback | Feedback provided to an operator via a local human-machine interface on whether a previously requested control operation has been successfully completed |
| Control Input - System | Enables an operator to control the operation of the shoreside system elements from a Monitoring & Control Centre |
| Control Input - System - Feedback | Feedback to an operator located in a Monitoring & Control Centre on whether a previously requested control operation has been successfully completed |
| Cryptographic Service Request | Request for cryptographic material (such as private/public keys and certificates) required for signing the Transmitted RF Signal and verifying the authenticity of the received R-Mode VHF signal, to be sent via a Wide Area Network to a cryptographic server |
| Cryptographic Service Request - Ship | Requests for cryptographic material (such as public keys and certificates) required for the authentication of the R-Mode VHF signal received at the ship, to be sent to a Multi-system Shipborne Radionavigation Unit |
| Cryptographic Service Response - Ship | Response from a Multi-system Shipborne Radionavigation Unit to a cryptographic service request sent by the VDES R-Mode Sensor |
| Cryptographic Service Response - Shore | Response from a cryptographic server to a cryptographic service request sent by a shore side system element via a Wide Area Network |
| Electrical Power - Ship | Electrical power from a Multi-system Shipborne Radionavigation Unit |
| Electrical Power - Shore | Electrical power from the facilities in which the shoreside system elements are installed |
| Far-field Monitoring Station | Participates in the following system functions: Monitor & Control System and Configure System |
| GNSS Antenna | Provides a GNSS RF signal to the GNSS Receiver Module within the VDES Base Station Unit |
| GNSS RF Signal | GNSS signal captured by the GNSS Antenna at the VDES R-Mode Beacon |
| GNSS Receiver Module | Provides reference time signals (such as 1 PPS and UTC datum) to the Generate Clock Signals Function performed by the VDES R-Mode Base Station Unit |
| GNSS Service Status | Status of the Provide GNSS Services Function |
| GNSS Time Signal | Reference time signals (such as 1 PPS and UTC datum) used within VDES R-Mode Base Station Unit |
| Incident GNSS Signal | GNSS signal incident on the GNSS Antenna, used for synchronization of the VDES Base Station Unit |
| Incident VHF Signal - Beacon | VHF signal incident on VHF Antenna - Beacon |
| Incident VHF Signal - Monitoring Site | VHF signal incident on the Far-field Monitoring Station |
| Incident VHF Signal - Ship | VHF signal incident on VHF Antenna - Ship |
| Input VHF Signal | Signal captured by VHF Antenna - Beacon |
| Monitoring & Control Station | Is installed in a Monitoring & Control Centre and performs or participates in the following system functions: Provide e-Navigation Service; Monitor & Control System; and Configure System |
| Monitoring Data - Input | Monitoring data from the shoreside system elements received via a Wide Area Network |
| Monitoring Data - Output | Monitoring Data generated by the shoreside system elements to be sent via a Wide Area Network to a Monitoring and Control Station (MCS) located in a Monitoring and Control Centre;  Several redundant MCS' may be used, installed at different locations |
| Monitoring Input - Local | Enables an operator to perform monitoring functions on a shoreside system element via a local human-machine interface |
| Monitoring Input - System | Enables an operator to perform system monitoring functions (such as selecting monitoring results to be displayed and acknowledging alarms) from a Monitoring & Control Centre |
| Monitoring Results - Local | Real-time monitoring results for a shoreside system element displayed to an operator co-located with that element |
| Monitoring Results - System | Real-time system monitoring results displayed to an operator located in a Monitoring and Control Centre |
| Navigation Data | R-Mode Navigation Data to be output to a Multi-system Shipborne Radionavigation Unit |
| Navigation Data Signal | VHF signal carrying the R-Mode Navigation Data |
| Navigation Data Signal Function Status | Status of the Generate Navigation Data Signal Function |
| Output VHF Signal | RF signal feeding VHF Antenna - Beacon |
| Power Supply Module | Provides DC electric power to modules within VDES R-Mode Base Station Unit |
| R-Mode Reference Time Signal | Time transfer signal used to distribute the R-Mode Reference Time to VDES Beacons |
| Ranging Signal | VHF signal carrying the R-Mode ranging sequence |
| Ranging Signal Function Status | Status of the Generate Ranging Signal Function |
| Reference Frequency Signal | e.g. a 10 MHz sine-wave signal |
| Reference Frequency Unit | Frequency standard (such as a Rubidium oscillator) providing a stable reference frequency signal to the VDES Base Station Unit |
| Reference Time Signal | e.g. a 1 PPS signal |
| Signal Observables | R-Mode signal observables to be output to a Multi-system Shipborne Radionavigation Unit |
| Synchronization Reference Signals | Reference signals input from a Multi-system Shipborne Radionavigation Unit (MSRU) allowing the VDES R-Mode Sensor to synchronize its clock to the MSRU clock |
| Time & Frequency Unit | Provides reference frequency and time signals to the VDES Base Station Unit; optionally may provide parameters of a clock error model |
| Timecode Data | Information required to disambiguate the Reference Time Signal |
| Transmit Function Status | Status of the Transmit VHF Signal Function |
| Transmitted VHF Signal | Transmitted VHF Signal having a Navigation Data and a ranging signal component |
| VDES R-Mode Base Station Unit | Includes the following components: VDES Transceiver Module; GNSS Receiver Module; and Power Supply Module, and performs the Transmit VHF Signal Function |
| VDES R-Mode Beacon | Includes the following components: Reference Frequency Unit; GNSS Antenna; VHF Antenna - Beacon; and VDES Base Station Unit, and performs or participates in the following system functions: Transmit VHF Signal; Monitor & Control System; and Configure System |
| VDES R-Mode Sensor | Performs the Provide Navigation Data and Observables Function |
| VDES Transceiver Module | Provides a VDES transmit / receive capability |
| VHF Antenna - Beacon | Antenna used for transmitting the R-Mode Navigation Data and ranging signals |
| e-Nav Service Function Status | Status of the Provide e-Navigation Service Function |
| e-Navigation Service Request | e-Navigation Service Requests sent from an e-Navigation Service Client via a Wide Area Network |
| e-Navigation Service Response | Response to an e-Navigation Service Request from an e-Navigation Service Client received via a Wide Area Network |

# Physical Layer

The physical layer of the R-Mode application requires a ranging sequence, additional navigation data and transports the validity and health data from the shore station. The ranging sequences consist of a special sequence that is prior known by the receiver and contains validity and health information from the R-Mode shore station. VDE-TER schedules the resources based on a TDMA scheme between base stations that are coordinated by the network provider(s).

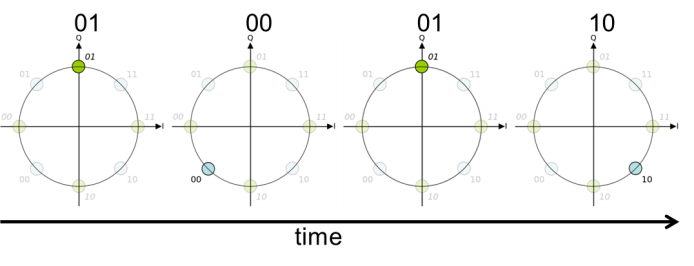
## Define ranging sequences (data payload)

The ranging sequence is known and part of the data payload. Each shore station shall send out the ranging sequence once per second.

The ranging sequence is a combination of two sequences to customize the required performance based on the given scenarios. The scenarios are:

* 1. Shorter distances between shore station and vessel
  2. Longer distances between shore station and vessel

The ranging sequences are defined in the following. The first sequence is based on the pi/4-QPSK modulation alphabet and alternates its constellation points. Figure 10 shows the principle on how the sequence is generated with an arbitrary length.



1. Generating alternating sequence (CC3.0 (Wikipedia))

The second part of the ranging sequence is a Gold code. Here the length of 1877 symbols are defined:

|  |  |
| --- | --- |
| **C\_I** | **1,1,1,1,0,0,1,0,0,0,0,1,0,1,0,0,1,1,0,0,0,0,0,0,0,1,0,0,1,1,1,0,1,0,1,0,0,1,1,0,1,0,0,1,1,1,1,0,0,1,1,0,0,0,1,0,0,0,1,1,0,1,1,0,1,1,0,0,1,0,1,0,1,0,0,0,0,1,1,0,0,0,1,1,1,1,1,1,1,0,1,1,1,0,1,0,0,0,0,0,0,1,0,0,0,0,0,1,1,1,1,0,1,1,1,1,1,0,1,0,1,1,0,1,1,1,0,1,1,0,0,0,1,0,1,1,1,1,1,0,0,0,0,1,0,1,1,0,1,1,1,1,0,0,0,1,0,1,1,0,0,1,1,1,0,1,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0,1,1,1,0,0,0,1,0,0,0,1,0,1,0,1,0,0,0,1,0,1,0,0,0,0,1,1,0,0,1,1,0,0,1,0,0,0,1,0,0,0,0,1,1,1,0,1,0,0,1,0,0,0,1,0,1,1,1,0,1,1,1,0,1,0,1,1,0,0,0,1,1,1,0,1,1,0,0,1,0,0,0,0,1,1,1,0,1,1,1,1,0,1,1,0,1,1,0,1,1,1,0,1,1,1,1,0,1,0,1,0,1,1,1,1,0,1,0,1,1,1,1,0,0,1,1,0,1,0,1,0,1,0,0,1,1,1,0,1,0,0,0,1,1,0,0,1,0,1,1,0,0,0,1,1,0,0,1,1,1,0,0,1,1,0,0,1,1,1,1,0,1,1,0,0,1,0,0,0,1,0,0,0,1,1,0,0,1,0,1,1,0,1,1,1,1,0,0,0,1,0,1,0,1,0,1,1,0,0,1,0,0,1,1,1,0,0,0,0,1,0,0,1,0,0,0,0,0,1,0,1,1,1,0,0,1,0,1,1,0,1,0,1,0,0,1,1,0,1,1,0,0,0,1,0,0,0,0,0,1,0,1,1,1,0,1,1,1,0,0,1,1,1,1,1,1,0,1,0,0,1,1,1,1,1,0,1,1,1,1,1,1,0,1,1,0,1,0,0,0,0,1,0,0,0,1,1,1,1,0,1,1,1,0,0,1,1,1,0,1,1,0,1,1,1,0,1,1,0,1,0,0,0,1,0,0,1,0,1,0,1,1,1,1,0,0,1,0,0,0,0,0,1,1,1,0,0,0,0,1,1,1,1,1,1,0,1,0,0,0,0,1,0,1,0,1,1,0,0,1,0,1,1,1,0,0,0,1,0,1,0,1,0,0,1,1,0,0,1,1,0,1,1,1,1,0,0,0,0,0,1,0,0,0,0,0,1,0,0,1,0,0,1,1,1,1,0,1,1,0,1,1,0,1,1,0,1,0,1,0,1,1,0,0,1,1,0,0,0,0,1,0,1,0,1,1,1,1,1,1,0,1,1,1,1,0,1,1,1,0,0,1,0,1,0,0,0,0,1,1,1,0,1,1,0,0,1,1,1,0,1,1,1,1,1,0,0,1,0,0,0,0,0,0,1,1,0,0,0,0,1,0,0,0,0,0,1,1,0,1,1,0,1,0,0,1,0,0,0,1,0,1,0,1,1,1,1,0,0,0,1,0,0,0,1,1,1,0,1,0,1,0,1,0,1,0,1,1,0,0,0,1,1,0,1,1,1,1,0,0,1,0,1,0,0,1,1,1,1,1,1,0,0,0,0,0,0,0,1,0,1,0,0,1,1,1,0,1,0,1,1,0,1,1,0,0,1,0,1,0,0,1,0,1,0,1,0,1,1,0,0,0,0,1,1,1,1,1,0,0,1,0,1,0,0,1,0,0,0,0,1,0,1,0,1,1,1,1,1,0,0,1,1,0,0,0,1,0,0,1,1,1,0,0,0,0,0,1,0,0,0,1,0,1,0,1,0,1,1,0,1,1,1,0,1,0,1,0,0,0,1,0,0,1,0,0,1,0,0,1,1,0,0,1,0,1,1,0,0,1,0,1,0,1,0,1,0,1,0,1,0,1,1,1,1,1,1,0,0,0,1,0,1,1,1,0,0,1,0,0,0,0,0,0,1,0,1,1,0,1,1,0,1,1,1,0,1,0,0,1,0,0,1,1,1,1,0,1,0,1,0,1,0,0,0,1,0,1,0,1,1,0,0,1,0,1,0,0,0,1,0,0,1,1,0,0,1,1,1,0,0,1,0,0,1,1,0,1,0,0,0,1,0,1,0,0,1,1,0,1,1,0,1,0,1,0,1,1,0,0,0,0,0,0,0,0,1,1,0,0,1,0,1,0,0,1,0,1,0,1,0,1,1,0,1,0,1,0,0,0,1,0,0,1,1,0,0,0,0,1,0,1,0,0,0,1,0,1,0,0,1,1,1,1,0,0,0,1,0,1,0,0,0,1,0,0,0,1,1,1,0,1,0,1,0,1,1,1,0,0,0,1,0,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,1,0,1,0,1,1,0,1,0,1,1,0,0,0,0,1,0,1,1,0,1,1,0,1,0,0,0,0,0,1,1,0,1,1,0,1,1,1,1,1,1,1,1,1,1,1,0,1,0,0,1,0,1,1,0,0,1,0,0,0,1,1,1,0,0,1,1,1,0,1,0,0,0,0,0,0,1,1,1,0,0,0,0,1,0,1,0,1,0,1,0,1,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,0,1,1,1,1,1,1,0,1,1,0,0,0,1,0,1,1,0,1,1,0,1,0,0,0,1,1,1,1,0,1,0,0,1,1,1,0,0,1,0,0,1,1,1,0,0,0,0,1,1,0,0,1,1,1,0,0,0,0,1,1,1,1,1,0,1,0,1,1,0,0,0,0,1,1,0,1,0,0,1,0,1,1,1,0,1,0,0,1,0,0,0,1,0,1,0,0,1,1,1,0,1,1,1,1,0,0,0,0,1,1,1,0,1,1,0,0,1,1,1,0,1,0,1,1,0,0,1,1,1,0,1,1,0,1,1,0,1,1,0,0,1,1,0,1,1,0,1,1,1,1,0,0,1,1,0,0,1,1,1,1,0,0,0,1,0,1,1,1,0,0,0,1,0,1,0,0,0,0,1,0,1,1,1,1,0,1,0,1,1,1,1,0,0,0,0,1,0,1,1,1,1,0,1,0,0,0,0,0,1,1,0,1,0,0,0,1,0,0,1,0,1,1,1,1,0,0,0,1,1,1,1,1,1,1,0,0,0,0,1,1,1,0,0,0,1,1,1,0,1,1,0,0,1,1,1,1,1,1,1,0,1,0,0,1,1,0,1,0,1,0,1,0,1,0,0,0,0,1,0,1,0,0,1,1,1,1,0,1,0,0,0,0,1,0,1,1,1,1,0,1,0,1,0,1,0,0,1,0,1,1,1,0,1,0,1,0,0,0,0,0,1,0,0,0,1,0,0,0,1,0,1,0,1,1,0,0,0,0,0,1,1,1,1,0,0,0,0,0,0,0,1,1,1,1,0,1,1,1,0,0,0,0,0,0,1,0,1,1,1,1,1,1,1,0,0,0,0,1,0,1,1,0,1,1,1,0,0,1,1,1,0,1,0,1,0,1,1,0,0,1,1,0,0,0,0,1,1,0,1,0,0,1,1,0,1,1,0,1,0,0,1,0,0,1,0,0,0,1,1,1,1,1,1,0,1,0,1,1,0,0,1,0,1,1,0,1,0,1,1,0,1,1,1,1,0,0,0,1,1,1,1,0,0,1,1,1,1,0,0,0,1,1,1,0,0,1,0,1,0,1,1,1,1,1,1,0,0,0,0,0,1,1,1,0,0,1,1,0,0,1,1,0,0,1,0,0,0,1,1,0,1,0,0,1,1,1,0,1,0,0,0,1,0,0,1,0,0,1,0,0,0,0,1,0,0,1,1,1,1,1,1,0,1,1,0,0,1,0,1,0,1,0,0,0,1,0,1,0,0,1,0,0,0,1,0,1,1,0,0,0,0,0,0,0,1,0,1,0,1,1,1,1,0,0,0,0,1,1,1,0,1,0,1,1,0,1,0,1,1,0,1,1,1,1,0,0,0,1,1,1,1,0,0,0,0,0,0,0,1,1,0,0,1,1,0,1,1,1,0,0,1,0,0,1,1,0,0,1,1,0,0,0,1,0,0,0,0,1,0,0,0,0,1** |
| **C\_Q** | **0,1,1,0,0,1,1,1,1,0,1,1,1,1,0,1,1,0,1,0,0,1,1,0,0,0,1,0,0,1,1,1,0,0,1,1,0,0,1,1,1,1,0,0,1,0,0,0,1,1,0,0,1,0,1,1,1,0,0,1,1,1,1,1,1,0,0,1,1,1,0,0,1,1,0,1,1,1,0,0,1,0,0,1,1,0,1,0,1,1,0,1,0,0,0,0,0,1,0,1,1,1,1,0,0,1,1,1,0,1,1,1,1,0,0,1,1,1,0,0,0,1,0,0,0,1,0,0,1,1,0,1,0,0,0,1,0,1,0,0,1,0,0,0,0,0,1,1,1,0,0,1,0,1,0,0,0,0,0,0,1,1,1,0,0,0,1,1,1,0,1,0,1,1,1,0,1,0,0,0,0,0,1,0,0,1,0,0,0,1,1,1,0,0,1,1,0,1,1,1,1,1,1,0,0,1,1,0,0,1,0,1,0,1,0,0,1,0,0,0,0,1,1,1,1,0,0,0,0,1,1,1,0,1,0,0,1,0,1,1,0,1,1,1,0,0,1,0,1,0,0,0,0,1,0,0,0,0,0,0,0,1,1,0,1,0,0,0,0,1,1,0,0,0,0,0,1,0,0,0,1,0,1,1,0,1,1,1,1,1,1,1,1,0,1,0,1,1,1,1,1,0,1,1,1,1,1,1,1,1,0,0,1,1,0,0,0,1,0,0,0,1,1,1,0,0,1,1,0,0,1,1,0,1,1,0,1,0,1,0,1,1,1,1,1,1,1,1,0,1,0,0,1,0,1,0,1,1,0,1,1,1,0,1,1,0,1,0,1,1,1,0,1,1,1,0,0,0,1,0,1,1,0,0,0,0,1,0,1,0,1,1,1,1,0,1,1,0,1,0,0,0,1,1,0,1,0,1,0,0,0,0,1,0,1,0,0,0,0,1,1,1,0,0,1,0,0,1,0,0,0,0,1,0,1,1,0,1,1,0,0,0,1,0,0,0,1,0,1,1,1,1,0,1,1,0,0,0,0,0,0,0,1,0,0,1,1,1,1,0,1,0,1,1,0,1,1,1,1,0,1,0,1,1,0,1,1,0,1,0,0,0,1,0,0,1,1,0,0,0,0,1,1,1,1,0,0,0,0,0,1,1,0,1,1,1,1,1,0,0,1,1,1,0,0,0,1,1,1,0,0,1,1,1,1,0,1,0,1,0,1,0,0,1,1,0,1,1,0,1,0,1,0,0,0,0,0,1,0,1,0,0,1,0,0,0,1,0,1,1,1,1,0,0,1,1,1,1,1,1,1,1,0,1,1,0,0,1,1,0,0,0,1,0,1,0,1,1,1,0,0,0,1,1,0,1,0,0,1,0,0,0,0,0,1,0,1,1,0,0,0,0,1,1,0,0,0,0,1,0,0,0,1,1,1,1,1,0,1,0,1,1,1,0,1,0,1,1,0,1,1,0,0,0,0,0,0,1,1,1,1,0,1,1,0,0,1,1,1,0,0,0,1,0,0,1,1,0,1,1,1,0,0,1,0,0,1,1,1,0,1,1,1,0,0,1,1,1,1,1,1,0,1,1,1,0,0,0,1,0,0,0,1,1,0,1,0,1,0,1,1,1,1,0,1,1,1,0,1,1,0,0,0,0,1,1,0,0,0,0,0,1,0,1,1,1,0,1,0,0,1,1,0,0,1,0,0,1,1,0,0,1,0,1,1,0,0,1,0,0,0,0,0,1,0,1,1,1,0,0,0,1,1,1,1,1,0,0,1,1,1,0,1,1,1,1,1,1,0,1,1,0,1,0,1,0,1,0,0,0,1,1,0,0,0,1,1,1,1,0,1,1,0,0,0,0,0,1,1,0,0,1,0,1,0,1,0,0,0,1,1,0,0,0,0,1,1,0,1,1,0,1,1,1,1,1,0,0,1,0,0,0,1,0,1,1,0,0,1,0,0,0,0,1,1,1,1,1,0,1,0,1,0,1,0,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,1,1,0,1,1,0,0,1,0,1,0,0,0,0,0,1,0,1,0,0,0,1,1,0,1,1,0,0,1,1,0,1,0,0,1,0,1,1,0,1,0,0,0,0,1,0,0,0,1,1,0,0,0,0,1,0,0,0,0,0,0,1,0,1,1,1,0,0,0,1,0,0,0,0,0,0,0,0,0,1,1,0,1,1,1,1,0,0,1,1,1,0,0,0,1,1,0,0,0,0,0,1,1,1,0,0,1,1,1,1,1,0,0,1,1,0,1,1,1,1,0,0,0,0,1,0,1,1,1,1,0,0,1,0,1,1,0,0,1,0,0,0,0,1,0,1,1,0,1,0,1,1,0,0,1,0,0,0,0,0,1,1,0,1,0,0,0,1,0,0,0,0,0,1,1,1,1,0,0,1,0,0,0,0,1,1,1,0,1,1,0,1,0,0,0,1,1,0,0,1,1,0,0,1,1,0,0,1,0,0,0,1,0,1,0,0,0,0,0,0,1,1,1,1,1,0,1,0,0,1,1,1,1,0,0,0,1,1,1,1,1,0,1,0,1,0,0,0,1,1,1,0,0,1,0,1,0,1,0,1,0,0,0,0,1,1,0,0,0,0,0,0,0,1,0,0,0,1,1,0,0,1,0,0,1,1,0,1,0,1,0,0,1,0,0,1,0,1,1,1,1,1,0,0,0,0,1,1,0,1,0,1,1,0,0,1,0,0,1,1,0,1,0,1,0,1,0,1,0,1,1,1,1,1,1,0,0,0,1,0,1,1,0,0,0,0,1,0,0,1,0,1,1,1,1,0,0,1,0,0,1,1,0,1,1,0,1,1,0,1,0,0,0,0,1,1,0,1,0,1,1,0,0,1,0,1,0,0,1,1,0,1,0,1,0,1,0,1,1,1,1,0,0,0,1,0,0,0,0,0,0,0,0,1,1,1,0,0,1,0,0,1,1,1,1,0,1,0,0,1,0,1,0,1,1,1,1,0,0,1,1,0,0,0,1,1,1,0,0,1,1,0,0,0,0,1,0,0,1,1,0,1,1,0,1,0,0,0,1,1,1,0,1,0,1,0,1,0,1,0,0,1,1,0,1,0,0,0,1,1,0,1,1,0,0,0,1,1,0,1,1,0,1,1,0,1,0,1,1,1,0,0,1,0,1,1,0,1,0,0,1,1,1,0,1,1,1,1,0,1,1,0,0,1,0,0,0,1,1,1,1,0,1,1,0,1,1,0,1,0,1,1,1,0,1,0,1,0,0,1,0,1,1,0,0,0,1,0,0,1,0,0,0,1,1,0,0,1,1,0,1,0,0,0,0,0,1,1,1,1,1,1,0,0,1,1,0,0,0,1,1,1,0,0,1,0,1,0,1,0,0,0,1,0,0,1,0,0,1,0,0,1,0,0,0,0,0,0,1,0,1,1,0,1,0,0,1,1,0,0,1,0,1,0,0,0,1,0,0,0,0,1,1,1,1,1,0,1,0,1,1,0,0,0,0,1,1,1,1,0,0,1,1,0,1,0,1,0,1,1,0,1,1,0,1,0,0,1,0,0,1,0,1,0,1,0,1,1,1,0,1,1,1,1,1,1,1,0,1,1,1,1,1,0,0,0,0,0,1,1,1,1,0,0,1,1,1,0,0,0,0,0,1,1,0,0,1,1,0,1,0,0,1,0,0,0,1,1,1,0,0,0,0,1,1,0,0,0,0,0,1,0,0,1,1,1,0,1,0,0,0,0,0,0,1,0,0,1,1,0,0,0,1,0,0,0,1,1,1,0,0,0,0,1,1,0,0,0,1,1,0,0,1,1,1,0,0,1,1,1,0,1,1,0,0,1,1,1,0,0,1,1,1,1,0,0,0,0,0,1,0,0,1,1,0,0,1,1,0,1,0,0,1,0,1,1,1,0,0,0,1,1,1,0,0,1,0,0,1,1,0,1,0,1,0,0,0,1,0,1,1,1,1,1,1,1,0,1,0,0,0,0,1,1,1,0,1,1,0,0,0,0,0,1,0,1,1,0,0,0,0,0,0,1,0,1,0,1,1,0,0,1,1,1,1,1,0,1,1,1,0,0,0,0,1,0,0,1,0,1,1,1,1,0,0,0,0,1,0,1,1,0,1,0,1,0,0,1,0,0,0,1,0,1,1,1,1,1,0,0,1,1,1,1,0,1,0,0,1,0,0,0,0,1,1,0,0** |

### Combination of Ranging Sequences

Both sequences are weighted and then added together. The alternating sequence is multiplied with a weighting factor for short distances (higher SNR) and for larger distances (lower SNR). The Gold code is multiplied with a weighting factor for short distances and for large distances.

The ranging sequence is followed by validity and signal health status bits. These bits are protected by a Hamming code (7,4).

## Navigation data

The navigation data contains all the data to calculate the range between the transmitter site and the receiver. The navigation data is transmitted every minute by the shore station by a message.

## Antenna characteristics

The antenna of the R-Mode shore station can be of any characteristics. Larger antenna gains are recommended to reach further and improve the GDOP.

## Clock requirements

For a positioning system, which provides time information in the ranging signals, synchronisation and calibration are essential for the performance of the R-Mode service. Therefore, each ranging signal generator, the VDES base station for VDES R-Mode, has to be synchronised to the R-Mode reference time in this region. The time information will be given by a 1 PPS and 10 MHz signal. Additionally, information to disambiguate the PPS pulses and about the clock error will be given over a data channel from the timing source, if not supplied internally. Further information about the clock requirements can be found in Chapter 9.

For the generation of accurate ranging signals it is important that all internal oscillators of the VDES base station are synchronised with the external 10 MHz signal.

# Link Layer

The link layer of R-Mode is described in detail in the following. R-Mode is part of VDE-TER and shall consider AIS.

## R-mode integration with VDE-terrestrial link layer

In order to introduce R-mode into VDE-TER there is a need for two new types of data transmission, i.e. both Navigation Data and Range Sequence need to be sent to Ship stations to enable ranging. For ***R-mode Navigation Data*** transmissions the ***Shore originated broadcast*** downlink protocol shall be used as depicted in the Figure 33 and described in C 4.30.1.

Obraz zawierający zrzut ekranu

Opis wygenerowany automatycznie

The following extensions shall be implemented into the VDE-TER Link layer:

* 1. Two new logical channels need to be defined and their definitions broadcasted within Bulletin Board. There is, however, no need for new protocols or Bulletin Board structure changes to enable it.
  2. The new logical channels require two new LC (Logical Channel) Functions for Terrestrial to be added into ***Table 44 - Logical Channel definition***, i.e. ***5 – R-mode Range Sequence*** and ***6 – R-mode Navigation Data*** LC Functions***.*** 
     1. The ***6 – R-mode Navigation Data*** function definition is optional (***3 – Data*** can be used instead).
  3. Logical channel definitions do not need to be described in this document – in general, they are part of the system configuration and not necessary part of the standard. A default LC configuration, however, could be proposed – like it is defined for VDE-TER data communication (see ***C 4.16. VDE-TER default physical channel and slot map***).
  4. For the purpose of R-mode Navigation Data transmission the payload of messages #74, #75 and #76 shall be used.
     1. Message Type #75 might be optional if there is enough data payload within message #74 and #76.
     2. Each Shore station may transmit either just its own Navigation Data or combined with neighboring stations data.
     3. For the purpose of R-mode Navigation Data both FEC and Scrambling shall be used (**existing VDE-TER Link IDs shall be used**).
  5. In order to enable different range sequences usage; there is a need to inform Ship station which code is used as a Range Sequence. This information needs to be included in Navigation Data (Message).
  6. Shore station shall allocate its resources (via message #4 and Announcement Signaling Channel current mechanism – see also C 4.9.3) and choose the existing Link ID for the purpose of the R-mode Navigation Data transmissions whenever updated/changed data needs to be sent – i.e. at least once per minute.
  7. In ***Table 32 – VDE Message Summary*** anew message type (i.e. #77) for R-mode Range Sequence transmissions needs to be defined – the message structure and processing shall, however, be significantly simplified. For the Range Sequence transmissions neither FEC, CRC nor scrambling should be applied. In general, the message #77 should be transmitted:
     1. As a one slot message (one full slot/fragment),
     2. Without: FEC, Scrambling, CRC and even Training sequence,
     3. None or minimum frame structure,
     4. With the **new Link ID defined for R-mode Range Sequence** taking into account the given above requirements (i.e a new Link ID needs to be added into ***Table 8 - VDE-TER Link ID parameters***).
  8. Shore originated broadcast (Figure 33) does not allow message types different than #4, #74, #75 and #76 and, moreover, this scheme would introduce a lot of overhead when used for one slot Range Sequence transmissions. Thus, a new downlink protocol for sending R-mode Range Sequences needs to be defined. It shall be based on ***Shore to Ship short data message*** solution (see figure 40 and C 4.30.8).

Obraz zawierający obiekt

Opis wygenerowany automatycznie

However, two modifications in this protocol are needed: (1) Ack (#13) should not be sent from Ships and (2) Message Type #77 (Range Sequence) need to be used instead of Type #92. In general, in order to send Range Sequences in VDE-TER a **Short Data broadcast message protocol originated from Shore** shall be defined.

## Bulletin board usage for R-mode

The existing Bulletin Board (BB) structure and its associated mechanisms (see C 4.15 in G1139) shall be exploited for R-mode purposes:

1. Control station service area parameters shall be used to define service area of the R-mode network,
2. Bulletin Board version, start time for this version and validity of this version fields shall be used to support updates of R-mode configuration to the newer version,
3. Modulation, coding and protocol versions supported (i.e. definition of the Shore station functionalities) shall contain general information concerning VDES Shore station R-mode capabilities,
4. Logical Channel definitions transmission mechanism shall be used to provide (to Ship stations) the R-mode LC configurations of Shore stations.

In general, Shore originated broadcast, as given in Figure 33, should rather be used to send R-mode Navigation Data. It is more flexible solution than potential Bulletin Board approach.

BB Data shall, however, support R-mode e.g. by defining the area and configuration of the network used for R-mode (e.g. logical channels configuration and functions).

Bulletin Board Signaling Channel shall transmit R-mode configuration data within its current definition (see C 4.9.1).

# Application Layer

## Navigation data

The navigation data provide essential information to calculate the range between the transmitter site and the receiver. The data are inspired by Galileo navigation data to facilitate easy combination with available GNSS.

### Traceable R-Mode Reference Time to UTC

The R-Mode reference time (RMRT) which is used in a certain region of one or several countries has to be traceable to UTC. This is a precondition that the R-Mode system can be used together with other navigation system (e.g. GNSS) for positioning without the necessity to estimate the system time offset at user site.

Depending on the realisation traceability can be reached as shown in Figure 11 below.



1. Traceability of RMRT to UTC

Important to know, UTC is calculated in post processing over one-month data batches of worldwide distributed atomic clocks. It is made available with monthly update rate. So it is not appropriate for real time applications. The UTC realisations of metrological institutes (UTC(k)) and of the GNSS systems differ usually by some leap seconds (GPS, Galileo, BeiDou) and some nanoseconds which varies over longer periods. These realisations are continuously available and therefore appropriate for real time applications. A similar difference of some leap seconds and some nanoseconds is awaited when the RMRT is derived from the GNSS system time, UTC(k) or another timing source in the future.

The RMRT can be seen as a realisation of UTC which deviates from UTC by some nanoseconds and a well-known number of leap seconds.

### Continuous R-Mode System Time

The handling of leap seconds is typically prone for errors especially in times when the number will be changed. Therefore, the R-Mode system uses a continuous time scale which can be converted to UTC at any time. To be in line with the number of leap seconds of GPS and Galileo the RMRT start epoch is defined as 13 seconds before midnight between 21st August and 22nd August 1999 UTC.

### R-Mode Reference Time

The RMRT is given as 32-bit binary number composed of two parameters as follows:

* The Week Number (*WN*) is an integer counter that gives the sequential week number from the RMRT start epoch. This parameter is represented with 12 bits, which covers 4096 weeks (about 78 years). Then the counter is reset to zero to cover an additional period modulo 4096.
* The Time of Week (*TOW*) is defined as the number of seconds that have occurred since the transition from the previous week. The *TOW* covers an entire week from 0 to 604799 seconds and is reset to zero at the end of each week.

The RMRT parameters are transmitted according to the characteristics stated in .

1. RMRT parameters (32 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| *WN* | Week Number | 12 | 1 | Week |
| *TOW* | Time of Week | 20 | 1 | s |

As RMRT is a continuous time scale, and UTC is corrected periodically with an integer number of leap seconds, the R-Mode navigation message contains all necessary parameters to convert between RMRT and UTC.

*WN* and *TOW* refer to the beginning of slot 0 of current VDES frame (60 s length).

### Clock and Delay Corrections

The start of transmission deviates by an amount of time from the start of a slot. This is due to the fact that the transmission has to take place in the slot so that a VDES message starts usually some microseconds after start of the slot. Furthermore, additional delays are caused by static calibration offsets, clock offsets and dynamic delays of the transceiver chain caused by aging or environmental sensitivity. These delays will be considered by the clock correction (*CO*) and an uncertainty (*CU*) as 1σ confidence level. So the user has to use this correction to consider any delay with respect of the start of ranging sequence to the theoretical start of the slot.

The parameters CO and CU are defined in Table 3.

1. Parameter to describe clock offset and delay of transmitted ranging sequence to start of slot (26 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| *CO* | Clock offset and delay | 21 | 10-10 | s |
| *CU* | Clock uncertainty | 5 | 10-10 | s |

### RMRT -UTC Conversion Algorithm and Parameters

The UTC time tUTC is computed through 3 different cases depending on the epoch of a possible leap second adjustment (scheduled future or recent past) given by DN, the day at the end of which the leap second becomes effective, and week number WNLSF to which DN is referenced. “Day one” of DN is the first day relative to the end/start of week and the WNLSF value consists of eight bits which are a modulo 256 binary representation of the R-Mode week number to which the DN is referenced.

The parameters for RMRT to UTC conversion are defined in Table 4.

1. Parameter for RMRT -UTC conversion (99 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 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 |
| Δ*t*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 |
| Δ*t*LSF | Leap Second count after leap second adjustment | 8\* | 1 | s |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the Most Significant Bit (MSB).

\*\* The value range of *DN* is from 1 (= Sunday) to 7 (= Saturday).

Calculation of RMRT -UTC conversion see subchapter section 5.1.7 “GST-UTC Conversion Algorithm and Parameters” in Galileo signal-in-space interface control document.

### GPS to RMRT Conversion and Parameters

The difference between the R-Mode and the GPS time scales, expressed in seconds, is given by the equation below.

Δ𝑡Systems = 𝑡R-Mode − 𝑡GPS = 𝐴0G + 𝐴1G [𝑇OW − 𝑡OG + 604800(*WN* − *WN*OG)]

with

* *A*0G constant term of the offset Δ*t*systems
* *A*1G rate of change of the offset Δ*t*systems
* *t*0G reference time for R-Mode / GPS time offset (RGTO) data
* *t*R-Mode RMRT (s)
* *t*GPS GPS time(s)
* *WN* RMRT Week Number
* *WN*0G Week Number of the RGTO reference

The user must account in the above formula for the truncated nature (roll-over) of the weekly parameters (*WN*, *WN*0G), considering that at the time of broadcast of the RGTO parameters, the absolute value of the difference between non-truncated *WN* and *WN*0G values does not exceed 31.

The RGTO parameters are formatted according to the values in Table 4.

When the RGTO is not available the RGTO parameters disseminated are: *A*0G (all ones -16 bits), *A*1G (all ones - 12 bits), *t*0G (all ones - 8 bits), *WN*0G (all ones - 6 bits). When a user receives all four parameters set to all ones the RGTO is considered as not valid.

1. Parameter for the R-Mode to GPS system time offset computation (42 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| *A*0G | Constant term of the polynomial describing the offset Δ*t*systems | 16\* | 2-35 | s |
| *A*1G | Rate of change of the offset Δ*t*systems | 12\* | 2-51 | s/s |
| *t*0G | Reference time for RGTO data | 8 | 3600 | s |
| *WN*0G | Week Number of RGTO reference | 6 | 1 | Week |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the Most Significant Bit (MSB).

This definition is in line with definition of GPS Time to Galileo system time offset computation in the Galileo signal-in-space interface control document.

### Navigation Data Validity and Signal Health Status

Each station should provide the validity status of provided navigation data and the signal health status. The parameters are defined in Table 6.

1. Parameter navigation data validity and signal health status (3 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| *DVS* | Navigation Data validity status  0 - Navigation data valid  1 - Working without guarantee | 1 | N/A | dimensionless |
| *HS* | Signal Health Status  0 - Signal OK  1 - Signal out of service  2 - Signal will be out of service  3 - Signal currently in test | 2 | N/A | dimensionless |

### Coordinates of transmitter antenna

The coordinates of the transmitter antenna are given in WGS84 as latitude, longitude and altitude.

To reach better then **dm** accuracy of antenna position the following resolution are necessary

* longitude of 1.57\*10-8 is necessary ( (2π) / (2π \*radius erath / 1 dm) ) => 26 bits (1.49\*10-8)
* latitude of 3.14\*10-8 is necessary ( (2π) / (π \*radius erath / 1 dm) ) => 25 bits (2.98\*10-8)
* altitude of 1.25\*10-5 (dm in 8000 m maximal altitude ) (1 / (8000 / 0.1)) => 17 bits (7.63\*10-6)

1. Antenna position in WGS84 (68 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| *LO* | longitude | 26 |  |  |
| *LA* | latitude | 25 |  |  |
| *AL* | altitude | 17 |  |  |

### For each ranging sequence

* Healthy status (3 bits) (at least every 10 s)
* Ranging sequence

### Navigation data message

Ones per minute:

* R-Mode System Time (32 bits)
* RMRT to UTC conversion (99 bits)
* RMRT to GPS conversion (42 bits)
* Clock and delay corrections (26 bits)
* Coordinates of transmitter antenna (68 bits)
* Differential corrections
* ID ranging sequence (8 possible)
* Define bits for signature
* Spare bits for future need?

### Performance requirements (Criteria: sort this to consider a mixed update rate)

* + - Time stamp,
    - Accuracy of antenna location (WGS-84),
    - Health status (synchronized to which time base (UTC, …)),
    - Clock deviation (clock model, UTC synch data),
    - data derived from a monitoring station (timing delays (cables),
    - error statistics),
    - downtime notifications,

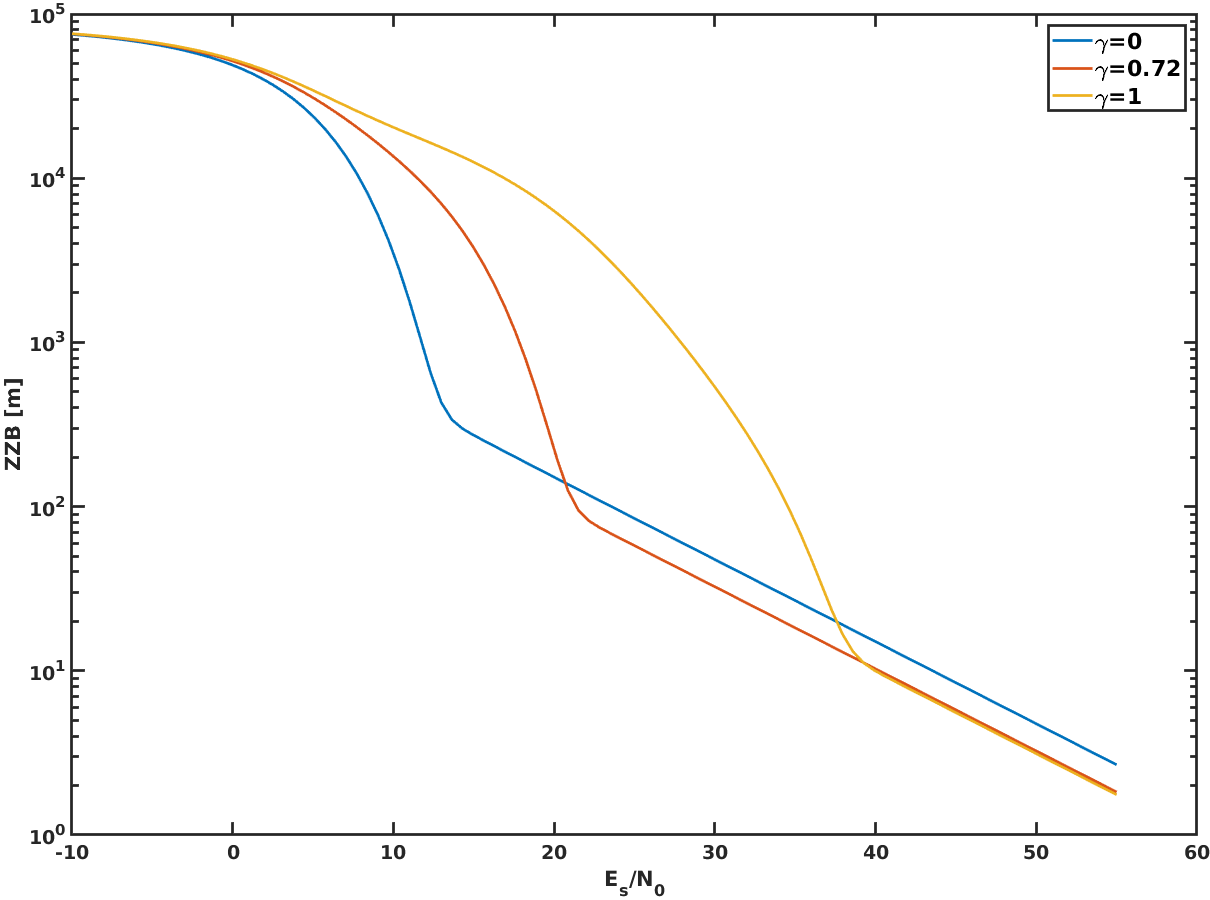
# Informative Content - for deeper understanding

## Reports of trials (Informative)

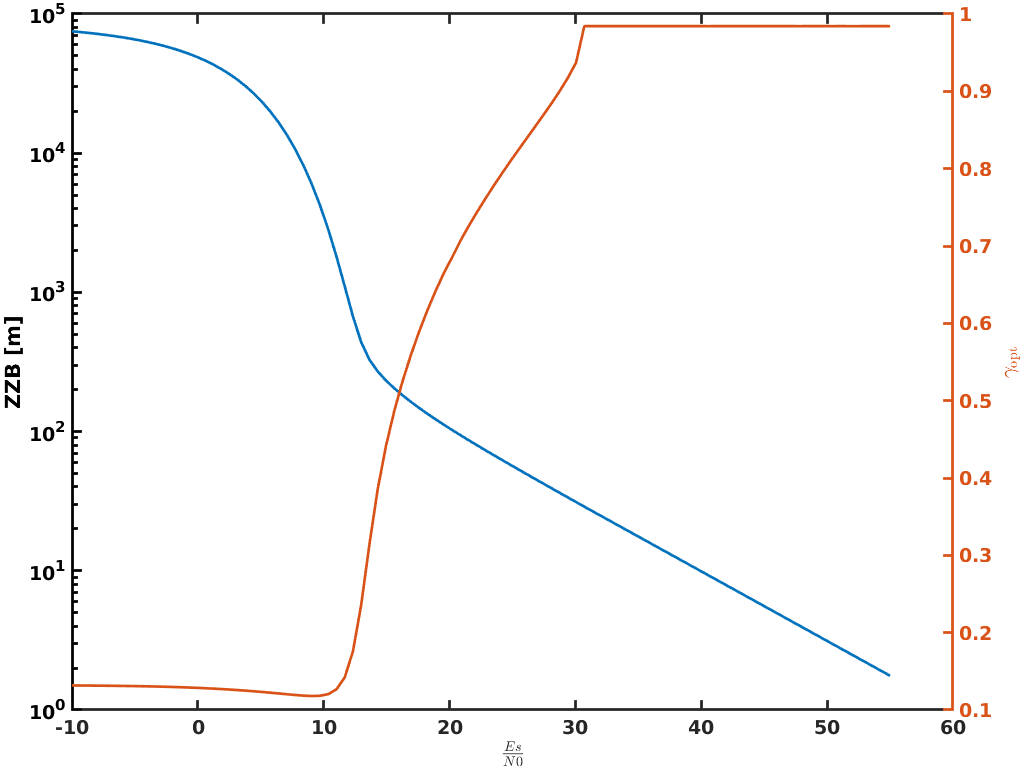
Figure 12 shows theoretical bounds describing the performance for different gamma combining both sequences. The performance curves for low SNR show a better performance of the Gold codes. For a ranging performance of better than 100 m the combined version improves by 4dB, and for ranging performances better than 10 m the pure alternating sequence is best. However, the further performance gains are marginal.

The search for an optimized gamma using an AWGN channel results in the best ranging performances that are shown in Figure 13.

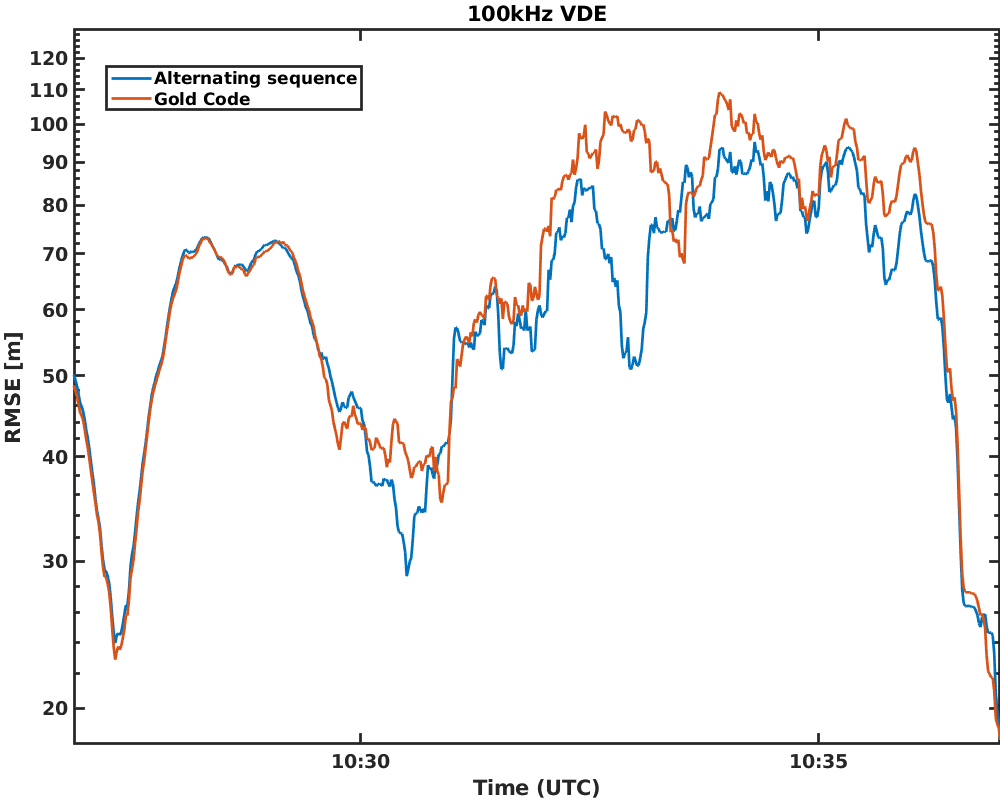
Figure 14 compares both sequences in measurements on the Ammersee. The applied transmit power was 30 dBm using a 100 kHz VDE waveform with both different codes individually. Measurements using a 100 kHz signal comparing the ranging performances of the Gold codes and the alternating sequence with a (Gold code in red)and (alternating sequence in blue).



1. Theoretical (Ziv-Zakai bound) for combined sequences versus Gold and alternating sequence. The proposed weighting factor .



1. Showing the ranging performances for the optimal weighting factor.



1. Measurement results

## Time source for R-Mode VDES base stations

A well synchronized network of R-Mode transmitters is the precondition of the R-Mode system. At any point in time, each transmitted ranging signal has to have a well-known time delay with respect to a time reference here referred to as R-Mode reference time (RMRT), which will locally be provided by a timing device (S). Therefore, each R-Mode VDES base station has to use

* Pulse Per Second (1PPS) and
* 10 MHz sinusoidal signal

of the external timing device as a time-base for all internal clocks which are used for the ranging signal generation. Coherence between the signals at the electrical reference plane is mandatory; the 1PPS carries the traceable timing used for disambiguation of the cycles of the 10 MHz signal. The datum of the 1PPS is communicated to the VDES base station as part of a data channel using an appropriated serial interface. Beside R-Mode VDES base stations also R-Mode monitoring stations are synchronized to RMRT (S).



1. Synchronization of R-Mode transmitter and monitor with R-Mode reference time (1 PPS and data link from timing device has an optional external interface – could also be integrated in the VDES base station.)

The local timing device, which is connected to the R-Mode VDES base station, has to be regularly synchronized with RMRT. To keep a high performance of the R-Mode system in times, when synchronization is not possible, each timing device has to provide hold over capabilities.

The following requirements are based on the assumption that the R-Mode VDES base station time device has to provide signals with less than 10 ns error with respect to the RMRT. This error may only be exceeded if the synchronization with RMRT was not possible for at least two hours [R-Mode Baltic: Baseline and priorities].

In the following the Maximum Time Interval Error (MTIE) and Time Stability (TDEV) are used as measures for the time device performance.

The given numbers below are minimum requirements. It might be necessary for certain regions or maritime applications that higher requirements on the time device will be defined.

**R-Mode reference time (RMRT)**

For each area of service RMRT has to be defined/specified. It is suggested to tie RMRT to other well established and accessible references of time.

RMRT may be based on

1. Realizations of Coordinated Universal Time, UTC(*k*), as realized by national metrological institutes[[3]](#footnote-3). Combinations of several UTC(k) spanning different administrations need to be communicated and applied by the timing devices.
2. Constellation time of one or more GNSS (e.g. Galileo, GPS, GLONASS, BeiDou, etc.). In this case RMRT will be the same as the GNSS time. Combinations of different GNSS need to take system offsets into account.
3. Central timing scale. It is strongly suggested to keep the time scale traceable to UTC and regularly publish its offset and uncertainty.

Numerically, RMRT shall be expressed with nanosecond resolution and with respect to the R-Mode epoch, which shall be suitably defined. Handling of leap seconds is in general discouraged; a leap second offset should be published if necessary for the application.

**Time synchronization**

All R-Mode transmitter sites, which are usable for R-Mode based positioning within the region of service, have to be synchronized to RMRT with the before mentioned time accuracy level. Typical time synchronization methods would

1. Wired time transfer based on optical fiber networks, such as White Rabbit/PTP[[4]](#footnote-4).
2. Common view methods with GNSS.
3. Use signals and data channel of R-Mode to distribute RMRT in the network.
4. GNSS receiver time solutions, representing GNSS system time[[5]](#footnote-5). To increase robustness of time synchronization, special services like Galileo PRS and/or OS-NMA could be used.

Any synchronization technique is required to be regularly calibrated with appropriated calibration methods. Calibration results need to be propagated to the R-Mode system in order to be applicate.

Requirements on timing performance with respect to RMRT when the time device is nominally synchronized:

* MTIE < 10 ns at all times
* MTIE < 1 ns at 5 s time intervals

**Time hold over**

The time synchronization between timing device and RMRT might be disrupted. In this case the R-Mode transmitter must continuously provide useable ranging signals for at least two hours. For this, a sufficiently stable local oscillator is needed, thus the free-running clock shall have the following general statistics:

* Short term 60 s TDEV shall be < 0.1 ns
* Medium term 2 h TDEV shall be < 1 ns

When losing synchronization and the timing device switches to a hold-over state, the device shall have the following characteristics with respect to the R-Mode reference time:

* Short term 60 s MTIE shall be < 1 ns
* Medium term 2 h MTIE shall be < 10 ns

**Timing uncertainty and clock error model**

Development of ranging errors can partly be described by a clock error model, which in turn can be used to minimize range errors and allow timing uncertainty propagation into the R-Mode positioning solution uncertainty. Timing uncertainties are a combination of calibration errors, modelling errors and local oscillator instabilities in hold over mode. It is recommended to describe the clock error with three parameters: (1) phase error, (2) frequency error and (3) frequency drift error referenced to the estimation epoch. Every error estimate is accompanied with its estimation uncertainty. The phase error and its uncertainty shall also accumulate the result from the current calibration. Likewise shall the instability of the above parameter set of the free running oscillator be described in term of an Allan Deviation.

The ranging user shall either[[6]](#footnote-6) infrequently (hours) receive a parameter set (sync\_status + epoch + model + uncertainty + Allan), or frequently (<minutes) receive phase error and uncertainty estimates calculated by the timing device. With infrequent model transmissions, other mechanisms need to be used to communicate clock- or synchronization events.

**Specification of data channel protocol**

The time device should continuously report every second over the data interface:

* connection status to the source of RMRT (connected or not)
* synchronization status (within defined accuracy level or outside)
* disambiguating time code of RMRT
* time difference to RMRT
* estimated error of time difference

## Clock and Delay Correction

### Assumptions

The VDES error budget for the slot transmission time is 1oo µs. Start of transmission of the fixed correlation sequence must be derived by the receiver. Nominal time of start of slot/frame is estimated from the frame number within the minute of frame transmission. Start of transmission is erroneous by an amount of time due to static calibration offsets, clock offsets and dynamic delays of the transceiver chain caused by aging or environmental sensitivity. The R-Mode timing device, a monitoring input and/or, possibly, other means may provide information about this time offset and the accompanying estimation uncertainty.

A special case arises when synchronization of the local oscillator, clock, is lost and the free running clock’s instability causes unpredictable development of start of frame timing. For the used clock it is required to have its frequency stability specified or measured; expressed in terms of an Allan Variance describing the statistics of the specific clock (or type) over relevant time intervals. The variance shall be used to estimate the station timing uncertainty during the time the synchronization to R-Mode Reference Time is lost. This function is internal to the timing device, which shall frequently relay the state of its synchronization and timing uncertainty of synchronization and hold over to the application layer of R-Mode.

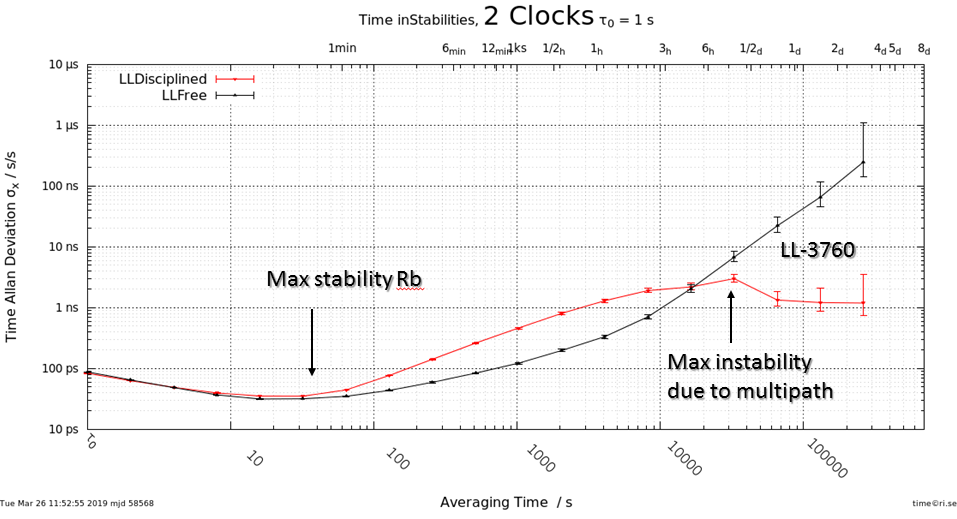
### Time Resolution

R-Mode is sensitive to mutual time errors of about 10 ns. The timing error estimate and its uncertainty should at least have a resolution one order better than the timing requirement. A choice of 1 ns resolution would be practical.

### Update Rate

We consider Rubidium atomic oscillators as the frequency standards with the lowest performance level required for R-Mode. Typically, the best frequency stability can be expected to be around some minutes of integration time, in the order of 1e-12 ADEV. The used synchronization method would normally require other, often longer, integration times (e.g. 10 … 60 minutes for GPS C/A receivers), restricting the rate of phase and/or frequency changes to the clock or a synthesizer.

The update rate shall be such that the offset estimate communicated to the user is of significance. It is reasonable to require that R-Mode synchronization of the clock to be done with fractional frequency uncertainties of maximal 1e-11, which corresponds to about 10 ps time error per second. Thus an update rate of 60 s would suit Rubidium stability and 1 ns time resolution. Better local oscillators generally provide higher stability, which allow decreasing the update rate.



### Offset and Uncertainty Dynamics

The offset that needs to be relayed is bounded by the allowable slot timing error of ± 100 µs. With 0.1 ns resolution 21 bits would offer ±105 µs. Table 8 defines the time offset distribution.

Uncertainty of the timing error is in principle bounded to the same dynamics as the offset. However, uncertainties much larger than the timing requirements of R-Mode are not meaningful, because users that assess the uncertainty would reject range measurement above a certain level of uncertainty. It is therefore suggested to introduce an exponential scale expressing the uncertainty in uneven steps but with the same resolution as the time offset. The oscillator depicted above has free running a statistical time deviation of 1 µs at some days integration times. 5 bits offer 32 levels *n* of uncertainty, using u = kn-1 and k=1.25, describes uncertainties ranging from 0 to about 1008 ns. Which is coded in Table 9, and 0 defines out of range or overflow.

1. R-Mode time offset distribution

|  |  |  |  |
| --- | --- | --- | --- |
| Offset | 21 bits | int21\_t | Δt = n/1010 [ns] |
| Uncertainty | 5 bits | uint5\_t | u=kn-1 and k=1.25 |
| Update rate | 60 s |  |  |

1. Uncertainty of the clock

|  |  |  |
| --- | --- | --- |
| Level of uncertainty: n | Uncertainty in [ns]: u |  |
| 0 | 0 | Out of Range (OOR) |
| 1 | 0.25 |  |
| 2 | 0.56 |  |
| 3 | 0.95 |  |
| … |  |  |
| 30 | 806.79 |  |
| 31 | 1008.74 |  |

## Modelling Conventions

### IDEF0

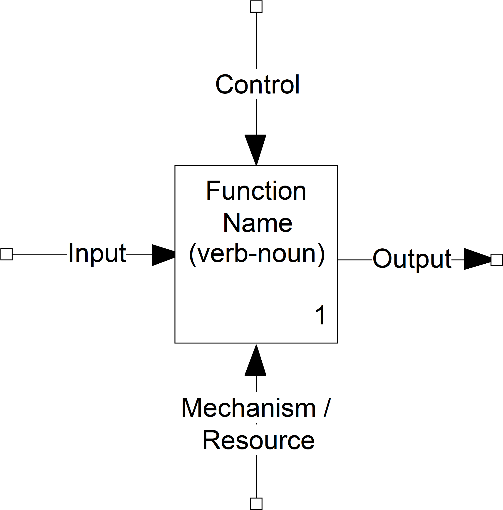
IDEF0 is part of the ICAM Definition for Function Modelling (where ICAM stands for Integrated Computer Aided Manufacturing) family of modelling languages, used to produce a structured representation of the functions, activities or processes within a system or subject area.

IDEF0 defines two basic semantical elements: functions and flows (of resources, energy or information).

A function is a transformation that turns inputs into outputs, represented by a box annotated with a verb-noun phrase and a number which provides context within the model.

A flow is represented by an arrow or an arc labelled by a noun phrase. The label represents the items being passed to/from the function to which the flow is attached.

Inputs enter the function box from the left, controls that guide the transformation of inputs into outputs enter from the top, mechanisms (physical resources that perform the function) enter from the bottom and outputs leave from the right, as illustrated in the diagram below.



1. IDEF0 Box format.

For clarity, the number of functions in an IDEF0 diagram should not exceed five or six. An IDEF0 diagram thus usually represents a particular viewpoint from which the system is observed rather than the system in its entirety.

For more information on IDEF0, see for example the IEEE 31320-1-2012 standard.

1. IALA defines a contingency Positioning, Navigation and Timing system as one that allows safe completion of a manoeuvre, but may not be adequate for long-term use. [↑](#footnote-ref-1)
2. A backup system ensures continuation of the navigation application, but not necessarily with the full functionality of the primary system and may necessitate some change in procedures by the user. [↑](#footnote-ref-2)
3. This approach faces the problem that UTC, which would be best choice as R-Mode reference time, is not defined continuously. [↑](#footnote-ref-3)
4. IEEE-1588 [↑](#footnote-ref-4)
5. The use of PT receiver solutions to access GNSS system time is in general discouraged. [↑](#footnote-ref-5)
6. Other, more optimal combinations of communicating clock error statistics are of course possible [↑](#footnote-ref-6)