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| IALA Guideline |

DRAFT

on Medium Frequency R-Mode signal structure and navigation message

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# Introduction

This Guideline provides a specification of the Medium Frequency (MF) R-Mode signal and the MF R-Mode navigation messages.

## Scope of Document

The members of IALA are developing with R-Mode (abbreviation for Ranging Mode) an alternative terrestrial navigation system [1] [2] [3] that can be used together with Global Navigation Satellite Systems (GNSS) and other sensors and services to increase availability, continuity and robustness of electronical navigation support on vessels.

R-Mode follows an signals of opportunity approach to provide navigation signals from modified existing maritime communication infrastructure. These are

* enhanced IALA radio beacons, which provide a modified MF signal including the legacy service transmitting differential correction for GNSS and
* Very High frequency data Exchange System (VDES) base stations, whose clocks are stabilised by an external oscillator and which implement the VDES R-Mode standard of the IALA Guideline 1158 [4].

Three signals of MF and / or VDES R-Mode transmitters has to be received to perform positioning on the surface of the earth. The receiver altitude cannot be estimated due to transmitter location on the earth surface.

This Guideline focusses on MF R-Mode signal structure and navigation message which will be provided as service of an R-Mode system of a certain region.

R-Mode is a system that provides navigational support especially for the coastal area and ports. In areas between countries R-Mode signal reception from different service providers is possible. Furthermore, VDES and MF R-Mode signals should be together usable to perform a navigation solution estimation. Therefore, harmonisation between different R-Mode service implementations is needed.

The navigation messages defined in this Guideline enable

* estimation of current date and time,
* transmission of station health status,
* transmission of transmitter position,
* transmission of detected deviations of the signal components and clock and
* combined use of different R-Mode and GNSS services because the provided time information is traceable to UTC.

IALA radio beacons [5] implement the ITU-R M.823-3 [6] respectively RTCM 2.3 [7] standards to transmit differential corrections for GNSS. This service shall not be impaired by the extension to R-Mode. Therefore, the design of R-Mode navigation messages follows the RTCM 2.3 standard with keeping the header of RTCM 2.3 and adding a new RTCM 2.3 message for R-Mode. In a practical implementation GNSS corrections and R-Mode navigation messages can be sent sequentially one after the other. Which will cause enlargement of the gaps in the transmission of the GNSS corrections.

## Structure of document

The Guideline consist of 3 chapters beside the introduction.

Chapter 2 gives an overview about the MF R-Mode system and service. It Introduces the overall system architecture and the components of the system and service. Furthermore, the R-Mode System Time (RMST) is introduced as reference frame for all signal transmission.

Chapter 3 explains in detail the structure of the MF R-Mode signals and its timing.

Chapter 4 lists the R-Mode RTCM 2.3 navigation messages and explains in detail the different parameters.

# MF R-Mode System and service

## R-Mode System architecture

The R-Mode system consists in general of the following components (Figure 1):



Figure 1 Logical R-Mode architecture

1. R-Mode transmitter station

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

1. R-Mode monitor

Station that monitors broadcasted signals of R-Mode 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.

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.

1. R-Mode user

User of R-Mode service. The functions include:

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

## 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:

* Realisations of Coordinated Universal Time, UTC(*k*), as realised by a national metrological institute. Combinations of several UTC(k) spanning different administrations need to be communicated and applied by the timing devices.
* 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.
* R-Mode own central timing scale. It is strongly suggested to keep the time scale traceable to UTC and regularly publish its offset and uncertainty.

Figure 2 shows three different approaches to realise the traceability of the RMST to UTC. Here, *xx* and *xxx* are typically small numbers. In reality, more complicated schemes then give in Figure 2 are used.



Figure 2 Different ways to realise the 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 is 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.

## Sources for MF R-Mode signal imperfection

MF R-Mode is a system that distributes time information using specified medium frequency broadcasts. Due to technical limitations delays occur during time transfer between different clocks and signal distortions in active and passive components of the transmitter chain as well as on the propagation path to the receiver. The task of the service provider is to measure the delays and signal distortions and sent this information to the R-Mode user with the help of the R-Mode navigation messages. The user will use this information to correct its own measurements before positioning.



Figure 3 Steps which take the time information from UTC to the receiver

Figure 3 gives an overview about the different steps the time information takes until it reaches the R-Mode receiver. Starting from UTC which is realised as UTC(k) by a national metrological institute or another organisation. The RMST can be directly connected to a UTC(k) e.g. with the help of optical fibre cables or an own realisation of UTC with a known offset to an UTC(k). In any case, the R-Mode service provider should be aware of the deviation of RMST to UTC. The deviation of RMST should be a low number of ns. The offset between RMST and UTC is part of the navigation message (Conversion RMST to UTC). It should be identical for all transmitters of a service provider.

The RMST is distributed by proper means to the different transmitter and monitoring sites of the R-Mode system. The RMST synchronised local clocks (“TX(n) clock” in Figure 3) provide frequency and timing to all components of the sites, e.g. signal generator. The local clock can have an offset of several ns to the RMST and vary over the time. This “clock offset” of the transmitter site is part of its navigation message. It deviates from site to site. Uncorrected clock offsets of one site will directly go into the range error on the receiver site.

The signal generator (“TX(n) signal generator” in Figure 3) uses as an input the data stream of R-Mode navigation information and GNSS code corrections as well as time and frequency from the local clock. Most often additional parameters for the predistortion of the signal are given. Latter should compensate the impact of active and passive components (including cables, “TX(n) transmitter, ATU, antenna” in Figure 3). In case, that predistortion cannot ensure proper transmission of the R-Mode signal as specified in Chapter 3, any measured signal distortion can be reported to the user using the parameters “Delay lower SIGNAL COMPONENT”.

The data set of “conversion RMST to UTC”, “clock offset” and “delay lower SIGNAL COMPONENT” provide all information to trace the R-Mode features of the transmitted signal back to UTC.

**R-Mode differential service**: As another block in Figure 3, “Signal propagation” summarises all effects that have an impact on the signal in the time between broadcast and reception. These are

* self-interference of the ground-wave, which is used in R-Mode for the ranging, with a signal reflection at the ionosphere mainly during night-time and
* a ground dependent delay, which can vary over the time due to direct or indirect weather impact.

These two effects can be measured by an area monitor stations and result in correction parameters for all transmitter stations in view. These corrections are valid in the vicinity of the area monitor. They are provided as information of the differential R-Mode message. Here only deviations from a correction map will be transmitted. Area monitor and mobile receiver have to apply the same correction map to the measurements.

Figure 3 shows a generic scheme. Especially the implementation may deviate in details. Expected delays and distortions in active and passive receiver components are not subject of this guideline.

# MF R-Mode signal

The MF R-Mode signal should be designed to enable ranging while not affecting the legacy DGNSS service. Research on the MF R-Mode signal structure has been conducted through the ACCSEAS project[x], and a proposal has been made to add continuous wave (CW) tone signals on both sides based on centre frequency of the minimum shift Keying (MSK) signal, taking into consideration such as technical feasibility, implementation cost and difficulty. All performed tests in the various projects and measurement campaigns use this transmission method.

## Signal spectrum

The MF R-Mode signal consists of the MSK signal and two CW signals. The MSK signal is intended for the existing DGNSS service, while the two CW signals are for ranging purposes. Therefore, the spectrum of the MF R-Mode signal is a combination of the MSK signal spectrum with the addition of two CW signals. The frequency of the added CW signals varies depending on the RTCM data rate of the MSK. Figure x shows a typical MSK signal (at a data rate of 100 Bit/s) with the added ±225 Hz continuous wave signals. Figures x and x represent signal spectra measured at the transmitting station, showing ±250 Hz and ±450 Hz CW signals at the data rate of 200 bps, respectively.



Figure X: MF R-Mode signal spectrum: MSK spectrum in blue (data rate 100 bit/s) and continuous wave signals in red (± 225Hz).



Figure X: MF R-Mode signal spectrum on transmitting site (data rate 200 bit/s, CWs at ± 250Hz).



Figure X: MF R-Mode signal spectrum on transmitting site (data rate 200 bit/s, CWs at ± 450Hz).

## CW frequency considerations

The CW signals should be positioned within the null intervals of the MSK frequency spectrum to ensure signal acquisition by the receiver. However, the null intervals of the MSK frequency spectrum vary depending on the RTCM data rate of the DGNSS service. Therefore, careful consideration is necessary when selecting the frequencies for the CW signals.

Figure x shows the MSK frequency spectrum according to MSK data rate. The allowable frequencies for CW signals are as follows: for a 100 bps rate, it is ±75 Hz ± 50\*N Hz (N=0,1,2,3, ...), and for a 200 bps rate, it is ±150 Hz ± 100\*N Hz (N=0,1,2,3, ...).

As the distance from the centre frequency increases, signal acquisition by the receiver becomes easier for CW signals. Therefore, in a 100 bps transmission, MSK±225 Hz is the most suitable CW frequency within the 500 Hz bandwidth. On the other hand, in a 200 bps transmission, theoretically MSK±250 Hz could be an appropriate CW frequency within the 500 Hz bandwidth, but in practice, it exceeds the bandwidth. Therefore, if RTCM messages are transmitted at the data rate of 200 bps, a bandwidth wider than 500 Hz is required for MF R-Mode.



Figure X: MSK Spectrum in red(200 bps), CW Signals in blue, adjacent channel MSK in green(100 bps) [x].

## Signal specification

The MF R-Mode signal should comply with ITU-R M.823-3[5] DGNSS standards while satisfying the following specifications:.

* Frequency Range of MSK:
  + Adjustable in the range between 283.5 kHz and 325.0 kHz.
  + Channel spacing of 500 Hz.
* RTCM data rate:
  + Should follow legacy DGNSS RTCM service data rates of 50, 100, and 200 bps.
* Frequency Range of CW Signals:
  + Adjustable in the range between 283.25 kHz and 325.25 kHz
  + Frequency resolution/increment of 1 Hz
* CW Signals Spacing:
  + Two CW signals should be positioned at the same interval on both sides of the MSK centre frequency
  + Possible CW spacings for 100 bps RTCM:
    - MSK ±225 Hz (highly required for 500 Hz bandwidth)
    - MSK ±325 Hz
    - MSK ±425 Hz
  + Possible CW spacings for 200 bps RTCM:
    - MSK ±250 Hz
    - MSK ±350 Hz
    - MSK ±450 Hz
* Bandwidth of MF R-Mode Signal:
  + 500 Hz for 50 and 100 bps RTCM transmission
  + 1 kHz for 200 bps RTCM transmission
* Amplitude:
  + The total amplitudes of the two CW signals and the MSK signal should be 1.0 Vpp
  + The ratio is 3:1:1 (0.6 Vpp of MSK, 0.2 Vpp of each CW signal)
* MF R-Mode Signal timing:
  + The MF R-Mode signal consists of the three frequency signals: MSK and two CW signals.
  + For accurate ranging, the phase of these three frequency signals must be precisely synchronized with 1pps timing.
  + Additionally, the bit transition timing of the MSK signal should also be synchronized as shown in the Figure x.



Figure 6 Example of time relations between MSK bit transition, 1PPS, MSK and CWs signal[x]

# R-Mode navigation message

The R-Mode receiver need some information about the R-Mode service and the transmitter site to perform positioning and timing. It is foreseen to use the data channel of the DGNSS radio beacon service. For the purpose of R-Mode a dynamic RTCM 2.3 [7] message with the ID 55 was defined. The message consists of a header with all important status information that has to be provided very frequently (approximately 1 / 5 s) and further static and dynamic navigation data in submessages which can be transmitted with lower frequency. The maximum length of message 55 is 240 bits.

Another submessage provides differential R-Mode correction data and User Defined Range Error (UDRE). This is a special version of the navigation message because different error components are summarized in one correction parameter per CW.

## R-Mode navigation information

For R-Mode based ranging and positioning different R-Mode navigation data are necessary. They have to be provided with different minimum update rates. Table 1 gives an overview.

Table 1 R-Mode static and dynamic navigation data

|  |  |  |
| --- | --- | --- |
| Information | Part of R-Mode message | Minimum update rate |
| Identification of transmitter and indication of transmission time | Header | Each transmission |
| Transmitter status | Header | 1 / 5 s |
| Signal health status and navigation data validity | Header | 1 / 5 s |
| Relation of the R-Mode System Time (RMST\*) to Universal Coordinated Time (UTC) | Submessage 3 | 1 / 5 min |
| Transmitter clock correction and delays of signal components | Submessage 1 | 1 / 1 min |
| Static navigation data | Submessage 2 | 1 / 1 min |
| Offset of free running local clock to RMST | Submessage 4 | 1 / 1 min |
| Differential R-Mode corrections\*\* | Submessage 5 | 1 / 1 min\*\*\* |
| Downtime and maintenance notification | Header | 1 / 1 min |

\* RMST is used as time reference for any signal generation and as reference for given clock deviations

\*\* Optional message in case of transmitting correction data and the UDREs

\*\*\* Higher update rate is required to mitigate the sky wave effect during night-time

The update rates were defined based on the following assumption: The R-Mode messages have to be integrated into the DGNSS data stream. Due to the length of certain DGNSS messages the next possible transmission of an R-Mode navigation message has to wait one or few seconds. To make sure that the R-Mode receiver gets at least one R-Mode status information within 10 s the transmission of R-Mode status is desirable each 5 s.

In case of a cold start the receiver should get all necessary information to perform R-Mode based positioning within one minute. Interoperability with other navigation systems should be possible after five minutes.

## R-Mode time and timing of signal

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 and 22nd of August 1999 UTC (GPS week number rollover). Every R-Mode related navigation message refers to the RMST. The local clock of the transmitter site is synchronised with RMST. Known deviations will be provided in the R-Mode navigation message. The R-Mode signal will be generated and transmitted based on the local implementation of RMST (local clock).

The time of transmission of an R-Mode message is given by three parameters. The week of RMST, the hour of the RMST week and the modified Z-count [7] which gives the time within the hour in 0.6 second steps. The time refers to the leading bit edge of the first bit of R-Mode message preamble.

The MSK signal component, the legacy differential GNSS correction data stream which is extended by R-Mode navigation messages, is the third usable signal component of R-Mode. The signal component is defined such that each change of RMST hours coincides with the transmission of the bit transition between two RTCM 2.3 words. That means each RMST hour starts with the transmission of a 30 bit word. Independent from radio beacon data rate each 3 s another the word transition coincides with the second change in RMST which is typically aligned to Galileo and GPS system time within an accuracy of few 10 ns.

The additional two aided carrier (the two CW) are transmitted as sine waves with phase 0.0 and at full seconds. They are transmitted with same frequency offset to both sites of the MSK carrier frequency in minima of the MSK-signal spectrum. Lower and higher CW refer to the CW with lower and higher frequency.

Deviations of the MSK or CW signal components from definition above are given as delays of the transmitted signal in the navigation data.

## R-Mode messages

Messages that follow the RTCM 2.3 definition have the fundamental structure of two header words and up to 31 data words. Each word has a length of 24 bit for data followed by 6 parity bits [7].

The transmission of R-Mode information shall not disturb legacy DGNSS receivers. Therefore, the two header words must not be changed. Already available information will be used for R-Mode purposes. The further use of the current header has also the benefit that DGNSS receivers will further receive DGNSS station health information.

For R-Mode a single message number is needed. The message ID 55 is proposed for this purpose.

The R-Mode message 55 has a dynamic length depending on the data it contains. It always starts with an R-Mode specific header word that follows the two header words of the RTCM 2.3 standard. Within the R-Mode specific header word is an indicator for an R-Mode submessage. Each R-Mode header can follow one of seven possible R-Mode submessages. If the submessage ID is set to 0 no submessage will follow the header. Each submessage has a defined length in data words.

The R-Mode header holds all information from Table 1 which requires a high update rate. Therefore, the status message which should be transmitted approximately every 5 s can be replaced by a message 55 with additional navigation data in a submessage.

The maximum length of the currently defined R-Mode message (with submessage) is eight words (240 bits) including the three header words. This implies a transmission time of up to 2.4 s for 100 bit/s radiobeacon transmission bit rate or in other words the DGNSS correction data stream will be interrupted for up to 2.4 s.

## RTCM 2.3 header

The following definition is given in the RTCM 2.3 standard for the two header words (Figure 4) [7].



Figure 4 First and second word of RTCM 2.3 messages

For R-Mode the following parameters are important.

**Message type**: For R-Mode message number 55 is proposed.

**Station ID**: It is proposed to use the radio beacon station IDs also as identifier for the MF R-Mode station.

**Modified Z-count**: Relates message transmission to RMST. See section 4.3 for more information.

**No. data words**: The number of data words will be adjusted to the R-Mode submessage. It can have values from 3 to 8 for the message defined below.

## R-Mode header

The R-Mode header is the third word of message 55. It follows the RTCM 2.3 header. It contains the overall status information of the R-Mode service provided by that station and five specific status indicators for parts of the system and service. Further parameters refer the beginning of message transmission to the week of RMST and inform about planned service unavailability. The last parameter is the identifier for the submessage which will follow the header (Table 2 and Figure 5).

Table 2 Content of the third R-Mode message word

| Parameter | Number of bits | Range |
| --- | --- | --- |
| Transmitter station health | 2 | 0 = fully operational  1 = limited use  2 = not usable  3 = *not used* |
| Monitoring status | 1 | 0 = R-Mode transmitter is monitored  1 = R-Mode transmitter is unmonitored |
| Status MSK signal | 2 | 0 = Signal usable for ranging  1 = Signal out of service  2 = Signal is under test  3 = *not used* |
| Status CW signals | 2 | 0 = Signal usable for ranging  1 = Signal out of service  2 = Signal is under test  3 = *not used* |
| Status clock | 2 | 0 = Local clock is synchronised to RMST and synchronisation link is available  1 = Local clock is synchronised to RMST and synchronisation link is not available (use hold over capabilities of station)  2 = Free running clock (separate message for offset to RMST)  3 = Deviation of local clock to RMST unknown |
| Status navigation data | 1 | 0 = Navigation data valid  1 = Navigation data not usable |
| Hour of week | 8 | 0 – 167 hours |
| Submessage ID | 3 | 0 = no additional information  1 = RMST week, signal delays and offset (3 words)  2 = Static navigation data (3 words)  3 = RMST to UTC conversion (5 words)  4 = Free running clock offset (2 words)  5 = Differential R-Mode corrections (2 words)  6 -7 = *not used* |
| Planned service interruption | 3 | See description below |
| Parity | 6 |  |

**Station health**: This is the fundamental indicator for usability of the R-Mode service which is transmitted by the station.

* Fully operational: Station is monitored and signals are within defined performance limits considering the provided navigation data.
* Limited use: Some status indicators show service limitation (for example, monitoring station or differential R-Mode station is not working). The user has to decide if the limitations given by the specific indicators in the message are acceptable for the planned application.
* Not usable: The R-Mode service is not usable.

**Monitoring status**: When set as monitored the R-Mode service of the station is continuously monitored. Any identified deviation will either be corrected in future transmissions or result in adjustments to the R-Mode navigation information.

**Status MSK signal**: The signal component is indicated as usable to perform ranging if the signal fulfils the definition given in section 4.2. Known deviations are given in the navigation data. Furthermore, an uninterrupted MSK modulated data stream with fixed data rate is transmitted. If these conditions are not met the signal is indicated as not usable. Signal under test is transmitted when the signal is usable but working without performance commitment.

**Status CW signals**: The signal component is indicated as usable to perform ranging if the signal fulfils the definition given in section 4.2. Known deviations are given in the navigation data. If these conditions are not met the signal is indicated as not usable. Signal under test is transmitted when the signal is usable but working without performance commitment.

**Status clock**: Status of the local clock synchronisation to RMST.

**Status navigation data**: Status of transmitted R-Mode navigation data in submessage 1 to 7.

**Hour of week**: Gives the hour of the RMST week in which the transmission of the message started. It is the same hour for GPS and Galileo system time. See section 4.3 for more information.

**Submessage ID**: Defines a submessage (ID from 1 to 7) that follows the R-Mode header word.

**Planned service interruption**: A planned R-Mode service interruption can be specified as given in Table 3.

Table 3 Parameter values for planned service interruption

|  |  |
| --- | --- |
| Value *n* | Explanation |
| 0 | R-Mode service interrupted / not available / do not use  The interruption is ongoing or will begin in less than 10 minutes. |
| 1 – 5 | Planned service interruption starts in time *T* with  10 \* 2*n*-1 min <= *T* < 10 \* 2*n* min  Intervals: (10, 20), (20, 40), (40, 80), (80, 160), (160, 320) |
| 6 | Interruption planned in more than 320 min |
| 7 | No service interruption planned |



Figure 5 Third R-Mode message word

## Submessage 1: RMST week, signal delays and offset

This submessage has three groups of parameters (Table 4 and Figure 6).

**Timing**: It provides the RMST week number of the transmitted message. The entire time information is given by the modified Z-count (second word), hour of week (third word) and week number (R-Mode submessage 1).

**Clock offset**: Typically, the local clock of the transmitter which is used to align the transmitted R-Mode signal with RMST deviates by several ns from RMST. The transmitter clock should have certain stability so that the clock offset can be described by a single clock offset parameter each minute. To inform the R-Mode service user about the timing quality of the transmitted signal a transmitter clock offset uncertainty is provided. These two parameters are used in case the transmitter site clock is in synchronisation mode.

**Signal delays**: The three signal components may face delays and phase shifts during transmission that cannot be compensated by other means. To inform the user about the timing of the transmitted signal components the delay of each component and a phase value for the MSK signal component are provided.

Table 4 Content of R-Mode submessage 1: RMST week, signal delays and offset

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Number of bits | Scale factor and units | Range |
| Week number | 12 | 1 week | 0 – 4095 weeks |
| Clock offset | 9\* | 1/3 ns | ± 85.0 ns |
| Clock uncertainty | 5 | - | See description below |
| Delay lower CW | 14\* | 1/3 ns | ± 2730.33 ns |
| Delay higher CW | 14\* | 1/3 ns | ± 2730.33 ns |
| Delay MSK | 14\* | 1/3 ns | ± 2730.33 ns |
| Phase MSK | 2 | 0.5 π rad | 0 rad - 1.5 π rad |
| *Reserved* | *2* |  | *For future use* |
| Parity | 18 |  |  |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the most significant bit.

**Week number**: Number of RMST week for the transmission of the message.

**Clock offset**: Current offset of local clock at the transmitter site to RMST.

**Clock uncertainty**: The clock offset uncertainty is given as 1σ confidence level. It offers 32 levels *n* of uncertainty *u* which are given by

*u* = (*kn* - 1) ns for 0 < *n* < 31 with *k* = 1.25 . Eq. 1

It describes uncertainties ranging from 0.25 ns to about 806.8 ns. The values of *n* = 0 and *n* = 31 have a special meaning (Table 5).

Table 5 Parameter values for station clock offset uncertainty

|  |  |
| --- | --- |
| Value *n* | Explanation |
| 0 | Clock offset uncertainty is unknown |
| 1 – 30 | Clock offset uncertainty is below *u*  *u* = 0.25 ns, 0.56 ns, 0.95 ns, …, 806.8 ns |
| 31 | Clock offset uncertainty is larger than 806.8 ns |

**Delay lower CW**: Delay of lower CW signal component.

**Delay higher CW**: Delay of higher CW signal component.

**Delay MSK**: Delay of MSK signal component. The delay is limited to about one period of the carrier frequency.

**Phase MSK**: This parameter provides the phase of the MSK signal component at the leading edge of the first bit in the preamble (first word). Possible values are 0, 1/2 π rad, π rad, and 3/2 π rad.



Figure 6 R-Mode submessage 1: RMST week, signal delays and offset

## Submessage 2: Static navigation data

The R-Mode submessage 2 provides all static parameters of the R-Mode transmitter. These are latitude and longitude of the MF R-Mode transmitter antenna phase centre given in WGS-84 reference frame. Furthermore, the broadcast bit rate of the MSK modulated data stream and the frequency of the two CW are provided (Table 6 and Figure 7).

Table 6 Content of R-Mode submessage 2: Static navigation data

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Number of bits | Scale factor and units | Range |
| Latitude | 28\* | 90 / (227-1) ° | ± 90 ° |
| Longitude | 29\* | 180 / (228-1) ° | ± 180 ° |
| Broadcast bit rate | 1 | - | 0 = 100 bits/sec  1 = 200 bits/sec |
| CW frequency offset | 3 | - | See description below |
| *Reserved* | *11* |  | *For future use* |
| Parity | 18 |  |  |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the most significant bit. “+” values indicate North Latitude or East Longitude.

**CW frequency offset**: The R-Mode signal consists of the MSK component and two CW components (Section 3.2). The two CW are symmetrically located in the radiobeacon channel of the station in two minima of the MSK signal spectrum. The parameter “CW frequency offset” *n* identifies the minima counted from the MSK carrier frequency. The frequency offset Δ*f* from CW to the MSK carrier frequency is computed according to the following equation:

Δ*f / f*bit = (3 + 2*n*)/4 with *n* = 0, 1, 2, …, 7 . Eq. 2

Here *f*bit is the broadcast bit rate.



Figure 7 R-Mode submessage 2: Static navigation data

## Submessage 3: RMST to UTC conversion

The RMST is established by the 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 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’s location.

The conversion between RMST and UTC is given by polynomial parameters for the deviation, parameter for the UTC reference time and week, and parameters for correct handling of leap seconds. The approach of RMST conversion to UTC is taken from the Galileo Open Service Signal in Space Interface Control Document [8] where the conversion algorithm for the Galileo System Time to UTC is described in detail. In deviation to Galileo the modulo 256 operation for week numbers is not required because with 12 bits the real RMST week can be given (Table 7 and Figure 8).

Table 7 Content of R-Mode submessage 3: RMST to UTC conversion

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Number of bits | Scale factor and units | Range |
| Constant term of polynomial | 32\* | 2-30 s | ± 1.9999999991 s |
| 1st order term of polynomial | 24\* | 2-50 s/s | ± 0.000000007451 |
| Leap second count before leap second adjustment | 8\* | 1 s | ± 127 s |
| UTC data reference time of week | 8 | 3600 s | 0 – 918000 s |
| UTC data reference week number | 12 | 1 week | 0 – 4095 weeks |
| Week number of leap second adjustment | 12 | 1 week | 0 – 4095 weeks |
| Day number at the end of which a leap second adjustment becomes effective | 3\*\* | 1 day | 0 – 7 days |
| Leap second count after leap second adjustment | 8\* | 1 s | ± 127 s |
| *Reserved* | *13* |  | *For future use* |
| Parity | 30 |  |  |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the most significant bit.

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



Figure 8 R-Mode submessage 3: RMST to UTC conversion

## Submessage 4: Free running clock offset

When the synchronisation of the R-Mode transmitter station with the RMST is interrupted, the station uses clock hold-over capabilities to keep an accurate time. It can be assumed that for such cases the local clock deviates further from the RMST from a certain point in time than provided for in submessage 1. Submessage 4 provides the information of larger clock errors. The local clock offset is given by the two coefficients of a 1st order polynomial and a reference time (Table 8 and Figure 9).

Table 8 Content of R-Mode submessage 4: Free running clock offset

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Number of bits | Scale factor and units | Range |
| Reference time | 14 | 1 min | 0 – 16383 min |
| Clock offset constant term of polynomial | 16\* | 1/3 ns | ± 10922.33 ns |
| Clock offset 1st order coefficient of polynomial | 8\* | 1 ns / h | ± 127 ns / h |
| Reserved | *10* |  | *For future use* |
| Parity | 12 |  |  |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the most significant bit.

**Reference time**: The reference time *t*R defines the reference point of the clock offset polynomial. It is given as minutes of the current RMST week. *t*R refers always to second 0 of the provided minutes.

**Clock offset constant term of polynomial**: Constant term of the clock offset *A*0.

**Clock offset 1st order coefficient of polynomial**: 1st order coefficient of the clock offset *A*1.

The corrected time *t*corr is computed from estimated time *t*E (given as seconds of RMST week) according to the following equations:

*t*corr = (*t*E - *t*offset) Eq. 3

*t*offset = *A*0 + *A*1 (*t*E - *t*R \* 60 s/min) . Eq. 4

*t*E and *t*R must be in the same RMST week.



Figure 9 R-Mode submessage 4: Free running clock offset

## Submessage 5: Differential R-Mode corrections and UDREs (Will be updated with separate input to ENG17)

Description of content of submessage 5.

Table 9 Content of R-Mode submessage 5: Differential R-Mode corrections and UDREs

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Number of bits | Scale factor and units | Range |
| Correction for lower CW | 12\* | 1 ns | ± 2,047 ns |
| Correction for higher CW | 12\* | 1 ns | ± 2,047 ns |
| UDRE for lower CW | 4 | See the table |  |
| UDRE for higher CW | 4 | See the table |  |
| Differential R-Mode station ID | 10 |  |  |
| Reserved | 6 |  |  |

\* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the most significant bit.

**Correction for lower CW**: Time varying correction data of signal propagation delay for lower CW.

**Correction for higher CW**: Time varying correction data of signal propagation delay for higher CW

**UDRE for lower CW**: UDRE is calculated after applying MF R-Mode correction for lower CW.

**UDRE for higher CW**: UDRE is calculated after applying MF R-Mode correction for higher CW

**Differential R-Mode Station ID**: Station ID generate the corrections

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Figure 10 R-Mode submessage 5: Differential R-Mode corrections and UDREs

Table 10 Parameter values for UDRE of lower and higher CW

|  |  |  |  |
| --- | --- | --- | --- |
| UDRE | Range [m] | UDRE | Range [m] |
| 0 |  | 8 |  |
| 1 |  | 9 |  |
| 2 |  | 10 |  |
| 3 |  | 11 |  |
| 4 |  | 12 |  |
| 5 |  | 13 |  |
| 6 |  | 14 |  |
| 7 |  | 15 |  |

# ACRONYMS & Definitions

## Acronyms

|  |  |
| --- | --- |
| CW | Continuous wave |
| DGNSS | Differential GNSS |
| GPS | Global Positioning System of the United States; originally Navstar GPS |
| GNSS | Global Navigation Satellite System |
| ITU | International Telecommunication Union |
| ITU-R | Radiocommunication Sector of ITU |
| MF | Medium Frequency |
| MSK | Minimum-Shift Keying |
| RMST | R-Mode System Time |
| RTCM | Radio Technical Commission for Maritime Services |
| UDRE | User Defined Range Error |
| UTC | Universal Coordinated Time |
| VDES | VHF data exchange system |
| VHF | Very High Frequency |

## 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

|  |  |
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