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| IALA Guideline |

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VDES R-Mode

Edition 1.0

December 2020

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

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| December 2020 | 1st issue | - |
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# INTRODUCTION AND SCOPE

The scope of this document sets out guidance for authorities to setup VDES R-Mode and developers to design a VDES R-Mode receiver or transmitter.

The document builds up on the stakeholder [3] and system requirements [4] and introduces the VDES R-Mode architecture. It defines the needed PHY and MAC layer essentials based on the VDES Specifications G1139 ed. 4 [6]. Further, the document provides support on how VDES R-Mode is setup in the VDES framework, the additional navigation data and outlines potential performance expectations under different conditions and environments.

## 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 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 [3].

## System Overview

The VDES R-Mode System will send accurately timed VHF transmissions from a network of land-based and, possibly, offshore Base Stations (BSs). 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.

# 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 2 and Figure 3 ):

* R-Mode transmitter station: A station that provides R-Mode service. It is intended to use existing VDES base stations.
* R-Mode monitor: Station that monitors broadcasted signals of R-Mode transmitter.
* R-Mode system time (RMST: Time distribution infrastructure that provides in a region the RMST which is used for R-Mode service provision.
* Command and control, Security centre 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 RMST

## R-Mode System Functional Architecture

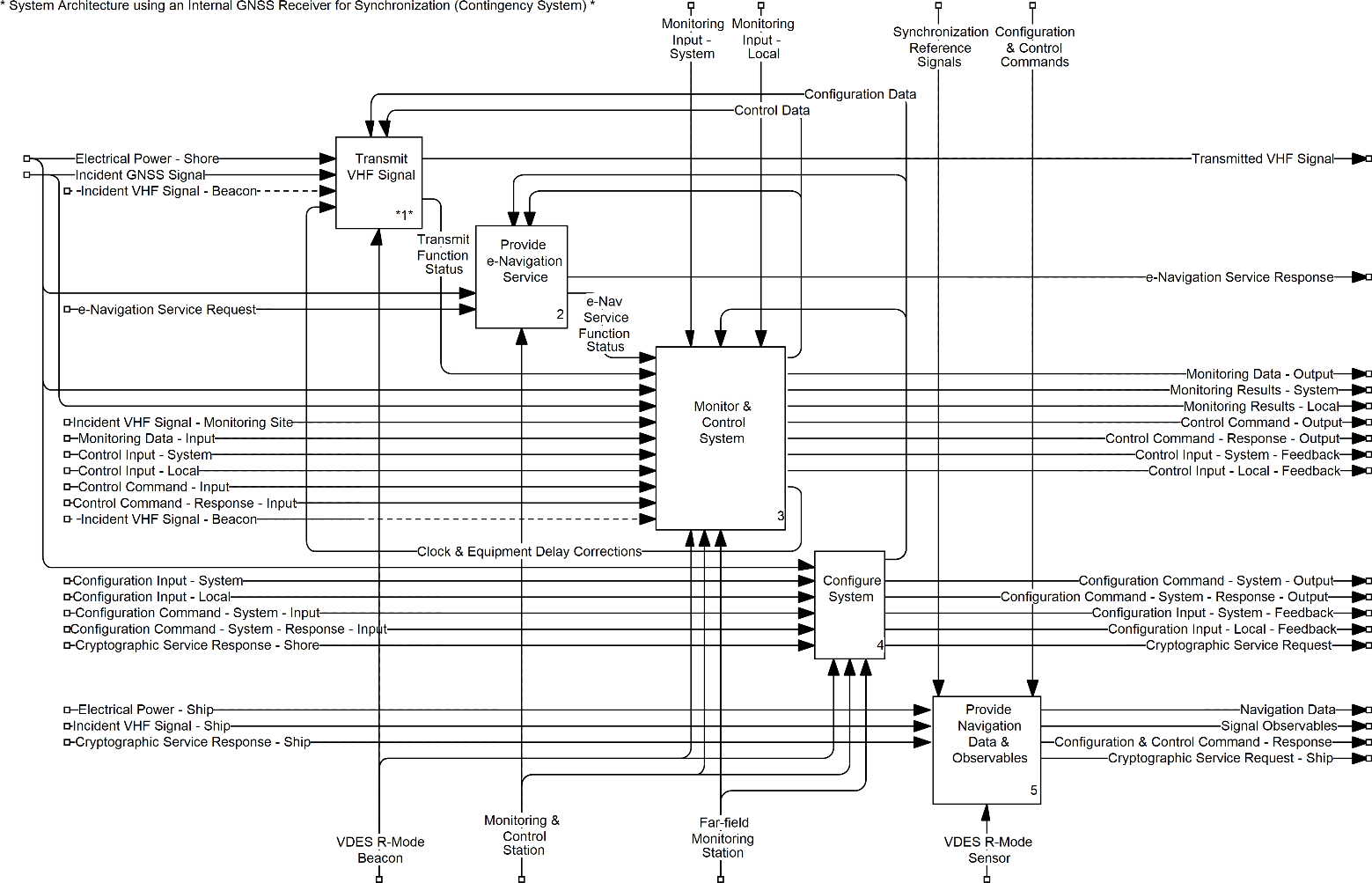
The IDEF0 modelling approach is used here to outline a functional architecture for VDES R-Mode. For an introduction to IDEF0 please see Annex A A.4. The architectural diagrams shown here are consistent with the External System Diagrams for the VDES R-Mode System contained in the Stakeholder Requirements Document [6].

Section 2.2.1 presents the 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-2)* 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 VDES R-Mode base station’s clock.

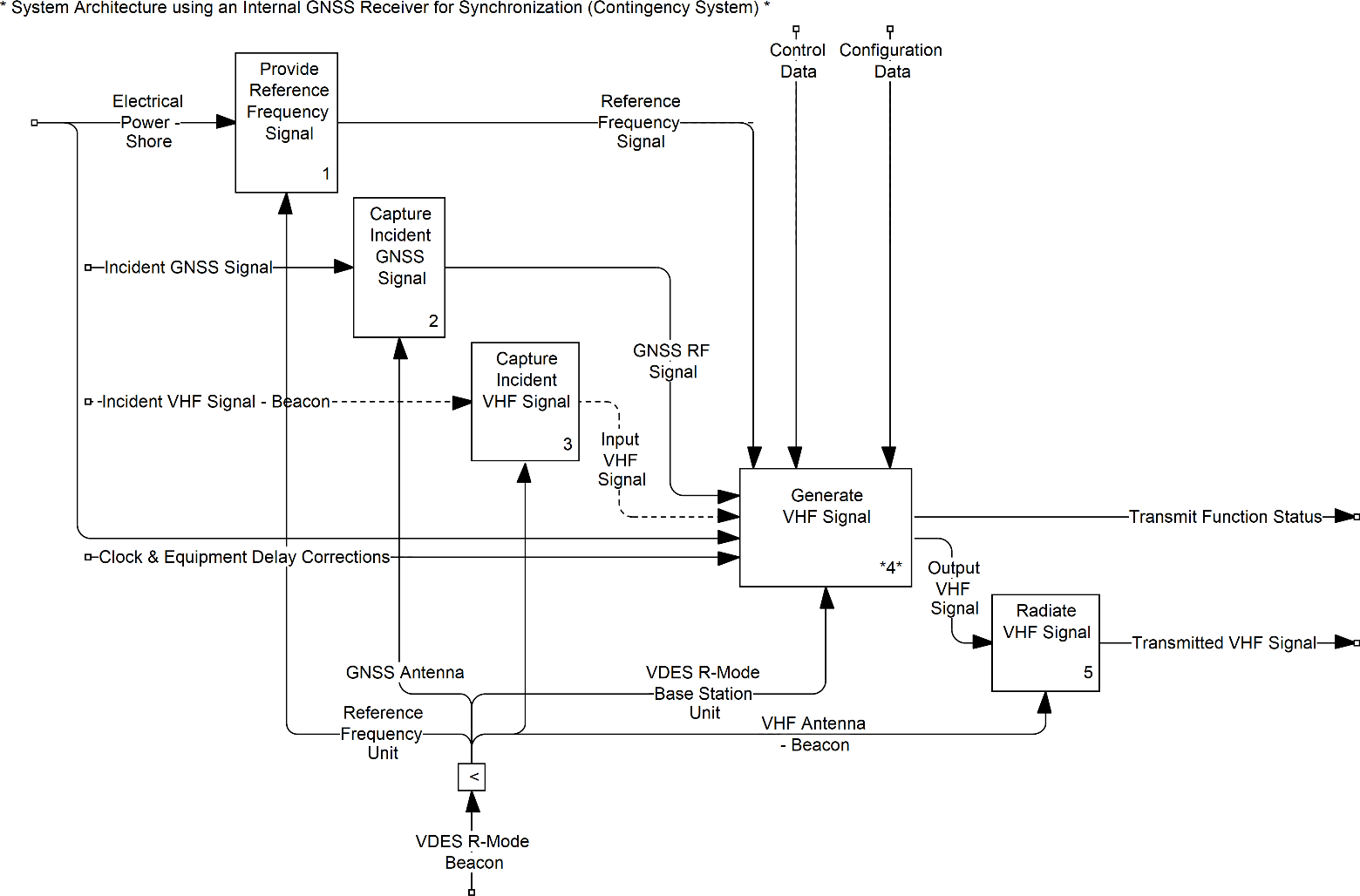
Section 2.2.2 presents an alternative system architecture using a timing device external to the VDES base station unit. Assuming this device operates independently of GNSS, this architecture represents a backup system*[[2]](#footnote-3)*.

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 alphabetical order) in Table 1 in Section 2.2.3.

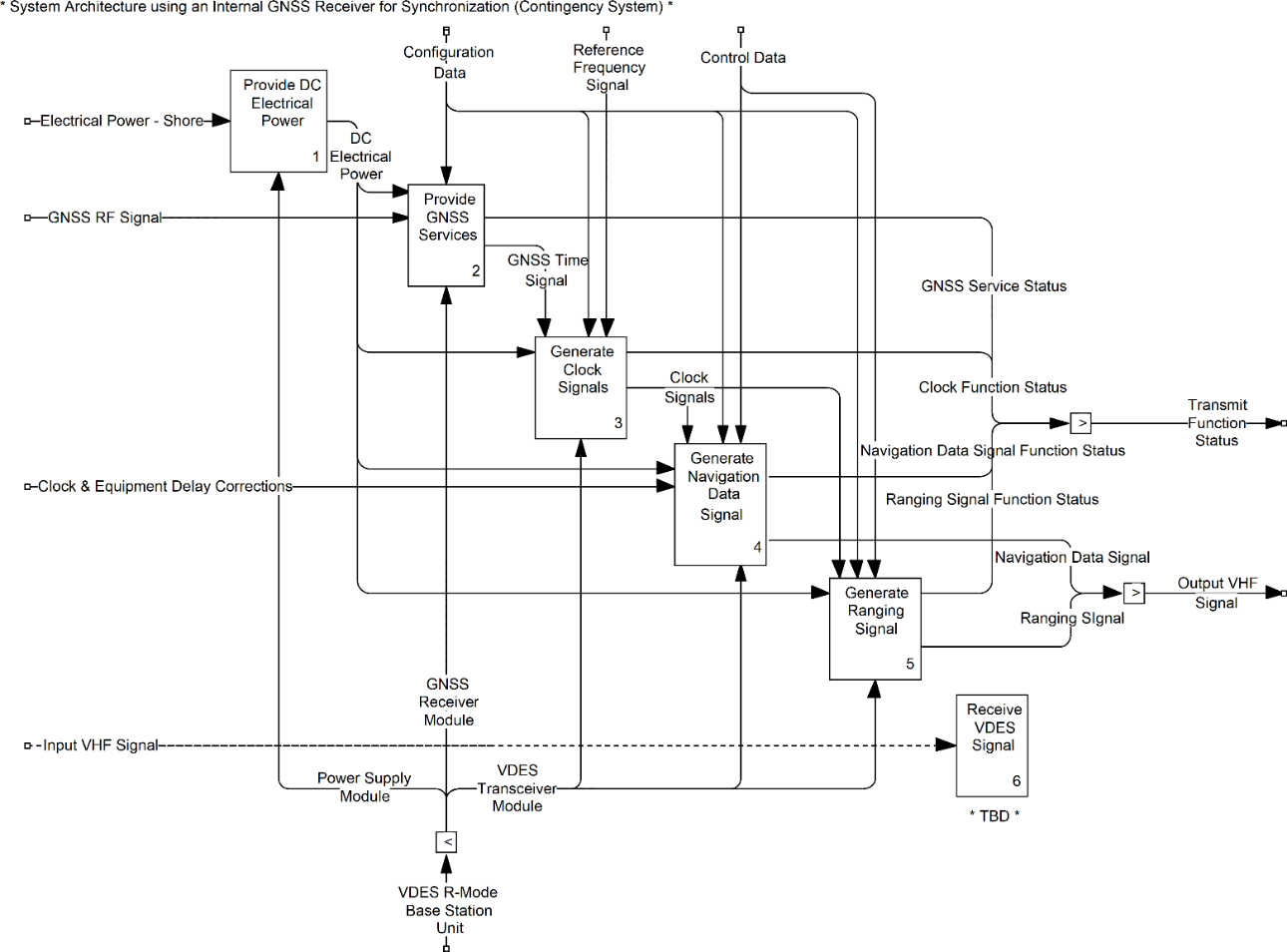
### System Architecture Using GNSS for Synchronization



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

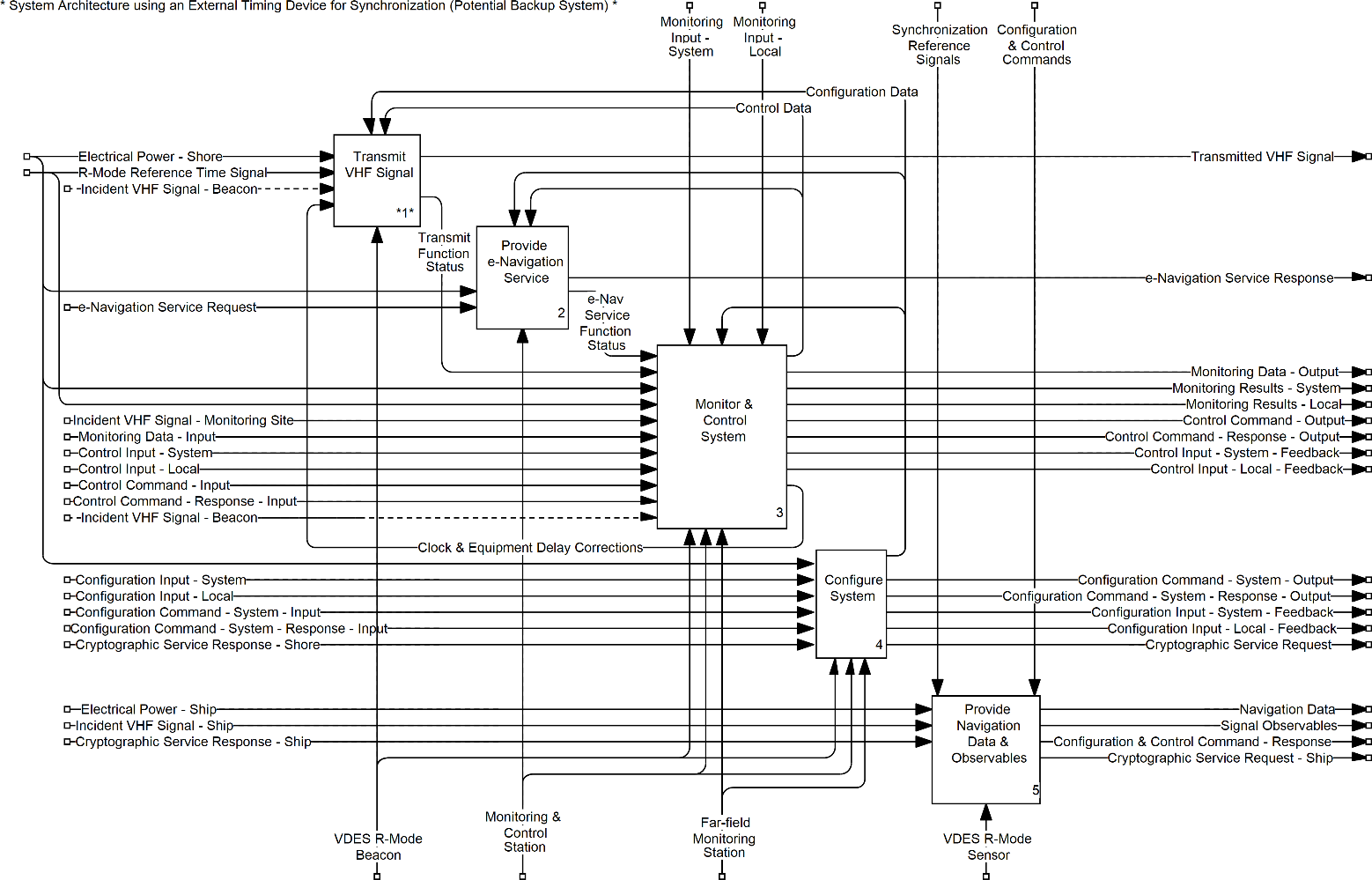


1. Transmit VHF Signal Function (contingency system configuration)

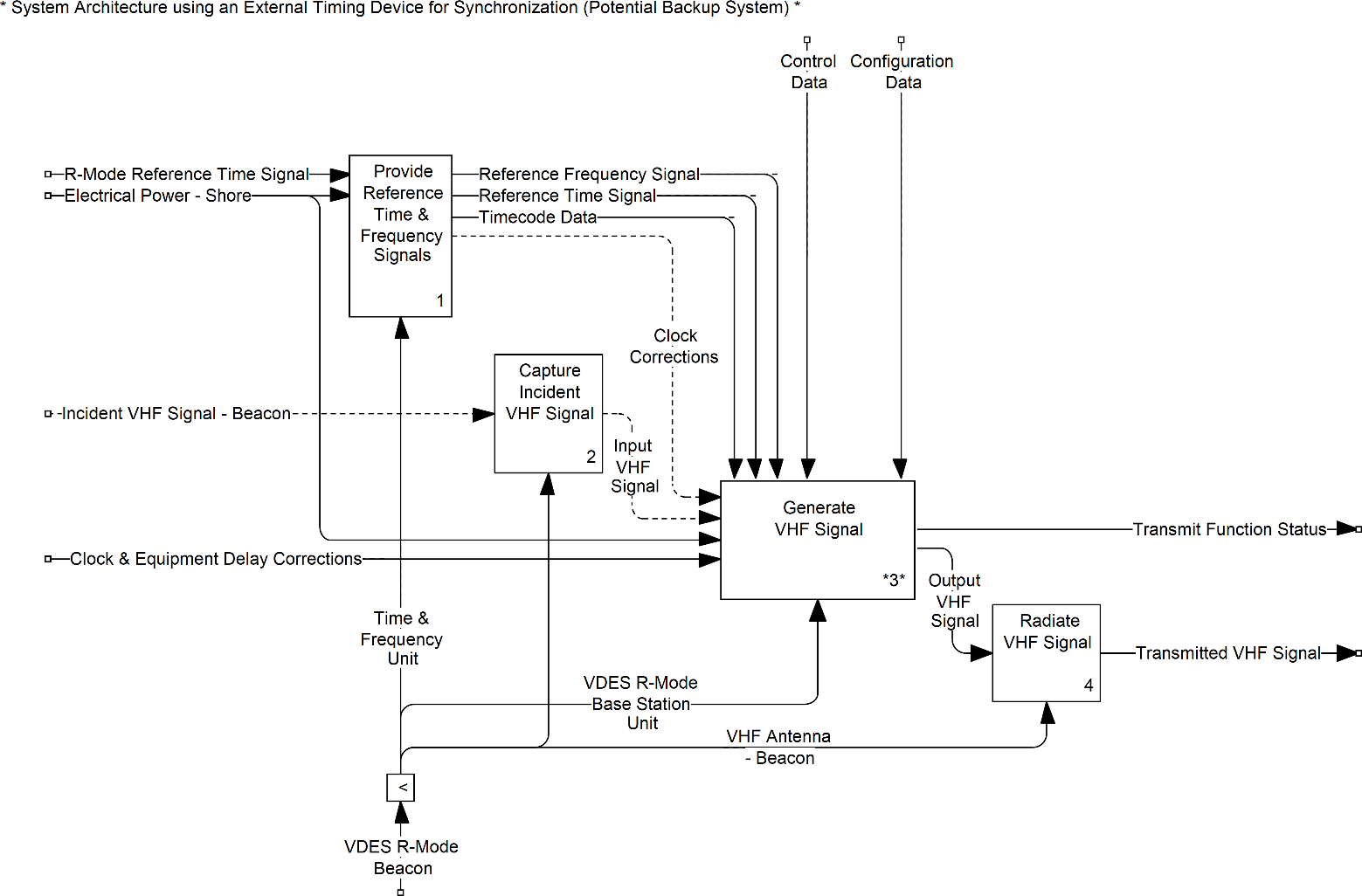


1. Generate VHF Signal Function (contingency system configuration)

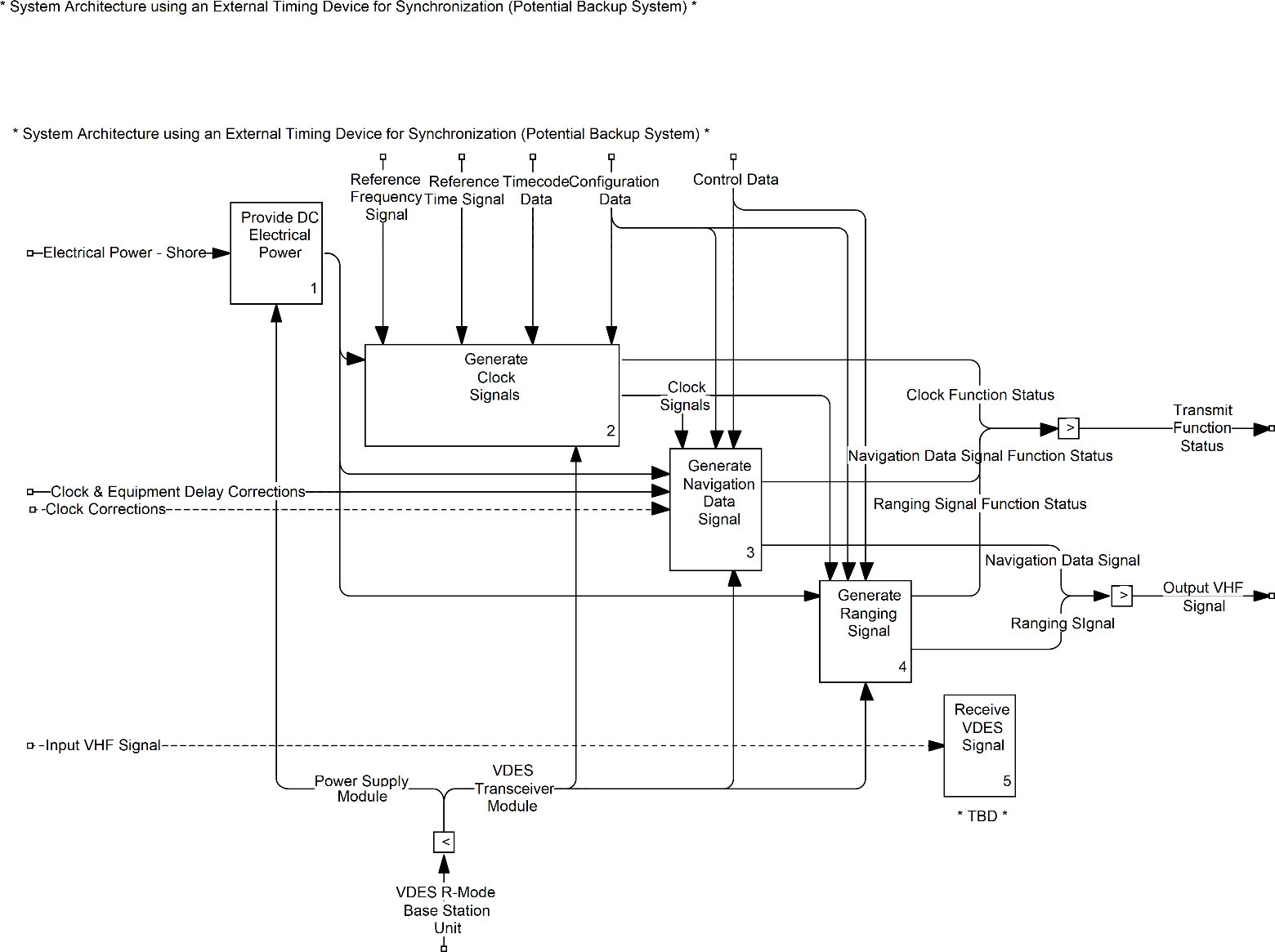
### System Architecture Using a Non-Gnss Source for Synchronization



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

VDES R-Mode is based on the specification of the VDE-TER specification in G1139 ed.4 (submitted to ITU-R WP5B to revise ITU-R M.2092-1). The physical layer of the R-Mode application requires a ranging sequence and additional navigation data to determine the distance between VDES R-Mode base stations, transmitters, and receiver. The ranging sequence is predefined and adapted by the network depending on the expected coverage areas. VDE-TER schedules the resources based on a TDMA scheme between VDES base stations that are coordinated by the network provider(s). The VDES R-Mode base stations shall transmit their ranging sequence every second based on the configuration of link-ID 37. The additional navigation data shall be communicated every minute via the link-ID 11 within the network and via one VDES R-M-mode base station.

## Ranging sequences

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

* 1. Shorter distances with high SNR between shore station and vessels ()
  2. Longer distances with lower SNR between shore station and vessels ()

Figure 10 describes how both sequences are concatenated as part of the data message of a VDE-TER slot based on the factor.

VDE-Slot: 26.67 ms

Gold sequence

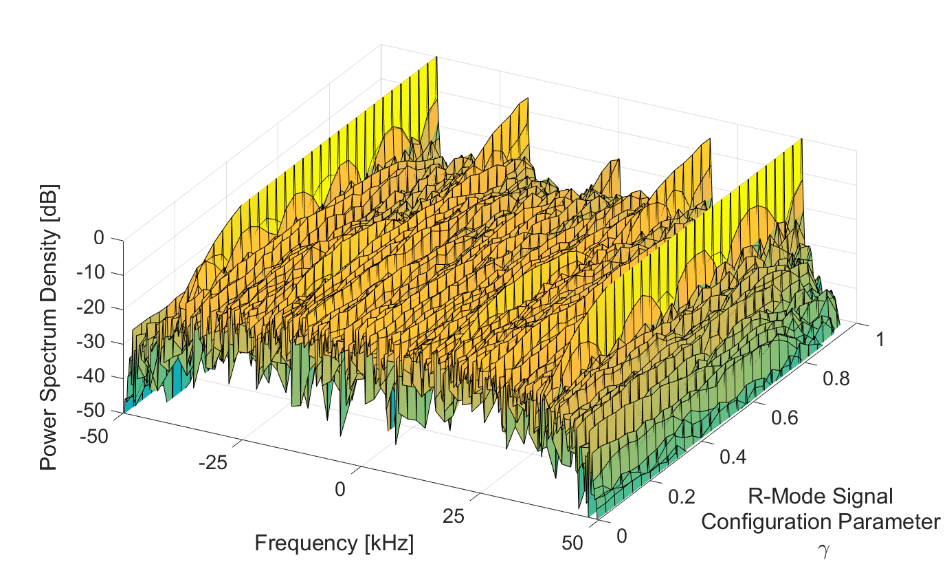
Alternating sequence

…

…

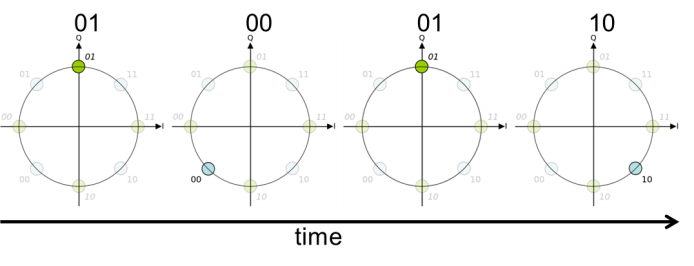
1. Example of sequence concatenation

Both sequences are concatenated, and factor γ defines the portion of the whole sequence used by parts of the Gold code sequence. The remainder is filled up by symbols of the alternating sequence.



1. Power spectral density expressed over the 100 kHz of the combined sequences depending on the γ factor

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 12 shows the principle on how the sequence is generated with an arbitrary length. The alternating sequence starts with 01.



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** |

Both sequences are shortened by a weighting and then concatenated. The length of the alternating sequence is multiplied with a weighting factor for short distances (higher SNR) and for larger distances (lower SNR). The length of the Gold code is multiplied with a weighting factor for short distances and for large distances.

## Navigation data

The navigation data contains all the data used to calculate the range between the VDES R-Mode base station and the receiver. The navigation data is transmitted every minute by a regular VDE-TER message. The navigation data of multiple R-Mode base stations can be combined in one VDE message and should indicate which base station the navigation data addresses with the network. This shall be covered by the network provider of the base stations.

## 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 RMST 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 Section A.3.

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 VDE-TER enables VDES R-Mode together with precise timing at the transmitter. The VDES R-Mode base station broadcasts the ranging sequence via the Ranging Channel once per second at a known and defined time instance with link-ID 37.

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

In the link layer the ranging sequence shall be transmitted by the Ranging Channel and utilizes the shore-to-ship short message (#93). The navigation data shall be communicated by a shore originated broadcast message.

# APPLICATION LAYER

## Navigation data

The VDES R-Mode receiver requires additional information, termed navigation data, to determine the distance to the base station utilizing the received ranging sequence.

The navigation data is transmitted via VDE-TER from a VDES base station with the link-ID 11 every minute. It accommodates information to allow a cold start and determines a position latest after 16 minutes. Up to 16 VDES R-Mode base stations have a unique ID within the local VDES R-Mode network. Each ID of a VDES R-Mode base station is linked to clock and delay correction data and the coordinates of the phase centre of the VDES R-Mode base station.

As shown in Table 2, the navigation data comprises of the R-Mode System Time (RMST) and conversion data to UTC, and clock information of four VDES R-Mode base stations. Therefore, the relevant clock information of up to 16 VDES R-Mode base stations is received latest every 4 minutes. The coordinates of the phase centre of specific VDES R-Mode base station. Therefore, the coordinates of all relevant VDES R-Mode base stations in the network are broadcast with an update rate of 16 minutes maximum.

If the VDES R-Mode network has less than 16 VDES R-Mode base stations, the system provider may repeat the clock and delay correction information more frequently.

1. Ordering and number of bits of the navigation data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bit order in the message | Purpose |  | Bits per stations | Total bits of network |
| 1 | RMST | 1 | 32 | 32 |
| 2 | RMST to UTC conversion | 1 | 99 | 99 |
| 3 | Clock and delay corrections + ID | 4 | 26+4 | 120 |
| 4 | Validity and signal health status in the network | 1 | 3 | 3 |
| 5 | Coordinates of phase centre of transmitter antenna + ID | 1 | 71+4 | 75 |
| 6 | γ factor of concatenated ranging sequences | 1 | 2 | 2 |
|  | **Total bits** |  | 241 | 331 |
|  | Spare bits for future use |  |  | 101 |
|  | **Total bits (link-ID 11)** |  |  | **432** |

### Continuous R-Mode System Time

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 RMST start epoch is defined as 13 seconds before midnight between 21st August and 22nd August 1999 UTC.

The R-Mode system accommodates the RMST which is represented by 32 bits.

1. RMST by week number (1-4096) and time of week (0-604799s)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| P**arameter** | **Definition** | **Bits** | **Scale factor** | **Unit** |
| WN | Week number | 12 | 1 | Week |
| TOW | Time of week | 20 | 1 | s |

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

### Traceable RMST to UTC

The RMST is established by the VDES R-Mode service provider which is usually the national maritime service provider. Neighbouring regions or countries may have deviating RMST. The RMST shall be traceable to UTC to enable positioning by VDES R-Mode from different regions and with other navigation systems, such as GNSS and MF R-Mode. Otherwise, the system time offset would have to be estimated at the user site.

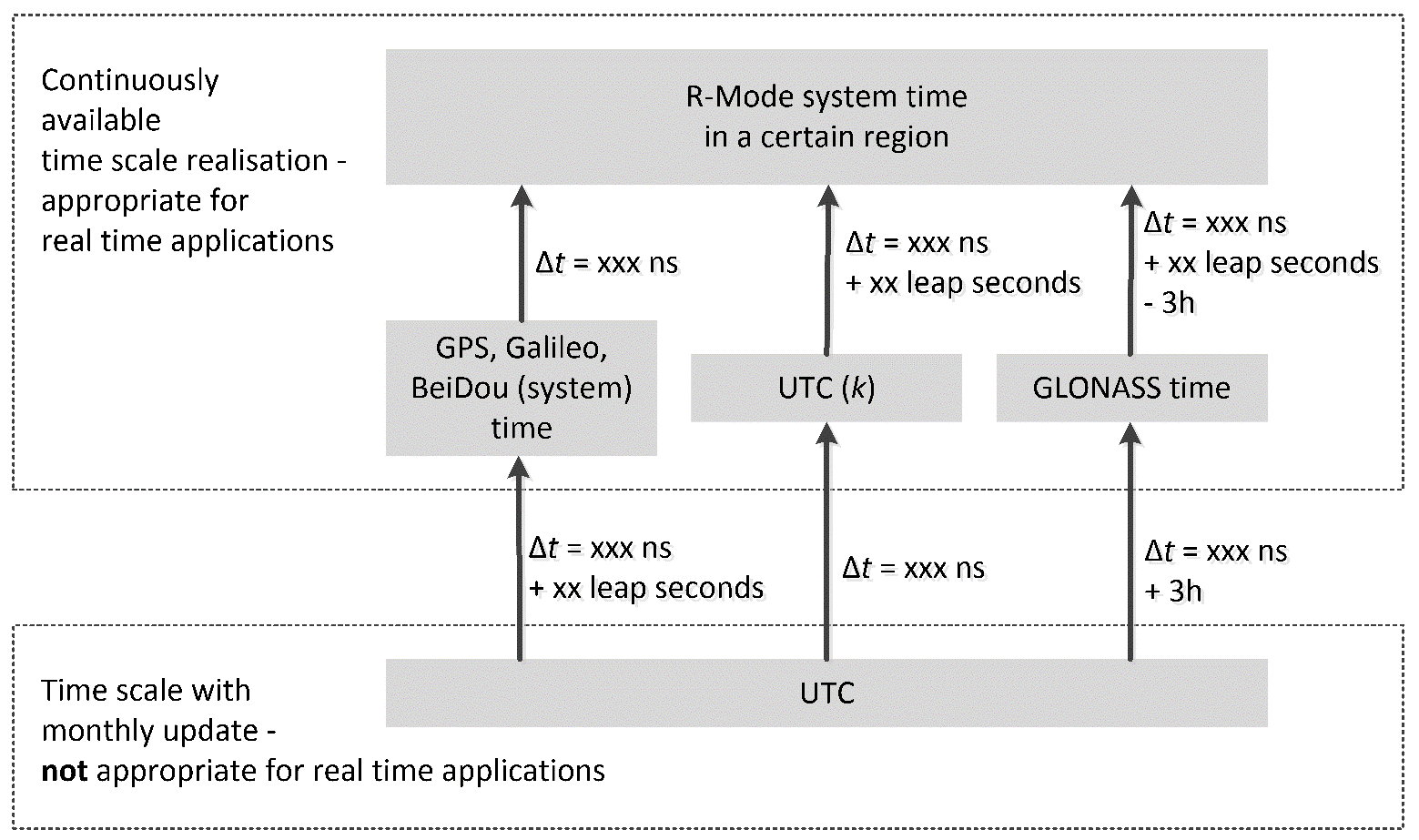
1. RMST UTC conversion

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| A0 | Constant term of polynomial | 32\* | 2-30 | s |
| A1 | 1st order term of polynomial | 24\* | 2-50 |  |
| tLS | Leap second count before leap second adjustment | 8\* | 1 | s |
| t0t | UTC data reference time of week | 8 | 3600 | s |
| WN0t | UTC data reference week number | 8 | 1 | Week |
| WNLSF | Week number of leap second adjustment | 8 | 1 | Week |
| DN | Day number at the when a leap second adjustment becomes effective | 3\*\* | 1 | Day |
| tLSF | Leap second count after leap second adjustment | 8\* | 1 | s |

\*Parameters are two complement, with the sign bit (+/-) occupying the Most Significant Bit (MSB).

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

Depending on the realisation traceability can be reached as shown in Figure 13 below.



1. Traceability of RMST to UTC

### Clock and Delay Corrections

The clock of the base station provides offset of transmission of VDE ranging message, and other delays as offset to the RMST. The clock error is given by an offset (CO) and its uncertainty (CU) as 1σ confidence level. The parameters CO and CU are defined in Table 5.

1. Parameter to describe clock effect of transmitted signal (26 bits)

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

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

### Navigation Data Validity and Signal Health Status

The network provider or each base station shall 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 than decimetre accuracy, a scaling factor of 7\*10-7 is used for latitude and longitude.

In addition, four bits are set for which of the 16 base stations of the covered area the coordinates are transmitted. The ID of the VDES R-Mode base station is set by the network operator and shall remain constant within a supported VDES R-Mode area.

1. Antenna position in WGS84 (75 bits)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Definition | Bits | Scale factor | Unit |
| LO | longitude | 29\* | 7\*10-7 | ° |
| LA | latitude | 28\* | 7\*10-7 | ° |
| AL | Altitude\*\* | 13 | 1 | m |
| ID | Base station identifier (set by network provider) | 4 |  |  |

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

\*\* Please the calculation of the altitude below.

The altitude *h*a can have values from -200 m to 7991 m. It is given by the equation below.

### factor of Ranging Sequence

The factor determines how the sequences are concatenated and is set by the following bit sequence. This sequence is unique for the base station with the given coordinates.

1. The chosen factor for concatenating ranging sequence is communicated for the indicated base station.

|  |  |  |
| --- | --- | --- |
| Parameter | Definition | Bits |
|  | 1 | 00 |
| 0.7 | 01 |
| 0.3 | 10 |
| 0 | 11 |

# 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 that provide autonomous geo-spatial positioning with global coverage. GNSS includes, GPS, GLONASS, Galileo, Beidou and other Regional Navigation Satellite System (RNSS) such as Indian Regional Navigation Satellite System (IRNSS) and Quasi-zenith Satellite System (QZSS).

*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 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 a single facility where one or more transmitters, receivers, or transceivers, including the accessory equipment is established for two way 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 equipment is housed and used to support safe navigation.

*Time of Arrival* is the absolute time instant when a radio signal emanating from a transmitter reaches a remote receiver.

*Time of Transmission* is the absolute time instant when a radio signal emanates from a transmitter

*Transmission Time* is the measurement of the time taken by a wave to travel a distance through a medium. Measured between Time of Transmission and Time of Arrival.

*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* 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 |
| 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 |
| RMST | R-Mode System Time |
| 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 |

# REFERENCES

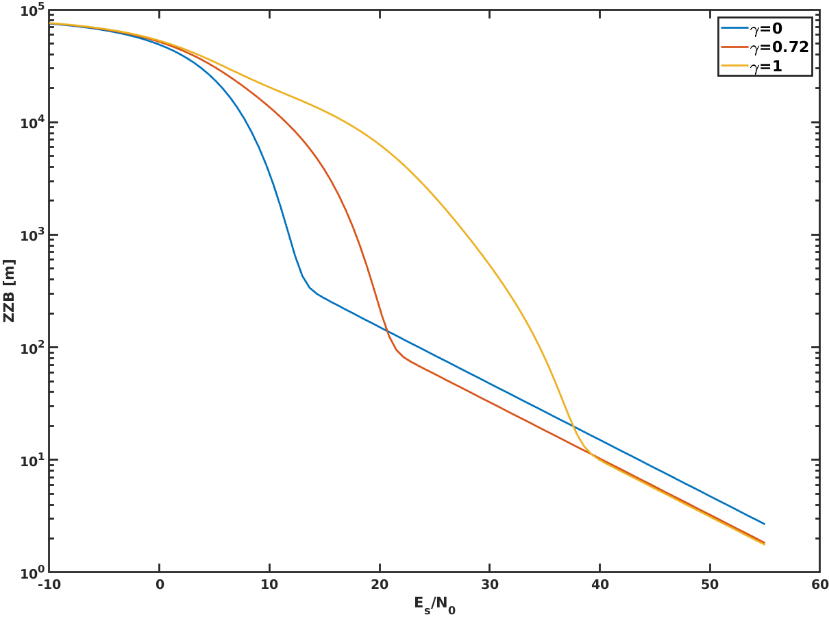
The following documents are referred to in this document:

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
5. IALA Recommendation: ‘R-129 GNSS Vulnerability and Mitigation Measures’, ed. 3, December 2012
6. IALA Recommendation: ‘G-1139 – The Technical Specification of VDES’, ed. 4, 2020
7. ISO/IEC/IEEE 31320-1:2012 Information technology — Modeling Languages — PART 1: Syntax and Semantics for IDEF0
8. Informative Content - for deeper understanding
   1. Reports of trials (Informative)

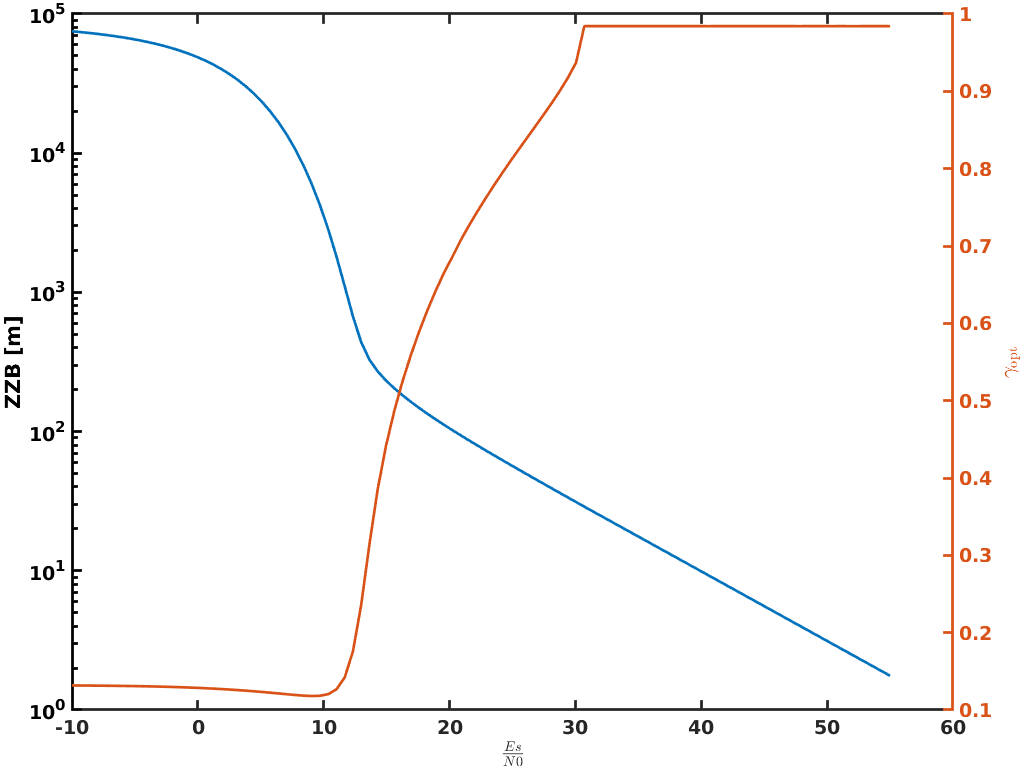
Figure *A 1* A1 shows theoretical bounds describing the performance for different gamma combining both sequences. The performance curves for low SNR show a better performance of the Gold codes. For a ranging performance of better than 100 m the combined version improves by 4dB, and for ranging performances 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 shown in Figure A2.

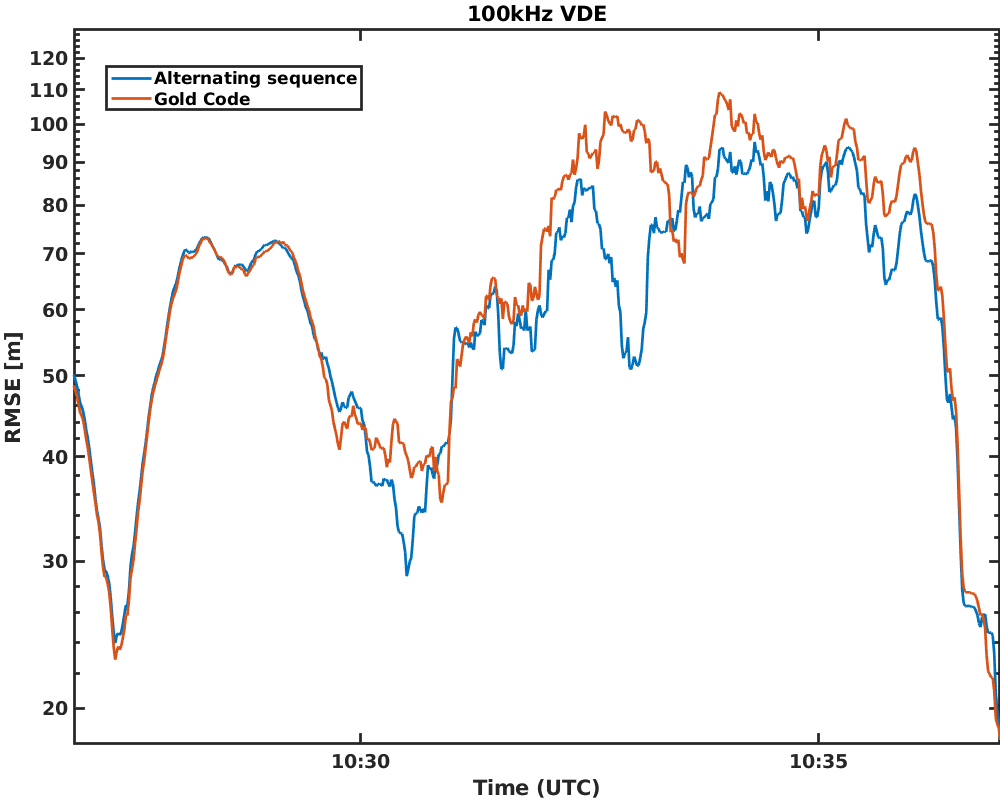
Figure A3 compares both sequences in measurements on the Ammersee. The applied transmit power was 30 dBm using a 100 kHz VDE waveform with both different codes individually. Measurements using a 100 kHz signal comparing the ranging performances of the Gold codes and the alternating sequence with a (Gold code in red)and (alternating sequence in blue).



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



*Figure A 2 Showing the ranging performance for the optimal weighting factor*



*Figure A 3 Measurement of results*

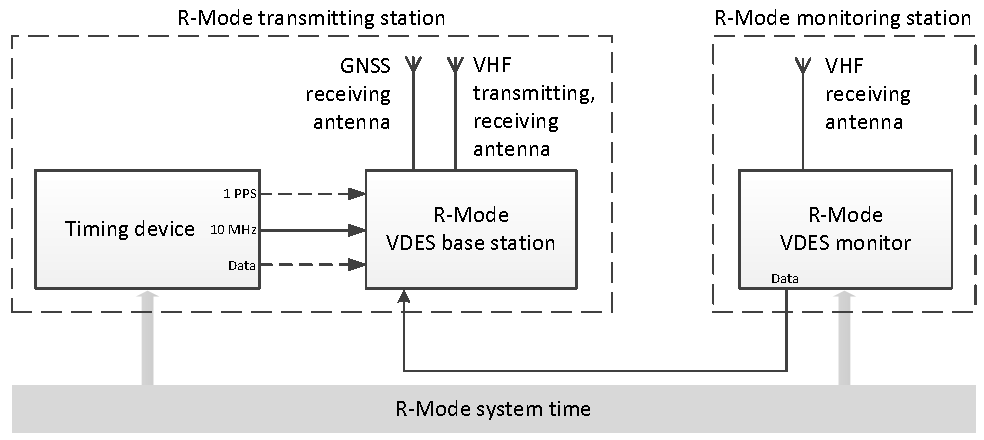
* 1. Time source for R-Mode VDES base stations

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 system time (RMST), which will locally be provided by a timing device(S). Therefore, each R-Mode VDES base station must 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 RMST (S).



*Figure A 4 Synchronization of R-Mode transmitter and monitor with RMST*

Figure A4 illustrates synchronization of R-Mode transmitter and monitor with RMST (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 RMST. 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 RMST. This error may only be exceeded if the synchronization with RMST was not possible for at least two hours [2].

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.

* + 1. R-Mode system time

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

RMST may be based on:

1. Realizations of Coordinated Universal Time, UTC(*k*), as realized by national metrological institutes[[3]](#footnote-4). 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 RMST 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, RMST 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.

* + 1. Time synchronization

All R-Mode transmitter sites, which are usable for R-Mode based positioning within the region of service, must be synchronized to RMST with the required time accuracy level. Typical time synchronization methods would be:

1. Wired time transfer could be based on optical fibre networks, such as White Rabbit/PTP[[4]](#footnote-5) protocol.
2. Derive timing information from GNSS to discipline a local clock.
3. Use signals and data channel of VDES R-Mode to distribute RMST in the network.
4. GNSS receiver time solutions, representing GNSS system time[[5]](#footnote-6). 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 RMST when the time device is nominally synchronized as follows:

* MTIE < 10 ns at all times
* MTIE < 1 ns at 5 s time intervals
  + 1. Time hold over

The time synchronization between the timing device and RMST 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 RMST:

* Short term 60 s MTIE shall be < 1 ns
* Medium term 2 h MTIE shall be < 10 ns
  + 1. 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, the instability of the above parameter set of the free running oscillator shall be described in terms of an Allan Deviation.

The ranging user shall either[[6]](#footnote-7) infrequently (hours) receive a parameter set (synchronization 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 the parameter set.

* + 1. Specification of data channel protocol

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

* Connection status to the source of RMST (connected or not).
* Synchronization status (within defined accuracy level or outside).
* Disambiguating time code of RMST.
* Time difference to RMST.
* Estimated error of time difference.
  1. Clock and Delay Correction
     1. Assumptions

The VDES error budget for the slot transmission time is 100 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 the start of frame timing. The clock used for signal timing 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 RMST 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.

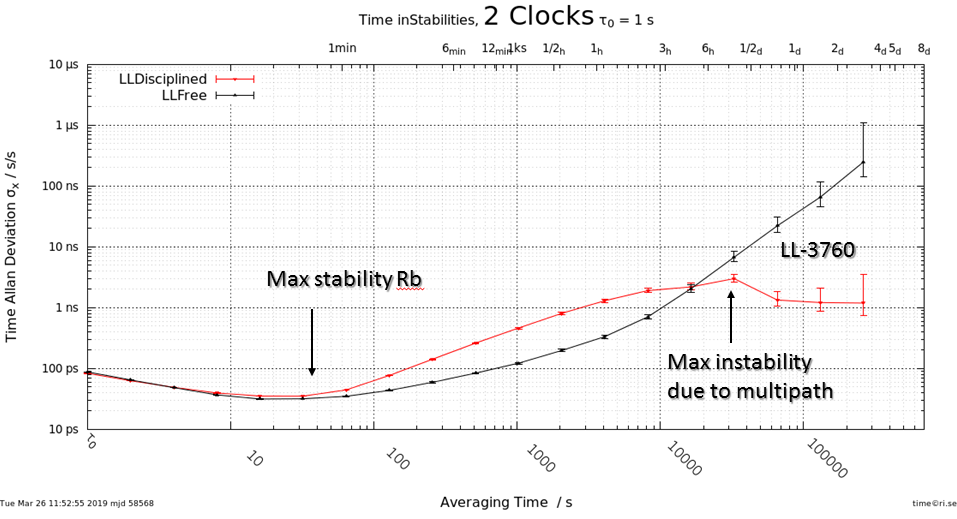
* + 1. Time Resolution

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.

* + 1. 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. Local oscillators with higher stability will allow the update rate to be decreased. Figure A5 shows the time Allan deviations over different averaging time spans.



*Figure A 5 Time Allan Deviation over different averaging time spans*

* + 1. 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 A1 *R-Mode time offset distribution* 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 recommended 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 a free running statistical time deviation of 1 µs over an integration time of several days. 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 , and 0 defines out of range or overflow.

*Table A 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 |  |  |

*Table A 2 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 |  |

* 1. Modelling Conventions
     1. IDEF0

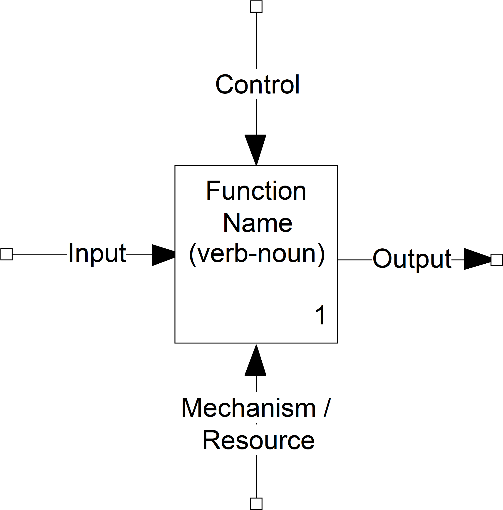
IDEF0 is part of the ICAM Definition for Function Modelling (where ICAM stands for Integrated Computer Aided Manufacturing) family of modelling languages, used to produce a structured representation of the functions, activities or processes within a system or subject area.

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.



*Figure A 6 IDEFO-1 IDEFO 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 in [5] 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-2)
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-3)
3. This approach faces the problem that UTC, which would be best choice as RMST, is not defined continuously. [↑](#footnote-ref-4)
4. IEEE-1588 [↑](#footnote-ref-5)
5. The use of PT receiver solutions to access GNSS system time is in general discouraged. [↑](#footnote-ref-6)
6. Other, more optimal combinations of communicating clock error statistics are of course possible [↑](#footnote-ref-7)