C75-12.1.1

Liaison Note to RTCM

Navigation message for medium frequency R-Mode

1 Introduction

Ranging Mode (R-Mode) is a maritime terrestrial navigation system that is designed as a backup for Global Navigation Satellite Systems (GNSS). Extending the functionality of existing maritime radiobeacons is one possible way to implement R-Mode on existing maritime radio infrastructure. The beacons broadcast differential GNSS corrections in the medium frequency band as a continuous data stream encoded with the format known as RTCM 2.3. To enable the use of the modified beacon signals for R-Mode based ranging and positioning additional navigation information is needed that provides static and dynamic information about the R-Mode transmitter. An obvious approach to distribute this information is to use the RTCM 2.3 data stream of the R-Mode enabled radiobeacon to provide the navigation information together with the differential GNSS corrections.

The IALA received as input to the 15th ENG committee meeting a proposal for an RTCM 2.3 message which allows the flexible provision of static and dynamic R-Mode navigation data. The message was designed to keep the delays in the differential GNSS service moderate. The input paper "ENG15-3.1.3.6 RTCM navigation message for medium frequency R-Mode" is attached as the annex of this document.

The document was discussed during the ENG 15 meeting. It was agreed that it is a good starting point for the standardisation of the medium frequency R-Mode navigation message.

IALA invites RTCM for a collaboration between the IALA ENG Committee and the RTCM Special Committee 104 on the further development of the RTCM version 2.3 to integrate the proposed R-Mode navigation message as an amendment.

2 Action requested

The RTCM is requested to:

1 Consider the annex about the proposed medium frequency R-Mode navigation message.

2 Check if the defined messages can be added as an amendment to RTCM 10402.3.

3 Inform IALA how to move the initiative of standardisation of R-Mode navigation message further.

Annex

Input paper: [1] ENG15-3.1.3.6

Input paper for the following Committee(s): check as appropriate

Purpose of paper:

□ ARM X ENG □ PAP

x Input

□ ENAV □ VTS

□ Information

Agenda item [2]

Technical Domain / Task Number [2] 3.2.2...............................

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RTCM navigation message for medium frequency R-Mode

1 SUMMARY

Ranging Mode (R-Mode) is a maritime terrestrial navigation system that is designed as a backup for Global Navigation Satellite Systems (GNSS). Extending the functionality of existing maritime radiobeacons is one possible way to implement R-Mode on existing maritime radio infrastructure. The beacons broadcast differential GNSS corrections in the medium frequency band as a continuous data stream encoded with the format known as RTCM 2. To enable the use of the modified beacon signals for R-Mode based ranging and positioning additional navigation information is needed that provides static and dynamic information about the R-Mode transmitter. An obvious approach to distribute this information is to use the RTCM 2 data stream to provide the navigation information together with the differential GNSS corrections.

This paper presents an RTCM 2 message proposal for the R-Mode navigation data which allows the flexible provision of static and dynamic navigation data. It is designed to keep the delays in the differential GNSS service moderate.

2 BACKGROUND

Medium frequency (MF) R-Mode is an extension of the radiobeacon system and service which is described in the IALA Guideline No. 1112 [1]. The radiobeacons provide code differential corrections for GNSS. This service is also known as DGNSS. DGNSS enables positioning with 10 m accuracy in the radiobeacon service area. Furthermore, integrity information will be provided together with the GNSS corrections. The data are provided using a Minimum-Shift Keying (MSK) modulated data stream encoded as messages which are defined in RTCM and ITU-R standards [2] [3]. In this document we will refer to that standards with the often-used acronym RTCM 2.

R-Mode is an extension of the current radiobeacon DGNSS service. The transmitted signal is modified such that two additional carriers (continues waves - CW) will continuously be transmitted together with the legacy DGNSS service. This signal modification has no negative impact on the DGNSS receiver performance [4]. Besides these two CW ranging signals additional static and dynamic navigation information as known from GNSS is necessary to perform ranging and positioning with R-Mode. It is obvious to use the DGNSS data

1 Input document number, to be assigned by the Committee Secretary
2 Leave open if uncertain

channel to distribute the R-Mode navigation data. Because the DGNSS service shall further be available, the R-Mode messages should coexist with DGNSS and do not cause interruption of the DGNSS service or significant delays in the provided continuous data stream.

Therefore, it is necessary to use the RTCM 2 data encoding for the R-Mode navigation data. Furthermore, the R-Mode message length should be short so that it can be integrated into the DGNSS data stream. Few delays are acceptable because the DGNSS corrections are usable for several seconds after Selective Availability was discontinued for GPS.

3 DISCUSSION

3.1 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
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

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.

3.2 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 [2] 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 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.

3.3 R-Mode messages

Messages that follow the RTCM 2 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.

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 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.

3.4 RTCM 2 header [2]

The following definition is given in the RTCM 2 standard for the two header words (Figure 1) [2].

Bits 1–8	Bits 9–14	Bits 15–24	Bits 25–30
Preamble	Message Type	Station ID	Parity

Bits 1–13	Bits 14–16	Bits 17–21	Bits 22–24	Bits 25–30
Modified Z-count	Seq. No.	No. data words	Station health	Parity

Figure 1 First and second word of RTCM 2 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 3.2 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.

3.5 R-Mode header

The R-Mode header is the third word of message 55. It follows the RTCM 2 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 2).

Table 2 Content of the third R-Mode message word

Parameter	Number of bits	Range
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 -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. 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 3.2. 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 3.2. 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 3.2 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

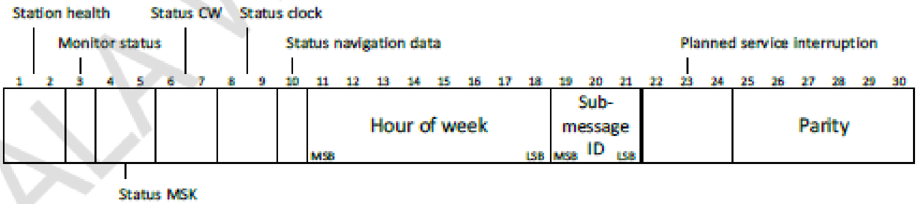

Figure 2 Third R-Mode message word

3.6 Submessage 1: RMST week, signal delays and offset

This submessage has three groups of parameters (Table 4 and Figure 3).

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 (MSB).

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

$$u = (k^n - 1)\ \text{ns} \quad \text{for} \quad 0 < n < 31 \quad \text{with } k = 1.25\,. \qquad \text{Eq. 1}$$

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.

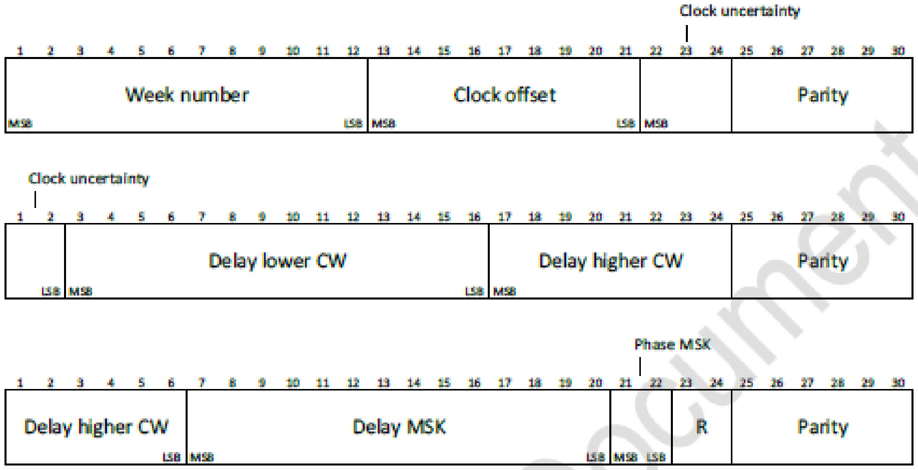

Figure 3 R-Mode submessage 1: RMST week, signal delays and offset

3.7 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 4).

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

Parameter	Number of bits	Scale factor and units	Range
Latitude	28*	90 / (2^{27}-1) °	± 90 °
Longitude	29*	180 / (2^{28}-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 (MSB). "+" 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 *Δf* from CW to the MSK carrier frequency is computed according to the following equation:

$\Delta f\,/\,f_{bit} = (3 + 2n)/4$ with $n = 0, 1, 2, \ldots, 7$. Eq. 2

Here f_{bit} is the broadcast bit rate.

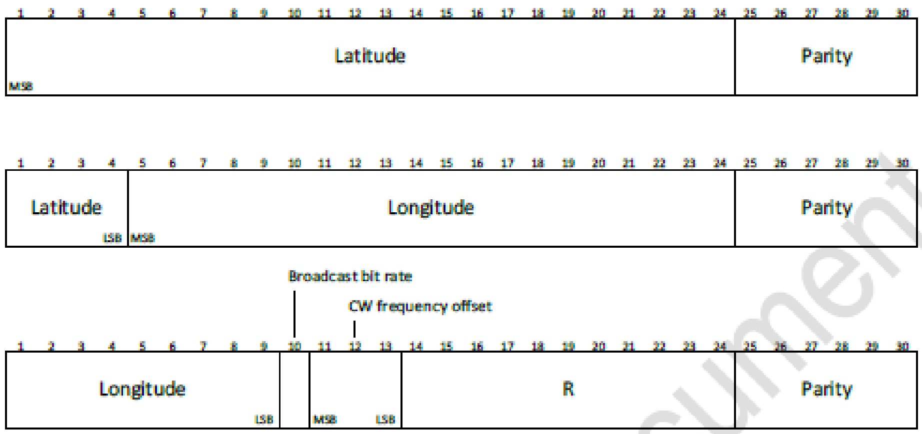

Figure 4 R-Mode submessage 2: Static navigation data

3.8 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 [5] 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 5).

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 (MSB).

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

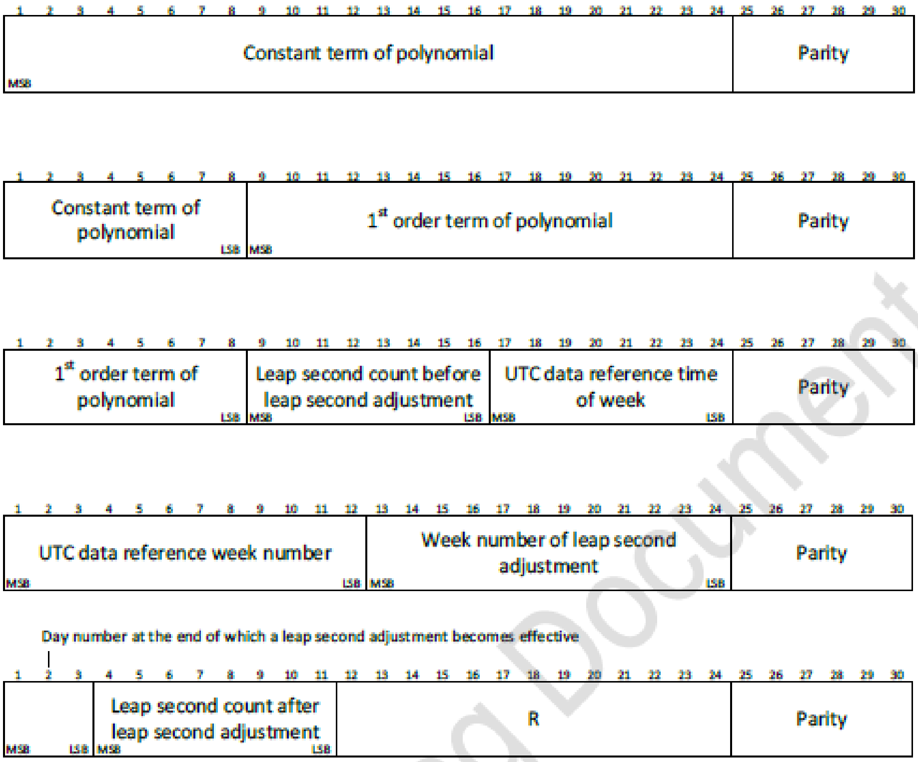

Figure 5 R-Mode submessage 3: RMST to UTC conversion

3.9 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 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 (MSB).

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 minute.

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:

$$t_{corr} = (t_E - t_{offset}) \qquad \text{Eq. 3}$$

$$t_{offset} = A_0 + A_1\,(t_E - t_R * 60\ \text{s/min})\ . \qquad \text{Eq. 4}$$

t_E and t_R must be in the same RMST week.

Bits 1–14 (MSB … LSB)	Bits 15–24 (MSB …)	Bits 25–30
Reference time	Clock offset constant term	Parity

Bits 1–6 (… LSB)	Bits 7–14 (MSB … LSB)	Bits 15–24	Bits 25–30
Clock offset constant term	Clock offset 1st order term	R	Parity

Figure 6 R-Mode submessage 4: Free running clock offset

4 REFERENCES

[1] IALA, "Guideline No. 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz", Edition 1, May 2015.

[2] RTCM, "RECOMMENDED STANDARDS FOR DIFFERENTIAL GNSS (GLOBAL NAVIGATION SATELLITE SYSTEMS) SERVICE", version 10402.3, August 2001.

[3] ITU-R, "TECHNICAL CHARACTERISTICS OF DIFFERENTIAL TRANSMISSIONS FOR GLOBAL NAVIGATION SATELLITE SYSTEMS FROM MARITIME RADIO BEACONS IN THE FREQUENCY BAND 283.5-315 kHz IN REGION 1 AND 285-325 kHz IN REGIONS 2 AND 3", Recommendation ITU-R M.823-3, March 2006.

[4] Gregory W. Johnson, Peter F. Swaszek, Michael Hoppe, Alan Grant, Jan Safar, "Initial Results of MF-DGNSS R-Mode as an Alternative Position Navigation and Timing Service," Proceedings of the 2017 International Technical Meeting of The Institute of Navigation, Monterey, California, January 2017, pp. 1206-1226.

[5] European Union, "European GNSS Galileo Open Service Signal In Space Interface Control Document", OD SIS ICD, Issue 1.1, September 2010.

5 ACTION REQUESTED OF THE COMMITTEE

The Committee is requested to:

1. Note the information provided.
2. Discuss the proposal and include the information into the IALA Guideline on Implementation of R-Mode on MF and VHF frequencies.
3. Consider RTCM SC 104 with liaison note about the R-Mode message proposal.