Digital Radio Broadcasting Network in the Arctic Region

Oleg Varlamov, Vladimir Varlamov, Anna Dolgopyatova
Moscow Technical University of Communications and Informatics
Moscow, Russia
vov@mtuci.ru, f.vvo@bk.ru, anna793@yandex.ru

Abstract—**Successful economic development of the Arctic zone is impossible without creating a continuous information field that covers its entire territory and is available not only at stationary objects, but primarily in moving vehicles - ships, cars, airplanes, etc. This information field must consist from transmission of audio information (broadcasting programs), data (weather maps, ice conditions, etc.), navigation signals, alerts and information about emergencies, and must be reserved from different sources. As a backup system (and in the coming years, the main one) it is advisable to use single-frequency digital broadcasting networks of the Digital Radio Mondiale standard in the low frequency range. This is the most economical system for covering remote areas. For the use of these systems, have all the necessary regulatory framework and standard high-efficiency radio transmitters. The possibility of using standard antenna systems is shown. An example of frequency-territorial planning and a program of preliminary field tests in the experimental zone were developed. It is shown that the entire Arctic region of the Russian Federation, including the Northern Sea Route, can be coverage by a total of 6 transmitters with three frequencies, a total power consumption of 450 kW and annual electricity costs of less than 250,000 US$.**

I. Introduction

Successful economic development of the Arctic zone is impossible without creating a continuous information field that covers its entire territory and is available not only at stationary objects, but primarily in moving vehicles - ships, cars, airplanes, etc. Under the information field refers to the transmission of audio information (broadcasting programs), data (weather maps, ice conditions, etc.), navigation signals, alerts and information about emergencies, as well as other service information in the interests of various departments. Given the harsh climatic conditions, the reliability of information support directly determines the safety of human life in the Arctic. To ensure the required level of reliability, it is necessary to use at least two systems operating in parallel and duplicating each other - the main and the backup, based on different principles of operation.

It is obvious that the information support of mobile objects can be implemented only with the help of various radio systems. (Solutions for stationary objects are more diverse and are not considered in this article). It is also clear that on mobile objects in most cases large-sized and space-dependent antenna systems cannot be installed. For this reason, even in the middle part of the Arctic zone (at latitudes higher than 75° and up to 81°), where the geostationary orbit (GEO) is observed very low above the horizon and only a small portion of it is visible, where the satellites of the required operator are not always present, providing information fields using satellites located on the GEO is not possible. Approximately from 81 ° to the poles GEO from the surface of the Earth is not visible even theoretically.

The most promising for the formation of the main information field in the Arctic zone can be considered satellite systems in highly elliptical (HEO) or low Earth (LEO) orbits. At the same time, the high cost of such systems, the long period of infrastructure deployment and the limited lifespan, combined with low population density in the service area, determine their planned unprofitability and the need for budget financing.

As a backup tool for the formation of the information field, it is advisable to consider terrestrial digital broadcasting systems (DBS). By providing a data transmission rate in a broadcast channel comparable to that available for receiving on an omnidirectional antenna in satellite systems, modern ground-based DBS systems can be significantly more economical to deploy and operate. Before the satellite segment is put into operation (on HEO or LEO), ground-based facilities can successfully perform the function of forming the main information field.

The article discusses the possibility of building a digital broadcasting network of the Digital Radio Mondiale (DRM) standard in the low frequency (LF) range (or "longwave" band) to create an information field in the Arctic zone of the Russian Federation. The cost of coverage of digital broadcasting systems in various frequency bands is considered. An analysis of the regulatory framework for the application of various DBS systems is carried out. The issues of building transmitting equipment and equipment for the organization of synchronous broadcasting are discussed. The possibility of using standard antenna devices is analyzed. An example of frequency-territorial planning and a program of preliminary field trials in the experimental zone are being developed.

II. Cost of territory coverage with DBS systems in different frequency range

The efficiency of a broadcasting network is defined as a set of capital (for building a network) and operating costs, referred to the number of listeners or to the service area. For

ISSN 2305-7254

commercial radio stations, only territories with a sufficiently high population density are of interest; therefore, they mainly operate in populated areas and use very high frequency (VHF) band, whose radio waves propagate within direct line of sight. State broadcasting, which has the function of creating an information field in the Arctic region, should be adopted throughout the service area. The method of calculating specific operating costs - that is, the cost of servicing one square kilometer of territory with transmitters of different power and different frequency ranges was developed by the author in [1]. The calculation results are shown in Fig. 1.

As can be seen from Fig. 1, the minimum cost of territory maintenance is achieved in the amplitude modulation (AM) mode in the high frequency (HF) range. DRM broadcasting also has minimal maintenance cost in the high-frequency range. However, the instability of radio waves propagation inherent in this range, which is especially pronounced in polar latitudes, does not allow recommending HF range for use to create a round-the-clock and year-round information field. And with near vertical incidence skywave (NVIS) transmission, even using an extraordinary wave, it is impossible to provide broadcasting at night, including during several months of the polar night, in the frequency bands of the HF range allocated for broadcasting [2]. In the medium frequency (MF) range, as shown by the experiments, one can only count on the daytime radius of the service area. Due to the resistance of the DRM signal to multipath reception, it practically does not decrease at night time [3], but does not increase due to a significant increase of noise and interference.

Approximately equal to broadcasting in the high frequency range costs has the use of the DRM mode in the low frequency range with transmit power of 20 ... 40 kW. However, to reduce the number of broadcasting stations, which may be especially relevant when servicing sparsely populated remote areas, it is more rational to use transmitters with a power of 50 ... 100 kW.

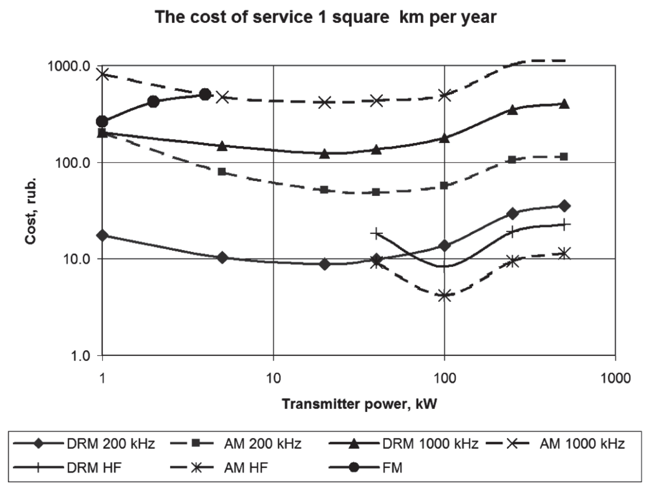


Fig. 1. The cost of servicing one square kilometer of territory per year (rubles, excluding VAT) by transmitters of various power and frequency ranges

Thus, in the example of the state broadcasting network of the Russian Federation developed in [1] (Fig. 2, Table I), the average transmitter power is 68 kW, which makes it possible to ensure that the cost of broadcasting is close enough to the minimum possible values.

The example of the state broadcasting network architecture of the Russian Federation developed in [1] contains 29 transmitters with a total power of 1940 kW (Table I). Lines connect the transmitters operating in clusters of a synchronous network, in Fig. 2. The number of transmitters used in the developed example of a powerful broadcasting network topology is significantly less than in the previously considered analogue versions. Transmitter's total power compared to the 2005 broadcasting network (254 transmitters) decreases by almost 22 times [1] and becomes half the power consumption of Digital Television (DTV) facilities. This was made possible by the use of a synchronous network with a 16 dB signal-to-noise ratio required in DRM mode instead of 36 dB in AM mode. Electricity costs, which in 2005 (at current prices) amounted to 2 billion rubles per year - which was one of the main reasons for the collapse of powerful broadcasting, reduced to 90 million rubles in year.

TABLE I. EXAMPLE OF THE STATE BROADCASTING NETWORK OF THE RUSSIAN FEDERATION. LIST OF TRANSMITTERS AND SERVICE AREAS

No	The name of the radio center	Transmitter power, kW	Radius of service area, km	Field strength, dBμV/m	Soil conductivity, Cm
1	Crest Mayor	60	550	50	0,001
2	Chersky	10	440	60	0,003
3	Anadyr	60	540	50	0,001
4	St. Petersburg	60	540	50	0,001
5	Moscow	60	540	50	0,001
6	Syktyvkar	60	540	50	0,001
7	Surgut	60	540	50	0,001
8	Baikit	60	530	50	0,001
9	Mirniy	60	530	50	0,001
10	Yakutsk	60	540	50	0,001
11	Arman	60	620	60	0,003
12	Kamenskoe	60	540	50	0,001
13	Tbilisi	100	570	50	0,001
14	Orenburg	100	570	50	0,001
15	Yekaterinburg	200	640	50	0,001
16	Novosibirsk	100	580	50	0,001
17	Angarsk	60	530	50	0,001
18	Chita	60	530	50	0,001
19	Tynda	60	730	60	0,005
20	Komsomolsk	60	610	60	0,003
21	Yuzhno-Sakhalinsk	60	610	60	0,003
22	Elizovo	100	790	60	0,005
23	Vladivostok	60	730	60	0,005
24	Crest Mayor	60	530	50	0,001
25	Chersky	60	530	50	0,001
26	Anadyr	60	740	55	0,003
27	St. Petersburg	60	530	50	0,001
28	Moscow	60	530	50	0,001
29	Syktyvkar	10	440	60	0,003

Fig. 2. An example of the architecture of a network of state digital broadcasting in the Russian Federation in the low-frequency range

Thus, the most economical solution to providing the information field in the Arctic zone, where signals from satellites located on the GEO are no longer received, regardless of the time of day, seasons of the year or solar activity, is the use of digital broadcasting in the LF range.

III. Regulatory framework

Practical application of any broadcasting system is possible only after its approval and standardization at the international and national levels. Digital broadcasting systems such as Digital Audio Broadcasting (DAB/DAB+), DRM/DRM+, In-band on-channel (IBOC) and Realtime audiovisual information system (RAVIS) are standardized by the ITU [1, 4]. In the Russian Federation, there are solutions of the State Radio Frequency Commission for the use of the DRM system in the LF, MF and HF bands [4, 5] and for the use of the DRM+ and DAB/DAB+ systems in the VHF band. Tests are also conducted for the RAVIS system. However, a complete set of the entire necessary legal and regulatory framework that allows for the immediate organization of digital broadcasting, which includes a number of state standards, requirements for electromagnetic compatibility, etc., currently exists only for the DRM system in the LF, MF and HF bands.

IV. Transmission equipment

Transmission equipment for digital broadcasting is fundamentally different from conventional transmitters with amplitude modulation, which were built before the 1980s. The radio frequency signal of digital broadcasting is a complex amplitude-phase-modulated signal, for amplification of which a sufficiently high linearity of the transmitting device is required [6]. Modern semiconductor transmitters, manufactured by a number of companies in the last 20 years, built according to the method of envelope elimination and restoration (EER) [7, 8], summarizing the power of a large number of cells [9], with pulse-width modulator (PWM) or with sigma-delta modulator [10, 11, 12], satisfy the specified requirements. The industrial efficiency of modern transmitters when operating in the DRM mode is 70 ... 80%, which, with relatively small output powers (50 ... 100 kW), does not place high demands on the energy supply of the transmitting station. The results of consideration and practical testing of equipment for organizing a synchronous broadcast network are given by the author in [13, 14]. Thus, a complete set of DRM transmission equipment is currently available on the market.

V. Antenna systems

In most practical cases, to translate signals from broadcast stations of the LF range various types of antenna systems installed on masts in height from 257 to 378 meters are used. The operation of modern high-efficiency transmitters in the DRM mode places higher demands on the quality of matching the antenna system [15]. In particular, it is necessary to ensure that the voltage standing wave ratio (VSWR) does not exceed 1.05 in the signal bandwidth and not more than 1.1 in the doubled signal bandwidth. This task for most standard antenna systems of the LF range (shunt-fed antenna et al.) can be successfully solved by applying the methods developed by the author in [16, 17, 18]. Moreover, in [1] it is shown that the use of this technology allows the use of existing antennas, including in the mode of simultaneous transmission of analog and digital signals - Simulcast [19] with a double frequency band. This mode of operation is especially useful during the transition period of network deployment - until the consumers are filled with digital receiving equipment [20]. The calculations carried out in [1] confirmed the possibility of using the Simulcast mode with a double frequency band with real antennas 257 meters high for the upper half of the LF range. For the lower half of the LF range, this possibility was shown based on theoretical calculations.

To confirm this possibility, based on the data on the input impedance of the actually operated antennas, we used the information given in [21]. The LF antenna system described in [21] is located on the island of Ingøy in Norway at the geographic coordinates of 71°4'N, 24°5'E, and is designed to operate at the lowest frequency of the LF range equal to 153 kHz. The height of the antenna mast is 362 meters. The measurement results of the input impedance of this antenna are shown in Table II.

TABLE II. Measurement results of 362 meter height antenna input impedance [21]

F, MHz	Re(Z)	Im(Z)
0.140	46.3	-52.8
0.1405	46.8	-50.3
0.142	47.6	-42.8
0.144	49.0	-33.2
0.146	50.6	-23.8
0.148	52.4	-14.8
0.150	54.1	-5.9
0.152	56.0	2.8
0.153	57.0	7.1
0.154	58.0	11.3
0.156	60.1	19.9
0.158	62.1	28.4
0.160	64.4	37.2
0.1619	67.3	45.9
0.164	70.2	55.0
0.166	73.3	64.2
0.168	76.7	73.1
0.170	80.6	82.8

Substituting this data into software tools for antenna matching circuit design of DRM digital broadcast transmitters [17], we find that the quality factor of the antenna is Q = 6. In the 9 kHz signal frequency band, the losses in the ballast load of the frequency-extension circuit do not exceed 4% (0.17 dB), and in the 18 kHz signal frequency band, no more than 13% (0.53 dB). The result obtained is somewhat better than the theoretically considered in [1] for shunt-fed antenna with a height of 378 meters (0.65 dB) and is due to a more extensive system of antenna elements (Fig. 3).

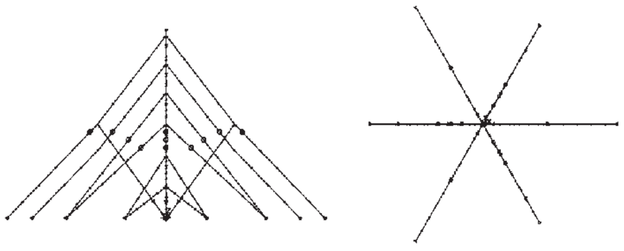
Circuit configuration and calculated ratings of the frequency-extension circuit elements for this antenna are shown in Fig.4. At the antenna's feeder entry point into a technical building, its impedance *Ra* at the center frequency is inductive in nature (57 +*j*7.1 Ohm). Therefore, the capacitance *C1* (Fig. 4) is the compensating reactivity tuning the antenna circuit into resonance and the inductance *L1* is not established.

The initial antenna VSWR and the resulting antenna VSWR with a frequency-extension circuit are shown in Fig. 5. The obtained degree of antenna matching is sufficient for the operation of a modern transmitter in the DRM mode in compliance with the requirements for electromagnetic compatibility.

Thus, the currently existing standard antenna systems, supplemented by frequency-extension circuits, can be successfully used to organize broadcasting in the DRM mode in the entire frequency range of the LF, including in the Simulcast mode with a double frequency band.

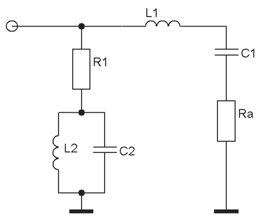
VI. Example of Frequency-Territorial Planning

The LF range is allocated by ITU for broadcasting purposes only in Region 1, which makes it impossible to build a broadcasting network throughout the entire Arctic zone, limiting it to the territory adjacent to the Eurasian continent.



Side view Top view

Fig. 3. Views of the Ingøy's antenna computer model [21]



C1	146,5 nF
L1	0
R1	57 Ohm
C2	109 nF
L2	9,9 μH

Fig. 4. Circuit configuration and ratings of the frequency-extension circuit elements

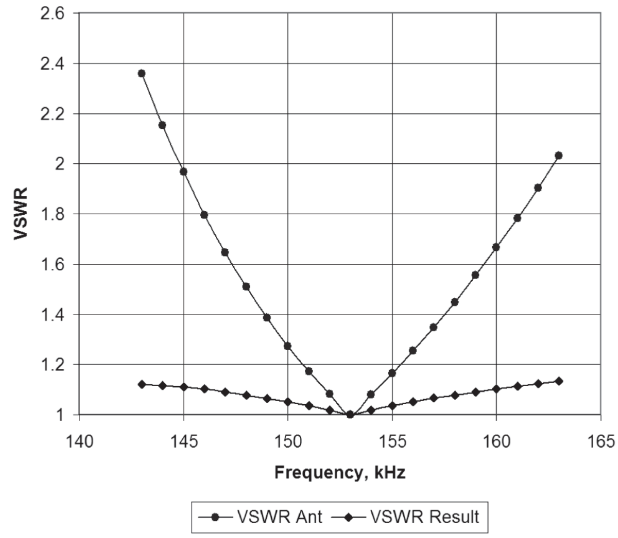


Fig. 5. The initial antenna VSWR and the resulting antenna VSWR with a frequency-extension circuit

The number of radio frequencies in the LF range is not enough to build a traditional broadcasting network in a given territory [22, 23, 24]. The solution of the problem is the use of synchronous digital broadcasting in the DRM standard when using the large-cluster method of network construction [25].

As applied to solving the task, the example of the architecture of the state digital broadcasting network of the Russian Federation developed in [1] in the LF range (Fig. 2) is redundant and does not cover the Arctic zone too well. In order to maximize the coverage of the Arctic zone and the Northern Sea Route, we can offer another option. In addition to the cut-off of all transmitters located outside the arctic zone, it seems advisable to organize an additional transmitting station in Sabetta. Sabetta is a rotational settlement in the Yamal district of the Yamalo-Nenets Autonomous District. It is located on the eastern shore of the Yamal Peninsula near the Ob Bay of the Kara Sea. The largest plant for the production of liquefied natural gas (Yamal LNG) in Russia is under construction in Sabetta, and there are also enough electric power capacities. LNG is transported by ships passing around the Yamal Peninsula, above 73° N, with limited access to information resources.

The distance from Sabetta to Murmansk is 1,500 km, which makes it possible to use these transmitters in a single-frequency network (the maximum allowable distance is 1,556 km [25]). The next single-frequency networks are Khatanga (1060 km from Sabetta) - Tiksi (920 km from Khatanga) and Chersky (1250 km from Tiksi) - Anadyr (850 km from Chersky). When calculating the service areas of the transmitters, the distribution of maximum levels of atmospheric radio noise in the LF range over the territory of the Earth [26, 29] was taken into account and the software [27] was used. The authors develop the method of calculating transmitter service areas for this case in [28].

As shown by the author in [24], in the northern latitudes, with a low level of atmospheric radio noise and low soil conductivity, the largest radius of the transmitter's coverage area is achieved at the lowest frequencies of the low-frequency range. The use of three single-frequency networks instead of six individual broadcast zones with different frequencies allows us to take only three frequency assignments. This not only saves the frequency resource, but also allows you to maximize the coverage area by selecting the lowest frequencies of the broadcasting low-frequency range.

The calculated coverage areas are shown in Fig. 6. All transmitters have a standard AM mode power equal to 100 kW. This allows you to get 60 kW of output power in DRM mode. Taking into account the high efficiency of transmitters, at least 80%, the total power consumption of the entire broadcasting network will be only 450 kW. With round-the-clock operation, the yearly electricity consumption will be 3,942,000 kWh, and its cost is less than 16 million rubles (less than 250,000 US$).

VII. Development of the field trial test program

For an approach to the practical implementation of the developed project, it is first necessary to carry out test trials in the experimental zone.

In the first point of the field trials program, it is necessary to include the measurement of the levels of atmospheric and industrial radio noise in open spaces on land and at sea, in vital facilities and in vehicles. It is known that passenger cars practically do not interfere with the reception of a DRM signal. This is confirmed by the author's measurements in the LF band [1] and the widespread introduction of DRM broadcasting in India in the MF band. Measurements on ships of various classes in the low-frequency range have not been carried out and the level of industrial interference on them is currently unknown. It should be noted that in order to measure such low noise levels, special calibrated measuring antennas developed at Moscow Technical University of Communications and Informatics (MTUCI) are required.

In the case of positive results, i.e. low noise levels; at the second stage, it is necessary to evaluate the effective conductivity of the soil in the Arctic region - both in traditional conditions (land, sea) and on layered tracks (ice - sea, snow - land, land - permafrost). These tests can be carried out using a transmitting station in Ingøy (Norway), where there is a transmitter and antenna capable of operating in DRM mode.

After clarifying the information on the effective conductivity of the soil, it is possible to clarify the above example of frequency-territorial planning, either by location of transmitters or by their powers. For the third stage of testing - a synchronous broadcast zone, the construction of two transmitting stations will be required. Given the relatively high cost of capital expenditures, it is advisable to place this construction at the points of their subsequent use. In particular, the construction of the single-frequency network Murmansk-Sabetta will immediately provide navigation information for the sea route for LNG delivery to Europe.

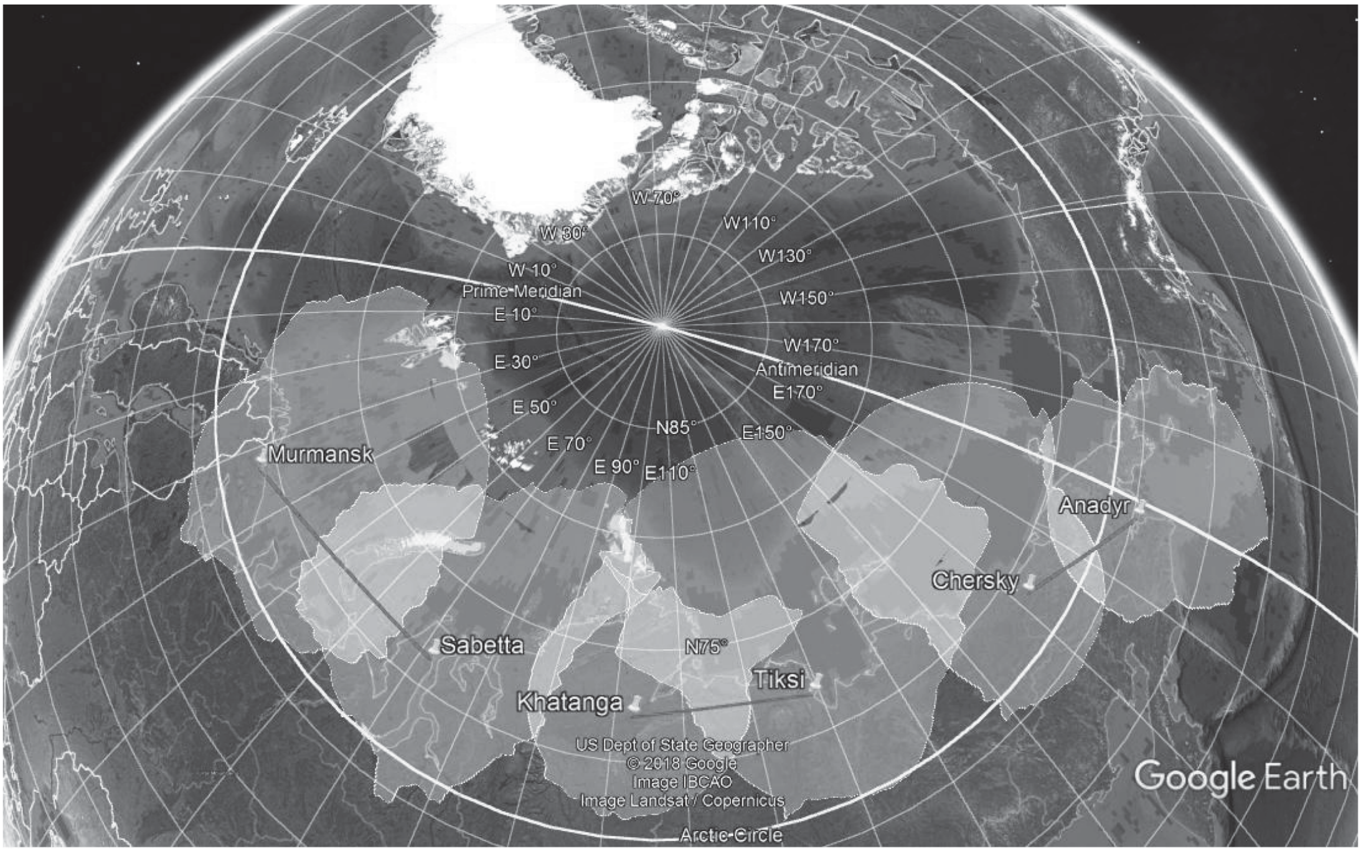


Fig. 6. Calculated coverage areas for the proposed digital radio broadcasting network in the Arctic region

VIII. Conclusion

The necessity of creating a continuous reserved information field in the Arctic region of the Russian Federation for its successful development is shown. As a backup system (and in the coming years, the main one) it is advisable to use single-frequency digital broadcasting networks of the DRM standard in the LF range. For the use of these systems, have all the necessary regulatory framework and standard high-efficiency radio transmitters. The possibility of using standard antenna systems is shown. An example of frequency-territorial planning and a program of preliminary field tests in the experimental zone were developed.

It is shown that the entire Arctic region of the Russian Federation, including the Northern Sea Route, can be coverage by a total of 6 transmitters with a total power consumption of 450 kW and annual electricity costs of less than 250,000 US$.

Acknowledgment

The staff of the CJSC MRB, the staff of the Radio Broadcasting and Radio Communication Department of FSUE RTRS, the branch of FSUE RTRS - Moscow regional center, rendered a great help in organizing and carrying out the test trials, so the authors expresses sincere gratitude to them.

References

[1] O.V. Varlamov, “The technology of creating a digital broadcasting network of the DRM standard for the Russian Federation," D.Sc. Thesis ["Tekhnologiya sozdaniya seti cifrovogo radioveshchaniya standarta DRM dlya Rossijskoj Federacii," Dis. Dokt. Tehn. Nauk], MTUCI, Moscow, 2017. (In Russian).

[2] O.V. Varlamov, "Using the extraordinary wave for digital DRM NVIS broadcasting," *T-Comm,* vol. 9, no.1, pp. 32–38, 2015. (In Russian).

[3] O.V. Varlamov, "Study of DRM digital broadcasting in the MF fading zone," *T-Comm*, vol.9, no. 2, pp. 41–45, 2015. (In Russian).

[4] O.V. Varlamov, “Development of national regulatory framework for DRM digital broadcasting,” *T-Comm*, 2013, No. 9, Pp. 47–50. (In Russian).

[5] O.V. Varlamov, "Qualitative characteristics of the sound path in the system DRM,” *Age of quality* ["Kachestvennye harakteristiki zvukovogo trakta v sisteme DRM," *Vek kachestva*], no. 1, pp. 48-52, 2014. (In Russian).

[6] O. Varlamov, "Research of influence of DRM broadcast transmitter nonlinearities onto the output signal parameters," *T-Comm - Telecommunications and Transport*, vol. 8, no. 2, pp. 59-60, 2014.

[7] L. Kahn, “Single-sideband transmission by envelope elimination and restoration,” Proceedings of the IRE, vol. 40, no. 7, pp. 803–806, July 1952.

[8] O.V. Varlamov, I.A. Goncharov, V.G Lavrushenkov, “High-power HF digital-analog converter for SSB signal power amplifiers,” *Telecommunications and Radio Engineering* (English translation of Elektrosvyaz and Radiotekhnika), vol. 44 (8), p.49, 1989.

[9] O.V. Varlamov, V.N. Gromorushkin, V.B. Kozyrev, A.V. Melan'in, “Addition of the power outputs from push-pull voltage-switching oscillators having a resistive load,” *Radioelectronics and Communications Systems* (English translation of Izvestiya Vysshikh Uchebnykh Zavedenii Radioelektronika), vol. 32 (7) , p.30, 1989.

[10] O.V. Varlamov, I.V. Chugunov, “Modeling of efficiency UHF class-D power amplifier with bandpass sigma-delta modulation,” 2017 Systems of Signal Synchronization, Generating and Processing in Telecommunications, SINKHROINFO 2017. 2017.7997508.

[11] A.O. Bolotov, R.G. Kholyukov, O.V. Varlamov, "EER power amplifier modulator efficiency improvement using PWM with additional sigma-delta modulation," 2018 Systems of Signal Synchronization, Generating and Processing in Telecommunications, SYNCHROINFO 2018. 2018.8456955.

[12] E.P. Stroganova, O.V. Varlamov, "Measurement accuracy analysis for on-board measuring devices," 2018 Systems of Signals Generating and Processing in the Field of on Board Communications, IEEE, pp. 8350638, March 2018.

[13] O.V. Varlamov, "Organization of single frequency DRM digital radio broadcasting networks. Features and results of practical tests," *T-Comm*, vol. 12, no.11, pp. 4-20, 2018. (in Russian).

[14] O.V. Varlamov, "Organization of single frequency DRM digital radio broadcasting networks. Features and results of practical tests," 2018 Systems of Signal Synchronization, Generating and Processing in Telecommunications, SYNCHROINFO 2018. 2018.8456925.

[15] J. Huber, "DRM on MF and LF, coverage and technical requirements," EBU-DRM Conference. Geneva, 26 Nov 2009, https://tech.ebu.ch/docs/events/drm09/presentations/ebu_drm09_huber.pdf.

[16] O.V. Varlamov, V.D. Goreglyad, "Bandwidth extension LW transmitting broadcasting antenna systems for operating in DRM mode," *T-Comm*, vol. 7, no.1, pp. 18-22, 2013. (in Russian).

[17] O.V. Varlamov, "Development of algorithm and software tools for antenna matching circuit design of DRM digital broadcast transmitters", *T-Comm*, vol. 7, no.2, pp. 47-50, 2013. (in Russian).

[18] O.V. Varlamov, E.P. Stroganova, "Frequency extension circuit for EER transmitters operating with electrically short antennas," *2018 Systems of Signals Generating and Processing in the Field of on Board Communications SOSG 2018*, pp. 8350577, 2018.

[19] O.V. Varlamov, "Analog to digital signal power ratio in simulcast DRM transmission," *T-Comm,* vol. 10, no. 12, pp. 81-84, 2016.

[20] O.V. Varlamov, "Development of requirements for receiving equipment of digital broadcasting networks of the DRM standard," *T-Comm*, vol. 7, no. 9, pp. 39-42, 2013.

[21] Description of ATU of Long Wave Antenna Ingøy 100 kW 153 kHz. Technical report. TELEFUNKEN SenderSysteme Berlin. 1E-8920-803-DO Waniewski. Berlin, 31.10.2000. http://www.waniewski.de/Pdf/1E-8920-803-DO_documentation%20Ingoy%20LW.pdf.

[22] O.V. Varlamov, "Peculiarity of frequency-territorial planning of DRM broadcasting networks for LW and MW bands," *T-Comm*, vol. 7, no. 9, pp. 43-46, 2013.

[23] O.V. Varlamov, "Correctly planning of DRM broadcasting networks," *Telecommunication*, ["Korrektnoe planirovanie setej DRM veshhanija," *Jelektrosvjaz'*], no. 6, pp. 26-34, 2014. (In Russian).

[24] O.V. Varlamov, "The radio noise effect on the coverage area of DRM broadcast transmitter in different regions," *T-Comm*, vol. 9, no. 2, pp. 90-93, 2015.

[25] O.V. Varlamov, "Method of organization global digital radio broadcasting network in the LW band," *T-Comm*, vol. 9, no. 5, pp. 63-68, 2015.

[26] O.V. Varlamov, V.O. Varlamov, "Distribution of maximum levels of atmospheric radio noise in LF and MF ranges in the territory of the Earth", *H&ES Research*, vol. 9, no. 5, pp. 42-51, 2017.

[27] O.V. Varlamov, V.O. Varlamov, "The program of calculation of the distribution of the maximum levels of atmospheric radio noises in the range of low and medium frequencies in the Earth territory" ["Programma rascheta raspredeleniya maksimal'nyh urovnej atmosfernyh radioshumov v diapazonah nizkih i srednih chastot po territorii Zemli"], certificate of registration of computer programs RUS 2018618338 05/30/2018

[28] O.V. Varlamov, V.O. Varlamov. "Determination of the coverage area of the digital radio broadcasting transmitter of DRM standard taking into account the distribution of atmospheric radio noises," In the collection: Technologies of the Information Society. Materials of the XII International branch scientific and technical conference. ["Opredelenie zony obsluzhivaniya peredatchika cifrovogo radioveshchaniya standarta DRM s uchetom raspredeleniya atmosfernyh radioshumov", V sbornike: Tekhnologii informacionnogo obshchestva Materialy XII Mezhdunarodnoj otraslevoj nauchno-tekhnicheskoj konferencii], Moscow, 2018, pp. 136-137.

[29] O.V. Varlamov, “Public digital broadcasting network organization in the range of long waves,” *Synchroinfo*, vol. 4, no. 6, pp. 2-5, 2018.