MF R-Mode-Modulator Specification

– MSK and CW's –

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This report was created within the framework of the **R-Mode Baltic** project, which aims to develop and demonstrate a new maritime backup system for Position, Navigation and Time (PNT) purposes based on R-Mode technology. Within the project life time of three years the project consortium develops solutions for R-Mode transmitter and receiver prototypes, for independent time synchronisations of broadcasting stations and for a testbed concept and its deployment. The dissemination of R-Mode technology is supported by work in international standardisation bodies. The world's first operational testbed for a transnational R-Mode system will be completed by the project in 2020.

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Executive Summary

The general aim in this paper is to provide a detailed specification for the Ranging Mode (R-Mode) / Minimum Shift Keying (MSK) modulator (R-Mode/MSK-Modulator). The document contains the harmonized specifications for the development, delivery, installation and operation of an R-Mode/MSK-Modulator for the R-Mode Baltic testbed used at DGNSS radio beacon sites transmitting GNSS corrections, R-Mode messages and R-Mode signals in the radio beacon band between 283.5 and 325 kHz.

Chapter 1 provides some background information based on a first feasibility study performed in the EU-Project ACCSEAS.

Chapter 2 provides information of the overall architecture as well as the typical in- and outputs of an R-Mode/MSK-Modulator.

Chapter 3 contains the specifications for the legacy MSK and R-Mode signal components, modulator interfaces and required configuration options.

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Abbreviations

ACCSEAS	-	Accessibility for Shipping, Efficiency Advantages and Sustainability
ADC	-	Analog-Digital-Converter
AIS	-	Automatic Identification System
BNC	-	Cable connector type: Bayonet Neill–Concelman
CW	-	Continuous Wave
DDS	-	Direct Digital Synthesis
DGNSS	-	Differential GNSS
EU	-	European Union
GAL	-	Galileo – European GNSS
GBAS	-	Ground-Based Augmentation System
GLONASS	-	GLObal Navigation Satellite System – GNSS provided by Russia
GNSS	-	Global Navigation Satellite System
GPS	-	Global Positioning System – GNSS provided by USA
IM	-	Integrity Monitor
MF	-	Medium Frequency
MSK	-	Minimum Shift Keying
NTRIP	-	Networked Transport of RTCM via Internet Protocol
PNT		Position, Navigation and Time
PPS	-	Pulse Per Second
RF	-	Radio Frequency
R-Mode		Ranging Mode
RS	-	Reference station
RSIM	-	Standard for Differential Navstar GPS Reference Stations and Integrity Monitors
RTCM	-	Radio Technical Commission for Maritime Services
SMA	-	Cable connector type: Sub Miniature version A
SNR	-	Signal to Noise Ratio
SoOP	-	Signals of Opportunity
TCP/IP	-	Transmission Control Protocol/Internet Protocol
TOA	-	Time of Arrival
UTC	-	Universal Time Coordinated
VRS	-	Virtual Reference Server

1 Background

High precision positioning in the maritime domain is now the norm since the introduction of Global Navigation Satellite Systems (GNSS). Unfortunately, it is well known that as low power, satellite-based systems, GNSS are vulnerable to interference (both naturally occurring and manmade). Hence, the development of an alternative backup system is recommended. A variety of technological solutions to this backup requirement are possible. In the radio frequency (RF) domain we have the so-called “Signals of OPportunity” (SoOP) approach. Of interest to this report is the use of the Differential GNSS (DGNSS) broadcasts. These medium frequency (MF) RF broadcasts, in the 283.5-315 kHz (Region I) marine band, currently transmit correction and integrity information for the GNSS using minimum shift keying (MSK).

Main work about this R-Mode method was developed in a feasibility study performed during the ACCSEAS project (2012-2015), [1], [2]. These reports summarize a variety of potential ideas and solutions to implement R-Mode using MF DGNSS transmissions. Each of the methods was evaluated using various metrics such as technical feasibility, implementation cost and difficulty. The most promising solutions were selected as follows:

- L1 – Optimum Existing Case: this solution combines adding a new message and an increased data rate of 200 bps to the existing MSK signal.
- L2 – Narrow Aiding Channel: this solution consists of adding Continuous Wave (CW) signal(s) to the existing MSK signal.
- L3 – Combination: this solution is a combination of L1 and L2.
- L4 – Wide Aiding Channel: this solution is similar to L2 but ignores the bandwidth constraints and could consist of, perhaps, the two-tone concept.

Each of the primary solutions (L1 – L3) is examined in some detail in this report. The analysis shows that they all can provide Time of Arrival (TOA) performance bounded by:

$$\sigma_{\hat{\tau}}^2 \geq \frac{1}{2{\omega_c}^2 T\, SNR}$$

In the case of L1 this is achieved using either an estimate on the phase of the carrier or on the bit transitions using a new (fixed) message. In the case of L2 and L3 this is achieved using a phase estimate on the CW signal. In all cases the cycle (lane) ambiguity must be resolved. In the case of L1 and L3 this is done using bit transition estimation on the new message. In the case of L2, this is done using the beat frequency of the two CW signals.

The recommended solution in the ACCSEAS study was L3, MSK with a single CW signal added. The TOA performance bound above is achieved using phase estimates on the CW signal, which is easier than phase estimates on the MSK carrier. Cycle resolution is achieved using bit transitions on the new message (but only needed periodically, not continuously, so the MSK data channel throughput is preserved).

For practical validation of these methods it is necessary to design an MF R-Mode modulator which enables the transmission of the legacy DGNSS data together with one or a combination of the above mentioned solutions. This report will provide technical requirements and specifications for such a modulator.

2 Concept

The R-Mode modulator shall enable the transmission of standard RTCM messages used for the DGNSS service. Further the modulator shall provide two independent CW signals with adjustable frequency and output level. The signal generation for MSK and the two CW signals shall be based on the same signal clock which is provided from an external clock, providing 10 MHz and 1 PPS (aligned to UTC). Figure 1 provides a schematic of the R-Mode/MSK-Modulator and the external equipment required to transmit an R-Mode signal. The output signal should be provided similar to a legacy MSK modulator, as typically used in standard DGNSS radio beacon reference stations.

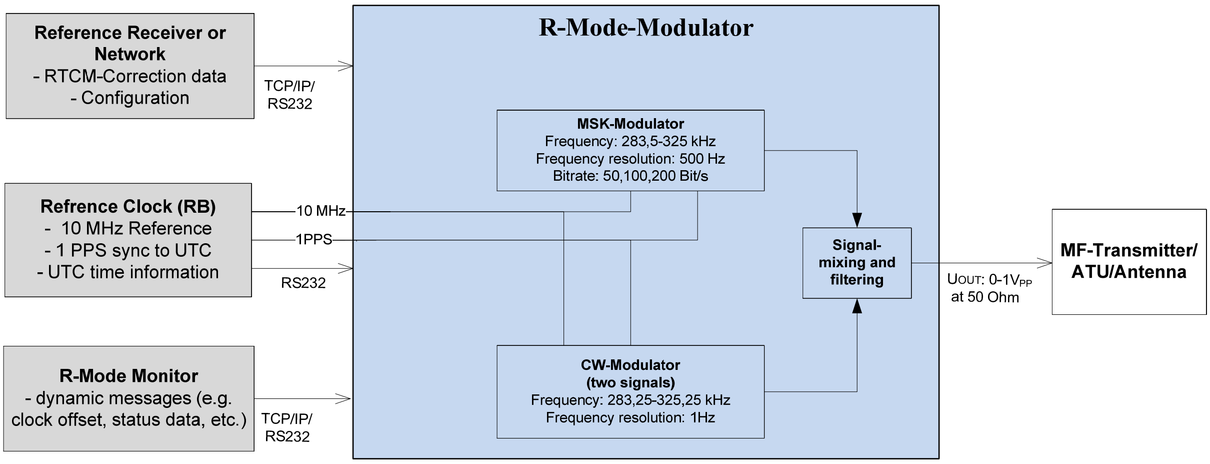

Figure 1: R-Mode/MSK-Modulator as part of the signal generation and transmitting chain

3 Requirements and Signal Specification

3.1 Requirements for legacy MSK-Signal generator

1.1. Minimum requirements as provided in ITU R. M-823-3.

1.2. Frequency range of MSK signal: adjustable in the range between 283.5 kHz and 325.0 kHz with a channel spacing of 500 Hz.

1.3. Three possible bitrate choices: 50,100 or 200 Bit/s.

1.4. MSK output level tunable between 0 to 1.0 Vpp at 50 Ohm.

1.5. Processing of following RTCM 2.3 message types, [3]: 1, 3, 6, 9-1, 9-3, (31 and 34 for GLONASS), 7 and 16.

1.6. The RTCM data shall be received by serial port and TCP/IP.

1.7. RTCM test data shall be readable from recorded data files.

1.8. The modulator shall enable RTCM message scheduling the same way the RSIM #22 message does.

1.9. Power supply: 230VAC/50 Hz.

3.2 Additional requirements for R-Mode-Signal generator

3.2.1 Continuous Wave Signals (CW)

2.1. The modulator shall enable the internal generation of two CW signals.

2.2. Frequency range of CW signals: adjustable in the range between 283.25 kHz and 325.25 kHz with a frequency resolution/increment of 1 Hz.

2.3. The CW signals start with phase 0 and rising edge at integer UTC-Seconds (1PPS) with a maximum jitter of 1 ns.

2.4. CW signal output level is tunable between 0 to 1.0 Vpp at 50 Ohm for CW1 and CW2.

3.2.2 R-Mode MSK Signal (Bit transition)

2.5. An external 1PPS synchronization shall be aligned with the bit timing (Bit alignment to 1PPS < 1 ns).

2.6. Processing of new developed R-Mode specific RTCM message types.

2.7. Generation of MSK message with information about MSK phase offset (Require further specification and should be handled optional).

3.2.3 Common specifications for CW signals and MSK (Bit transition)

2.8. To reduce the phase noise an external 10 MHz reference signal shall be used for generation of all R-Mode signal components (CWs and MSK).

2.9. R-Mode signal components (CWs and MSK) shall be adjusted to 1PPS reference (Figure 2; see also requirement 1.3 and 1.5 for R-Mode signals)

2.10. The Modulator shall allow to adjust the starting phase of each signal (MSK bit transition and CW's) within a defined time period relative to 1 PPS to compensate for phase delays in the complete transmitter chain (e.g. connecting cables, transmitter, ATU and MF antenna.

2.11. The amplitudes of the two CW signals and the MSK signal shall be independently adjustable between 0 to 1.0 Vpp.

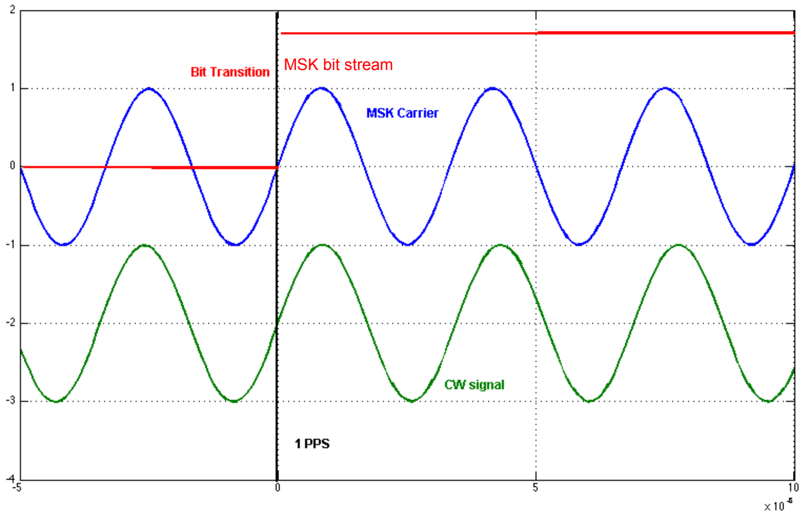

Figure 2: Example of time relations between MSK bit tact, 1 PPS, MSK carrier and CW's signals

2.12. The R-Mode-MSK-Modulator shall provide two separate analogue signal outputs.

a. The first output contains the combined MSK and CW signals.

b. The second output shall provide two signals (selected by configuration):

i. Test signal to check the bit alignment with 1PPS.

ii. Copy of the transmitted MSK/CW signal.

2.13. The frequency stability of the generated output signals should be in a range of 1 µHz according to the stability of the supplied clock signal. In case that the frequency will be derived from a DDS the phase accumulator, tact generator and the D/A converter shall be designed accordingly.

2.14. The R-Mode/MSK-Modulator shall allow to choose one of the following signal output options (according to the methods describe above):

- only MSK signal
- only CW signals (one or two)
- MSK signal with two CW signals
- MSK signal with one CW signal

2.15. The combined analogue output signal (ready for the input to an MF transmitter) shall be provided on an output interface with 50 Ohm.

3.3 Interfaces of the R-Mode/MSK-Modulator

3.1. Interface to external clock. The R-Mode-MSK-Modulator shall have input for the use of external timing and synchronization:

- 10 MHz
- 1 PPS with UTC synchronization.
- Serial port with UTC time information

3.2. Interface to RTCM data input. The R-Mode/MSK-Modulator shall have the following input ports to receive standard RTCM SC104 V2.3 data or new R-Mode specific messages:

- Serial interface RS232 (e.g. to connect a local GNSS reference receiver)
- TCP/IP (e.g. to connect to VRS-Server using NTRIP protocol)

3.3. Interface to MF transmitter: The R-Mode/MSK-Modulator shall have the following BNC or SMA output connector to forward the combined MSK-R-Mode signal to an onsite MF transmitter: UOUT: 0-1.0 Vpp at 50 Ohm (BNC or SMA).

3.4. The modulator shall have a TCP/IP interface to receive external information (e.g. clock error, integrity monitoring, etc.).

3.4 Configuration of the R-Mode/MSK-Modulator

The R-Mode/MSK-Modulator shall provide configuration possibilities as follows:

4.1. Configuration and selection of used RTCM data streams (TCP/IP, RS232 or data file)

4.2. Configuration of the standardized and new (static and dynamic) RTCM-Messages (Message type, sequence and interval)

4.3. Tuning of the MSK signal frequency in 500 Hz steps within beacon band

4.4. Tuning of two CW signal frequencies in 1 Hz steps within the range of 283.25 kHz to 325.25 kHz

4.5. Tuning the data rate of the MSK signal (50, 100 and 200 bit/s)

4.6. Tuning of the output amplitude of MSK and CW signal components (UOUT: 0 - 1.0 Vpp)

4.7. Configuration of 3 signal generation delays: MSK bit transition and two CW signals according to 1 PPS

4.8. Configuration of second output: test signal or copy of first output

4.9. Provide means of self-monitoring

4 References

[1] P. F. S. G.W. Johnson, „Part I “Feasibility Study of R-Mode using MF DGPS Transmissions",“ January 2014.

[2] P. S. G.W. Johnson, „Part II, "Feasibility Study of R-Mode using MF DGPS Transmissions",“ March 2014.

[3] ITU, „Recommendation M.823-3, 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,“ 2006.