Advanced methods of marine radio communication in the Arctic

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Abstract. At present the Arctic Ocean is considered to become in the nearest future the most attractive territory for many industrial companies that are mining oil and gas throughout the World at the continental shelf. Also Arctic sea routes considerably save time for overseas transport back and forth from Asia to the Europe. At the same time navigation in the Arctic is the process that involves a lot of risk. That’s why the radio communication in the Arctic is supposed to be the tool which is extremely crucial to provide the safety of life in the polar seas. At present the international marine community as well as international academic community strongly supports the idea that GMDSS equipment doesn’t provide the high efficiency of radio communication in the polar waters and it must be considerably improved in the nearest future. The new methods of marine radio communication in the Arctic must be based on the updated structure of receiver equipment which provides considerable noise suppression. The structure of GMDSS equipment to be used to improve the efficiency of communication in severe High North conditions must also include auxiliary subsystem that gives the forecast of radio wave propagation for the short-term time interval.

1. Disadvantages of GMDSS equipment

SAR activities in the Arctic require the use and availability of multiple systems in order to respond to the variety of emergencies that can and do occur in the Arctic. Given the vast areas in the Arctic, wireless systems (including those formed by intergovernmental organizations) provide the connectivity between those in need of rescue and the first responders who will come to their aid. The Global Maritime Distress and Safety System (GMDSS) has introduced new technology which has completely transformed maritime radio communications.

GMDSS system has individual limitations with respect to the geographical coverage and services provided, the equipment required to be carried by a ship is determined in principle by the ship’s area of operation [1]. In all areas of operation the continuous availability of alerting is required. Today in the
area A4 only COSPAS-SARSAT system and high-frequency band radio equipment can be used in the case of emergency [2].

The general GMDSS concept looks good and it seems to be no any limitation to provide effective radio communication at every point of World Ocean. But in reality GMDSS faces the significant troubles in the High North. The reasons for such situation are as follows. More than 80% of Arctic sea waters are located in the area A4. So in the distress situation seafarers must inform rescue coordination center primarily using COSPAS-SARSAT system and high-frequency band radio equipment. The structure of COSPAS-SARSAT system is based on the set of satellites circling the Earth along relatively low-altitude orbits. Vessels sailing in A4 area are equipped by COSPAS-SARSAT emergency position indicating radio beacons. As a result this system has advantages and certain drawbacks. The coverage of this system is really global and moreover since the satellites are moving at extremely high speed the position of every radio beacon can be determined automatically. As for negative factor this system doesn’t provide quick RCC alerting about distress. The maximal time delay alerting for COSPAS-SARSAT system is one and half hour which is quite long time period.

The satellite radio communication via geostationary satellites is also difficult in the northernmost parts of the Arctic [3]. Therefore, Inmarsat cannot be relied upon for the provision of GMDSS in much of the Arctic. However, work is ongoing in order to gain recognition by IMO for an expansion of the GMDSS to include Iridium satellites [4]. The Iridium satellite communications system, if included, would help to augment the GMDSS, with operations possibly beginning as early as 2022. The Iridium satellite network provides complete pole-to-pole satellite coverage for voice and data services. Portable handsets allow for immediate access to the network in order to communicate any emergency event. Iridium provides communications services beyond where existing wireless or wire line networks exist, including remote land areas, Open Ocean, and Polar regions [5]. Iridium is currently launching a new satellite constellation, called the Iridium NEXT system, which will allow Iridium to evolve its bandwidth and offer data-centric services with greater performance. But at the same time the price of Iridium telecommunication services is almost twice more expensive than Inmarsat prices. The price of Iridium equipment also is twice more than price of HF GMDSS radio station.

Alternatively seafarers in A4 area are able to inform RCC about distress using high-frequency band radio communication equipment. But in the Arctic region often there are also significant troubles to establish stable radio communication in this frequency band [6]. The reason for such phenomenon is susceptibility of Arctic atmosphere to powerful solar radiation during so-called solar flares. As a result the propagation of high frequency band radio wave becomes unstable and a set of negative phenomena occur regularly and last the same as the auroral storm. Auroral storms cause the extremely large increasing of electron concentration in the upper ionosphere. In turn there is considerable attenuation of radio wave power during these storms. One more negative effect caused by auroral atmosphere is cross-interference.

The up-to-date GMDSS equipment is not able to provide high effective communication in the Arctic despite the fact that it corresponds to all International requirements. This equipment only guarantees that distress signal will be delivered to RCC by COSPAS-SARSAT signal. As for radio communication its efficiency will depend significantly on the atmosphere conditions and skills of radio officers aboard vessels.

So we can conclude that none of considered above approaches is able to improve GMDSS efficiency in the case of extremely weak radio signals received in combination with powerful interferences. That’s why we need to develop new measures and more effective methods of signal processing to provide high quality of marine radio communication in the Arctic region.

2. Advanced signal processing and updated structure of GMDSS equipment

Today there are two different approaches to solve the issue of poor radio communication in the High North: one of them is to integrate new satellite system into GMDSS. This system will provide communication via set of satellites circling the Earth along the low-altitude orbits.
Such system is able to solve completely the troubles of communication in the High North, but in the nearest future it will remain quite expensive communication tool.

The second approach to improve GMDSS efficiency in the Arctic is based on the hypothesis that it’s possible to decrease or even eliminate the effect of negative factors that have influence on the equipment performance. This idea is strongly supported by academic community and is supposed to be excellent alternative to the Iridium system.

This method of radio communication equipment improvement is to integrate into HF radio station the special device which provides the measurement of ionosphere parameters to predict radio wave propagation in this frequency band.

There are two main approaches to make such prediction:

1) the first one is atmosphere sounding. In this case additional transceiver emits radio wave with frequencies varying from minimal to maximal value. This signal is reflecting from ionosphere and part of this signal is coming back to transceiver aerial. Special software compares emitted and reflected signal to calculate the optimal frequency and direction of radiation in present situation. This method provides high accuracy but requires special transceiver and generates additional interferences.

2) alternatively we can predict HF radio wave propagation without any transmitter. In this case we need to analyze the radio signals coming from navigational satellites [7]. It was found out that there is a strong correlation between propagation of HF radio waves and navigational satellite signals receiving on the Earth ground [8].

The method of ionosphere analysis is based on the measurement of radio signals sent by navigational satellite received on two different frequencies. At the same time it’s possible to improve the efficiency of this method if we supplement the information received from satellites by results of measurements of radio signals coming from the ship establishing radio communication [9].

In this case two vessels can communicate each other in heavy HF radio traffic conditions in the following way. The hardware-software complex intended for monitoring the ionosphere state in real time (HSMIS complex) provides information about frequencies which are likely to be used to establish the radio communication. The ships start the communication session using the recommended frequencies. During communication HSMIS complex continuously updates the information about optimal frequencies. At the same time DSC (digital selective call – the ship on-board equipment used to call certain radio station) of master ship (the ship establishing radio communication session) send the test call on these frequencies. The ship on the opposite side of the radio link (slave ship) replies this call. Then master ship computer determines the efficiency of communication on the recommended frequency by bit-error rate calculation. If this parameter is negligible quantity the session to be continued on the recommended frequency. Otherwise the reserve frequency is tested and used in the case of success (the reserve frequencies must be less than maximal applicable value calculated by HSMIS complex). To organize such radio communication session it’s necessary to use the following scheme of ship radio installation:
At the same time to achieve the best possible efficiency of communication in heavy HF radio traffic it’s necessary to change the algorithms of radio communication equipment operation [10]. During the radio communication session the transmitter will operate in hop-frequency auto-mode. It means that during session the transmitter is likely to change signal frequency rapidly. According to the communication procedures established by International Telecommunication Union (ITU) master ship must call slave ship by DSC on the allocated frequencies which are free at the certain time moment. So during the 1st stage of the session master ship scans the DSC frequency which is close to frequency recommended by HSMIS complex. If it’s occupied the frequency which is next after the occupied one is used. As a result the communication initially will be established on the free frequency which is the closest to the recommended one. During next several second tenths communication is being continued on the chosen frequency. During the same time interval DSC of master ship will monitor the frequency recommended by HSMIS complex. As soon as the DSC frequency closest to the recommended one is free the master DSC will call slave ship radio station on that frequency. The slave DSC will reply this call on the same frequency and master DSC will send this reply on the ship on-board computer. This device calculates the bit-error rate in the reply message. In the case if it’s negligible quantity the computer will send the confirmation by DSC to the slave ship (it is also like DSC call message but the main message block consists of unique bit sequence). This signal will be command for the slave ship radio equipment to switch on the recommended frequency at the nearest time moment when there is a pause between words in the speech or the text.

In the case when the bit-error rate in the DSC reply is more than significance value the master ship will repeat DSC call to the slave ship on the next (reserve) DSC frequency and so on until the time moment when the chosen frequency provides the best possible efficiency.

Since the frequency scanning is being done automatically the searching the optimal frequency will take extremely short time interval (not more than 0.1 – 0.2 sec). And the switching to the optimal frequency is also extremely short-time process (not more than 0.05 sec in the up-to-date equipment). So the hops of frequency during radio communication session will not make any interference on the intelligibility of the received message. Also it’s good to mention that the efficiency of the method proposed above can be improved more if to use telex terminal instead of DSC. In this case telex can monitor almost exactly the recommended frequencies. But it suits only for telephone mode (in the case of telex session it’s necessary to use additional transceiver).

One more thing to be used to improve the efficiency of communication in heavy HF radio traffic is to change a little bit the structure of radio receiver. In this updated structure the additional block will convert the spectrum of signal and noise combination in such way that noise bandwidth will be considerably increased without significant influence on the processed signal. It means that after such conversion the signal can be detected against the background of depressed noises. Such spectrum conversion can be performed by frequency multiplier which is included in the front-end of the receiver.
before mixer. The efficiency of such method is twice more than in receivers built by basic structure. Below the results of simulation the proposed method of signal processing are depicted:

In the Fig. 2 the input receiver signal is a sum of rectangle pulse sequence and noise (the noise power is twice more than the power of pulse sequence signal).

In the Fig. 3 the signal-to-noise ratio of output signal is less than 1. It means that it’s impossible to filter pulse sequence from the noise. As a result the communication is also impossible in such conditions.

In the Fig. 4 the signal-to-noise ratio of output signal is a little bit more than 1 (approximately is 2.5). It means that the pulse sequence signal can be separated from the noise. As a result the receiver provides such output signal that it’s possible to read the transmitted message.

This method of spectrum conversion will provide better signal-to-noise ratio in the case when the frequency multiplier is the low noise device. The internal noise of every equipment depends on the number of its components that have resistive impedance and the total value of this parameter. The
basic possible schematic circuit of frequency multiplier is depicted in the Fig.5. This device provides doubling of input signal frequency. But this circuit has at least 6 elements that have significant level of internal noise (2 oscillating loops and 4 diodes). The noise power spectrum density for this circuit is presented in the Fig.6. Nevertheless this circuit can’t provide frequency doubling in the front-end of the receiver. The voltage of receiver input signal is expected to be approximately about $10^{-6} \ldots 10^{-5}$ V. It means that the voltage of signal coming on the input of frequency multiplier will be about $10^{-5} \ldots 10^{-4}$ V. At the same time the signal frequency can be doubled by the device depicted in the Fig.5 only in the case when voltage of its input signal is more than 0.6 V (the barrier voltage). So the input receiver signal must be amplified at least $10^5$ times before it can be processed by the basic frequency multiplier. So this device can’t be used in the front-end of the receiver. The frequency multipliers are also widely used in the precise rectifiers that are the components of electronic measurement equipment. In such rectifiers the frequency multiplication is provided for signals those voltages are about $10^{-4}$ V. The possible schematic circuit of advanced frequency multiplier which is widely used in the precise rectifier is depicted in the Fig.7. This circuit provides doubling of input signal frequency but it doesn’t suppress the spectrum frequency components that correspond to the zero and first harmonic of its input signal. So this circuit only rectifies the input signal. To improve the efficiency of this device it’s possible to add the circuit by 2 more blocks: the first one is the rectifier which provides the processing of input signal negative semi wave; the second block is differential amplifier which summarizes positive and inverted negative semi waves of input signal. The output signal of this amplifier corresponds to the absolute value of the signal at the input of frequency multiplier. As a result the spectrum component of this signal that corresponds to the second harmonic of input signal will be increased twice. The diagrams illustrating the signal processing provided by advanced frequency multiplier are depicted in the Fig.8 – 9. These diagrams show that signal amplitude is not distorted during the process of frequency doubling. The noise power density of advanced frequency multiplier is presented in the Fig.10. Comparing the results depicted in Fig.6 and Fig.10 it’s possible to conclude that advanced frequency multiplier provides lower noise power density relative to the basic circuit of this device.

Figure 5. The basic schematic circuit of frequency multiplier
Figure 6. The noise power spectrum density of basic frequency multiplier

Figure 7. Schematic circuit of advanced frequency multiplier

Figure 8. The spectrum of signal at the input of advanced frequency multiplier
3. Conclusion
Data presented in the article confirm that the methods considered above provide at least twice better efficiency of radio communication relative to the basic GMDSS equipment. To sum up it’s necessary to mention that in the case when every method described above is integrated into GMDSS equipment the efficiency of this system will be improved considerably and comparable to the efficiency of satellite radio communication system. But at the same time this alternative will save a lot of money for ship owners.

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