# METHOD OF AUTOMATIC TRANSMISSION OF THE INTEGRITY BREACH SIGNALS OF THE RIVER LOCAL DIFFERENTIAL SUBSYSTEM

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**The integrity of the navigation system is one of the important factors affecting the safety of navigation. Currently, on the inland waterways of Russia, alerts on the integrity of the GLONASS global navigation satellite system (GNSS) are transmitted through river local differential subsystems (LDSS), which include one or more reference stations. Industrial interference from industrial zones and power lines, mutual interference from neighboring reference stations and, especially, the inhomogeneity of the underlying surface affect the range of the reference stations, which leads to the integrity breach of the differential field and transmission of unreliable corrective information to the navigator. However, the navigator is not notified of the incorrect operation of the reference stations. As a result, inaccurate corrective information leads to errors in calculating the vessel position, which reduces the level of navigation safety. A method for the automatic transmission of notifications about the LDSS integrity breach from a remote control and management station (RCMS) to the ship is presented in the paper. The structure of the message transmitting the notification signal has been formed. Criteria characterizing the quality of the differential correction signal are presented. Possible combinations of such criteria, which determine the performance of the differential mode of the reference station, are identified. Each combination of criteria is juxtaposed the corresponding notification texts displayed on the monitors of the LDSS operators and on the navigator's display. A scheme for the automatic transmission of an alarm message from a remote control point through the RCMS, the regional command and control center, the vessel traffic control center and base stations of the automatic identification system (AIS) to ship transponders has been developed. As a result, the developed method for transmitting the alarm message containing combinations of quality criteria for the differential correction signal allows to automatically inform the navigator about the reliability of the corrective information transmitted by one or another reference station.**

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### Introduction

The effectiveness of any navigation system is characterized by its accuracy, availability, continuity and integrity. In terms of the navigation safety, integrity is one of the most important factors. The integrity of the global navigation satellite system (GNSS) is its ability for a given time interval and with a given probability to provide consumers with alarms about the unreliability of GNSS navigation signals. Without confidence in the system integrity, there is no way to know if the information being received is correct.

GNSS augmentation systems improve the positioning accuracy of objects in differential mode and allow you to monitor the integrity of GNSS such as GPS (USA), GLONASS (Russia), Galileo (EU) and BeiDou (China).

The US Coast Guard DGPS Service provides GPS and DGPS integrity breach alarms within 10 seconds of detecting a failure [1]. Safety of Life (SoL) service of Europe's regional satellite-based augmentation system - EGNOS, provides 6 seconds warning of system failures [2-4].

Currently, on the inland waterways of Russia, notifications about the integrity of the GLONASS GNSS are transmitted through the local differential subsystems. The time during which such notifications should be transmitted is regulated by IMO resolution A.915 (22) and should not exceed 10 seconds [5]. Reference stations (RS), which are the basis of the river local differential subsystem (LDSS), are also capable to transmit notifications about the failure of any equipment that is part of their composition. However, notifications that, due to certain factors, the range of the RS has changed, and it no longer covers the required section of the waterway, which means that the integrity of the differential correction (DC) field in this place is breached, are not transmitted. Therefore, the problem of transmitting this type of notifications to the user arises.

Taking into account the strict requirements for the frequency of monitoring the integrity of differential field in the river conditions, the transmission time of such signals for most inland waterways should not exceed 6 seconds. The use of vessel traffic service dispatchers or operators of river stations for monitoring distress messages for the transmission of such notifications in the differential field monitoring and control system (M&CS) proposed in articles [6-8] cannot provide the required notification rate. The article [9] described the structural diagram of an automatic system for transmitting signals of the integrity breach of the LDSS from a remote control and management station (RCMS) to the ship, but the means by which the transmission of such signals becomes possible were not presented.

### Methods and materials

Navigation data transmission is governed by the Radio Technical Commission for Maritime Services (RTCM) standards. In particular, Special Committee-104 (SC-104) has developed standards for functioning the differential global navigation satellite system (DGNSS). The standards of 2.0-3.3 versions regulate the format for transmitting corrective information (RTCM messages). Initially, the standard was being developed for the transmission of corrections to GPS signals (version 2.0), then the standard was expanded by the transmission of corrections to GLONASS signals (version 2.2), and in version 3.2, the transmission of corrections to the signals of the navigation satellite systems BeiDou, Galileo and to the signals of Quasi-Zenith Satellite System QZSS was added.

The standard of 1.2 version regulates the transmission format of another type of message – RSIM-messages, and was developed for the reference and control stations of the GPS differential subsystem. The RSIM standard was originally written for maritime LDSS, but then it was successfully implemented in the Eurofix system [10-12].

Also, this committee standardizes the RINEX navigation data exchange format independent of the receiver model and the protocol for transmitting RTCM messages over the Internet - Ntrip (version 10.0-10.1) [13-14].

Thus, there are two formats for data transmission in DGNSS: RTCM and RSIM. The article [15] describes the use of RSIM messages for the information exchange between the control station (CS) and an additionally created remote control station. The authors introduced a new non-standardized data transfer format between the CS and the remote control station, using the known structure of RSIM messages, and successfully tested it. This fact has demonstrated the possibility of using RSIM messages not only for transmitting data between the RS and CS, but also for transmitting notifications in the M&CS of LDSS.

Table 1

Basic RSIM messages and their functions

| RSIM message No. | Function | RS | IMS | CS |
|---|---|---|---|---|
| 1 | Requesting a specific RSIM message and setting its transfer interval | Receives | Receives | Transmits |
| 2 | Alarm when receiving an unidentified message | Transmits | Transmits | Receives |
| 3 | Parameters reset control | Receives | Receives | Transmits |
| 5 | Diagnostic Report / Hardware Fault Alert[1] | Transmits | Transmits | Receives |
| 6 | GPS receiver parameters | Receives | Receives | Transmits |
| 7 | GPS satellites parameters | Transmits /Receives | Transmits /Transmits | Receives /— |
| 8 | Satellites health management | Receives | Receives | Transmits |
| 9 | GPS satellites status | Transmits | Transmits | Receives |
| 10 | RS data transmission channel parameters | Receives | — | Transmits |
| 11 | RS alarm thresholds | Receives | — | Transmits |
| 12 | R   alarms | Transmits | — | Receives |
| 13 | RS corrective data | Transmits | — | Receives |
| 14 | IMS data transmission channel parameters | — | Receive | Transmits |
| 15 | IMS data transmission channel status | — | Transmits | Receives |
| 16 | IM   alarm thresholds | — | Receives | Transmits |
| 17 | IM   alarms | — | Transmits | Receives |
| 18 | Integral control of differential mode status (DGPS) | — | Tran mits | Receives |
| 19 | Integral control of corrective data | — | Transmits | Receives |
| 20 | System feedback of IMS with RS | Receives | Transmits | — |
| 21 | RS almanac parameters | Receives | — | Transmits |
| 22 | RTC   messages broadcast schedule | Receives | — | Transmits |
| 23 | Universal RTCM message | Receives / — | —/ Transmits | Transmits /Receives |
| 24 | Transmitter status and controlling it | — | — | Transmits |
| 25 | Radio transmission control and status | — | — | Transmits |
| 26 | General text message | Transmits /Receives | Transmits /Receives | Transmits /Receives |

[1] Data transmission is carried out in ASCII format

The RSIM standard [16] describes the performance, functional parameters, interface and environment parameters for DGNSS reference station and was developed to ensure consistency among GNSS differential service providers. The RSIM standard defines the number of RSIM messages that provide communication between the various equipment of reference station (RS), integrity monitoring station (IMS) and control station (CS) regardless of the manufacturer.

At the moment, 99 types of RSIM messages have been standardized, of which messages 1 to 27 are used for GPS mode, and 51 to 55 - for GLONASS mode; messages 28 to 50 are reserved for DGPS mode, and messages 56 to 99 are reserved for DGLONASS and GALILEO. Some of the used RSIM messages are presented in table 1.

It should also be noted that RSIM messages 1-8 and 10-27 are also used for DGLONASS. Fig. 1 shows the RSIM messages transmission between the RS, IMS and CS.

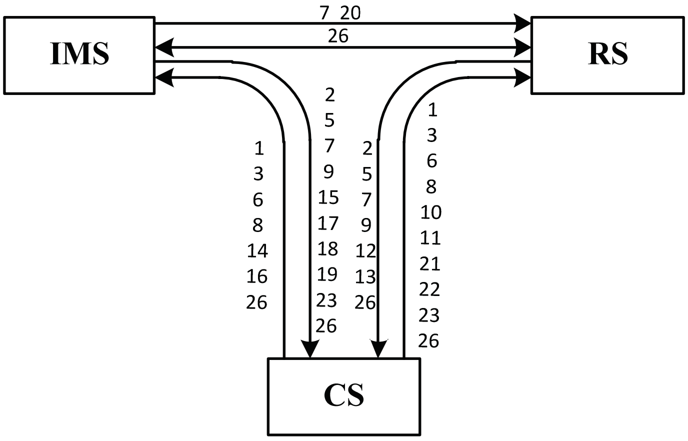


**Fig. 1.** RSIM messages flow

Each RSIM message begins with the address field "$ PRCM" and the message type (its number), and ends with a separator "*", a checksum "hh" and a separator for the end of the sentence "<CR> <LF>" [16]. Thus, the structure of the RSIM message is represented as follows:

$$\$PRCM, N, x.x, \ldots *hh<CR><LF>, \quad (1)$$

where N – number of the transmitted RSIM message; x.x, . . . – fields of the RSIM message depending on its type.

## Results

Already standardized messages RSIM#12 and RSIM#17 can serve as a prototype of the structure of a message that transmits an alert signal in the M&CS. The first message is used by the reference station to transmit the alarm signals that appear in it to the control station. The second message also contains alarm signals sent to the CS, but here the sender is the IMS. These standardized messages, in addition to the message type ("N" in formula (1)), differ in the content and number of fields "x.x, . . .". RSIM#12 has 5 such fields, and RSIM#17 has 12.

The first field for both types of messages is used to transmit the alarm time, which is specified as UTC time (Coordinated Universal Time). Therefore, it is advisable to use the purpose of this field also in the generated non-standardized message for transmitting the notification signal in the M&CS.

The rest of the fields in messages RSIM#12 and RSIM#17 are used to transmit the various types of alarms. For example, exceeding the threshold value of the pseudorange correction, which is calculated in the RS, or a low signal level in the correction information receiving channel located in the IMS.

In the M&CS, the quality of the differential correction signal at the border of the reference station coverage area is checked according to three criteria, namely:

1) the electr field intensity of the signal at the receiving point $E_s$ should be higher than the receiver sensitivity $E_{min}$;

2) the signal-to-noise ratio ($E_s/E_n$) must exceed the threshold value $M$;

3) the error probability of an element-by-element reception of a digital message ($p_{err}$) should not exceed the permissible value ($p_{max}$).

The first two parameters are determined at the remote control points (RCP) of the M&CS installed on the calculated boundaries of the reference station coverage areas, and the last one is calculated in the RCMS. Thus, if all three criteria are met, then the differential correction signal at the calculated boundary of the reference station coverage area will be correctly decoded by the users' navigation equipment, the integrity of the differential field is preserved, and the user can use the corrective information transmitted by this RS when calculating his position. Otherwise, when at least one of the criteria is not met, the M&CS should send an alarm signal that will notify the user that the integrity of the differential field is breached, the range of the reference station has changed, therefore, it is impossible to use the corrective information transmitted by this RS.

Taking into account the existing criteria for assessing the quality of the differential correction signal, the structure of a non-standardized message containing an alarm in the M&CS is as follows:

$$\$PRCM, N, hhmmss.ss, \underset{1}{\underbrace{a}}, \underset{2}{\underbrace{a}}, \underset{3}{\underbrace{a}} * hh <CR><LF>, \quad (2)$$

where

hhmmss.ss – alarm transmission time (UTC);

1 – the signal level in the channel for receiving corrective information in the RCP:

L – the signal level at the receiving point is less than or equal to the receiver sensitivity; the alarm is triggered;

A – the signal level at the receiving point exceeds the receiver sensitivity; the alarm is reset;

2 – the signal-to-noise ratio in the channel for receiving corrective information in the RCP:

L – the signal-to-noise ratio below or equal to the threshold value; the alarm is triggered;

A – the signal-to-noise ratio exceeds the threshold value; the alarm is reset;

3 – the calculated error probability of an element-by-element reception of a digital message:

H – the error probability of the element-by-element reception of a digital message is greater than or equal to the acceptable value; the alarm is triggered;

A – the error probability of the element-by-element reception of a digital message is below the acceptable value; the alarm is reset;

Based on the fact that the alarm message contains three parameters, which can take two values (L/A or H/A), the total number of possible combinations of RSIM message is eight. Each combination is assigned a specific code, which corresponds to a specific notification text for the user. Table 2 shows the possible combinations of three fields of the RSIM message (“$\underbrace{a}_{1},\underbrace{a}_{2},\underbrace{a}_{3}$” from formula (2)) and the corresponding alert texts displayed on the monitors of the operators of the remote control and management station (RCMS), the regional command and control center (RC&CC) and the vessel traffic control center (VTCC), and Table 3 shows the alert text corresponding to the same combinations of three fields of the RSIM message, but already displayed on the skipper's display.

Table 2

RSIM messages transmitted to the operators of the RCMS, RC&CC and VTCC

| No. | $a, a, a$ | ALERT TEXT |
|---|---|---|
| 1 | L,A,A | «low signal level of RS» |
| 2 | L,L,A | «low signal level, low SNR» |
| 3 | L,L,H | «GNSS correction information is not reliable» |
| 4 | L,A,H | «low signal level, high probability of error» |
| 5 | A,L, | «low SNR» |
| 6 | A,A,H | «high probability of error» |
| 7 | A,L,H | «low SNR, high probability of error» |

Table 3

RSIM messages transmitted to the skipper

| No. | $a, a, a$ | ALERT TEXT |
|---|---|---|
| 1 | L,A,A or L,L,A or L,L,H or L,A,H or A,L,A or A,A,H or A,L,H | «differential mode of RS “Name” does not work» |

**Discussion**

The remote control point (RCP), consisting of a corrective information receiver (CIR) and a communication terminal, transmits the signal power and signal-to-noise ratio $E_s/E_n$ to the RCP monitoring equipment installed in the RCMS. The software, which, using these parameters, calculates the error probability of the element-by-element reception of the message $p_{err}$ and evaluates the quality of the differential correction signal, is installed in the RCMS. In the alarm signal generation unit, based on the data received from the RCP and calculated in the RCMS, an alarm message $RSIM_{al}$ is generated, which is sent to the RC&CC, where the RSIM message monitoring equipment is installed, which, according to the received $RSIM_{al}$ type, generates a text message that is displayed on the operator's monitor. Further, this message is sent to the Basin traffic service, which is served by this reference station (Fig. 1).

AIS provides short informational messages that are transmitted as needed – text messages related to the safety of navigation and binary messages used to transmit additional information [17-18].

At the vessel traffic control center (VTCC) $RSIM_{al}$ is included in AIS message No. 12 [18-19], which is a safety-related addressable text message in free format using ASCII encoding, where each symbol is a sequence of eight zeros and ones. This type of message can contain data up to 936 bits, which occupy from 1 to 5 slots.

Converting an RSIM message into an AIS message can be carried out by analogy with a ready-made solution implemented by JSC Kronshtadt Technologies when creating a complex of CCS-BS AIS equipment [20-21]. Here, the conversion of the reference station message into the AIS message occurs by converting the RTCM SC104 format into the VDL format, which is accessed using the FATDMA algorithm in accordance with the IALA Recommendations A-124 [22-23].

Further, through base stations (BS) of AIS the message is transmitted to ship transponders.

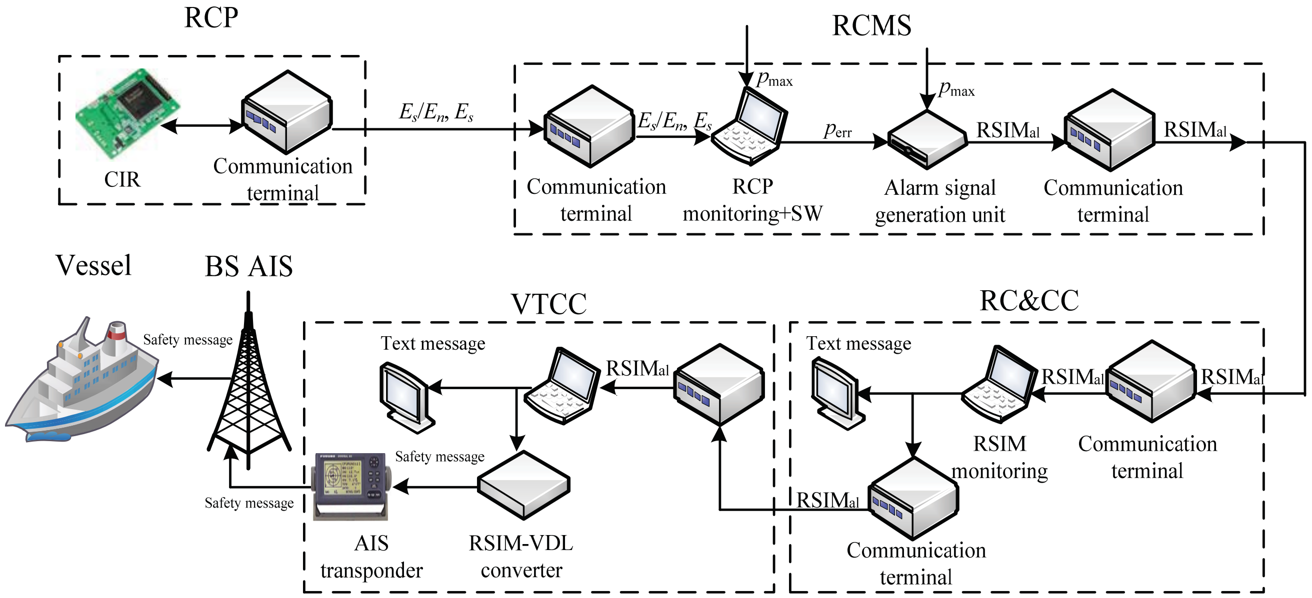


**Fig. 1.** The scheme of the automatic transmission of alarm messages:
RCP – remote control point; CIR – corrective information receiver; SW – software; RC&CC – regional command and control center; VTCC – vessel traffic control center; BS AIS – base stations of AIS

## Conclusion

The paper presents a method for automatic transmission of alert signals in the M&CS using the RTCM SC-104 version 1.2 standard, which describes the composition and transmission format of RSIM messages. The method is based on the calculation of the error probability of element-by-element reception of a digital message $p_{err}$. When this probability, calculated using the software installed in the RCMS, exceeds the permissible value $p_{max}$, an alarm message $RSIM_{al}$ is generated in the RCMS and transmitted through the RC&CC to the VTCC, where it is included in the short safety messages of the coastal AIS. These messages are received by the ship's AIS transponder, informing the user that the corrective information transmitted by this reference station is not reliable, and it cannot be used to calculate the position of the ship.

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# СПОСОБ АВТОМАТИЧЕСКОЙ ПЕРЕДАЧИ СИГНАЛОВ НАРУШЕНИЯ ЦЕЛОСТНОСТИ РЕЧНОЙ ЛОКАЛЬНОЙ ДИФФЕРЕНЦИАЛЬНОЙ ПОДСИСТЕМЫ

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**Аннотация**

Целостность навигационной системы является одним из важных факторов, влияющих на безопасность судовождения. В настоящее время на внутренних водных путях России оповещения о целостности глобальной навигационной спутниковой системы (ГНСС) ГЛОНАСС передаются посредством речных локальных дифференциальных подсистем (ЛДПС), в состав которых входит одна или несколько контрольно-корректирующих станций (ККС). Индустриальные помехи от промышленных зон и линий электропередач (ЛЭП), взаимные помехи от соседних ККС и, особенно, неоднородность подстилающей поверхности оказывают влияние на дальность действия ККС, что приводит к нарушению целостности дифференциального поля и передаче судоводителю недостоверной корректирующей информации. Однако оповещения о некорректной работе ККС судоводителю не поступают. В результате, недостоверная корректирующая информация приводит к ошибкам при вычислении местоположения судна, что снижает уровень безопасности плавания. В работе представлен способ автоматической передачи оповещений о нарушении целостности ЛДПС от удаленной контрольно-управляющей станции (УКУС) на судно. Сформирована структура сообщения, передающего сигнал оповещения. Представлены критерии, характеризующие качество сигнала дифференциальной поправки (ДП). Выявлены возможные комбинации таких критериев, определяющие работоспособность дифференциального режима ККС. Каждой комбинации критериев сопоставлены соответствующие тексты оповещений, отображающиеся на мониторах операторов ЛДПС и на дисплее судоводителя. Разработана схема автоматической передачи сообщения тревоги от удаленного пункта контроля (УПК) через УКУС, региональный центр управления и контроля (РЦУК), центр управления движением судов (ЦУДС) и базовые станции автоматической идентификационной системы (АИС) на судовые транспондеры. В результате, разработанный способ передачи сообщения тревоги, содержащего комбинации критериев качества сигнала ДП, позволяет в автоматическом режиме информировать судоводителя о достоверности корректирующей информации, передаваемой той или иной ККС.

***Ключевые слова:*** *целостность навигационной системы, нарушение целостности, локальная дифференциальная подсистема, контрольно-корректирующая станция, сигнал оповещения, дифференциальная поправка, АИС.*

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