Liaison Note to RTCM

Liaison Note to RTCM on SC-104 2.X

1 Introduction

According to IMO *SN/Circ.223*, IALA was assigned the task of maintaining the radiobeacon Differential GNSS (RBN-DGNSS) service for allocating identification (ID) numbers for the reference stations and transmitting stations in the frequency band 283.5–325kHz.

With the recognition of new GNSS and RNSS services in WWRNS by IMO, and the extending of SBAS and terrestrial navigation system applications in maritime, national administrations are facing choices on the way forward of the RBN-DGNSS services.

The existing RTCM DGNSS broadcast standard 10402.3 provides correction information mainly for the GPS L1. The new RTCM 10402.X (version 2.4) standard has been in development for many years but has not yet been finalised. During IALA ENG13 and ENG 15, the delegation of the RTCM SC-104 working group on DGNSS posed the following questions:

1. Does version 2.3 cover the needs for next years?

2. Is it likely that 2.4 will be used by service providers?

3. Should 2.4 include other message types (like R-Mode support, integrity mode support)

4. Alternative use of the marine radio beacons (new RTCM standard supporting ARAIM, R-Mode)

These issues have been discussed among IALA members, and certain requirements and comments have been provided. **With reference to these discussions IALA invites RTCM to consider the following**:

- The radiobeacon frequency band is valuable to maritime safety, so it is important to maintain this application in the maritime sector.
- **From RBN-DGNSS perspective**. Some IALA national members have been shutting down their DGNSS in recent years, but there are also many IALA national members maintaining their services, some of whom are seeking to provide corrections for multiple GNSS systems from their RBN-DGNSS. Therefore, the update to RTCM v2.3, supporting differential corrections for multiple GNSS is required by some IALA members (Annex 1 provides details of DGPS and DBDS corrections implemented in China).
- **For R-Mode navigation data.** 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 system. 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. Annex 2 provides an initial proposal for a message structure for consideration.

10, rue des Gaudines - 78100 Saint Germain en Laye, France
Tél. +33 (0)1 34 51 70 01- Fax +33 (0)1 34 51 82 05 - contact@iala-aism.org
www.iala-aism.org
International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

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.X to support future RBN-DGNSS and R-Mode.

2 Action requested

The RTCM is requested to:

1. Consider the annexes when revising the RTCM 10402.X.
2. Check if the defined R-Mode messages can be added as an amendment to RTCM 10402.3.
3. Review the RTCM 10402.X to support BDS, Galileo, QZSS and other newly recognized GNSS systems.
4. Consider publishing a new version of RTCM 10402.X as soon as possible.
5. Provide advice to IALA on how to progress the initiative of standardization of new GNSS and R-Mode navigation messages.

Annex 1

IALA

Input paper: [1] ENG13-3.1.3.2

Input paper for the following Committee(s):		check as appropriate	Purpose of paper:
☐ ARM	☑ ENG	☐ PAP	☑ Input
☐ ENAV	☐ VTS		☐ Information

Agenda item [2]	(from agenda)
Workplan Task Number / Technical Domain [2]	2018 - 2022 / Task 2.2.7
Working Group	WG1
Author(s) / Submitter(s)	China MSA

Dual-mode transformation of maritime RBN-DGPS stations in China

1. SUMMARY

Since 2014, China has launched the technical exploration and experiment of the dual-mode transformation of maritime RBN-DGPS. The main objective is to transmit the DGPS&DBDS information simultaneously on the existing RBN-DGPS stations, in order to improve the availability of RBN differential signal, and improve the positioning accuracy of ship users. There are two technical schemes: one is to broadcast DBDS information through the station sub-carrier frequency, and the original DGPS information transmission link does not be affected; The other scheme is to transmit DBDS & DGPS information on the same radio beacon frequency. Due to the limitation of frequency resource, DGPS & DBDS information transmitted on the same radio-pointing carrier frequency is demonstrated to be more feasible and reasonable, as the effect of time delay on the system performance is within the acceptable range (up to 8 seconds).This scheme has been adopted in 22 RBN-DGPS stations in China's coastal areas since 2015.

1.1. PURPOSE OF THE DOCUMENT

The proposal introduces the exploration, relevant technical scheme and test results of the dual-mode transformation of maritime RBN-DGPS stations in China, it provides a reference for IALA developing guidelines on "DGNSS service provision, upgrades and future uses" and other countries building and uparading RBN-DGNSS . It also introduces the research and exploration based on RBN-DGNSS station, and provides some practical experiences for IALA to formulate the future development direction of RBN-DGNSS.

1.2. RELATED DOCUMENTS

1. R-150 DGNSS service provision, upgrades and future uses

2. IALA workshop on the future of marine radio beacon DGPS/DGNSS report 27 to 31 January 2020

2. BACKGROUND

With the development of technology, the single point positioning accuracy of satellite navigation system is getting higher and higher, and the satellite based augmentation system is more and more favored by the navigation users because of its wide area coverage. Some countries are considering shutting down the RBN-DGPS system , no longer providing related services, and then using Wass, EGNOS and other satellite-based augmentation systems as an alternative, because RBN-DGPS equipment aging and maintenance cost increasing is bcoming more and more prominent. IALA's attitude about it is that these countries need to ensure the integrity of their waters when considering alternatives. As the same frequency band of Satellite Navigation Systems and their satellite-based augmentation systems are , their signals are vulnerable to interference and camouflage, furthermore, the existing satellite-based augmentation system receiver automatic integrity monitoring (RAIM) is not as effective as the reference station Integrity Monitoring (RSIM) for maritime applications, so in the short term, RBN differential enhancement system is still an effective and reliable way to provide high-precision positioning service for ships entering and leaving ports.

3. DISCUSSION

Due to the need of autonomous navigation of unmanned vessels and pilotage of large ships, the positioning accuracy of RBN-DGPS system has no obvious advantages compared with other means. Therefore, upgrading the existing RBN-DGPS system to achieve the compatibility of multi-satellite navigation system constellations can increase the number of observable satellites in a specific region, the user selects the optimal satellite correction information through the software for the multi-satellite system fusion solution, which can theoretically improve the positioning accuracy and signal availability of the system. The test of signal receiving and positioning after the dual-mode reconstruction in the Chinese coastal area also verified this point.

3.1. PRINCIPLE OF TRANSFORMATION

3.1.1. THE ORIGINAL DGPS USERSHOULD NOT BE AFFECTED

Since most of the domestic and international ship user terminals are RBN-DGPS equipments, the broadcast signal format and radio characteristics of the reformed system should not be changed and need to be received and located normally by the existing RBN-DGPS equipments, existing users will not be required to replace equipment or upgrade related software, and the system characteristics shall comply with the relevant requirements of the global radio navigation system as set out in IMO Resolution A. 1046(27) .

3.1.2. USING BDS/GPS/GLONASS INTEGRATED EQUIPMENT

The Reference Station and Integrity Monitoring Station should adopt BDS/GPS/GLONASS integrated equipment to support multi-satellite system, multi-frequency, multi-channel, and ensure the system performance while leaving the possibility for further upgrading and compatibility.

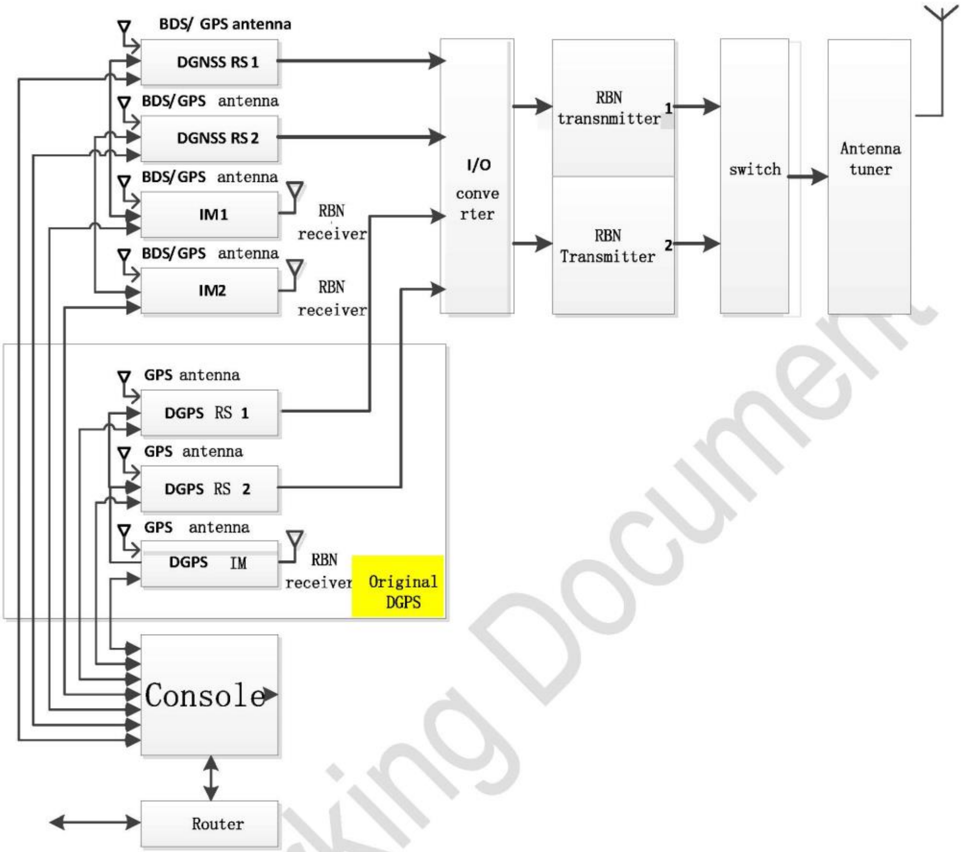
3.1.3. SUPPORT FOR REMOTE MONITORING

The Reference Station Server, Integrity Monitoring Station server and console can be connected to the network remotely. The real-time operation parameters and various reports of the station can be monitored and displayed locally and remotely.

3.2. TECHNICAL SOLUTION

The station transformation is carried out on the basis of RBN-DGPS station, using the existing power supply and lightning protection facilities, adding 2 sets of DGNSS reference stations, 2 sets of DGNSS integrity monitoring stations, routers and other network equipment to a single station, and replace the console, I/O converter, transmitter, automatic antenna tuner and other equipment, the original DGPS reference, DGPS integrity monitoring equipment as a backup system. The operating frequency, identification number and transmitting power of the retrofitted station remain unchanged. Key components such as reference station, Integrity Monitoring Station and transmitter power amplifier unit can be switched automatically and manually by double-click hot backup to ensure continuous and stable operation of the system.

The improved RBN-DGNSS dual-mode station is shown in figure 1. In the dotted frame is the original RBN-DGPS equipment, as a backup system, outside the dotted frame, for upgrading the new RBN-DGNSS equipment.



Figture 1 Composition of RBN-DGNSS station after transformation

The differential messages are encoded by a combination of DGPS and DBDS, and both of which are encoded by a group of three satellites in RTCM format (see Appendix A: The Beidou differential message data format) , and are transmitted alternately. Integrity monitoring uses the reference station integrity monitoring standard (RSIM) V1.2. Message broadcasted as explained in the Table 1:

Messeage type	Broadcasting frequency	instructions
9 (Differential correction of partial GPS satellite)	Continuously	Broadcasting corrections by a group of three GPS satellites circularly, of which elevation is more than 7.5 °.
42 (Differential correction of partial BDS satellite)	Continuously	Broadcasting corrections by a group of three GPS satellites circularly, of which elevation is more than 7.5 °.
16 (Station text information)	When necessary	Message type 16 shall not be transmitted for at least 90 seconds before or after message
3 (GNSS RS parameters)	The 15th and 45th minute after the hour	Broadcasting when necessary.
5 (GPS constellation health status)	The 5th minutes after the hour, then broadcasting every 15 minutes	Broadcasting when an unavailable GPS satellite can be used in RBN-DGNSS system.
7 (Transmitter information)	The 7th minutes after the hour, then broadcasting every 10 minutes	When the status of the transmitter station changes, the message type 7 should be modified and broadcast within 2 minutes from the 7th minute of the next hour.
27 (Extended Transmitter information)	The 9th minutes after the hour, then broadcasting every 10 minutes	When the status of the transmitter station changes, the message type 27 should be modified and broadcast within 2 minutes from the 9th minute of the next hour.
43 (BDS constellation health status)	The 6th minutes after the hour, then broadcasting every 15 minutes	Broadcasting when an unavailable BDS satellite can be used in RBN-DGNSS system.

Table 1 Messeage broadcasting instructions

3.3. TEST RESULTS

The technical verification of the station's dual-mode transformation is carried out at Beitang station in Tianjin. The equipment of the reference station, integrity monitoring station and transmitting station are replaced, and relevant software configuration is carried out. The transmitting antenna adopts the existing antenna ground network of the station, and the signals broadcast by the station are tested at fixed points on land and dynamically at sea.

3.3.1. FIXED-POINTS TEST

Six land static test points are selected within the coverage of Beitang station. The distance and distribution between the test points and the reference station are shown in Figure 2.

Figture 2 Distance and distribution between test point and Beitang reference station

After two hours of continuous static acquisition and observation at the sampling rate of 1 second, the plane / elevation results of six fixed-point tests are shown in Tables 2 and 3:

fixed-point	Distance to Beitang (km)	BDS (m)	GPS (m)	BDS+GPS (m)
Huanghua Port	66.2	1.08	0.79	0.69
Caofeidian Port	91.3	0.87	1.68	0.92
Dongying Port	154.7	1.40	1.20	0.62
Changdao	292.3	1.24	1.37	1.03
Laotieshan	315.7	2.53	1.55	1.68
Yantai Mountain	368.7	2.36	2.03	1.78

Table 2 statistical error of plane static test (confidence level 95%)

fixed-point	Distance to Beitang (km)	BDS (m)	GPS (m)	BDS+GPS (m)
Huanghua Port	66.2	2.94	1.12	1.37
Caofeidian Port	91.3	1.38	2.21	1.30
Dongying Port	154.7	2.03	1.29	1.29
Changdao	292.3	2.64	2.14	1.42
Laotieshan	315.7	2.99	2.91	1.76
Yantai Mountain	368.7	4.21	2.51	3.13

Table 3 statistical error of elevation static test (confidence level 95%)

Based on the above results, we can see that:

(1) The results show that the plane positioning accuracy of the dual-mode differential system is about 1 m (95%), and the elevation accuracy is about 2 m (95%); the positioning accuracy of BDS, GPS and BDS + GPS becomes better in turn.

(2) The coverage of the receiving reference station outside 300 km (Laotieshan and Yantai mountain) is weakened, the plane positioning accuracy is about 2 m (95%), the elevation accuracy is basically around 3 m (95%), and the positioning accuracy of BDS, GPS and BDS+GPS becomes better in turn.

3.3.2. MARINE DYNAMIC TEST

In the coverage area of Beitang station, Tianjin Port - Lushun Port and Dalian Port - Yantai port are selected for the sea dynamic test. In the continuous observation mode, the data are collected continuously at the sampling rate of 1 second. There are three different modes of GPS, BDS and BDS + GPS on each test path. The motion trajectory of marine dynamic test is shown in Figure 3.

Figure 3 Schematic diagram of marine dynamic test track

The dynamic statistical results of positioning accuracy and two-dimensional error distribution are as follows:

route	Distance to Beitang (km)	BDS(m)	GPS (m)	BDS+GPS(m)
Tianjin Port—Lvshun Port	40-310	1.55	1.31	0.87
Dalian Port—	360-360	1.77	3.11	2.44

Yantai Port				

Table 4 Statistics of plane accuracy of marine dynamic test (confidence level 95%)

route	Distance to Beitang (km)	BDS(m)	GPS(m)	BDS+GPS(m)
Tianjin Port—Lvshun Port	40-310km	2.55	2.01	1.69
Dalian Port—Yantai Port	360-360km	2.85	4.45	4.29

Table 5 Statistics of elevation error in marine dynamic test (confidence level is 95%)

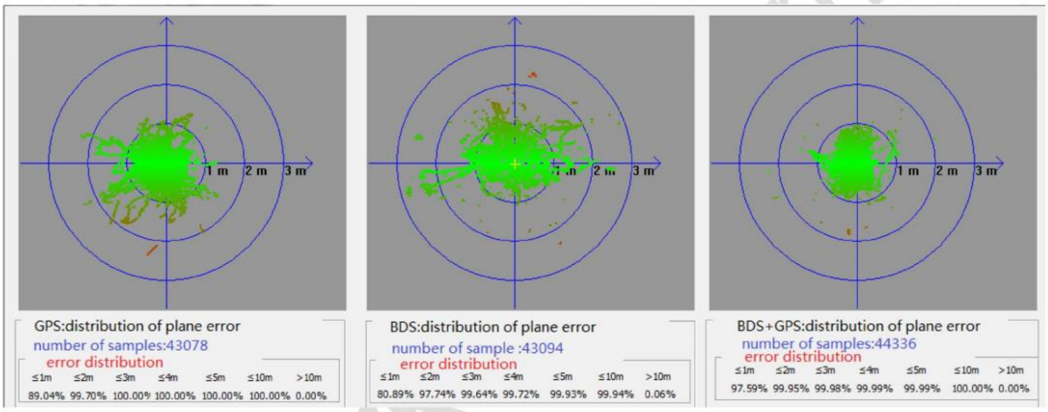


Figure 4 two dimensional plane error distribution of of marine dynamic test (GPS / BDS / BDS + GPS)

From the above statistical results, it can be seen that the accuracy of dual-mode differential system is greatly improved compared with single DBDs and DGPS, and the plane accuracy is improved more. At the same time, the analysis of signal availability shows that the percentage of epochs with pseudo range differential failure in the total epochs is maintained at a very low level, DBDs and DGPS single system are maintained at about 2%, while BDS + GPS combined differential system is less than 1%, which indicates that the dual-mode differential system is more robust and has better performances.

3.4. OVERALL TRANSFORMATION

There are 22 RBN differential stations in China's coastal areas, which will be transformed in phases since 2015. In 2016, the 14 stations of Qinhuangdao, Laotieshan, Chengshanjiao, Beitang, Haozhigang, Dinghai,Shitang,Lingkun,Tiandashan,Zhenhaijiao,Sanya,Baohujiao,Luyu,Naozhoudao were transformed . In 2017, the 7 stations of Yingkou, Wangjiamai, Dasanshan, Yanweigang,Yangpu,Sanzao,Fangchenggang were transformed. In 2018, Dajishan stations was transformed, all the 22 stations transformation was completely by then.

In addition, in 2016, three sea level remote centralized monitoring centers and nine remote integrity monitoring stations were built in the North China Sea, the East China Sea and the South China Sea. In 2017, four integrity monitoring stations were built. Remote integrity monitoring of station broadcast signals and centralized monitoring management realized.

3.5. TECHNICAL PARAMETERS AND SYSTEM PERFORMANCE AFTER TRANSFORMATION

3.5.1. WORKING FREQUENCY

The working frequency of the transformed station is the same as that of the original RBN-DGPS station (see Appendix B technical parameters of China maritime RBN-DGNSS station), which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA. It is the frequency range of maritime radio (283.5 -325.0 Khz) divided by the International Telecommunication Union, and adopts single frequency transmission to produce and broadcast differential correction information.

3.5.2. IDENTIFICATION CODE

The identification code of each station is the same as that of the original RBN-DGPS station (see Annex 2 technical parameters of China maritime RBN-DGNSS station), which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA.

3.5.3. TRANSMITTING POWER

200 WATTS, which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA.

3.5.4. SINGLE STATION SIGNAL RANGE

When the receiving field strength is 75 V / m, the operating distance is 300 km.

3.5.5. MODULATION MODE AND BROADCAST CATEGORY

The minimum shift- frequency keying (MSK) modulation mode is adopted, and the broadcast type is phase modulation single channel data transmission (g1d).

3.5.6. SIGNAL FORMAT AND MESSAGE TYPE

The signal format adopts RTCM sc-104 signal format standard v2.3, GPS Differential message type is 9-3, and Beidou differential message types are 41 and 42 (see Annex 1 Beidou differential message data format).

3.5.7. DIFFERENTIAL DATA TRANSMISSION RATE

200 bits/s, which is consistent with the list information of China RBN-DGPS stations published on the official website of IALA.

3.5.8. COORDINATE SYSTEM

The coordinate system of reference station is CGCS2000.

3.5.9. POSITIONING ACCURACY

After fixed-point and marine dynamic test, the positioning accuracy of meter level receiver is better than 5 meters (95%) and that of sub meter level receiver is better than 2 meters (95%) in the sea area 300 km away from the reference station, which is better than that of single RBN-DGPS system.

4. EXPLORATION OF OTHER RELATED APPLICATIONS ON RBN-DGNSS STATION

The exploration and other related application on RBN-DGNSS station in China are as follows:

(1) Broadcast differential Loran information. The positioning accuracy of Loran system has been greatly improved by broadcasting differential Loran information through RTCM data format on the radio beacon carrier frequency, Loran and the differential Loran are considered as land-based backup systems.

(2) Forward the differential information of satellite based augmentation system. At present, China is building a BDS satellite based augmentation system, and studying the technical scheme of usingRBN-DGNSS stations to forward BDS satellite based augmentation information, so that existing ship users can enjoy differential augmentation service without upgrading shipborne terminals.

(3) MF R-mode. In addition to the R-mode of AIS and VDES, China has carried out the application research of R-mode based on radio beacon MF signal to explore its feasibility and positioning effect, and also takes it as a possible land-based backup system.

5. REFERENCES

None.

6. QEQUEST

The committee is requested to review the proposal and focus on China's actions in the future development of RBN-DGNSS stations.

Appendix A: The Beidou differential message data format

Appendix B: Technical parameters of China maritime RBN-DGNSS station

APPENDIX

Appendix A: The BDS differential message data format

1. MESSAGE TYPE 41

The data format of differential message adopts RTCM (v2.3) standard, and the two words in the header are general data structure. BDS pseudo range correction message is type 41 message. See Figure 1 for format and table 1 for content.

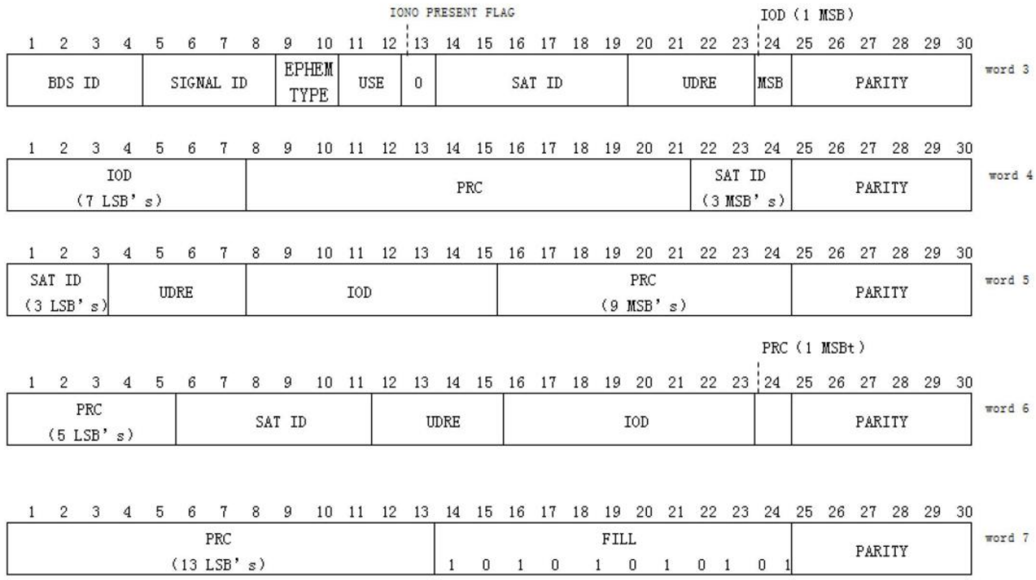


Figure 1 message type 41 format

PARAMETER	NUMBER OF BITS	UNITS	RANGE
BDS ID	4	1	BDS:0110
BDS SIGNAL ID	4	1	0~15, as shown in table 2
EPHEMERIS ID	2	1	0~3, as shown in table 3
USE flag	2	1	0~3, as shown in table 4
IONO PRESENT	1	—	0: IONOSPHERIC DELAY not present in the messeage
SAT ID	6	1	BDS SAT ID: 1~63, corresponding to BDS satellite PRN code, satellite ID "0" is not available
UDRE	4	as shown in table 5	16 states
IOD	8	1	—
PRC	14	0.02m	±163.84

FILL	The remainder of the total count divided by 24	—	Fill in the last part of the message alternately with 1 and 0
PARITY	6×N	—	

Table 1 message type 41 content

The parameters of message type 41 are described as follows:

a) BDS ID and BDS SAT ID: BDS ID is used to indicate the Beidou satellite navigation system, and BDS SAT ID is used to indicate the BDS satellite number.

b) BDS SIGNAL ID: BDS SIGNAL ID is used to indicate the type of observation value of differential message correction number, and the code is shown in Table 2.

SIGNAL ID	SIGNAL
0	RESVERD
1	B1 I
2	B1 Q
3	B2 I
4	B2 Q
5	B3 I
6	B3 Q
7~15	RESVERD

Table2 BDS ID

c) Satellite ephemeris type: the satellite ephemeris type identifies the resources and methods for calculating the satellite position in the message, and uses the ephemeris type and IOD to compare the satellite ephemeris used by the user, so as to ensure that the user and the station use the same satellite ephemeris. The types of satellite ephemeris are shown in Table 3.

Ephemeris type	Satellite position calculation	IOD	reference
0	NAV	—	BDS-SIS-ICD-2.1
1~2	—	—	BDS-SIS-ICD-2.1

Table 3 Ephemeris type

d) USE Flag: use flag indicates the maximum correction period used in t0 and t periods. When the time domain of the indicator is exceeded, the corresponding correction number should be stopped. See Table 4 for the contents of satellite use identification.

USE Flag (binary)	Use maximum correction (s)
00	15s
01	30s
10	60s

11	120s

Tabel 4 Satellite USE Flag

e) UDRE: the final UDRE value is obtained from the UDRE scale factor of the health status information of some stations in the message header and the UDRE bit value of the satellite. GNSS UDRE is shown in Table 5.

Example 1: if UDRE scale factor of message header is 0.30 and UDRE bit value of satellite is 0, then 0.0m ⩽ UDRE ⩽ 0.012m;

Example 2: if UDRE scale factor of message header is 0.75 and UDRE bit value of satellite is 6, then 0.268m ⩽ UDRE ⩽ 0.416m;

Example 3: if UDRE scale factor of message header is 1.00 and UDRE bit value of satellite is 15, UDRE > 18.480 M.

UDRE Unit	1.00	0.75	0.50	0.30	0.20	0.10
UDRE（bit）	UDRE（m）	UDRE（m）	UDRE（m）	UDRE（m）	UDRE（m）	UDRE（m）
0	0.040	0.030	0.020	0.012	0.008	0.004
1	0.062	0.047	0.031	0.019	0.012	0.006
2	0.096	0.072	0.048	0.029	0.019	0.010
3	0.149	0.112	0.074	0.045	0.030	0.015
4	0.231	0.173	0.115	0.069	0.046	0.023
5	0.358	0.268	0.179	0.107	0.072	0.036
6	0.555	0.416	0.277	0.166	0.111	0.055
7	0.860	0.645	0.430	0.258	0.172	0.086
8	1.333	0.999	0.666	0.400	0.267	0.133
9	2.066	1.549	1.033	0.620	0.413	0.207
10	3.202	2.401	1.601	0.961	0.640	0.320
11	4.963	3.722	2.481	1.489	0.993	0.496
12	7.692	5.769	3.846	2.308	1.538	0.769
13	11.923	8.942	5.961	3.577	2.835	1.192
14	18.480	13.860	9.240	3.544	3.696	1.848
15	>18.480	>13.860	>9.240	>3.544	>3.696	>1.848

Table 5 GNSS UDRE

f) IOD: data issue number IOD identifies BDS navigation data. There is no IOD parameter in BDS navigation message. According to BDS-SIS-ICD-2.1, the BDS IOD parameter of this message is generated based on TOC, that is, BDS IOD = (TOC / 720)% 240, with a length of 8 bits.

2. MESSAGE TYPE 42

Message type 42 provides the pseudo range differential correction number of some BDS satellite groups. Three satellites form a group, and less than three satellites form a group. Its format and content are the same as message type 41. Maritime RBN-DGNSS stations in China use this message format to broadcast differential BDS information.

Appendix B: Technical parameters of China maritime RBN-DGNSS station

Sea area	Serial	Station	Location		Identification Code			Frequency (kHz)
			North latitude	East longitude	RS1	RS2	Transmitter	
North China Sea	1	Dasanshan	38° 52'	121° 50'	602	603	601	301.5
	2	Laotieshan	38° 44'	121° 08'	604	605	602	307.5
	3	Qinghuangdao	39° 55'	119° 37'	606	607	603	287.5
	4	Beitang	38° 50'	117° 30'	608	609	604	310.5
	5	Yingkou	40° 17'	122° 06'	610	611	605	291.5
	6	Chengshanjiao	37° 24'	122° 41'	612	613	606	317.0
	7	Wangjiamai	36° 04'	120° 26'	614	615	607	313.5
East China Sea	8	Yanweigang	34° 29'	119° 47'	620	621	610	291.0
	9	Haozhigang	32° 01'	121° 43'	622	623	611	304.0
	10	Dajishan	30° 49'	122° 10'	624	625	612	307.5
	11	Dinghai	30° 01'	122° 04'	626	627	613	310.0
	12	Shitang	28° 16'	121° 37'	628	629	614	295.0
	13	Tiandashan	25° 28'	119° 42'	630	631	615	313.0
	14	Zhenhaijiao	24° 16'	118° 08'	632	633	616	320.0
	15	Lingkun	27° 58'	120° 54'	634	635	617	286.5
South China Sea	16	Dezhoudao	23° 20'	116° 45'	640	641	620	317.0
	17	Sanzaodao	22° 00'	113° 24'	642	643	621	291.0
	18	Naozhoudao	20° 54'	110° 36'	644	645	622	301.0
	19	Fangchenggang	21° 35'	108° 19'	646	647	623	287.0
	20	Baohujiao	20° 00'	110° 55'	652	653	626	310.5
	21	Sanya	18° 17'	109° 21'	654	655	627	295.0
	22	Yangpugang	19° 43	109° 12	656	657	628	313.0

Annex 2

Input paper: [1] ENG15-3.1.3.6

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

◻ ARM	X ENG	◻ PAP	
◻ ENAV	◻ VTS		

Purpose of paper:

x Input

◻ Information

Agenda item [2]

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

Author(s) / Submitter(s) Stefan Gewies (DLR), Michael Hoppe (WSV)

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].

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Preamble	Message Type	Station ID	Parity

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 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

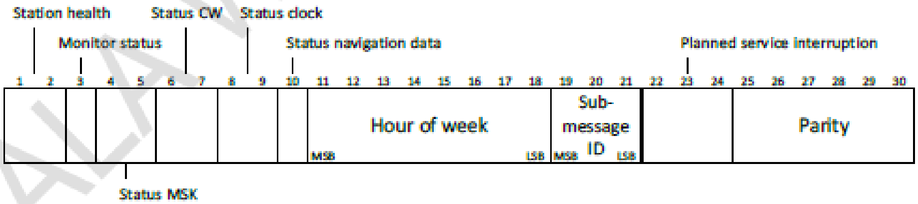


Figure 2 Third R-Mode message word

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.

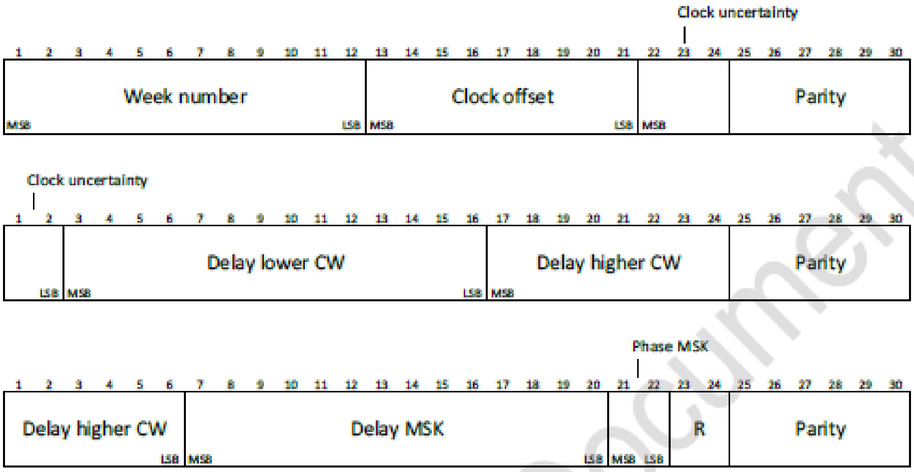


Figure 3 R-Mode submessage 1: RMST week, signal delays and offset

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:

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

Here f_{bit} is the broadcast bit rate.

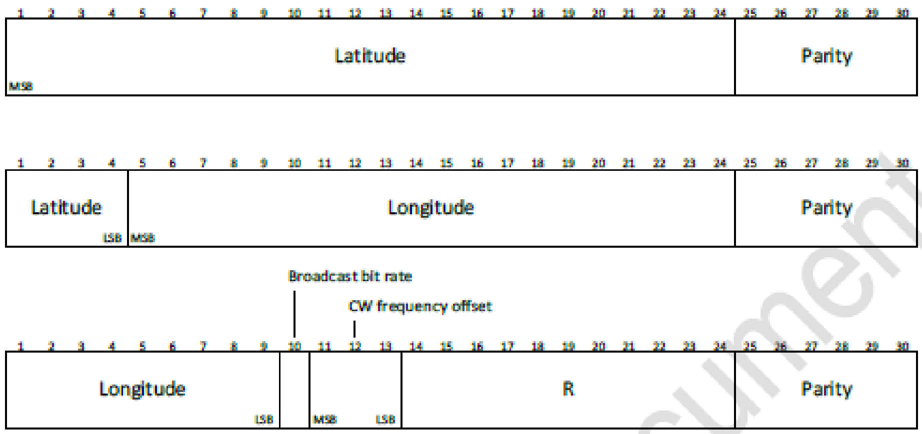


Figure 4 R-Mode submessage 2: Static navigation data

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)

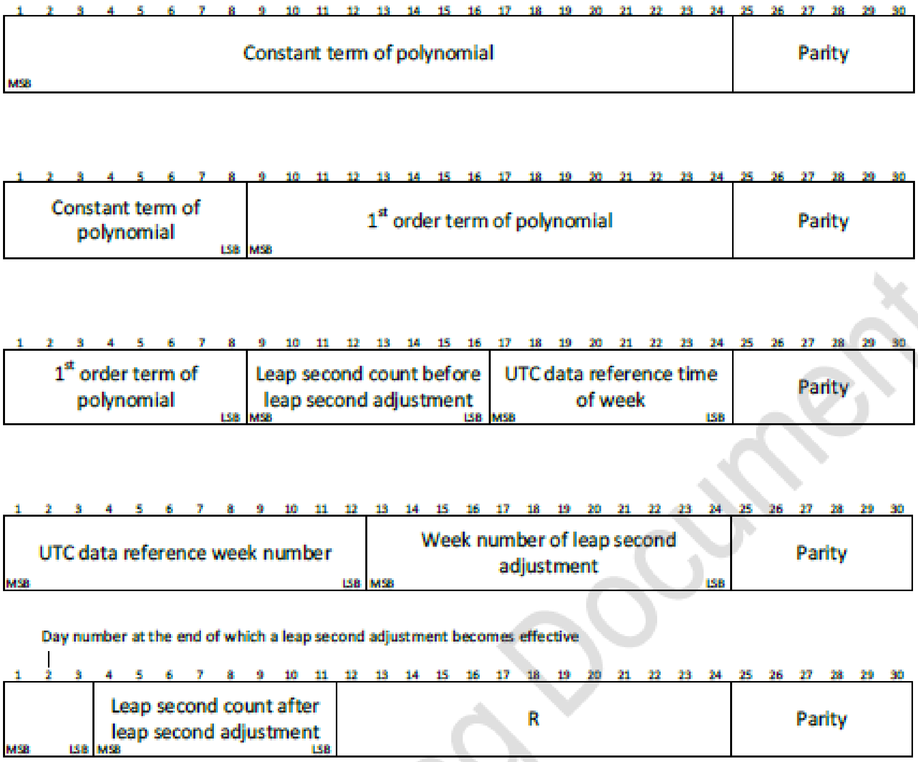


Figure 5 R-Mode submessage 3: RMST to UTC conversion

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.

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

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