|  |
| --- |
| IALA Guideline |

DRAFT

on Implementation of R-Mode on MF and VHF frequencies

Edition x.x

Document date

|  |  |  |
| --- | --- | --- |
| Date | Details | Approval |
| 06.10.2020 | Update during ENG12   * Chapter 2 Requirements |  |
| 12.10.2020 | Merge modified chapters 2, 3 and 7 post closing meeting held at 9th October2020 ENG12 |  |
| 14.10.2020 | Final Working paper to ENG13 |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

1. Introduction 5

1.1. Scope of Document 5

1.2. Structure of document 5

2. Performance requirements 5

2.1. Definitions 5

2.2. General R-Mode Requirements 5

2.3. R-Mode user requirements for onboard positioning performance 6

3. System Architecture 7

3.1. Logical R-Mode System architecture 8

3.2. Physical R-Mode Architecture 9

3.3. Components of a MF Radio Beacon Transmitting site 11

3.4. Components of A VHF transceiving site 11

3.5. Monitoring 12

4. R-mode Service 13

4.1. MF R-Mode Service 13

4.2. VHF R-Mode Service 13

4.3. Timing Service 13

4.4. Use cases 13

5. Required Modificationd for R-Mode using MF Transmissions 13

6. Required Modificationd for R-Mode using VHF Transmissions 13

7. Timing, Synchronisation and Calibration 13

7.1. R-Mode System Time (RMST) 13

7.2. Synchronization of R-Mode stations 14

7.3. Time hold over 14

7.4. Processing of time information in the station 15

8. Operational Aspects 16

8.1. Operation and Maintanance 16

8.2. Performance Verification 16

8.3. Monitoring 16

8.4. Service Provider Aspects in a R-Mode Network 16

8.4.1. Exchange of Information 16

8.4.2. Memorandum of understanding (MOU) 16

8.5. Publication of Information 16

9. ACRONYMS & Definitions 16

9.1. Acronyms 16

9.2. Definitions 16

10. REFERENCES 16

List of Tables

**Es konnten keine Einträge für ein Abbildungsverzeichnis gefunden werden.**

List of Figures

Figure 2: R-Mode embedded in the overarching IMO e-Navigation architecture 8

Figure 3 Logical R-Mode architecture 9

Figure 4 Physical system architecture 10

Figure 5 General R-Mode Components 11

Figure 5. 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.) 15

List of Equations

**Es konnten keine Einträge für ein Abbildungsverzeichnis gefunden werden.**

# Introduction

## This Guideline provides the design, implementation and operational principles for R-Mode using MF and VHF frequencies. Scope of Document

Global Navigation Satellite Systems (GNSS) (today GPS, Galileo, GLONASS and BeiDou) have become the primary source of positioning, navigation and timing (PNT) for maritime operations. Furthermore GNSS-based positioning is used by many systems on vessels, like AIS (Automatic Identification System), ECDIS (Electronic Chart Display and Information System), ARPA (Automatic Radar Plotting Aid), GMDSS (Global Maritime Distress and Safety System) and other navigation sensors. Safe navigation, the protection of the marine environment and the efficiency of access to ports are highly dependent on the availability, continuity, accuracy and integrity of GNSS based positioning.

However, it is well known that low power satellite-based systems are vulnerable to jamming and natural interference, [1]. When GNSS is corrupted or unavailable, PNT information are seriously affected resulting in an increase in risks to the safety of navigation. Unavailable PNT data, even for short periods, results in numerous alerts raised by multiple systems on the bridge systems. Hazardously misleading information may occur in position errors that are large enough to have a severe impact on navigation safety but may be small enough to remain undetected and raise no alerts.

Within the overall e-Navigation strategy the IMO has identified the user need on improved reliability, resilience and integrity of bridge equipment and navigation information as one of the five prioritized e-Navigation solutions.

A variety of technological solutions provide the potential to serve this backup requirement; for example, within the radio frequency (RF) domain “Signals of OPportunity” (SoOP) can deliver possible solutions. This term refers to the opportunistic use of RF signals, typically communications signals, which already exist in the geographical area of the user receiver. While these signals are not primarily intended for positioning, a SoOP navigation receiver attempts to exploit them as such. Specifically, if each SoOP can provide a (pseudo-)range to the receiver from a known location, a trilateration position solution is possible. The use of such ranging signals from existing DGNSS maritime radio infrastructure is known as “R-Mode” (ranging mode). Even if it is impossible to derive a complete position solution from R-Mode (e.g. due to insufficient, less than three signals being present), the available pseudorange information combined with measurements from existing positioning systems can provide a position solution.

The IMO opened up the usage of multiple position fixing systems by the inauguration of the Multisystem - Radionavigation Receiver Performance Standard (MSC.401(95)) [4] and the associated GUIDELINES FOR SHIPBORNE POSITION, NAVIGATION AND TIMING (PNT) DATA PROCESSING (MSC.1/circ.1575), [5].

For the first time this new performance standard allows the combination of any recognised IMO World-Wide Radionavigation System (WWRNS) with terrestrial position fixing systems as well as wide area augmentation systems. The rising numbers of available ranging signals from any source benefit the determination of position accuracy and associated integrity.

Based on various studies and implementation projects this guideline will focus on the R-Mode implementation using MF DGNSS radio beacon frequencies as well as VHF transmissions using the VDE terrestrial frequencies of VDES. Further a combination of such signals, including also LF ranging signals (e.g. from eLoran), is a possible approach and will be described in this guideline.

## Structure of document

# Performance requirements

## Definitions

System performance is characterised by a number of different aspects, including Accuracy, Integrity, Continuity,

Availability and Coverage2, as:

**2.1.1. ABSOLUTE ACCURACY (GEODETIC OR GEOGRAPHIC ACCURACY)**

The accuracy of a position estimate with respect to the geographic or geodetic co‐ordinates of the Earth.

**2.1.2. INTEGRITY**

The ability to provide users with warnings within a specified time when the system should not be used for

navigation.

**2.1.3. CONTINUITY**

The probability that, assuming a fault‐free receiver, a user will be able to determine position with specified

accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable

for a particular operation within a limited part of the coverage area.

**2.1.4. AVAILABILITY**

The percentage of time that an aid, or system of aids, is performing a required function under stated conditions

(i.e. when it provides the required integrity for the given accuracy level). Non‐availability can be caused by

scheduled and/or unscheduled interruptions.

**2.1.5. COVERAGE**

The coverage provided by a radionavigation system is that surface area or space volume in which the signals are

adequate to permit the user to determine position to a specified level of performance.

## General R-Mode Requirements

Many operational, technical, economical, and radio frequency spectrum allocation related factors are considered in determining the set of required parameters for a potential backup to GNSS as a component of PNT system. . Most leading IMO and IALA documents show, that important technical parameters include: system accuracy, integrity, coverage, continuity, availability, reliability and radio frequency spectrum usage. Certain parameters, such as anti-jamming immunity, will also affect civil PNT service availability. The expected investment in the shore-based service provider equipment and user onboard equipment must also be considered. In most cases, the systems that are in place today were developed to meet different user requirements but can easily be reused. This resulted in the proliferation of multiple use of existing systems and is one of the strong advantages of R-Mode radionavigation service. R-Mode is intended to provide backup functionality to GNSS, either as a contingency system that allows safe completion of a manoeuvre or as a backup system that ensures continuation of the navigation application, but not necessarily with the full functionality of GNSS, [IALA R-129].

In contrast to GNSS, which has global coverage, the R-Mode system cannot achieve global coverage due to the limited range of the MF and VHF signals. To support the mariner world-wide it is important that navigation services are globally harmonization and in line with the e-Navigation. The highest risk for degradation of the GNSS signals due to intentional and unintentional interferences is expected to be in coastal waters. R-Mode, as a system, is designed for coverage in coastal waters and for port approach and restricted waters.

## R-Mode user requirements for onboard positioning performance

Since 1974 the UN/ IMO SOLAS (Safety of Life at Sea) Convention and its amendments enforce the carriage requirements on minimum equipment needed for safe voyage at sea. Currently any vessel operated under SOLAS is required to carry at least one electronic position fixing system (EPFS). The minimum performance of this system is described in IMO Performance Standards. These standards are available for single GNSS like GPS,

Galileo, GLONASS and BeiDou as well as for combined GPS/GLONASS.

IMO Resolutions A.915 (22), [x] and A.1046(27), [x] detail the requirements for future GNSS and WWRNSs considering vessels operating in ocean and harbour entrances, harbour approaches and coastal waters. These requirements are typically described by: accuracy, integrity, availability, and continuity for positioning.

A stand-alone fully operational R-Mode receiver would need to comply with the above stated values at any time within R-Mode reception area. The R-Mode system will be a regionally offered service unlike the GNSS. Depending on the different levels of R-Mode realization, as described in chapter y, the R-Mode capability varies from simple augmentation service to fully operational, GNSS independent, EPFS.

In general, two ways of R-Mode inauguration are considered:

* First approach would be the development of an R-Mode Performance Standard within IMO, just as those already in force for GNSS. This implies an R-Mode development as stand-alone EPFS.
* Second approach would be an open approach making use of the latest developments on the Multi-System Radionavigation Receiver (MSR). An integration of R-Mode capability into the MSR as a terrestrial component does not rely on fully stand-alone R-Mode capability and enables the exploitation of any kind of R-Mode signals at least for integrity calculations.

IMO opened up a new path towards major improvements in accuracy, availability, continuity and integrity by the inauguration of the new Performance Standard for Multi-System Radionavigation Receivers (MSR) (MSC.401(95)) and the associated GUIDELINES FOR SHIPBORNE POSITION, NAVIGATION AND TIMING (PNT) DATA PROCESSING (MSC.1/circ.1575), [5].

Minimum requirements for a terrestrial GNSS backup system were extracted from IMO and IALA publications. As a result, “suggested minimum user requirements for general navigation

(backup system) are shown in Table x-y (see Appendix 1 of IALA Recommendation R-129, [X]). These requirements must be taken into consideration while designing components of the R-Mode system and service.

Table 1: Suggested minimum user requirements for general navigation – backup system, [6]. The red rectangle highlights the designated R-Mode service areas

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | System level parameters | | | | Service level parameters | | |  |
| Maritime region | Absolute Accuracy | Integrity | | | Avail-ability % per 30 days | Continuity % over 15 minutes | Coverage | Fix interval [s] |
| Horizontal [m] | Alert limit [m] | Time to Alarm [s] | Integrity Risk (per 3 hours) |
| Ocean | 1000 | 2500 | 60 |  | 99 | N/A² | Global | 60 |
| Coastal | 100 | 250 | 30 |  | 99 | N/A² | Regional | 15 |
| Port approach and restricted waters | 10 | 25 | 10 |  | 99 | 99,97 | Regional | 2 |
| Port | 1 | 2.5 | 10 |  | 99 | 99,97 | Local | 1 |
| Inland Waterways | 10 | 25 | 10 |  | 99 | 99,97 | Regional | 2 |

The R-Mode system and service should fulfil the requirements for coastal waters, port approach and restricted waters.

In addition to Table x the R-Modeservice should fulfil the following requirements:

* are based on existing but modified infrastructure,
* work partially or completely independent from GNSS,
* have unlimited user-capacity,
* provide a two-dimensional position fix (x,y),
* provide a position referenced to geographical system WGS84,
* the R-Mode System Time (RMST) has to be traceable to the Coordinated Universal Time (UTC),
* the R-Mode signals of a site should be synchronised to 10 ns with the RMST,
* be designed to support self-test ability (e.g. clock), remote monitoring and integrity warning-reporting to the user,
* not disturb or degrade any legacy services (e.g. additional R-Mode messages should not prevent transmission of legacy service integrity information within the defined time to alarm),
* provide in each minute all necessary dynamic information for a cold start of the receiver (e.g. clock error) and
* MF and VHF R-Mode transmitters shall be usable for positioning in a mixed signal mode.

## Technical requirements

Technical requirements on system and system components can be derived to meet the user requirements.

### Timing, synchronisation and hold over

**Requirements on a contingency system (R-Mode Baltic testbed):**

**Requirements on a backup system:**

# System Architecture

The overarching architecture as adopted by IMO for e-Navigation is developed from IALA Guideline 1113 on “DESIGN AND IMPLEMENTATION PRINCIPLES FOR HARMONISED SYSTEM ARCHITECTURES OF SHORE‐BASED INFRASTRUCTURE”, [x]

Figure 2 shows how R-Mode fits in the overall e-Navigation system architecture. R-Mode will be implemented as a new shore site service which could provide data and ranging information to the ship side. The R-Mode system with its services to provide synchronised ranging signals is part of the overall PNT supporting e-Navigation architecture.

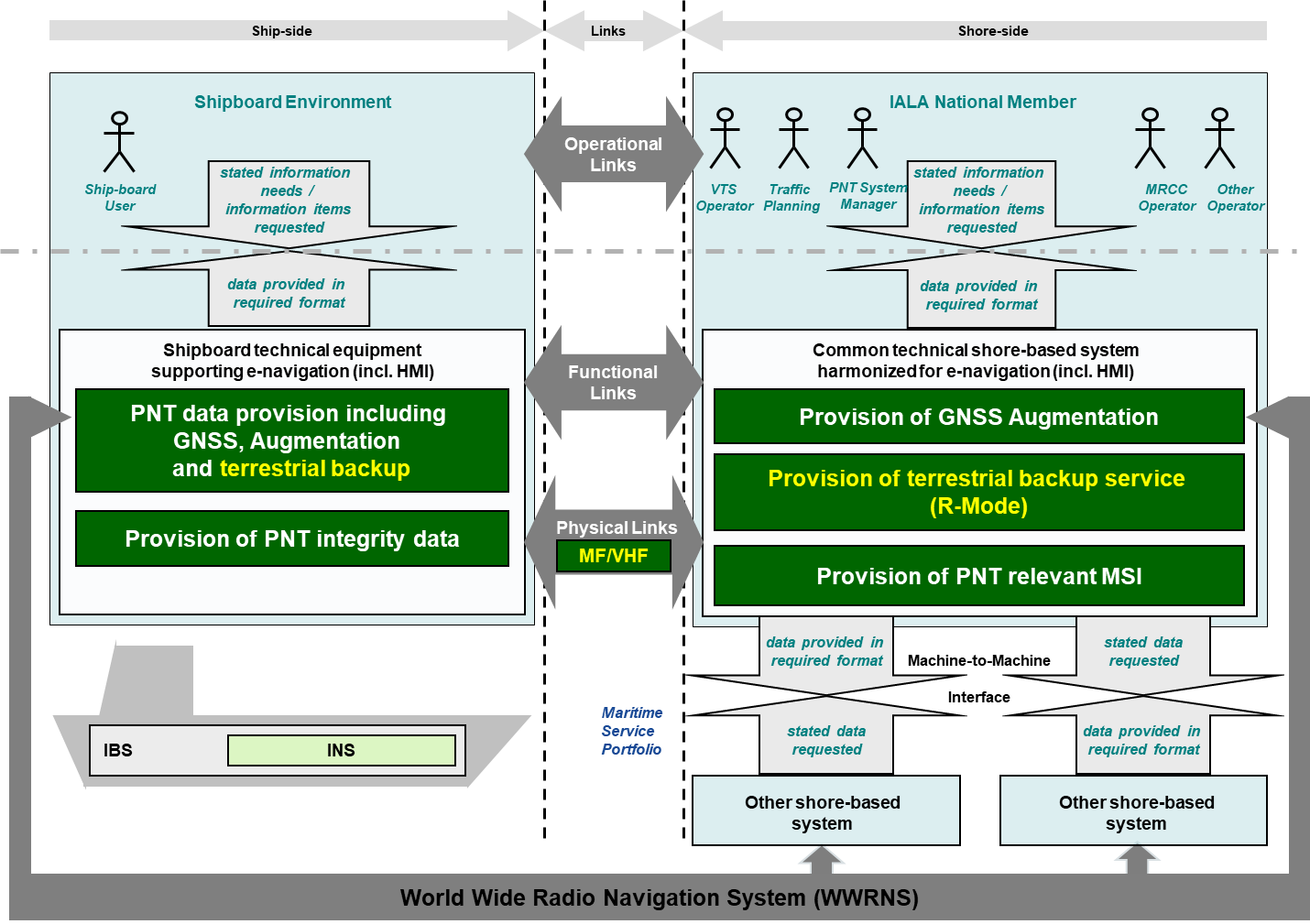


Figure 1: R-Mode embedded in the overarching IMO e-Navigation architecture

## Logical R-Mode System architecture

The R-Mode system consists in general of the following components:

1. R-Mode base station

A station that provides R-Mode service. It is intended to use existing maritime radio beacon installations and VHF (AIS/VDES) shore sites. The functions include:

* Synchronize with R-Mode reference time
* Hold over synchronized time
* Generate MF/VHF R-Mode Signal
* Transmit MF/VHF R-Mode Signal
* Receive VHF R-Mode Signal

1. R-Mode monitor

Station that monitors broadcasted signals of R-Mode transmitters. The functions include:

* Monitor availability of MF/VHF signal
* Monitor integrity of R-Mode navigation messages
* Estimate the health status of the transmitters

1. 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. The functions include:

* Synchronize to UTC or keep the time scale traceable to UTC
* regularly publish its offset and uncertainty

1. 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. The functions include:

* Configure R-Mode base stations inside the region
* Collect and share information
* Monitor status of R-Mode system
* Alarm and control of R-mode base stations in the region

1. R-Mode user

User of R-Mode service. The functions include:

* Receive MF/VHF R-Mode Signal
* Ranging
* Positioning



Figure 2 Logical R-Mode architecture

## Physical R-Mode Architecture

Figure 4 provides a common physical R-mode architecture identifying physical elements which are required for both, R-Mode using MF transmissions as well as R\_mode using VHF transmissions.

The physical R-mode architecture of a region is composed of R-mode base station & monitoring station pairs, user stations, RMRT system and command and control, Security center. The R-mode base station generates and transmits MF / VHF R-mode signal, and the user station receives the signal and calculates the position information. At the same time, the R-Mode monitoring station also receive the MF / VHF R-mode signal from the corresponding base station. It evaluates the health status of the base station by the analysis of the received signals, transmits the dynamic messages to the corresponding base station in real time, and also transmits monitoring results to the command and control, security center through network. The command and control, security center manages all base stations, monitoring stations and RMRT system in the region, and evaluates the operation status and security of the R-mode system. RMRT system provides synchronized time for base stations, monitoring stations and command and control, security center.



Figure 3 Physical system architecture

1. R-Mode base station

It consists of timing device and R-mode MF transmitter / VHF transceiver.

The timing device is a precise clock, which can be optional disciplined by GNSS. It can regularly synchronize with RMRT, and hold over the synchronized time in the interval of synchronizations, and also in the case when the time synchronization between timing device and RMRT is disrupted. Different synchronization methods might be used. VHF transceiver might receive signals from adjacent base station, and synchronize time with it to achieve precise time synchronization between adjacent R-Mode base stations. Timing device provides R-mode MF transmitter / VHF transmitter with:

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

The R-mode MF transmitter generates and transmits MF signals, while the R-mode VHF transceiver generates and transmits VHF signals, and receives VHF signals from other base stations. It is recommended to use the longitude and latitude of survey and RMRT time provided by time device. When the above position and time information is not available, GNSS is optional to provide position and UTC time information.

1. R-Mode monitor

* Receive the MF / VHF R-mode signal from the corresponding base station.
* Analyze the received signals.
* Transmit the dynamic messages to the corresponding base stations.
* Transmit monitoring results to the command and control, security center through network.

1. R-Mode reference time system:

It provides following information for timing device in R-Mode base station, monitoring station and command and control, security center:

* Pulse Per Second (1PPS)
* Data of RMRT (year, month, day, hour, minute, second)
* Data of RMRT offset and uncertainty
* Offset to UTC

1. Command and control, Security center

The center can receive the data information of R-mode base stations, monitoring stations and RMRT system through the network, manage and share these received information. It can also send command to R-mode base stations, monitoring stations and RMRT system for control.

1. R-Mode user

Receive signals from at least three R-mode base stations to calculate position information.

## Components of a MF Radio Beacon Transmitting site

The following sketch includes general components of a MF R-mode transmitting site:



Figure 4 General R-Mode Components

## Components of A VHF transceiving site



Figure 6 VHF Transceiving Site Components

The components of VHF transceiving site is as shown in Figure 6, including RF circuit, VHF modulator/ demodulator, timing device, the matching monitoring station and optional GNSS receiver.

## Monitoring



Figure 7 VHF Monitoring Site Components

# R-mode Service

## MF R-Mode Service

## VHF R-Mode Service

## Timing Service

## Use cases

# Required Modificationd for R-Mode using MF Transmissions

* Performance requirements
* System architecture
* Modification of MF transmission service including R-Mode modulation
* Timing and Synchronisation
* Technical implementation

# Required Modificationd for R-Mode using VHF Transmissions

* Performance requirements
* System architecture
* Modification of MF transmission service including R-Mode modulation
* Timing and Synchronisation
* Technical implementation

# Timing and synchronisation

## R-Mode System Time (RMST)

The RMST is as a realisation of UTC the time reference of an R-Mode system which provides R-Mode signals through a limited network of R-Mode stations in a region. Each component of the system consisting of R-Mode station network, monitoring facilities and control segment are synchronized to the RMST. Any deviation of local clocks or deviation of the timing of the signals in the network are reported with respect to the RMST.

Compared to a GNSS the R-Mode systems follow a decentralised approach. Therefore, adjacent R-Mode systems which are operated by different service providers may differ in their RMST. Beside a time offset also the stability of the RMST may differ dependent on the used approach for the realisation of UTC, synchronisation and hold-over capabilities in the R-Mode system.

The RMST is traceable to UTC. This is a precondition that the signals of different adjacent R-Mode systems or in general of an R-Mode system and another positioning or navigation systems like GPS can be used for the generation of reliable positioning and timing data without the necessity to estimate the intersystem time offset. Each R-Mode system provides an estimate of the current and predicted offset of the RMST to UTC by its navigation data.

Usually the RMST is tied to another timing source by appropriate means of synchronisation. Possible RMST sources are:

1. ss
2. R-Mode own c

Figure 5 emphasis the possible dependency of the RMST from other realisations of UTC.



Figure 5 Traceability of RMST 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. Therefore, UTC 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 can be assumed when the RMST is derived from the GNSS system time, UTC(k) or another timing source.

The RMST is a continuous time scale like GPS and other GNSS. The handling of leap seconds is typically prone for errors especially in times when the number will be changed. Therefore, the R-Mode system should use 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 it is suggested to be defined as 13 seconds before midnight between 21st August and 22nd August 1999 UTC. A change in the number of leap seconds has to be published by the R-Mode navigation data.

Requirements on the R-Mode system with respect to RMST

* RMST should be traceable to UTC; deviations and uncertainties has to be published in the navigation data.
* RMST should refer in each implementation of R-Mode (MF, VDES, AIS/ASM/VDES) on a specific time during signal transmission (e.g. zero crossing of a signal component, bit transition or beginning of a slot).
* RMST should be stable and traceable to UTC even if the mean for synchronisation with primary time source is interrupted for a longer time.
* The user should be notified if the RMST lost traceability to UTC or any R-Mode station lost its local realisation of RMST.
* Depending on the requirements on the R-Mode system the deviation of RMST to UTC should be known within reasonable accuracy.
* R-Mode system should have sufficient hold-over capacity or/and self-synchronisation capabilities to keep the RMST and fulfil the regional requirement of a backup or contingency system.

Numerically, RMST is expressed with sub-nanosecond resolution and with respect to the R-Mode epoch, which shall be suitably defined for each R-Mode implementation.

## Synchronization of R-Mode system components

All R-Mode system components use the RMST as reference time. Any local clock is therefore synchronised to RMST within a defined accuracy level which depends on the supported applications in that region. Typical time synchronisation methods are

1. Wired time transfer based on optical fiber networks, such as White Rabbit/PTP[[1]](#footnote-3).
2. Common view methods with GNSS.
3. Use signals and data channel of R-Mode to distribute RMST in the network of R-Mode transmitters.
4. GNSS receiver time solutions, representing GNSS system time[[2]](#footnote-4). 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.

## hold-over capabilities of local clocks

The connection between the source of RMST and the local clock of an R-Mode system components, e.g. transmitter site, can be disrupted. To keep the deviation of the local time to the RMST within defined limits the local clocks have to have hold-over capabilities. The allowed deviations depend on the requirements on the R-Mode system in that regions and is dependent on the supported maritime applications.

The following technologies can be used to keep an accurate time:

* Crystal oscillators
* Rubidium atomic clock
* Caesium atomic clock
* Hydrogen maser clock

## Processing of time information in the station

A well synchronised 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 RMST, 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 RMST (S).



Figure 6. 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.)

# Calibration

## Station Timing

## Signal generation

## Transmitter chain

## R-Mode monitor

# Operational Aspects

## Operation and Maintanance

## Performance Verification

## Monitoring

## Service Provider Aspects in a R-Mode Network

### Exchange of Information

### Memorandum of understanding (MOU)

## Publication of Information

# ACRONYMS & Definitions

## Acronyms

## Definitions

The definition of terms used in this Guideline can be found in the International Dictionary of Marine Aids to

Navigation (IALA Dictionary) at (<http://www.iala‐aism.org/wiki/dictionary>).

# REFERENCES

1. IALA ….
2. Information gathered during the R-mode workshop

(Saved separately)

1. IEEE-1588 [↑](#footnote-ref-3)
2. The use of PT receiver solutions to access GNSS system time is in general discouraged. [↑](#footnote-ref-4)